Integrated Façade Systems for Highly- to Fully-Glazed Office Buildings in Hot and Arid Climates

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A thesis submitted in partial fulfilment of the requirements of the University of Brighton for the degree of Doctor of Philosophy

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Dedication

To my country, Iraq,

and my family, I dedicate this thesis.

Abstract

Buildings have a significant share in climate change due to their environmental impacts and energy consumption. While embodied carbon and energy of buildings throughout their life cycle can be managed and reduced with strict measures, operational carbon and energy are not easy to target and tackle. One of the components of a building with direct impact on its energy consumption and indoor comfort conditions – e.g. light, glare, temperature, and humidity to name but a few – is the building façade where architectural design manifestations also materialises. Designing building facades is not an easy task as many contradictory variables – from the most aesthetic to the most technical ones – need to be taken into account. This task is even more complex where the building is, more often than not architecturally, required to have a highly- to fully-glazed façade. To fulfil such a demanding task, technological solutions such as Integrated Façade Systems (IFS) have been developed and deployed. IFS are systems where different technological solutions are integrated to improve performance and lower the impact of the building. The research on IFS is scarce and scattered with reference to coverage, scope and focus. Moreover, many different aspects of integration can be considered for IFS, where technology is considered as the integrated element into façade compartments to address energy consumption, solar gain and indoor thermal and visual comfort conditions.

This study investigates the integration of Photovoltaic Shading Devices (PVSD) and High Performance Glazing (HPG) – within the scope of IFS – as a specialised and highly flexible area of research with a promising scope to establish a methodology for a systemic investigation of highly- to fully-glazed façades. The aim of this study is minimising heat and solar gain while maximising natural daylight and electricity generation, which will result in reducing the overall energy and carbon footprints of buildings in general and specifically office buildings in hot and arid climates. This however, is just one of the several application of the proposed methodological approach devised in this study whose application can be extended to other studies within this area but with different objectives. In doing so, this study develops an approach informed by the 'Systems Theory' to classify different parameters and variables with a potential impact level on the topic of the study. It uses a sequential combination of qualitative and quantitative methods (but not a mixed method), to first develop a base model and then through simulation measure and evaluate the energy consumption, indoor solar gain and visual comfort of different variations of the designated façade parameters through the boundaries and scope of this research defined through the systemic methodology, to optimise the use of IFS in the design of highly- to fully-glazed office buildings. In-depth and comprehensive analysis of inter-dependency of variables has been carried out, followed by sensitivity analyses to measure the impact of change of parameters and elements of the façade – within the systemic boundaries of this research – on the net energy, heat and solar gain and visual comfort in such buildings.

The methodology developed exclusively for this research can provide a frame of reference as a flexible platform with modular structure which supports full parametric alternatives that can be customised to meet the context specifics of any similar given study. It is envisaged that such methodology provides an unprecedented example which contributes to the existing knowledge, where a multitude of elements, criteria and factors are involved in studies on or around energy and Carbon footprints as well as environmental impacts of buildings. As a secondary contribution, the methodology has been developed, demonstrated and hence can be used as a practical decision support system to help designers make the best design decisions when designing office buildings with highly- to fully-glazed facades in hot and arid climates. With minor systemic adjustments in the modular structure of this methodological frame, both the research and its by-product – the design decision support tool – can be customised and used to assist both researchers and designers for other building types, and in other climatic conditions.

Extended tables of simulation results of 1620 possible combinations of variables for the design and application of IFS in highly- to fully-glazed office buildings in hot and arid climates have been provided which contribute to ongoing development of building codes in the context of this study. The research concludes with some interesting findings which challenge the common understanding of significance and impact of design elements. To name but one example, reducing the impact of one variable (e.g. the inclination angle of the PVSDs) due to its correlation with another variable (e.g. the ratio between the depth of PVSD and the distance between them) to overcome one or more of design constraints (e.g. building orientation) and to provide a multitude of design options for trade-offs between rather contradictory functions, such as reducing energy use, improving daylighting and increasing energy generation.

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Acronyms

AWC	Australian Window Council
ADI	Annual Daylight Illuminance
BC	Base-case
BES	Building Energy Simulation
BFRC	British Fenestration Rating Council
BIM	Building Information Modelling
BIPV	Building-integrated photovoltaic
BPS	Building Performance Simulation tool
BSM	Building services management
CBDM	Climate-Based Daylight Modelling
CWCT	Centre for Window and Cladding Technology
d/l	Ratio of Depth of PVSD to the distance between PVSDs
DA	Daylight Autonomy
DC	Double-Clear Glazing
DF	Daylight Factor
DHI	Diffuse Horizontal Irradiance
DL	Double-Low-e Glazing
DMF	Decision-making framework
DNI	Direct Normal Irradiance
DR	Double-Reflective Glazing
DSM	Dynamic Simulation building energy Modelling approach
DV	Dependent Variables
EWERS	European Window Energy Rating Systems
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
HGFs/FGFs	Highly- to Fully-Glazed Façades
HPG	High-Performance Glazing
HVAC	Heating, Ventilation and Air-conditioning system
IBPSA	International Building Performance Simulation Association
IEA	International Energy Agency
IES-VE	Integrated Environmental Solutions-Virtual Environment
IFS	Integrated Façade Systems
IV	Independent Variables
LBNL	Lawrence Berkley National Laboratory
MW	Megawatt
NFRC	National Fenestration Rating Council
NREL	National Renewable Energy Laboratory
OAAT	One-at-A-Time
OHR	Overhang ratio
PCM	Phase Change Material
PV	Photovoltaics
PVSD	Photovoltaic Shading Devices
SA	Sensitivity analysis
SC	Single-Clear Glazing
SD	Shading Devices
SHGC	Solar Heat Gain Coefficient
SL	Single-Low-e Glazing
SR	Single-Reflective Glazing
$UDI_{300\text{-}3000lux}$	Useful Daylight Illuminance for ‘300 to 3000 lux’ range
$UDI_{less\ than\ 300lux}$	Useful Daylight Illuminance for ‘less than 300 lux’ range
$UDI_{more\ than\ 3000lux}$	Useful Daylight Illuminance for ‘more than 3000 lux’ range
UHI	Urban Heat Island phenomenon
VT	Visible transmittance
WERS	Window Energy Rating Scheme
WWR	Window-to-wall ratio

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Thank you Brighton for being such an open, lovely and welcoming city. My memories of being here will be everlasting.

Author’s declaration

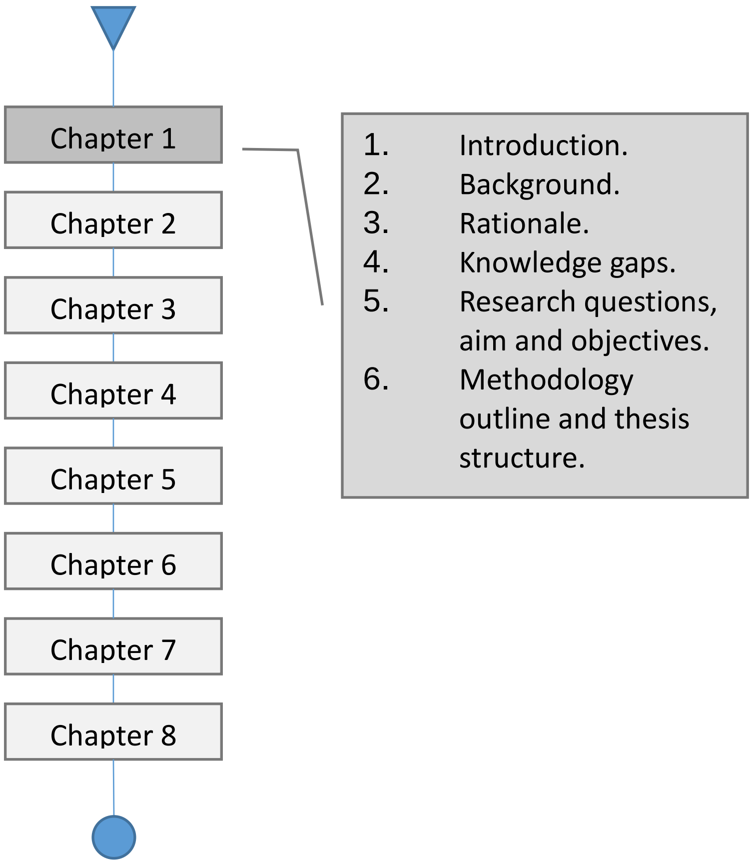
I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any other university for a degree, and does not incorporate any material already submitted for a degree.

Signed

Dated 4/3/2019

Chapter One

Introduction



CHAPTER 1. INTRODUCTION

1.1 Background

Reducing energy consumption in buildings is one of main priorities in the construction industry to help reduce carbon footprints. Buildings are responsible for 34% of global energy consumption (Bahr, 2013; IEA, 2013) (Figure 1.1). This makes the building sector the largest contributor to global greenhouse gas (GHG) emissions (UNEP, 2015). Most of this demand is for space cooling and heating (IEA, 2011). Energy consumption for cooling is expected to increase dramatically by 2050 by almost 150% globally, and by 300% to 600% in developing countries (IEA, 2013).

With the growing interest in global warming and climate change, buildings have become more important worldwide but even more so in hot and arid climates. In this type of climate, passive and low-cost solutions, such as exterior shading, and low-emissivity window coatings and films, can have a curtailing impact on energy consumption and cooling loads (Fasi and Budaiwi, 2015; Hamza, 2008; IEA, 2013).

A wide range of strategies has been applied to minimise energy consumption, especially in office buildings. The International Energy Agency (IEA) has also recommended that in developing countries, new office buildings should be fitted with integrated façade systems that optimise daylighting while minimising energy requirements. Its report also asserts that exterior shading with proper orientation should become a standard feature in new buildings globally with a clear understanding of the window-to-wall ratio (WWR) (IEA, 2013).

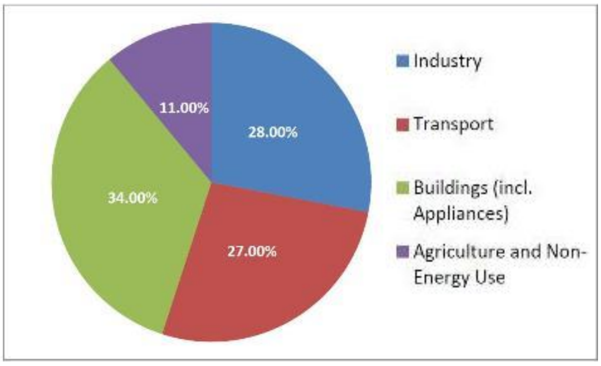


Figure 1.1 Global energy demand by sector (IEA, 2012)

Iraq has been at war for more than three decades, which has directly affected the building industry in many ways. Most of the government buildings – that are regarded as office buildings – and also private sector commercial and office buildings have either been destroyed, damaged or looted. Today, because of the absence of strict building codes and regulations, the increasing amount of new build is not considered to be energy efficient.

On the other hand, highly-or fully-glazed buildings have become a global trend in modern buildings (Aboulnaga, 2006; Bouden, 2007). Such buildings unquestionably put more demand on already overloaded energy resources and result in intensive use of air-conditioning to provide an acceptable indoor environment.

To date, there are no clear building codes or legislation to control the standards, construction, materials and the way buildings are designed in this country (Al-Taie et al., 2014). In the absence of such codes and legislation, the demand for highly- to fully-glazed buildings has been continuing at an unprecedented pace and in a very relaxed manner, which in turn has resulted in exponential growth in low quality buildings where the running and maintenance costs are high and the indoor environment is of poor quality (Figure 1.2).

Figure 1.2 Increasing number of highly-glazed buildings in Iraq

This effect can be seen in the intensive demand for electricity that has often exceeded the electricity supplied on a massive scale thereby causing regular power blackouts. The IEA Information and Analysis Unit reported that in 2010, Iraq was generating 8,000 Megawatts (MW) while the demand was 13,000-15,000 MW (IAU/UNDP, 2010), as shown in Figure 1.3. To date, there is still a wide gap between electricity supply and demand in Iraq especially in summer time where peak demand reaches its highest at 21,000 MW – which is when people turn on air conditioning systems to cope with temperatures of 50° - far exceeding the 13,359 MW that the Iraqi national grid is currently providing, according to Iraqi officials (Kalin, 2016; MOE, 2018).

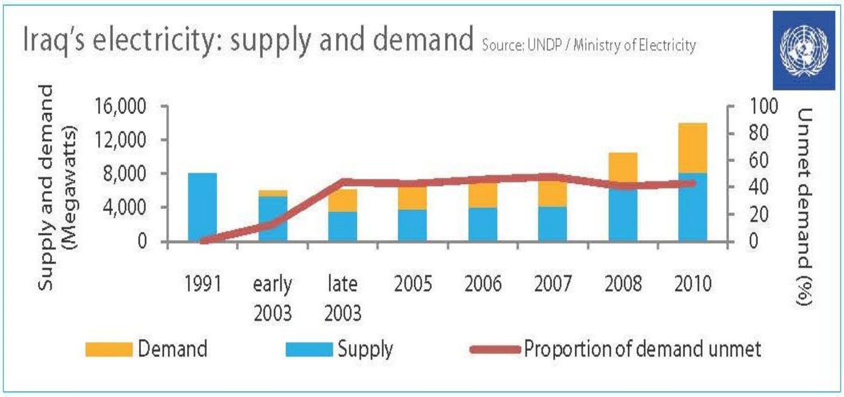


Figure 1.3 Iraq's electricity: supply and demand(IAU/UNDP, 2010)

Highly-glazed buildings have been developed in cold and warm climates and their performance has been investigated (Aboulnaga, 2006; Bojić and Yik, 2007; Bouden, 2007) but they are still the subject of research (Cuce and Riffat, 2015). This type of building has largely been adopted in hot countries as well, such as Iraq, but literally with very limited adaptation of the concept to make them appropriate for the hot and arid climate.

In order to improve energy consumption and the indoor environment, the undesirable heat, which is caused by the solar radiation inside the building, should be controlled alongside lighting through the careful study of design options (Bouden, 2007). This can be done by utilising appropriate thermal insulation, glazing type and shading elements to determine the energy exchange between the outdoor environment and indoor spaces (Sozer, 2010).

When properly designed, façade elements – such as shading devices – with careful consideration of climate and orientation, can save energy by up to 14.58% (Yassine and Abu-Hijleh, 2013); however, this result seems to be limited to their design. They go on to recommend that external shading devices should be considered during the early stages of design by performing shading calculations that are specific to the building type, climate and other elements.

Different types of façade elements, such as glazing systems, size of windows, type and position of shading devices, have large impacts on the energy efficiency of buildings. However, these elements showed a wide range of variation – most likely including contradictions – in the building performance where those elements are investigated (Poirazis et al., 2008). Those very same elements can also have negative impacts on other aspects, such as daylighting. Therefore, striking a balance between different aspects (e.g. between natural lighting and solar heat gain) becomes a prime objective if, and when, an improved energy and daylighting performance is aimed at. This means that a suitable integration of different façade elements can offer a successful solution to achieve trade-offs between rather contradicting functionalities.

1.2 Rationale

Integrated design has been gaining momentum in the built environment, architecture and design disciplines over the past two decades. One of the areas integration in design attempts to address is physical integration: fusing new technologies into conventional or established building systems, components, materials or detailing. Façades represent both a physical barrier between inside and out, and a medium to express or manifest architectural style, impression, school of thought or personal statement/signature of their designers or a combination of those. With recent advancements in technology, façades are presenting more and more opportunities as a canvas to put the idea of integration into practice and that is probably why the idea of Integrated Façade Systems (IFS), in general, and integrated PV Shading Devices (PVSD), in particular, are gaining momentum and attracting unprecedented levels of attention both in the theory and practice of design. IFS are systems where different technological solutions are integrated into the course of the building façade to improve performance and to lower the impact of the building. These technological solutions can broadly be classified under three categories, i.e. High-performance Glazing (HPG), Shading Devices (SD) and Photovoltaics (PV).

Although there have been advances in integrating solutions such as shading device technologies, the suitability of their application to different contexts are still subject to research. This is especially so in the context of the current study, Iraq, where research efforts that consider the energy performance of buildings have been limited. The fact that little research has been conducted in hot and arid climates, such as in the Gulf States in the Middle East, which have different climate characteristics and a different building construction industry, suggests that there is a need to develop knowledge on energy efficient building skins, especially for office buildings in Iraq, and likewise for similar climatic conditions.

1.3 Knowledge gap

Integrated façade systems are known to be systems where technological solutions are integrated into the course of the building envelope to help improve its performance and meet requirements above and beyond what has traditionally been expected to be achieved. The critical literature review in Chapter 3 revealed that most of the research is about how calibration of some parameters influences the performance of the system while knowingly or unknowingly freezing or excluding some others. Therefore, they were not able (or at least aiming) to realise or outline the problem in its entirety, which has, in turn, caused many contradictions in the findings of previous researches. Such contradictions are presented as a partial findings of the literature review in this study. The review also indicates that there are many interrelated factors, especially when trade-offs are aimed at in the design of integrated façade solutions. This means that any partial solution which aims to address but some of the aspects pertaining to the performance of façades using a positivist paradigm, where reductionist approaches are deployed, is destined to be easily challenged (if not falsified) if the overall performance of the façade is intended.

The typical dual functionality of shading devices, which is regulating daylighting, coupled with visual comfort on the one hand and controlling solar heat gain on the other, now has a third function in PVSDs, which is generating electricity. The trade-offs now are not aimed at being achieved only by striking a balance between two functions but with a third function, i.e. the production of solar renewable energy, which, in theory, results in reducing the energy and carbon footprint of the building and increases its environmental credentials. However, the balance between energy production and energy consumption remains to be a function of, or at least correlated with, the two other purposes that PVSDs are supposed to serve. The main components of IFS, namely PVSD and HPG, have been proved to have several advantages in this regard once numerous variables pertaining to them are taken into account and parametrically altered. Despite this very fact, to date there is no systemic investigation of the trade-offs between such output variables which IFS have direct impact on and the full benefits such façade systems can offer in this regard. As such, a full and comprehensive account of all potentially influential factors is still missing. It can be concluded that the application of IFS is far more complex than what appears in the literature to-date and still very much in its infancy. As these façade systems essentially comprise PV technologies, a handful of studies, which have been carried out to assess the energy production of PV panels in different climates, can be used as a reasonable starting point.

1.4 Research questions

In an attempt to fill the knowledge gap articulated in the course of a critical literature review of the research, this study set out to answer three research questions which are not mutually exclusive but rather they are interrelated, conditional and correlational questions, with the aim of contributing to the existing understanding of, and knowledge about, the area of the research. These questions are as follows:

1- Can IFS have an impact on a more environmentally-concerned approach to the design of buildings in hot and arid climates?
2- If IFS prove to have some level of impact on the approach to a more environmentally-concerned design of buildings, then how can some of the performance criteria pertaining to IFS be adopted and adapted such that, while the energy consumption of the building is kept under control, other major indoor comfort conditions can be improved so that a reasonable balance can be struck in the design and specifications of highly- to fully-glazed façades?
3- If IFS show they are capable of contributing to a more environmentally-concerned design of buildings with their components or pertaining criteria, then can a systemic approach be developed so that all potential significant variables can be accounted for, and evaluated proportionally, to be able to systematically contain, manage and configure different elements and parameters of IFS in order to strike a balance between the impacts that IFS might have on the environmental performance of the building in question?

1.5 Aim and objectives

This study aims to investigate the impacts of different configurations and elements of IFS on energy performance and indoor comfort conditions/natural daylighting to contribute to the theory and practice of designing highly- to fully-glazed office buildings in a hot and arid climate, utilising a systematic approach specially developed for this study through mapping out different determinants and elements of those systems in office buildings in this type of climate.

To achieve this aim, a set of seven objectives is presented as follows:

1. To establish the boundaries of this research by setting the contextual conditions of the study, the climate, the building type, simulation prerequisites and tools.

2. To evaluate the working principles and establish the thermal and illuminance performance of IFS.
3. To identify suitable IFS configurations and establish their physical and operational characteristics that may affect the building's energy and daylight performance.
4. To develop configurable simulation models of highly- to fully-glazed office buildings with combinations of the identified influential IFS components.
5. To simulate the building performance under different settings and combinations of parameters as determined in objective one and to monitor and evaluate the effect of change in those variables on the building performance.
6. To develop an approach to systematically investigate the influential factors in the design and configuration of façade systems.
7. To evaluate and optimise the operational energy and daylighting of highly- to fully-glazed office buildings with IFS.

1.6 Outline methodology

Three main stages, which are not parallel but rather in series, form the outline of the methodology of this research. The first stage includes a professional survey to find out about the prevailing typologies in office buildings in Iraq to inform the following stage. The type of data intended for the first stage is qualitative and builds upon the working experience of Iraqi practising architects, whereas the type of data, which the second stage onwards would be dealing with, suggests quantitative methods would be the most appropriate ones to generate, handle, collate, analyse and interpret those data. A representative building typology is developed based on the outcome of the first stage that is used for data generation, which will be carried out using building simulation modelling in the following stage. The second stage is mainly about the development of a generic model that represents highly- to fully-glazed buildings in the context of the study, followed by defining the key parameters that affect the assessment criteria based on the literature review. The final stage comprises two sub-stages: 1) simulation of the models and 2) analysis of the results. This methodology outline will be further discussed and detailed in CHAPTER 4.

1.7 Research Contribution

It is essential to clearly understand the variations in, and the impact of, different façade elements, such as shading devices and glazing system combinations and even more so when those elements are integrated and perceived as one system in IFS. In order to develop models which will help establish the combined effects of different alternatives of IFS for each orientation in a certain climate and for a certain building type, this research introduces a comprehensive and holistic methodology where the topic is looked into through the lens of the 'Systems Theory'. This has been done to ensure that:

1. This research is not missing out any potentially influential parameter or any possible combination of those parameters which may have some impact on the overall performance of the IFS.
2. This research is not destined to fall into some of the common traps or forced to give in to some limitations which may subject its findings to some conditions imposed from the outside of the boundaries and scope as set in, for and by this research.
3. This research provides a methodological frame of reference which can serve a broader purpose than that intended and delivered by it.

To fulfil the above intended goals, this methodological approach has been developed with twofold benefits in mind; both at theory and practice levels. Not only can it facilitate the systematic studies of the topics related to those of this research, but it can also help classify the impacts of the parametric alteration of all variables, and further provides a decision support system for the course of intervention or action when it comes to proposing design solutions for practical applications of building façades.

The study proposes a modular structure for this methodology, which facilitates its high flexibility and customisability to best suit different study-specifics and contextual conditions. In doing so, it will benefit from a main underlying core structure to support all possible contextual, building and façade elements that can be included and parametrically altered as plug-ins (or add-ons) which are compatible and will work with the main backbone structure of the methodology. Although this methodology is formulated using the particular context-specifics of Iraq, it is designed to be modular and customisable in order to provide flexibility to allow this methodology to be used globally (Figure 1.4).

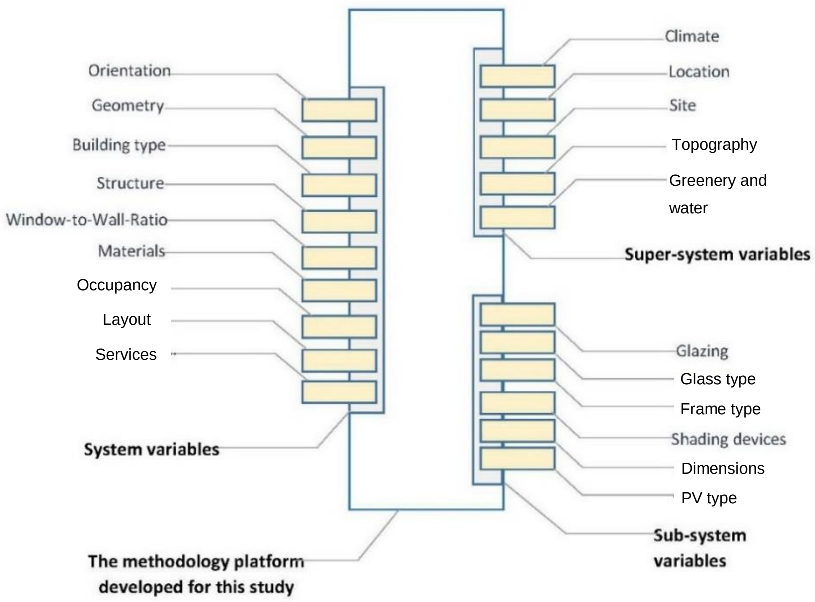


Figure 1.4 Customisable/modular methodology developed in this research

The systemic method developed for mapping, and used as the basis for inclusion/exclusion criteria of the boundary settings and contributing factors, is one which is believed to be capable of being adopted and adapted to many other studies where parametrisation is key to, or the focus of, the study.

This research – in addition to its contribution as a theoretical/methodological frame of reference and a design decision support tool – will also provide a key contribution to legislation and policy by providing information and support for the preparation and proposal of comprehensive building codes and regulations in Iraq; what is now in its early stages of development.

1.8 Structure of the thesis

This thesis encompasses eight chapters, in addition to the appendices. A brief description of each chapter and the appendix is presented as follows:

Chapter one- (current chapter)

An introduction to the topic is presented in this chapter including the background, the problem, the rationale and the knowledge gap; then research questions are posed followed by the aim and objectives of this research. An outline methodology is presented and finally the structure of the thesis is proposed.

Chapter two- Review of the research context

In this chapter an overview of the context of the research is presented in order to understand the influence of climate on building performance as the building and its envelope work in response to those factors. The patterns of those factors are analysed in order to highlight the impact they may have on the buildings and show the viability of the use of integrated PVSD and HPG in Iraq as an effective passive strategy that can mitigate the negative impacts of building on the environment.

Chapter three

This chapter reviews the state-of-the-art of the current body of literature on IFS and its main components: SD, HPG and PVSD. A detailed review of the literature on these components is presented, explaining the working principles of the technology when applied to highly- to fully-glazed façades. A systematic approach is developed to facilitate the study of literature on this topic. The chapter concludes with a set of parameters, which are expected to have an influence on the thermal and visual performance of buildings with IFS in hot and arid climates, and these are then analysed and categorised systematically.

Chapter four

The approach developed specifically for this research is presented followed by research design and the proposed methodology of this study based on the knowledge gained from the literature review. A closer look at the main research methods for evaluating building energy performance is taken in this chapter where those methods are analysed, to enable the selection of the appropriate methods for this research.

Chapter five

A detailed description of strategies adopted in and the process of data generation for this research are presented in this chapter. It describes the outcomes of the professional survey that informed the process of model development. The key parameters selected for evaluation, the modelling and simulation processes, and the procedures used to demonstrate the influence of each individual key parameter on the building's thermal performance, are elaborated on in this chapter.

Chapter six

Analysis of the results is presented in this chapter, demonstrating the influence of each individual key parameter on the building's thermal and visual behaviour. It also includes the development and analysis of the models, which utilise a combination of solutions to strike a balance between the main three functions of

IFS. Results are presented for energy and daylighting. Sensitivity analysis of the results will also be presented and discussed in this chapter.

Chapter seven

This chapter puts the findings of the study back into the broader context of the knowledge in this field and triangulates them with the state-of-the-art literature, providing the ground for the conclusions of the study.

Chapter eight

Chapter eight summarises and concludes the study based upon reflections on the discussion of the findings. It also points out the limitations of the research and speculates on further studies that might emanate from this study.

These chapters are followed by references and appendices. Appendix 1 includes the publications written so far over the course of this research. Those include: 1) journal papers 2) conference papers and book chapters.

Appendix 2 includes a summary table of available HPGs that have been collected from the literature, categorised, described and their best achieved performance listed.

Appendix 3 presents a summary and review of available façade assessment tools that have been used globally to assess the performance of buildings when glazing types and shading devices are the main focus.

Appendix 4 presents a review of methodologies and approaches to glazing selection.

Appendix 5 includes the remote questionnaire survey form which was devised and deployed for the data collection at the first stage of the research methodology.

Appendix 6 presents snapshots of the LBNL Windows 7.5 interface where the glazing systems were generated to be imported into the IES-VE construction library.

Appendix 7 includes the full set of dynamic simulation results for both energy and daylighting at all of the investigated orientations.

Appendix 8 presents PVSD product specifications and dimensions that have been collected from the relevant literature and manufacturers' websites and catalogues.

Appendix 9 includes the full set of graphs of all combinations that have been generated for phase one of the analysis for south-east and south-west combinations.

Appendix 10 contains further details of the assumptions of linear regression analysis for the sensitivity analysis of the results.

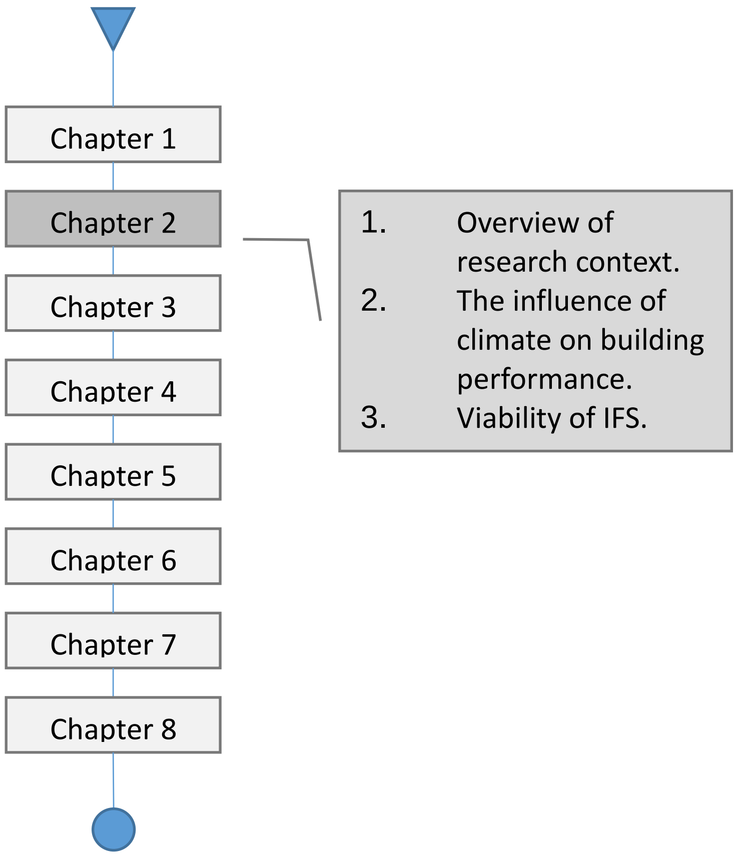
Appendix 11 presents decisional synopses tables of combinations at south-east and south-west orientations.

Appendix 12 contains the results of the base-case scenario for all of the investigated orientations in this study.

And finally, Appendix 13 contains the results of Predictor Importance that have been discussed in the sensitivity analysis of all input/output variables.

Chapter Two

Review of the Research Context



CHAPTER 2. REVIEW OF THE RESEARCH CONTEXT

2.1 Introduction

In this chapter an overview of the context of the research is presented in order to understand the influence of climate factors on building performance as the building and its envelope work in response to these factors. The patterns of these factors are analysed in order to highlight their impact on buildings and show the viability of the use of IFS in Iraq as an effective passive strategy that can mitigate their negative impact.

2.2 Outline of the study context

Climate is essentially characterised by: solar radiation, ambient temperature, air humidity, precipitation, wind and sky conditions (Nayak and Prajapati, 2006). Iraq lies between latitudes 29° and 38° N, and longitudes 39° and 49° E. covering 437,072 km^2. According to the Köppen-Geiger Climate Classification world map (Rubel and Kottek, 2010; Peel et al., 2007), most of Iraq has a hot arid climate with subtropical influence, as shown in Figure 2.1.

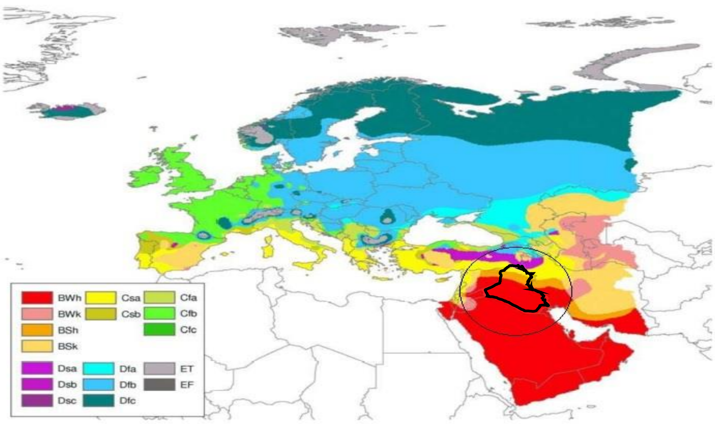


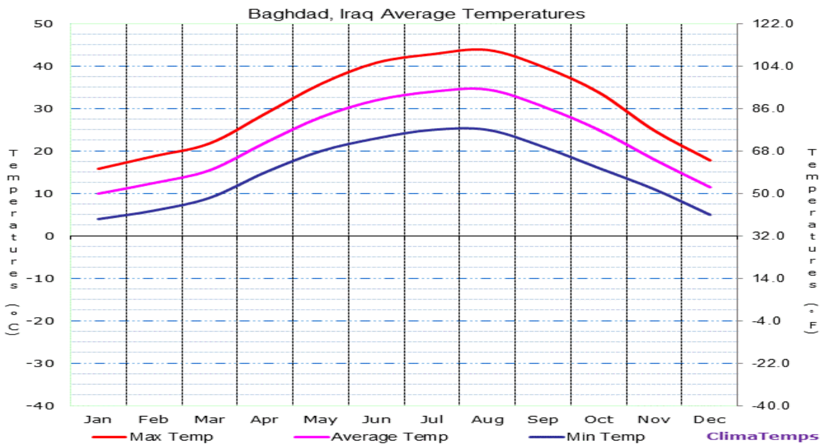
Figure 2.1 Köppen-Geiger Climate Classification-Middle East and Europe. Updated by Peel et al. (2007)

Summer temperatures average above 40°C for most of the country and frequently exceed 48°C. Winter temperatures infrequently exceed 21°C with maxima roughly 15 to 19°C and night-time lows 2 to 5°C. Typically, precipitation is low; most places receive less than 250 mm annually, with maximum rainfall occurring during the winter months. Rainfall during the summer is extremely rare, except in the far north of the country. The most challenging factors in this climate are the direct solar radiation and dust storms (Kazem et al., 2014).

Baghdad has been chosen as the city where the investigations are carried out. Baghdad, the capital city of Iraq, is located at 33°13'N, 44°13'E, and altitude is 34 m. It has a subtropical desert/low-latitude arid hot climate. What is known in the Köppen-Geiger classification as BWh. According to the Holdridge life zones system of bioclimatic classification[1], Baghdad is situated in or near the subtropical desert biome. The average temperature in Baghdad is 22.8°C. The variation in mean monthly temperatures is 24.5°C, which is a below moderate range. The average diurnal temperature range/variation is 15.6°C. The warmest month is August with an average temperature of 34.5°C. January is the coolest month with a mean temperature of 10°C (CLIMATEMPS, 2015), as shown in Table 2.1 and Figure 2.2.

Table 2.1 Monthly and annual climate variables of Baghdad/Iraq (CLIMATEMPS, 2015)

Climate Variable	Jan	feb	mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Temperature °C	16	19	22	29	36	41	43	44	40	34	25	18	31
Average Temperature °C	10	13	16	22	28	32	34	35	31	25	18	12	23
Average Min Temperature °C	4	6	9	15	20	23	25	25	21	16	11	5	15
Average Precipitation mm	26	28	28	17	7	0	0	0	0	3	21	26	156
Number of Wet Days	5	5	6	4	2	0	0	0	0	1	5	6	34
Average Sunlight Hours/ Day	6	7	8	9	10	12	11	11	10	9	7	6	9
Average Daylight Hours/ Day	10h 12'	10h 56'	11h 55'	12h 58'	13h 51'	14h 18'	14h 06'	13h 20'	12h 19'	11h 16'	10h 24'	9h 58'	12h 00'
% of Sunny Daylight Hours	62	67	67	67	71	82	80	86	86	79	69	64	73
% of Cloudy Daylight Hours	38	33	33	33	29	18	20	14	14	21	31	36	27
Sun altitude at noon on 21st day(°)	36.8	46.1	57	68.7	76.9	80.2	77.1	68.8	57.4	45.9	36.8	33.4	57.1



[1] The Holdridge life zones system is a global bioclimatic scheme for the classification of land areas. It was first published by Leslie Holdridge in 1947, and updated in 1967. It is a relatively simple system based on few empirical data, giving objective mapping criteria (EPA-US Environmental Protection Agency). A basic assumption of the system is that both soil and climax vegetation can be mapped once climate is known (Harris SA,1973).

Figure 2.2 Average dry bulb temperature of Baghdad/Iraq (CLIMATEMPS, 2015)

It can be seen in Figure 2.3 that the total annual precipitation averages 156 mm which is equivalent to 156 litres/m². On average there are 3244 hours of sunshine per year (CLIMATEMPS, 2015).

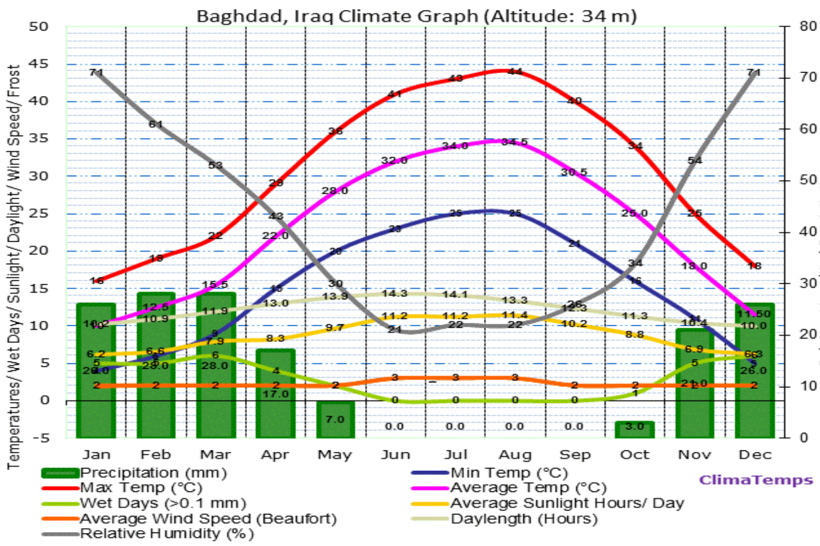


Figure 2.3 Climate graph of Baghdad/Iraq

2.3 Average temperature

The months of March, April and November have a pleasant average temperature. The hot season/summer is from April to October. On average, the warmest month is July and the coolest month is January. The monthly mean minimum and maximum temperatures over the year in Bagdad, Iraq are shown in Figure 2.4.

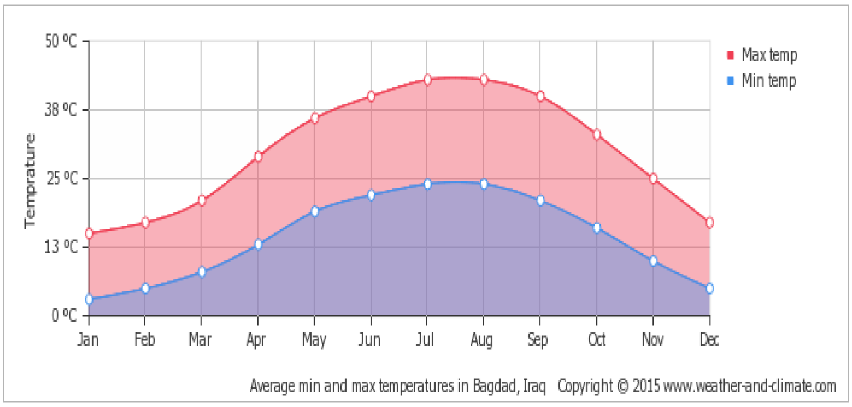


Figure 2.4 The monthly mean minimum and maximum temperatures over the year in Bagdad, Iraq[2]

2.4 Average monthly sunshine hours

[2] www.weather-and-climate.com

On average, August is the sunniest month and January has the lowest amount of sunshine. The monthly total sunshine hours over the year in Bagdad, Iraq are shown in Figure 2.5.

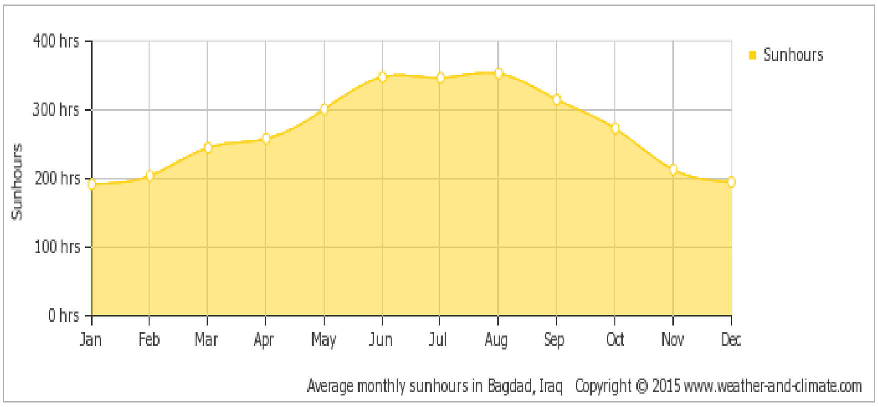


Figure 2.5 Average monthly sunshine hours, Baghdad/Iraq www.weather-and-climate.com

2.5 Average humidity

On average, December is the most humid month; July is the least humid month. The monthly mean relative humidity over the year in Bagdad, Iraq is shown in Figure 2.6.

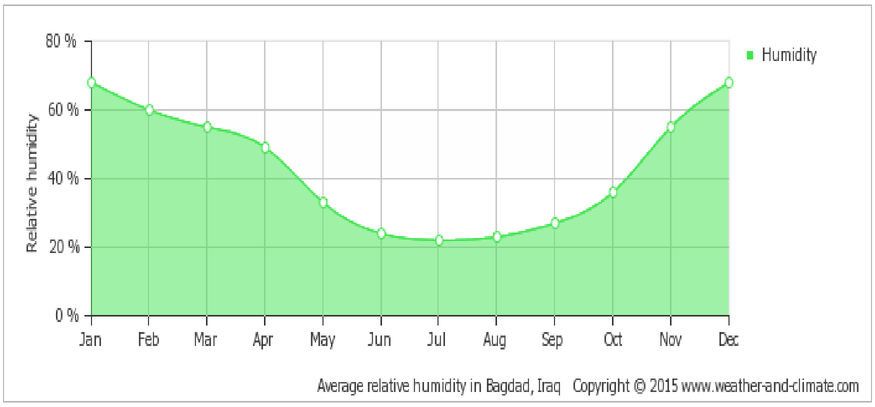


Figure 2.6 Average relative humidity, Baghdad/Iraq www.weather-and-climate.com

2.6 Average wind speed

On average, the most wind is seen in August; the least wind is seen in December. The mean monthly wind speed over the year in Bagdad, Iraq (metres per second) is shown in Figure 2.7.

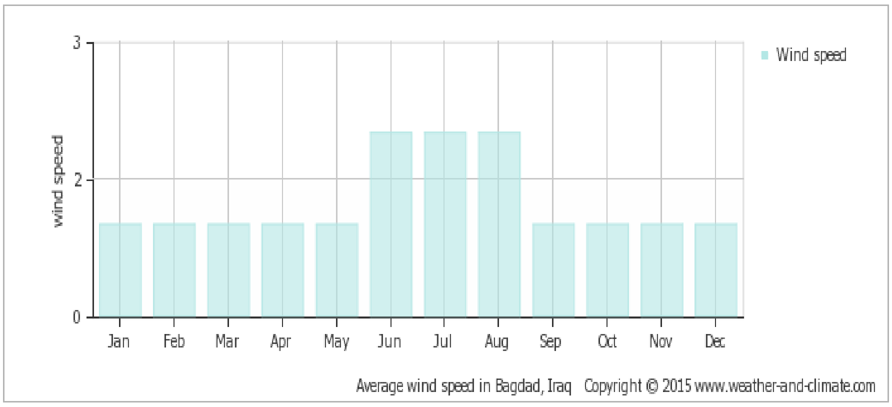


Figure 2.7 Average wind speed, Baghdad/Iraq www.weather-and-climate.com

2.7 Average global solar radiation

Looking at Iraq's location on the Global Horizontal Irradiation (GHI) map in Figure 2.8, it can be seen that Iraq lies in the area that has over 2300 KWh/m² of horizontal irradiation per year (Al-Helal, 2015). This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHI) as it refers to the total amount of shortwave radiation received from above by a surface horizontal to the ground.

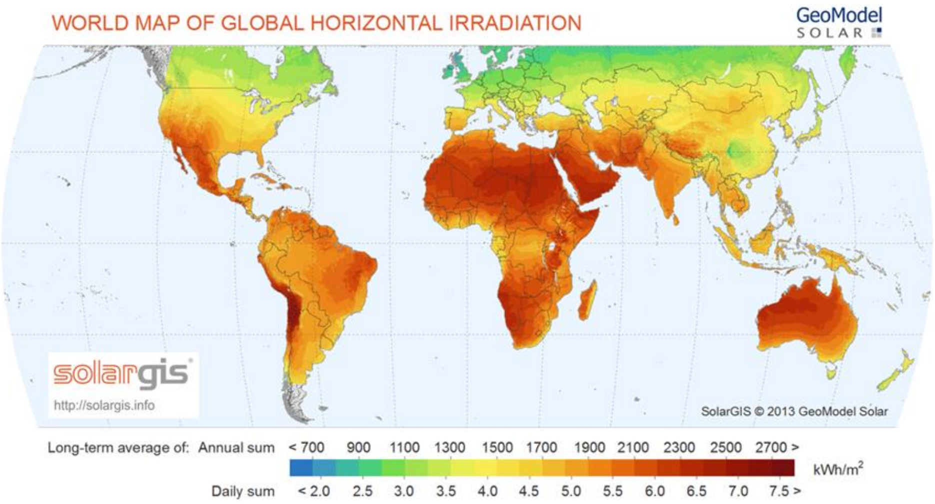


Figure 2.8 World map of global horizontal irradiation[3]

In a more detailed view, in the location of Baghdad city, which this study intends to investigate, the DNI received in Baghdad is around 1800 kWh/m^2 (Figure 2.9). This quantity is of particular interest for concentrating solar thermal installations and installations that track the position of the sun. It also shows that special care needs to be taken to mitigate the negative effect of this quantity of irradiance on buildings.

[3] http://solargis.info/doc/_pics/freemaps

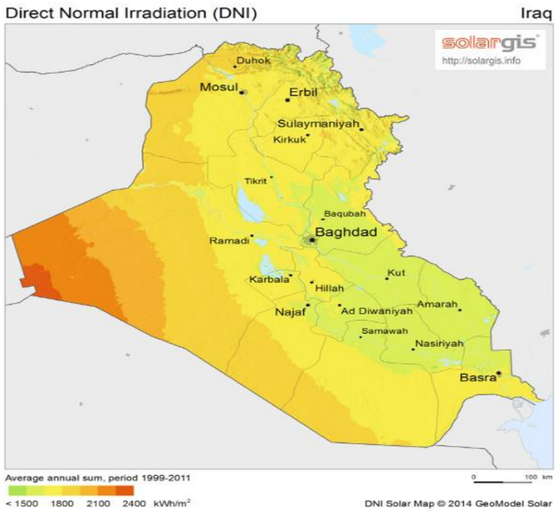


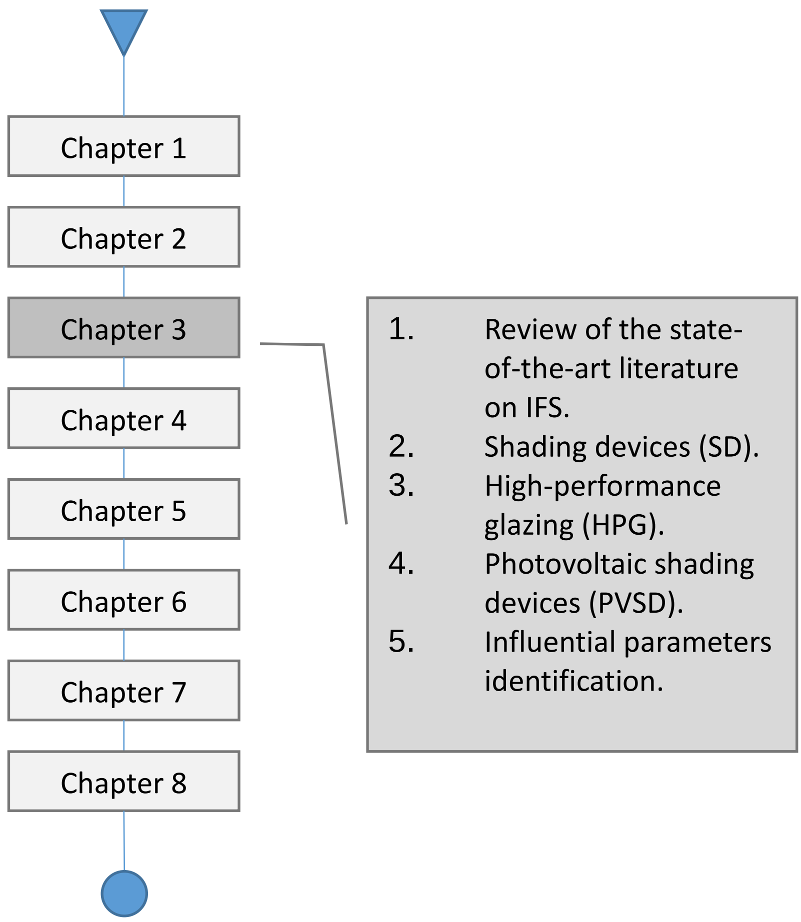
Figure 2.9 Direct normal irradiation DNI in Iraq[3]

2.8 Summary

The climate context analysis is the initial fundamental evaluation of the conditions surrounding the building. This analysis helps the designer to identify the seasons during which the occupants of a building may experience comfortable/uncomfortable conditions. The climatic analysis indicates the possible passive design strategies –such as shading devices and high-performance glazing – that can be applied to buildings in order to improve energy consumption of mechanical systems and indoor comfort conditions. The amount of sunny days throughout the year provides a good opportunity for generating solar power; however, it is regarded as the most significant climate factor that influences the thermal/visual performance of the building envelope. The next chapter will review the relevant literature where attempts have been made to provide good grounds for developing the research arguments, highlighting the knowledge gaps where further research is needed and developing a methodology that leads to filling these knowledge gaps.

Chapter Three

Literature review



CHAPTER 3. LITERATURE REVIEW

3.1 Introduction

A comprehensive review of the existing body of knowledge on the main constituents of IFS published over the last decade has been carried out. Some examples of older but seminal contributions have also been included in this review. The literature review aims to provide an in-depth understating of the shading systems, high-performance glazing (HPG) and integrated PVSD as the main components of IFS. The characteristics of each component and their impact on energy consumption, daylighting and electricity generation will be investigated to highlight the main findings of the related studies. The knowledge boundaries of this subject will be defined, links between these components that facilitate their integration will also be established to understand how the combined system in form of IFS can be studied, analysed and improved, questions will be formed and the methods to answer these questions will be identified.

The review also aims at establishing the criteria for the selection of these components, which will be investigated further under the umbrella of IFS. The most relevant outcomes will be synthesised and a summary of the chapter contents will be presented to be used in the following chapters to help build up the envisaged contribution of this research.

3.2 Integrated Façade Systems (IFS)

In hot and arid climates, solar protection is a strategy that has proved to be one of the most effective approaches to control solar heat gain (Carmody and Haglund; 2006; Bellia et al., 2013; Freewan, 2014). With highly glazed façades, it becomes more crucial to integrate shading with glazing to achieve optimum performance (Cellai et al., 2014a); however, integral glazing/shading systems are rarely considered although they improve both overall energy performance and visual comfort (Capeluto and Ochoa, 2006).

Office buildings represent a challenge for reducing energy consumption since they are characterized by high internal loads due to electrical equipment and illumination. Office buildings are also characterized by large fenestrations in order to provide sufficient natural daylighting (Mazzichi and Manzan, 2013). Solar shading and HPG are both recommended, in climates with intensive solar radiation throughout the year, to reduce solar gain and control daylighting and glare (Awadh and Abuhijleh, 2013; Ochoa et al., 2012).

To strike a balance between energy and carbon footprint at one end, and indoor comfort conditions of the building, at the other, by the means of building façades, IFSs are introduced; systems where different technological solutions can be integrated to improve performance and to lower the impact of the building. Although IFS have been used in a very broad meaning, mostly concentrating on: BIPV in general, services integrated in facades or construction, facades customisation and installation. The first comprehensive and inclusive definition of IFS is probably introduced in this doctorate research project but it is based on the previous attempts where the combined impact of integrating glazing and shading have been considered. This said, IFS has got a broader scope than what the current research concentrate on but for the sake of the research size, depth and breadth appropriate to the doctorate research protocol, this very specific area of IFS have been chosen to concentrate on. Therefore, IFS in this research will include the technological solutions that can broadly be classified under three categories: High-Performance Glazing (HPG), Shading Devices (SD) and Photovoltaics (PV).

This integration can have a significant impact on controlling solar heat gain/loss, improving energy use for cooling/heating (Poirazis et al., 2008; Farrar-Nagy et al., 2000), enhancing human indoor comfort conditions (Atzeri et al., 2014; Poirazis et al., 2008) and eventually contributing to the efforts of GHG emissions (IEA, 2011). The reduction in annual cooling loads in hot climates can be improved by up to 6% using SD and 10% integrating SD with glazing lowering the heat gain by up to 41% (Awadh and Abuhijleh, 2013). Better results from an earlier study indicate that reduction in cooling loads can be up to 30% (Farrar-Nagy et al., 2000). Farrar-Nagy et al. (2000) investigated combinations of HPG and shading in the hot arid climate of Arizona where 0.4 kW (14%) reduction in peak electricity demand and 12.4 kWh (30%) reduction in daily cooling energy were achieved against the same house with standard double-glazed windows with no shading. Energy and visual performance of combinations of electrochromic glazing and overhang with different positions and control was assessed by Lee and Tavil (2007). They concluded that a reduction of 10% and 5% was achieved in cold and hot climates respectively. HPG would enhance the energy and daylighting performance of the buildings but the impact of other factors such as orientation and geographical location is also significant (Huang et al., 2014). The variation in results can be caused by different configurations, the building type or the building orientation. These factors were found to be highly implemented solutions for integration (Huang et al., 2014).

Some attempts in the previous studies have been reported, where fully-glazed façade was studied. It was found that while those facades allow enormous solar gain, they can still lower energy consumption when glazing and shading are properly integrated. For example, the reduction can be up to 15% (100% glazed alternative compared to a typical reference building with 30% window-to -wall ratio) and at the same time maintaining an acceptable level of thermal comfort (Poirazis et al., 2008). The authors included WWR alternatives, in addition to different shading and glazing configurations and hence possible solutions can be determined such as 55%, however, the results might not be applicable to other percentages, such as Thalfeldt et al. (2013).

Different typologies of windows and SD (fixed shading, mobile shading, roller blinds, and curtains) have different effects and each performs in a totally different way. This is probably based on the orientation of the building (Ebrahimpour and Maerefat, 2011), type of glazing when considering combined effect (Manzan, 2014) and the geographical location where solar radiation and solar angle vary (Cellai et al., 2014a).

Some researchers devised a detailed table of comparative analysis for evaluating different typologies (Cellai et al., 2014a), whereas others suggested an energy rating tool for appropriate SD type, such as overhangs or side fins on the south, west and east windows. Those SDs led to the optimal reduction of the annual energy, in form of heat transferred into the buildings, and can have an improved energy behaviour that is equivalent to HPG (Ebrahimpour and Maerefat, 2011).

Other studies have investigated the impact of different glazing systems on energy consumption but limited variations of shading devices and climate conditions, where it is claimed that the electricity consumption for lighting has been considered in devising an energy-efficient SD (Manzan, 2014).

When aiming to choose optimum façade solutions, a detailed simulation would be the best approach (Tzempelikos et al., 2007), as it facilitates inclusion of as many variables as possible. However, there should be an efficient and rather practical way of doing so whose significance and necessity seem to have widely gone unnoticed and overlooked by the previous research up until now.

To date, only few researches have attempted on investigating comprehensively and holistically these two solutions in different climates and orientations. But it is imperative to note that these two conflicting factors – providing a good amount of daylighting and providing protection from direct solar radiation – make an optimum design for transparent envelope of a building a very hard-to-achieve task (Huang et al., 2014; Goia et al., 2013).

To conclude so far, achieving low energy use and acceptable thermal/visual comfort is possible when the careful design of façade elements e.g. type and size of windows, position of SDs and the distance between SDs to name but a few.) is targeted, especially for highly glazed buildings; however, there are a number of factors that have a significant effect on the results. These factors affect the performance in different aspects, on different levels, and are interrelated with all areas of this topic.

Studies concerned with integrated glazing and shading in building design consist of two different sub-categories based on their level of influence, i.e. climate, site, building shape, glazing type and SD configurations, etc. Most often, design considerations of these factors cannot directly be changed or modified. This is because the level of control of designers is limited over those considerations, such as climate condition, topography, etc. Design configurations by contrast can be changed by the designer and are accounted for as a part of the project that can be shaped by the design process. Such variables include building orientation, building geometry, size and geometry of opening and their sub-elements, e.g. their location, height, shape, form, angle, etc. In order to facilitate studying and investigating these factors in a more effective and systemic manner, these variables and considerations are reviewed and analysed under three categories: context, building and component, based on their level of influence and the level of control of designers over those factors. This will be further discussed in section 3.5.2 where the systemic approach was developed for this study.

The results of the review of the literature indicated that some factors are context-specific, some others are related to the external envelope (skin), while some are more about at the components level which are to be taken into account when configurations of variables such as SD, HPG and PVSD is intended. These are all interrelated and the integration of variables should therefore be looked into as a whole and at different levels of influence to help gain a more holistic overview of all possible factors, and within the context-specific issues that need to be considered when IFS is implemented (Figure 3.1). This will pave the way for a full parametric approach to studies of a nature similar to that of this study.

Using an approach informed by the Systems Theory, the review of literature on these elements will be conducted which will then be used for mapping the key factors and for establishing the levels of their influence. Therefore, the next sections will review the related literature of SD, HPG and PVSD to help build towards introducing a comprehensive and holistic methodology that takes all influential factors into consideration in a systemic manner.

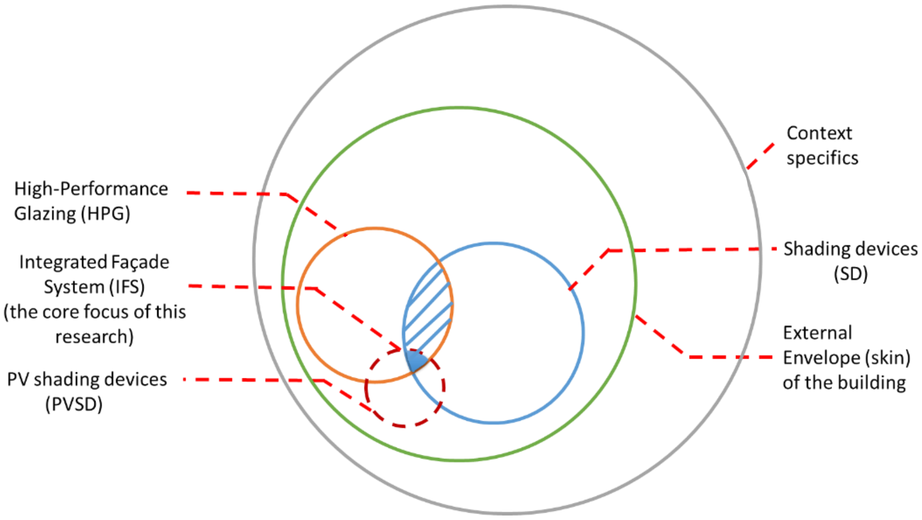


Figure 3.1 Venn diagram showing the areas of the research in this field and the scope of the current research

3.3 Shading devices (SD)

The critical review of the literature in this section will focus on the design of SD which is affected by many considerations and factors that are context-specific, related to the external building skin and also inter-linked to other combinations of variables, such as glazing and other integrated elements (e.g. PV), as seen in Figure 3.1. SD definitions, classifications, functions and the influence of SD on building performance will also be reviewed to build the links to the bigger picture of this study, IFS, to map the literature, highlight the gaps and extract key conclusions to inform the development of the model for the current study.

The definition of the SD has witnessed quite a radical change over the past decade or so, most likely due to the definition and pace of change of the technologies which have been used to manufacture, install or operate them. In earlier definitions, integration seems to be a key characteristics (see for instance Olbina and Beliveau (2004) and CIBSE (2006) among others) while the more recent ones seem to have taken a more liberated approach in their definitions (see for instance Cellai et al. (2014b)).

It is however the function of the SD which has almost always been imperative to all definitions associated with this technology. This is supported by some robust institutions, such as the RIBA where two main functions of solar SD were defined; reducing the total amount of radiation entering the room by reflection/absorption and improving the distribution of the light in the room.

Many classifications of SD have been found in the literature (Cellai et al., 2014a; CIBSE, 2006; Dubois, 1997; Robinson and Selkowitz, 2013; Olgyay, 1963; Rungta and Singh, 2011). Classification of SD can be based on one or more of the following criteria: type of SD, location of the SD, operation and material.

In a more detailed view, Olgyay (1963) and Dubois (1997) classified SD according to their shading coefficient[4] from the least to the most effective in reducing solar radiation as follows: 1) Venetian blinds, 2) roller shades, 3) insulating curtains, 4) outside shading screen, 5) outside metallic blind, 6) coating on glazing surface, 7) trees, 8) outside awning, 9) outside fixed shading device, and 10) outside movable shading device. This classification, however, is very specific to certain manufactured types and cannot be generalised because of the continuous advancement in technologies, therefore, a basic classification should suffice when designing SD and then a further classification can be made in detail, according to the project for which it is designed.

The parameters of different SD that influence the energy use, thermal and visual comfort in buildings are numerous and they affect the building performance at different levels; context level such as climate, geographical location, building

[4] Shading coefficient is the fraction of solar heat gain that passes through a transparent solar aperture compared to the amount of solar radiation incident upon it and is expressed as a decimal value without units between 0 and 1. Standards are now moving away from a previous standard, referred to as Shading Coefficient (SC), to Solar Heat Gain Coefficient (SHGC), which is defined as that fraction of incident solar radiation that actually enters a building through the entire window assembly as heat gain. To perform an approximate conversion from SC to SHGC, multiply the SC value by 0.87 (CARMODY, J. 2004. *Window systems for high-performance buildings,* New York, Norton.

shape (Palmero-Marrero and Oliveira, 2010; Bellia et al., 2013; Goia et al., 2013), building level such as orientation (Alzoubi and Al-Zoubi, 2010; Atzeri et al., 2013) and façade elements level such as dimensions of SD (Ebrahimpour and Maerefat, 2011; De Lima et al., 2013; Manzan, 2014), angle of SD (Ossen et al., 2005; Palmero-Marrero and Oliveira, 2010), location of SD (Eicker et al., 2008; Atzeri et al., 2014). These parameters however are interrelated and their effect needs to be examined under specific contexts (De Lima et al., 2013) and building type (Carmody and Haglund, 2006). The level of influence of these factors changes, based on the focus or nature of the study (Manzan, 2014). Therefore geometric optimisation can be a powerful tool for the designer, as it shows the influence of SD on buildings energy use.

Although this may sound quite obvious, studies have been carried out to investigate the role of location of the shading system on user's comfort in buildings. O'Connor et al. (2013), for instance, used this classification to carry out a study on shading devises with special reference to their location where their finding indicate that occupant visual and thermal comfort can significantly be improved while minimizing mechanical cooling loads.

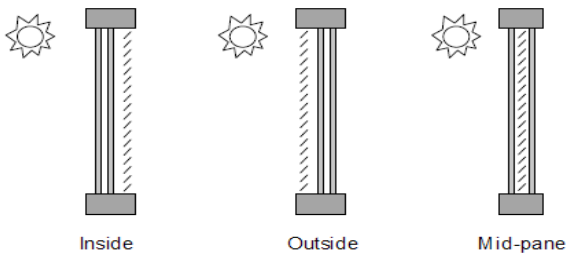


Figure 3.2 Locations of shading devices

Outside (external) Location of the shadings in buildings is preferable/desired/favoured. Because located externally it could reduce energy transmission of solar radiation by up to 90% as opposed to internally placed ones which are effective by only 55% (Eicker et al., 2008). Atzeri et al. (2014) concur that external systems always perform better than internal ones in terms of thermal, visual comfort and overall primary energy use. To improve solar control, using selective glazing can provide more useful daylight for up to 80% of the working hours in offices (Goia et al., 2013).

The impact of shading devices on thermal and visual comfort can significantly vary. This variation can be caused by many factors, such as the type of building and its orientation (Ali and Ahmed, 2012) or the typologies of SD used (Al-Tamimi and Syed Fadzil, 2011) or in more detail, the dimensions of the SDs (Ali Ahmed, 2012). In a residential building in Egypt, Ali and Ahmed (2012) studied the impact of different SD on the thermal performance, where different SDs for different orientations were simulated and analysed. The results show that vertical fins offer a reduction of 1.5°C in indoor temperature for the northern, eastern, and western orientations, whereas combined devices (e.g. egg-crate) also reduce the temperature by 1.5°C for the southern orientation. Although the building type was residential, the results may vary in the case of high-rise residential buildings. This was proved by Al-Tamimi and Syed Fadzil (2011) where combined shading (horizontal louvre + vertical side fins) were found to have a significant impact on decreasing discomfort times[5], compared with other shading types (horizontal or vertical). This variation may be caused by building configuration, climate, height of the building and orientation.

However, changing or calibrating the dimensions, such as depth, can dramatically change the effect of these SD (Ali Ahmed, 2012); the author studied the effects of vertical louvres' length on the thermal performance of residential buildings in Egypt. The results of the study showed that the vertical louvres with a protrusion of 38 cm or more result in a decrease of 2°C in indoor temperature in all four orientations. However, this result is exclusive to the type and dimensions of the investigated SDs and may not apply to other configurations, especially when the SDs are set up on an independent external skin of the building. In this case, other variables, could influence the thermal performance much more than simply the dimension of the DSs. Hence a need for a more holistic and comprehensive analysis is still lacking.

The quality of daylighting in buildings is highly influenced by the type and orientation of SD. Different types such as vertical and horizontal have different effects (Alzoubi and Al-Zoubi, 2010); they examined the effect of vertical and horizontal SD for south-facing façades on the quality of daylighting in buildings and the associated energy saving. They analysed the correlation of the illuminance level to the expected energy saving in buildings. Their study concluded that there

[5] Discomfort time is a technical term refers to the number of the hours or percentage of time during which indoor dry bulb temperature falls either below or above the human comfort temperate range.

is an optimal orientation for SD that keeps the internal illuminance level within the acceptable range while minimising the amount of solar heat gain.

The selection and design of SD depends on many determinants. Previous research has suggested routes of which this decision can be made. For example Olbina and Beliveau (2004) suggests that a decision-making framework (DMF) is used to make decision about the optimum design of SD (Figure 3.3). This suggests that the selection and design of SD should be based on variables that influence the SD daylight performance.

However, this might not be agreed by other researchers because some have suggested alternative routes (Ossen et al., 2005). While some others agree to this recommendation or suggested proposition but to some extent because they also take into account the daylight variables but they add other measures, such as solar gain (Kirankumar et al., 2018) or SD material (Haghighi et al., 2015) to help make the decision.

To sum up this point, DMF can be a useful tool but only if the investigation is solely focusing on daylighting performance and limited to a single type of SDs. (Venetian blinds). Furthermore, the fact that the study was focusing on office buildings where internal heat gain is highly influenced by appliances e.g. computers and artificial lightings, makes the subsequent energy use in the building highly influenced by the installation of SD. Therefore, it is of paramount importance to include all the influential factors on energy performance, especially in studies where combining SD with HPG are intended, which the study of Olbina and Beliveau (2004) did not take into account.

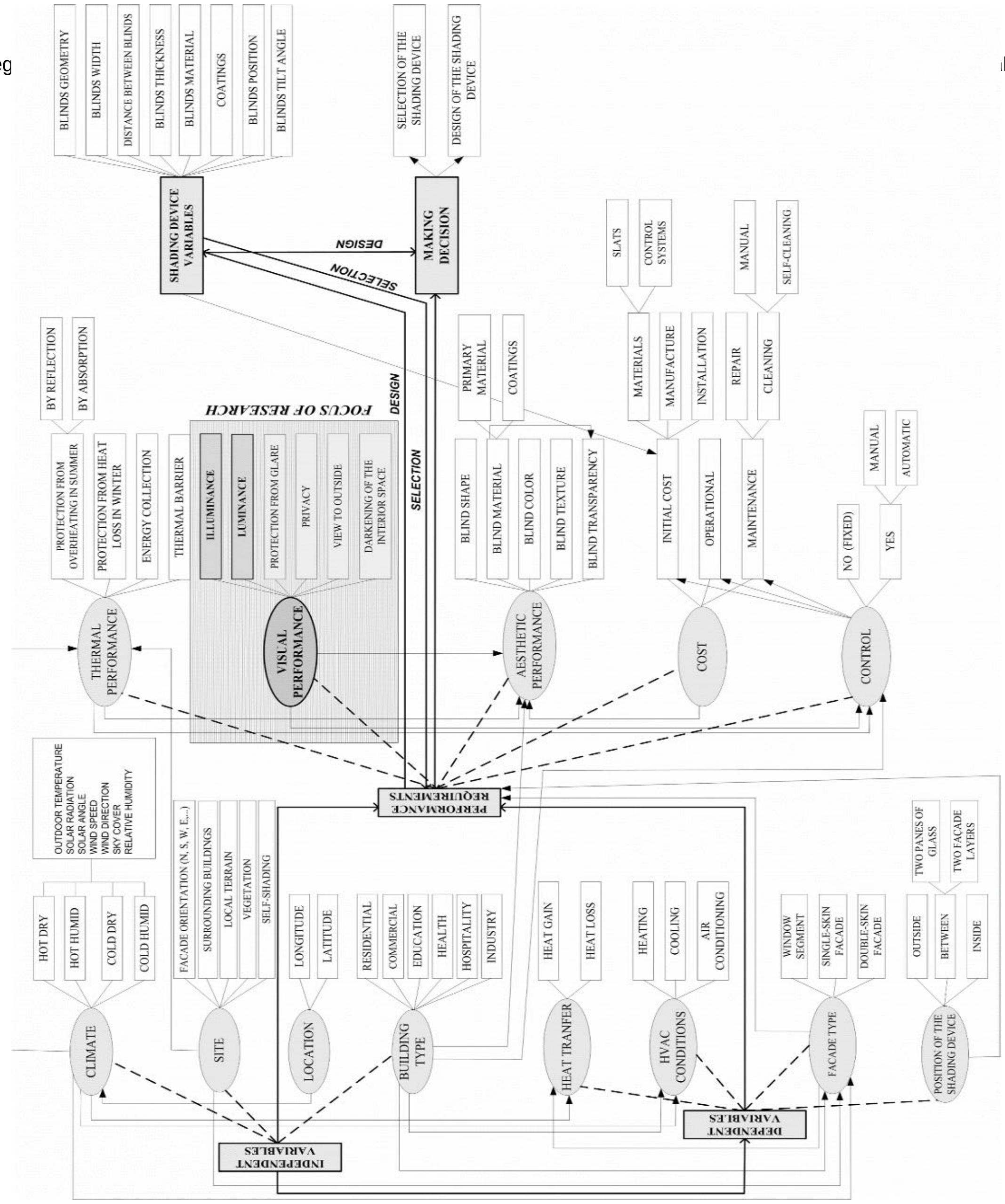


Figure 3.3 DMF developed by (Olbina and Beliveau, 2004)

Tzempelikos et al. (2010a) presented an experimental study of indoor thermal environment in a near-to-full-scale glass façade with different types of SD in winter using different building envelope and shading properties, façade location and orientation under different climatic conditions in winter. Their results show that even in very cold outdoor temperatures, interior glass surface temperatures can be quite high during sunny days, resulting in excessive operative temperature and radiant temperature. This work was further developed to include glazing properties (Tzempelikos et al., 2010b). The results show that comfortable conditions can still be maintained with high-performance façades (glazing and shading) and even eliminate the need for secondary heating in cold climates.

Furthermore, glare problems that can be caused by the large amount of daylight entering a highly-glazed working space often reduce the quality of visual comfort

(Ochoa et al., 2012). Thus, SD are used more frequently in highly-glazed buildings often maintaining the same levels of daylight used in a building with a conventional façade (Poirazis et al., 2008).

To summaries, the use of external SD is considered as one of the main design strategies (Bellia et al., 2013) that allows for an enhanced and energy-efficient use (Carmody and Haglund, 2006), and enhanced indoor comfort conditions of glazed façades for office buildings in hot climates, (Palmero-Marrero and Oliveira, 2010; Freewan, 2014). In addition, in highly-glazed facades, it is important to understand the coupled effect of SD and glazing systems. This is probably because both represent the main two barriers that share the same functions, such as reducing solar gain and providing daylighting. This is what has been picked up by previous researchers, such as Poirazis et al. (2008) or Ochoa et al. (2012).

In this sense, the next section will critically review the literature of High-Performance Glazing (HPG) as one of the main IFS elements.

3.4 High-Performance Glazing (HPG[6])

Glazing systems have been studied from different perspectives with the focus on: daylighting performance (Aboulnaga, 2006; Capeluto and Ochoa, 2006; Hee et al., 2015; Ibrahim and Ahmed, 2007), energy performance (Grynning et al., 2013; Ihara et al., 2015; Jelle et al., 2012; Lee et al., 2013; Macka and Yasar, 2011; Namini et al., 2014), enhanced functions such as photovoltaic glazing (Cuce and Riffat, 2015; Jelle et al., 2012; Liao and Xu, 2015; Quyen et al., 2015) and integrated shading function (Huang et al., 2014; Musunuru, 2014; Sun et al., 2014).

The focus of this section shifts more towards HPG literature in order to review, study and analyse the methods used to study the impacts, the measures and the selection criteria of HPG and establish the links to IFS (Figure 3.1). There have been major advancements in glazing technology, which are considered HPG, such as tinted glazing, reflective glazing, low-emissivity glazing, and gas filled (Chow et al., 2010; Carmody, 2004; Cuce and Riffat, 2015; Jelle et al., 2012). Today, there are many types of glazing that can be classified either as HPG or emerging glazing (Cuce and Riffat, 2015). HPG, however, is preferable to emerging types

[6] HPG denotes glazing systems with specific and enhanced features such as low-e, tinted and insulated Phase Change Material (PCM), etc. The terms "high performance glazing", "fenestration systems" and "building façades" at times appear to be used interchangeably, although they have distinct meanings in the glass and buildings business SELKOWITZ, S. E. High Performance Glazing Systems: Architectural Opportunities for the 21st century. Glass Processing Days Conference, June 13-16, 1999 1999 Tampere, Finland.

because of the wide range of application possibilities – especially for glazed buildings. Emerging types are limited in availability and still under development (Cuce and Riffat, 2015).

Tables were produced with illustration for each HPG system reported in the latest three review papers on HPG in the last decade. The comprehensive evidence which comprises a summary of HPG and their best achieved performances to date can be found in Appendix 2 for further reading. The outcome of this appendix has informed the development of the models in the current study. The current study will review the previous studies on HPG according to the general performance criteria, and study methods/approaches to context-specific criteria. This will then help establish selection criteria specially devised for IFS. Detailed of this recommendation will be discussed in section 5.3.5.

3.4.1 Performance criteria

Although HPG mainly and expectedly addresses aspects of performance, such aspects, which can correspondingly be used as bases for classification, can be more specifically driven/determined by:

- HPG as a thermal barrier, (represented by U-value[7]).
- HPG as a means of light control, (represented by T_{vis}[8]).
- HPG as a barrier to solar heat gain, (represented by SHGC[9]).

or any combination of the above three referred to by Bell (2005), Carmody and Haglund (2012) and Chow et al. (2010), to name but a few.

The characteristics of windows, including glazing type, window configuration, and shading strategies, have been taken into consideration to improve lighting distribution inside the space while cutting down the heating/cooling and lighting load. For daylighting, the visible transmittance (T_{vis}) affects the light amount going through the glazing and connects to the solar heat gain which dominates the heating or cooling load from radiation directly. A light to solar-gain ratio is applied to indicate the relationship between Solar Heat Gain Coefficient (SHGC) and T_{vis} (Stegou-Sagia et al., 2007; Gueymard and duPont, 2009).

[7] U-value indicates the rate of heat flow due to conduction, convection, and radiation through a window as a result of a temperature difference between the inside and outside.

[8] Tvis indicates the percentage of the visible portion of the solar spectrum that is transmitted through a given glass product.

[9] SHGC indicates how much of the sun's energy striking the window is transmitted through the window as heat (Ander, G. F., 2015).

Energy performance based on HPG as a thermal barrier

Building glazing is responsible for about 60% of the total energy consumption of the building (Jelle et al., 2012) where this energy is mainly used for space heating, cooling and lighting (Lee et al., 2013). The energy performance of a building depends on the building envelope, especially the windows, since the overall heat transfer coefficient (or U-value) of windows is normally five times greater than that of other components of the building envelope, such as walls, and about 20-40% of energy in a building is wasted through windows (Bülow-Hübe, 2001). A significant number of studies concerned with energy performance associated with glass and glazing systems have been reviewed by Grynning et al. (2013). The review indicated that the studies had been conducted in different climates and the glazing performance was analysed using U-value, SHGC and T_{vis} as the main investigated parameters.

In studies concerned with the reduction of annual energy demand, both U-value and SHGC of the windows can be considered as the main effective façade properties, either separately (Bell, 2005) or combined (Tibi and Mokhtar, 2014; Ihara et al., 2015). For example, the reduction of SHGC and U-value were found significantly influential in reducing the annual energy demand (Ihara et al., 2015), where SHGC reduction was found to be the most effective means of reducing the annual energy demand, followed by reduction in the window U-value.

These three approaches could be used to reduce the annual energy demand, regardless of design factors such as the building volume, floor aspect ratio, and WWR. Ihara et al. (2015) recommended that future work should consider other factors that affect the energy performance of façades (e.g. other combinations of façade properties, behaviour, building types, and dynamic façade properties).

Macka and Yasar (2011) simulated double-glazed window units composed of tinted glass, clear reflective glass, low emissivity (low-e) glass and smart glass in a cold climate in Turkey. These types were applied to one of the layers of double glazing once and then to the other layer, where one surface consisted of a high-performance heat-reflective glass and the other surface had a low-e coating. This method was found to reduce the heating and cooling loads of buildings by providing both solar control and heat gain. An example where U-value was found to be much more influential is a study conducted by Namini et al. (2014), which contradicts what Macka and Yasar (2011) and Ihara et al. (2015). This suggests that other variables related to glazing can also affect the energy performance of a building. This effect varies in different climates, WWR and building types. The routes of the variation in the results lie in the parameters that constitute the calculation of cooling and heating loads in the building, such as U-value, SHGC, emissivity, visible transmittance, monthly average dry bulb temperature, monthly average percent humidity, monthly average wind speed, monthly average direct solar radiation, monthly average diffuse solar radiation and orientation (Namini et al., 2014).

It can be concluded that in order to reduce the heating and cooling loads of buildings, glazing that provides both solar control and heat transfer control should be considered. However, this needs to be correlated to the building orientation and climatic parameters, which can have a significant impact on the glazing performance.

Daylighting performance based on HPG as means of light control

Efficient daylighting techniques depend on the proper exposition of glazing and performance characteristics such as T_{vis} and SHGC. Glazing systems with those two performance measures improved, cooling and heating loads in buildings can be saved by up to 5.1% for single-low e glazing and up to 6.4% by double-low e glazing (Hee et al., 2015) . The selection of proper glazing could lead to a dramatic increase in both the daylight factor and daylight level by up to 99% by using HPG, such as spectrally selective glazing (Aboulnaga, 2006).

Despite the significance of glazing type in providing daylight, some researchers have argued that this is not on its own sufficient enough as a factor (Ibrahim and Ahmed, 2007) . This is because the more light is allowed in, the more heat also penetrates with the direct solar radiation. Therefore, additional solar control devices are needed. This result was obtained for tropical climates whereas in hot dry climates such as Kuwait, glazing systems, orientation, daylighting, shading and HVAC were investigated and a HPG type low-e with minimum T_{vis} of 0.4 and SHGC of 0.4 was deemed to be the minimum requirement in order to meet the requirements of the building codes in hot and arid climate(Assem and Al-Mumin, 2010). However, other researchers such as Capeluto and Ochoa (2006) suggested that for each orientation, different glazing should be considered. This was recommended based on the evaluated three daylighting systems, which they compared for illuminance and glare performance. This somehow remotely suggests that when investigations are intended with the aim of improving the building performance, both energy and lighting performance measures of HPG systems should be considered, and probably alongside with other rather integral elements such as SD. This in turn suggests that more factors need to be included in the analysis, especially those that are considered determinants at the context level.

Integration of thermal and daylighting performance of glazing based on HPG as a barrier to solar heat gain

Daylight has a great impact not only on artificial lighting systems but also on heating and cooling (Ochoa et al., 2012). Optimising daylight aspects influences energy consumption through improving the artificial lighting profiles, while solar radiation affects cooling and heating systems performance (Jenkins and Newborough, 2007), as shown in Figure 3.4, when optimising windows exclusively for visual comfort, large energy consumption is likely to result (Goia et al., 2013). On the other hand daylighting – as an only target to better visual comfort and energy saving – could be unachievable (Ochoa et al., 2012).

To summaries, integrating daylighting when calculating energy performance will help save energy by reducing the need for artificial lighting and will also improve visual comfort, by admitting a sufficient amount of natural light besides providing a healthy and productive environment (Aboulnaga, 2006). This is essential in façades with high solar gains (Tzempelikos et al., 2007) where using different assessment criteria for a single aspect, of the same problem, can lead to diverse valid solutions, requiring the introduction of new additional criteria.

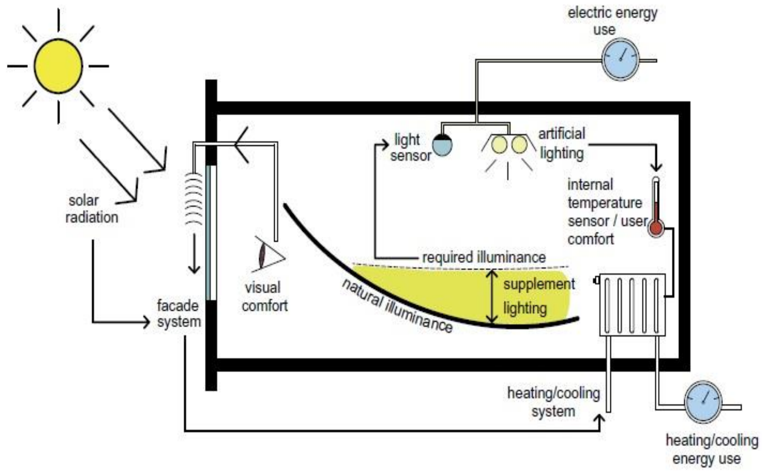


Figure 3.4 Influence of daylight on heating, cooling and artificial lighting (Ochoa et al., 2012)

Therefore, when energy and visual criteria are selected, HPG and SDs must be combined to regulate solar radiation, the amount of admitted light and glare, while reducing cooling and heating loads.

3.4.2 Glazing selection

. Selecting a window glazing is a complicated task, especially when saving energy and the daylighting aspects of a building are considered . When carefully selected, glazing might outperform an opaque wall in terms of cooling and heating demand (Grynning et al., 2013). Usually with different aspirations and sometimes with controversial or opposite drivers, academic research (ÇETİNER et al., 2012; Carmody, 2007; Haglund, 2010a), national research and standard institutions (BRE, 1992; LBNL, 2013; EWC, 2015) and materials or component suppliers (Pilkington, 2013, Viridian, 2015) have provided classifications of and criteria for selection of glazing systems with reference to the thermal and optical performance.

Climate and building type have become more effective in determining the impact on other contextual elements, such as orientation, daylighting control, shading conditions and window type (Carmody, 2004). Carmody (2007) and Haglund (2010b) propose that decisions should be made in different scales, or levels from large to small scales. However, those studies still missing on the interactions between these levels which are important to ensure that a building has been designed towards attaining performance goals (Figure 3.5).

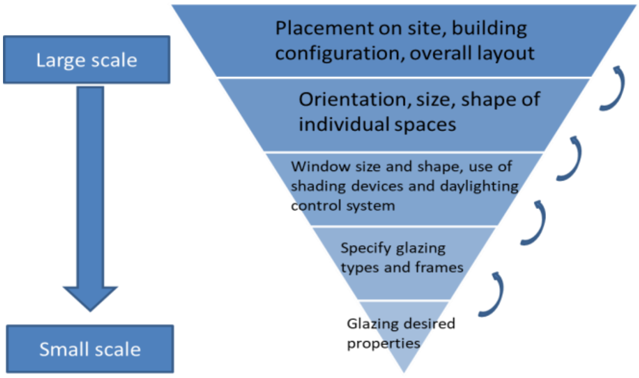


Figure 3.5 Scales of decisions in Context, Building and component levels

Different bodies of literature provide procedures or methods to conduct the task of glazing selection. The current study has critically reviewed these methodologies, tools and approaches and presented them in Appendix 4 in order to highlight gaps which should be addressed, to help develop a comprehensive method to be used as a global tool for selection of glazing, specially devised for the specific design of IFS; what will be discussed in section 5.3.5.

The critical review in the appendix revealed that there are different ways to select window glazing, which are currently being actively pursued: window energy rating schemes and window selector tools, checklists and standards. The purpose of these is to provide more information to building designers, building occupiers and building owners (and also the wider construction industry professionals and end-users) about glazing and their performance, which will help in making decisions about glazing selections. Simplified simulation tools can be used to calculate performance but there is still a need to use detailed simulation tools to involve all possible variables that are not only directly related to glazing types but also context-specific. Tools that were provided by manufacturers can calculate or provide performance information solely about their own types of tools. This suggests that there is still room for developing such methodologies that consider other abandoned aspects, such as local climate, building type, SD configurations, pattern of use, number of occupants and equipment to name a few.

Therefore, there is still a need for developing a glazing selection method for the specifics of IFS. This will be detailed in the data generation chapter later on, in section 5.3.5.

3.4.3 Interim summary of HPG

There are many ways to achieve lower heat gain through windows. In hot or warm climates, window design should follow two basic principles: (a) to minimise the solar transmission, in particular the infrared portion; and (b) to utilise the incident solar radiation as a renewable energy source thereby reducing the air-conditioning load (Chow et al., 2010). Criteria such as solar control of glass, building function, orientation, window area, window location, and climatic factors, strongly affect energy efficient window design (Macka and Yasar, 2011). These criteria should be known so that designers can make the best possible selection. Although the impact of different HPG systems on cooling/ heating savings, and solar control have been intensively studied in previous literature, for example Macka and Yasar (2011), it does not provide enough details to assist designers and practitioners because simply a list would help no one in such a complicated task, being integration of SD and HPG.

Moreover, it seems that when HPG is combined with SD, the change of how SD responds to its context may result. From what have been gathered from the review of the literature, more specifically where the combined effects are studied, it seems that there is still a lack of clear criteria for choosing appropriate glazing systems to be integrated with SD and for both to work as one system which in turn serves the design of a building in its specific context. Furthermore, the combined effects of such systems are still unclear and need further investigations.

The main performance criteria – U-value, SHGC and T_{vis} – should be assessed carefully when designing a building under different climate conditions; for instance, U-value is essential to increase heat insulation of glass in cold climates, whereas in hot climates, solar heat gain is more influential. All of these criteria need to be considered simultaneously when optimisation is intended for more that one function e.g. improving daylighting while reducing energy consumption or cooling/heating loads. This need to be done using detailed simulation modelling.

Furthermore, shading needs to be combined appropriately with glazing to be able to distribute the function of controlling solar heat, daylighting and glare (Ochoa et al., 2012). This is part of what is intended to be delivered by the current study.

Performance aspects should not be limited to a fixed set of criteria such as annual energy, cost and energy use but rather it should be open to a wider range of criteria, such as solar gain, lighting gain, in addition to daylighting assessment indicators.

3.5 Photovoltaic Shading Devices (PVSD)

This section aims to: review the state-of-the-art of the literature on the application of PVSD in buildings to present the advances in this field, investigate the methods that have been used to assess the performance of this technology, and highlight the main influencing parameters affecting the energy performance of buildings with PVSD. This will help further understand the application of PVSD in different climatic conditions (please see Figure 3.1 for the focus of this section in respect to other areas forming this multi-disciplinary literature review).

The body of literature on PV as SD in buildings was reviewed and classified under three main categories: design considerations/configurations, performance aspects, and assessment methods. It has emerged from the study of the literature that application of the Systems Theory/Systemic Approach to this research from the very early on starting with the literature review to the end (i.e. offering recommendations/conclusions) to facilitate the approach of this methodology to decision making and to organise and categorise the ways in which this research delivers its outcome, conducts its analysis, presents its discussions and offers its practice-oriented solutions for decision making. In doing so, all the parameter, methods and findings that have been collected from the literature were studied and analysed at different systemic levels, based on their level of influence and the level of control of designers over those parameters. The systemic approach comprises three levels, which has been devised and applied to the abovementioned categories, to facilitate the study of the literature on the topic of integrated PVSD (Figure 3.6).

The development of this approach is discussed in Chapter 4, section 4.2. This review takes the building level as ‘the system’. The upper level, ‘the super-system’, includes the context of the building such as site, geographical location, climate, etc. and the lower level, ‘the sub-system’, involves the façade.

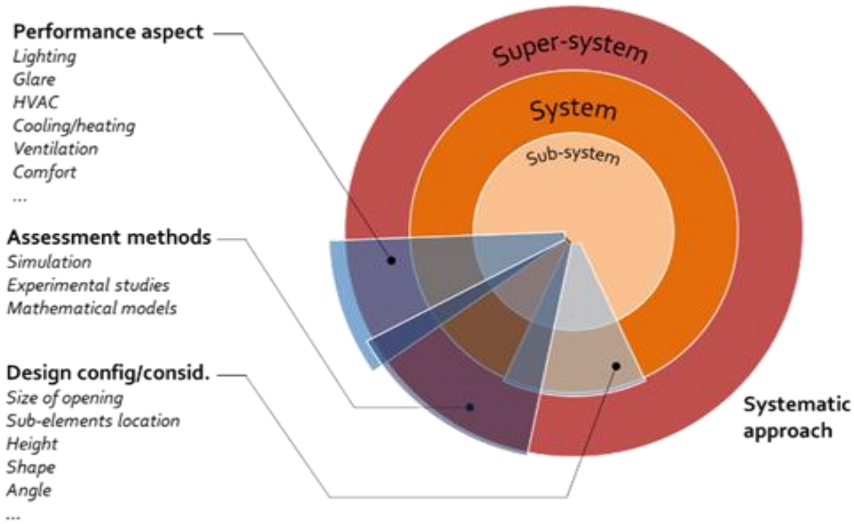


Figure 3.6 The identified scopes of literature superimposed on the systemic approach

3.5.1 PV Shading Devices (PVSD): definitions, functions and applications

Building façades impact on the energy consumption and quality of the indoor environment, hence require careful design optimisation (Lee et al., 2009). As a part of the façade components, SD play a significant role in reducing the heat gain into the building and providing acceptable indoor conditions (Alzoubi and Al-Zoubi, 2010). Although the application of PV in buildings was introduced in the late 1970s, it was first characterised as a building integrated component in the late 1990s (Patankar, 2010) but it was not until 1998 that a group of researchers proposed, most probably, for the first time, integrated PV as SD (Yoo et al., 1998). Combining external solar SD and photovoltaic panels has many advantages (DGS, 2008). Advantages can include:

- Adding to or promoting integration in design of facades and façade elements.
- Introducing a new concept as IFS where at an entry level these two technologies can be integrated, but what also offers to accommodate more features to be integrated in the future to help move the AEC industry to a more autarkic/intelligent paradigm.
- Reducing the need for space to have two systems separately.
- Promoting green and renewable energies as a design feature as opposed to an additional feature imposed on the design or construction.
- Opening new avenues for creativity and innovation using those combined technologies.

generating clean energy, which reduces reliance on fossil fuels as well as adding architectural features specific to the design of SD when combined with photovoltaic panels either traditional or the more recent transparent see-through panels. As suggested by Sun et al. (2012) transparent shades that incorporate solar PV cells convert the sunlight into electricity in addition to their function as a shading device. However, the application of PVSD has significant challenges due to the complexity of the system and the adaptability of these systems to different contextual conditions (Lee et al., 2009). It is, however, important to note that integration of PV panels, what is commonly known as ‘Building Integrated Photovoltaic’ or BIPV, is not limited to SD only. They can be integrated into any part of the building that can potentially receive a considerable amount of solar radiation, such as windows, claddings, skylights as well as external SD (BCA, 2008).

PVSD are usually an external building skin layer that can be applied independently in both new and existing buildings. This technology has the dual advantage of generating electricity directly from the incident sunlight and the normal function of external blinds in protecting the building from overheating, providing visually comfortable interior spaces and saving energy (Zhang, 2014; Kang et al., 2012). They have proven technical advantages over other types of PV installations, such as rooftop stand-alone PV systems (Mandalaki et al., 2014a), including ease of inspection, ease of maintenance, freeing the roof space for other uses, and higher possibilities to integrate kinetic technologies to track the sun, while acting as an interactive solution for optimising solar gain throughout the year. In order to appropriately apply this technology into a building, it is essential to highlight the main influential parameters that affect the performance of buildings with PVSD such as providing an optimal tilt angle of the devices with the right size and correct distance from the glazing so that they can eliminate excessive sunlight during summer while allowing it in during winter and letting diffuse solar radiation penetrate into the building (DGS, 2008) .

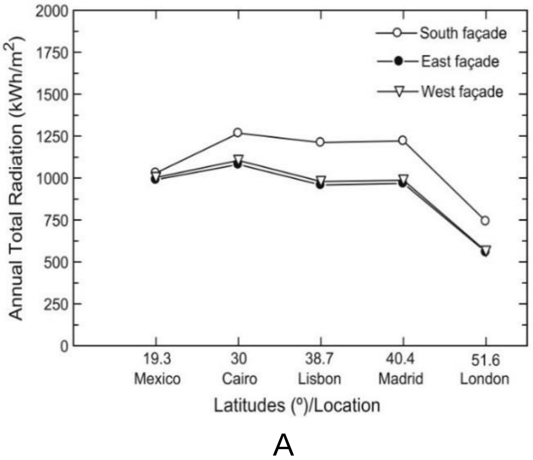
3.5.2 Design considerations/configurations of PVSD

Studies concerned with design can be categorised under two categories i.e. design considerations and design configurations. Design considerations are the considerations which need to be taken into account when the design process of the building or the course of the façade (depending on the type of project) is being carried out. These can include climate, site, topography, neighbouring buildings, etc. Most often design considerations are those factors over which there would be no direct control, and where they cannot directly be changed or modified. Design configurations by contrast are those elements which can be adjusted, changed or manipulated by the designer and are accounted for as a part of the project that can be shaped by the design process and/or impacted on by it. Such variables include building orientation, building geometry, size and geometry of opening and their sub-elements, e.g. their location, height, shape, form, angle, etc.

These considerations and configurations are studied-according to the systemic approach- under three levels:

1- Context as Super-system level

At the 'super-system' level, or the building context level, building latitude (geographical location) determines several essential inputs such as the amount of solar radiation, temperature, sky conditions and other climatic parameters. Solar gain is the main factor that varies from cities such as London with lower solar gains to cities such as Cairo, Lisbon and Madrid, with high solar radiation. In these cities (latitudes) energy demand showed a range of variation between different geographical locations where the same SD configuration was examined (Palmero-Marrero and Oliveira, 2010) (Figure 3.7)



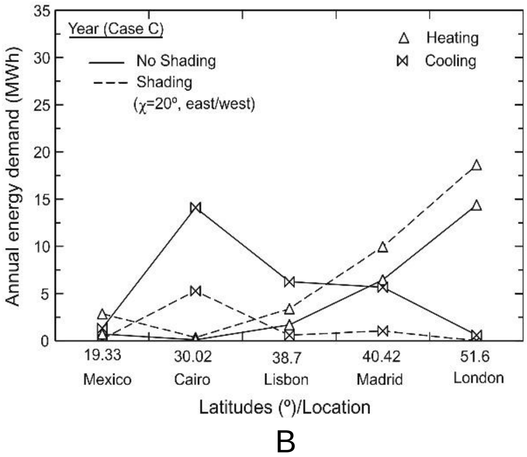


Figure 3.7 Total annual radiation on vertical surface in south, east and west façades, for different latitudes (cities)(A) and annual energy demand (B) (Palmero-Marrero and Oliveira, 2010)

Through considering latitude, besides other variables, the type and shading dimensions can be determined (Bahr, 2009) and the optimal design option for each location can be proposed (Bahr, 2013).

In the northern hemisphere, horizontal layouts can considerably reduce solar heat gain on south façades during late spring, summer, and early autumn. On east and west exposures, solar altitude is generally so low that to be effective horizontal layouts would have to be excessively long (ASHRAE, 1997). Therefore it can be concluded that in the northern hemisphere, horizontal SD are more effective than overhangs and fins; vertical shading was relatively less effective on the south, east and west elevations. This is consistent with previous studies by (Al-Tamimi and Syed Fadzil, 2011; Gutierrez and Labaki, 2007; Ebrahimpour and Maerefat, 2011; Palmero-Marrero and Oliveira, 2010). On the other hand, the use of vertical fins was found to give a reduction of 2°C in indoor temperature for the northern, eastern, and western orientations in a study carried out by Ali and Ahmed (2012) in Egypt for a residential building. It was also found that the combined fin and overhang reduced the temperature by 2°C for the southern orientation. However, these results could be exclusive to the location of the study and what it implies regarding solar radiation and latitude. In addition, the type of the building may have some impact on the behaviour or the resultant energy use if compared to office building for instance. Furthermore in another study by Alzoubi and Al-Zoubi (2010), it was found that for façades with south exposure, vertical louvres can be used to improve energy saving better than horizontal overhangs. However this contradicts Palmero-Marrero and Oliveira (2010) and Bellia et al. (2013). Horizontal overhang, horizontal louvres, vertical fins and side fins were studied in each of them but in two different climates and locations; Bellia et al. (2013) for Italy whereas Palmero-Marrero and Olivera (2010) for Dubai where three orientations were compared to a base-case without shades. This could be because in the former study, the model was a whole building with highly-glazed façade (i.e. WWR=60%) whereas the latter used a single room with specific window sizes that results in a wide range of variation of WWR.

All shades improved performance on south façade. Horizontal louvres were the best in all orientations (horizontal louvres were used on the south and vertical louvres on the east and west façades). A very recent study by Asfour (2018) conforms to those findings. These results were evaluated based on energy consumption improvement. For daylight performance, vertical louvres are preferable but for energy saving (reduced heat gain) horizontal ones are more desired. The contradictions might be caused by the variation in the building models, shading devices configurations, and the location of the study.

Another trend in the literature was spotted where shading devices configurations were compared to HPG rather than combined with it. For instance, overhangs and fins were compared to HPG, represented by double clear (DC) and double low-e (DL) glazing and they were found to outperform HPG, though in residential buildings in Tehran (Ebrahimpour and Maerefat, 2011). The results of this study show that using fins for both east and west facades, overhangs for south facade, while leaving the north façade unshaded, resulted in improvement in cooling, heating and annual loads. It also showed that changing glazing from single to other types, such as single-low e, double-low e, and double-clear, made a remarkable difference in the results.

Another rather influential factor at this higher level of influence, being the context or super-system level, is the surrounding of the building. This factor can be considered constant in any analysis where the designer has no control of but have to respond to, so it is unique and specific to each building. This varies from the layout of the roads *to the building shape (Di Vincenzo et al., 2010), as shown in Figure 3.8.*

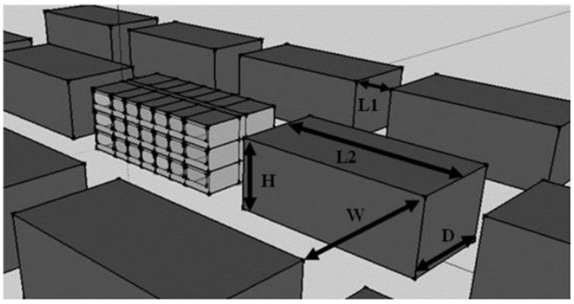


Figure 3.8 Surroundings in urban scenario (Di Vincenzo et al., 2010)

Diffuse radiation may not be considered to have a positive impact from a pure urban design point of view but can be reduced by 82% where PVSDs are installed, which in return reduces the building reliability on the grid (Tongtuam et al., 2011). Karteris et al. (2014), use GIS to investigate the effect of the architectural and technical aspects of the PVSD to predict their performance at urban scale. As such their work overarches all three system levels.

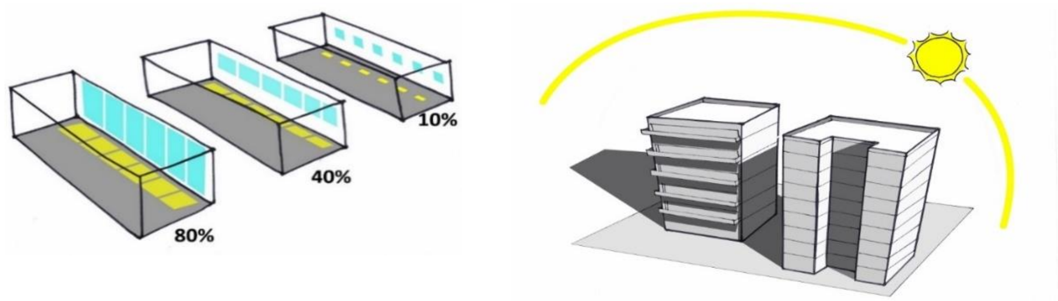
2- Building as system level

At the building level, or what is referred to in this current research as 'system' level, building orientation is considered to be one of the key determinants to optimise PVSD. For instance, Bahr (2013) studied the building orientation for different latitudes and was found to be south then south-eastern. This finding was assessed with respect to reduction in cooling loads, solar gain control and average daylight factor. The results were also confirmed by other researchers such as Kang et al. (2012). Interestingly enough, others have suggested slightly different orientations to maximise solar power generation by PV panels. Suggested alternatives include south-eastern or south-western (Yoo, 2011). Vassiliades et al. (2014) suggest architectural functions that can be affected by the application of PVs including: weather proofing, noise reduction, shading, flexibility, transparency, colour and texture. However, these architectural functions can significantly vary, depending on the technology, building type aims and objectives of different design projects. Therefore, they are out of the scope of the current research.

In order to determine the appropriate type of SD that is suitable for integration, the dimensions, location and orientation have to be considered, as suggested by many researchers (see for instance Bahr (2009) and Mandalaki et al. (2012)) among others). Orientation is one of the dominant factors that, in combination with glazing, affects the performance of external shading on both visual and thermal comfort and total building energy needs for heating, cooling and artificial lighting (Atzeri et al., 2013). The results showed that the shading configuration that gives the best energy performance appeared to be strictly related to the orientation of the windows, to their position and to the glazing system to which they are coupled (Atzeri et al., 2014). However, a contradictory result was found where an optimal configuration of a combination of shading and glazing can be achieved regardless of the orientation (Goia et al., 2013). This could be because Goia et al. (2013) concluded the optimal configurations that are exclusive to a range of WWR between 30% and 45%. Whereas Atzeri et al. (2014) suggested the optimum configurations can be found for WWR between 20% and 80%. It seems that this difference in the ranges lies in the different optimisation parameters between those two studies. The optimisation in the former study includes the electricity for artificial lightings which are often not addressed in many studies, such as Atzeri's.

WWR (Figure 3.9, A) is another significant parameter at the building level at which buildings are designed to achieve optimum performance (Carmody and Haglund, 2006). The global energy requirements of the building with a WWR of 30% without shadings are almost equal to those of the building with a WWR of 60% with shadings (Bellia et al., 2013); they found that the highest saving of about 20% can be achieved. It was also found that this result shows that the use of suitable SD eliminates or significantly reduces the increase in energy demand typical of a highly glazed building; this conclusion is coherent with that reached by others such as Poirazis et al. (2008) where fully- and highly-glazed buildings were where the energy consumption is likely to increase but when considering both shading and glazing in combination, the increase is reduced by 15% (100% glazed alternative compared to a typical reference building with 30% WWR) maintaining at the same time an acceptable level of thermal comfort. This suggests that the influence of WWR can significantly affect the energy and daylighting where similar configurations are studied regardless of climate and geographical location.

The potentially architecturally suitable area of a façade needs to be considered according to the building type and the proposed PV solutions (Karteris et al., 2014). This area can possibly be boosted when using 3D designs at the early stages (Sampatakos, 2014). Building shape is one of the determinants, where variations in dimensions of the building and the building height can help in optimising a building envelope that is most suitable for PV integration based on power generation and economic impact of different BIPV systems (Youssef et al., 2015) as shown in Figure 3.9, B.



A: WWR

B: Building shape

Figure 3.9 A: Window-to-wall ratio (WWR), B: Effect of variation in building shape on BIPV

3- Façade components as sub-system level

At the components level or sub-system level, variations found to have a significant impact on the performance aspect of PVSD are categorised under:

- Material (glass/PV types).
- Configurations (size/distance/ratio/location of element).
- Geometry/shape (vertical/horizontal/egg-crate).
- Settings (inclination).

At the building façade level, or what is referred to in this research as the 'sub-system' level or, envelope variations is one of the factors at this level as it relates to the configuration of the façade. Youssef et al. (2015) studied a range of envelope variation. The variation was mainly about the shape of the building. Their study introduces a framework of an optimization method that formulates the best building envelope shapes and the most matching PV systems. However. This factor can have an unlimited number of options as many as the building shapes can vary, hence, no generalisation can be made in this regard. One of the most influential parameters determining the PVSD's performance is the angle of inclination, shown in Figure 3.10, A, which helps ensure an optimum value for both internal solar gain control and electric generation (Kang et al., 2012; Bahr, 2013; Hwang et al., 2012; Kim et al., 2014). Probably one of the most researched, yet still one of the least agreed upon, areas at the sub-system level, is the tilt angle of the PV panels, either as an independent installation or as an integrated unit. This is because it is completely and utterly dependent on the geographical location of the building as a super-system level parameter, the orientation of the building as a system level parameter and even the type of shading device as a suggests that horizontal installation (0° inclination angle) reduces the blinds' self-shading, and a tilt angle equal to the location's geographical latitude maximises the harvested solar energy especially for horizontal louvres (Bahr, 2009, Bahr, 2014), others have proposed more prescriptive and almost blanket solutions, asserting that a horizontal inclination angle of 60° and a vertical inclination angle that is smaller than 15° will provide the best results, almost totally regardless of the orientation of the building or its altitude (Hwang et al., 2012). Another aspect of the various effects of changing the tilt angle of SD is providing a desirable indoor environment in relation to the sky conditions (Kim et al., 2010). While Jung (2014) also suggested that controlling the angle was effective a parameter in providing visual comfort and reduction in cooling loads, interestingly, they found that changing the inclination angle made no difference in glare. Experiments with motorised louvres to optimise control methods of the inclination angle to track the sun have been conducted for two different climates by Kim et al. (2009). Various glazing types were compared and evaluated for different tilt angles and orientations of PVSD installation by (Tongtuam et al., 2011). They found that maximum energy generation can be achieved when the tilt angle is nearly 30° on the south, south-east or south-west facing facades. These results were inclusive of the investigated modules that are installed on the exterior wall and have the diffuse reflectance value of approximately 30%, such as a rough, semi-glossy surface.

In a recent study in the hot and arid climate of Riyadh in Saudi Arabia, Asfour (2018) studied different PVSD configurations at different orientations with 0°, 30°, 40° and 60° inclination angle and found that 40° was best to reduce the cooling load in summer times. Whereas in another recent study, low angles were found best for PV and high angles were found best for shading as they reduce cooling loads (Popa and Brumaru, 2018). This variation in the findings of those two studies may be caused by the exclusion or fixing some variables that may affect how the blades respond and perform, such as distance of the blades from the main façade or the distance between every two blades, or in case of overhangs, the height of the building/floor.

The dimension of the PV panels is one of the effective parameters that has been the focus of several studies (Kang et al., 2012; Mandalaki et al., 2014b; Sun and Yang, 2010). They differ from one product to another according to the overall outlines of the devices selected, as shown in Figure 3.10, B.

Regardless of the area of the surface, different dimensions showed different responses (Kang et al., 2012). Kang et al. (2012) concluded that the length of the module was less effective than the width regarding electricity generation. Mandalaki et al. (2012) agree that performance of different PVSDs differ according to their configurations and, subsequently, their dimensions.

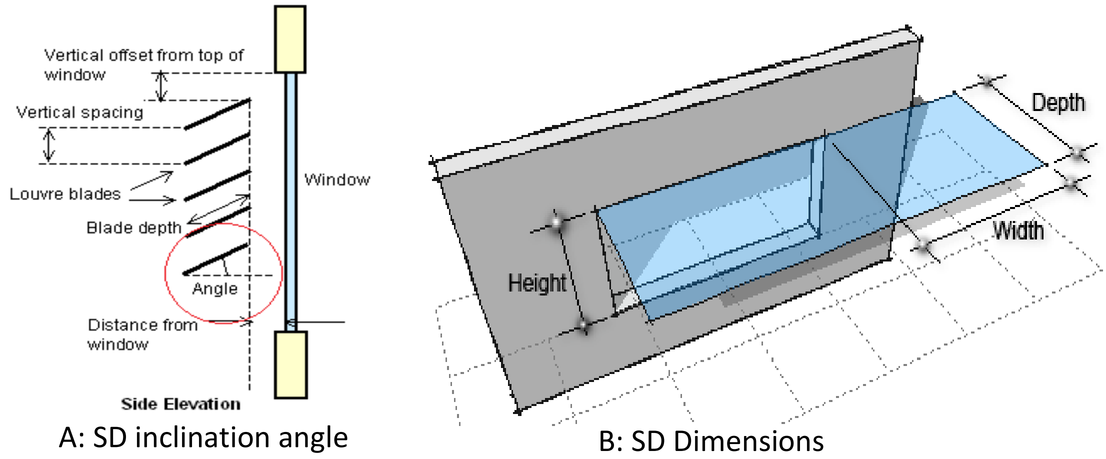


Figure 3.10 A: Inclination angle of SD-horizontal louvres, B: Dimension of SD

Sizing SD is essential to ensure that they function efficiently, especially when devices such as overhangs, fins or combinations of both are used (Aldawoud, 2013). Different settings have been found including: SD types, dimensions, number of louvres, spacing between louvres, and position above the window (Bellia et al., 2013; Palmero-Marrero and Oliveira, 2010). These settings were investigated under three different climatic conditions in Italy. The settings for overhang were: depth (0.5cm, 1cm, 1.5cm), and for louvres: depth (0.7cm, angle 25°, vertical spacing 0.3cm and distance from window 0.3cm).

These settings, shown in Figure 3.11, has been chosen on the basis of an energy optimisation carried out, but for a given climate and location. The results showed that glazed areas which are fully shaded from the outside reduce solar heat gain by as much as 80%. Inclination angle, location and window to wall ratio also affect the performance of shades. However, these findings do not agree with Thalfeldt et al. (2013) where large window sizes performed worse in highly glazed office building in Sweden. This is probably because the climate and location are different between those two studies. In such cold climates, increased window areas do not necessarily mean reducing electricity consumption. It is probably because the heat loss increases radically due to the bigger sizes of the windows.

Correlation between overhang depth and energy is an important aspect compared to correlation between overhang depth with building cooling loads and daylight level (Ossen et al., 2005). This implies that there is no single indicator or measure that can be solely used to assess the performance adequately unless the other influential factors, such as solar gain are considered. Solar gain influences cooling loads and subsequent energy consumption.

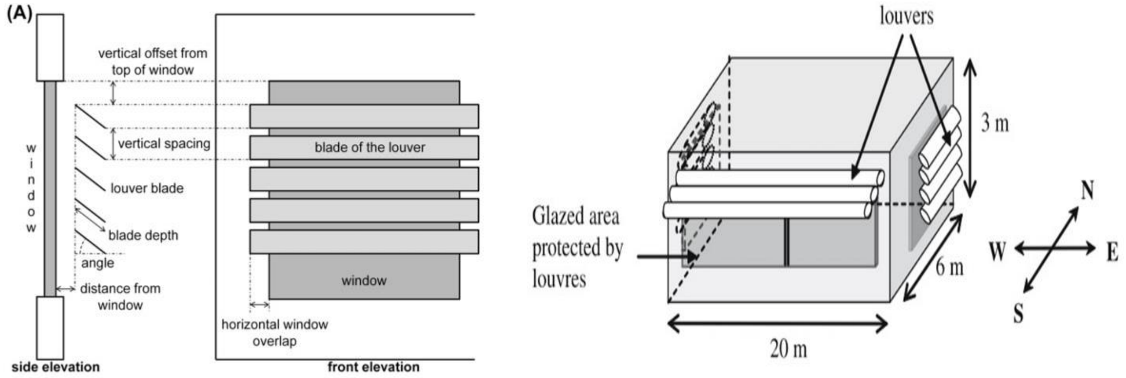


Figure 3.11 Configurations of the investigated shading devices (Bellia et al., 2013)

From what has been discussed in this section, various recommendations can be found in the literature which suggest that there can be optimum configurations of SD that can be used for different buildings. However, this needs to be exclusive to the climate, location and settings of the specific building. For example, a summary of optimum dimensions for overhang for different targets was provided by (Ossen et al., 2005) for Malaysian climate, as can be seen in Table 3.1.

Table 3.1 Optimum overhang dimensions for different targets (Ossen et al., 2005)

Orientation	Optimum OHR* for target mean work plane illumin.(500lux)	Optimum OHR for building cooling load	Optimum OHR for energy cons. For space cooling	Optimum OHR for total energy cons.
East	1	1.4	1.4	1.3
West	1.4	1.4	1.3	1.2
North	0.4	1	1.2	1
South	1	1	1.2	1
* OHR is the corresponding overhang ratio.				

The relationship between the depth of overhangs and the height of the opening is important. It has been proved that the ratio of the distance between the shading device slats and the depth of the slats have significant effects on the performance of such systems (Bahr, 2009; Bahr, 2014; Hwang et al., 2012). This ratio has been used as an installation method to estimate the proportion of electricity generation as it determines the effect of shading on the panels (Hwang et al., 2012). Figure 3.12 shows the ratio d/L and L/H.

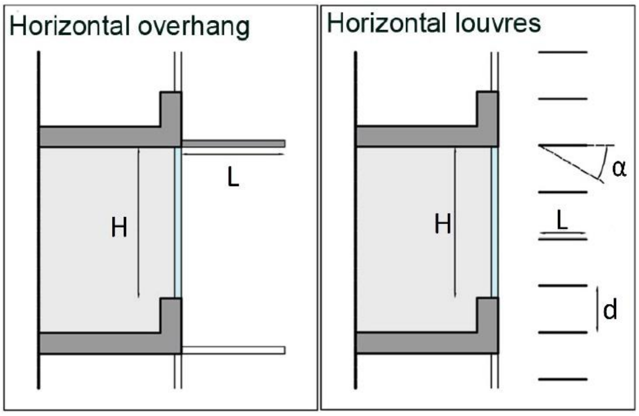


Figure 3.12 L/H and d/L ratios in shading devices (Bahr, 2009)

Regardless of the sizes and dimensions, it is recommended that PVSD should be applied in such a way that they are not shaded by the panel above (Yoo and Lee, 2002), as shown in Figure 3.13. This means the area is not the only effective parameter in electricity generation, and other parameters, such as spaces between shading elements or tilt angle (Kang et al., 2012; Hwang et al., 2012), should be considered in order to minimise the shading effects.

Figure 3.13 Self-shading effect and preferable installation of PV cells according to Hwang et al. (2012), Kang et al. (2012), and Yoo & Lee (2002).

The material used in SD can also have some influence on the performance of the SD used regardless of their shape. For example, horizontal louvres, vertical fins and egg-crate typologies made of concrete and wood were investigated in Brazil for different orientations by Gutierrez and Labaki (2007). Results show that the most significant response was the horizontal concrete louvre on the north façade in spite of the good insulation properties of wood. Needless to say that this is southern hemisphere hence the most significant changes are introduced by the SD on north façades (which is equivalent to south façade in northern hemisphere).

In addition to the SD material, colour also plays a role, especially in daylighting. Dubois (2001) studied the effect of the colour of six types of SD on the daylighting in offices. The results show that overhangs, white awning and horizontal Venetian blinds affect positively the work plane illuminance levels that are more suitable for offices and the grey specular screen produce unacceptably low work plane illuminance. These results are based on illuminance, regardless of the glazing type, glass type or glass colour.

3.5.3 Performance aspects of PVSD

Various criteria for performance evaluation of PVSD have been developed by several researchers, mostly with the aim of identifying the optimum PVSD configurations improved energy efficiency and visual comfort. However, the performance evaluation of PVSD could be a decisive factor because any decision is made based on a set target which is supposed to be met. For instance, when designing for renewable energy application, some PVSD can prove to be efficient for this particular purpose but less effective with regard to thermal comfort needs (Mandalaki et al., 2012). Therefore, it is of paramount importance to set quite clearly, from the beginning, the purpose, target and deliverables intended for the study to avoid any further confusion or misleading. The performance aspects were found to be either limited to one aspect or a simultaneous consideration of multiple aspects, based on the design or research targets. Those aspects could be, but not limited to, energy consumption, visual comfort, thermal comfort, cooling and/or heating load reduction, electricity production-to name a few. The following paragraphs in this section will elaborate on the performance aspects in more detail.

For energy efficiency and visual comfort, an optimal design parameter of PVSD would be the annual total solar insolation on the panels per metre squared of the panel area (Wh/m²), the reduction of the cooling load during summer per metre squared of floor area (Wh/m²), the average daylight factor inside the office space (%) and the geometric shading coefficient on the glass façade (%) (Bahr, 2013). Other researchers suggest that electricity saving can be calculated by assessing the electricity production and the cooling load reduction per unit of PV to achieve optimum design for PVSD (Sun and Yang, 2010; Sun et al., 2012).

For cost-benefit analysis, different design options can be assessed based on electricity production per year in correlation with electricity saving for cooling, additional electricity consumption for artificial lighting and maintenance and cleaning cost of PV panels (Bahr, 2014). Electricity production of PVSD has been investigated by Bahr (2017), Di Vincenzo et al. (2010), Hwang et al. (2012) and Kang et al. (2012).

Electricity production (PV output) has been a reliable indicator, especially when combined with other criteria such as visual comfort (Mandalaki et al., 2014a) and its maximum profit can be accounted for when solar intensity is maximum and while the electricity price is at its peak rate (Bahr, 2017). In some specific cases, the electricity produced by PV can cover the artificial lighting (Mandalaki et al., 2014b). It is even more useful when multi-criteria assessment is intended where factors such as cooling and heating loads of inner space, electricity needed to ensure visual comfort, electricity production of PV panels and the factor of visual comfort, i.e. the ratio of electricity produced by PV to the electricity needed for visual comfort are considered (Mandalaki et al., 2012). Karteris et al. (2014) evaluated the building energy consumption represented by the energy potential prediction, domestic hot water, electrical appliances, lighting systems, and heating and cooling. The energy behaviour of the studied buildings with applied PV installations, was assessed without taking into account the electricity production to allow for emphasizing the effect of PV on heating and cooling loads.

The influence of solar irradiance has been studied by Yoo (2011), Yoo and Lee (2002) and Yoo and Manz (2011). This was an indicator of the insulation ability of the systems studied but in most of the cases, other criteria should also be studied to be able to achieve an informed decision about the system design.

The annual energy yield per square metre of PVs was also evaluated by Tongtuam et al. (2011). This is a valid indicator of the system’s efficiency but cannot be referred to as the only criterion that helps in deciding the optimum design of the system

Another very important point which was identified during the course of this review was that performance aspects are not mutually exclusive from either design configuration or design considerations. This means that although they often are the main focus of the studies, where reviewed and classified under this category, their context needs to have been set with a series of pre-set and pre-defined values in design-related areas. For instance, sometimes variations in design configurations and considerations are introduced to investigate the performance. However, the main purpose and focus of these studies are still chiefly performance, rather than an investigation of the possible alternatives that the design can potentially have. Comprehensive review of the literature suggests that there still is a major gap in parametric studies where different design configurations can be procured rapidly and their impact on the performance aspects can be comparatively analysed.

3.5.4 Assessment methods of PVSD

Assessment methods vary based on the availability of the tools or the type of study and variables investigated, all of these methods have proven their reliability within their contexts. Through the course of the literature review for this study, three main methods were articulated: computer simulation, mathematical models and experimental models (test beds either in real buildings or in lab-controlled conditions), which have been used by a number of researchers as below:

Experimental studies

Experimental studies include both scale models, either in lab or real-life conditions, and real building set-ups. When optimising operation and control methods of motorised devices, a physical scale model can be constructed to investigate the performance of these devices, such as PV integrated SD, under real-life conditions (Kim et al., 2010; Kim et al., 2009). the need for this type of experimental/real-life studies is because these motorised devices are responsive to light sensors, therefore their efficiencies and response need to be validated to approve the design.. However, an experimental study most likely gives very specific results that cannot be generalised, or some cases cannot be repeated i.e. specific weather conditions. In addition, the main disadvantages of this method are both time and money consuming.

Mathematical models

Studies using mathematical models are those which have used a single formula or a multitude of formulae, depending on the purpose, application, breadth and depth of the study. This approach can be adopted to carry out theoretical analysis to investigate integrated photovoltaic modules (Kang et al., 2012). However, in order for this study to be doable and to be able to change few parameters, this study was therefore limited to a façade component of a building rather than a whole building which compromises the effect of some other rather important parameters.

Although there have been some attempts to include as many parameters as possible in previous literature, those studies were missing out on some other important elements in each of them. For example, variation of elements have been investigated to find the optimum values, such as azimuth or tilt angle of PV cladding at different orientations using mathematical models (Sun et al., 2012) or to describe the impacts of integrated photovoltaic modules on electricity generation and cooling load (Sun and Yang, 2010). In addition, mathematical modelling have been used to assess PV installation based on the profit generated by a photovoltaic system with the aim to develop a decision tool (Bahr, 2017). Some other studies have used mathematical models to study the performance of these modules (Sun et al., 2015). A mathematical model is a static representation of a system hence its main limitation lies in the inability of emulating the dynamic characteristics of the system under investigation, which suggests preference of more developed methods to facilitate the study of rather complex systems.

Simulation studies

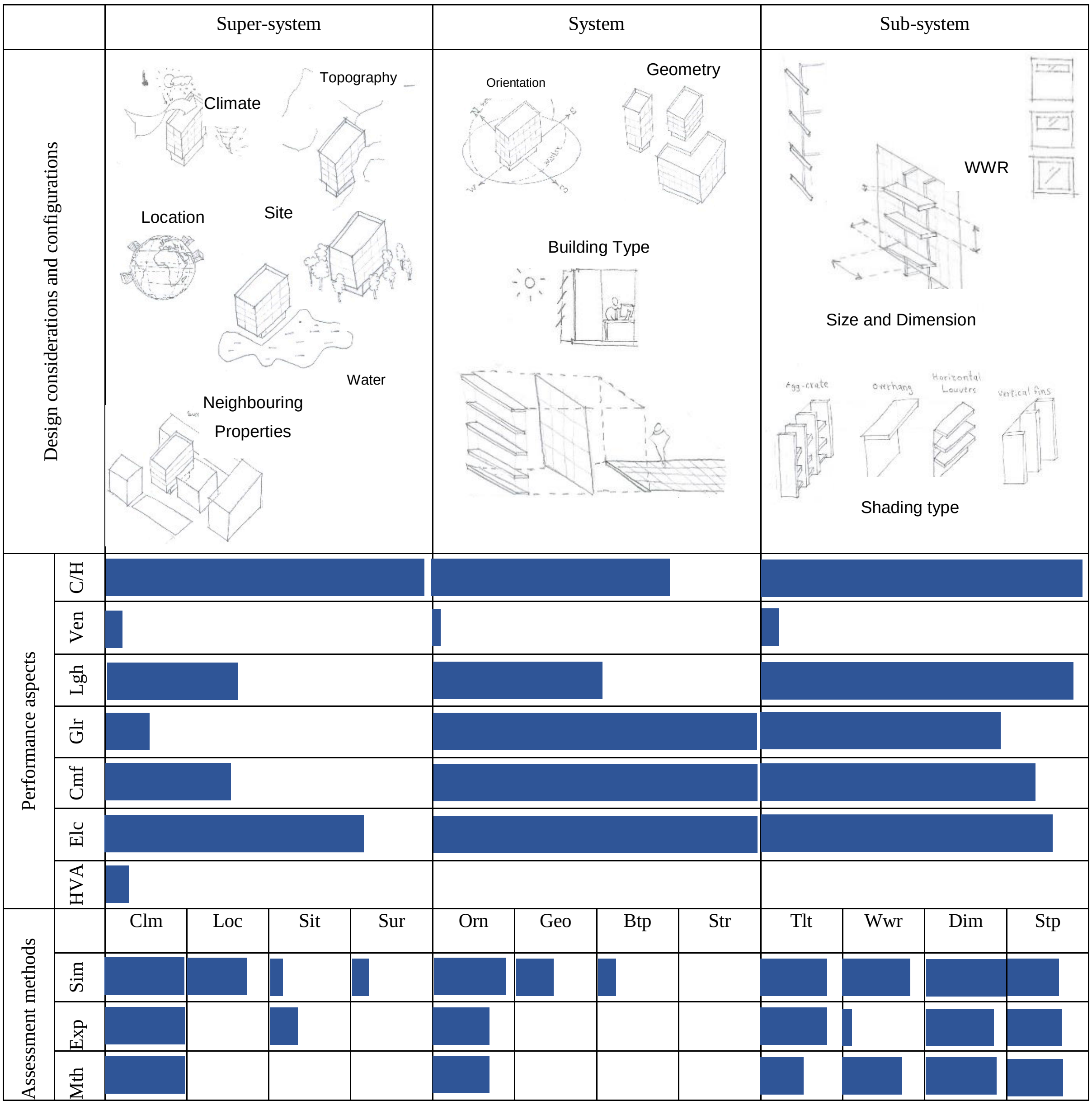
Research in different contexts is governed by many factors which will lead to the choice of the simulation tool. Different tools such as Ecotect™ (Kang et al., 2012; Bahr, 2009; Bahr, 2013; Bahr, 2014), Energy plus™ (Mandalaki et al., 2014a, Mandalaki et al., 2014b; Mandalaki et al., 2012), SolCel as a simulating tool for PV systems (Yoo, 2011; Yoo and Lee, 2002; Yoo and Manz, 2011), and IES-VE™ (Ayyad, 2011; Awadh and Abuhijleh, 2013; El Sherif, 2012; Kim et al., 2012) have been used as direct energy simulation tools, and GIS mapping software (Karteris et al., 2014) has been used as an information tool to assist design and optimisation of energy use in buildings in different geographical locations.

3.5.5 Analyses of the literature on PVSD

Integration of photovoltaics into buildings has different methods and has been studied from different perspectives, of which PVSD are a significant category. as indicated before (see Figure 3.6) the review of PVSD literature identified three main categories – design configurations/ design considerations, performance aspects, and assessment methods – under which existing literature on PVSD is clustered at three different systemic levels, namely super-system: context level;

system: building level; and sub-system: façade level. The key elements that emerged from the literature review are categorised, as shown in Table 3.2.

Table 3.2 Mapping the literature based on three identified clusters in three systemic levels



Clm: Climate Loc: Location Sit: Site Sur: Surroundings Orn: Orientation Geo: Geometry Btp: Building type Str: Structure Tlt: Tilt angle Wwr: window-to-wall ratio Dim: Size and dimensions Stp: Shading type Sim: Simulation tool Exp: Experimental study Mth: Mathematical model C/H: Cooling/heating loads Ven: Ventilation Lgh: Lighting Glr: Glare Cmf: Visual/thermal comfort Elc: Electricity generation HVA: HVAC systems

The current study has developed this table to be used as an illustration tool which comprises the systemic levels of the influential parameters and factors that have been identified in the body of literature on PVSD. It is divided vertically based on the systemic levels and horizontally based on the main three aspects identified, namely design configuration and considerations, performance aspects and study methods. In each of those categories, sub-categories are provided. The size of each blue bar in the table reflects and quantifies how much this specific element has been studied in the literature. This can help conclude where the research and design efforts have been focused on. Furthermore, it can help identify where gaps in knowledge are and what the possible future research can help address.

PVSD have been proven to have several advantages but have not been investigated systematically so far. Most of the studies have concentrated on variation of façade components at the sub-system level. Significant progress has been noticed in the simulation software as a practical and precise tool that has considerably helped to develop methods of evaluation and optimisation. Configurations and installations in different locations and climates showed dissimilarities in performance.

The review of PVSD literature also showed that most of the research has been done in cold and mild climates. Little has been done in hot and hot-arid climates, as seen in Table 3.3.

Table 3.3 Location of various studies on PVSD

Reference	Study location	Reference	Study location
(Bahr, 2009)	Florence, Italy	(Yoo and Lee, 2002)	Korea
(Bahr, 2013),	Abu Dhabi, UAE	(Yoo and Manz, 2011)	Korea
	Larnaca, Cyprus	(Yoo, 2011)	Korea
	Piacenza, Italy	(DI Vincenzo, 2010)	UK
(Bahr, 2014)	Abu Dhabi, UAE	(Jung, 2014)	Korea
(Hwang et al., 2012)	Seoul, Korea	(Karteris, 2014)	Thessaloniki, Greece
(Kang et al., 2012)	Seoul, Korea	(Khezri, 2012)	Norway
(Kim et al., 2010)	Cold region, Korea	(Kim et al., 2009)	Korea
(Karteris et al., 2014)		(Kim et al., 2010)	Korea
(Kim et al., 2009)	Michigan, USA	(Ochoa et al., 2012)	Amsterdam, Netherlands
	Seoul, Korea	(Peng et al., 2015)	Nanjing, China
(Kim et al., 2014)	Seoul, Korea	(Saranti et al., 2015)	Chania, Greece
(Mandalaki et al., 2014a)	Chania, Greece	(Youssef et al., 2015)	Egypt
	Athens, Greece	(Ebrahimpour and Mehdi, 2011)	Tehran, Iran
(Mandalaki et al., 2014b)	Greece	(Asfour, 2018)	Riyadh, SA
(Mandalaki et al., 2012)	Greece	(Sun and Yang, 2010)	Hong Kong
(Sun et al., 2012)	Hong Kong	(Tongtuam et al., 2011)	Thailand, Bangkok

Moreover, research showed that some of such regions, such as Middle East and more specifically Iraq, can potentially be leading solar energy production for the amount of solar energy available (DOYLE and JAAFAR, 2010) but it still remains a challenge to eliminate the dust effect on PV panels in a UK climatic condition setting (Ghazi et al., 2014) and even more so in hot and arid climates.

Furthermore, the typical dual function of SD, which is providing daylight on the one hand and controlling solar heat gain on the other, now has a third function, which is producing electricity. The trade-offs now are not only between two functions but also the third function as the demand for buildings with lower impacts on the environment is growing at an unprecedented rate. There is still a need for a holistic and comprehensive methodology that helps architects and designers in evaluating and optimising the performance of buildings with this technology taking into account the weather patterns and context-specific parameters.

3.6 Summary

So far, the existing literatures related to the key areas of this research have been reviewed, including: shading devices (SD), High Performance Glazing (HPG), all with a focus on Photovoltaic Shading Devices (PVSD).Their application in different buildings and climates has been carried out with an aim to investigate the influential factors, parameters and strategies, as well as assessment methods and indicators, for measuring the energy performance of buildings where such technologies are used, with an emphasis on the necessity of having a full-fledged methodology that takes into consideration all the influential variables. It seems that the shared functions of the elements of IFS need to be studied holistically but the interrelation between the parameters need to be comprehended.

A critical comparative analysis method has been used to review the literature related to this topic. In doing so a systemic approach was adopted so that the study can be used as a point of reference for future research where interventions at different systemic levels can be investigated, decisions for making such interventions can be made, justified, objectively evaluated and design solutions can be devised or recommended. From a methodological point of view and with an intended output for professional practice, this approach can also form a basis for a decision support system when design decisions are to be made in practice.

The literature review has revealed the following findings which have helped identifying the knowledge gaps:

- The review indicates that most of the research is about how calibration of the parameters influences the performance of the system. It also reveals that the vast majority of existing studies where the main elements of IFS are considered focus on some parameters to assess either energy saving, daylight performance or PV electricity generation, while knowingly/admittedly or unknowingly/inadvertently freezing the others.

Therefore, they were not able to portray the whole picture. This has in turn caused contradictions of results and findings of many previous researches.

- Additionally, the studies on IFS impacts and, more specifically PVSDs, are heavily underdeveloped in the academic literature and have shown many discrepancies in the findings of many researches in this field. The main discrepancies in the findings of the previous research can be summarised according to their systemic levels in Table 3.4.

Table 3.4 Contradictions of findings in previous studies related to IFS components

Systemic levels	Parameter	Contradictions in findings of previous studies
Super-system level	N/A	
System level	Orientation	Orientation was found to be either a significant parameter (Huang et al., 2014, AlAnzi et al., 2009) or an insignificant parameter (Carlo and Lamberts, 2008, Poirazis et al., 2008).
	WWR	The general trends identified in the literature, such as Bellia et al. (2013) and Athalye et al. (2013) shows that the bigger the WWR, the more energy intensive the combinations will be. However, Carmody (2004) believes that increasing WWR could reduce energy use only if daylight potential is optimised.
Sub-system level	Angle of inclination	The optimum angle of inclination was suggested to be either equal to latitude (Bahr, 2013) or low angles to be preferable, as suggested by Sun et al. (2012), over high angles, as suggested by Kang et al. (2012) and Hong et al. (2016).
	d/l ratio	Some discrepancies were flagged in the findings of different studies where d/l was one of the parameters. For instance, opposite to what Bahr (2014) found, Hwang et al. (2012) suggest that a greater d/l ratio will result in a greater amount of sunlight, but it is not proportionate to the amount of power generated due to a decrease in the area of power generation.
	Depth	Generally it was found in the literature, especially by those who focused on the PV electricity generation and with a variation of PVSD dimensions (see among others: Hwang et al., 2012; Sun and Yang, 2010; Sun et al., 2015) that the depth is a significant parameter in terms of the reduction of energy. Sun and Yang (2010) suggest otherwise, asserting that deeper overhangs result in greater cooling loads reduction.
	Glazing system	The extent of the influence of HPG was not found as significant in Assem and Al-Mumin (2010) when combined with shading elements. DL and DR glazing have low SHGC, which is recommended in climates with high solar gain (Awadh and Abuhijleh, 2013). Glazing with low T_{vis}, show high lighting gain but low cooling loads (Carmody, 2004; Cuce and Riffat, 2015).

- The integration of IFS's elements presents a very complex scenario that incorporates established and new methodologies, definition of the IFS, the choice of impact indicators and calculation methods, data quality checks and sensitivity analyses, and many other parameters.
- Although there have been some studies where a number of influential parameters have been considered, studied and analysed in an integrated manner, there is not yet any overlap (no academic work) that involved systemic consideration of all influential IFSs parameters.

- The review has shown that HPG energy performance is a robust field of research. In this context, the use of IFSs in new-built seems to be gaining momentum with a few recent publications that have addressed the combined effect of its elements i.e. glazing and shading or glazing and PVSD.

To summaries, it seems that IFSs can suit highly- to fully-glazed office buildings but this is only an emerging trend. The energy and daylight performance analysis of literature has revealed a constant and consistent energy reduction potential of the IFS across all the considered parameters. However, this does not seem to be an area on which a great deal of agreement between different researchers can be spotted. It is partially due to the fact that some parameters have been shown to have broad variation ranges as far as the energy reduction potential is concerned, which makes it even harder to select a numerical value to be used as a benchmark for the energy savings of IFSs alternatives. Adding to the complexity of the problem in hand, is that most likely due to the size and scale of variations of such elements, many previous studies have shown little willingness or tendency to take account of a full parametric combination of those variables or any established systemic method to factor some of such elements, combinations or variations out. This suggests the need to undertake an all-inclusive systemic analysis and assessment of IFS energy savings, daylight control and energy generation.

For buildings with PVSDs and more specifically in hot and arid climates where such studies are scarce, there still is a substantial need for further investigation to provide a methodology that takes into account all these variables in a systemic way to improve the energy performance of buildings, to better their energy and carbon footprint without any need to compromise on their architectural or aesthetic appeals. Thus, a comprehensive investigation of the Systems Theory application is needed to further the understanding of performance of such systems. In addition, despite the lack of comprehensive and systemic studies on the application of IFS, some of the generic principles identified in the literature can be applied to the developed model in this study. They are therefore, adopted but also accordingly adapted into the context-specifics of this study as guidelines in defining a base-case model and the key design parameters affecting the energy/daylighting performance of buildings with IFS. This is illustrated in Figure 3.14 and will be discussed in detail later in Chapter 5.

All of the above-mentioned findings significantly helped in designing the current research, both at the methodology and methods levels. These will be discussed in the next chapter.

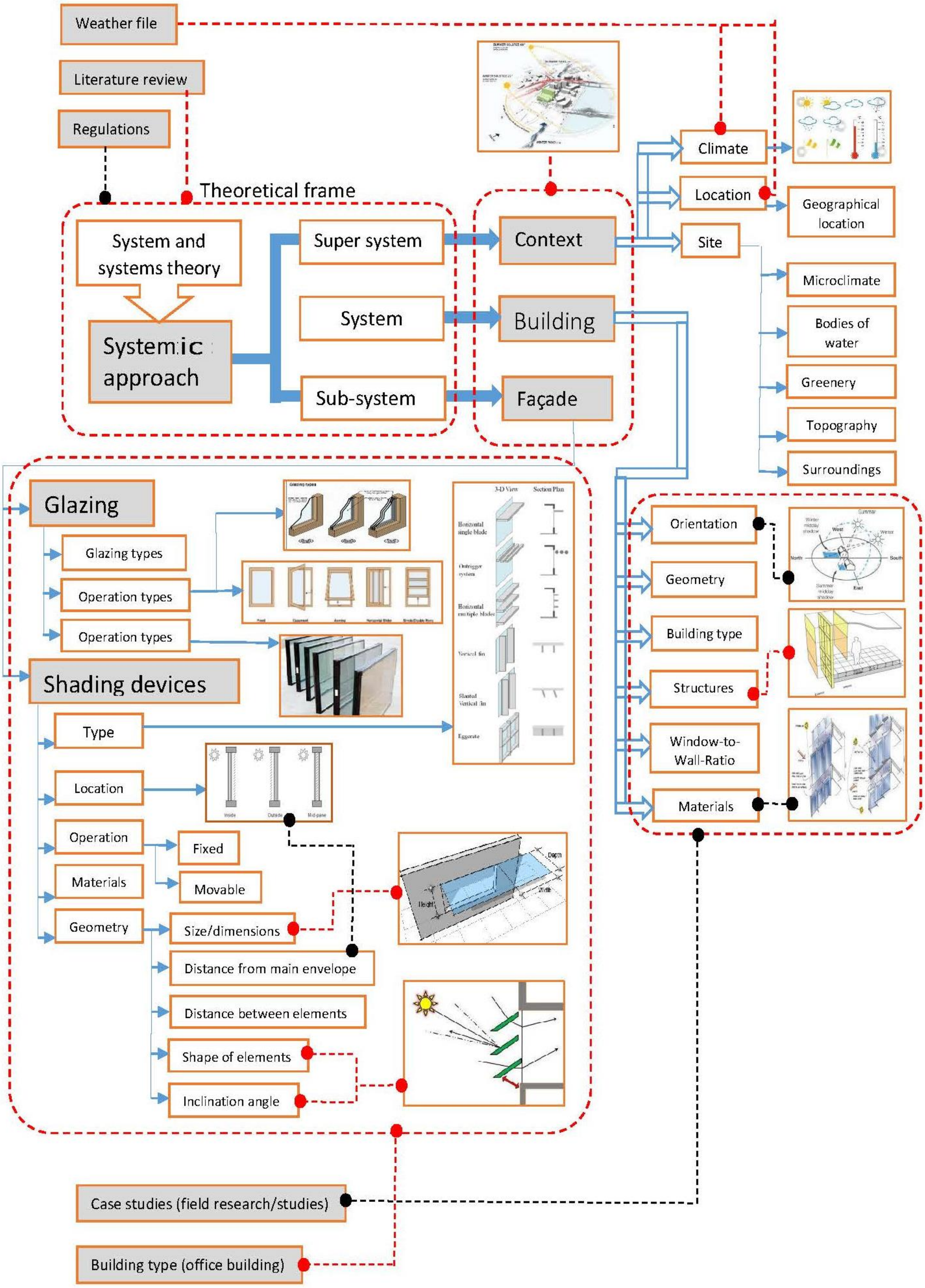
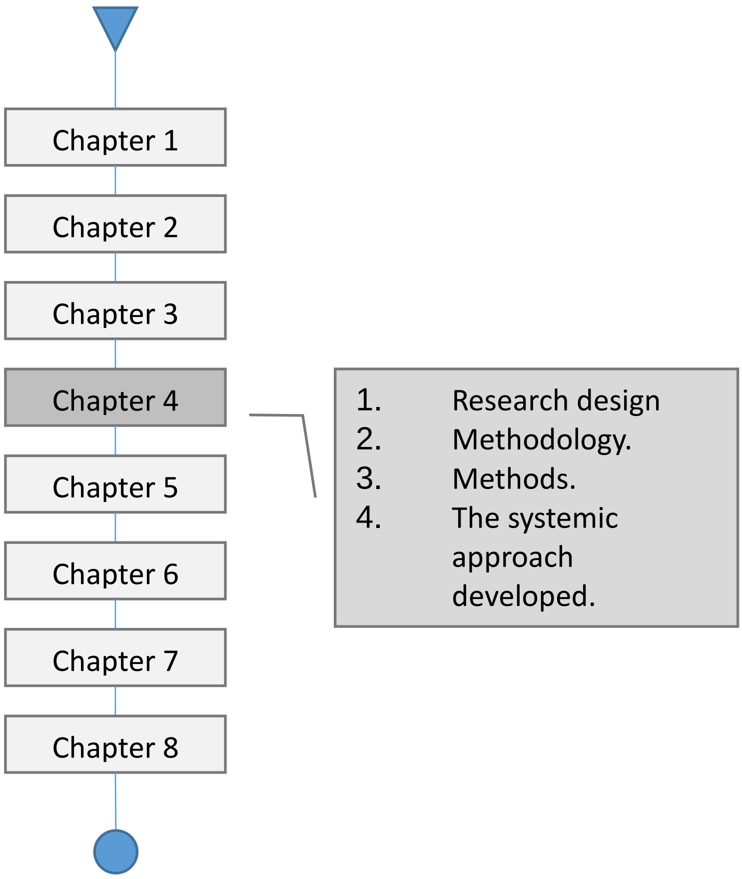


Figure 3.14 Systemic approach developed for investigating IFS in this research

Chapter Four

Research Design, Methodology and Methods



CHAPTER 4. Research design, methodology and methods

4.1 Introduction

This chapter presents the proposed methodology to achieve the aim of this study. Based on the outcomes of the literature review, this chapter also presents methods used, the process of model development and key parameters selected to evaluate the impact of those parameters on the building performance. This chapter on research design, methods and methodology is building upon part of the literature review and developing further what was found in a critical literature review of methods and methodologies; it is also developing them to go further in order to propose assessment methods, with a focus on energy performance in general, and to be able to conclude the appropriate criteria of assessment for this research, its indicators and parameters.

4.2 The approach

This research utilises a methodology where the topic is looked into through the lens of Systems Theory as its underlying philosophy or approach because the way the building is seen in this approach is as a system. The new notion of ‘Systems’ was developed through different branches of science, mostly in the six decades post WWII. Five names were remarkably influential in this field. Karl Ludwig Von Bertalanffy (General Systems Theory), Claude Elwood Shannon (Information Theory), Norbert Wiener (Cybernetics), Warren Sturgis McCulloch (Neurophysiology, AI), and Jay Wright Forrester (System Dynamics Theory) are the main figures in forming and improving Systems Theory.

The idea of the building as a system was derived from modern systems theory and the application of building science to building performance (Kesik, 2014). Piroozfar (2008) investigates the building envelope as ‘the system’, the building as ‘the super-system’ and the façade components as ‘the sub-system’ to investigate the trade-offs in mass customisation of envelope systems using off-site production methods; what has then been further developed to investigate the application of Building Information Modelling (BIM) for a fully customisable façade system by Farr et al. (2014). A slightly different approach has been used for this study to also include the contextual determinants to facilitate a global systemic approach to the concept of the Integrated Façade System (IFS) in buildings. This research takes the building level as 'the system'. The upper level, 'the super-system', includes the context of where the building is located (e.g. site, geographical location, climate, etc.) and the lower level, 'the sub-system', involves the façade (Figure 4.1). This triadic systemic classification can be expanded further into the next lower level, which includes the façade components when a closer, more detailed investigation is needed.

This methodological approach has twofold benefits, both at the theory and practice levels. It can facilitate not only the study of the literature on the topics related to those of this research, but can also help classify their impacts and further enable the decision support for the course of intervention/action when it comes to propositions of solutions for practical applications of building façades design.

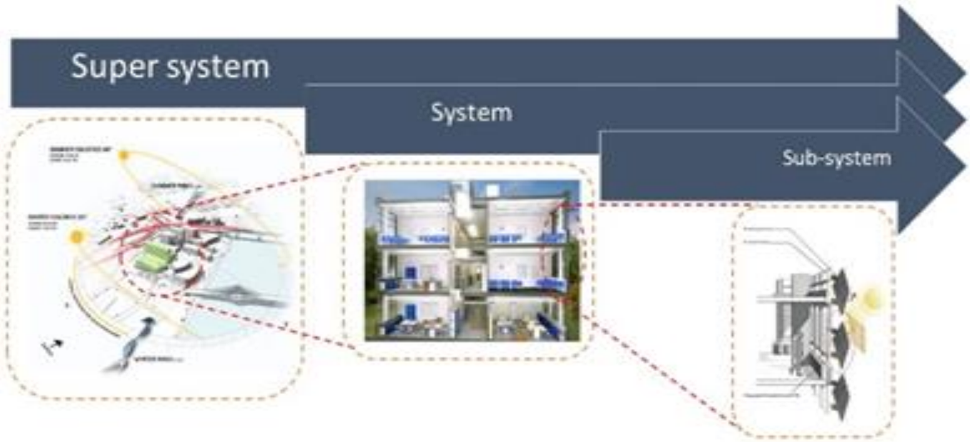


Figure 4.1 Systemic approach developed and deployed for this research

4.3 Research design

The term 'research design' as identified by Bryman and Bell (2003) in Knight and Ruddock (2009) is described as "*the ways which the data will be collected, analysed in order to answer the research questions posed and to provide a framework for undertaking the research*". In this sense, this section provides an overview of the research design and its links to the topics of this research, as shown in Figure 4.2.

- Step 1 Background/contextual studies have been used as a starting point to identify the research area, general gap in knowledge then define the research questions, aim and objectives. In addition, historical background, climate context are analysed. This stage interlinks with the literature review and methodology stages. The next stage is an in-depth critical literature review where a critical comprehensive literature review is carried out to identify IFS and their main elements: PVSD and HPG, then shading devices prototypes and their influential parameters will be established. For the assessment in hot climates, the suitable glazing types will be identified and studied, and criteria for selection will be established. This also includes the selection of glazing types that are suitable for highly-glazed office buildings in hot arid climates.

This stage serves as a tool to inform the following stages of the research and contextualise IFS, analysing its components and methods, tools used, and awareness of area-specific issues. This stage provides bases on which the methodology is designed. The third step is the methodology, which is detailed in the following steps.

• Step 2 Development of a reference model (building shape, characteristics, fabric materials, orientation). A remote questionnaire survey is intended for data collection of this step, where professional practitioners will be asked questions in order to inform the development of the prototype before moving onto the case study.

• Step 3 Application of parameters for the reference model – the results of this step are heat gains and daylighting. Simulation is used to understand the influence of each option on the heat gains and level of daylighting into the building.

• Step 4 A fully-fledged configuration of all possible combinations of parameters will be conducted using a simulation tool.

• Step 5 Analysis of cases of energy consumption in an office building. This step will consider the whole building – including internal gains – and the simulations will be run for the whole year. Based on the results of the parametric analysis, sensitivity analysis (SA) will be run to identify the most influential parameters.

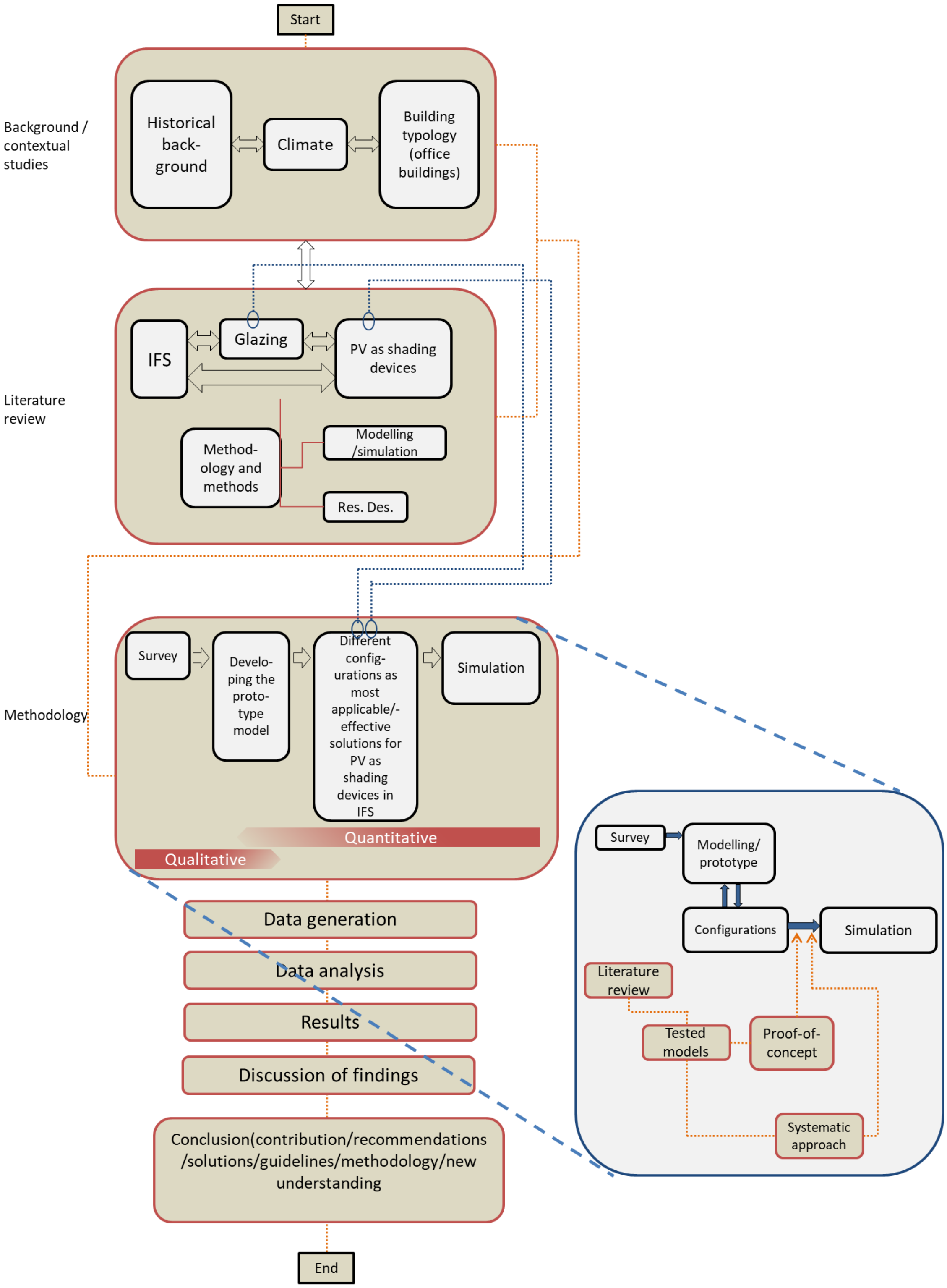


Figure 4.2 Research design

This step will also help in accounting for the validity of the results, as well as the model. An improvement process on the design will be conducted to achieve an optimised model.

4.4 Methodology

The type of data which this research would be dealing with suggests that a quantitative methodology is the most applicable to this study. However, this research builds on a data collection/generation strategy which is not strictly purely quantitative. This is where this research starts by building up a knowledgebase using a professional expert survey of office building types through a phased consultation process with architecture professionals in Iraq to find out about the prevailing types of small- to medium-sized office buildings. The findings of that survey will then be used to develop a building prototype model for conducting what will chiefly be quantitative analysis of output variables as a result of a full parametric combination of designated façade elements and parameters in the following stages of this study.

In this research, there are three main stages that take place in sequence (Figure 4.3). In the first stage, the outcome of the professional expert survey will be used to inform the development of a representative building model.

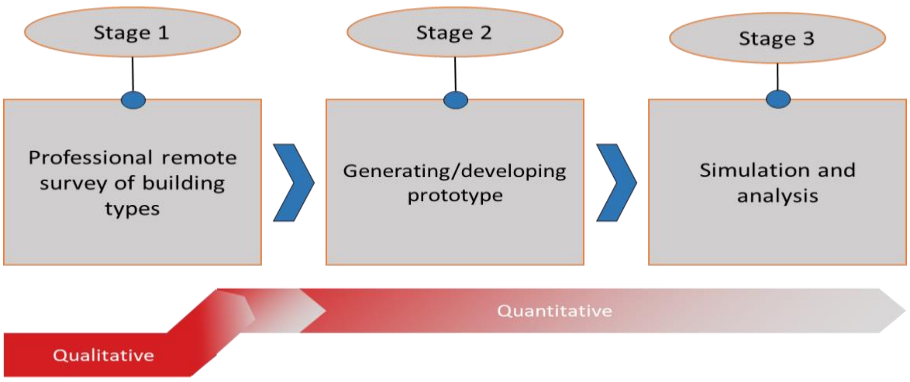


Figure 4.3 Methodology overview

In the first stage, professional practitioners with relevant experience in designing office buildings in Iraq in the last two decades were recruited. This was deemed necessary to make sure that the reliability and validity is achieved and can be built on. This will be elaborated on in more details in section 5.3.1

The second stage of this research involves the development of a base model of a highly- to fully-glazed office building suitable for the climatic and regional contextual conditions. In addition, as a result of the conclusions obtained from CHAPTER 3, the key parameters affecting the energy performance of buildings with IFS and the variations proposed for each parameter were also defined. This will be detailed in section 5.4.

In the third stage, an investigation into the impact of each key parameter on the building performance will be conducted through computational simulations. Using the base model as a reference, a parametric analysis will be performed for each parameter. Chapter 6 will provide detailed explanations on the process of this parametric analysis.

Finally, Sensitivity Analysis SA will be performed to show the impact of change of/in each parameter on the output and to help in deciding where the design efforts are to be focused in order to achieve optimised models.

4.5 Methods of evaluating building energy performance and daylighting

The focus of the literature review on the assessment methods was specifically related to and around the main element in the topic (PVSD). In this section, however, the focus slightly shifts towards an important but rather general aspect, related to the topic as well, i.e. evaluating building energy performance. In doing so, the criteria for assessment, indicators and these methods are: observation and monitoring, experimental studies, and computer simulation (Ayyad, 2011; El Sherif, 2012). Besides these three common methods, numerical and mathematical modelling have also been identified; however, a very limited number of studies has considered them during the last decade.

4.5.1 Monitoring a building

In analysing and studying a real building, climate, and usage, the influence of the researcher is limited. However, the results are reliable and accuracy is high as they are obtained from instruments, not equations and software. Errors are limited. The disadvantages are both time and money consuming. To guarantee high accuracy, expensive instruments and sensors should be used. Technical problems with devices can cause errors.

Monitoring a building is most likely to give very specific results that cannot be generalised. Sometimes occupants are not helpful when using the building and spaces to set up instruments. Any changes in parameters (external or internal) would change or affect the results and may cancel the whole process and so result in failure in accomplishing the research.

4.5.2 Experiments

A small scale mock-up building or test bed (or test cell) is built to represent a real case under real climatic conditions. The results are accurate. No occupants need to be disturbed by the sensors or instruments. This gives the researcher flexibility to try different scenarios and test their effect.

The disadvantages are also time and money consuming and there needs to be enough money available to cover both instruments and constructing the mock-up. In some cases, a mock-up building could be difficult to mimic a real building, which may result in ignoring or neglecting some factors, such as occupants' data. If this type of data is need for the analysis, then assumptions should be assumed by the researcher rather than collecting the data. This is because it is not possible to get people inside this type of mock-up building. The researcher should be highly experienced to deal with instruments and data; researcher's errors and bias are difficult to avoid.

4.5.3 Computer software

This is fast and cheap, and therefore less time and money consuming. It has high flexibility so the researcher can design different cases and scenarios, and from simple or complicated buildings predict their energy, light, carbon emission, different data inputs and different locations and climates, all of which would help in understanding the exact impact of each variable. Tools can be learned and purchased by the researcher. Accuracy and reliability are always questioned and tools providers work on developing their tools to be more accurate and reliable. Errors can happen from input data. Dealing with input data and manipulating them should be treated carefully as any modification may result in errors and unreal energy performance predictions. Performance prediction is still an assumption as there is no evidence that this will happen in real life.

4.5.4 Numerical and mathematical modelling

Having presented the advantages and disadvantages of each methodology, comparison criteria are used to compare these methodologies to help decide which is most appropriate to be used in this research.

4.6 The decision made for the choise of the main method in this study

The following criteria have been used to justify the choice of the main method that is suitable for conducting the current study:

Applicability to the case that is being investigated: The first and the most important criterion in choosing appropriate methodology is identifying the parameters that are to be investigated. The research first determined the parameters to be studied besides analysing and comparing different methodologies that have been used by others in similar cases. In similar studies carried out by Ayyad (2011) and El Sherif (2012), the parameters were; constant (climate and building usage data) and variable (design data and materials).

In the current study, weather and location parameters are also constants (i.e. weather file), building parameters (orientation, design and materials) will be variables, and internal gain, systems and profiles of use will also be constants. In this case, more details about the variables and the available and applicable methods should be highlighted in greater detail.

Cost: It is now obvious that the computer simulation method is the least expensive compared to experimental data and a mock-up building as it costs only the tool, licence purchasing and training on the tool. This would cost much less than buying instruments or constructing a mock-up building.

Time: Monitoring a building and conducting an experiment consume much time compared to the time used in the computer simulation method.

Accuracy and reliability: Obtaining results from monitoring a real building or a mock-up are still more accurate and reliable, but it is worth mentioning again that computer tools are being developed and the results are becoming more accurate. The so-called ‘bridging the performance gap’ between real and predicted performance is intensively under research nowadays and the main outcome of this will help in reducing any inaccuracy in this method.

Flexibility: Undoubtedly computer simulation is the most flexible methodology compared to other methodologies because it gives the researcher unlimited chances to examine a wide range of variables and different designs and locations.

It difficult to change variables in other methods and in some cases it is not possible.

Bias and objectivity: The influence of the researcher in monitoring a real building is minimal compared to other methodologies, such as simulation where the researcher is able to determine factors to be tested.

Expertise: Researchers should be highly experienced in dealing with instruments and the type of data they are testing and gathering both in monitoring and experimenting methodologies. In computer simulation methodology, the researcher should know how to use the tool as it is easier and faster than other methodologies.

According to what has been explained above and the nature of this research, computer simulation methodology is considered to be the most appropriate methodology to be adopted in this research. Furthermore, the funding for this research and the time are both too limited to go for monitoring a real building or constructing a mock-up one.

4.7 Building Energy Simulation (BES)

The literature review revealed that the simulation tool is the most commonly used method in building performance assessment and design in similar studies (Awadh and Abuhijleh, 2013; Ayyad, 2011; Kim et al., 2012; Lamnatou et al., 2015; Namini et al., 2014). BES is performed to analyse the energy performance of a building dynamically and to understand the relationship between the design parameters and energy use characteristics of the building. The effects of all kinds of changes can be simulated and observed in a fraction of the time and cost it would take to study these alternatives in real life (Anderson, 2014; Hui, 1998).

Therefore this method is chosen as the main method for evaluating the influential parameters in designing IFS; however, this decision is based on a comprehensive comparison between all methods. A summary of the pros and cons was prepared then an informed decision was made and justified.

After deciding on the method, a decision on which tool will be considered in this research is also made and justified. Hence another comprehensive approach was taken to make an informed decision based on a detailed comparison between the most likely tools that could be used. Finally, IES-VE was the choice. The next section will give details to demonstrate what has been done in this regard.

4.8 The tool

Architects today can choose from a wide range of simulation tools that have been validated for the last four decades. A number of energy simulation programs are available such as ESP-r, e-QUEST and EnergyPlus and IES-VE to name a few, each of which requires different input characteristics and provides various outputs (Crawley et al., 2008) and all of which have been continuously improved over this period (Anderson, 2014). Any of these tools can be successfully utilised to predict the potential energy performance of a building in the initial stage of design where variations such as shading devices can be studied and analysed in detail as a key design factor in the determination of energy assessment (Kim et al., 2012) and also model energy flows on an hourly basis with flexibility of variation in construction systems, materials, thermal characteristics, profiles flexibility and availability and reliability of weather data (Ayyad, 2011).However, choosing the appropriate tool for a specific investigation can be a complicated task, therefore an informed decision is essential for any researcher to comprehensively compare and contrast the features of these tools.

The major tools in the building energy field have been analysed and compared based on their features and capabilities. An example of this analysis was carried out by Crawley et al. (2008) where the tools were: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, IES-VE, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES /VES, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS; these were compared in terms of their capabilities and features. The features were: modelling features; zone loads; building envelope; daylighting and solar; infiltration, ventilation and multi-zone airflow; renewable energy systems; electrical systems; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability; results reporting; validation; user interface, links to other programs, and availability. A checklist of capabilities of these 20 BES tools was provided for BES users based on the evaluation results, as shown in Table 4.1. Users with specific BES requirements can benefit from this list; however, users are advised to consider adopting a suite of tools which would support the range of simulation needs.

In the interests of this research, the previously-mentioned capabilities are interlinked and they influence the building performance in different levels, such as climate in the super system level, building orientation in the system level and heat exchange through IFS in the sub-system level, therefore they all need to be systematically analysed; IES-VE shows good potential in this regard.

Another comparison of available tools (most popular tools) from an architectural point of view has been carried out by Attia et al. (2009) based on the criteria of being 'architect friendly'. The criteria were found to be:

- Usability and information management of the interface.
- The integration of an intelligent design knowledge base.

Table 4.1 Comparison of the 20 software programs according to zone loads (Crawley et al., 2008)

	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES (VE)	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
• Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
• Dependent on air flow	X						X		P		X		X		X			X		E
• Dependent on surface heat coefficient from CFD									E		E		X							
• User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
• Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
• Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
• User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
• User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

X feature or capability available and in common use; P feature or capability partially implemented; O optional feature or capability; R optional feature or capability for research use; E feature or capability requires domain expertise; I feature or capability with difficult to obtain input.

D.B. Crawley et al. / Building and Environment 43 (2008) 661–673

IES was found preferable in 85% of the respondents due to its usability of information (Figure 4.4), better graphical representation of simulation input and output, simple navigation and flexible control (Attia et al., 2009). The final results of Attia's study shows that IES-VE was marked at 100% according to information management and 72% for integration of an intelligent design knowledge base. This explains how architects would prefer to see results in a concise and straightforward way with a visual format or 3D in preference to numerical tabulation (Attia, 2010).

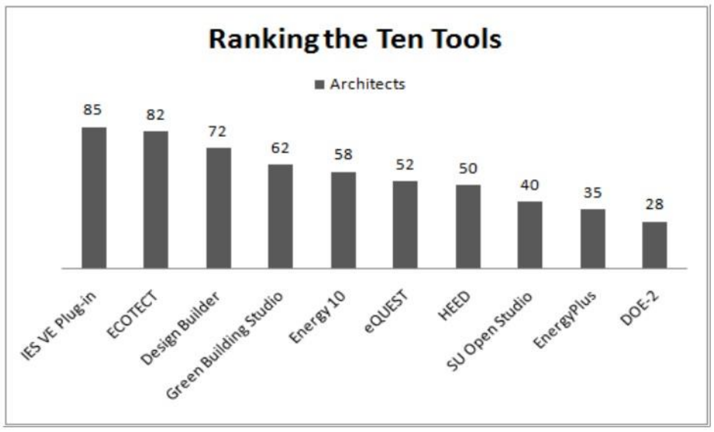


Figure 4.4 Most used BES ranked by Attia (2010)

These results agree with the ultimate purpose of this research, which is to help architects evaluate and optimise their designs using tools with less complexity but with enough capabilities.

It is essential that tools support sustainability design decisions and detailed comparison between different design measures (Attia et al., 2009) because this will encourage BES users to incorporate techniques that reduce the impact of the building on the environment.

Any comparison, however, is out of date because simulation tools providers update their tools annually or even monthly (Anderson, 2014). The International Building Performance Simulation Association (IBPSA) hosted by the US Department of Energy website[10] provides simulation tools information and allows the user to establish a comparison table of differences between any tools. This comparison helps in providing data about the features of tools. Different comparisons between EnergyPlus and other tools have been established (IBPSA, 2015). An example of this was IES-VE. However, it is clear that the amount of data and details about EnergyPlus are clearer and to some extent, biased, but this would be understandable because EnergyPlus was first designed and used in the US and it was concerned about the building industry there with all the analyses based on ASHRAE codes, whereas IES-VE is mainly UK-based.

[10] http://www.buildingenergysoftwaretools.com/

A series of simulations by an energy analysis program, IES-VE, have been adopted in Ayyad (2011), Bojic (2006), El Sherif (2012), Kim et al. (2011) and Yu et al. (2008), and other studies. Ayyad (2011) stated that the IES-VE simulation program has the ability to integrate valid weather data, having a user-friendly interface, and the flexibility to perform different types of simulations. This computer simulation software was used to model a case study house design at first, then different case scenarios were applied to study their impacts on solar heat gain, cooling loads, and energy consumption. This software has different modules that can perform different calculations for the same model but with specific data inputs. This tool is gaining more market attention and is expected to gain more market share (Anderson, 2014).

4.9 Integrated Environmental Solutions-Virtual Environment (IES-VE)

IES-VE is a powerful dynamic simulation tool which has been widely used by leading sustainable design experts around the globe according to the retailer's website[11]. As far as this study is concerned, many researchers have used it successfully in virtually testing the feasibility of different energy saving strategies, especially shading design and new technologies (Awadh and Abuhijleh, 2013; Ayyad, 2011; Sherif, 2012; Kim et al., 2012). Flexibility, fairly user-friendly interface, and accurately addressing different aspects related to buildings, are the main benefits of IES. The software tool integrates different modules, as shown in Figure 4.5, to provide more accurate and reliable simulations.

In this research, IES is used to ensure a correct conversion from models drawn in different environments into IES and perform the sun shading calculations that take into account solar gains and evaluate human comfort. The dynamic thermal analysis will be performed in IES ApacheSim. In addition, the tool has plugins that import models from widely used CAD drawing tools to improve the accuracy of the models used for simulation. IES-VE provides results in figures, such as energy consumption, heat gains and cooling loads; this research is aiming at a full investigation of these indicators.

[11] https://www.**iesve**.com/

Figure 4.5 Modules integrated in IES-VE

This tool can obtain results categorized according to each scenario in a variation of calibrations such as evaluating the thermal cooling load performance through the results of the simulation for variable parameters (i.e. location, orientation, the U-Values of constructions elements, the ratio of glazing, and the variation during seasons and daytime) (Al-Badri, 2013). An important feature that is closely related to the performance of shading devices is that solar calculations can also be presented based on simulating and calculating the shading effects (El Sherif, 2012). When a full image about the most efficient scenario is needed, evaluations of the total energy consumption of buildings in different formats such as electricity for cooling, heating, artificial lighting, and equipment can be carried out (Ayyad, 2011).

In addition, renewable energy such as PV electricity generation, can be evaluated and analysed in terms of the impact of each parameter on the total electricity production and in terms of savings compared to the total energy results. It compares the PV output and energy savings, examines different locations, angles, and types to determine the appropriate one based on PV electricity production. Analyses including daylighting and glare will also be included, as trade-offs between the three main functions of IFS-shading, daylighting and PV production are needed.

To summarise, IES-VE is an integrated tool of a collection of modules linked by a common user interface and a single integrated data model. This means that the data input for one module can be used for other modules within the tool. Each of these modules performs a specific calculation, such as “Apachesim” for thermal simulation, “Radiance” for lighting simulation and “SunCast” for solar shading analysis. The output data will be dealt with and prepared for extraction in “VistaPro”.

4.10 Establishing the base-case model

The development of reliable and representative building models for office buildings in Iraq forms an important part of this research. It is needed in all simulation studies to serve as a benchmark for comparison and evaluation. Development of any model is subject to the research goals and depends on its application (Attia et al., 2012). Because of the lack of data that documents office building prototypes in Iraq and because conducting a field survey to identify office building prototypes and building characteristics is not possible at the moment due to security reasons, it is intended to conduct a remote questionnaire survey and send it to a number of Iraqi architectural practices to establish a representative model of office buildings. As the researcher here is a practising architect in Iraq with more than 15 years' experience in buildings such as offices, he decided to design several prototypes for the survey based on his experience.

For the pilot study (proof-of-concept stage) and the time being, the researcher has designed a simple prototype office building based on his experience in the field. This prototype will later be confirmed or refined based on the response of the participants in the remote survey. This base-case model represents the prevalent practices of construction of office buildings in Baghdad, Iraq. This next section presents the model description, occupancy profiles, and a simulation of key parameters.

4.11 Description of the model

This section is an important part of the data collection/generation of the methodology in this research because the establishment of a base-case model provides a prototype building that is designed for the hot climate of the country of study, Iraq. It is the first stage of the main three stages of the methodology. It starts by identifying the model configurations that consist of three categories, as shown in Figure 4.6. These are (1) the physical entity of the model that represents the geometry (dimensions of the building, size, and height) and materials, (2) the building services managements (BSM) that are related to the indoor temperature and air flow, and (3) the human factors such as patterns of use, number of occupants and type of use. All these configurations will be included in the design of the prevailing types of office buildings to be used in the next step within this stage which is the data sampling strategy.

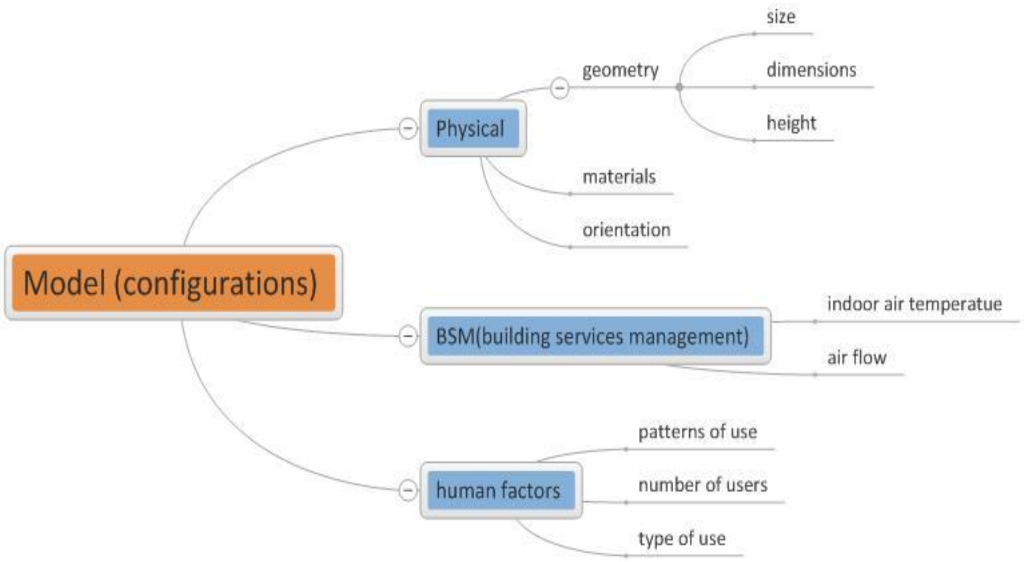


Figure 4.6 Representative prototype building configurations

4.11.1 Data sampling strategy

The data sampling strategy will be conducted using a remote survey to approach architects who will be selected based on inclusion/exclusion criteria. These criteria are that the architect should:

- Be a professional practitioner.
- Have been active in Iraq for at least 10 years.
- Have designed office buildings and have experience in this type of building.

The outcome of the survey will inform the next stage where a prototype building will be developed. This step is further explained in the CHAPTER 5.

4.11.2 Model configuration

Having collected and analysed the data and concluding the survey, the model was configured. The configuration and characterisation of the simulation model are detailed in section 5.3.5. It starts with the building geometry, with all the dimensions (length, width and height of the floors), layout, number of zones/rooms/offices and floor numbers, followed by setting the geographical location in the simulation tool to account for the location specifics (e.g. latitude and sun path). The building construction and materials were then assigned, as detailed and illustrated in section 5.3.5. One of the most important parts, which represents one of the main elements of IFS is the glazing system. Section 5.3.5 elaborates in detail on the creation process of the glazing systems using an advanced tool called LBNL Window 7.5. The characterisation of all glazing systems were calculated using this tool and have been exported to IES-VE construction library to then be used in the simulations. Appendix 6 provides details on how this process has been carried out using LBNL Window 7.5.

Once the model was constructed, several profiles were then devised and applied, such as occupancy/cooling/heating/lighting profiles. These profiles were applied as daily, weekly and annual profiles. This is also detailed in section 5.3.5. Artificial lighting profiles, internal gains and electricity meters were also applied. Subsequently, photovoltaic settings attributed to the PV technology used in the simulation were also set up, as shown in section 5.3.5. However, there is a newly introduced feature in IES-VE 2017 which is the Geometric PV Setting. This feature offers the possibility to place geometric free-standing panels exclusively for estimating PV potential. It also allows for taking into account both the physical location and the solar shading received by the panels in the assessment of PV potential. This was used to create the PVSDs by applying a PV layer on the shading devices. The applicability and reliability of this approach was validated using simplified models (see section 5.3.6 for details).

4.12 Data analysis

The analysis will be conducted in two stages: a) proof-of-concept stage and b) detailed simulation stage. The first stage represents the proof-of-concept stage where the preliminary results of two rounds of simulation will be presented to demonstrate the application of such a methodology to a full parametric study of IFS technology. This stage consists of two rounds of simulations which are carried out to investigate the impact of change of one parameter while the rest of parameters are kept fixed. This stage will use a preliminary model created for this stage and then scenarios will be created. A discussion about the preliminary results of the simulation of this stage will be further discussed in CHAPTER 66.2. Once the proof-of-concept is verified, the adopted strategy will be rolled out to other combinations of different variables at system and sub-system level in the second stage. The second stage of the analysis will be conducted in three phases to include the detailed parametric analysis of all the assessment indicators under investigation.

The second stage of the analysis will include the detailed parametric analysis of the full set of combinations of parameters and will be conducted in three phases, as shown in Figure 4.7.

Phase one is inferential analysis where all results are grouped and clustered using the systemic approach developed for this study.

Phase two represents a decisional synopses approach where all results are ranked based on their actual values.

Phase three is the Sensitivity Analysis SA which will be carried out using IBM SPSS v22 to show the impact of change of the inputs on the each of the outputs. The methods used in SA are justified based on the comprehensive review of the literature where SA was conducted. Further details are presented in the following section.

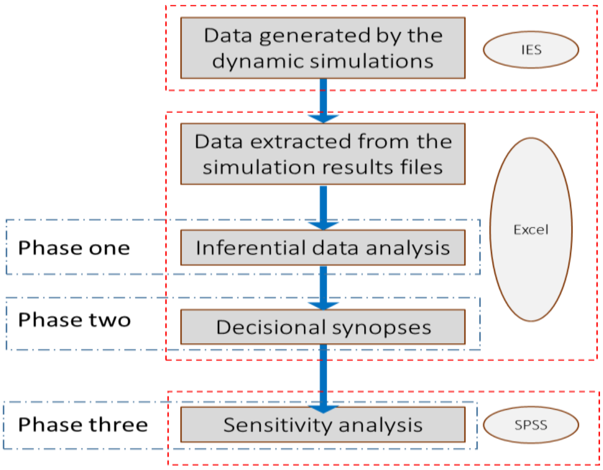
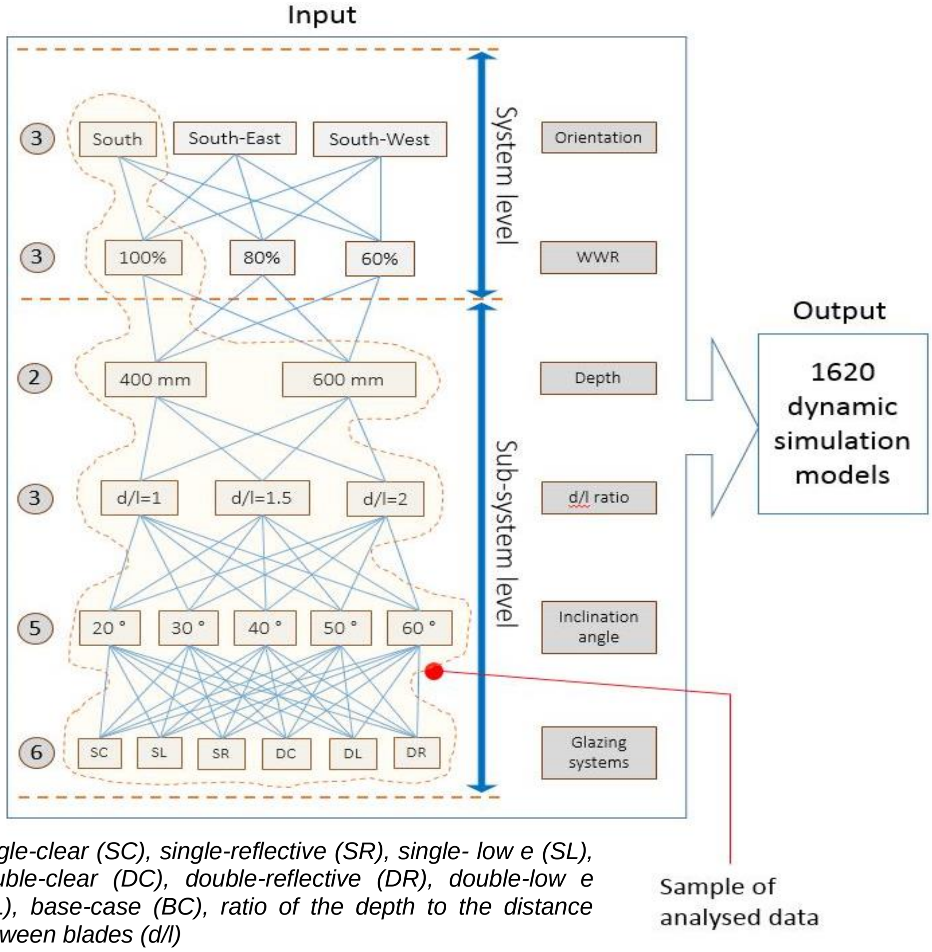


Figure 4.7 Workflow of stage two of the ata analysis

A sample of the data analysed is presented CHAPTER 6, 6.3 for the south orientation while the other two orientations are presented in Appendix 7. The samples of the data will be looked into using their systemic cluster, as shown in Figure 4.8.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 4.8 Sample of the analysed data

4.12.1 Sensitivity analysis (SA): review of the methods and applications

An important issue in detailed design is how to quantify and verify the information obtained from a simulation study and to translate it into aggregated performance measures that are easily understood by the design team and support rational decisions (Hopfe, 2009). The relationship between simulation inputs and outputs is often unknown or uncertain due to the complexity of building energy models (Nguyen and Reiter, 2015). If the change in an input parameter (X) results in a change in the output parameter (Y) and these changes can be measured, then the sensitivity of Y with respect to X can be determined (Lam and Hui, 1996 cited in Nguyen and Reiter, 2015).

Direct or indirect approaches can be followed to measure the sensitivity, i.e. $S_{x1} = \delta Y / \delta X_j$ (where Y is the output of interest and X_j is the input factor) (Saltelli et al., 2004). Once the SA is measured and determined, the relationships and relative importance of the design parameters can be understood and the building performance can be easily improved by focusing on important design parameters.

SA is defined as a measure of the effect of a given input on another given output (Saltelli et al., 2004). Another definition of SA is that it is a technique that aims at estimating how the uncertainty in the independent variables of a mathematical model affects a particular dependent variable, given a predefined set of assumptions (Eggebø, 2017). This method can be used in building performance analysis to:

- Help in assessing the significance of various input parameters.
- Provide a robust tool to quantify the effect of different design parameters.
- Identify sources of uncertainty.

SA can be categorised in different ways (Frey et al., 2003; Hamby, 1994; Nguyen and Reiter, 2015; Tian, 2013). It can be grouped based on the input/output approach into three groups according to Hamby (1994):

- Those that evaluate the output on one variable at a time (six methods).
- Those that are based on the generation of a sample of input vectors and associated outputs (including 10 methods).
- Those that perform a partitioning of a particular input vector based on the resulting output vector (including four methods).

Or categorised into three groups based on the type of approach according to Frey et al. (2003):

- The “mathematical approach” typically involves calculating the output for a few values of an input within its possible range. This approach basically consists of the Nominal Range Sensitivity Analysis Method, the Differential

Sensitivity Analysis, the method of Morris, most of the methods using the one-parameter-at-a-time (OAT) approach.

- The “statistical (or probabilistic) approach” involves the running of a large number of model evaluations on an input sample, which is usually generated randomly. Depending upon the method, one or more inputs are varied at a time. The statistical methods allow quantifying the effect of simultaneous interactions among multiple inputs. The statistical approach includes: the linear Regression Analysis (RA), the analysis of variance (ANOVA), the Response Surface Method (RSM), the Fourier Amplitude Sensitivity Test (FAST), the Mutual Information Index (MII), Sobol’s method, methods using statistical indices: PEAR (Pearson product moment correlation coefficient), SPEA (Spearman coefficient), SRC (Standardized regression coefficient), and SRRC (Standardized rank regression coefficient).
- SA methods using “graphical assessment” to estimate a qualitative measure of sensitivity using graphs, charts, or surfaces of pairs of inputs – corresponding outputs.

Or into three groups based on the number of inputs and the interactions between them according to Heiselberg et al. (2009):

- Local: often the OAT approach.
- Global: the significance of an input factor is evaluated by varying all other input factors as well.
- Screening: the significance of each input is evaluated in turn and the sensitivity index is evaluated by the average of the partial derivatives at different points in the input space. The method of Morris (1991) is one of the most commonly used screening methods.

The last categorisation is the most commonly adopted categorisation and has been followed by many researchers such as Tian (2013) and Nguyen and Reiter (2015) as shown in Table 4.2.

Various applications of SA methods have been found in the literature, such as Hopfe and Hensen (2011) and McLeod et al. (2013) where uncertainty was coupled with SA when the input parameters variation were not available.

Hopfe and Hensen (2011) used uncertainty analysis as a pre-processing and then SA on three groups of input parameters of an office building, such as physical, design and scenario parameters. In the absence of the ranges of variation of input parameters, the Latin Hypercube Sampling (LHS) method was used to generate the input data and variation ranges, whereas Standardized Rank Regression Coefficient (SRRC) was used as the quantitative measure of sensitivity. Infiltration rate and room geometry were found to be the most sensitive parameters of the model.

McLeod et al. (2013) conducted scenario modelling using probabilistic data derived from a weather generator tool in conjunction with dynamic simulation. They used Global SA techniques to assess the future performance of a range of typical Passivhaus dwellings in order to account for the climate change on those dwellings and possible overheating risk. The results concluded a small number of design inputs, including glazing ratios and external shading devices can play a significant role in mitigating future overheating risks.

The selection of SA methods for a model requires some knowledge of the model input/output, especially building energy models where it is not easy to understand the output behaviour of a model (Nguyen and Reiter, 2015). In addition, Variance-based SA methods, e.g. the Sobol method, need a large number of model evaluations to calculate sensitivity indices (Nguyen and Reiter, 2015).

Nguyen and Reiter (2015) performed global SA using the Monte Carlo sampling-based approach to provide statistical answers to a problem by running multiple model evaluations with a probabilistically generated input sample, and then the results of these evaluations were used to determine the sensitivity indices.

Table 4.2 SA methods (Nguyen and Reiter, 2015).

Regression-based sensitivity indices (Nguyen 2013; Yang 2011; Calleja Rodríguez et al. 2013)	1. PEAR	PEAR measures the ***usual*** linear correlation coefficient between Y and a given input X_j. This sensitivity index is strictly applied to linear models.
	2. SRC	SRC gives the strength of the correlation between Y and a given input X_j through a linear regression model having the form $y_i = a + \sum_j b_j x_{ij} + \varepsilon_i$; where y_i , $i = 1, \ldots, m$, are the output values of the model; b_j, $j = 1, \ldots, n$, are coefficients that must be determined and ε_i is the error (residual) due to the approximation (m being the number of inputs in the sample, n being the number of input variables). Reliability of the SRC strongly depends on the R^2 of the linear model.
	3. PCC	PCC gives the strength of the correlation between Y and a given input X_j ***cleaned of any effect due to any correlation between X_j and any of the X_i , $j \neq i$.*** If input variables are uncorrelated, the order of variable importance based either on SRC's or PCC's (in their absolute values) is exactly the same.
Regression-based sensitivity indices (using rank transformation techniques) (Nguyen 2013; Hopfe and Hensen 2011)	4. SPEA	SPEA is essentially the same as PEAR, but using the ranks of both Y and X_j instead of the raw values, i.e.: $SPEA(Y,X_j) = PEAR[R(Y),R(X_j)]$ where $R(*)$ indicates the transformation which substitutes the variable value with its rank.
	5. SRRC	SRRC is used instead of SRC when R^2 is low. In this case, the input and output variables are replaced by their ranks, and the regression is then performed entirely on these ranks. SRRC is better than SRC if the model output varies non-linearly, but monotonically with each independent variable.
	6. PRCC	PRCC is the PCC calculated on the rank of input variables. The performance of the PRCC shows the same features of performance as the SRCC: good for monotonic models, and not fully satisfactory in the presence of non-monotonicity.
Variance-based sensitivity methods (Mara and Tarantola 2008)	7. Sobol index 8. FAST* sensitivity index	Both Sobol and FAST methods are model-independent approach in SA. They decompose the variance of model outputs into fractions which can be attributed to inputs or sets of inputs. These methods can deal with nonlinear and non-monotonic models or models with strongly correlated inputs. For each method, two measures of SA can be used: - "First-order sensitivity index": is the contribution to the output variance of the main effect of X_i, hence it measures the effect of varying X_i alone, but averaged over variations in other input parameters. - "Total-effect index": measures the contribution to the output variance of X_i, including all variance caused by its interactions, of any order, with any other input variables.
Screening-based method (Heiselberg et al. 2009)	9. Morris's SA method	Morris method is also a model-independent approach in SA. It computes partial derivatives of a model at evenly-distributed points (often called "level") within input ranges and these derivatives are then average out. Morris method gives 2 indicators related to SA: one (μ) is to estimate the main effect of the input factor on the output and the other (σ) is to assess the interaction with other factors or the nonlinear effects. This method does not support uncertainty analysis.

* This study uses the extended FAST method which allows calculations of both first and total-order sensitivity indices.

In this paper, the Monte Carlo-based SA consists of five major steps:

1. Selecting the model to perform SA.
2. Identifying simulation inputs of the model to be included in the SA and the probability distribution functions of these variables.
3. Generating a sample of N input vectors for the model using a probability sampling method.

4. Running the simulation model N times on the input sample to produce N corresponding outputs.
5. Calculating the sensitivity indices for each input and drawing necessary conclusions.

This study used nine SA methods to test them to see which the appropriate one is.

The two main approaches found in the literature are either using a discrete distribution provided by the user or using a probabilistic distribution drawn from a given problem space (Eggebø, 2017). Discrete distribution can be used for input variables such as window constructions, where a limited number of options are available and each one is as good as the next (Eggebø, 2017). Probabilistic distributions are relevant if the input variable is continuous, and there is a higher likelihood of choosing within a certain range of the distribution.

In those, and similar, studies, there have been no previously identified variations of input parameters, therefore a probabilistic input was essential to those studies to account for uncertainties in the inputs and the range of variations of each of the input parameters. In this current study, however, a robust systemic methodology was developed and followed in order to factor out the irrelevant input changes and to make informed decisions about the range of variations of each of the input parameters.

SA has been widely used to explore the characteristics of building thermal performance in various types of applications, such as building design, calibration of energy models, building retrofit, building stock, impact of climate change on buildings (Tian, 2013). It is used to identify the key variables affecting a building's thermal performance from both energy simulation models and observational study. The main difference among these applications is the variations (uncertainty or probability). Tian (2013) categorises SA into local, global, screening-based, variance-based and meta-model methods as follows (Figure 4.9):

- Local. A straightforward method which belongs to one-factor-at-a-time methods where the choice of a base-case is important. However, its drawbacks are: it only explores a reduced space of the input factor around a base-case, interactions cannot be considered using this method, and no self-verification is available in this method.

- Global. Regression and screening-based methods are the mainstream methods of global SA. Regression is the most widely used. It is usually used after MCA. In this method the types are: SRC (Standardised Regression Coefficients), PCC (Partial Correlation Coefficients), and their rank transformation (SRRC standardized rank regression coefficient, PRCC partial rank correlation coefficient. SRC and PCC are only suitable for linear models. SRRC and PCC can be used for non-linear monotonic functions among inputs and outputs. The difference between SRC and PRC is that PRC is suitable for correlated input because it excludes the effects of correlations between input factors, but the SRC is only valid in the case of uncorrelated inputs.

	Method	Subtype	Characteristics	Literature
Local	Local	–	Explore a reduced space of the input factor around a base case; low computational cost; simple to implement; easy to interpret; not consider interactions between inputs; no self-verification	[6,16–24]
Global	Regression	SRC	SRC and *t*-value, suitable for linear models; SRRC, suitable for non-linear but monotonic models;	[1,7–9,25–27,29,34]
		SRRC	moderate computational cost for energy models; fast to compute; easy to implement and understand;	[2,13,25,30–32]
		t-value	high SRC means more important of the variable	[10,33]
	Screen	Morris	Suitable for a larger number of inputs and computationally intensive models; model-free approach; qualitative measure to rank factors; no self-verification; not suitable for uncertainty analysis	[35–41]
	Variance	FAST	Decompose the variance of the model output for every input; model-free approach; consider both main and	[12,42]
	based	Sobol	interactions effects; quantitative measures; high computational cost; FAST is not suitable for discrete distributions	[44]
	Meta-	MARS	Suitable for complex and computationally intensive models;	[7,45]
	model	ACOSSO	quantify output variance due to different inputs;	[9]
		SVM	the accuracy dependent on the meta-model	[46]

Notes: SRC, standardised regression coefficients [47]; SRRC, standardized rank regression coefficient [47]; FAST, Fourier amplitude sensitivity test [49]; MARS, multivariate adaptive regression splines [52], ACOSSO, adaptive component selection and smoothing operator [52], SVM, support vector machine [61].

Figure 4.9 Comparison of SA methods used in building performance analysis (Tian, 2013)

Some inputs could be correlated. When inputs (also called predictors) are correlated, SRC (or t-value) cannot be used in the presence of correlated factors. Many other statistics can also be used to determine which factors are important in regression analysis. These statistics include t-value, F-value, change of R2 (coefficient of determinations). The higher the absolute value of t (or F, change of R2), the more important is the corresponding variable.

Ballarini and Corrado (2012) proposed a methodology that involves analysing different contributions to the internal air convective heat balance and their interrelations with different boundary conditions. The main sensitivity method was standardised regression, which was applied by means of a multi-step dynamic numerical simulation, to a parametric analysis of two case studies. A semi-empirical[12] parameter was then defined to quantify this aspect and to perform the SA. The standardised regression coefficients were calculated to determine which of the various independent variables X1, X2,. . ., X6 has the most influence on the dependent variable Y (Ballarini and Corrado, 2012).

- Screening-based: The Morris method is the most common in this category where input factors are taken as a discrete number of values (also called levels), which are different from other global methods in which input values are taken directly from distributions. Two sensitivity indexes can be obtained from the Morris method (Saltelli et al., 2004). One (μ) is to estimate the main effect of the input factor on the output and the other (σ) is to assess the interaction with other factors or the non-linear effects. A new measure (μ*) has been proposed to estimate the total effects of the input factor (Saltelli et al., 2004).

The drawback of this method is that this approach cannot quantify the effects of different factors on outputs. As a result, this method does not allow self-verification, which means the analyst does not know how much of the total variances of outputs have been taken into account in the analysis. The other types of global SA (such as regression or variance-based methods) can usually provide this information (Tian, 2013).

Brembilla et al. (2017) used Morris analyses to rank input parameters such as the classrooms' interior surfaces here. The method helped in ordering their influence on the overall results, as displayed on the left of Figure 4.10. They can also give an indication of the parameters' relationship with the results based on the ratio $\sigma/\mu*$, where σ is the standard deviation of the elementary effects (i.e. differences in results due to input variations) distribution, and $\mu*$ is the mean absolute value of the distribution. Those parameters that sit in the graph below the line $\sigma/\mu* = 0.1$ can be considered to have an almost linear relationship with the results; if they appear below the lines $\sigma/\mu* = 0.5$ and $\sigma/\mu* = 1$ than they have respectively a

[12] Means to assign quantitative indices to qualitative aspects for SA purposes, i.e. U-value, g-value…etc. were used for glass/glazing alternatives Ballarini & Corrado (2012)..

monotonic and an almost-monotonic behaviour; above the line $\sigma/\mu* = 1$, the parameters show a highly non-linear relationship with the final results, indicating that there might be an interaction with other input factors (Brembilla et al., 2017), as shown in the right side of Figure 4.10.

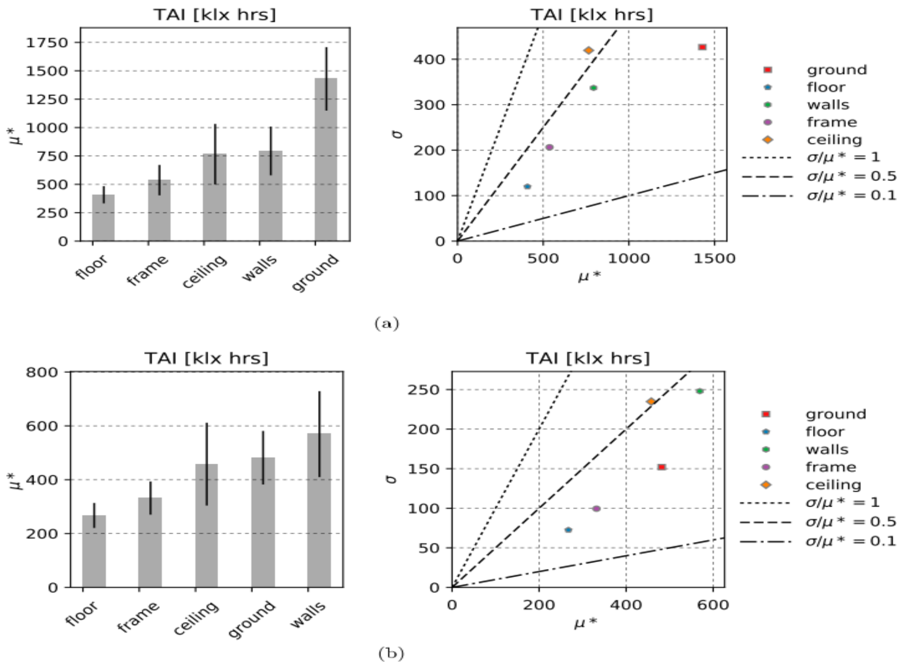


Figure 4.10 Morris plots (Brembilla et al., 2017)

The Morris method presents its outcome using the mean of the absolute value of the elementary effects (μ_j) and the standard deviation of the elementary effects (σ_j), as sensitivity indices. μ_j measures the influence of the j^{th} independent variable on the dependent variable, and σj measures the interaction or non-linearity of the j^{th} independent variable with respect to the dependent variable (Iooss and Lemaître, 2015).

- Variance-based: Sobol, FAST (Fourier Amplitude Sensitivity Test). The variance-based method is to decompose the uncertainty of outputs for the corresponding inputs (Saltelli et al., 2004).

Two main sensitivity measures used in this approach are the ‘first order’ and ‘total effects’. The first order effects consider the main effects for the output variations due to the corresponding input. The total effects account for the total contributions to the output variance due to the corresponding input, which includes both first order and higher-order effects because of interactions among inputs. Hence, the difference between the first order and total effects can show the effects of interactions between variables.

The use of a measure depends on the objective of the research; if it is to fix the factors which are not important in the energy models, the total sensitivity effects should be used or in contrast, if the objective is to rank energy saving measures, the first order effects are a better choice. This variance-based method is regarded as a model free approach that is suitable for complex non-linear and non-additive models (Tian, 2013). This method can quantify all the variances of the output due to every input and it can also consider the interaction effects among variables. The classical FAST method considers only the non-linear effects, but not interaction effects. The Sobol method can decompose all the output variance, which means no variance for the output is left in the analysis. However, the Sobol method is much more computational expensive compared to other global SA methods (Tian, 2013).

- Meta-model. This method is a two-stage method. First, a meta-model is created using non-parametric regression methods, which do not have a predetermined form (such as linear or non-linear regression) and consequently it can be suitable for complex models. Second, sensitivity measures are calculated using this meta-model based on the variance-based method (Tian, 2013).

The meta-model uses statistical (or machine learning) models to approximate the objective functions that needs much less time than running detailed building energy simulation models (Eggebø, 2017).

Song et al. (2014) implemented a meta-model SA based on the Treed Gaussian process model for office building (). Firstly they constructed a meta-model from detailed dynamic building energy simulation, then implemented a variance-based method using this meta-model. The thermal performance for this office building is assessed in terms of three outputs: annual heating energy, annual cooling energy, and annual carbon emissions. Two types of input factors have been used: building envelope and internal heat gains: Wall U value, Roof U value, Window U value, Window SHGC, Peak equipment gain, Peak lighting gains, Daylighting, Heat recovery unit, Heating setpoint temperature, Cooling setpoint temperature, and

Infiltration rate when building is ventilated. SA based on the Sobol method is then used to identify the key variables in the models by using the variance-based method. The combinations for the inputs were then generated using LHS in Simlab 2011 (software package for sensitivity and uncertainty Analysis). This approach, shown in Figure 4.11, helped to quantify the uncertainty of change of building thermal performance for every input.

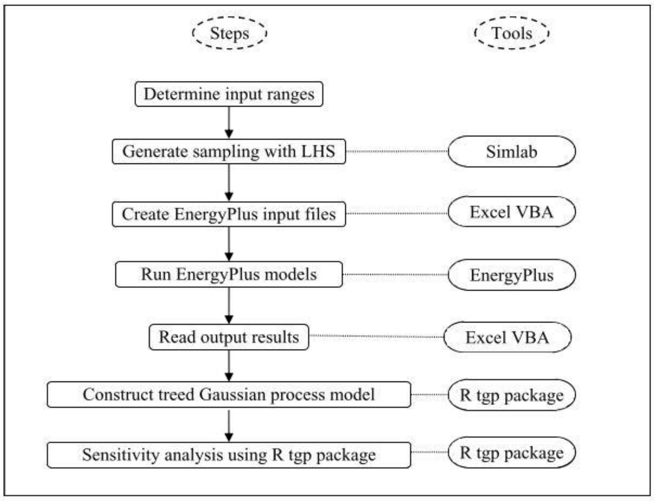


Figure 4.11 SA steps suggested by Song et al. (2014)

To date, there is no Building Performance Simulation tool (BPS) that offers the integration of SA. Therefore, a workflow is needed to account for the integration of this type. In some cases where input variations are probabilistic, a pre-processing is needed. Eggebø (2017) suggested a workflow, as shown in Figure 4.12

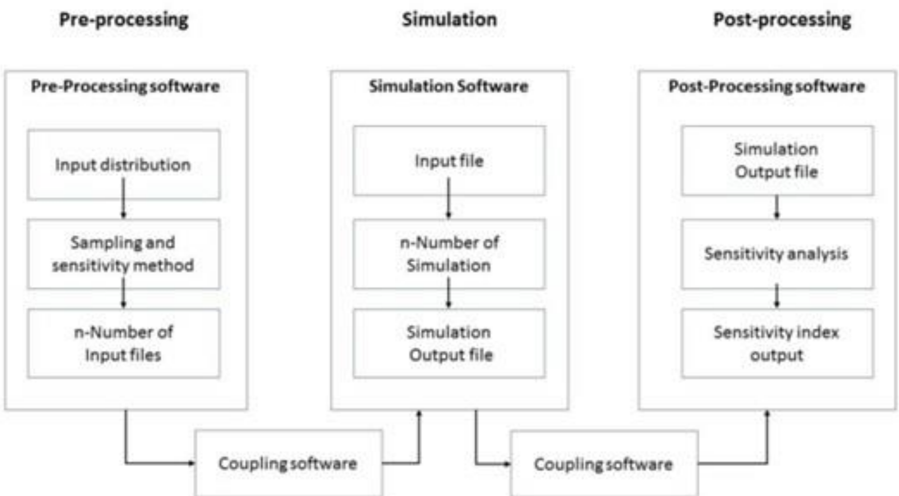


Figure 4.12 Typical workflow (Eggebø, 2017)

4.12.2 Interim summary of the review of sensitivity analysis methods

The review showed that there have been good attempts of classifying SA. Those classifications were either based on the input variables propagation, the type of analysis, the type of sample used, and the statistical technique used, such as regression-based methods, variance-based methods, meta-model-based methods, screening methods, and graphical methods. Another way of classifying SA methods is based on the definition of the problem, such as Mathematical (Morris) or Probabilistic (MCA).

The main difference between LS, GSA and screening SA methods is that LS uses OAT, whereas GSA assesses the impact of the input by changing other inputs as well and the screening method fixes some input variables out of a large number of variables without having to reduce the output variance, i.e. Morris method. The downside of this is that it cannot quantify the combined effect of different variables on the output.

The review of the literature on SA also reveals that recent research has been concentrated on global methods because they can explore the whole input space and most of them allow self-verification.

Therefore, based on the nature of the data generated in this study and the simultaneous variation of the input data, local SA methods are not applicable but global SA are. Moreover, considering that the variation range of each of the parameters is fully controlled and no element of randomness is involved, regression-based analysis seems to be the most appropriate technique for this study amongst Global Sensitivity analysis methods and it also allows for self-verification of the method and will be adopted in the analysis phases of this study.

4.13 Assessed dependent variables for combined thermal and visual analysis

When combined thermal and daylight analysis is intended to assess the efficiency of shading systems, a number of measures should be considered concurrently (González and Fiorito, 2015). For example: shading coefficient, cooling energy demand, daylight autonomy, sun patch index on work plane, and useful daylight illuminance (UDI) can be used as indexes for rating the performance of different typologies of external overhangs (David et al., 2011). Any of those measures or other measures can be used as a tool to optimise design variables. Goia et al. (2013) used total energy consumption to optimise window-to-wall ratio (WWR). They found that, for continental climates, the optimal solution could be obtained when the WWR is between 35% and 45%, regardless of the façade's orientation.

As this research targets the improvements to energy from both aspects, be they energy consumption or energy generation, and also daylighting of interior spaces and controlling solar gain, a full account of the indicators that influence those objectives should be taken. Multiple criteria are preferable when multi-objective analysis is intended. For example Ochoa et al. (2012) proposed four criteria to optimise WWR in order to minimise total energy consumption in addition to using illuminance and UDI to improve daylight performance.

There are different methods to evaluate daylight performance in buildings. Although the daylight factor (DF) method is easy to analyse and apply, there will still be uncomfortable and energy intensive daylight conditions in buildings. This is because DF takes no account of the building's geographical location, its orientation or varying sky conditions. In addition, it provides no indication of glare or visual discomfort, and on top of that DF does not account for solar shading. The solar shading is of paramount importance to low energy buildings where solar shading is very commonly used.

Climate-Based Daylight Modelling (CBDM) is a feature lacking in the commonly used DF analysis; it makes daylight assessments tailored to each building, whilst producing information on lighting energy savings, indoor illuminance conditions and occupant comfort (Vangeloglou and Rasmussen, 2015). CBDM allows for informative analyses of daylight conditions in the building by taking into account the location-specific climate characteristics of the building's position and showing the impact of the use of solar shadings.

The next two sections will elaborate in more detail on the main aspects: Energy consumption/generation, solar gain control and daylighting.

4.13.1 Whole building energy performance analysis

Energy in office buildings is mainly used for cooling, heating, lighting and office equipment (IEA, 2011; Santamouris and Dascalaki, 2002). In non-residential buildings, such as offices, intensive use of HVAC systems was noticed (close to 50% of the energy, lighting 15% and appliances 10%) (Pérez-Lombard et al., 2008).

In the earlier stages of a design process it is of high importance to obtain energy consumption estimations. The energy consumed by a building during its occupancy stage is defined by many independent research chartered institutions such as CIBSE in the UK or ASHRAE in the States. According to different energy end use types, this energy consumption can be categorised as follows (Cheshire and Menezes, 2013):

- Heating, hot water and cooling.
- Fans, pumps, controls.
- Lighting and office equipment.
- Catering electricity.
- Servers/ Computer room (where appropriate).
- Lifts.

These categories however are mostly applicable to colder climates, such as the UK or Europe, and may vary in quantity and importance depending on the climate. For example, in hot climates cooling loads represent the majority of energy consumption whereas heating loads are negligible in many hot regions, such as Iraq. In addition to this, office equipment energy consumption does not correlate to the choice of façade technology. For these reasons, cooling load and heat gain will be the measures of this research. In terms of measuring unit, the energy consumption is often measured in kWh per annum Whole building energy performance is associated with heat gains. These gains are translated into loads that the auxiliary systems need to remove in order to maintain indoor comfort conditions. The following sub-sections present these gains with an insight on measures that this research will adopt in the analyses.

Heat gains

Heat gain is the major component of the total building cooling load, especially for office, commercial, institutional and industrial buildings; it can be internal or external. Sources of internal heat gain are: lighting, people, computers, office equipment, small appliances and other devices, and sources of external heat gain are heat passing through glass or walls. Measures of these gains are:

- Annual energy use for lighting (kWh).
- Annual cooling/heating loads (peak loads are indicated when designing and sizing an HVAC system).

Cooling loads

Energy consumption for cooling is the indicator that accounts for the total energy used yearly, on site, for feeding the electric cooling system and is measured in kWh consumed per year.

Indicators of energy

Total Energy Consumption. This is the sum of the site energy consumed for heating, cooling, artificial lighting and other appliances, such as annual energy consumption of the HVAC and lighting system. Annual cooling energy consumption (kWh) is the energy criterion that indicates the whole building energy performance and will be adopted in the analysis. Within the total energy, energy consumption for heating/cooling indicates the total energy used yearly, on site, for feeding the gas/electric heating/cooling system and is measured in kWh consumed per year.

Energy Consumption for Lighting. This indicator accounts for the total energy used yearly on site for feeding the electric lighting system and is measured in kWh consumed per year. This indicator is accounted for as well.

Total Energy Savings. This indicator compares each scenario with the base-case on a yearly base and, in this current research, an account for the electricity generated by the photovoltaics is also included to measure the percentage of savings as a result of the application of IFS.

4.13.2 Daylight performance analysis

A review in 2005 by the chair of the International Commission on Illumination (CIE) Technical Committee on glare, concluded that the “available assessment and prediction methods are of limited practical use in daylit situations” (K. E. Osterhaus, 2005). In the CIBSE Lighting Guide LG7, glare is defined as a “Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or to extreme contrasts" (CIBSE, 2015). CBDM relies on hourly meteorological data over a year. It also presents simple, accurate and informative measures of the daylight performance in comparison to other traditional measures, such as DF. It is expected to replace DF in regulations and scheme requirements (Vangeloglou and Rasmussen, 2015).

Climate-based daylight modelling

The climate-based approach uses time varying sky and sun conditions whilst predicting hourly levels of daylight illuminance. The advantage of CBDM is evident over the DF method which is a single number, takes no account of orientation, and only considers overcast skies. Therefore, it is not meaningful for climates with predominantly sunny conditions. In addition to this, the CBDM take solar shading into account, hence making it feasible and possible to properly integrate energy versus daylight in an integrated manner.

Daylight Autonomy (DA) is defined as the percentage of the annual daytime working hours in a year when a specific point (threshold) of a specific illuminance is achieved and/or exceeded; this threshold is often 200 lux (Figure 4.13). Thus, it is an index directly related to the potential of artificial lighting energy savings (Vangeloglou and Rasmussen, 2015).

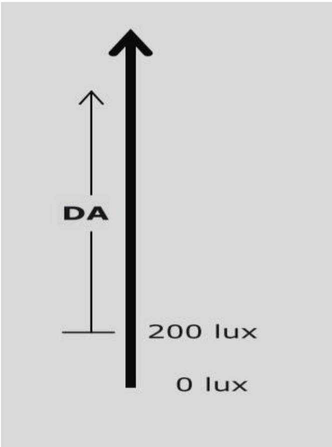


Figure 4.13 Daylight Autonomy concept (Vangeloglou and Rasmussen, 2015)

However, UDI is a more advantageous method compared to DA because it covers specific ranges. Numerous field studies and surveys of office buildings have led to defining the upper and the lower threshold of UDI. UDI also shows that it serves as a proxy for measures of daylight glare probability (Mardaljevic et al., 2012).

UDI is a parameter first introduced by Nabil and Mardaljevic (2005) and was further developed by them in 2006 to replace DF and was adopted in many researches, for example, González and Fiorito (2015), Berardi and Anaraki (2016), and Brembilla et al. (2017), to name a few. This simple scheme can provide useful information on the intrinsic shading effectiveness of the building as well as on the daylight, and gives accounts of the overall percentage of time during a statistical year in which the indoor illuminance at the selected reference point falls within a defined range (Figure 4.14). The UDI model reports not only on useful daylight illuminance levels but also on indicating excessive levels of daylight that can lead to occupant discomfort and unwanted solar gain. Hence, UDI offers a simple approach whereby the provision of daylight and the levels of solar exposure are quantified by means of a single evaluative scheme (Nabil and Mardaljevic, 2006).

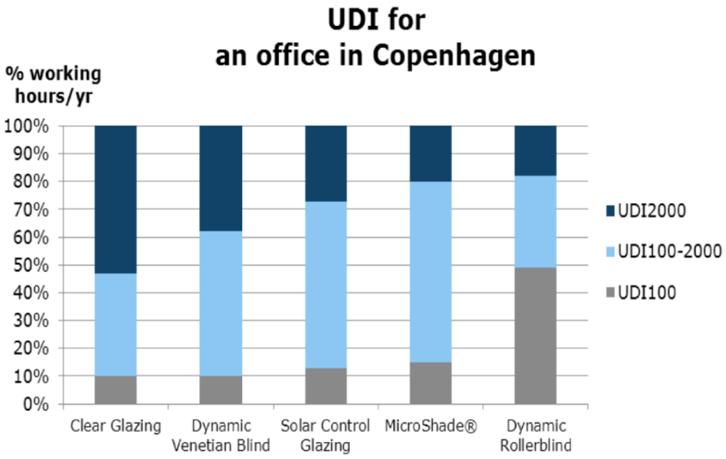


Figure 4.14 Useful Daylight Illuminance of three ranges(Mardaljevic et al., 2012)

At first Nabil and Mardaljevic (2006) suggested this range to be as follows:

- 100-500 lux is considered effective either as the sole source of illumination or in conjunction with artificial lighting.
- 500-2000 lux is often perceived either as desirable or at least tolerable.
- Higher than 2000 lux is likely to produce visual or thermal discomfort, or both.

It was further developed based on intensive investigations and examination by the same authors, mainly for offices, and was then suggested to be as follows (Mardaljevic et al., 2012):

- UDI fell-short (UDI-f). It represents the occurrence of daylight illuminance levels lower than 100
- UDI supplementary (UDI-s). It represents the occurrence of daylight illuminance levels in the range 100–300 Lx.
- UDI autonomous (UDI-a). It represents the occurrence of daylight illuminance levels in the range 300–3000 Lx.
- UDI exceeded (UDI-e). It represents the occurrence of daylight illuminance levels greater than 3000 Lx.

The UDI scheme can be applied in different ways depending on the evaluation scenario (Nabil and Mardaljevic, 2006). UDI methods are applied by the UK Education Funding Agency for the evaluation of designs submitted for the Priority Schools Building Programme (PSBP) (Vangeloglou and Rasmussen, 2015). For this study, three ranges of UDI are considered for the analysis:

- UDI less than 300lux: where the illuminance level is below the minimum threshold.
- UDI 300-3000lux: where acceptable and useful daylight level is achieved
- UDI more than 3000lux: where the illuminance level exceeds the maximum threshold, suggesting glare possibilities.

4.14 Factors dependency

In this section, independent, dependent and interdependent variables are explained, such as energy consumption, energy generated, and daylighting. The contributing factors to those main indicators are explained from a systemic point of view as follows:

Daylighting is interdependent with energy production and energy consumption because energy consumption, together with energy generation, are dependents. An example of this is the angle of inclination of the PVSDs which affects the amount of energy production. It also affects the amount of light penetrating the building’s interior spaces and the heat transfer as well. So energy production is linked with energy consumption and the internal lighting is linked with energy production because part of the energy produced can go to lighting, for example. The outcome of this variable, the inclination angle, is energy production and since the outcome here is also associated with the light that goes inside, it can then be decided how much energy is needed for additional artificial lighting. When optimisation is intended, the angle is changed probably to let less light in but at the same time producing more energy that is required to compensate for that natural lighting or it might be opening up the blades to allow natural lighting. The simulation of all the possible scenarios will shed the light on this question.

There are also interdependencies between some of these elements. For instance, both solar gain and cooling load are considered dependent factors, whereas Glare and lighting are interdependent. Energy consumption, energy production and lighting are inter-dependent, similarly, cooling load and energy consumption are inter-dependent. To summarise, there are either dependencies between some factors whereas others are totally independent, such as lighting and cooling loads that are separate (independent from each other). The systemic approach, when applied to the evaluated indicators, will help understand the level of influence on each indicator, be it at system level or sub-system level for example (Figure 4.16).

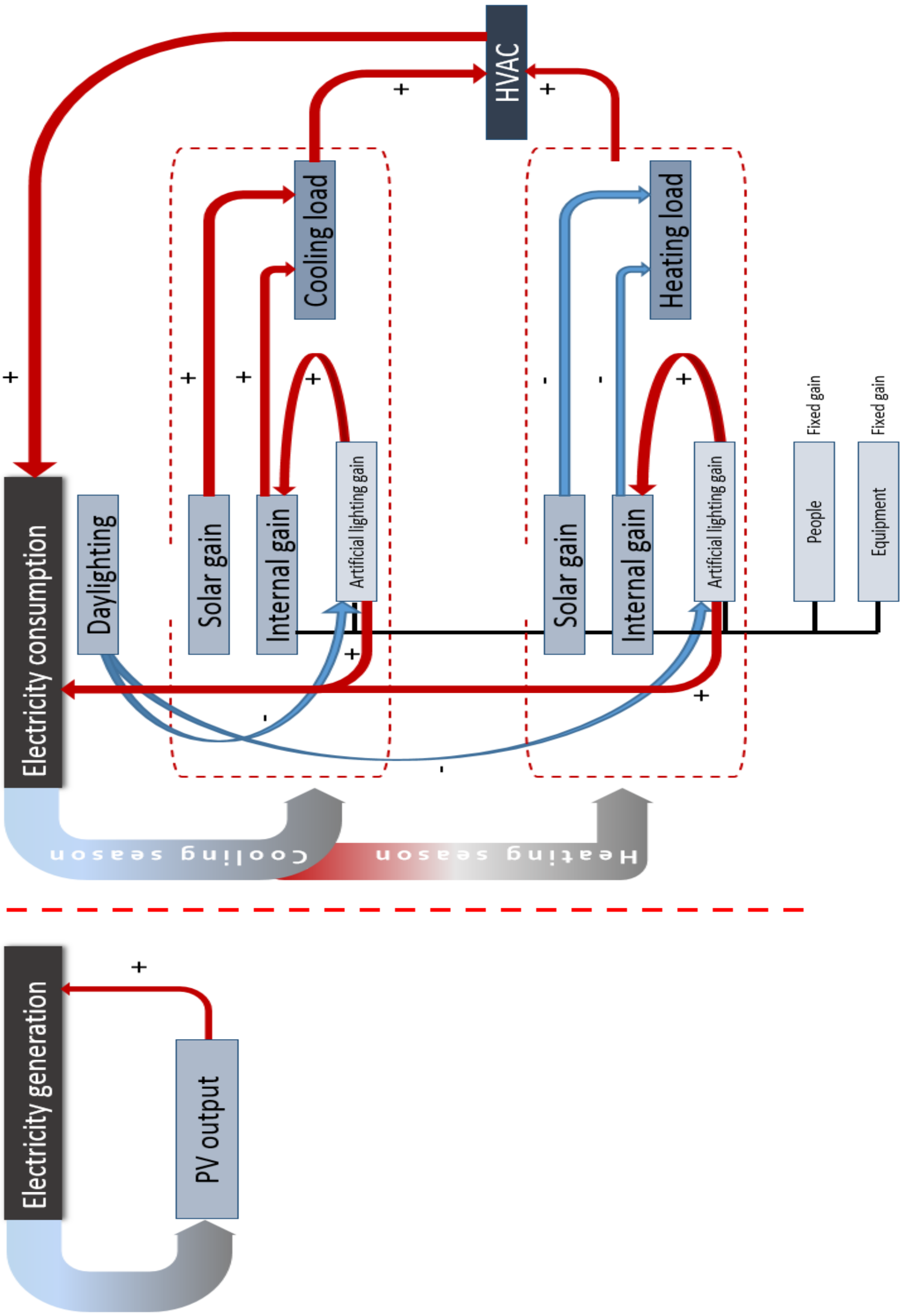


Figure 4.15 Factors dependency diagram

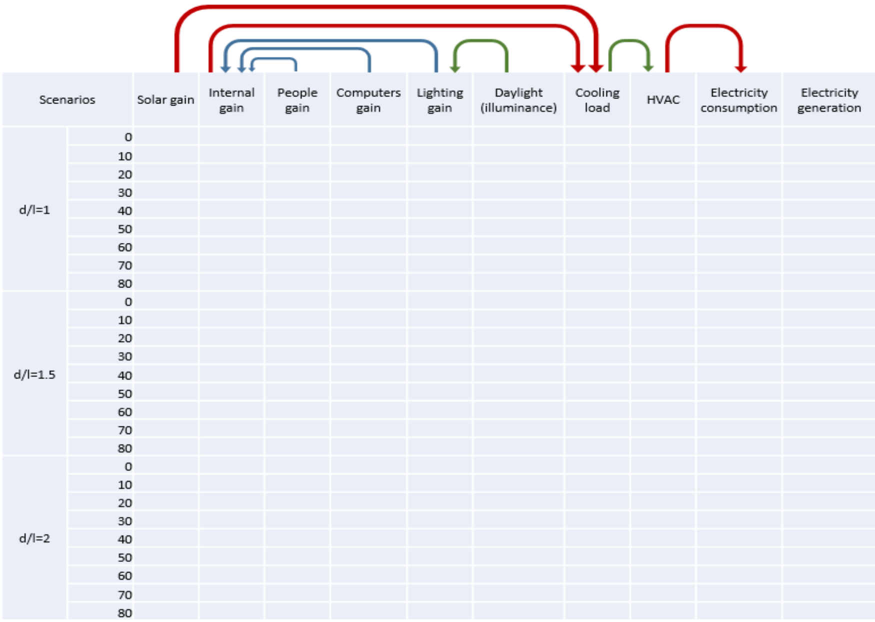


Figure 4.16 Assessed indicators with factors dependency for possible scenarios

In the analysis, only the cooling load will be considered. This is because the heating load is not a sub-system element of the systemic levelling, as can be seen in Figure 4.15, but is a parallel system to the cooling loads. In addition, the base-case scenario was simulated and the cooling and heating loads results were compared. The results show that heating season loads are 20% of cooling loads – in other words the cooling loads are five times more significant than the heating loads – hence heating loads will not be included in the analysis.

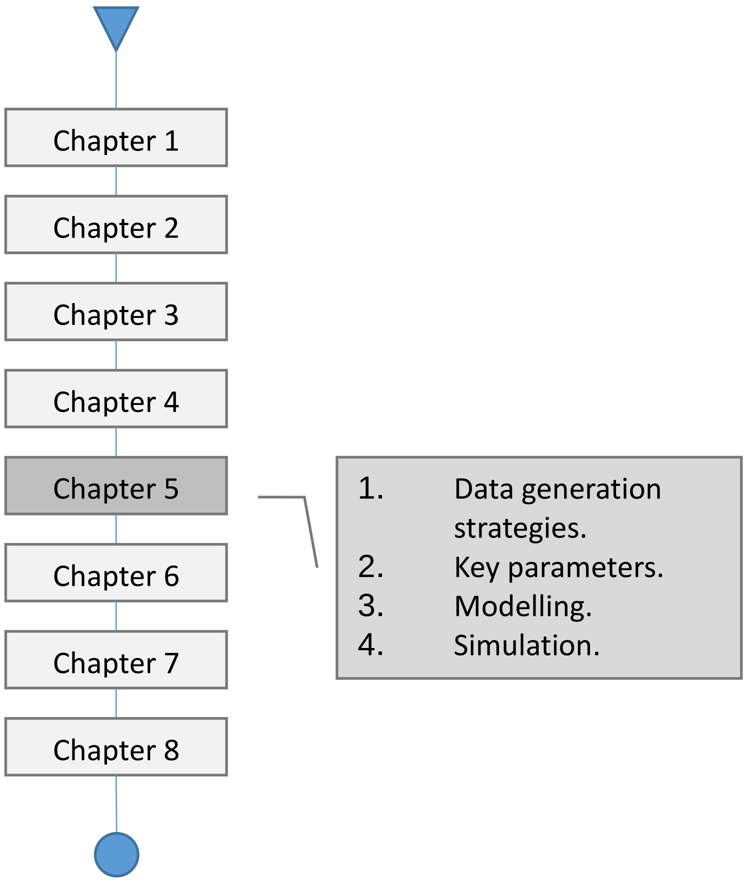
To elaborate more on this point, the optimum angle of inclination is by default different due to the season. Since the cooling season is five times the heating season, it is more important in terms of targeting as much saving as possible. In addition to that, the optimum angle for electricity generation is expected to be lower during the heating season as a result of the angle of sun (azimuth) so it is less likely to be able to show a significant amount of energy saving.

4.15 Chapter summary

This chapter presented the approach developed specifically for this research and the systemic philosophy behind it. This was followed by research design, then the proposed methodology of this study was defined based on the knowledge gained from the literature review. A closer look at the main research methods for evaluating building energy performance was analysed to enable the selection of the appropriate methods for this research. Furthermore, the simulation tool that was chosen for this research was justified. In addition, generation of the base-case model and the parametric analysis was presented. The analysis methods adopted in this research were justified and substantiated by the relevant literature. The chapter carries on to present and analyse the choice of the assessment indicators that will be used to enable an in-depth and thorough analysis that will lead to improving solar control, energy generation/consumption and daylight provision. Moreover, the systemic approach has also been applied to the assessed indicators (dependent variables) to constitute, in a systemic manner, the factors' dependency that will be implemented while analysing the results of those factors.

Chapter Five

Data Generation



CHAPTER 5. DATA GENERATION

5.1 Introduction

In this chapter, a detailed description of strategies adopted and the process of data generation for this research is presented. The data generation was mainly divided into two stages: the first stage starts by building a model for the proof-of-concept stage, followed by dynamic simulations of this model. In the second stage, the chapter describes and analyses the outcomes of the professional survey that inform the representative model development. A full factorial parametric study is explained in this chapter, the key parameters selected for evaluation, modelling and simulation processes are also presented. The influence of each individual key parameter on the building's thermal and visual performance will be elaborated on in this chapter based on the followed procedures.

5.2 Modelling and simulation of stage one: the proof-of-concept

The modelling and simulations are carried out using IES-VE which is an integrated tool with a range of components. These components are defined as modules and are used in this research at different stages and serve different purposes. The development of the model for the first stage purposes is elaborated on in the following sub-sections. A base-case model is developed and suggested to be used for the investigations of the pilot study (Figure 5.1).

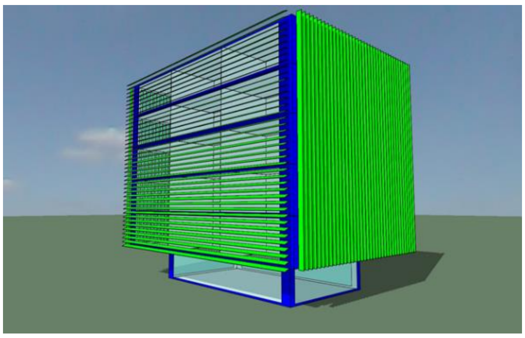


Figure 5.1 Base-case model for the pilot study

5.2.1 Layout and office room description

A simple six-storey office building is developed. Each floor area is 436m^2 divided into nine zones. These zones are different regarding the thermal behaviour. Each zone represents an office room of 9m x 6m (L x W) as shown in Figure 5.2.

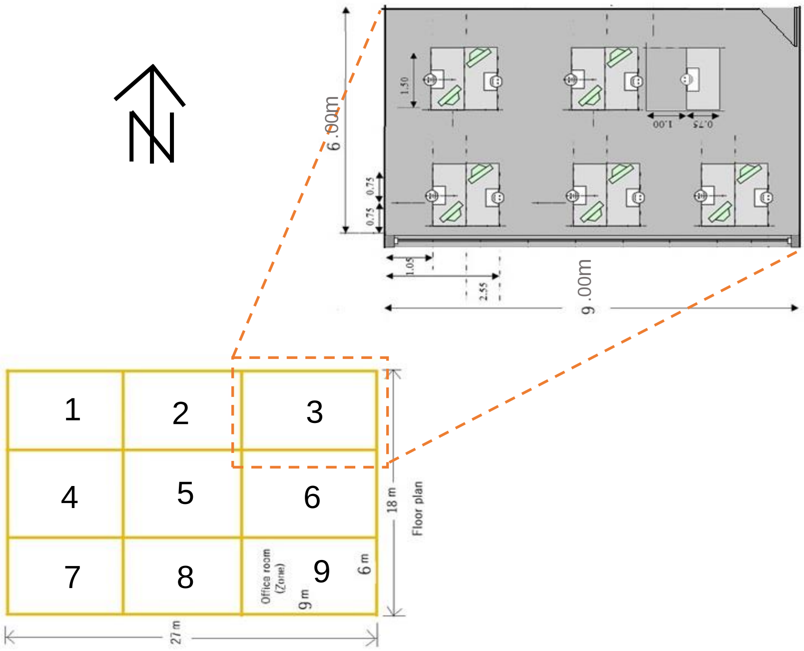


Figure 5.2 Floor and detailed office room layout

The height of each office room is 4.00m. The Window-to-Wall ratio (WWR) is 80% as a representative percentage of highly-glazed buildings. In this model, reflectance of the used material was 0.85 for the ceiling, 0.65 for the walls and 0.20 for the floor, as shown in Figure 5.3.

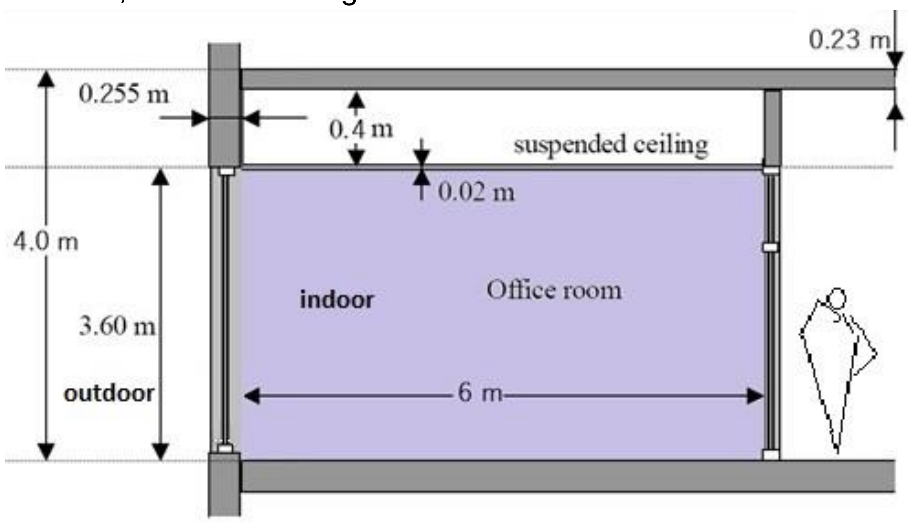


Figure 5.3 Section view of an office room

The room temperature set points are between 19°C and 24°C (CIBSE, 2016) and the lighting levels at 500 lux and above. Any typical intermediate floor specifications are listed in Table 5.1.

Table 5.1 Specifications of intermediate floors

Layer, from top to bottom	Thickness m	Thermal conductivity Wm-1K-1	Thermal resistance m^2KW-1	Specific mass kgm-3	Specific heat capacity Jkg-1K-1
Carpet	0.01	0.1	0.1	200	1400
Cement floor(screed)	0.02	0.9	0.022	1800	1100
Concrete slab	0.2	1.6	0.125	2200	1070
Floor/ceiling cavity	0.4	-	0.17	1.23	1000
Suspended ceiling (particle board)	0.02	0.1	0.2	300	1700
Total	0.9	-	0.617	-	-

5.2.2 Modelling with ModelIT

The modelling process was carried out in ModelIT – the modelling component of IES-VE – which allows the user to create 3D models that can be used in other integrated modules of IES-VE, based on the investigations needed. It enables appropriate levels of complexity to be incorporated within a model across the entire design (Al-Badri, 2013). This is based on patterns of use, temperature control, solar gain, perimeter and interior location, and HVAC system type (IBPSA, 2012).

Each floor in the model was divided into nine different thermal zones. External shading devices (SD) were also defined in ModelIT. These devices are defined based on specific characterisation of the module (IES-VE, 2014). ModelIT gives a green colour to SD in the model appearance to differentiate them from other building components, as shown in Figure 5.1. The dimensions of the SD at this stage are kept fixed (or frozen) and in a later stage they will be investigated simultaneously with the other variables.

These dimensions are as follows (Figure 5.4):

- Distance from the main façade is 0.5m.
- Distance between the blades is 0.5m.
- Depth of the blades is 0.5m.
- The blades were as the same length as the façade's.

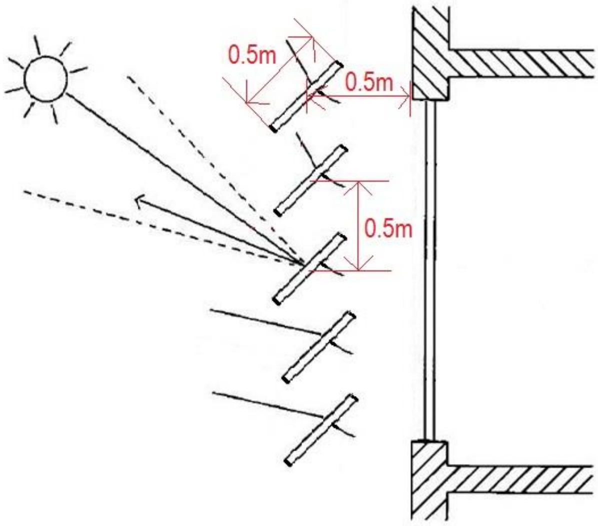


Figure 5.4 Shading devices dimensions for the pilot study

The materials and their application to surfaces in the model were carried out using the ApacheSim module. Profiles of openings were set up in the MacroFlow module. Simulations were conducted for the whole year to determine the peak months for total energy consumption.

5.2.3 Weather and location data

An important feature of IES is the APLocate. This module allows for choosing locations and weather files for different cities around the globe. However, some cities are not available within the database, such as Baghdad-Iraq, which is the intended city of the study. The IES official website also provides references such as the US Department of Energy (DoE)[13] in which weather files can be found. DoE provides a wider range of weather databases, such as Meteonorm[14] which has been contacted by the researcher to acquire Baghdad's weather file to be used in IES-VE.

The weather file allows IES-VE to generate hourly output data for the entire year. The weather data file for each city includes hourly values of dry bulb and wet bulb temperature, wind speed and direction, cloud cover, direct and diffuse solar radiations, azimuth and solar altitude. A sun path diagram for Baghdad was generated using the SunPath module in IES (Figure 5.5).

[13] https://www.iesve.com/support/weatherfiles
[14] http://www.meteonorm.com/

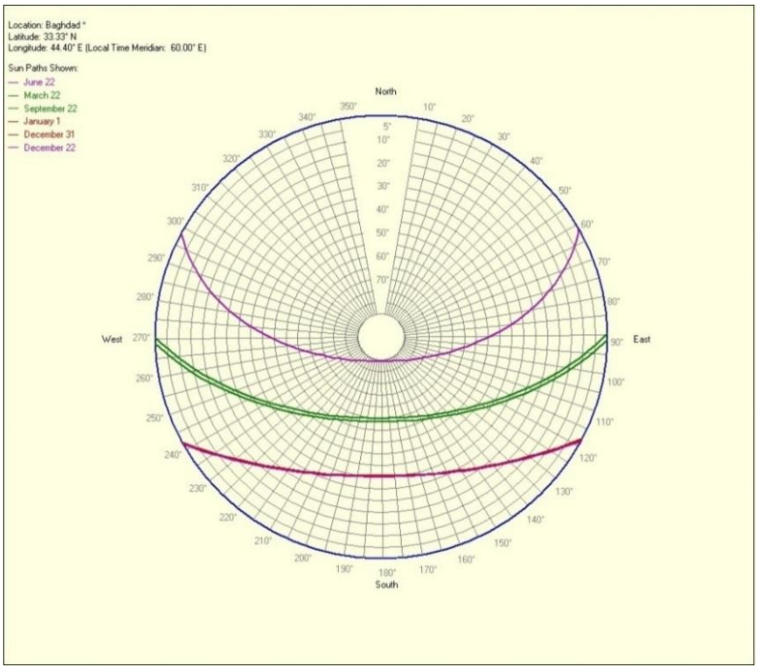


Figure 5.5 Sun path diagram for Baghdad city-Iraq

5.2.4 Internal heat gains

Internal heat gains are set based on standards and relevant literature. Heat gain from occupants is set to 70W according to Table 6.3 in CIBSE (2016). Heat gain from equipment for each office was set to 18W continuously (24 hours, seven days per week) plus 172.5W during working hours, as suggested by Van Dijk and Platzer (2001). Therefore average heat gain in each office was 89.8W.

According to Mandalaki et al. (2012), the cooling set point was set to 24°C during working hours and 28°C outside working hours, and the heating set point is 20°C during working hours and 16°C at other times. Office working hours in Iraq are 08:00–16:00, five days a week and the usage profile is eight hours a day. Therefore:

Weekly working hours = working days x daily working hours

5 x 8 = 40 weekly working hours

The total annual working hours = no. of weeks in a year x weekly working hours

48 x 40 = 1920 total working hours a year.

Public holidays are not taken into account at this stage.

5.2.5 The combination matrix of possible façade configurations

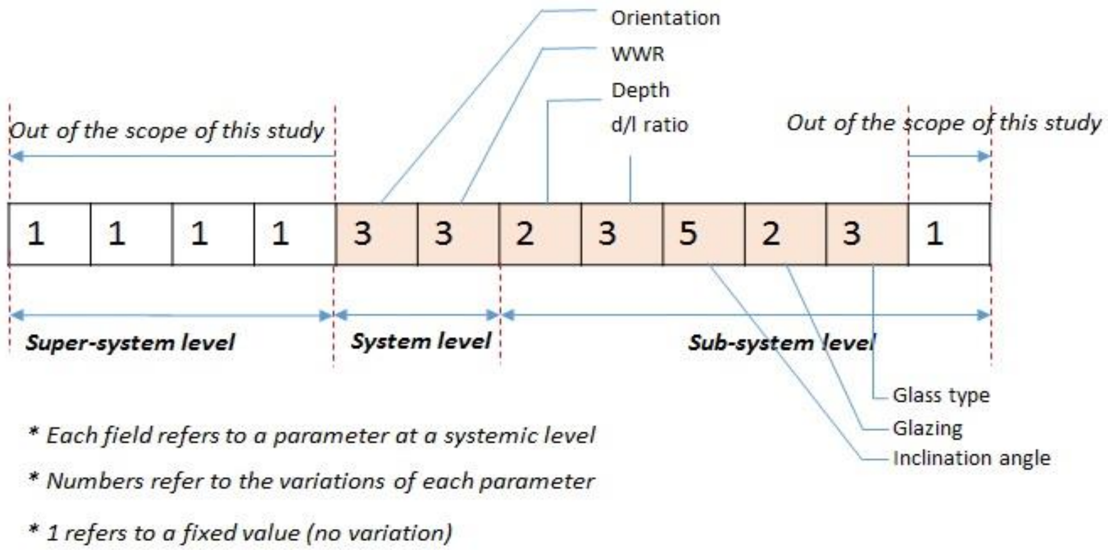
A combination matrix was developed to include all the variables and the number of variations of each of them. Based on the findings of the literature review, the variables that will be investigated are presented in a table and categorised based on the systematic approach developed in this research (see Figure 5.6).

This will be further discussed in detail in section 5.4.

Figure 5.6 Combination chart

5.3 Development of the prototype model for the detailed simulation

The benchmark building models represent a starting point for analysis projects,



especially those focusing on the effect of energy efficiency technologies on buildings, or to understand the effects of energy efficient technologies on specific building types in different climates (Torcellini et al., 2008). The use of an office prototype as a representative model of real buildings dates back to 1990 when details about the building envelopes and other geometric characteristics were provided based on real offices. Amongst these models, there are those with the purpose of investigating the effect of SD on energy performance (Leighton and Pinney, 1990). Those prototypes allow for detailed analysis when it comes to studying the influence of energy measures on a building scale (Torcellini et al., 2008). Attempts to develop such models have been recorded in the literature: the U.S. Department of Energy (DOE), Lawrence Berkeley National Laboratory LBNL, Pacific Northwest National Laboratory PNNL, and National Renewable Energy Laboratory NREL have developed standardised benchmark building models for simulation purposes. Although those models have been widely used by other researchers to develop knowledge about thermal and visual performance of fenestration systems (Carmody, 2004; Haglund, 2010b), they represent the characteristics of offices in the US and therefore are exclusive to that context. Furthermore, these models have been applied to other open-source tools to serve the purpose of that context, so they cannot be applied to other contexts (EWC, 2012; Haglund, 2010a) and a representative model or a benchmark is always needed in order to represent real practices in a particular context.

Building prototypes are developed in such an abstract way that they are mock, not real buildings, for the purpose of representing a population of buildings of a given type – such as an office, hospital, etc. – and the data are collected on real buildings then used to formulate a representation of building construction, systems, and operations (Hoffmann et al., 2016).

Therefore, the models should acquire the characteristics of that context besides representing most of the building stock with a small set of building models. It is difficult, because of the diversity of buildings and the limited data on existing buildings, to conclude a representative model (Torcellini et al., 2008). A recent review of the literature on approaches to developing benchmarks for energy simulation purposes has been conducted by Pomponi and Piroozfar (2015). They developed a benchmark office building to investigate the application of a double skin façade as a strategy for refurbishing office buildings. In their work, a step-by-step procedure to develop the 3D model of a benchmark has been demonstrated. The outcome was a representative 3D model of office buildings in the UK. Some attempts to use standardised offices to provide details about the envelope are also found, such as Leighton and Pinney (1990), whereas others have focused on grouping benchmarks based on their ventilation type and layout (EEBPP, 2000), or classified those types into four categories, such as Dascalaki and Santamouris (2002) who categorised them as follows:

- Free standing or enclosed, based on location in the urban context.
- Heavy or light, based on the structure and construction materials.
- Skin or core dependent, based on the envelope and systems.
- Internal layout-open plan or cellular, and corridors organisation.

In places where data archives are not available or accessible, generating benchmarks could be achieved by conducting a questionnaire survey of buildings in order to make a prototype model to represent the targeted buildings (Hernandez et al., 2008). Alternatively, due to issues with the representativeness of the majority of buildings, a parametric archetype benchmark could be developed based on archived data and a historical review of buildings characteristics.14 defining parameters have been defined which led to the development of the models, such as elements' U-value, layout, glazing ratio and building type (Korolija et al., 2013).

To summarise, it is of high importance to develop a model that represents as many real buildings as possible in order to be able to generalise and conclude from the results of the research. There have been many ways noted in the literature for developing models for simulation purposes. In general, databases should be available in order to be able to acquire the necessary information that leads to developing such models.

In the absence of databases and historical records, which is the case in this study, surveys and questionnaires could be reasonable approaches. Parametric modelling could be conducted to lead to generating representative 3D models that can then be used for the analyses. This approach is not unprecedented and can be applied. However, slight tailoring of the parameters might be necessary for the intended analysis of the energy and lighting simulations. Therefore, a specific approach to the development of a model for the specific purpose of this research is conducted and will be presented in the next sections.

5.3.1 The approach developed to produce the representative model

The definition of an adequate model needs to take into consideration the level of accuracy and details required. Time and computational resources available also need to be considered. More detailed models are usually more time- and resource- consuming, and, therefore, appropriate and suitable models have to be developed based on the specific design objectives. The office building prototype is developed based on the outcome of a remote survey, which was further refined and simplified to serve the purpose of the intended simulations.

The design of the survey

The intention of this questionnaire survey is not to fully and completely survey buildings precisely but to best serve the intent of the simulation modelling, to simulate the typical office building in its climate condition. In addition, it is to enhance the validity and reliability of the findings of this research. The remote questionnaire survey has been sent to those architectural professionals in Baghdad who have met the following criteria:

- Have been practising in Baghdad for the last two decades.

- Have designed office buildings.

This professional remote questionnaire seeks their opinions and expertise in order to find out about the prevalent types of office buildings. The questions are grouped into four main categories:

- Building form.
- Building footprint and layout.
- Building access and services.
- Building structure and materials.

- **Building form**

In this group of questions, the participants have been asked to comment on two main types of building forms: rectangular and non-rectangular (Figure 5.7).

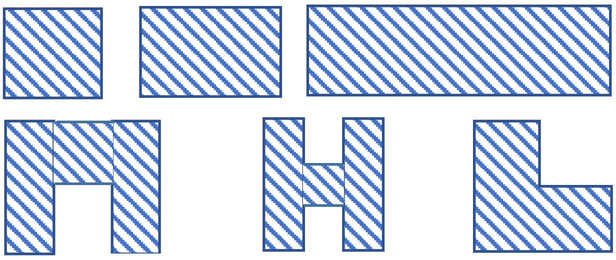


Figure 5.7 Proposed building forms

The participants were also given the chance to elaborate more and to provide the form they thought was the most common if it was not included in the questionnaire. The second question aimed to check whether or not there is a significant internal layout feature, such as central courtyard or atrium; following that is the number of floors, where three main categories were provided to choose from: low-rise buildings (3 to 6 floors), mid-rise building (7 to 14 floors), and high-rise building (15 floors and above).

- **Building footprint and layout**

Five categories of building footprint (built area to land plot) ratio have been provided to choose from: up to 40%, 40% to 60%, 60% to 80%, more than 80%, with a fifth category as N/A, meaning that the size of the building is not dependent on the land plot (i.e. building in a park). A variety of the site plan that is typically representative has been included (Figure 5.8).

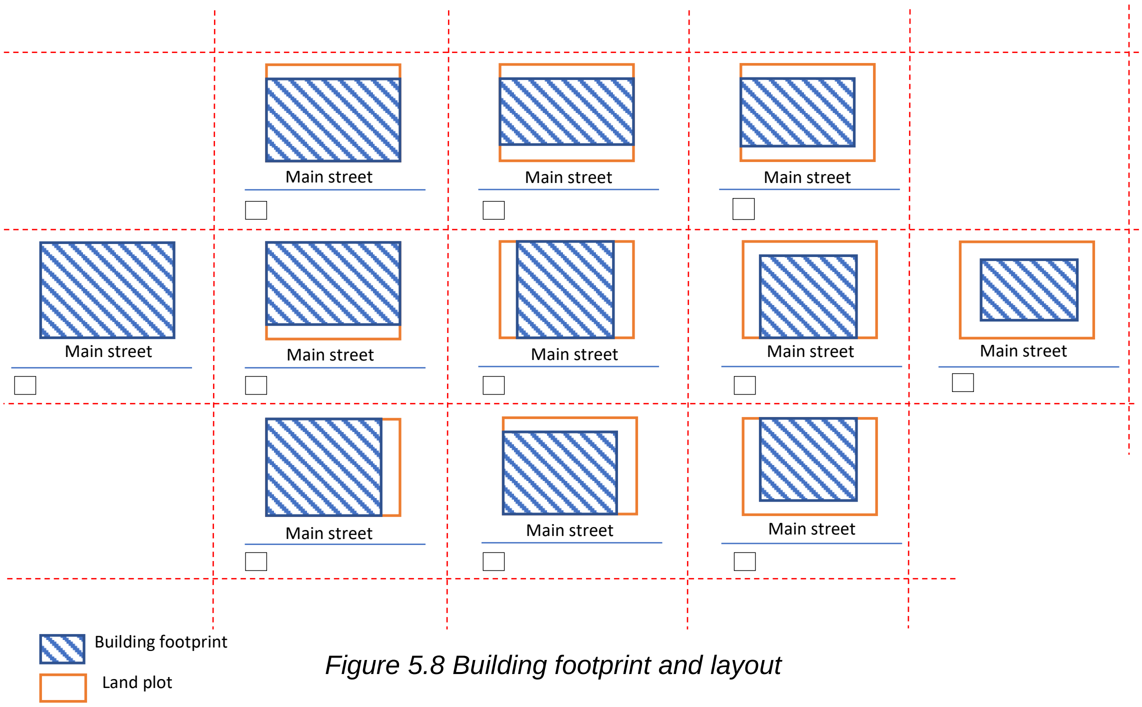


Figure 5.8 Building footprint and layout

- **Schematics of the ground floor layout**

Figure 5.9 shows eight schematics of the ground floor layout that have been provided to check which resembles the ground floor layout most closely.

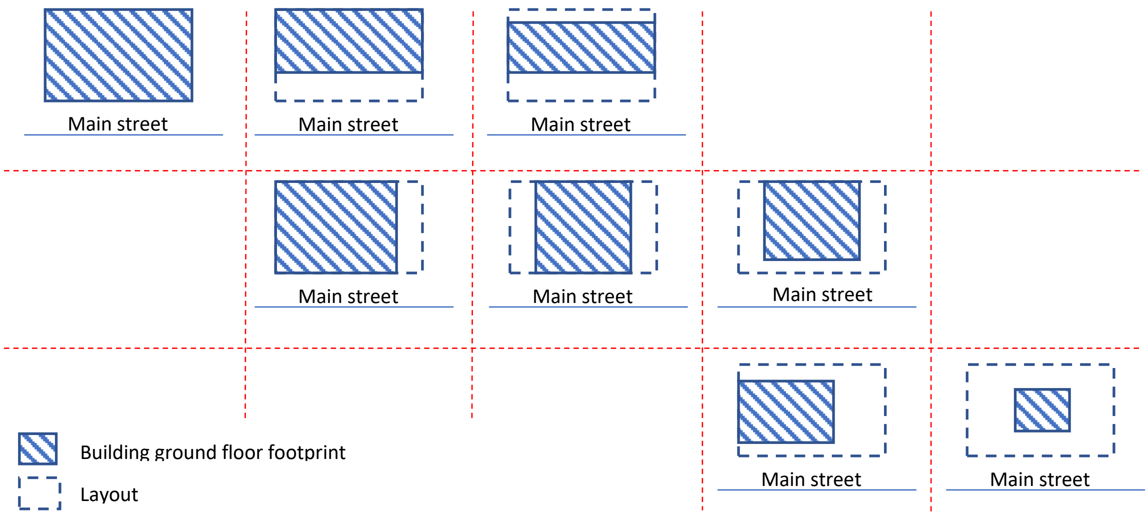


Figure 5.9 Schematics of the ground floor

- **Internal layout**

According to Neufert et al. (2012), the main prevailing two internal layouts are cellular and open-plan. Those have also been checked (Figure 5.10).

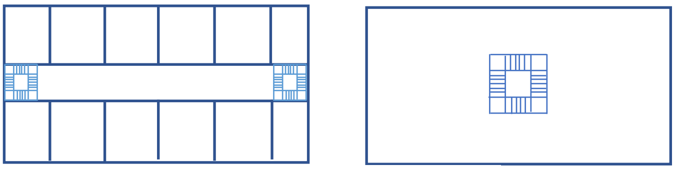


Figure 5.10 Internal layout

Office space dimensions

Three office space dimension groups, namely 3.5m x 5m, 4m x 6m, and 4.0m x 8.0 have also been investigated. Those sizes follow the main prevailing grid of structural systems in the context of the study and participants are given the chance to suggest if there is any other option they might have come across during their experience.

- **Floor-to-floor height**

Floor-to-floor height is another parameter that significantly influences the simulation models, especially for non-domestic buildings in general where false ceilings and floors are used and can contribute to the total height of the building. Based on the practice in the context of the research, four possibilities are given: 3m, 3.5m, 4m, 4.5m and an empty field is provided to check if there are suggestions to add. These heights comply with Neufert et al. (2012).

- **Building services (wet zones)**

The locations of the buildings' wet zones, shown in Figure 5.11, are provided to participants in order to check the prevailing location, so that they are properly located within the simulation model later. This also helps to set appropriate occupancy profiles for energy purposes.

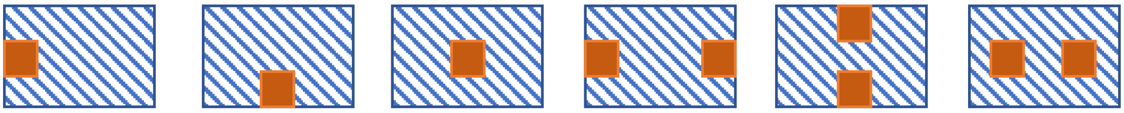


Figure 5.11 Building services (wet zones)

- **Building main entrance**

In order to appropriately locate the building main entrance, schematics of four possibilities, with regard to the main street, are also checked (Figure 5.12). This will help in identifying the main building façade, where all interventions will be conducted (or applied).

Figure 5.12 Schematics of building main entrance

- **Vertical access**

The vertical access schematics were provided to choose the most representative schematic of the staircases and lifts, as shown in Figure 5.13.

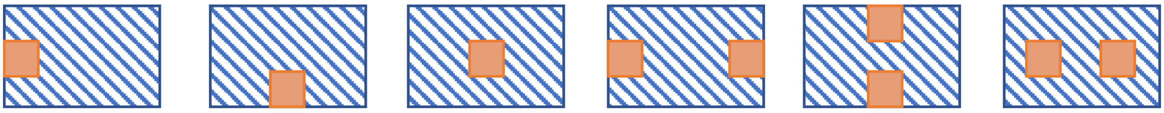


Figure 5.13 Schematics of vertical access

- **Building structure and materials**

In this group of questions, structural systems commonly used in the context of the study are investigated, such as masonry (load bearing), steel frame and concrete structural frames, with 'Others' available for participants in case they have another suggestion. Following the structural system, internal and external partitioning/walls are investigated under the categories of concrete blocks, brick, or thermo-stone, and the possibility of any other material, should the participant have any other suggestions. Then more details are enquired about, such as the finishing layers of the opaque parts of the façade, which are: aluminium composite cladding panels, cement render, plaster render and, again, Other, for any other suggestions.

The above-mentioned finishing layers are for the external surface. For the internal surface there are Gypsum and clay mix + plasterboard; Gypsum and clay mix + plaster; plaster render, and Other (for the participant to specify).

5.3.2 Analysis of the outcome of the remote questionnaire survey

All the information was collected, analysed and implemented wherever applicable in the model creation procedure. The survey was conducted in two stages. The first stage is a pilot survey when the form was devised and four architects consulted in order to gain some insights about any aspect that might be missing and could be needed for the development of the model. Refinements and amendments were then implemented to produce the final version of the survey for stage two.

In stage two, the remote questionnaire survey was carried out between Nov 2016 and Feb 2017 and distributed via email, social and professional media and local PSRBs[15] to 88 professionals. 72 responses were received and the final number of valid responses was 65, bringing the response rate to 74% due to the purposive snowball sampling strategy utilised. The researchers' professional experience, expertise and local knowledge which were used to develop the initial questionnaire, were also used as expert witness to factor out the invalid responses and as a point of reference where inferences were needed to help make decisions. A sample of the questionnaire survey form can be found in Appendix 5. The decisions about the building model layout will be discussed in section 5.3.5.

5.3.3 Simplifications of the model

A few simplifications have been applied to the final model in order to increase the accuracy of the intended results of the simulations. Those simplifications were conducted because the simulations could either result in variations that do not have any implications for the thermal performance of the building or there was no agreement in the survey, such as the location of both the wet zones and the vertical access, which meant no data were available for a more realistic model.

The vertical access and corresponding services (wet zones) were not included in the model due to the variation they may have from one design to another, which makes it hard to represent identical occurrences in the design with any reasonable frequency. Similar approaches have been noted in the literature on developing benchmark models, such as Pomponi and Piroozfar (2015).

[15] Professional, Statutory and Regulatory Body (PSRB) accreditation is a general term used to describe organisations which are authorised to accredit, approve or recognise specific programmes in the context of the requirements of the PSRB. http://www.port.ac.uk/departments/services/academicregistry/qmd/psrb/

An accepted principle in building physics is that similar zones are combined vertically and horizontally. Therefore, another simplification was made to the model on both the number of floors and the layout. From the thermal zoning point of view, in an internal layout, the number of thermal zone variations should cover all the possible zones with unique or specific characteristics to facilitate an accurate and detailed, yet efficient, model for a comprehensive and optimised simulation and analysis. For example, the layout of the developed prototype model shows unique thermal zones characteristics. This is the minimum number of unique thermal zones introduced in the layout of the model and, if increased, will result in similar zones that have no different thermal characteristics and consequently will result in using unnecessary simulation time. In other words, similarly treated floors and zones can be omitted or combined and one floor or zone can represent specific unique thermal characteristics (Figure 5.14).

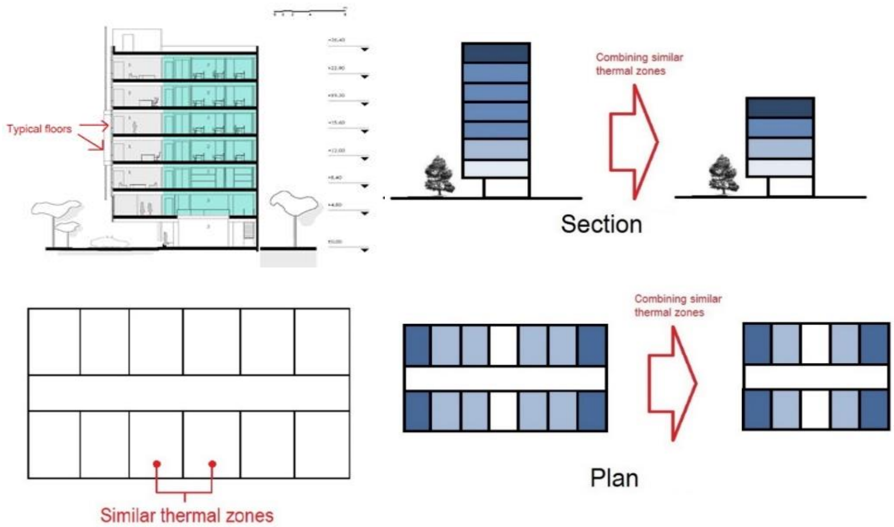


Figure 5.14 Model simplifications by means of eliminating similar thermal zones vertically (in section) and horizontally (in plan)

5.3.4 Modelling process and data quality checks

- **generating the simplified models**

The modelling process, as explained in the methodology chapter, comprises four stages (Figure 5.15):

- Stage one: where a simplified model is developed mostly for data-quality check purposes.

- Stage two: a proof-of-concept model is developed to test out the basics which are intended for simulations in a full combination of the variations in this study.
- Stage three: a base-case model will be developed which is informed by the outcome of the remote questionnaire survey.
- Stage four: combination models for all possible scenarios of the variables will be created for detailed simulations.

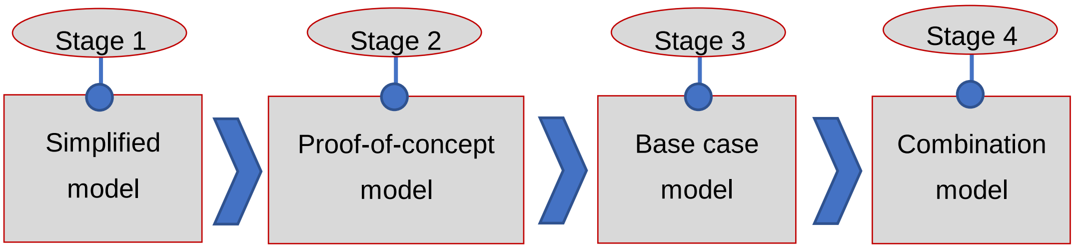


Figure 5.15 Modelling stages

This step-by-step procedure for model creation is important to ensure that the procedure is capable of simulating and delivering accurate results and a valid output. Between each of those stages, data quality checks have been carried out in order to maintain data quality and ensure the reliability of the findings. This will be elaborated on in section 5.3.6.

In stage one, a simple 3D model was produced using ModelIT, the model generator module integrated within IES-VE. The geometry of the model is a two-storey building: ground floor of a single thermal zone with dimensions 4 x 4m^2 and the first floor is mostly similar but extruded by 2m at the main façade (Figure 5.16).

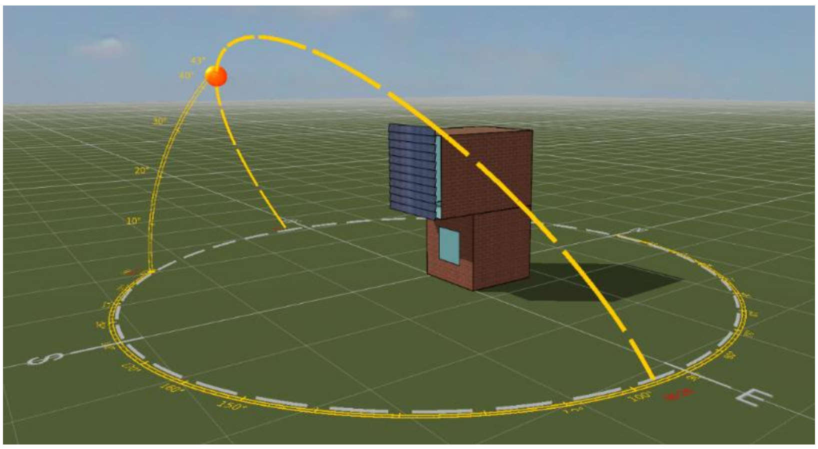


Figure 5.16 Simplified model

The simplified models have twofold benefits:

- Exploratory simulations to gain insights about how the modelling process meets the intended outcome and to gain expertise for further development of accurate models towards the final combination models.
- Reducing the number of unnecessary simulation runs that could consume time, since the building models will be used not only for thermal analysis purposes but also for daylighting and PV output, which means the ultimate number of the actual simulations is not **1620** but rather **4860**.

5.3.5 Building model characterisation

This section demonstrates the process of setting up the geometric configuration and dimensions defined for the building model. It also comprises the internal layout, materials applied to the building fabrics, the internal sources of heat gains, which are defined by their corresponding profiles of use (IES-VE, 2016a), and the occupancy patterns and the number of occupants. In addition, glazing systems have been generated in LBNL Windows 7.5. This is recommended as it is preferable to use data reports or results from Window 7.5, where possible, because of the specific information provided (Waddell et al., 2010). All these model settings, in addition to other model settings that need to be done, are shown in Figure 5.17.

- *Building geometry and layout*

The geometry of the building is defined by its shape and dimensions, which has a significant influence on the thermal performance of the IFS. This influence is determined by the exposure of the façade to solar radiation that interact with the building through the building skin to the indoor environment. The model was built according to the findings of the professional expert survey (as discussed in section 5.3.4).

The building is a representative of mid-sized office buildings – a prevalent typology in Iraq contemporary architecture – with office modules (also known as the 'thermal zone' in BES applications) aligned to the two main façades with an internal cellular layout, separated by a central hallway of 2m wide. Each thermal zone is 4m x 6m x 4m (*W*x*L*x*H*), with a near-rectangle shape. 4m storey heights are floor to floor. The building footprint (built area to land plot ratio) is between 40% and 60%. The ground floor layout has a setback of 2m from the edges of the land plot, unlike the rest of the above floors which fill the layout. The entrance to the building is in the middle of the front façade that faces the main street providing the main access to the building.

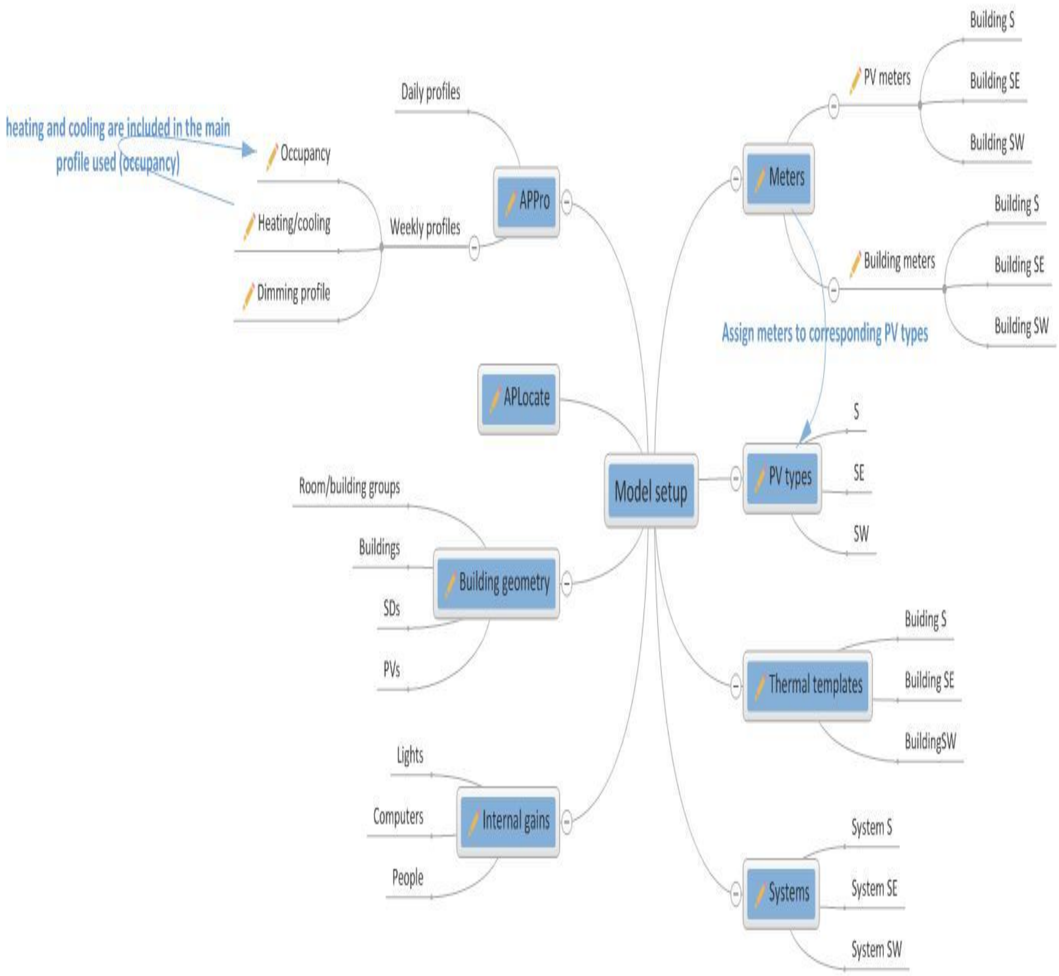


Figure 5.17 Model set-up

The model was generated using ModelIT within IES-VE and will be used, for simulation, in other tools within the integrated environment of IES, such as Radiance for the daylighting and SunCast for the shading calculations.

- *Geographical location settings*

Once the first model is created, it will be used as a base for generating other models, each of which has a unique combination of variables. This model will then be taken into APLocate – another integrated tool (utility) within the IES-VE environment – in order to apply the relevant specifications of geographical location. This will allow for the tool to generate the necessary set of the location-specific data. The weather file is then linked to this tool to integrate all these data to the final thermal simulations (Figure 5.18).

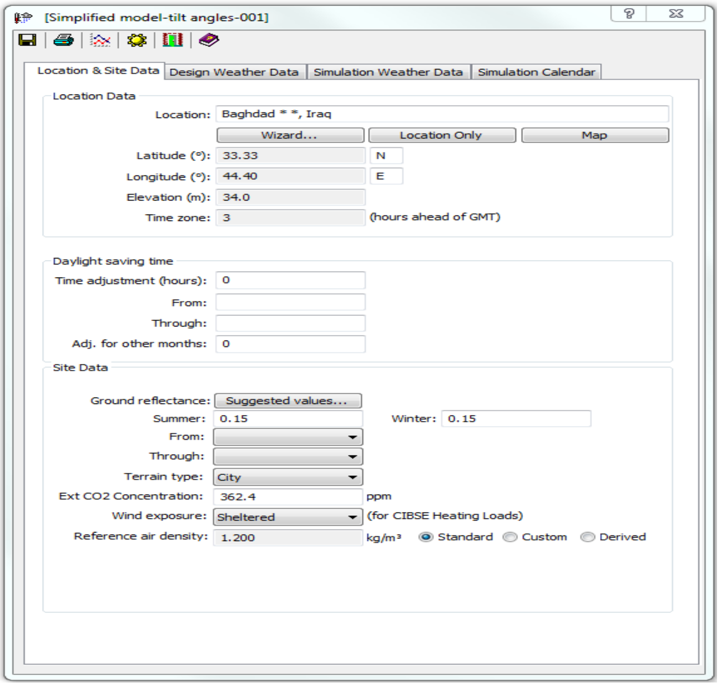
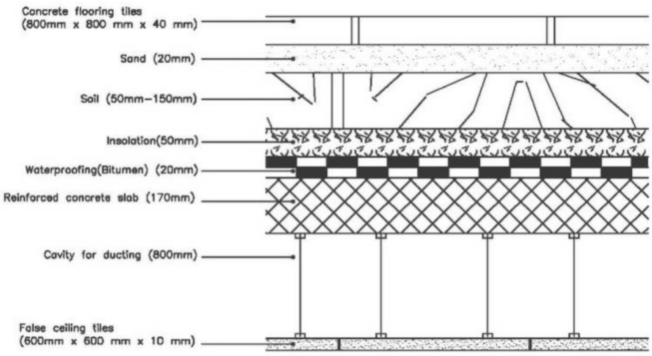
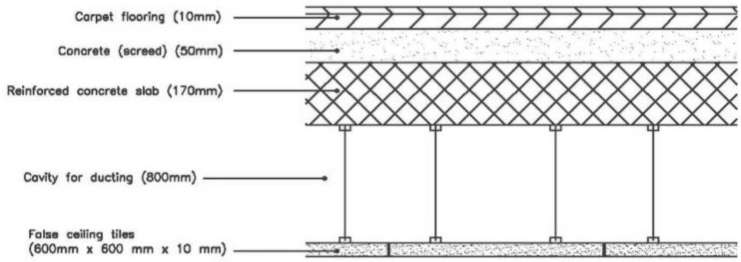
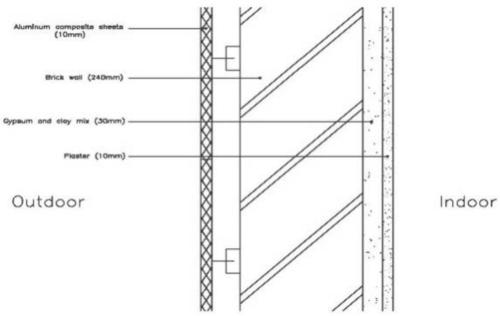
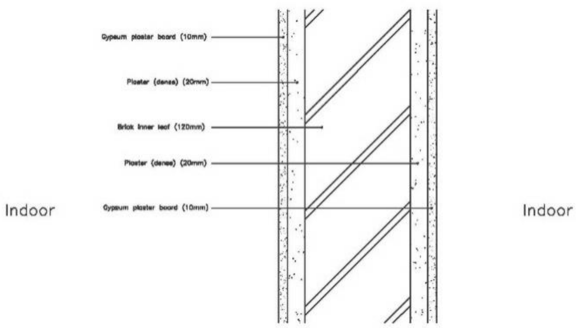


Figure 5.18 Geographical location settings

- *Construction settings*

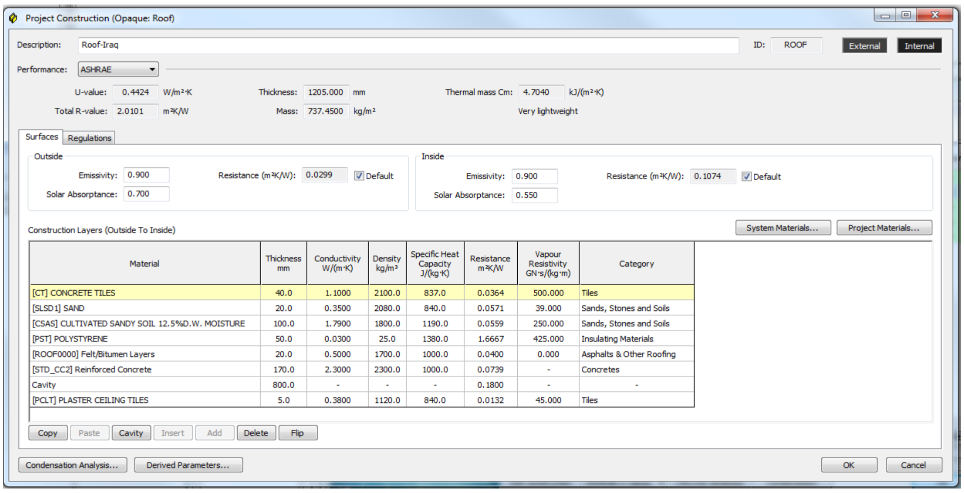
The next step is to set up a construction template to establish the construction elements (i.e. roof, floor, walls, etc.) in Apache. This was informed by the remote questionnaire survey as detailed in Table 5.2. According to IES-VE (2016a), Project Construction is to be created layer-by-layer, starting from the outside (facing the outdoors) to the inside (last layer facing indoors), except internal walls, which should be established according to the very first zone created. The following sections will elaborate on the specifications of each construction element.

Table 5.2 Construction elements details

Compo-nent	Layer	Thickness	Illustration
Roof	Concrete	40mm	
	Sand	20mm	
	Soil	150mm	
	Insulation	50mm	
	Waterproof	20mm	
	Reinforced concrete	170mm	
	Cavity	800mm	
	Plaster ceiling Tiles	20mm	
Floor	Carpet	2mm	
	Screed	50mm	
	Reinforced concrete	170mm	
	Cavity	800mm	
	Plaster ceiling tiles	5mm	
External wall	Aluminium sheets for cladding	5mm	
	Brickwork	240mm	
	Gypsum and clay mix	30mm	
	Plaster	10mm	
Internal partition	Gypsum plasterboard	10mm	
	Plaster (dense)	20mm	
	Brickwork	120mm	
	Plaster (dense)	20mm	
	Gypsum plasterboard	10mm	

- **Roof**

The construction layers of the roof are established, starting from concrete tiles of 40mm, followed by a layer of sand (20mm), soil (100), polystyrene (50mm), bitumen layer (felt) (20mm), and reinforced concrete slab (170mm). These layers are followed by a cavity of 800mm for ducting and covered by plaster ceiling tiles (5mm), as shown in Figure 5.19.

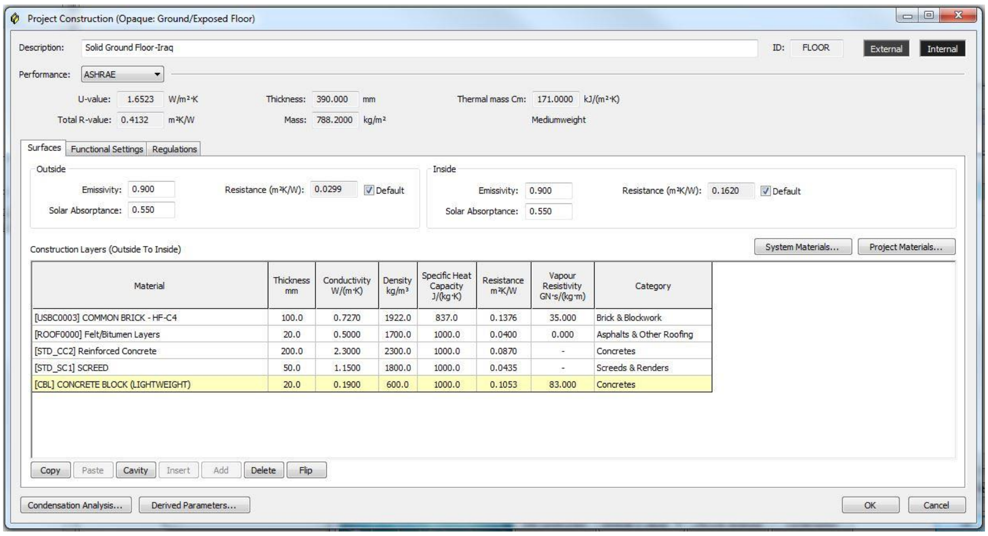


Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[CT] CONCRETE TILES	40.0	1.1000	2100.0	837.0	0.0364	500.000	Tiles
[SLSD1] SAND	20.0	0.3500	2080.0	840.0	0.0571	39.000	Sands, Stones and Soils
[CSAS] CULTIVATED SANDY SOIL 12.5%D.W. MOISTURE	100.0	1.7900	1800.0	1190.0	0.0559	250.000	Sands, Stones and Soils
[PST] POLYSTYRENE	50.0	0.0300	25.0	1380.0	1.6667	425.000	Insulating Materials
[ROOF0000] Felt/Bitumen Layers	20.0	0.5000	1700.0	1000.0	0.0400	0.000	Asphalts & Other Roofing
[STD_CC2] Reinforced Concrete	170.0	2.3000	2300.0	1000.0	0.0739	-	Concretes
Cavity	800.0	-	-	-	0.1800	-	-
[PCLT] PLASTER CEILING TILES	5.0	0.3800	1120.0	840.0	0.0132	45.000	Tiles

Figure 5.19 Roof construction and material settings

- **Ground- and exposed-floor**

The layers of the ground floor are established as follows: common brick (100mm), felt (bitumen layer) (20mm), reinforced concrete (200mm), screed (50mm), and concrete blocks of 20mm as floor finishing (Figure 5.20).



Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USBC0003] COMMON BRICK - HF-C4	100.0	0.7270	1922.0	837.0	0.1376	35.000	Brick & Blockwork
[ROOF0000] Felt/Bitumen Layers	20.0	0.5000	1700.0	1000.0	0.0400	0.000	Asphalts & Other Roofing
[STD_CC2] Reinforced Concrete	200.0	2.3000	2300.0	1000.0	0.0870	-	Concretes
[STD_SC1] SCREED	50.0	1.1500	1800.0	1000.0	0.0435	-	Screeds & Renders
[CBL] CONCRETE BLOCK (LIGHTWEIGHT)	20.0	0.1900	600.0	1000.0	0.1053	83.000	Concretes

Figure 5.20 Ground/exposed floor construction and material settings

- **Internal floor/ceiling**

The term 'internal floor/ceiling' is used in Apache to refer to the intermediate floors that are considered as ceilings to a floor and at the same time a floor to the next floor above. To form this construction element, the information in Table 5.2 has been used to establish the layers as follows: carpet flooring (2mm), screed (50mm), reinforced concrete (170mm), a cavity (800mm) for ducting, and suspended plaster ceiling tiles (5mm) to finish with (Figure 5.21).

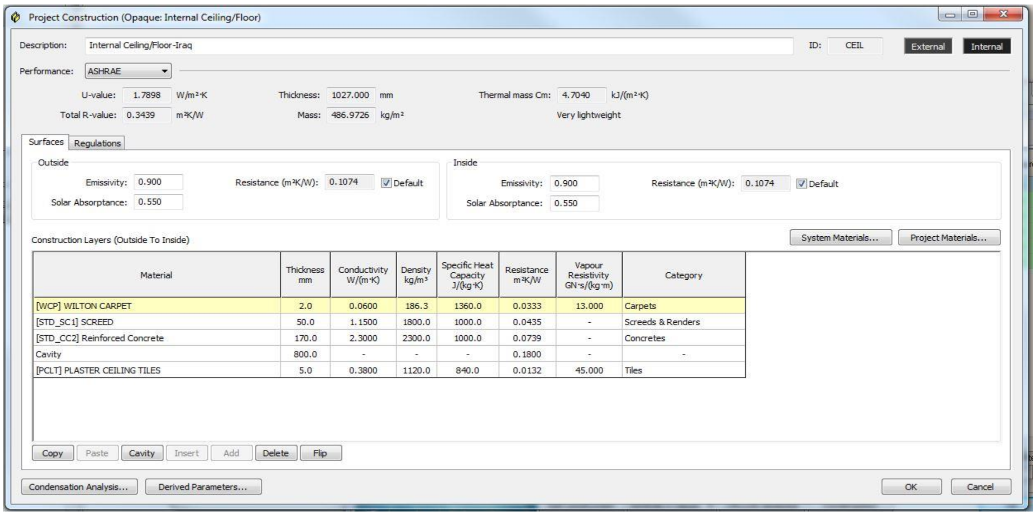


Figure 5.21 Internal floor/ceiling construction and material settings

- **Internal partition**

The information in Table 5.2 has also been used to form the layers of the internal partitions (Figure 5.22).

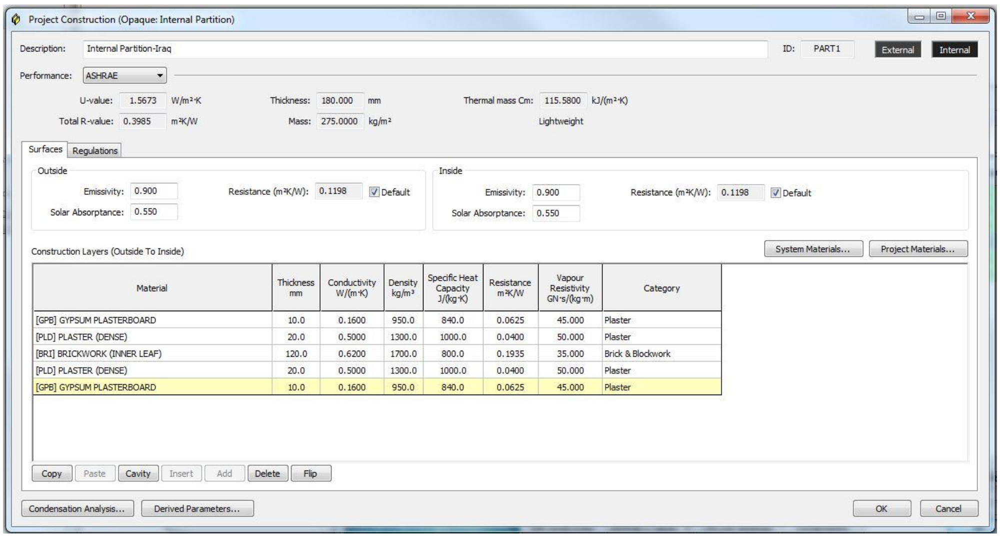


Figure 5.22 Internal partition construction and material settings

- **Photovoltaic Shading Devices PVSD**

In addition to the construction elements of the building model, the shading devices which are important elements of the model, especially when integrated with PV, were built as per the following steps (as illustrated in Figure 5.23):

- The length of the PVSD is considered to be equal to the length of the building, (i.e. 20m), to ensure maximum possible coverage of PV area.
- There are two depths of the PVSD that were included in the investigation which were concluded from the discussion in section 5.4.3 (Geometry of Shading Devices). Those were 400mm and 600mm.
- The thickness of the PVSD was 20mm. This was included to insure the closest proximities to a real-life scenario but simulation test-runs during the course of creating the model indicated that this will play an insignificant, if any, role in the outcomes of the simulations both in terms of shading and electricity generation.
- The geometric PV panel, which is a feature introduced in IES-VE 2017, was used to create PV layer and added on top of the shading devices. The performance of this combined shading device and geometric PV was checked and verified, as explained in section 5.3.6.

Although SDs can be made with a wide range of materials, this research does not take into account the material and the impact of change of different materials as a variable. This is because:

1. The environmental impacts associated with the choice of materials are more significant with regards to their embodied energy compared to impacts they may have on the operation energy during the service life of a building
2. This requires a different scope and focus which may shift the focus towards microflow and the external thermal phenomenon of the shading elements.

Therefore, the decision was to go with the most generic type of material which is Aluminium and keep this constant in different configurations.

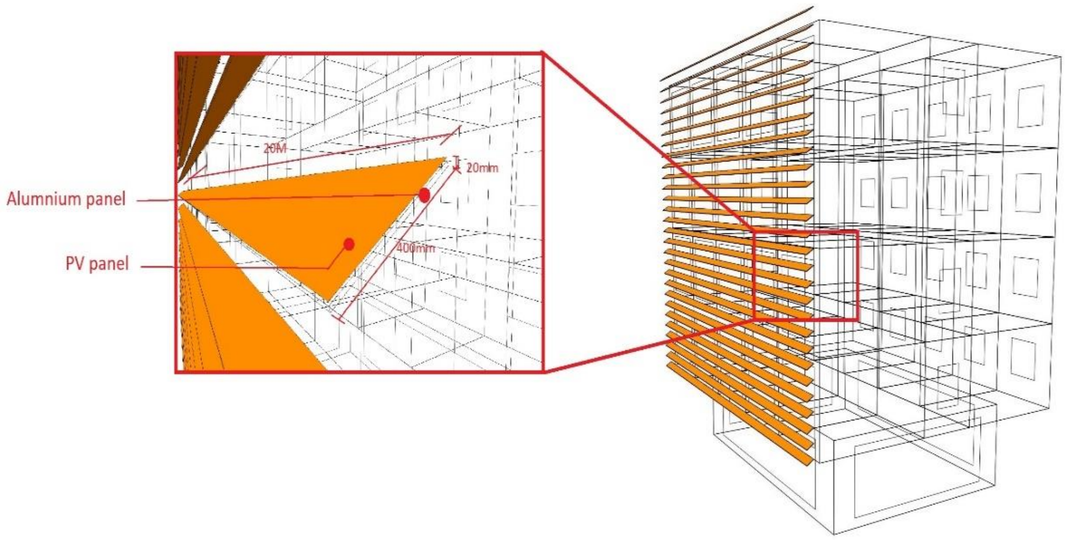


Figure 5.23 PVSD modelling

- *Glazing selection method for the specifics of IFS*

In order to develop appropriate IFS for highly-glazed office buildings in hot climates, a comprehensive method needs to be followed, especially when IFS includes HPG as one of its main integrated elements. The current research has developed a method as part of its comprehensive and systemic approach. This method is simply an input-process-output procedure. The input is informed by the literature review which has helped making deductions that are applicable to the context and the purpose of this study. The process is basically applying an inclusion and exclusion criteria which has been developed in, and for this study. These criteria form the requirements that the glazing system should meet. It comprises: 1) Building function, 2) Climate effect, 3) Building fabric, and finally 4) energy/lighting performance, as shown in Figure 5.24.

The available glazing and glass technologies that the literature suggests being suitable are presented in Appendix 2. These types have been analysed and then chosen according to the inclusion/exclusion criteria as follows:

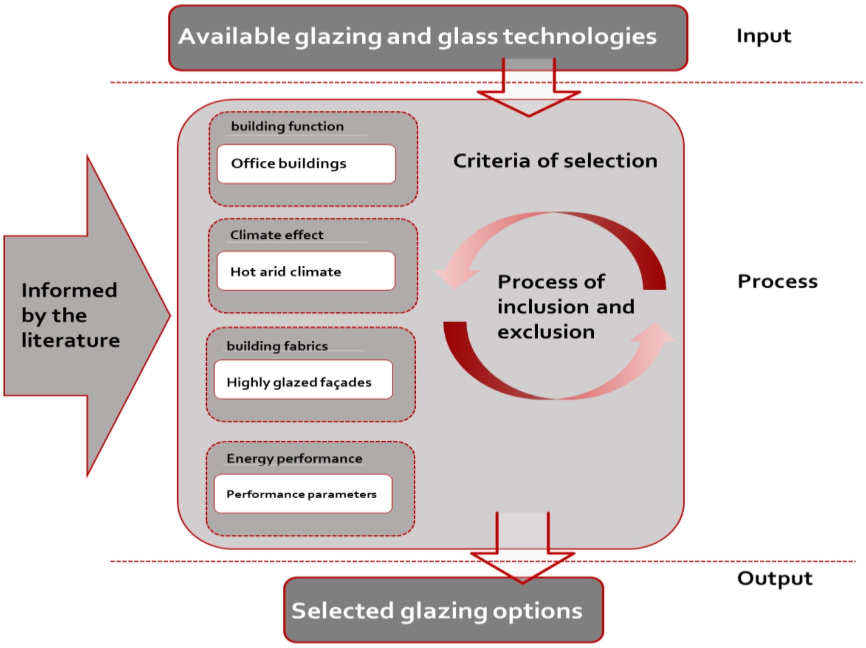


Figure 5.24 Glazing selection method developed in this study

Building function

The building function of the current study is office building. Therefore, attributes to this type of buildings are to be considered when choosing glazing systems. Recommendations for using HPG in office buildings in hot climates are summarised as follows based on Carmody and Haglund (2012), DoE (2015), EWC (2015a) and LBNL (2013). For instance, tinted or coloured glass can help minimise heat transfer but minimises light transmittance, which is not preferable in office buildings where daylighting is fundamental. To the contrary spectrally selective glazing is preferable to exclude an unwanted range of spectrums, e.g. short wave, such as reflective glazing. however, those types need to be evaluated against the other criteria in this inclusion/exclusion criteria to make a final decision about whether those types would be included in the analysis.

Climate effect

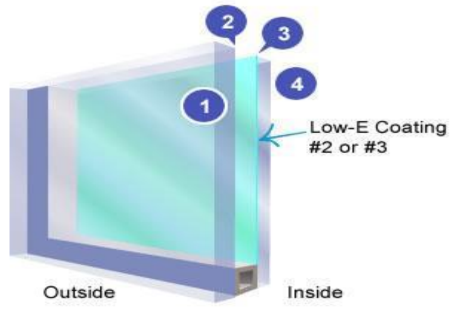
The climate of the current study is hot and arid. The main challenges of this type of climate (as discussed in chapter two) is the reduction of solar heat gain so that cooling loads are kept within an acceptable level. Therefore, glass type with low SHGC are recommended due to its effectiveness at reducing cooling loads. Furthermore, the material choice of glass becomes highly important in single skin façades, for instance, reflective glazing which is preferable for hot arid climates (Hamza, 2008).

Building fabrics

This criterion is mainly governed by the percentage of glass in the outer skin of the building. In highly- to fully-glazed buildings, heat transfer through windows needs to be carefully considered. Heat-absorbing tints are a good option but some heat, however, continues to pass through by conduction and re-radiation, so the tint does not lower a window's U-factor. Inner layers of clear glass or spectrally selective coatings can be applied to help reduce these types of heat transfer. Alternatively, low-e coatings control heat transfer through windows with insulated glazing, so this type is also preferable in this type of buildings. Insulating glazing (multi-layer) primarily lowers the U-factor and the SHGC, therefore they are recommended.

Buildings with highly- to fully-glazed façades need careful consideration of how multiple pane glazing is designed. For example, Low-e glass is effective, depending on the placement of the coating within the double-glazed glass faces. For single pane windows it is recommended that low-e coating is placed on the inside face surface because this coating is sensitive to weather and pollutants, which makes it harder to clean without damaging the surface. In double-glazed systems low-e glass can be placed on a particular side of the glass pane, depending on the objective of the specific project. In cold climates, maximising solar heat gain is a priority, therefore the coating performs better when facing the outer face of the inside glass pane (surface #3 in Figure 5.25). The coating will then absorb the inside heat and re-radiate it back to the indoor environment. In hot climates, such as Iraq, summer heat reduction is a prime objective, so the low-e coating should be placed on the inside face surface of the outside pane (surface #2 in Figure 5.25) in order to minimise the heat gain penetrating the indoor environment, by absorbing solar radiation and reflecting it back to the outside.

For fully-glazed office buildings, low-e glazing with a minimum visible transmittance of 40% should be used in order to reduce the use of energy for artificial lighting. Furthermore, in order to reduce the amount of solar heat gain from the large glazed area, SHGC values lower than 0.4 should be used (Assem and Al-Mumin, 2010).



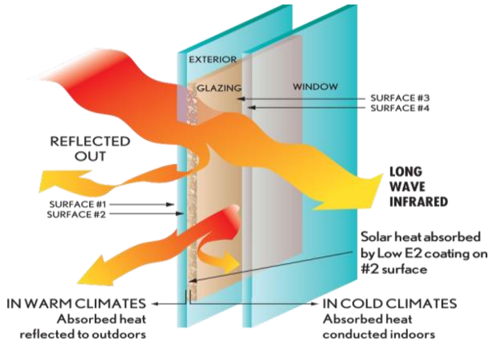


Figure 5.25 Placing low-e coating on the recommended surface for hot climates http://www.windowworldar.com/everything-need-know-low-e-glass-windows/

Energy performance

The performance parameters vary widely depending on the design targets. For instance, when the design targets are about controlling solar heat gain in hot climates while maintaining an acceptable level of daylighting, parameters such as solar gain, cooling loads, daylight factor/availability are the parameters that should be considered. In this sense, tinted glass absorbs a large fraction of incoming solar radiation through a window, reflective coatings reduce the transmission of solar radiation, and spectrally selective coatings filter out 40% to 70% of the heat normally transmitted through insulated window glass or glazing, while allowing the full amount of light to be transmitted. Except for spectrally selective, these types of glazing also lower a window's visible transmittance (VT). Some heat, however, continues to pass through tinted windows by conduction and re-radiation, so the tint does not lower a window's U-factor. Inner layers of clear glass or spectrally selective coatings can be applied on insulated glazing to help reduce these types of heat transfer.

Grey- and bronze-tinted windows are not spectrally selective, and reduce the light and heat. Blue- and green-tinted windows give a better visible light but heat transfer is not reduced when compared with other colours. In hot climates, black-tinted glass should be avoided because it absorbs more light than heat. Tinted, heat-absorbing glass reflects only a small percentage of light, so it does not have the mirror-like appearance of reflective glass.

Reflective coatings on window glazing or glass reduce the transmission of solar radiation, blocking more light than heat. Therefore, they greatly reduce VT, glare and also reduce SHGC which means they are also suitable for hot climates.

Spectrally selective coatings are optically designed to reflect particular wavelengths, but remain transparent to others. Such coatings are commonly used to reflect the infrared (heat) portion of the solar spectrum while admitting more visible light. They help create a window with a low U-value and SHGC but a high VT.

To conclude, the properties of the glazing materials selected for the IFS impact on the heat transfer, particularly the solar gain. As a result of the above-mentioned findings, and the selection method, the glazing systems that are going to be used are:

- a- Single glazing provides highest transmittance of heat energy and highest transmittance of daylight therefore it will be applied to the base-case for comparison purposes as a worst-case scenario.
- b- Double glazing will be chosen with multiple glass materials, such as clear, low-e, and reflective.
- c- Single-tint glazing will not be included because it has no effect on the U-factor, reduces visible light compared to clear glass, although reduces solar heat gain which is of benefit in summer only.
- d- Double-clear glazing will be included because it provides high visible light but also high solar heat gain. Therefore, it will be included in the analysis for comparison purposes.
- e- Reflective glazing is preferable on the outer pane of multiple glazing to reflect some of the heat that would have passed through otherwise.

Therefore, a set of six different glazing systems have been chosen for the analysis so that their properties cover a wide range of commonly used glazing, especially high-performance glazing such as reflective and low-e coatings. In order to accurately calculate the thermal and visual characteristics and performance indices of glazing, ASHRAE recommends using LBNL Windows v7.5[16] (NFRC, 2010). This method has proved to be successful in many researches, for example Waddell et al. (2010) and (Assem and Al-Mumin, 2010). Having done so, the reports of the properties were imported into the IES construction library to be applied to the models. Table 5.3 shows the glazing systems used and their

[16] LBNL WINDOW is a publicly available computer program for calculating total window thermal performance indices (i.e. U-values, solar heat gain coefficients, and visible transmittances). https://windows.lbl.gov/software/window

performance indices that will be used in the analysis. Snapshots of the glazing systems data that have been generated in LBNL Windows v7.5 are presented in Appendix 6.

Table 5.3 LBNL Windows 7.5 calculated specifications for glazing and glass types

Glazing systems generated in LBNL Windows7.5				
Glazing type	Glass type	U-value	SHGC	Tvis
Single	Clear	6.437	0.812	0.88
Single	Low-e	3.138	0.387	0.7
Single	Reflective	5.788	0.414	0.4
Double	Clear	2.625	0.571	0.786
Double	Low-e	1.636	0.283	0.64
Double	Reflective	2.661	0.325	0.3

- *Setting occupancy/cooling/heating/lighting profiles*

Having set the construction template – and building up all the construction library – for this study, a thermal template is then established to include the set-up of all relevant thermal profiles. These profiles are established in the APPro tool – a tool integrated within IES-VE that helps in setting up the following profiles:

- A daily occupancy profile; which has been used to incorporate the working hours of the day, as shown in Figure 5.26. A value of (1) means that this profile is in place between 8.00am and 4.00pm. Above and beyond this period, a value of (0) is then replacing (1), meaning that this profile is not in use during those periods.

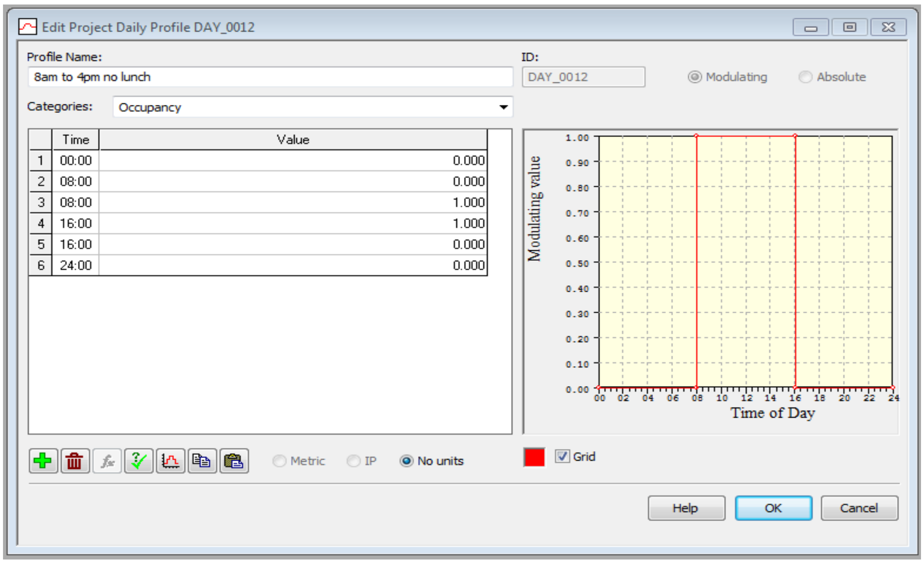


Figure 5.26 Daily profile setting in APPro

- Weekly profiles of usage and occupancy; which have been set up, as shown in Figure 5.27. This applies the daily profiles according to the working days of the week.
- HVAC systems working profiles; which have set up on three levels: daily, weekly and annual. The daily profile of cooling and heating starts working one hour ahead of the first working hour (Figure 5.28). This is necessary to allow the internal spaces to be cooled in advance of the occupants' arrival at their working spaces to ensure a comfortable indoor working environment.

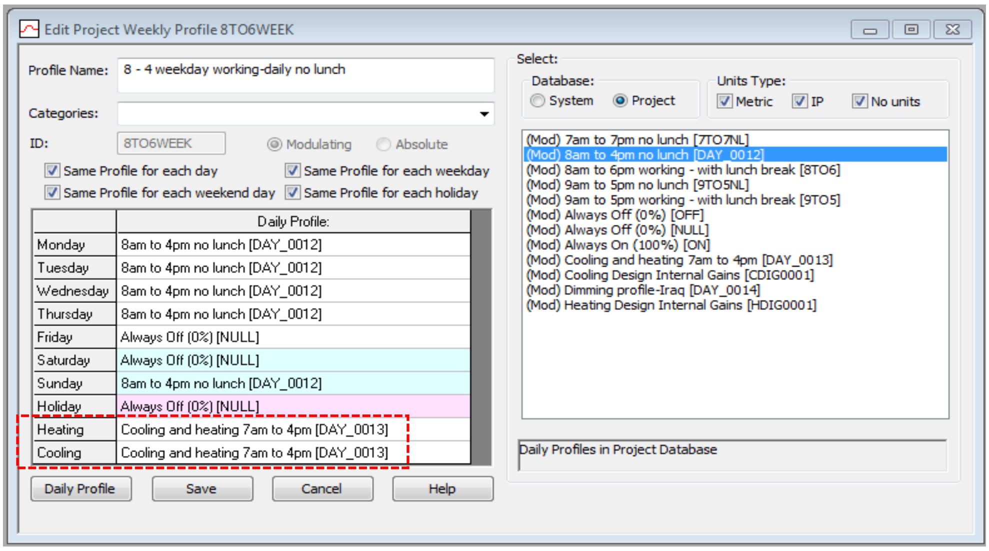


Figure 5.27 Weekly profile setting in APPro

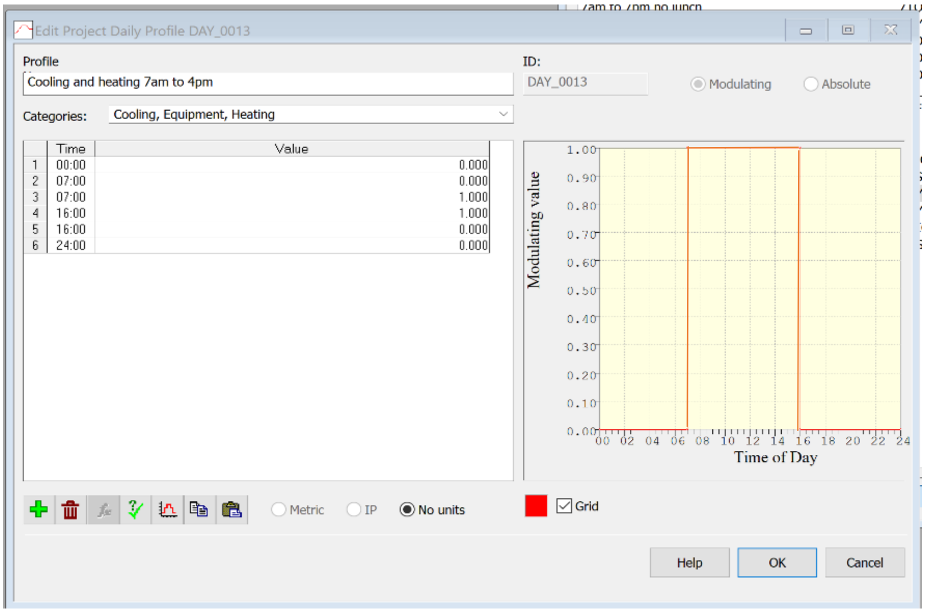


Figure 5.28 Heating/Cooling profile setting in APPro

The HVAC systems will be 'ON continuously' only during this period of time but this will be conditional in accordance with the set points. Figure 5.29 shows the HVAC system set-up – including set points and profile – that are also set up and linked to the thermal template to be used in the simulations.

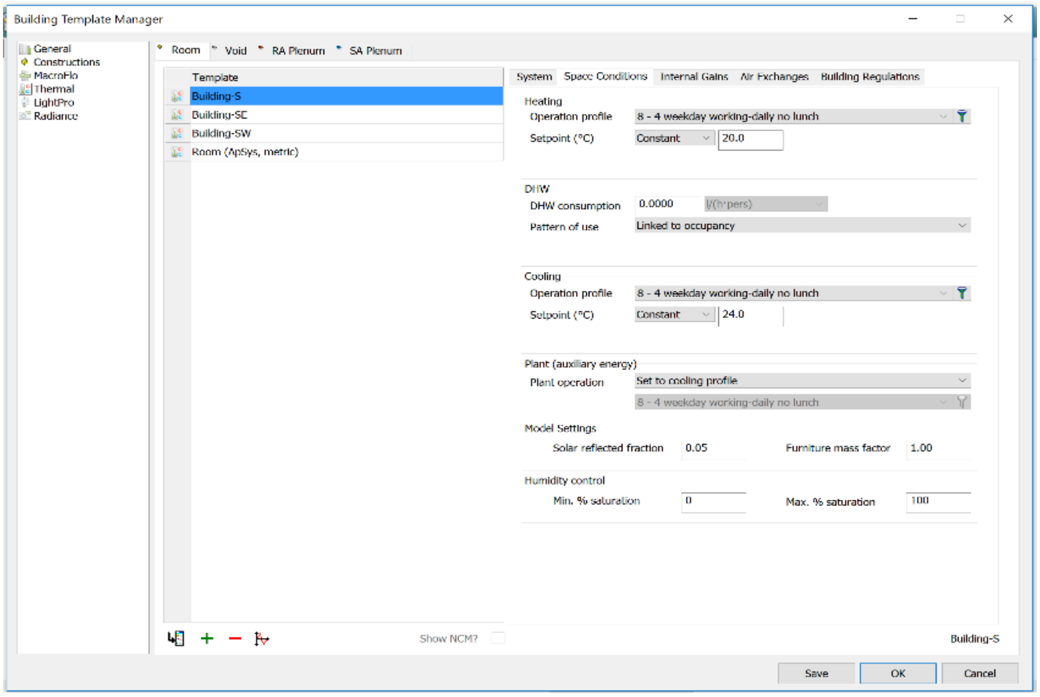
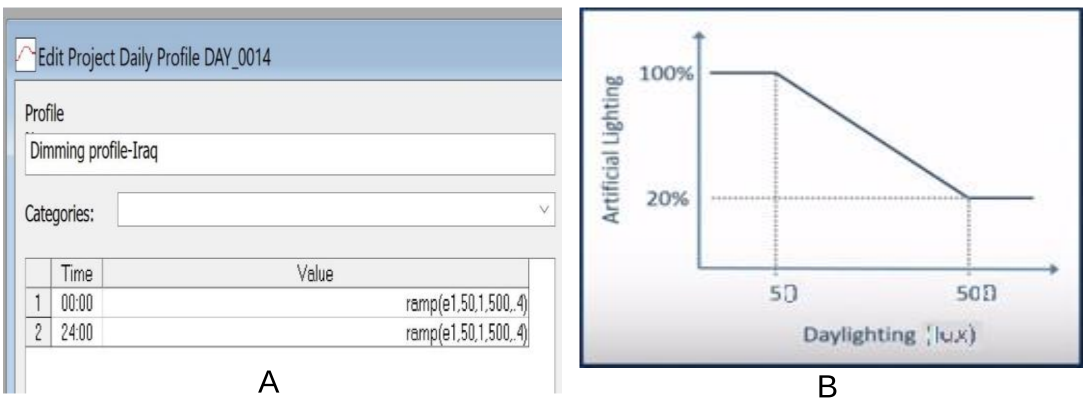


Figure 5.29 HVAC systems settings in Apache

- **Dimming profile**

In order to maximise the benefits of daylight harvesting, dimming the artificial lights is used so that they can change in response to the daylight provision. This will ensure that the unnecessary energy consumption and glare – as a result of excessive space lighting – can be prevented. An appropriate procedure recommended by IES-VE (2016b) was followed to apply the formula profile, as shown in Figure 5.30 (A).



A B

Figure 5.30 Dimming profile setting in APPro (A) and the ramp equation (B) *e1* is the daylight illuminance within the space and this is a ramp function which means at 50 lux and lower, 100% (1.0) of the artificial lights in each of the spaces will be on. Above 500 lux of daylight, the artificial lighting system will be working at 20% or 0.2 of full power ON. For office spaces, between 50 and 500 lux, a proportional ramp between a 100% and 20% of artificial lighting is taking effect (CIBSE, 2015), as shown in Figure 5.30 (B).

- **Annual profile**

The only annual profile used is applied to the simulation calendar in the APLocate tool so that the simulation takes into account the working days only, which means all profiles are OFF during weekends and national holidays. Iraqi national holidays have been applied for the accurate simulation measures, as shown in Figure 5.31.

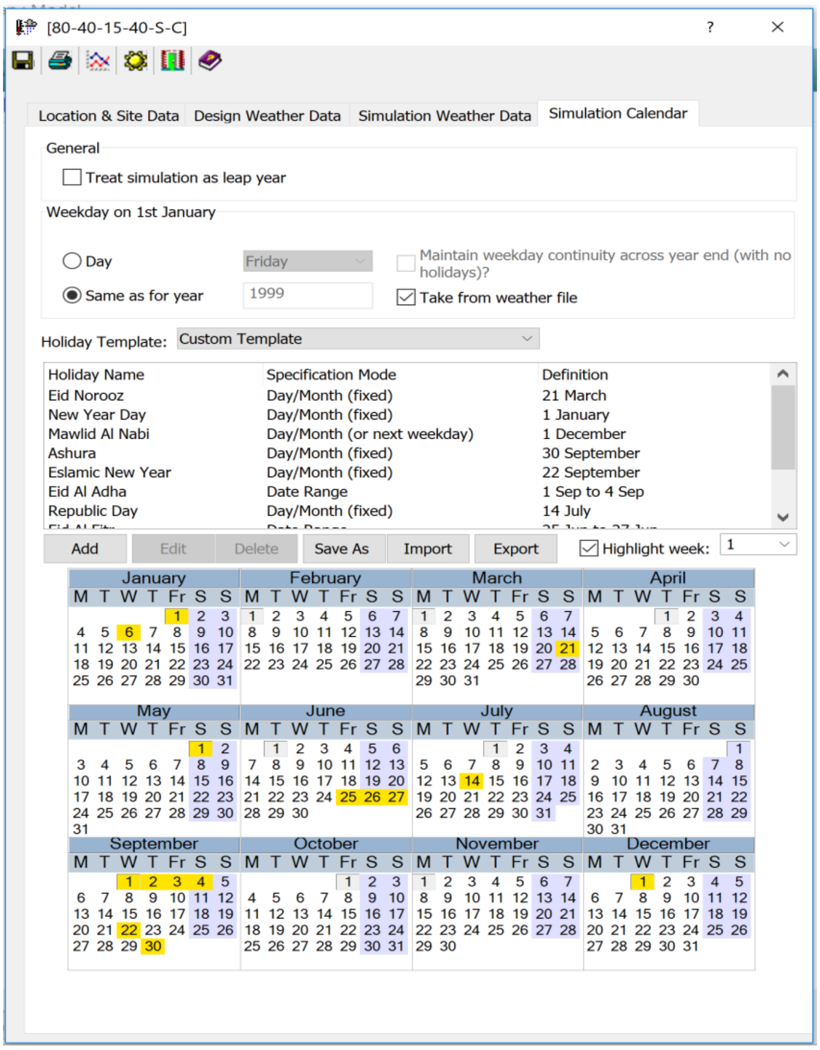


Figure 5.31 Simulation calendar in APPro

- **Internal gains**

The last step in setting up the model before running the simulations is applying the internal gains. Generally, the main sources of those gains are internal artificial lights, occupants, computers and other appliances which act as heat sources. People's gain and equipment's gain are considered fixed values (IES-VE, 2016a). However, since lighting gain is a function of the dimming profile responses of the sensors in the office spaces, they are not considered constant and will be included in the analysis to establish the daylight performance effect on both energy and lighting. Figure 5.32 shows the settings of each source of internal gain.

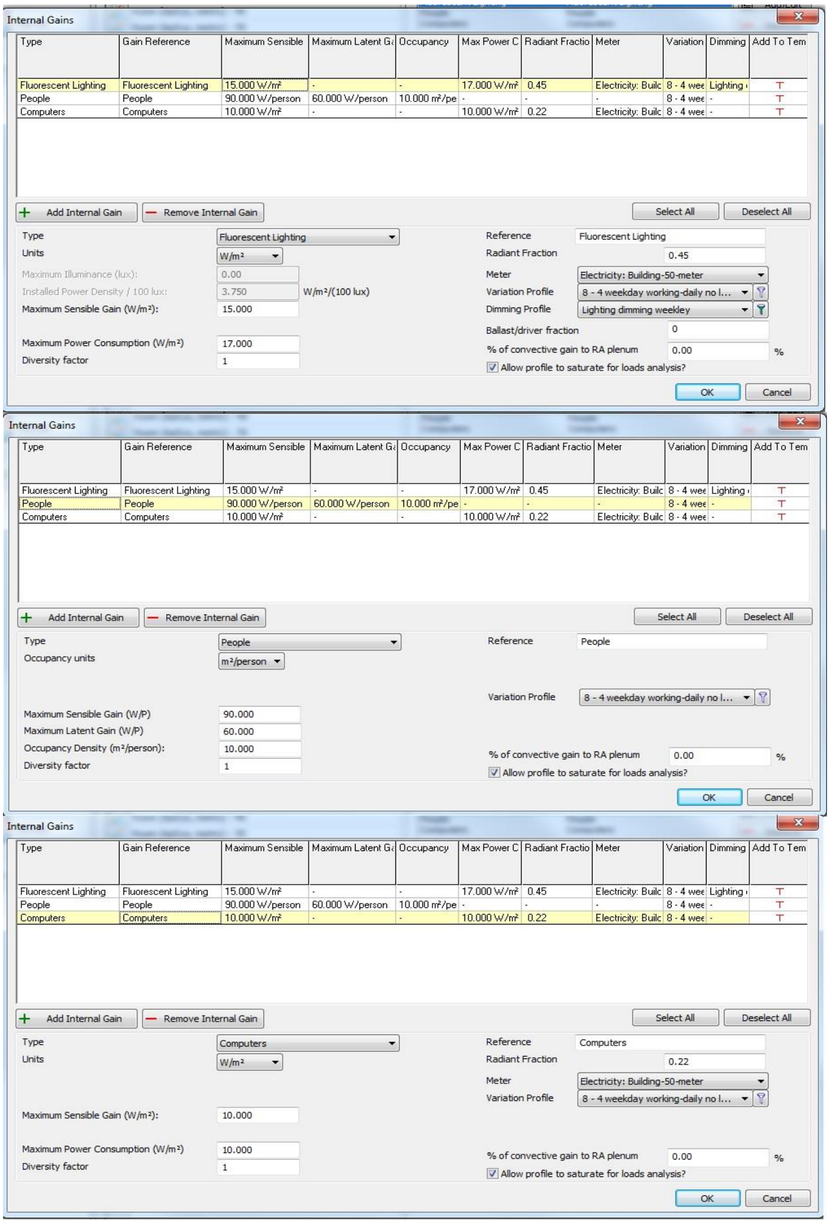


Figure 5.32 Internal gains settings in Apache

- *Electricity meters' settings*

Meters are set to monitor and measure fuel and energy consumption. A default meter is normally set and applied to a building. However, due to the in-depth analysis intended in this study and based on the dependency of the output factors, such as electricity consumption, lighting, PV generated electricity etc., a separate meter has been applied at each point of consumption and at the PV systems, which is a feature that is available within Apache (Figure 5.33).

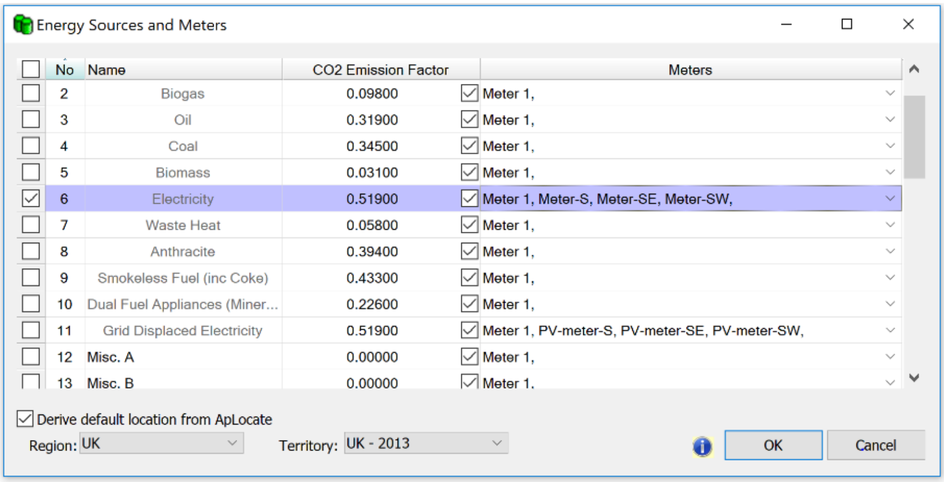


Figure 5.33 Electricity meters used in the simulations

- *Photovoltaic settings*

IES has recently integrated geometrical PV panels that can be added to the 3D model in ModelIT, in addition to the detailed PV settings in Apache. This newly introduced feature has many benefits for this study: it uses the same model without the need to remodel the building in other external tool. This will significantly reduce the error possibilities due to interoperability of the models between tools and user input. Moreover, it will have the ability to visualise the geometries and integration of the solar shading calculations of SunCast to account for shading effects on the panels. Electricity meters have also been applied to the PVs in order to measure the electricity production (Figure 5.34).

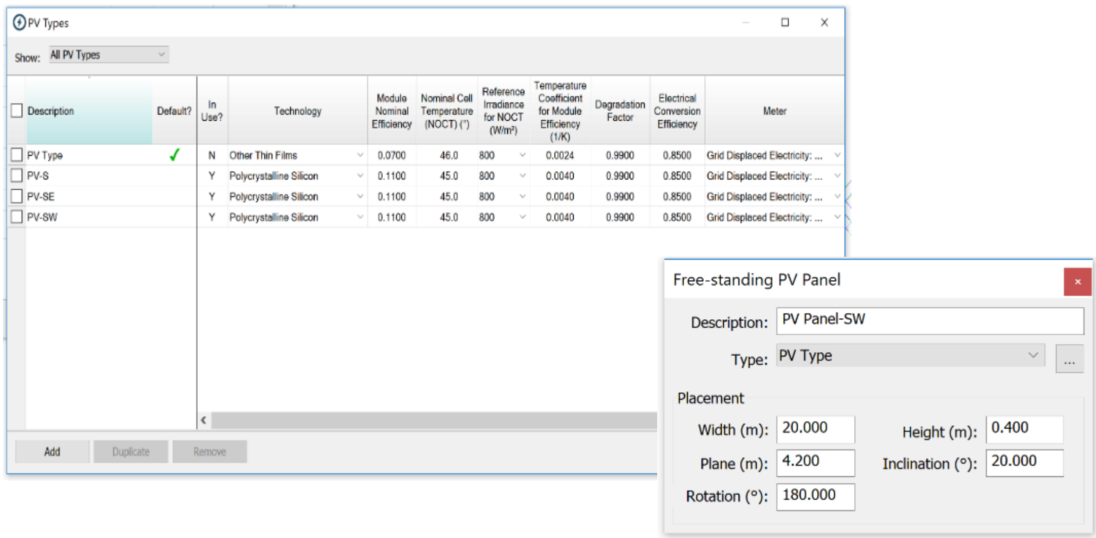


Figure 5.34 Photovoltaics settings

- *Radiance set-up for the integration with the thermal simulation*

The next stage is to set up the optical properties of the surfaces used in the simulations, namely the glazing systems imported from LBNL Windows 7.5. This is deemed imperative because the lighting simulation calculations differ from the thermal simulation calculations and hence some values need to be calculated and entered manually. For example, to allow for a correct account of the change in the glazing type's visual light transmittance, the Transmissivity should be calculated. This is because the specific calculation of Radiance embeds Transmissivity[17] value, whereas in thermal calculations, transmittance is the value that is included. If this is not carried out in advance of the daylighting set-up, a default transmissivity value will be included for all types of glazing, which does not indicate the actual difference between one glazing type and another. Hence IES-VE provides a simple calculation tool to convert visible light transmittance of the glazing system into transmissivity value. This value is then copied and entered into the External Glazing properties set-up in Radiance (Figure 5.35).

[17] Transmittance is the measured ratio of light at normal incidence, whereas transmissivity is the ratio of the total light that passes through the glass.

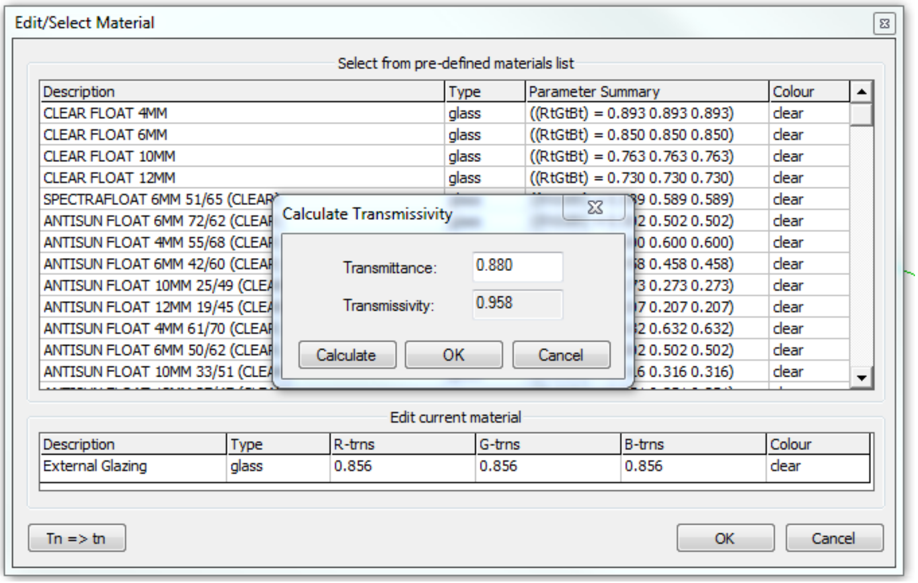


Figure 5.35 Radiance transmissivity calculation

Now that the whole simulation set-up is ready, the first batch of simulations will be run to investigate the accuracy of the simulations on the simplified models. The first objective is to check if there is any consumption untraced or unmetered. Then the sensors' locations and number of sensors are also checked. The second objective will be pursued after ensuring the accuracy of the model. A round of simulation runs – on the simplified models – will be conducted on the main three d/l ratios identified in the literature in order to investigate the thermal and visual performance of the full range of variation of inclination angles. This ranges from 0° to 80° with intervals of 10°. 90° was excluded for two reasons: first, depending on the d/l and size of panels it would allow for full closure of the PVSD that does not allow any daylight or view to the outside and it is the least preferable vertical angle for PV electricity generation. The following section will elaborate on the runs of simplified models.

5.3.6 Simplified model simulations for data quality checks and excluding unnecessary simulations

Eight simplified 3D models have been built using ModelIT and all the previously mentioned set-ups and materials have been applied to them. The purpose of this simulation is to check whether or not the light sensors are appropriately set up. Six buildings have been investigated, each with a different glazing type, as shown in Figure 5.36.

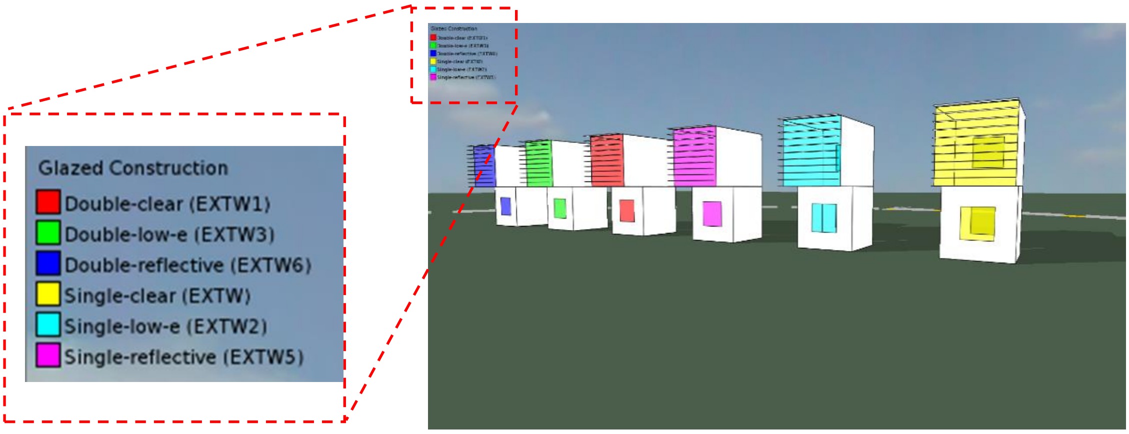


Figure 5.36 Simplified models

The next step was applying PV panels as SD. In each model, the same configuration of PVSD was used but with a different inclination angle. Light sensors have been set up in the middle of the room, facing down at the height of 850mm from the floor, which is the standard desk height. This sensor reads the illuminance level at one-hour intervals in the working days of a year. The first run of this series of thermal simulations has been successful. However, when running daylight simulation, some issues appeared and needed careful attention.

Figure 5.37 and Figure 5.38 show the visualisation of the resultant daylight availability. The simulations are run on 21st of March at noon. Interestingly, no difference has been observed between the simulated cases when using a geometric PV panel as the shading element and a solid shading element. After feeding back to the software vendor’s developers, it appeared that geometric PV panels are visually considered as 0.00mm thickness and therefore their optical properties will not be considered in the daylight simulations.

Furthermore, identical results were found in models without any PV as SD. This is an interesting and overlooked issue with the software and the software vendor’s developers acknowledged that (copies of the communications with the software vendors are available on request).

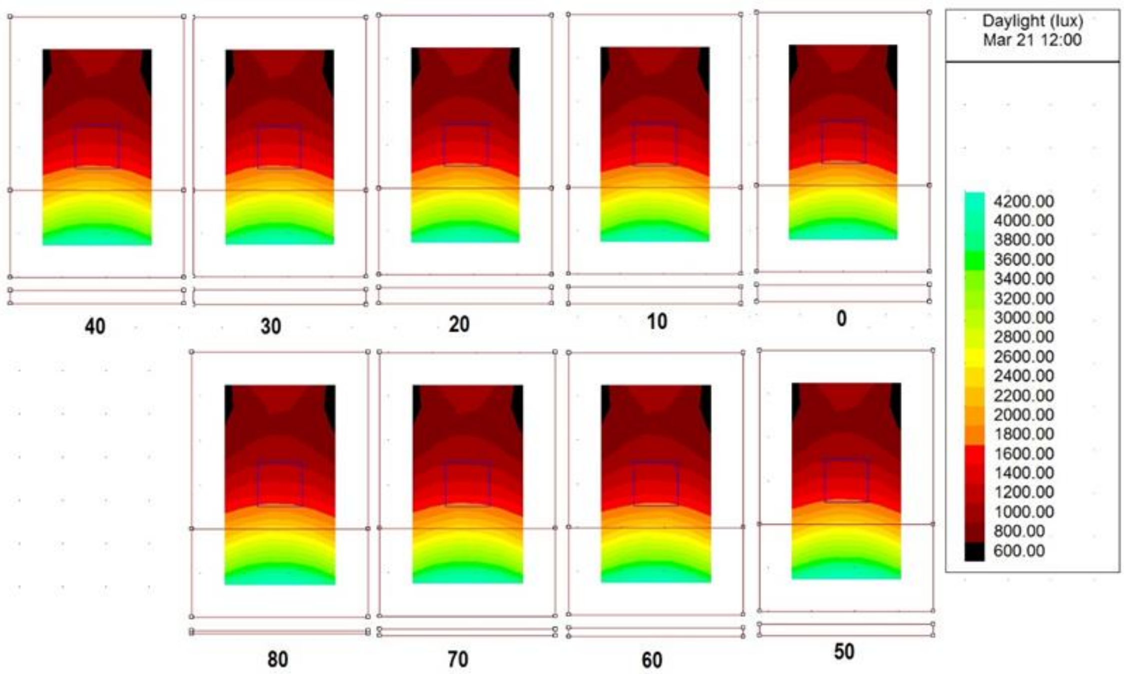


Figure 5.37 Data quality checks for daylight-round 1

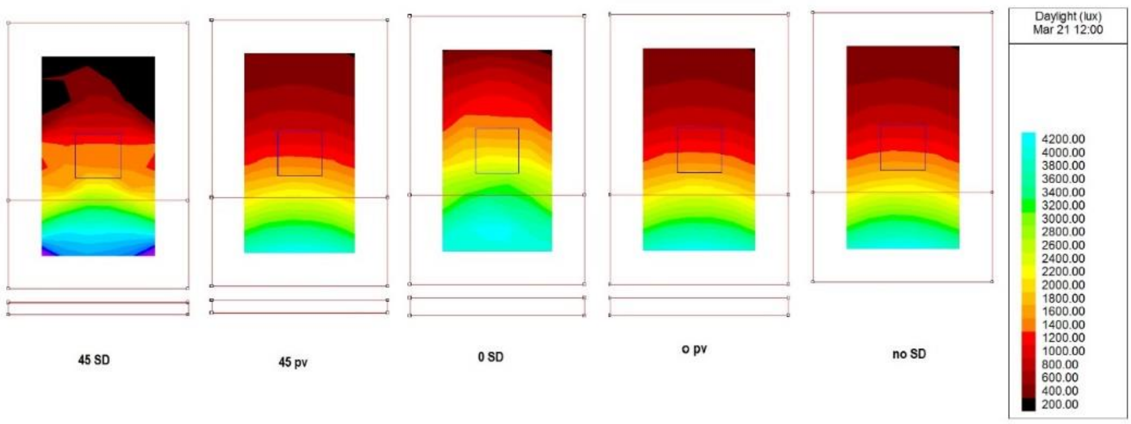


Figure 5.38 Data quality checks for daylight-round 2

After consulting with the software developers, it was decided to combine geometric PV panels with geometric SD to be able to reach accurate and reasonable results. Having done that, a third round of simulations has been run with this integration and Figure 5.39 shows that reasonable results are achieved because there have been differences in the visualisation results of daylight levels due to the change of the inclination angle. This procedure was also cross-checked with the PV electricity production and the thermal implications of this geometrical virtual integration and the software developers have verified this method (Figure 5.40).

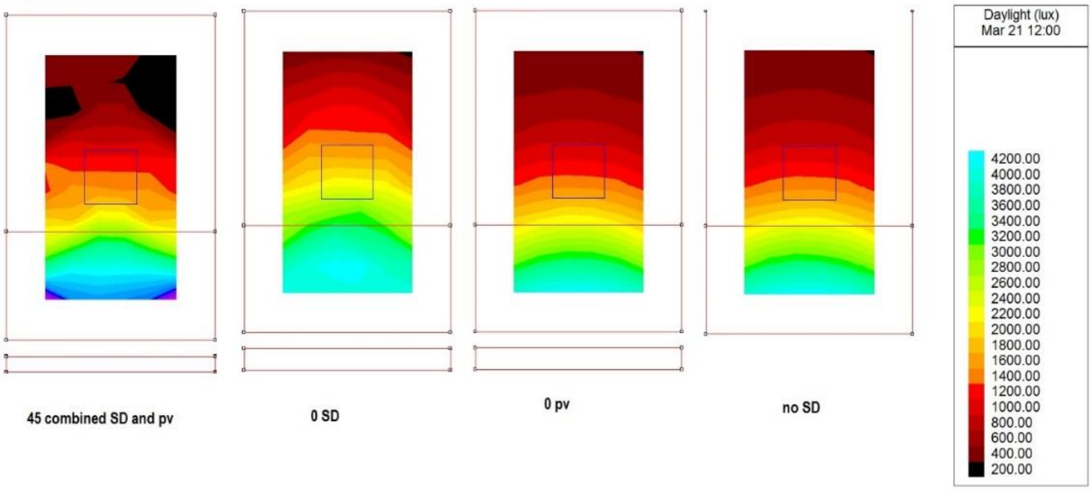


Figure 5.39 Data quality checks for daylight-round 3

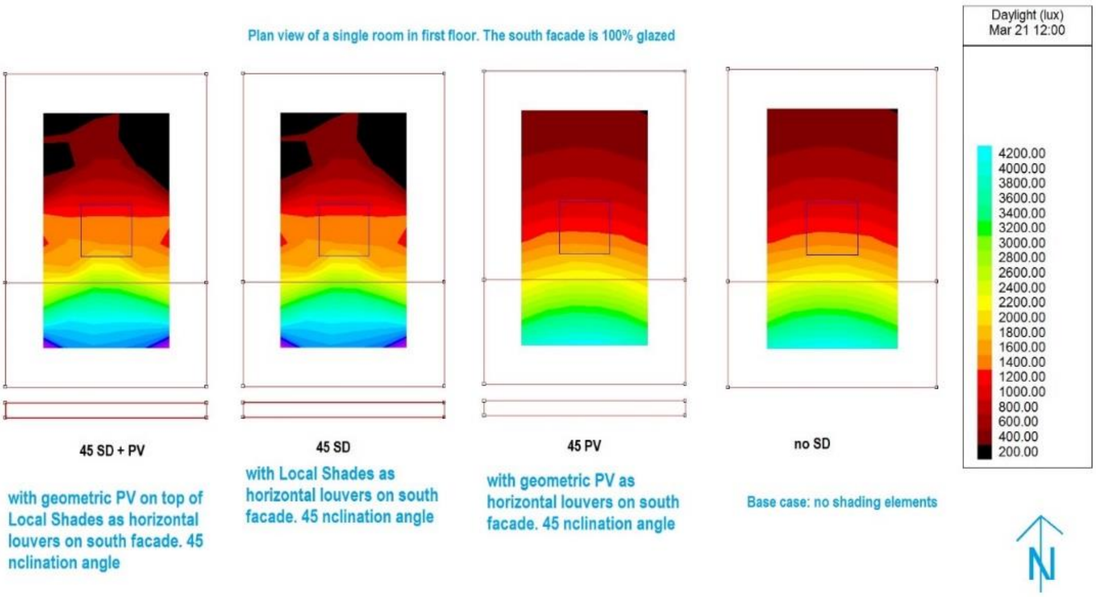


Figure 5.40 Data quality checks for daylight-round 4

Another issue to check was to make sure that running different models together gives the same results as when the models are run separately. At first there was a difference in the results which proved that something was not right (Table 5.4). An investigation with the help of the IES developers' team was done. It appeared that there was a system for HVAC within IES and this is assigned by default to all models in the simulation. It cannot be deleted as it is a default system. However, the solution is to create and assign a separate system to each of the buildings and then assign a meter to only read that HVAC system in order to be able to exclude the effect of the default system. Having done so, all simulation results were satisfactory.

Table 5.4 Cooling loads-data quality check

Room cooling plant sens. load (MWh)- Separate simulations			
Date	Simplified-test 0inc only.aps	Simplified-test-40inc only.aps	Simplified-test-80inc only.aps
Jan	0	0	0
Feb	0.0001	0	0
Mar	0.0485	0.0365	0.0305
Apr	0.2699	0.2437	0.2331
May	0.6949	0.6805	0.675
Jun	1.0896	1.0873	1.086
Jul	1.2803	1.2741	1.2715
Aug	1.441	1.4297	1.4233
Sep	0.8082	0.7891	0.7764
Oct	0.521	0.4784	0.4717
Nov	0.0492	0.0061	0.0061
Dec	0	0	0
total	6.2026	6.0254	5.9736
Room cooling plant sens. load (MWh)- Group simulations			
Jan	0	0	0
Feb	0.0001	0	0
Mar	0.0484	0.0364	0.0305
Apr	0.2699	0.2437	0.2332
May	0.6949	0.6806	0.6751
Jun	1.0897	1.0875	1.0861
Jul	1.2804	1.2743	1.2716
Aug	1.4411	1.43	1.4234
Sep	0.8078	0.7882	0.7758
Oct	0.5211	0.4786	0.4717
Nov	0.0492	0.0061	0.0061
Dec	0	0	0
total	6.2027	6.0255	5.9735

- **Reducing unnecessary simulations**

Now that the above-mentioned problem has been solved, another set of simulations were run, using the simplified models, to attempt to reduce unnecessary simulations. The investigation of this stage was focused on the main assessment indicators, namely: solar gain, lighting gain, cooling load, space cooling electricity and total energy consumption, which have been assessed for three series of simplified models of d/l ratios:1, 1.5 and 2 respectively. In each series, the angle of inclination was varied from 0° to 80° in interval of 10°, as shown in Figure 5.41 and Figure 5.42.

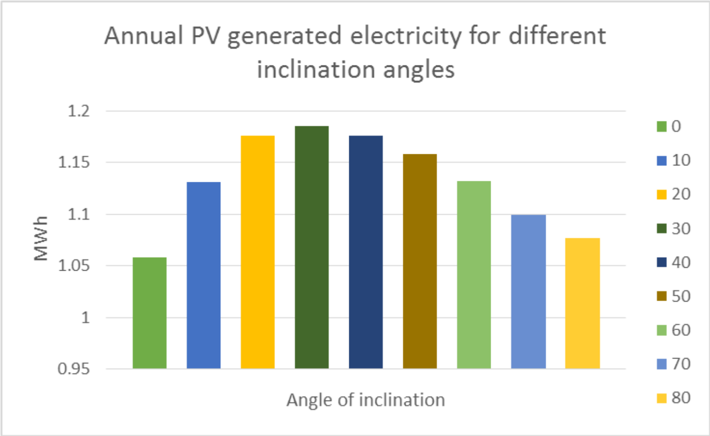


Figure 5.41 Annual PV generated electricity for full range of angles

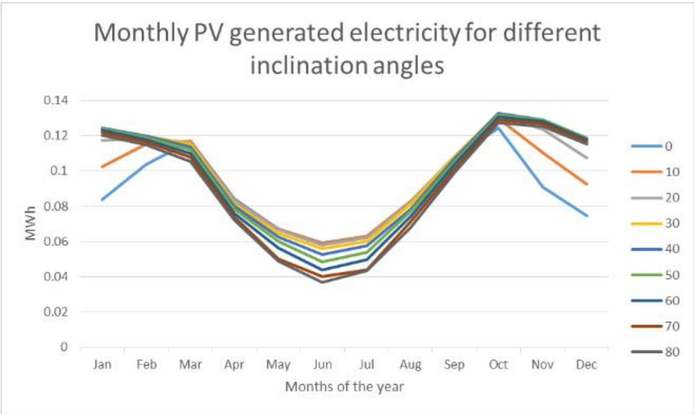


Figure 5.42 Monthly PV generated electricity for full range of angles

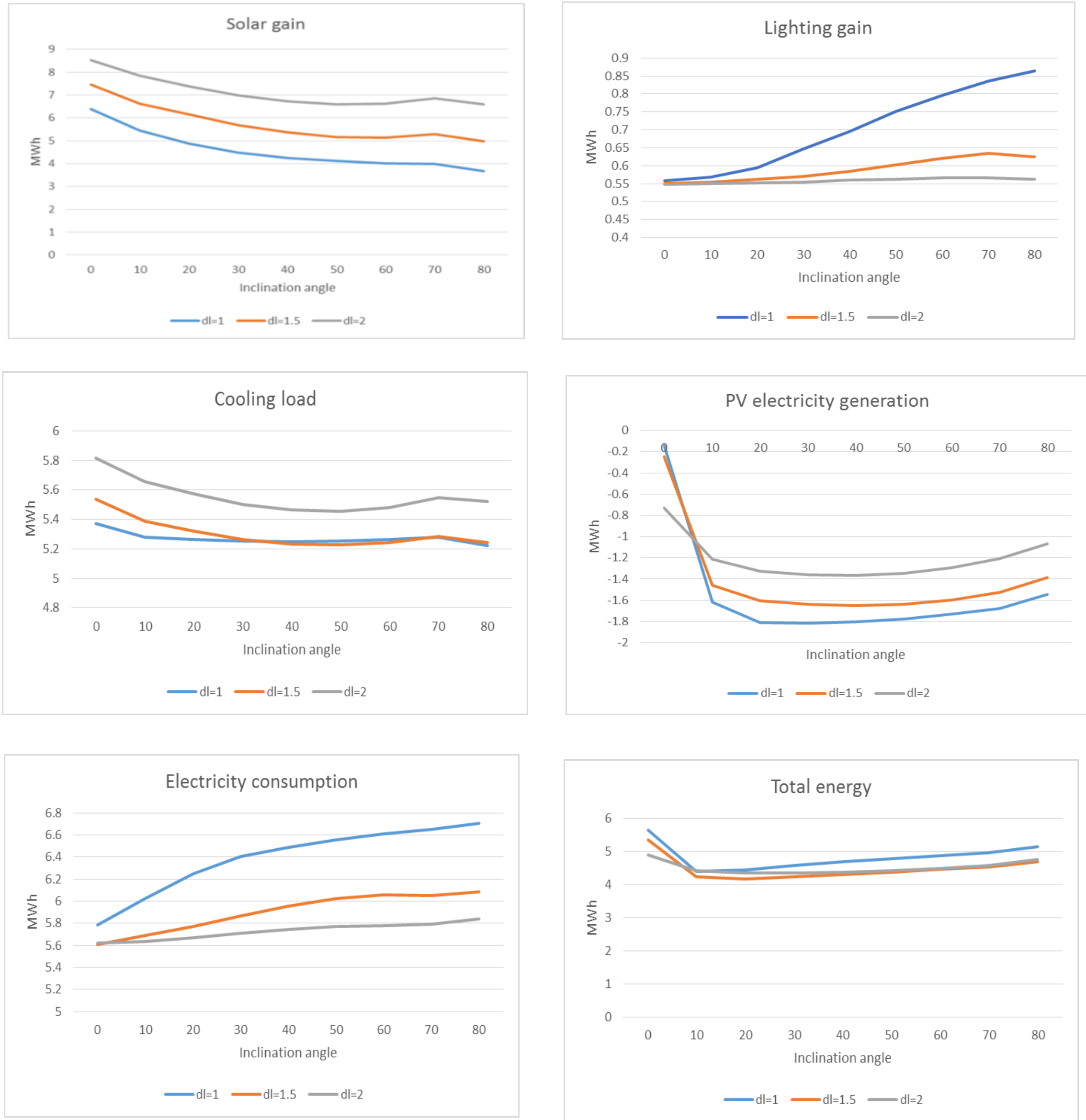


Figure 5.43 Assessment indicators for data quality check

In addition to all previously demonstrated energy assessment indicators, daylight illuminance levels have also been evaluated for all the three series of d/l ratio and for all the possible inclination angles, as discussed in the previous section. The eight simplified models have been simulated in Radiance in conjunction with Apache thermal simulation to account for the combined effects of daylighting and thermal analyses. Three levels of UDI (as explained in the methodology chapter, section 4.13.2) were evaluated. These are $UDI_{\text{less than 300 lux}}$, $UDI_{\text{300 to 3000 lux}}$, and $UDI_{\text{more than 3000 lux}}$. (Figure 5.44).

Figure 5.44 UDI ranges for d/l ratios; 1, 1.5, and 2 for all inclination angles

The graphs in the figures above show percentages of the hours of the working year where each of these three ranges of UDI are occurring. Those results are also tabulated in Table 5.5 and given scores and weighting factors.

Based on the evidence from the procedures that have been explained so far, the range of variation in the inclination angle for the main analysis is chosen based on three different perspectives:

1- The anticipated optimum range of PV generated electricity based on the geographical location, according to NREL (2015). (Further details can be found in section 5.4.3).
2- Evaluation of the UDI ranges resulting from the simplified models that have been defined based on the weighting and scores given to each one of the angles under investigation.
3- Matching those scoring and weighting factors with energy performance figures (Figures 96 to 99).

Table 5.5 Weighting of all inclination angle ranges for scoring purposes

	d/l=1			d/l=1.5			d/l=2						
Inclination angle	UDI less than 300 lux	UDI 300-3000 lux	UDI more than 3000 lux	UDI less than 300 lux	UDI 300-3000 lux	UDI more than 3000 lux	UDI less than 300 lux	UDI 300-3000 lux	UDI more than 3000 lux	Score			Weighting
Coefficient	0	+1	-1	0	+1	-1	0	+1	-1				
0°	1%	99%	0%	1%	87%	13%	1%	79%	20%	2.64863	2.321233	232	
10°	2%	98%	0%	1%	95%	4%	1%	85%	15%	2.775342	2.592123	259	3
20°	7%	93%	0%	1%	99%	0%	1%	89%	10%	2.808904	2.710959	271	1
30°	20%	80%	0%	2%	98%	0%	1%	95%	4%	2.725685	2.682192	268	2
40°	34%	66%	0%	4%	96%	0%	1%	97%	1%	2.586301	2.571575	257	3
50°	53%	47%	0%	8%	92%	0%	2%	98%	0%	2.371918	2.369521	237	4
60°	68%	32%	0%	12%	88%	0%	2%	98%	0%	2.184932	2.181849	218	5
70°	85%	15%	0%	15%	85%	0%	1%	97%	1%	1.974315	1.962671	196	
80°	93%	7%	0%	16%	84%	0%	1%	95%	4%	1.860616	1.82363	182	

Therefore, the optimised range of variation of the inclination angle of the PVSDs is 20° to 60° with a 10° interval.

5.4 Full factorial parametric study and design configurations

A factorial design encompasses choosing a given number of changes within each parameter variation range and running the resultant models for all the possible combinations (Hamby, 1994). Each parameter's sensitivity will be estimated using the results obtained in this manner. This experimental design would require a large number of model runs, depending on the total number of combinations. Therefore, it is considered to be a thorough examination of the models (Montgomery, 2014).

In the next sections, a comprehensive and thorough procedure is followed to make informed decisions about the number of variables that will be included in the analysis and the range of changes of each of them. This approach is substantiated by the relevant findings of the literature, the findings of the remote questionnaire survey and common practice in the architectural/construction field. Based on the findings and recommendations of the literature, variables at super-system, system and sub-system levels are discussed and the inclusion and exclusion of the variables are justified. Each level has a range of variables/factors as below:

5.4.1 Super-system level variables

Super-system level comprises factors and variables at the context-level, which is the higher systemic level such as climate, geographical location, etc.

With the help of the systemic approach, factors are categorised into systemic levels based on their level of influence. These factors can either be considered as variables, with a specific range of variations, or constants (fixed values) for all of the cases under investigation. This depends on the type and boundary conditions of the study as they are set. In this study, there are constant factors that can vary only when another study uses this systemic approach in different contexts (i.e. different location, climate etc.). Therefore, in the systemic approach developed for this study, climate is considered as a fixed factor as this study is only concerned with one type of climate, which is hot and arid in Baghdad city where this study has been conducted. The climate is represented as a weather file in the form of a plugin to the current customisable/modifiable methodology. [Location could be a variable for other studies, depending on the purpose of the study itself. However, it is considered as constant (N/A) for this study as the focus is for Baghdad city so it is a single location]. The methodology developed in this study could give billions of combinations if all types of climates, city locations. etc. are included, which is not applicable to the purpose of the current study. For location for example, hypothetically speaking, if London was to be considered as the city of the study, the available land plots for buildings can be taken as variations of location, while the rest of the factors can be frozen in the systemic levels. Microclimate, bodies of water, greenery and topology can be considered as dependent variables of a 'site' category.

To summarise, this study is not concentrating on the ‘super-system’ level but taking all of its factors into consideration. Therefore, this study has taken out climate as a variable because it is concerned with a specific climate and a specific location, and microclimate because these can be unlimited. Only factors in the super-system level which have a limit are taken into account in this study.

5.4.2 System level variables

As a result of the comprehensive literature review (see section 3.5.2), system level variables will include: Building type, Building Geometry, Orientation and window-to-wall ratio (WWR). The inclusion and exclusion criteria which have been used to determine the effective range of change for different variables at the system level, will be explained in the next sections.

- **Building type**

Since the focus of this study is on office buildings, the building type will not be considered as a variable but will therefore be treated as constant. In other studies where building type is aimed at or a cross-functional analysis (e.g. between educational and healthcare buildings) is intended, then 'building type' can easily be reverted back into a variable again. This means, for this study, other factors such as type of use, number of occupants, services, patterns of use etc. are all considered as constants, and hence outside the scope of this study.

- **Building geometry**

The geometry of the building was determined by the outcomes of the remote questionnaire survey (section 5.3.1). Other benefits of the systemic approach developed in this study are that it can be used as a tool for investigations of specific design solutions when the designer considers 'building geometry' as a variable, and it can also be used for research when studying the effect of a wide range of different combinations of glazing solutions is intended. 'Building materials' and 'structural systems' and their specifications, geometries and properties were inputted based on the remote questionnaire survey, therefore treated as constants in this study. Suffice to say that typological studies on any of those criteria can be conducted where the aforementioned factors can be switched back to variables and contribute to building up a parametric study on them.

- **Orientation**

There are two categorical groups of situations where different rules may apply, hence different readings or operationalisations of the systemic approach and levels may be required. The first one is that the orientation is a dependent variable of the location of the site. For example, in Iraq it is likely that the designer would follow the lines of the land plot and the main façade of the building would have to face the main street. This does not give many options to the designer. The second is that in big sites, where there is a flexibility of orienting the building freely, then there will be a need to have 'orientation' as a variable.

In the literature, many researchers used different orientations as a variable and in most cases the main eight orientations are used (Al-Tamimi and Syed Fadzil, 2011; Alzoubi and Al-Zoubi, 2010; Atzeri et al., 2013; Bellia et al., 2013; Carmody and Haglund, 2006; De Lima et al., 2013; Ebrahimpour and Maerefat, 2011; Gutierrez and Labaki, 2007; Palmero-Marrero and Oliveira, 2010). For this research, aimed at the integration of photovoltaics into building elements, such as SD, another requirement arises, which is the electricity generation of the PVs. In this regard, three main orientations, namely: South, South-East and South-West are included in the analysis to demonstrate variations of electricity generation. This decision was made based on a thorough review of the literature, especially those studies that looked into the integration of PV panels into SD. It was found that, for horizontal louvres integrated with PV panels, the best solutions were found to be those facing these three orientations. Considering the northern hemisphere, Table 5.6 shows the literature that investigated orientations for PV electricity generation when integrated with SD. The colour scheme indicates the ranking of the best orientation in terms of electricity generation (the darker the tone, the better the orientation with regard to PV electricity generation).

In all of this literature, in the northern hemisphere, a common recommendation can be noted when the investigation of PV electricity generation is intended, which is that the three best orientations are: South, South-East and South-West. For both east and west, some positive results are found, suggesting acceptable PV electricity generation. On the other hand, when PV are integrated with the SD, a contradiction occurs. This contradiction comes from the conclusion that for both east and west, horizontal louvres are the least efficient. This is because of the generally lower sun's altitude at those orientations, so the designer should then switch to vertical louvres. Vertical louvres, if integrated with PV panels, would significantly reduce the electricity production because the sunbeam will hit the panels at low angles and result in a reduction of the efficiency of the PV panels. This, therefore, contradicts the recommendation in most of the literature regarding PV electricity generation, which does not prefer vertical elements for such integration at all.

Table 5.6 Investigated orientation for PV electricity generation in the literature

Literature	Main orientations							
	East	South-East	South	South-West	West	North-West	North	North-East
Bahr, 2009			x					
Bahr, 2013		x	x	x				
Kim et al., 2010			x					
Hwang et al., 2012	x	x	x	x	x			
Kang et al., 2012	x	x	x	x	x	x	x	x
Mandalaki, 2014b			x					
Sun et al., 2012	x	x	x	x	x			
Sun and Yang, 2010			x					
Tongtuam et al., 2011	x	x	x	x	x	x	x	x
Yoo and Lee, 2002			x					
Yoo and Manz, 2011			x					
Yoo, 2011	x	x	x	x	x			
Sun et al., 2015			x	x				
Khezri, 2012	x		x		x			
Mandalaki et al., 2012			x					
Saranti et al., 2015			x					
Stamatakis et al., 2016			x					

x investigated orientation for PV electricity generation

Note: colour scheme reflects the preferable orientation

– – – – – Range selected for this study

Considering that horizontal louvres are the shading type that will be used in the analysis, hence, south, south-east and south-west are the orientations that will be included in the investigation in the current study. This will be discussed and justified in section 5.4.3)

- **WWR**

The window-to-wall ratio can vary from a very small fraction of an opaque wall to A fully-glazed wall. The building façade that is intended for this study ranges from highly- to fully-glazed façades. Fully-glazed façades are by definition 100% glazed. The definition of ‘highly-glazed’ in the literature has been referred to as a glazing percentage of 60% and above (Aboulnaga, 2006; Bahaj et al., 2008; Carmody, 2004; Ochoa et al., 2012; Poirazis et al., 2008). Hence, this research will consider this range (60%-100%), with 80% as the middle of this range. Other ratios that have been used to derive some dimensions, such as height, are outside the scope of this research because the dimensions of the building and its layout have already been concluded from the outcomes of the remote questionnaire survey, where clear questions about the prevailing dimensions of the office rooms are asked.

5.4.3 Sub-system level variables

The sub-system level is the level where the components' (façade) variables are. IFSs' two main categories of variables are 'glazing' and 'shading'. In the glazing category, the variables are: glazing system, glass type and open-ability. In the shading device's category, there are: shading type, shading location, operability, geometry (dimensions) and displacement (distance) from the main façade. The decisions made about the variables at this systemic level are explained in the following section:

- **Glazing**

Glazing system

Glazing systems that will be included are 'single' and 'double'. Single-glazing will be used in the worst-case scenario – which will form the base-case, against which the improvements will be measured – as representative of the most prevailing system. Triple- and quadruple-glazing are not practical due to cost, weight, availability and the common trends in the design and construction practices. These systems hence are not variables.

In this study, the analysis of the glazing and glass types (5.3.5) concluded a set of criteria to allow for a basic choice. Based on those criteria, the choice of glazing will be 'single' as representative of the most prevailing type used in Iraq and 'double' as a second option. Variations of glass types and coatings are discussed in the following section.

Glass type

The main requirement for the use of glass is to provide high levels of solar control to minimise solar heat gains and air-conditioning loads (Hamza, 2004). The types of glass that will be used in the analysis are within the most prevailing and available in Middle Eastern markets (Aboulnaga, 2006). Moreover, these types should meet the requirements that the literature review concluded as appropriate for hot climates. Therefore, it is recommended to use low-e, reflective and clear. Those are the generic types as variants/options for the variable 'glass type' in this study (this has been discussed in detail in section section 5.3.5). Other advanced types such as electrochromic have not yet gained momentum in the global markets and are still under research and development though they have a large potential in terms of becoming part of future glazing solutions (Jelle et al., 2012). However, the systemic methodology is open/flexible so that any glass type can be replaced with any other type which may be applicable in other contexts or as new products are introduced, and become more popular and/or affordable to use.

Open-ability

Openable, and non-openable windows can be considered as two variants of 'open-ability'. However, the current study only uses 'non-openable' windows and therefore it is considered as a fixed/constant. This because in hot and arid climates, the external dry bulb temperature in summer time is extremely higher than the thermal comfort temperature. In addition, buildings in this context are only served by centrally-controlled HVAC systems where natural ventilation either does not exist or is not recommended due to its negative impact on energy consumption (Brager et al., 2004). In other contexts where the systemic methodology is intended, open-ability could be a variable and could easily be accounted for in the simulations (a value of 0 for non-openable and 1 for openable).

- **Shading**

Although this systemic methodology gives the possibility of including all possible scenarios, it is imperative that, for each study, the elimination of irrelevant variables should be aimed at and conducted in a comprehensive manner, and needs to be substantiated and justified. In this research, the elimination of some of the variations have been justified in different ways: some such justifications come from the literature review, some come from the systemic point of view (where the variable sits/falls outside the remit of this study, i.e. system or super-system levels), and some come from the practice in the context of this study or the manufacturing/production/limitations/boundaries of some building materials and components. The literature provides strong evidence to assist with eliminating one variable by means of another variable, for example, orientation and recommended shading type. The SD category in the sub-system level will be elaborated on in the following sections.

Type of shading devices

The literature review on the types of SD has revealed a wide spectrum of types and suggests that the orientation of the building determines how SD are supposed to be installed (i.e. vertically or horizontally). For example, in the northern hemisphere, it is recommended that horizontal louvres are the most suitable SD for the south orientation, and for east and west, it is then vertical louvres; south-east and south-west could benefit from both and there is no need for any shading on the north façade as there is very limited non-direct sunlight against which protection/control would be required or which can be used for solar-generated electricity (Bellia et al., 2013; Cellai et al., 2014a; Dubois, 2001b; De Lima et al., 2013; Mandalaki et al., 2014a; Yassine and Abu-Hijleh, 2013). In other words, the type of SD is considered a dependent variable of building orientation. Moreover, in office buildings, for a better daylighting allowance, better outside views, and last but not least more space available for PV cells, louvres are the most common configuration used in offices (see section 3.3 for more detail). Hence, the decision for the current study is to choose horizontal louvres.

Location of shading devices

In the literature, there are three possibilities for shading locations: external, inter-mediate and internal (section 3.3). 'Shading devices' are mostly referred to in the literature when used externally (Cellai et al., 2014; CIBSE, 2006), intermediate SDs are the ones that are within double-glazing (between two panes of glass). It is worth mentioning that Venetian Blinds are considered SD if they are used outside but if they are inside, they are rather considered as curtains. Those that are considered high-tech and not commonly used, especially in Iraq, are not a practical option when it comes to cost-effectiveness, repair and maintenance. The internal ones are normally curtains and they are preferred in cold climates when maximising heat gain is aimed for. They are not preferable in hot climates because the priority is to obstruct the heat gain before it enters the building. Internal SD could be used in hot climates but for glare control only (O'Connor et al., 2013).

Moreover, SD when used externally are considered to be a building element, unlike internal ones which are considered to be soft furnishing (Carmody and Haglund, 2012).

Operability of shading devices

Operability of SDs depends on the type of SD and whether they are manual or motorised. Dynamic external shading devices might have an impact on reducing the building's energy consumption. However, studies on occupants' satisfaction in buildings where occupants do not have any control over the automated systems showed that occupants were dissatisfied in those buildings and favour overriding those systems by direct manual control (Stevens, 2001; Reinhart and Voss, 2003). In the current study, the decision, as explained earlier, is to utilise horizontal louvres hence the variation in this type is therefore the change of inclination angle of the louvres. This will be explained later.

Opacity of shading devices

Generally speaking, opacity as a variable can take two options: opaque and transparent. However, the available software is limited in that it cannot adequately function when both solar shading calculation (SunCast) and illuminance calculations are simultaneously considered. This was explained in detail in section 5.3.6. This factor, therefore, will be set as 'opaque' as a constant input into the simulations.

Geometry of shading devices

Geometry refers to the dimensions of the blades (louvres) which are as follows:

-**Length**: the length of the louvres (PVSD) follows the length of the façade of the building, therefore it is a dependent variable of the size of the building and, for the purpose of the model simplifications, the length will follow the total length of the building and will be considered as a fixed value in the simulations, hence constant.

-**Width**: the decision about the range of the variation of the width of PVSDs should cover both the minimum and maximum widths. The minimum width comes from the limitations for the installation of PV panels. Minimum and maximum dimensions of blades or louvres can be determined by the minimum dimensions that can accommodate PV cells in the form of arrays. The dimensions should also consider the risk of self-shading between panels which is determined by the angle of inclination and the distance between blades (d/l ratio).

An online research was carried out to investigate the size of the mainstream photovoltaic products and the inclusion criterion was to limit the search to products that are applicable to SD, either in the form of add-ons or integrated products. The purpose of this search is to achieve a realistic range of the PVSD depths. The research included world leading manufacturers of solar shading and projects carried out using this type of integration, such as UK (Colt, 2012; Kawneer, 2011; Levolux, 2017), Italy (Merlo, 2017), Singapore (BCA, 2011), USA (I. L., 2013), the Netherlands (Lundgren and Torstensson, 2004, Reijenga, 2003) and Germany (Schüco, 2017). (For further details please see Appendix 8).

The results of the research showed that PV cells are produced in 200mm x 200mm slates (150mm x 150mm for the cell, surrounded by space of 25mm to allow for connections with the next cell in the row/column). This meant the width of the louvre should be a multiplier of 200mm. A 200mm louvre is considered too small and not feasible to manufacture and use in SD. Therefore, the first choice was 400mm, followed by 600mm.

The research also considered that the louvres should not need additional or an independent structure due to their high weight, which would result in a more complicated design. Hence, it was decided that the range of the depth to be included in the analysis should be 400mm and 600mm.

Distance from main façade

The main determinant of this factor is providing a sufficient space between the external additional skin that holds the PVSDs and the main façade. This space should allow for safe installation of the PVSDs, sufficient space for rotation of different inclination angles of the PVSDs and for safe maintenance. This comes from the depth of the PVSDs, for example if the depth is 400mm then it takes no less than 200mm to 250mm to allow for rotation. Ideally it should not be less than that and no more than 500mm to allow for maintenance as well (Neufert et al., 2012). This distance is governed by the principles of micro-flow in fluid dynamics, which are outside the remit of this study.

Distance between PVSDs

The distance between the louvres – where the photovoltaic cells are integrated (PVSDs) – is a function of the angle between the PVSDs and also a function of the sun azimuth (time of the year) because of self-shading effects and because of creating effective shading on the façade of the building. The literature review on this variable defines the distance between every two louvres depending on a ratio referred to as the 'd/l ratio' where 'd' is the depth of the PVSD and 'l' is then the distance between them (please see section 3.5.3 for further details). In the literature, instances where this ratio was considered in the analysis was found to be varied between 1 and 3 in intervals of 1 or 0.5 (Bahr, 2013, 2014; David et al., 2011; Hwang et al.; 2012, Kang et al., 2012). However, the authors did not provide clear justification as to why such a decision was made. Therefore, the current research has attempted to establish the range of d/l ratio variations that will be included in the analysis by following this step-by-step procedure:

- Establishing the sun altitude data.

The monthly sun altitude angle for the specified location of this study (Baghdad) was generated using APLocate and then tabulated in average hourly values per each month (Table 5.7).

- Identifying the period of interest.

In order to factor out irrelevant altitude angles that may affect this decision, the months in which cooling is needed in Baghdad have been highlighted (light blue shaded area in Table 5.7), which is April to October (Kharrufa and Adil, 2012). The working hours of the day in Baghdad are 08:00 to 16:00 which have also been identified (red dotted line in Table 5.7).

Table 5.7 Average hourly sun altitude angles of Baghdad in each month

	Time														
Month	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Jan	-	-	-	8.92	18.81	27.02	32.78	35.33	34.2	29.6	22.24	12.93	2.31	-	-
Feb	-	-	1.46	13.12	23.86	33.08	39.89	43.2	42.26	37.3	29.31	19.34	8.14	-	-
Mar	-	-	8.41	20.59	32.09	42.28	50.04	53.74	52.12	45.77	36.39	25.32	13.36	0.96	-
Apr	-	4.61	17.1	29.59	41.76	53.03	62.07	66.07	62.68	53.94	42.79	30.67	18.2	5.7	-
May	-	10.47	22.72	35.21	47.7	59.81	70.43	75.46	70.02	59.28	47.14	34.64	22.16	9.92	-
Jun	0.59	12.04	24.05	36.4	48.92	61.34	72.99	79.97	73.92	62.42	50.02	37.5	25.12	13.08	1.57
Jul	-	10.04	22.11	34.5	47.02	59.39	70.88	78.06	73.52	62.61	50.36	37.84	25.39	13.22	1.53
Aug	-	6.2	18.58	31.1	43.49	55.28	65.3	70.4	66.98	57.66	46.12	33.81	21.29	8.86	-
Sep	-	1.9	14.41	26.68	38.32	48.61	56.18	58.88	55.54	47.59	37.1	25.36	13.05	0.54	-
Oct	-	-	9.49	21.03	31.47	40.04	45.61	46.97	43.73	36.74	27.27	16.3	4.46	-	-
Nov	-	-	3.72	14.52	24.03	31.57	36.31	37.44	34.76	28.76	20.31	10.2	-	-	-
Dec	-	-	-	9.79	19.16	26.69	31.64	33.33	31.48	26.38	18.75	9.31	-	-	-

Daily working hours

Summer cooling load period

Max. & min. sun Altitude

- Identifying the minimum and maximum sun altitude angles where shading is needed.

During the period of interest, the highest and lowest maximum sun altitudes were found in June at noon. Those are (79.97°) and (46.97°) respectively. The range between those two values will cover most of the working hours of the period of interest (shaded in brown in Table 5.7).

- A section view of the base-case model – that will be used in the analysis – was drawn in Autodesk AutoCAD Architecture 2016.

Two lines representing both low and high sun altitude angles have been drawn as a sun beam. Since the SD in this research integrate PV, perpendicular SD have been drawn to ensure optimum electricity generation by the integrated PV. The second in the line shading device has then been drawn at the edge of the sun beam to ensure full shading on the façade (Figure 5.45). The depth of each device is 400mm and both are displaced 500mm off the main façade.

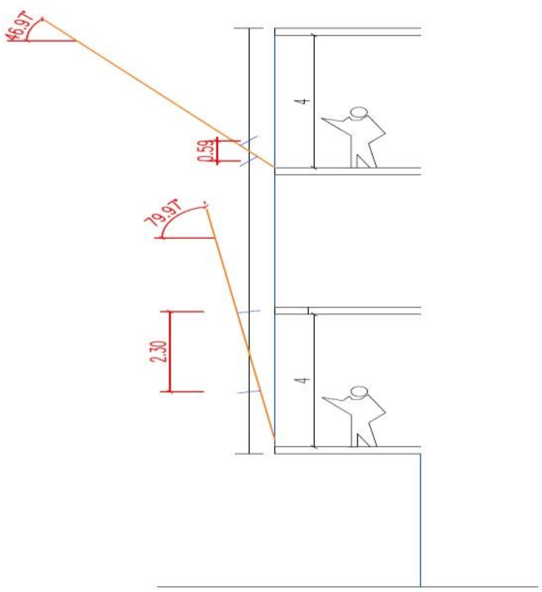


Figure 5.45 Section view showing the highest and lowest maximum sun altitude angles with the corresponding distance between each two devices

As a result of the method developed here it can be concluded that:

For the altitude of 79.9°, the distance between the PVSD is 2.3m to fully eliminate the heat gain excess as a result of direct solar radiation. This however, only blocks the unwanted direct solar radiation at a single point in time when this sun altitude is taking place and the interior spaces will be left unshaded during the rest of the times. This is an unrealistic scenario therefore it was excluded. For the lowest maximum sun altitude of 46.97°, the resultant distance between each two devices is 0.59mm. This suggests that the d/l ratio is almost 1.5. Moreover, considering that a sufficient space between each two devices is needed to allow for a change in the angle of inclination, a minimum d/l ratio of 1 is then included. In addition to that, a ratio of 2 will also be included to account for a bigger distance between the devices. More than 2 will leave most of the façade unshaded for most of the time.

To summarise, the d/l ratios to be considered in this study are: 1, 1.5 and 2.

Angle of inclination (of PVSDs)

Generally, the range of the inclination angle, with the purpose of electricity generation by the integrated PV, is between 0° and 90°. Good practice often sets the tilt angle to the latitude of the selected location. However, setting the tilt equal to the latitude does not necessarily maximise the net annual output of the system, as lower tilt angles favour peak production in the summer months and higher tilt angles favour lower irradiance conditions in the winter months (Rhodes et al., 2014). NREL's guides suggest, in general, that using a tilt angle greater than the location's latitude favours energy production in the winter and using a tilt angle less than the location's latitude favours energy production in the summer (NREL, 2015). This recommendation was also found in the literature but in different locations, such as the UK (REUK, 2017) or Iraq (Khadim et al., 2014). Table 5.8 (SolarPV, 2017) shows the variation of tilt angle and the PV output for the UK, confirming what has been found by Rhodes et al. (2014).

Table 5.8 Orientation and tilt angle (SolarPV, 2017)

Orientation Chart showing yearly output for different orientation and tilt angles (%of maximum).													
Tilt (°) from horizontal	Orientation - Compass bearing (°) measures from North												
Horizontal	West			S.W.			South			S.E.			East
	270 °	255 °	240 °	225 °	210 °	195 °	180 °	165 °	150 °	135 °	120 °	105 °	90 °
0 °	90	90	90	90	90	90	90	90	90	90	90	90	90
10 °	89	91	92	94	95	95	96	95	95	94	93	91	90
20 °	87	90	93	96	97	98	98	98	97	96	94	91	88
30 °	86	89	93	96	98	99	100	100	98	96	94	90	86
40 °	82	86	90	95	97	99	100	99	98	96	92	88	84
50 °	78	84	88	92	95	96	97	97	96	93	89	85	80
60 °	74	79	84	87	90	91	93	93	92	89	86	81	76
70 °	69	74	78	82	85	86	87	87	86	84	80	76	70
80 °	63	68	72	75	77	79	80	80	79	77	74	69	65
90 °	56	60	64	67	69	71	71	71	71	69	65	62	58
Vertical	Near horizontal 0 ° inclinations are not recommended as the self-cleaning cannot be relied on at less than about 10 °												

The performance of PV modules and building-integrated photovoltaic (BIPV) systems is highly influenced by both the modules' orientation as well as the tilt angle. Therefore, the PV modules must be oriented and tilted in such a way that the maximum solar radiation is gained while unwanted shading is avoided. Different methods of calculating the optimum angles and orientations have been developed (Deetjen et al., 2016; Elbakheit, 2015; Landau, 2015; Rhodes et al., 2014; Yang and Lu, 2005). The literature review has shown that there is no general rule of preference for angle of inclination and the conclusions made by different researchers are mostly exclusive to their locations and setting. In this study, the test run simulations (detailed in section 5.3.6) showed that angles of inclination more than 60° will completely block the light inside. In addition to that, some higher angles, such as 70°, showed similar PV output to low angles, such as 20°. Therefore, the range of change of the inclination angle that will be included in the analysis is between 20° and 60°.

The shape of PVSDs

The shape of PVSDs can vary from a flat surface to convex or concave. Depending on the photovoltaic technology applied, this can have an impact on the efficiency of electricity production of the PV panels. Some more imperative use of specific technology or design, or both features, can help improve the efficiency of the PVSD system used. For example, convex can be combined with the concave effect by concentrating light in the middle, or solar tubes. The shape could result in an infinite number of possibilities and very much depends on the design. Therefore, 'shape' will be considered as a fixed/constant in this study, as a flat surface of the panels; however, this could also be a future work.

- **Type of photovoltaic (technology)**

IES-VE includes the most commonly available PV technologies on the market and the most common types that are widely used, such as Monocrystalline and Polycrystalline. The main characteristics of each type within the software are also modifiable, such as efficiency, and can be changed to match the intended characteristics of a specific product. Although the latest generation of PV cells are capable of delivering up to 29.8% efficiency of the conversion coefficient, according to EnergySage (2018) – one of the biggest world-wide marketplaces – (Figure 5.46), and NREL (2018) (Figure 5.47), they are not included in this study because the mainstream PV panels available on the markets are capable of delivering 14-17% (NREL, 2018) which are attributable to the types included in the software.

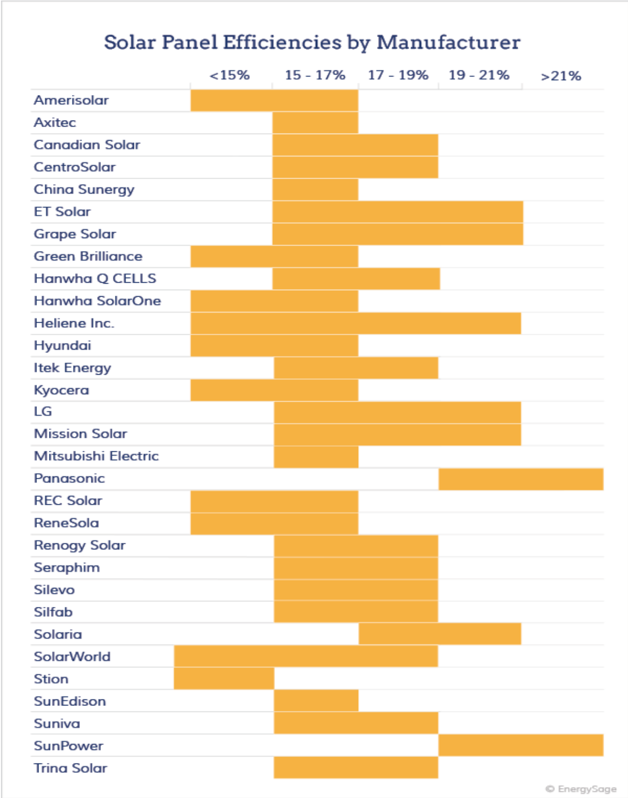


Figure 5.46 Solar power efficiencies by manufacturers (EnergySage, 2018)

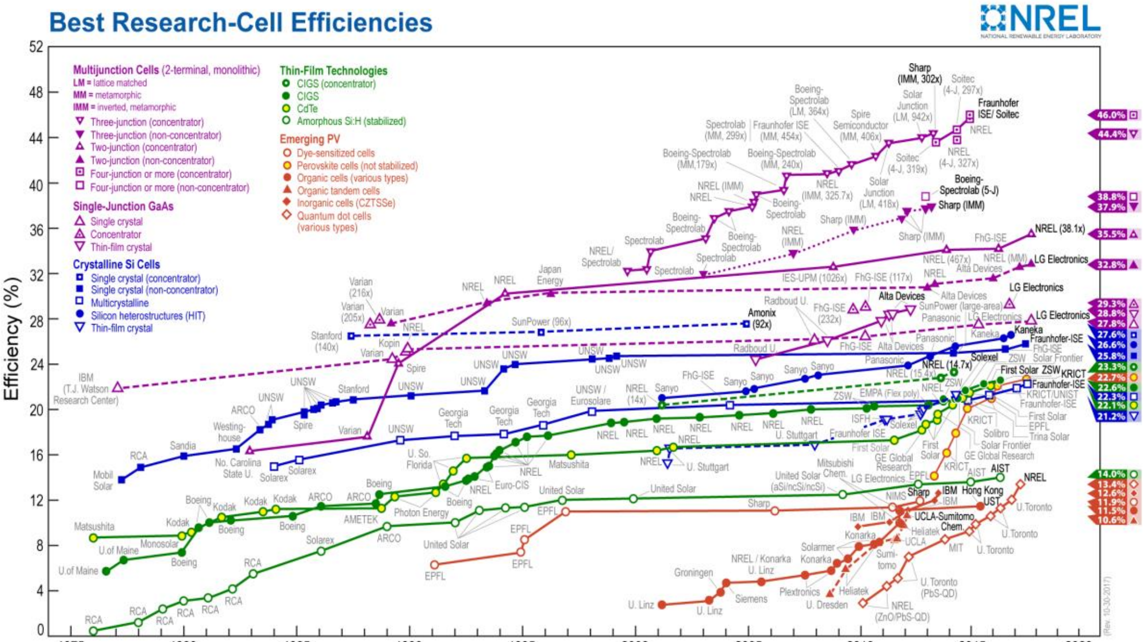


Figure 5.47 PV cell efficiencies (NREL, 2018)

Monocrystalline solar panels have higher efficiency rates (15-20%) compared to Polycrystalline (13-16%) but they cost much more. Polycrystalline solar panels tend to have a slightly lower heat tolerance than Monocrystalline solar panels, meaning that they technically perform slightly worse than Monocrystalline solar panels in high temperatures, such as in the context of the current study. However, this effect is minor compared to the self-shading effect to which Monocrystalline is much more sensitive. If the Monocrystalline panels are partially shaded, the entire circuit can break down. Since the application in the context of this study is within PVSD, and it is very likely that panels are self-shaded during some of the daytime, therefore, Polycrystalline was the technology chosen for the integration in the current study. The efficiency was set to 14% to account for the negative impact due to the expected increase in the panels' temperature.

5.5 Source codes of configuration (combination matrix)

To effectively manage a big number of simulations that resulted from the combination of the number and the range of variation of the variables, a coding system was developed so each unique simulation's file/run name can clearly indicate the exact combination of variables with which it is associated. Figure 5.48 presents a chart indicating all included variables and their corresponding variations.

The total number of combinations is calculated as a result of multiplication of all the variables and their corresponding variations by the equation below:

$$N_e = {n_1}^{k_1} \times {n_2}^{k_2} \times \ldots \times {n_n}^{k_n}$$

Where:

N_e*: total number of combinations*

$n_{1,\,2,\ldots n}$*: variables*

$k_{1,\,2,\ldots,n}$*: number of variations of each variable*

As a result of the full factorial parametric study of this research, ***540*** unique geometrical models have been produced for each of the three orientations under investigation. The total number of combinations of variables therefore is ***1620***. These models will then be run in: SunCast for solar shading calculations, Radiance for illuminance calculations, and then integrated in a third run in Apache for dynamic thermal simulation. The final total number of all simulation runs therefore is ***4860*** runs.

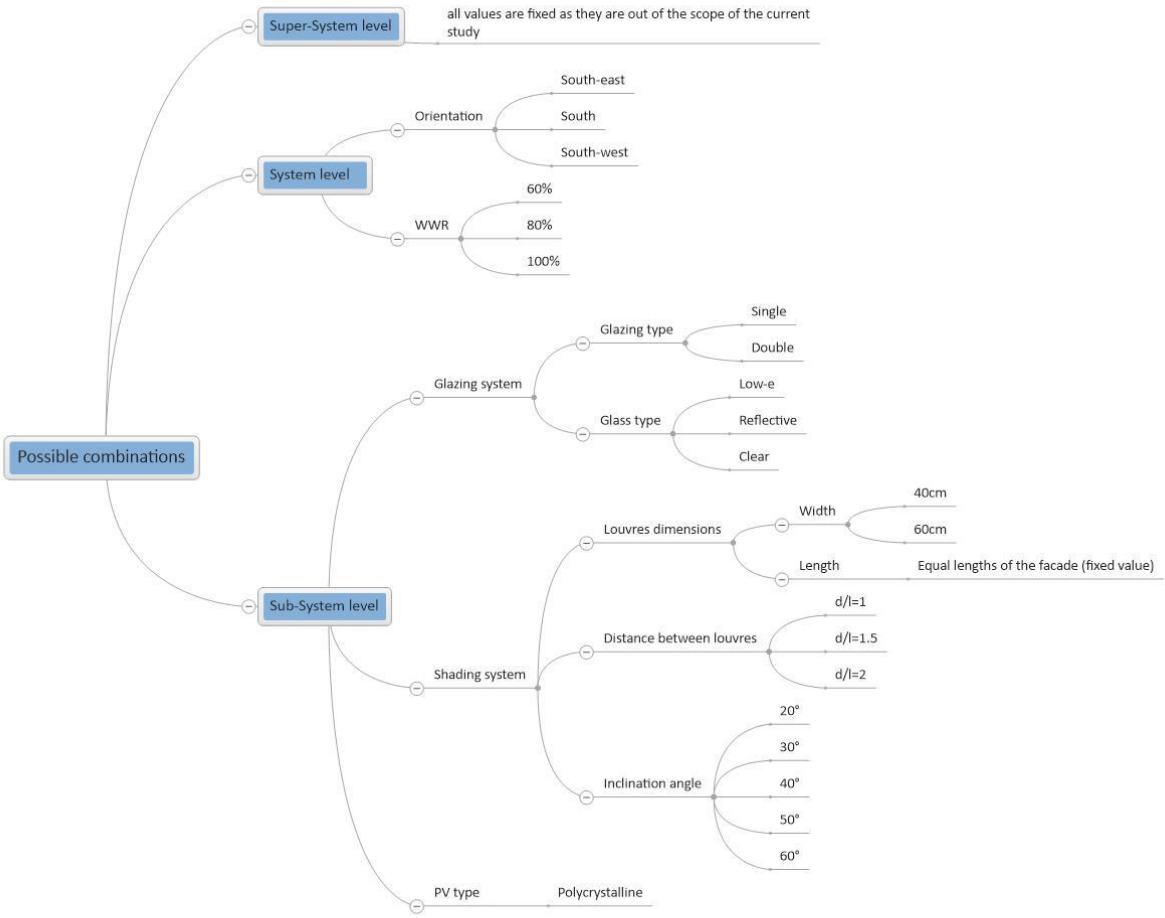


Figure 5.48 All possible combinations of variables

The generic source code is: Orientation-WWR-Depth-d/l ratio-Inclination angle-glazing system-glass type. Table 5.9 shows the source codes that will be used for the modelling simulations in this research.

Table 5.9 Source code of combinations

Variable/parameter	Variations	Source code
Orientation	South, south-east and south-west	S, SE, SW
Window-to-wall ratio (WWR)	100%, 80% and 60%	100, 80, 60
Depth of PVSD	400mm and 600mm	40, 60
d/l ratio	1, 1.5 and 2	1, 15, 2
Angle of inclination of PVSD	20°, 30°, 40°, 50° and 60°	20, 30, 40, 50, 60
Glazing system (HPG)	Single and double glazed	S, D
Glass types	Clear, low-e and reflective	C, L, R

For example, a combination of variables at the south orientation, WWR of 100% with a depth of 400mm of the PVSD, d/l ratio of 1.5, inclined downwards to 30° and double-low-e glazing would result in a coded combination of:

S-100-40-15-30-DL

This is a unique combination that refers to the specific model and all the corresponding results of this unique model (as shown in Figure 5.49).

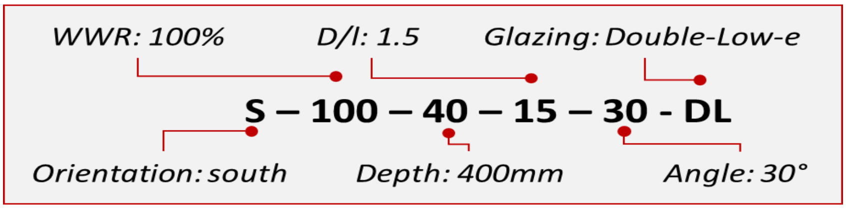


Figure 5.49 Coded combination of the examined variables

5.6 Running the detailed simulations

The simulations are run to calculate the output variables: Solar gain, cooling loads, lighting gain, PV generated electricity and total energy consumption (excluding PV generated electricity). All simulations are organised in *Tasks-IES*[18] so that for each of the models, SunCast solar energy and the shading calculation runs first, followed by Radiance simulation for full year daylight simulation. Both of those result files are then fed back into Apache thermal simulation as a last run to integrate their results into the dynamic thermal simulation. Figure 5.50 shows a snapshot of a queue of models on one of the computers used for this task.

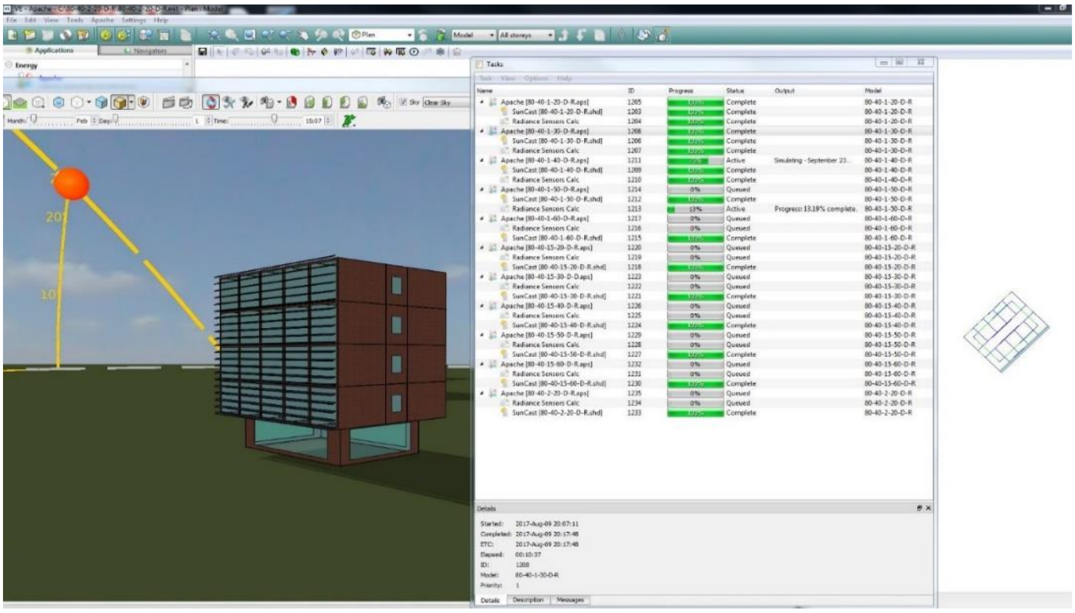
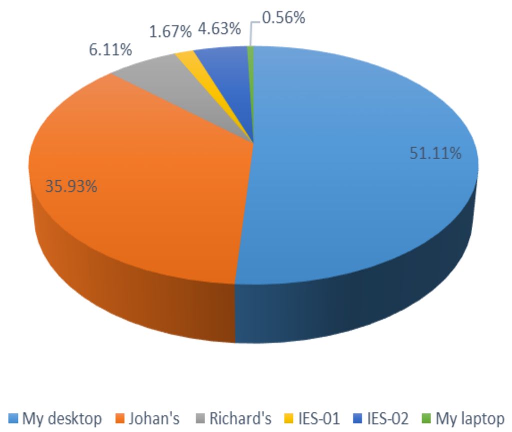


Figure 5.50 Models queuing on Tasks

In order to effectively use the time required to run simulations in parallel, six computers have been assigned for this task (Figure 5.51). For data quality check

[18] Tasks is an IES-VE Parallel Simulations tool which allows users to run multiple simulations concurrently. It provides a single user interface for displaying and managing all of the user's simulations (IES-VE, 2017. Parallel Simulations User Guide. Glasgow, UK: Integrated Environmental Solutions Ltd.)

purposes at this stage, a verification procedure of the simulations on all those machines was followed in order to ensure the accuracy and reliability of the parallel simulations on different machines. To do so, a model was randomly picked for this task and the same simulation settings have been set up on each of those computers. The resultant aps files (results files) were compared against each other. The result of this was satisfactory as a 100% matching of the results was achieved. This method was repeated on two more models in which the same matching of results was positive, meaning that it is feasible and reliable to use these computers to conduct parallel simulations without any discrepancies as a result.



Computer name	Code	Number of Parent simulations*	Percentage of completed simulations	Total number of all simulations
My desktop	Y	276	51.11%	2484
Johan's	J	194	35.93%	1746
Richard's	R	33	6.11%	297
IES-01	1	9	1.67%	81
IES-02	2	25	4.63%	225
My laptop	L	3	0.56%	27
	total:	540	100.00%	4860

* Each parent thermal simulation also runs two sub-simulations; SunCast and Radiance to integrate their results with Apache

Figure 5.51 Summary of simulations

After having the simulation results ready, another data quality check was conducted to ensure that there are no discrepancies in the models. A number of models showed some discrepancies and that resulted in having to diagnose what has been causing them. After the diagnosis step was taken, further steps to correct those discrepancies were followed, for example some models needed to be checked throughout the model set-up, while others needed to be rerun. A sample of the data quality check at this stage can be found in Table 5.10.

Having run all the batches of simulations, results files have then been organised and extracted using VistaPro-IES. The results were then exported to Microsoft Excel™ for the full factorial analysis. Those results were then imported to IBM SPSS™ to conduct the sensitivity analysis.

Table 5.10 Data quality check on simulation for discrepancies

Model	Issues identified	Further action	Result
7 random models	Failed due to either SunCast of illuminance file failure	Redo set-up and rerun	Checked. Done. Resolved
100-40-1-30-S-C	Check Rad/surface properties	May need rerun	Checked. Looks fine.
100-40-1-50-S-C	Looks like mistakenly overwritten by S-L	Either comparing with S-L or re-run	Rerun is done. Resolved
100-40-15-40-S-C	Same as above but with S-R. Either rerun or compare with S-R	Same as above but with S-R	Checked. Looks fine.
100-40-2-30-S-C	Overwritten by 80 by mistake.	Check if aps file hasn't been affected	Checked. Looks fine.
100-60-15-30-S-C	Same as above	Same as above	Checked. Looks fine.
100-40-2-40-S-C	No Rad and Sun found. Might have been deleted by mistake	Check if aps file hasn't been affected	Checked. Looks fine.
100-40-2-60-S-R	It says S-C in the assign construction	Check and compare	Checked. Looks fine.
100-40-15-30-S-C 80-40-15-30-S-C	Number of blades is wrong	Check results if they make sense or rerun	Checked. Looks fine.
60-40-1-40-S-C	Some floors were left hidden	Check if this affects results	Checked. All rooms have been simulated. I need to unhide rooms before extracting data
100-40-15-30-S-L	PV output is wrong	Check number of panels, if wrong then rerun	Reset, rerun
100-60-2-50-S-L	IES stops working when trying to run Vista.	Check and rerun (note that this was run on Richard's computer)	Reset, rerun
100-40-2-60-S-R	Glazing/results is similar to SC.	Reassign construction and rerun	Glazing corrected, rerun
80-40-1-30-S-C	Results are not reasonable because some glazing is standard!	Check and rerun if needed	Glazing corrected, rerun
60-40-1-30-S-C	Some glazing is not correct	Reassign construction and rerun	Corrected, rerun
60-60-15-60-D-R	Glazing/results are similar to SC.	Reassign construction and rerun	Corrected, rerun
60-40-15-30-D-L	Results are not reasonable	Check and rerun if needed	WWR corrected, rerun
60-60-1-20-D-C	Results are not reasonable	Check and rerun if needed	WWR corrected, rerun
80-40-2-60-S-C	Results are not reasonable	Check and rerun if needed	WWR corrected, rerun
100-60-2-40-S-L	Glazing/results are similar to SC.	Check and rerun if needed	Glazing corrected, rerun

5.7 Chapter summary

This chapter described the strategies of data generation adopted in this research and it detailed the process of data generation. It described the modelling and simulation processes for the first stage (proof-of-concept), followed by stage two which is the detailed modelling and simulations. The outcomes of the remote questionnaire survey of professionals that informed the process of model development was also elaborated. In addition to the survey outcome, conclusions from the literature review, related to modelling of a representative base-case model, were drawn and fed into the creation of the model. The simplified models and data quality checks were demonstrated.

The full factorial parametric study of the key parameters selected for evaluation, the modelling and simulation processes and the procedures used to demonstrate the influence of each individual key parameter on the building's thermal and visual performance have also been elaborated in this chapter.

The modelling procedure started by creating the geometry of the model in ModelIT-IES, followed by creating the glazing systems in LBNL Window 7.5. This tool creates reports of the desired input, and contains all the optical and thermal properties. Those reports were then imported to APcd-IES to add them to the construction database of the model. In APcd-IES, other construction and materials have been inputted to the library too. The assignment of the materials and glazing systems are then done in Apache-IES. The model used the Baghdad weather file. This file fed into the thermal simulation, Radiance analysis and SunCast analysis. The glazing systems were created in LBNL Window 7.5 and were also set up in Radiance-IES to account for the optical properties of those systems. Profiles of occupancy, internal gains, HVAC systems, dimming profiles, weekly and daily profiles were set in APPro-IES. The geographical location was set up in APLocate-IES to be used in thermal, solar and radiance analysis. The simulation file was then set up to run SunCast for solar shading calculations and Radiance illuminance calculations. For each unique model, a simulation set up file was imported to Tasks to line up with the simulation queue. Each task contains: thermal simulation, SunCast simulation and Radiance simulation. SunCast simulation generates a shading file and Radiance simulation generates an illuminance file. Both shading and illuminance files were integrated into the thermal simulation run so a full account of illuminance, shading and thermal is taken when generating the final results file.

Having run all the simulations in the queues on all six computers, extraction of the results was conducted via VistaPro to prepare the data for analysis in Microsoft Excel™. Excel was then used to analyse the data and to provide the database for IBM SPSS™ to conduct sensitivity analysis. To summarise the simulation procedure, from the beginning to the end, Figure 5.52 shows the workflow of the modelling, simulation, analysis, the methods and applications used, and the inputs and outputs formats.

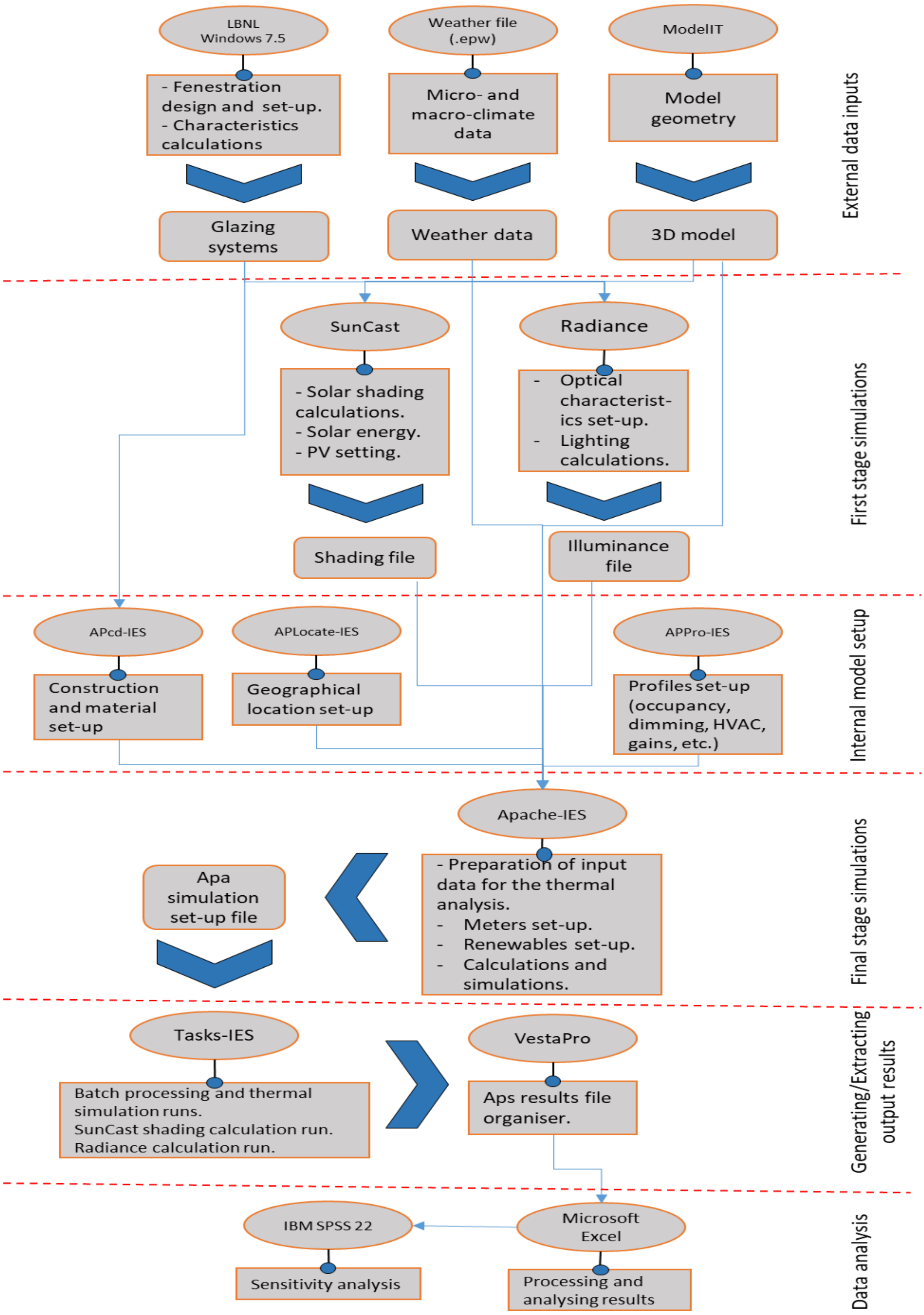
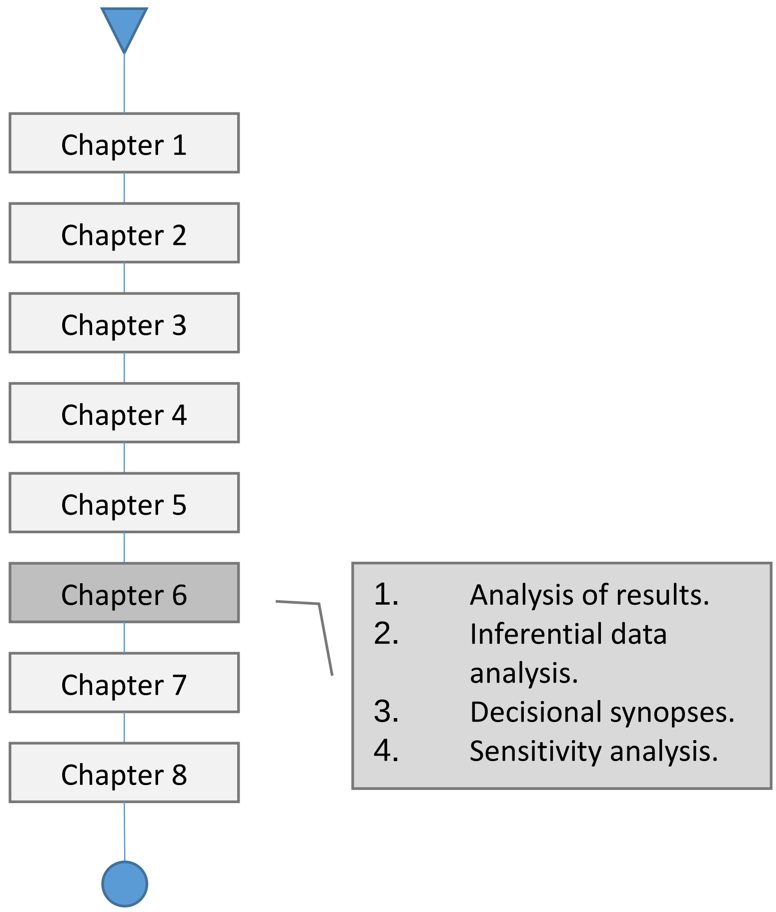


Figure 5.52 Workflow and applications used for modelling, simulation, analysis and analysis

Chapter Six

Analysis



CHAPTER 6. ANALYSIS

6.1 Introduction

This chapter presents the analyses stage/results of this study. The analysis is mainly divided into two stages: a) proof-of-concept results and b) detailed simulation results. In the first stage, the preliminary results of two rounds of simulation are presented as a proof-of-concept to demonstrate the application of such a methodology to a parametric study of IFS technology. A discussion about the preliminary results of the simulation of one parameter is also provided. Once the proof-of-concept is sorted out, the adopted strategy will be rolled out to other combinations of different variables at system and sub-system level. The second part of the analysis in this chapter will include the detailed analysis of all the assessment indicators under investigation and will be conducted in three phases as explained in section 6.4.

6.2 Stage one: Proof-of-concept

Prior to the full-scale study, a proof-of-concept is established and examined in order to demonstrate the feasibility of the methodology developed for this study. The following sections will discuss the details of this stage.

6.2.1 Creating the base-case

The analysis starts by creating a base-case scenario that was simulated, in which one thermal zone was analysed, to provide a benchmark as the worst possible scenario against which improvements could be measured. The base-case has no shading devices applied to the façades. Window-to-wall ratio was chosen to be 80% of WWR as being representative of a highly-glazed façade (Figure 6.1).

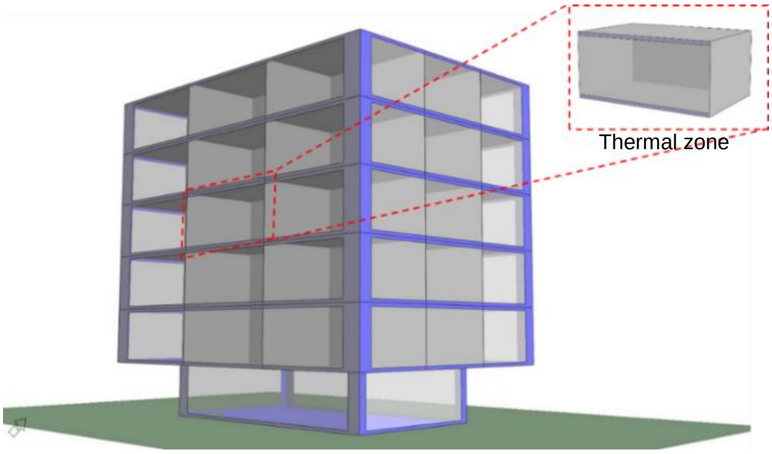


Figure 6.1 Base-case developed for the proof-of-concept stage showing the selected thermal zone for the analysis

6.2.2 Establishment of the scenarios

The systemic approach developed in this study has had some outcomes, one of which has been the way in which the critical literature review has been carried out. As a result, the literature review has concluded that several key parameters are to be assessed in the parametric analysis. These parameters are systematically categorised in three systemic levels, as follows:

- The first is the context parameters as a super-system level, such as climate, site, surroundings, geographical location, etc.
- The second is the building level or the system level of the building type, geometry, orientation, etc.
- The last is the component level, or the sub-system level, where façade configurations can be altered, such as dimensions of shading devices, glazing properties, angle of inclination, etc. (for detailed explanations of parameters at systemic levels please see Table 3.2).

One scenario was then selected and factors from system and sub-system levels are also chosen to carry out the simulations. a single variable was modified to be compared to the base-case while the rest of the parameters are kept fixed. It aims to investigate the consequences of each modification on the solar gain, cooling load and natural daylighting (Figure 6.2).

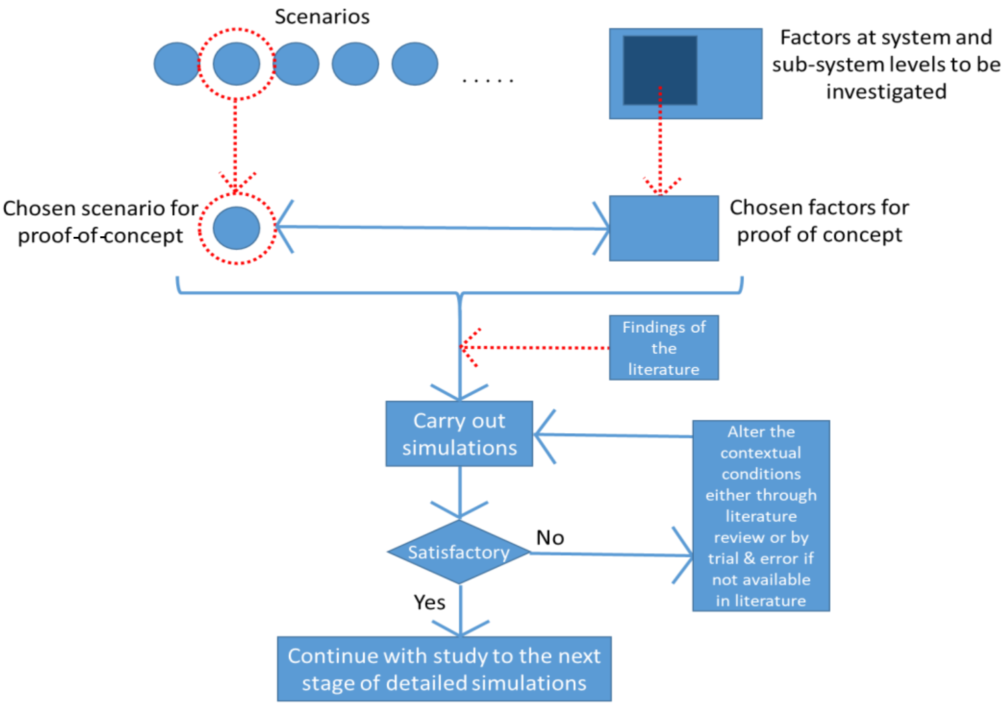


Figure 6.2 Proof-of-concept (please see in conjunction with Figure 6.3)

To inform the recalibration of the input for simulation, findings in the literature, which are related to the chosen factor, feed into the simulation to assess whether sensible results have been achieved or not. If proved to be satisfactory to fulfil the aim and objectives, the investigations will be carried on. Otherwise, alterations to contextual conditions will be carried out, either through the literature review or by trial and error where contextual conditions have not already been tested if findings are not available in the literature. This is repeated until the results help in concluding the study at this stage. If not, the process will be repeated by going back to select another scenario and proceeding through the same flow, as seen in Figure 6.3.

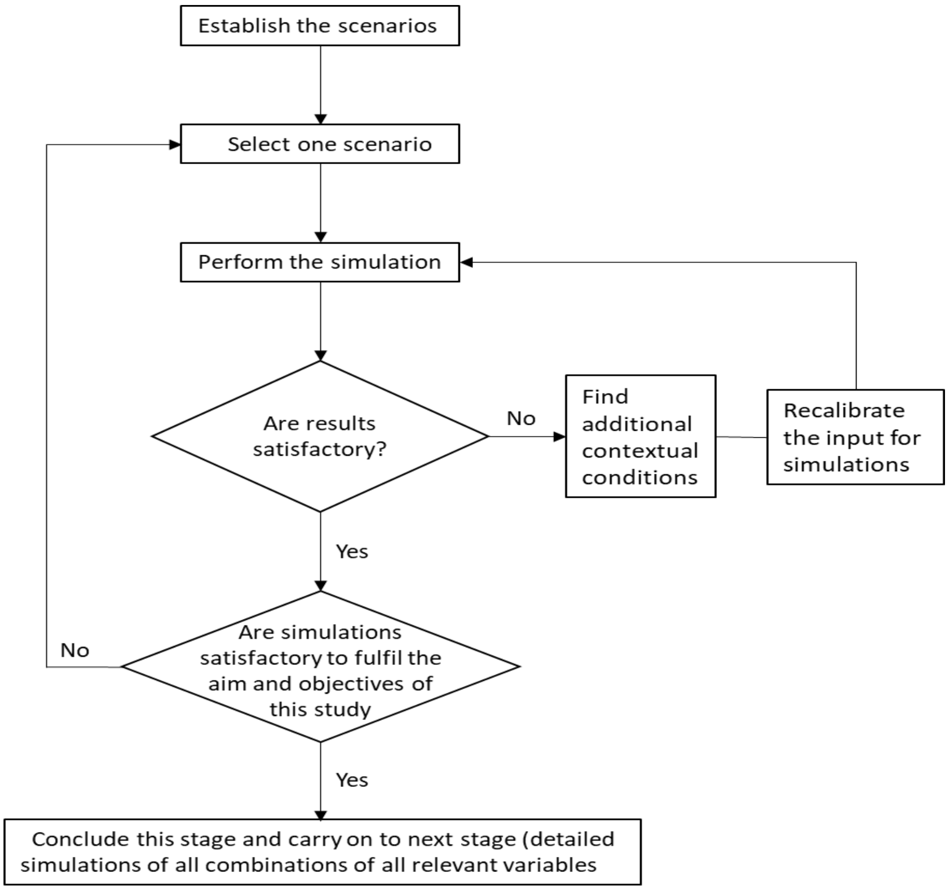


Figure 6.3 Flowchart of the analysis for the proof-of-concept stage

6.2.3 Model settings and simulation

The day selected for the simulation was 15th June, representing the highest average temperature on record for Iraq (CLIMATEMPS, 2015). The alternative scenarios will then be modelled for the simulations where horizontal louvres were applied to the south-facing façade and vertical louvres were applied to the east and west-facing façades. The horizontal inclination angle of the louvres on the south-facing façade were set to 0°, 25° and 60° as suggested by Bahr (2013) while the vertical louvres on both the east and west-facing façades were kept unchanged.

The results were assessed based on the influence of this calibration on solar gain and the monthly cooling plant sensible load. In addition, daylight was also compared.

6.2.4 Analysis of the first round of simulations

For the proof-of-concept stage, the assessed indicators are solar gain and cooling loads, followed by daylight analysis, as in the following sections.

- *Solar gain*

Amongst all four simulated cases [the base-case and the three selected inclinations as suggested by Bahr (2013)], the highest solar gain was observed in the base-case, as expected, where no shading devices were applied. When applying shading devices, a sharp decrease in solar gain was observed between the base-case and the 0° inclination. Then a less significant decrease was observed from 0° inclination onwards. The decrease between 25° and 60° inclination is less than the decrease between 0° and 25° inclination, as shown in Figure 6.4. This observation is not as significant as suggested by Bahr (2013).

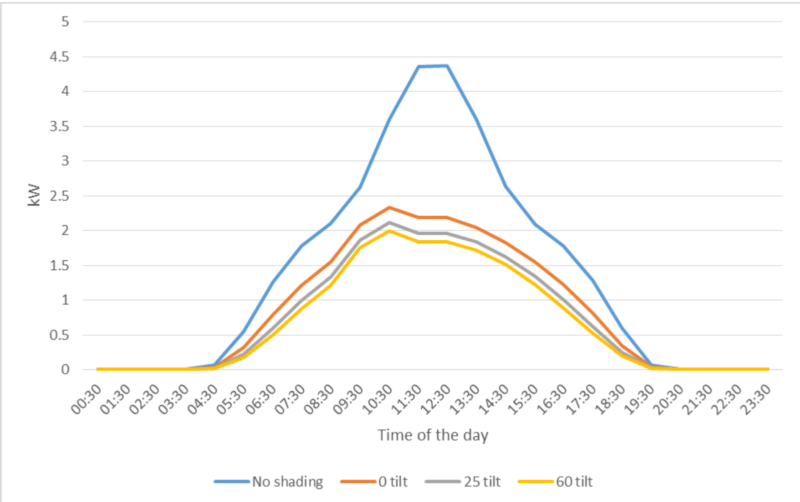


Figure 6.4 Solar gain in office room (tested thermal zone) on 15 June for the four simulated cases

- *Cooling loads*

On the system level (or the building level), the effect of modifying the inclination angle of horizontal shading devices on the south-facing façade can also be confirmed by looking at the results of the yearly cooling plant sensible load; as expected, a significantly high percentage of this load, was observed in the base-case. A major 50% reduction in cooling loads was observed in the case of shading device use, with 0° inclination against the base-case. However, the reduction in cooling loads was not significant when changing the inclination angle to 25° and 60° where cooling loads levelled off (Figure 6.5).

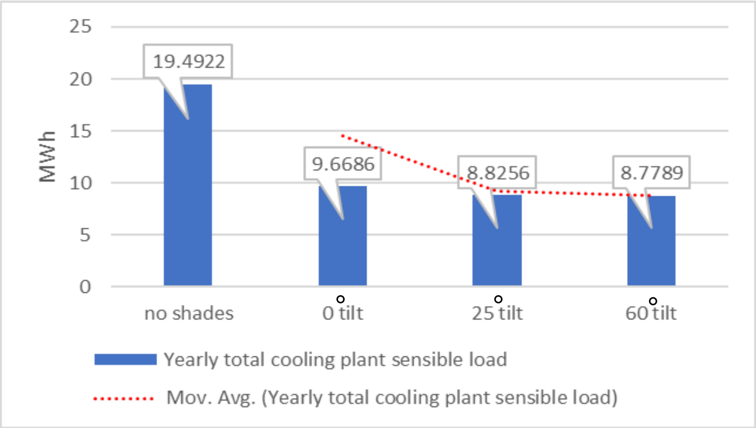


Figure 6.5 Cooling plant sensible load yearly totals

There is a significant difference in the percentage of the monthly cooling loads compared to the base-case. However tilting the angle to 25° and 60° did not have as significant an effect as suggested by Bahr (2013). A shift in the peak load was observed when the peak load changes from early August back to early June once the shading devices on the south-facing façade were applied. Altering the inclination angle clearly affected the cooling loads but this effect varies seasonally. During moderate seasons, a significant reduction was observed in all cases in comparison with the base-case. While in the cold season, 0° inclination did not bring the cooling loads down to zero, compared to other inclination angles, i.e. 25° and 60°. During the hot season (April-October), the load was slightly different, even though the inclination angle was kept unchanged or inclined to 25° and 60° (Figure 6.6).

This effect is due to the low sun angle, during moderate and cold seasons, on the south façade, which results in additional solar gain. This gain will subsequently contribute to cooling loads. To ensure that the results are meaningful and the correlation is verified, the next step will be to add more variations of inclination angle, as suggested by other literature, in addition to what was proposed by Bahr (2013).

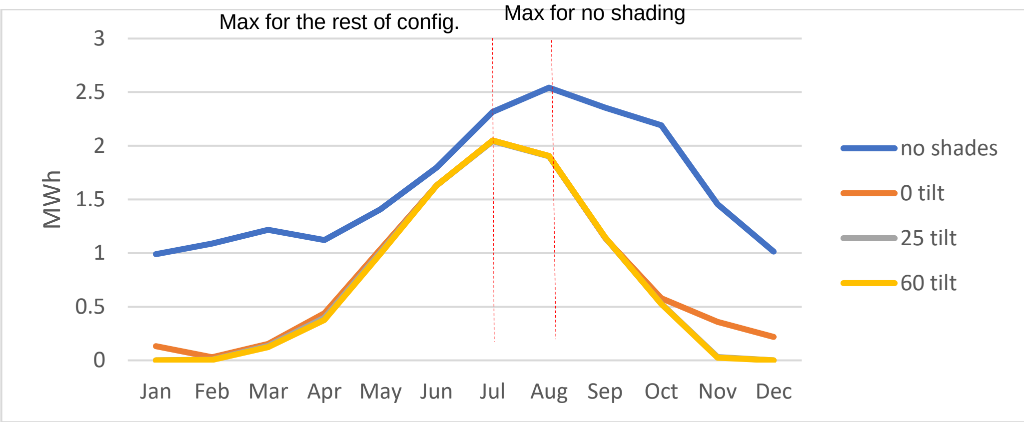


Figure 6.6 Monthly cooling load for the cases: no shading, 0°, 25°, and 60° inclination angles

6.2.5 Analysis of second round of simulations

The second run of analysis was developed based on the findings of literature. Sun et al. (2012) suggest that the optimum inclination angles for different designs vary from 30° to 50°. Since the simulated angles were 0°, 25° and 60 °, it is reasonable to provide a variation that covers the possible values of the inclination angles spectrum. Therefore, the angles that will be added to the simulations are: 15°, 45° and 80°.

- *Solar gain*

Amongst the simulated cases in the second round of simulations, a less significant change in the trend of the decrease of solar gain was observed compared with the first round of simulation. The results in Figure 6.7 show that there is a clear pattern as a result of the change of inclination angle. Therefore, it is evident that the variation in inclination angle can have a remarkable impact on solar gain and hence this variable should be included in the detailed analysis but the range of change should be further analysed.

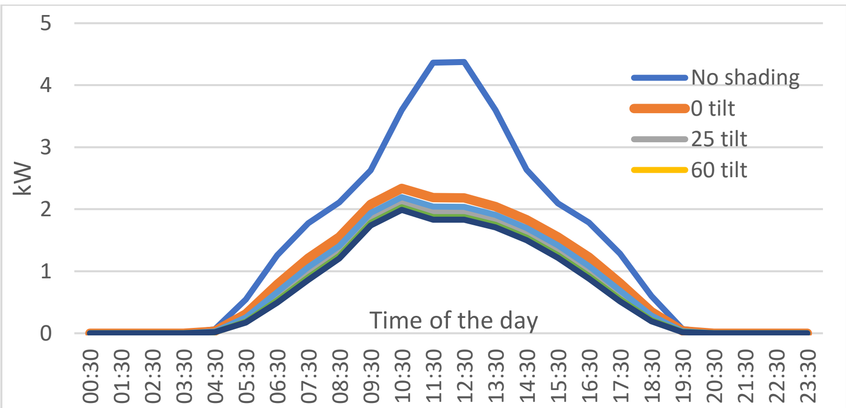


Figure 6.7 Solar gain for all simulated cases

- *Cooling loads*

Figure 6.8 shows that there is hardly any difference in the cooling load between the additional simulated angles. Moreover, when combining all the results, there is no significant change between all alterations (15°, 25°, 45°, 60° and 80°) compared to the 0° inclination. In addition, these alterations have considerably reduced the cooling loads during the moderate season and have brought the load down to zero during the cold season in comparison to the 0° inclination.

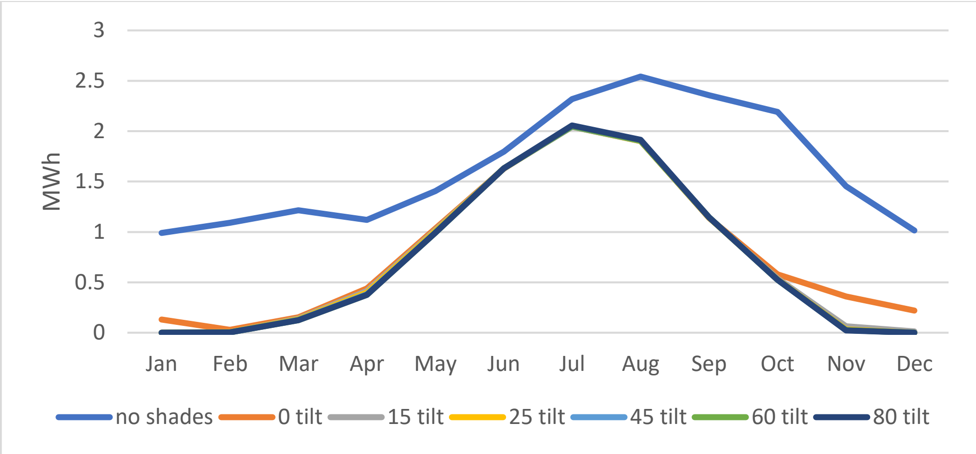


Figure 6.8 Monthly total cooling plant sensible loads for all simulated cases

The results from the first round of simulations can also be substantiated when combined with the results of the second round of simulations. The same pattern was observed in the yearly summed cooling plant sensible load for all simulated cases (Figure 6.9). However, a slight increase in the load was observed in the case of 80° inclination which represents a small fluctuation in the trend. This suggests that the impact of change of the inclination angle on cooling loads is negligible.

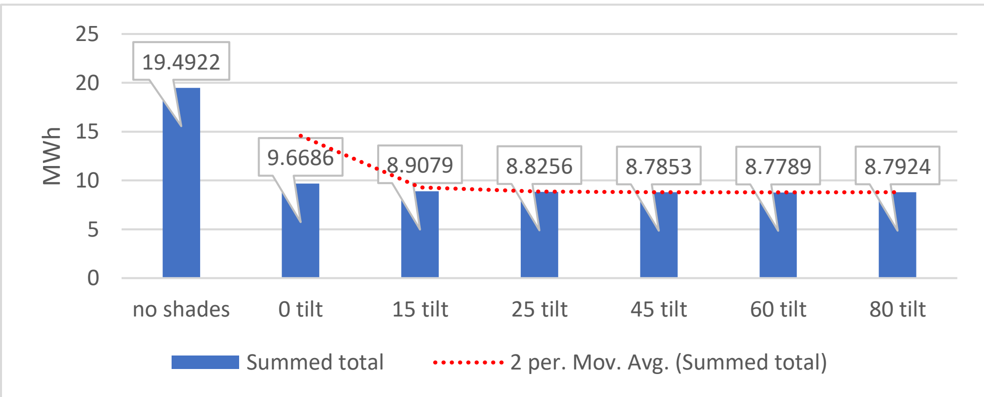


Figure 6.9 Annual summed cooling plant sensible load for all simulated cases

6.2.6 Daylighting analysis

For lighting analysis, Flucs DL, one of the IES-VE modules, was used. Flucs DL uses the radiosity method[19] to calculate point by point illuminance and daylight factors in the user room. Seven cases were simulated and analysed (Figure 6.10). The average illuminance of the user room in question was calculated for all cases for the same designated day, 15th June at 12:00pm. The results show a substantial decrease once shading devices were applied.

Overall, on the designated day, there was a steady decrease in the average daylight in the user room. From the case where the angle was set to 15° up to 60°, a significant reduction of the available daylight was observed. However, in the base-case, the average daylight was found to be 1350lux which meets the requirements of daylighting as it is above the minimum average illuminance for office spaces (500lux) according to the ASHRAE standard (reported in O'Connor et al. (2013)). This decrease can be explained as a result of change of the inclination angle where the space between two louvres is reduced, which reduces the allowance of daylight passing through to the interior user space.

The case where the angle is 80° can be considered as the worst case regarding daylight availability to the user space as it showed a complete lack of daylighting. In this case, the room will require a significant amount of artificial lighting. This additional lighting will result in additional energy consumption not only because of the energy required for the artificial lighting itself but also, depending on the type and specification of the lighting system, it adds internal heat gain to the user space. This heat gain presents an additional load that needs to be removed by the HVAC systems and subsequently another source of load added to the one that is already caused by external heat gain. Figure 6.10 shows the average daylight available in the simulated user room on 15th June at 12:00 pm.

[19] In 3D computer graphics, radiosity is an application of the finite element method for solving the rendering equation for scenes with surfaces that reflect light diffusely.

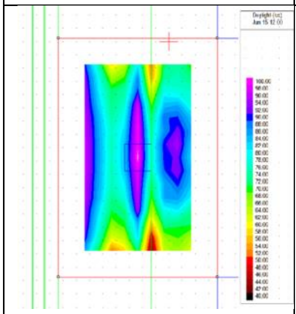
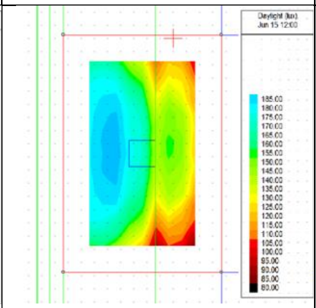
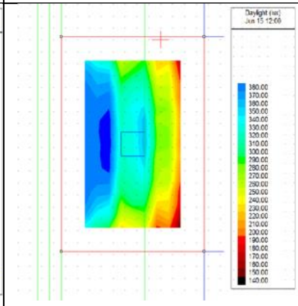
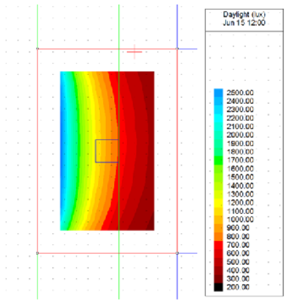
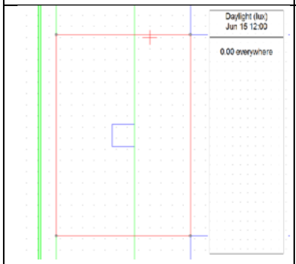
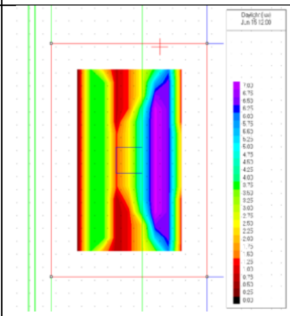
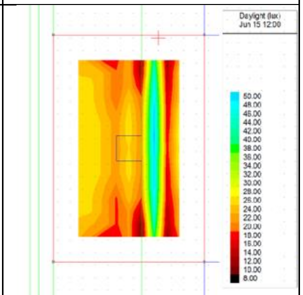
25° tilted	15° tilted	0° tilted	No shading
			
80° tilted	60° tilted	45° tilted	
			

Figure 6.10 daylight analysis of user room

To summarise, it is observed that changing the inclination angle results in significant reduction of daylight availability once shading devices are applied. Keeping the angle unchanged (0°) will result in a reduction of about 81% compared with the base-case. When the angle is changed to 15°, the reduction in daylight availability decreases by a further 50% against 0°, then a steady decrease in the trend is observed until the daylight becomes completely unavailable when the inclination angle is 80° (Figure 6.11).

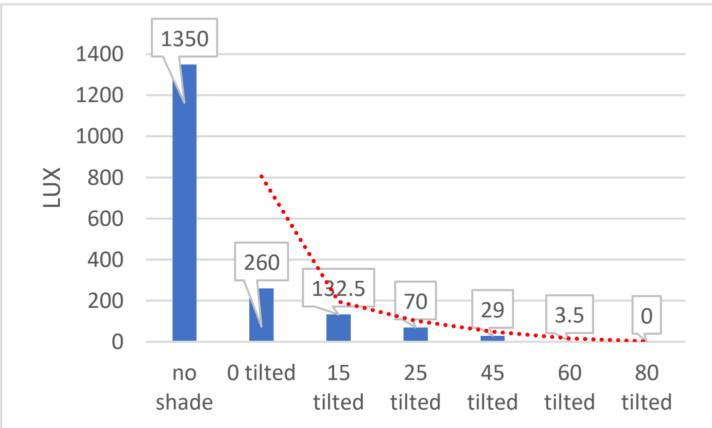


Figure 6.11 average daylight illuminance (in LUX) for the simulated cases

These results suggest that manipulating the angle only would negatively affect the performance. Therefore, other factors in the sub-system and system levels need to be taken into account when investigations are carried out to be able to optimise the model.

6.2.7 Optimisation

When optimised solutions are aimed for, trade-offs need to be considered, taking into consideration the integration of the daylight results with the energy analysis results. For example, the case with 80° tilted angle showed the best results regarding energy performance; however, this angle cannot be considered as it does not provide any daylighting. The case of 0° inclination would be preferable regarding the significant improvement of solar gain and cooling load while allowing a reasonable amount of daylight. In this research, the trade-offs are not only between daylight and solar gain but also with a third function, which is PV electricity generation when integrated with shading devices (PVSD). The PV electricity generation will also influence the overall energy use of the building (Figure 6.12). Once the proof-of-concept is demonstrated and tested, the next stage of this research is to develop a prototype of prevailing office buildings in Iraq then start building up full-scale cases with all internal gains, loads, patterns of use, etc.

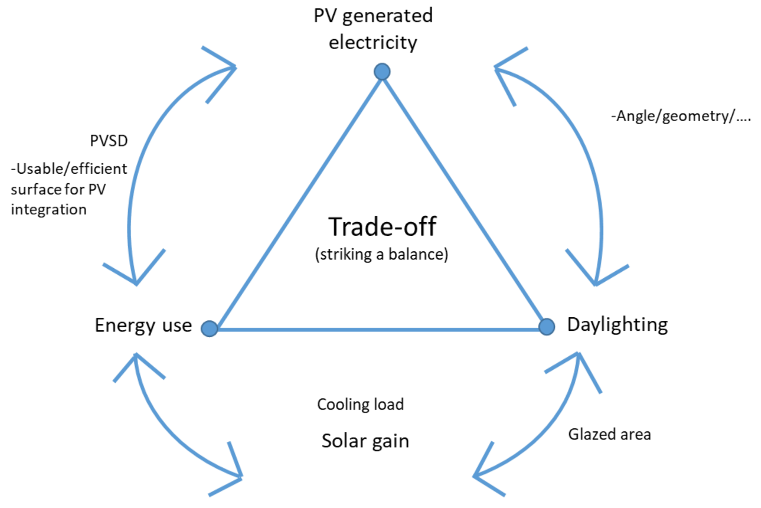


Figure 6.12 Trade-offs between different performance indicators to achieve optimised solutions for IFS

6.2.8 Concluding and summarising the proof-of-concept stage

A proof-of-concept was presented where the analysis begins by establishing the scenarios to be simulated. Two rounds of simulations were carried out considering a single variable to be modified and compared to the base-case while the rest of the parameters were kept constant. The inclination angle of horizontal louvres was the chosen parameter due to its possible significant impact as suggested by the literature. The input used from the literature was alterations of 0°, 15°, 25°, 45°, 60° and 80°. The consequences of each modification were evaluated based on the solar gain, cooling load and natural daylighting as the criteria for assessment. Some of the findings were reasonable, as suggested by the literature, whereas others were not.

It was found that the inclination angle has a significant impact on solar gain and subsequently influences cooling loads. However, its impact on cooling loads is much less significant. This suggests that other parameters might have more impact on cooling loads. Furthermore, this effect is due to the low sun angle during moderate and cold seasons on the south façade. Therefore, further investigations will be required to include all the other influential parameters, such as lighting gain in the interior spaces.

The simulations also included daylight analysis to account for the control of daylighting as one of the functions of the shading devices. The alteration of the inclination angle was found to have a considerable impact on reducing the availability of daylighting which may cause an increase in the energy use. This increase is due to additional artificial lighting and additional cooling loads that the artificial lighting will create.

The proof-of-concept analysis has helped to exclude some variations which showed either negative impact on at least one aspect or similar impact. For example, the range of the variation of the angle of inclination can be reduced as some angles, such as 80°, has negative impact on daylighting; or 15° and 45° which both have had nearly the same impact and hence these angles can be excluded from the further analysis. However, the latter angles can be further investigated in combination with other parameters, such as the distance between each two louvres or the distance of the louvres from the main façade.

The day selected for simulation was the day when the maximum average solar radiation was recorded. The impact of these variables can vary greatly and hence no specific time or hour can represent the annual pattern. Hence the assessment indicators will be evaluated based on annual loads and the average of each of them in order to account for all 8760 hours within a year.

The proof-of-concept showed that the approach and expected outcomes were in line with what this research has set out to achieve in its aim and objectives and hence it is possible to carry on with full-scale investigations; however, when accounting for simultaneous change in different parameters, other measures should be included. Furthermore, to be able to differentiate between the impact of change of each of the input parameters on a certain output, advanced analysis will also be needed.

A combination matrix is therefore developed, as explained in CHAPTER 55.4 and 5.5, to include all possible façade configurations and the simulations for each scenario will be carried out. Results will provide optimised models and guidelines on the practical level with detailed analysis and expected performance/saving.

In the next section, the detailed analysis will be presented and discussed.

6.3 Stage two: Detailed analysis of full parametric combinations of input variables

The detailed data analysis of this study is formed of three phases (as shown in Figure 6.13), starting with inferential data analysis as phase one, followed by decisional synopses as phase two. Those two phases are carried out using Microsoft Excel. The third phase is sensitivity analysis (SA), which was conducted in IBM SPSS v22. Classification of all the variables under investigation is carried out using the systemic approach developed in this study.

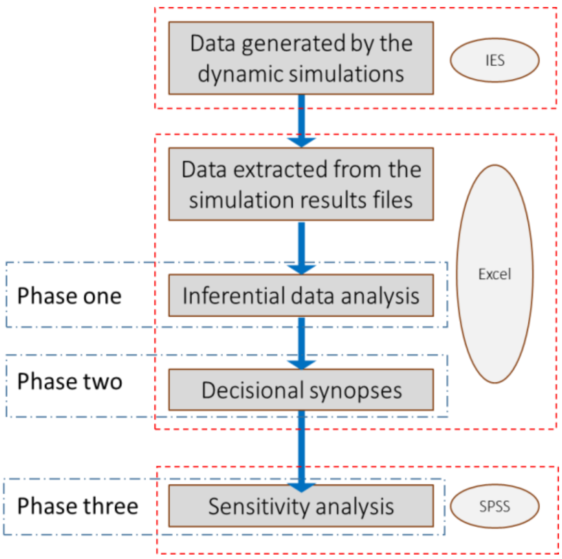


Figure 6.13 Analysis stages of this study

Variables at system level are clustered separately to form the main groups: Orientation and WWR. The analysis starts with orientation as the higher-level classification in the systemic structure of this study and breaks the groups down into elements and sub-elements.

Then sub-system variables are included and clustered into sub-groups within the system level main groups, i.e. depth of panels, d/l ratio, angle of inclination and glazing systems. Figure 6.14 shows the inputs at different systemic levels and the assessment indicators for both energy and daylighting aspects, with daylight assessment indicators as outputs.

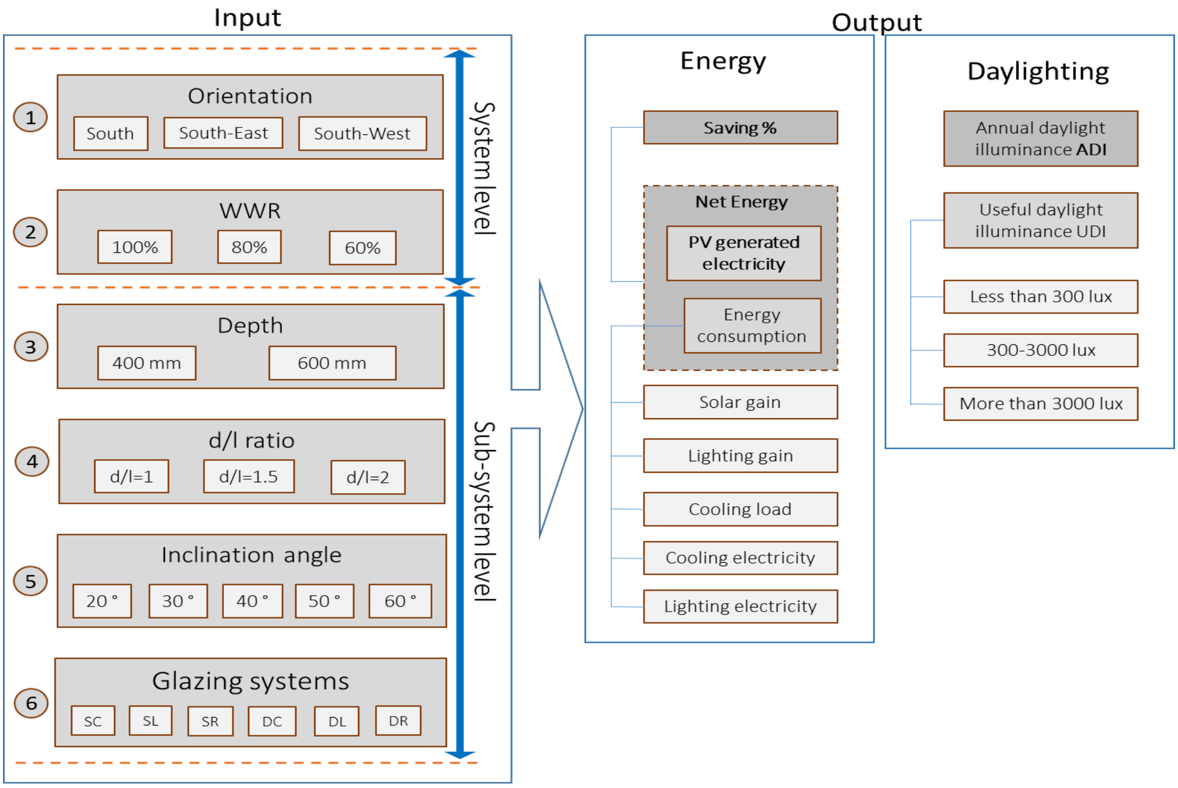


Figure 6.14 Inferential data analysis process for energy consumption

This systemic cluster is used in the analysis phases because the level of control is different from super-system, system and sub-system variables. They are different in terms of ease of manipulation and complexity when they are changed. For example, the orientation of a building cannot be easily changed, while the WWR of the façade can be adjusted/changed in the design process. Furthermore, it is much easier to change the external shading devices' depth from 400mm to 600mm. Therefore, if anything needs to be changed at different levels, the level of integration, and the level of ease of those changes are different in real settings. Hence, the systemic approach can be very useful in classifying different parameters and different variables in different categories.

To understand the mutual performance between the variables, and the interaction between the dependent and independent variables, results from all **1620** dynamic simulation models will be discussed not only based on their final energy consumption figures but also with reference to the contributing factors that influence those figures.

6.4 Phases of the detailed analysis

Analysis of the generated data is conducted in a three-phased analysis. Phase one is the inferential data analysis, which is conducted to help determine if there is a relationship between an intervention and an outcome. Systematically examining the data, with the purpose of highlighting useful information, will lead to a detailed examination of the impact of the interventions and communicating the results. The output variables which will be presented in the analysis are those that are concerned with energy and daylighting performance. those are: energy consumption, solar gain, lighting gain, cooling loads, PV-generated electricity, UDI and ADI

In phase two, decisional synopses will be presented and analysed to provide a practical design decision tool in the form of ranking tables of results for each dependent variable. The highest ten scenarios in each table are highlighted so that the user of the tables will be able to compare and make an informed decision about the optimum scenarios within their own targets.

Phase three of the analysis will include in-depth SA, which will be conducted to examine the models' accuracy regarding all dependent variables and then to quantify the influence of each independent variable on the outcomes and to show the effect of the changes of each variable on the final outcomes. This procedure is deemed necessary to account for both model validation and verification of the results.

6.5 Phase one: inferential data analysis

This phase will demonstrate both energy and daylight in the form of graphs. These graphs are presented as groups that have been established systematically, following the systemic approach and systemic levelling developed in this research. Section 6.5.1 will first discuss the results of overall energy consumption followed by solar gain, cooling loads and lighting gain to be able to analyse the results. Electricity used for lighting, cooling and PV-generated electricity will also be discussed. Total energy savings, as a result of including PV-generated electricity within the consumption, are also presented as net energy figures. Then daylight performance analysis will follow the energy analysis. The base-case scenario results for each orientation are used as the worst-case scenario that provides a benchmark for comparison purposes (all base-case results are presented in Appendix 12).

6.5.1 Energy analysis

The assessed indicators that will be presented in this section are as follows: solar gain, cooling load, lighting gain, electricity consumption and electricity generation by the photovoltaics (PV). These indicators will be evaluated so that a full picture can be established and an enhanced understanding of how the building behaves, thermal wise, can be achieved. The following sections will help elaborate on the evaluation of these indicators.

- *Energy consumption*

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for energy consumption analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.15 shows the annual energy consumption[20] of those combinations. The dotted red line on each of the graphs represents the base-case (BC) scenario energy consumption that is 195.6702 MWh.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (energy consumption) for different glazing systems and with different inclination angles, as presented in Figure 6.15, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally

[20] In this study, energy consumption is related to electricity as the only form of fuel used in the buildings under investigation.

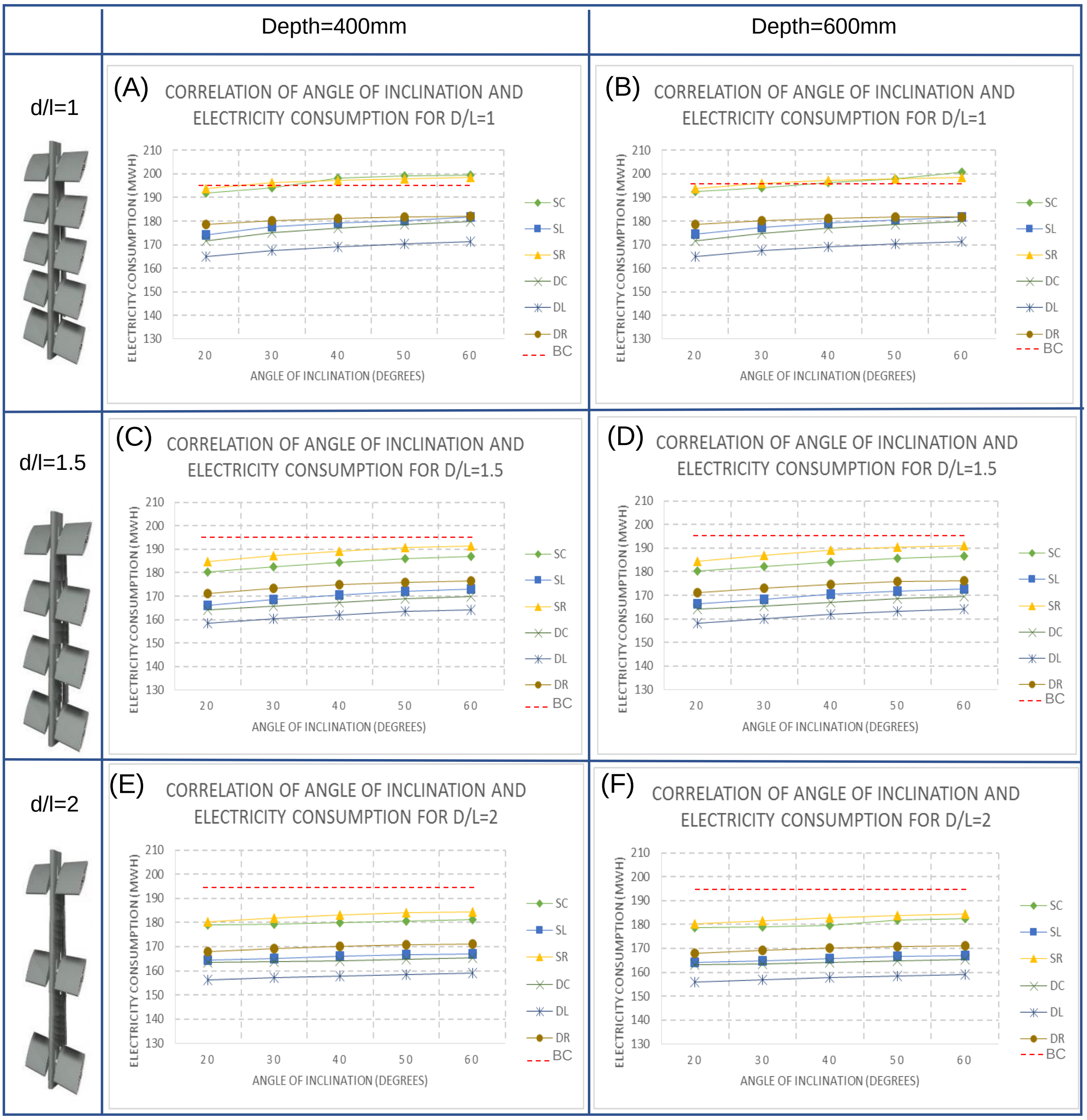
(for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

Clearly most of the interventions of IFS configurations on the south-facing façade have helped improve the energy consumption of the building. SC and SR configurations at d/l=1 with inclination angles of 20° and 30° have shown a slight improvement whereas, 40°, 50° and 60° with those glazing systems have increased consumption compared to the BC, which was supposed to be the worst-case scenario by default Figure 6.15, A and B). The improvement begins at as small as 1% resulting in a total of 194.1261 MWh energy consumption for scenarios with both SR and SC glazing systems, at 30° and 20° inclination for both 400mm and 600mm depths. The improvement then increases as the savings go up to 16% with the final figure of 165.07 MWh for the combination of DL glazing, at 20° angle of inclination with 400mm depth of PVSD. While both cases (SC and SR) showed an increase in energy consumption, this was slightly higher for SC compared to SR.

This means that both glazing types have some negative impact due to increased solar gain which adds to the cooling load for both cases. What makes SR a little more energy efficient compared to SC, is that although SR adds to the need for artificial lighting (which in return adds to the electricity consumption), the higher solar gain in SC (compared to SR) adding to cooling load , seems to outweigh the extra load for artificial lighting in which is higher in SR than in SC glazing type.

Configurations on the south-east and south-west facades seems to show a different trend altogether. In both orientations, all configurations have helped improve the energy consumption of the building (Appendix 8 shows all the results of combinations for both south-east and south-west orientations to allow for comparisons with south). Had the only intended outcome to improve been the energy consumption in this study, it could have been concluded that south-east and south-west orientations in average are better than the south orientation. However, in a more comprehensive approach, as intended in this study, where other output variables (i.e. daylighting and PV generated electricity) are also taken into account and an improvement in the overall performance of the building as a result of application IFSs is aimed at, this conclusion looks a little immature. It is of paramount importance to bear in mind that this study has a multiple point output which also includes – in addition to energy consumption – energy production and daylighting provision.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.15 Energy consumption figures

A noticeable pattern can be observed, looking at glazing systems' performance changes between different d/l ratios. For example, when d/l=1 (Figure 6.15, A and B), SC and SR perform almost similarly, ranging between 190.5 and 198.5 MWh and with the least improvements. The rest of the types however vary, ranging between around 165 MWh and 185 MWh. The gap in performance between the two abovementioned glazing systems (SC and SR) and the rest of the systems becomes less significant (Figure 6.15, A to F) due to the change in d/l ratio. In other words, when more daylighting is admitted into the spaces, the effect on the dimming system decreases, hence the optical properties of the glazing systems becomes less influential.

It can be concluded that energy consumption is a function of d/l ratio, meaning that an increase in this ratio will improve the energy consumption.

Depth analysis:

A similar pattern of performance of the glazing types can be spotted at both depths (400mm and 600mm) for all the scenarios. When d/l=1 (Figure 6.15, A and B), for instance, a nearly similar result can be observed between combinations with SC and SR, regardless of the angle or depth. Energy consumption of glazing types can be ranked at both depths from the best to the worst across different combinations as follows: DL, DC, SL, and DR, with SC and SR being the worst by far. This suggests that glazing systems with improved thermal properties, such as DL, have a noticeable positive impact on the energy consumption, whereas for the glazing systems where optical properties are improved – e.g. SR – a negative effect on energy consumption is observed.

Furthermore, a preference of double glazing can be observed compared to single glazing. This happens because in double glazing the gap between the two glass panes plays a significant role in the reduction of solar heat gain especially in combinations where coated low-e glass is used. The coat cuts down the solar gain and hence reduces the cooling load which eventually decreases energy consumption.

On the other hand, as the distance between blades (d/l) increases from 1 to 1.5 and then to 2 (Figure 6.15, C to F), further reduction in energy consumption can be observed, bringing the variation of combinations with different glazing systems to a range between 184MWh and 156 MWh (which is equivalent to 15% reduction). This is because increasing the distance (from d/l=1 to d/l=1.5 and 2), will allow for more solar gain, but at the same time, it reduces the need for artificial lighting which will then result in a significant reduction in both cooling loads and lighting gain, hence considerable reduction in energy consumption.

Overall cross-sectional analysis:

Overall, different inclination angles have different effects on the annual energy performance. A nearly steady increase can be observed as the inclination angle of the PVSDs is increased from 20°. Although tilting the PVSDs downward reduces the solar gain, it affects the dimming of the internal artificial lights which in turn results in additional internal heat gain. This has a dual negative effect on energy consumption, meaning that the additional lighting gain – in form of heat added to the cooling loads – and the electricity needed to operate the artificial lighting will both add to the energy consumption much more than what solar gain would have added. This will be discussed in detail in section 6.5.2. In all cases (Figure 6.15, A to F), the angle of inclination of 20° seems to be the optimum combination but this is only valid when considering the energy performance on its own, regardless of other output variables, i.e. daylighting and PV-generated electricity, which will be discussed in detail in the following sections.

The pattern of improving energy consumption due to tilting down the inclination angle and increasing d/l ratio of combinations with SL, DC, DR, and DL is similar across the board. However, this does not mean that the similarity is rooted in the same cause or achieved through the same route, meaning that, for example, if combinations with DC and DR are to be compared, DC glazing introduces better u-value than DR. However, the compromise is the reduction of daylight due to lower T_{vis} of DR. This introduces a more pressing need for artificial lighting which emits more lighting into the spaces resulting in higher lighting gains and also adds up to electricity required to operate those artificial lightings, both of which eventually contribute to additional energy consumption. So while cooling load is reduced due to better u-value of glazing, there will still be a need for more artificial lighting. The next section will present an in-depth analysis of… to help understand, in more details, how the building performs in response to its context.

- *Solar gain*

A main north south orientation building model representing typical office buildings in Iraq, with 100% WWR, was used for solar gain analysis. IFS configurations are set up on the south-facing façade of the model. For two depths of 400mm and 600mm, inclination angle of the blades (PVSDs) varied from 20° to 60° with 10°

intervals. These settings were probed for d/l ratios of 1, 1.5 and 2. The configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.16 shows the annual solar gain of those combinations (on the left y-axis). The dotted red line on each of the graphs represents the base-case (BC) scenario (on the right y-axis). Solar gain results of BC is 285.4 MWh.

based on the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (solar gain) for the six above-mentioned glazing systems and with the range of inclination angles, as presented in Figure 6.16 A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

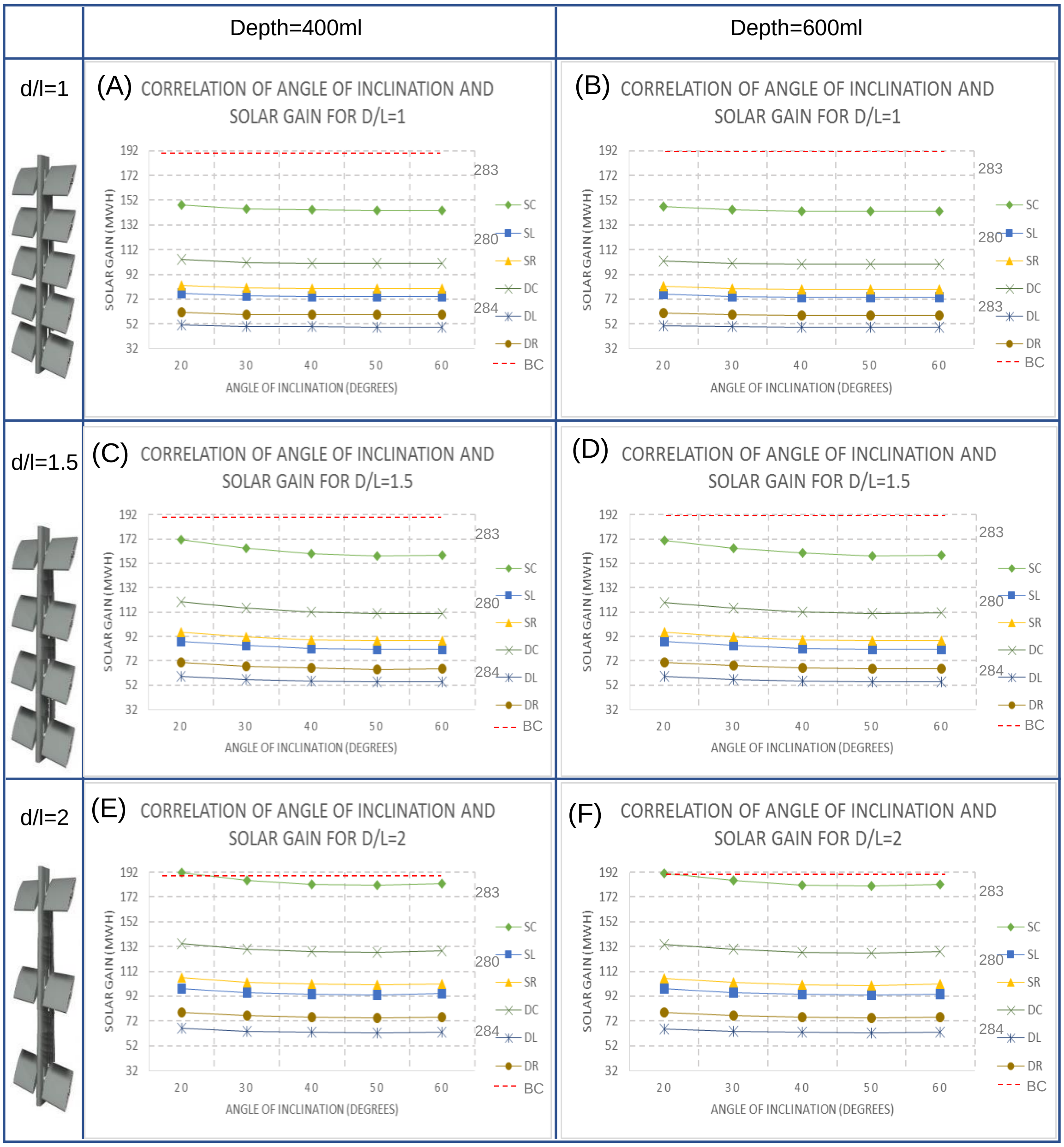
d/l analysis:

In all interventions, significant improvements on solar gain control are observed as seen in Figure 6.16 at both depths (400mm and 600mm). At d/l=1, the improvements start from a reduction in solar gain of 82.7% (49.6 MWh) for scenarios with DL glazing and 60° inclination angle with 400mm depth of PVSD to 48% (148.396 MWh) for scenarios with SC glazing and 20° angle of inclination with the same depth. This range of improvement in solar gain control is then declined when d/l=1.5. The range varies from 80% (54.62 MWh) for scenarios with DL glazing and 50° inclination angle with 400mm depth of PVSD to 40% (171.1995 MWh) for scenarios with SC glazing and 20° inclination angle within the same depth. The range of improvements is further reduced in scenarios with d/l=2, resulting in 78% (62.5427 MWh) for scenarios with DL glazing and 50° inclination angle within the same depth of 400mm to 32.9% (191.4266 MWh) for combinations with SC and 20° inclination angle within the same depth.

It is therefore evident that the range of variation of d/l ratio in all scenarios has a considerable impact on the solar gain pattern of the six glazing systems examined.

The effect of change of angle of inclination becomes more evident when it comes to various d/l ratios. For example, the optimum angle seems to be 60° for all glazing systems where d/l=1, whereas it is 50° for d/l=1.5 and 40° for d/l=2. This is because the space between PVSDs will be reduced as the blades/panels are closing downwards, allowing less solar beam to penetrate the indoor spaces.

It can be concluded that solar gain is a function of d/l ratio, meaning that an increase in this ratio will result in an increase in solar gain.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.16 Solar gain figures

Depth analysis:

A similar pattern in solar gain results of the glazing types can be spotted at both depths (400mm and 600mm) for all the scenarios. When d/l=1 (Figure 6.16, A and B), for instance, a nearly similar result can be observed between combinations with SC, SL, SR, DC, DL and DR, regardless of the angle or depth.

Solar gain of glazing systems can be ranked from the best to the worst across different combinations as follows: DL, DR, SL, SR, DC, and SC being the worst by far.

While both clear glass (SC and DC) showed the least improved glazing systems in terms of solar gain reduction, SL and SR showed better improvement than both clear glass combinations (SC and DC). What makes SL a little more energy efficient compared to SR, is that SR has higher SHGC (0.41) compared to SL (0.39). The best performing glazing seem to be double glazing (both DL and DR). This is because of their even more improved SHGC (0.32 for DR and 0.28 for DL).

Overall cross-sectional analysis:

In all cases, DL glazing scores the best in terms of the reduction of solar gain, outperforming DR, SL, and SR, whereas the least improvements are observed in scenarios with DC and SC glazing respectively. These results are regardless of the depth of PVSDs or d/l ratio. The main reason behind this is the improved thermal characteristics of the DL glazing system that seems to have the most dominant impact on controlling solar gain, proving successful applications of HPG over the other types of glazing.

It can be concluded that solar gain is a function of the d/l ratio which means that a reduction in this ratio will improve the solar gain admittance.

Furthermore, solar gain needs to be considered alongside with other influential outputs, such as cooling load and lighting gain. This can be explained with the help of the dependency diagram of the factors (please see section xx), solar gain will add up to cooling loads and subsequently energy consumption. On the other hand, glazing systems with improved thermal properties will help reduce solar gain while reducing daylight and those with improved optical properties will allow more daylight but more solar gain. The decision is then to weigh the contribution of solar gain to energy consumption against lighting gain contribution to energy consumption. For example, if combinations with DC and DR are to be compared, DR glazing introduces better SHGC than DC. However, the compromise is the reduction of daylight due to lower T_{vis} of DR. This introduces a more pressing need for artificial lighting which emits more lighting gain into the spaces which adds up to electricity required to operate those artificial lightings, both of which eventually contribute to additional energy consumption. So while cooling load is reduced due to reduced solar gain, there will still be a need for more artificial lighting.

the next section will shed the light on how lighting gain is changed due to various combinations of parameters of IFS.

- *Lighting gain*

Lighting gain is the sum of the heat emitted into the room by the artificial lighting. As explained in section 4.14, the factors' dependencies show that this form of heat gain contributes to cooling loads, which in return contributes to energy consumption. In addition, it results in an increase in electricity required for artificial lighting which also contributes to the final energy consumption figures. It is not hard to assume that since the base-case (BC) does not have any form of obstruction to the natural daylight that penetrates into the building, the need for artificial lighting is much less in the base-case compared to all other scenarios with IFS.

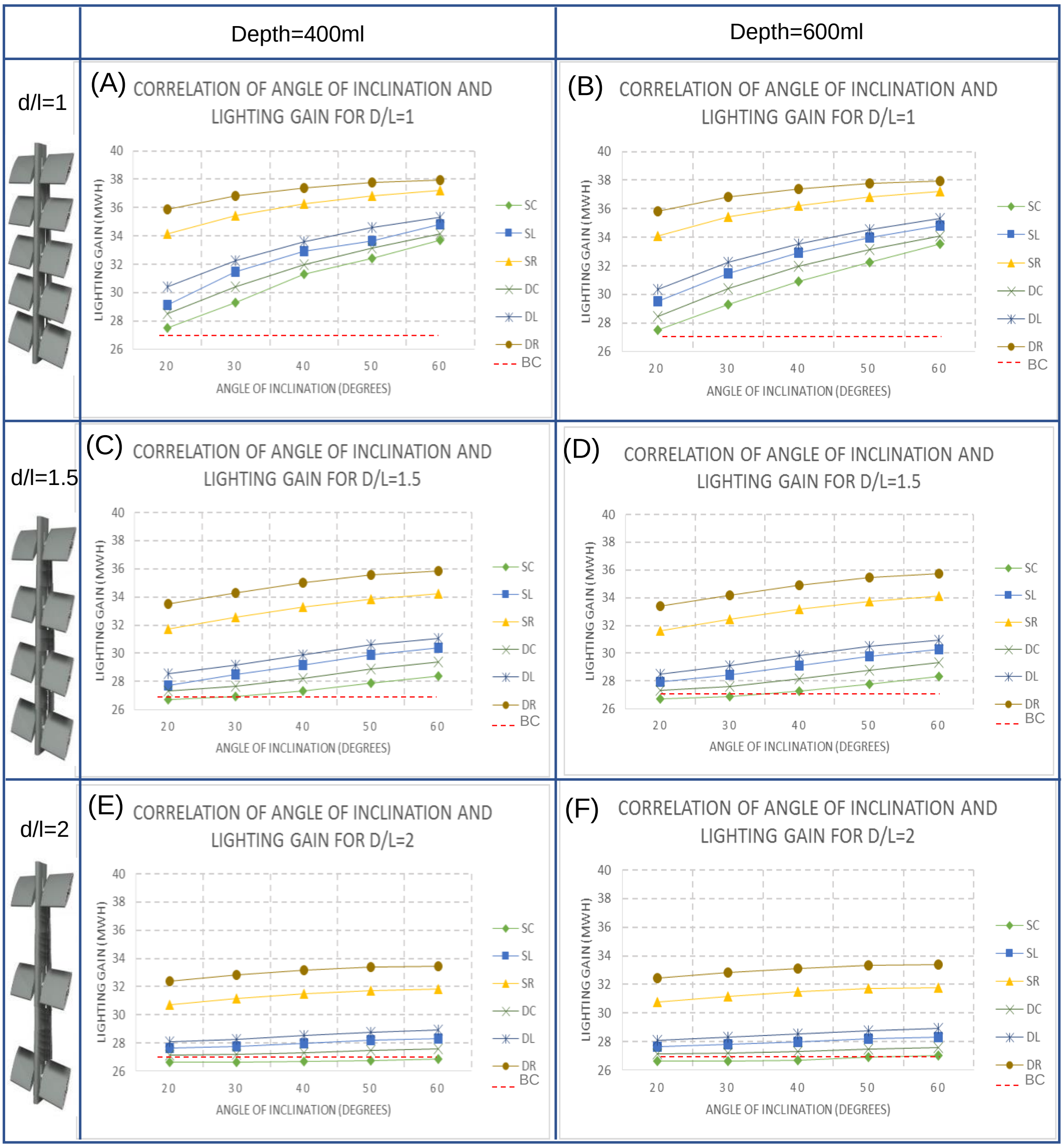
A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for lighting gain analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.17 shows the lighting gain of those combinations, compared to the base-case (BC) scenario. The dotted red line on each of the graphs represents the lighting gain of the BC scenario result (27.06 MWh).

According to the systemic approach developed for this study, 400mm and 600mm depths and d/l=1 to 2 were investigated in a group for studying this output (lighting gain) for different glazing systems and with different inclination angles, as presented in Figure 6.17, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

In almost all the interventions, significant increases in lighting gain are observed, starting from an increase of 0.85% (27.3 MWh) to 40.21% (37.94 MWh) as a final figure, compared with the BC lighting gain results of 27.06 MWh. There is a positive correlation between the inclination angle and the lighting gain in all scenarios. In other words, any increase in the inclination angle will result in a significant increase in the lighting gain. This is because when the PVSDs close downwards (i.e. tilting the angle from 20° to 60° with 10° intervals), the need for artificial lighting increases due to the increased space or distance between every two blades and results in more lighting gain. However, the effect of this change (i.e. tilting the angle from 20° to 60° with 10° intervals) will decrease when it comes to different d/l ratios. For example, regardless of the depth, all the combinations within d/l=1 with 400mm depth underperform the BC. In this series of d/l (Figure 6.17, A and B), the impact of change of the angle is much more influential and ranges from 27.53 MWh to 37.94 MWh, compared to combinations with d/l=1.5 where the variation is from 27.32 MWh to 35.87 MWh. Furthermore, combinations with d/l=2 will only vary from 26.62 MWh to 33.45 MWh. However, in the d/l=2 scenarios for both d=400mm and d=600mm, the SC curve is the only case where the performance is almost equal to that of the BC. This can be explained easily because the distance between the PVSDs is large enough to allow daylighting that provides sufficient illuminance in the indoor spaces, so that the dimming system responds accordingly, resulting in bringing the artificial lighting down to its minimum level of illuminance (50lux), thereby much less lighting gain.

Therefore, it can be concluded that lighting gain is a function of d/l ratio, in other words, any increase in this ratio will improve the lighting gain and in the same time this increase in d/l ratio will result in reducing the impact of change of the inclination angle on the lighting gain. This is an important finding as it gives the designer a wider range of variations of the angle of inclination to improve daylighting as well as the reduction in energy consumption. It also provides wider range to optimise electricity generation of PVSDs. Examples on how this can be practically achieved will be discussed in detail in phase two of the analysis in this chapter.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.17 Lighting gain figures

Depth analysis:

A similar pattern of lighting gain of the glazing systems can be seen at both depths (400mm and 600mm) for all the scenarios regardless of depth or d/l ratio, suggesting that the depth is not influential when it comes to lighting gain. As expected, clear glazing showed the best improved performance when it comes to minimising lighting gain in the indoor spaces. For instance, SC outperforms other glazing systems due to its high visible transmittance (0.88) compared to other types, followed by DC. However, this is not conclusive as those two types have a way more negative influence on solar gain and hence their negative contribution to cooling loads and eventually energy consumption. The fact that both SR and DR are the worst glazing systems in terms of lighting gain is that those two types, although they showed improved solar gain (as explained in the previous section), they have the least allowance of daylighting to the indoor spaces. This is because SR and DR have a reduced optical property (T_{vis}). For SR, T_{vis} is 0.34and for DR, T_{vis} is 0.3.

On the other hand, both SL and DL showed improved lighting gain, although less than what SC and DC have shown. This is because SL and DL have improved T_{vis} (0.7 for SL and 0.64 for DL).

The glazing systems therefore, can be ranked for their performance with respect to lighting gain, at both depths, from the best to the worst across different combinations as follows: SC, DC, SL, DL, SR and DR.

Overall cross-sectional analysis:

Overall, different inclination angles have different effects on the annual lighting gain. A nearly steady increase can be observed as the inclination angle of the PVSDs is increased from 20°. Although tilting the PVSDs downward reduces the solar gain (as shown in the previous section), it affects the dimming of the internal artificial lights which in turn results in additional internal heat gain. This additional internal gain indicates a dual negative effect on energy consumption, meaning that the additional lighting gain – in form of heat added to the cooling loads – and the electricity needed to operate the artificial lighting will both add to the energy consumption much more than what solar gain would have added.

When comparing the results of WWR=100% (above) with the results of WWR=80% and WWR=60%, the same conclusion can be drawn, only the range of the effect shifts down, meaning that the less the WWR, the less the lighting gain is generated. This is also noticed in both south-east and south-west results (for comparison of results between models with different WWR and different orientation groups, please see Appendix 9). The justification of this is that with the decrease of WWR the transparent parts of the façade are reduced, while the PVSDs configurations (i.e. size) are still the same, the daylight admittance into the indoor spaces are therefore reduced. The next section will carry on with cooling load analysis to show how lighting gain contributes to this output.

- *Cooling load*

A main north south orientation building model representing typical office buildings in Iraq, with 100% WWR, was used for cooling load analysis. IFS configurations are set up on the south-facing façade of the building model. For the two investigated depths of 400mm and 600mm, inclination angle of the blades (PVSDs) varied from 20° to 60° with 10° intervals. These settings were probed for d/l ratios of 1, 1.5 and 2. The configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.18 shows the annual cooling load of those combinations (on the left y-axis). The cooling load of the combinations were compared against the base-case (BC) scenario (on the right y-axis). The dotted red line on each of the graphs represents the BC cooling load results of 204.4 MWh.

based on the systemic approach developed for this study, d/l=1 to 2, depth of PVSD of 400mm and 600mm were investigated in a group for studying this output (cooling load) for the six above-mentioned glazing systems and with the range of inclination angles, as presented in Figure 6.18, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

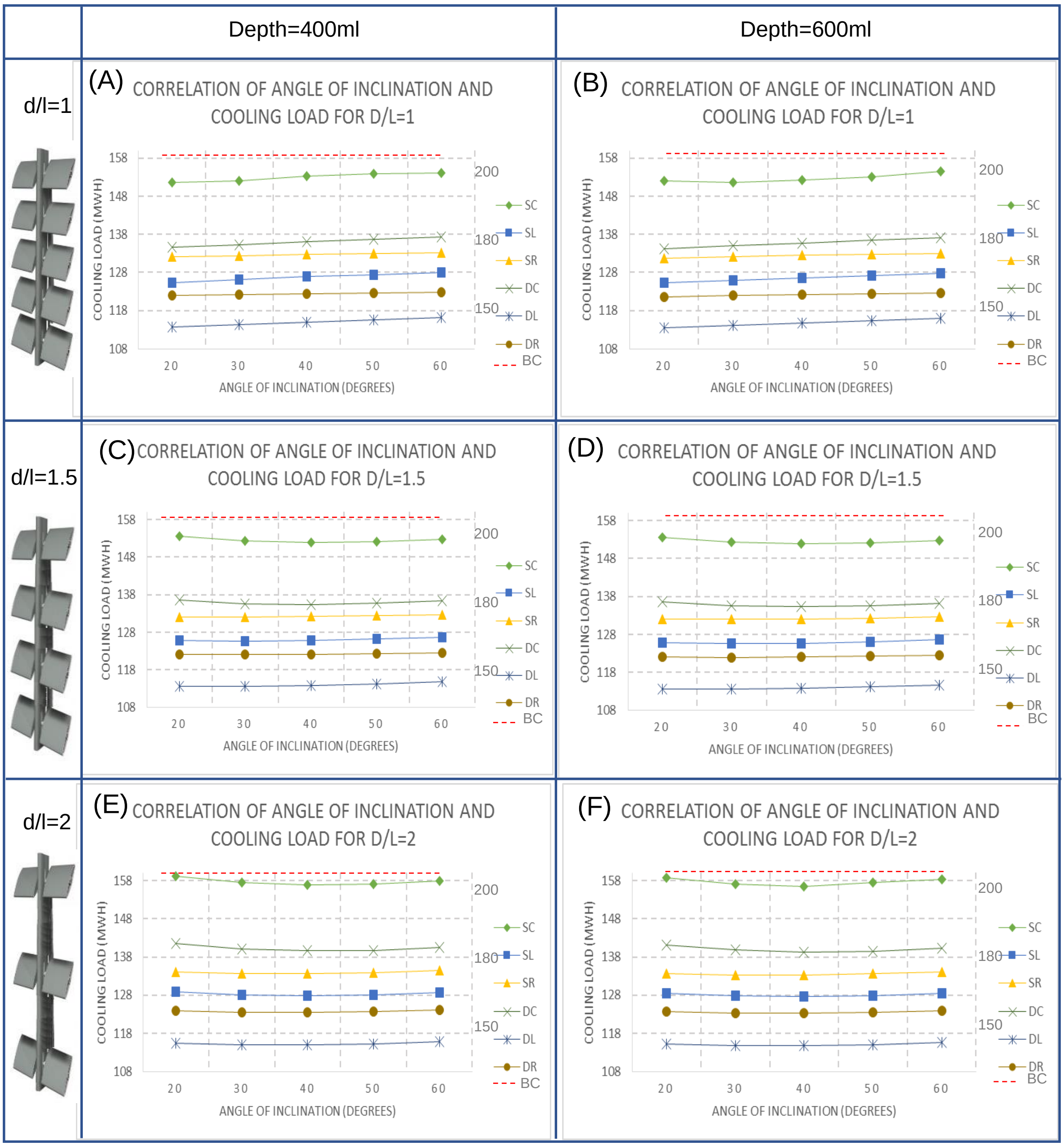
In all scenarios, considerable improvements in cooling load have been observed in the model when applying IFS in comparison to the BC scenario results. These improvements start with 22% (159.22 MWh) for combination with SC glazing, 400mm depth, with angle of inclination of 20° at d/l=2 (Figure 6.18, E) up to 44.5% (113.45 MWh) for combination with DL glazing, 400mm depth, with angle of inclination of 30° at d/l=1.5 (Figure 6.18, C) compared to the base-case with 204.4 MWh.

A noticeable pattern can be observed, looking at glazing systems' cooling load changes between different d/l ratios. For example, when d/l=1 at both 400mm and 600mm depths (Figure 6.18, A and B), combinations with SC glazing will show an increased cooling load figure when tilting the inclination angle downwards from 20° to 60°, showing that scenarios with 20° are optimal. When the angle is increased, cooling loads begin to increase, leaving the inclination angle of 60° being the worst-case scenario. This pattern changes when d/l increases to 1.5 and 2, suggesting that the optimal angle is 40° for both d/l groups. This suggests that when the distance between the blades increases, the angle of inclination need to be adjusted to be tilted more downwards to increase the resultant shaded area of the blades onto the main façade, so that the solar beam is obstructed by more area of obstacles (PVSDs). This will reduce solar gain contribution to cooling load.

Furthermore, regardless of the depth, the impact of change of the inclination angle becomes less effective when d/l ratio is increased. For instance, when d/l=1, with 400mm depth, with DL glazing and inclination angle of 20°, the annual cooling load is 113.7 MWh, presenting the best-case scenario. The worst-case scenario for the same glazing system (DL), being that with 60°, results in 116.1 MWh. The difference between those combinations is 2.4 MWh. Whereas the difference between the same combination but with d/l=15 is 1.3 MWh and with d/l=2, the difference between the best case and the worst case is 0.76.

SC and SR perform almost similarly, ranging between 190.5 and 198.5 MWh and with the least improvements. The rest of the types however vary, ranging between around 165 MWh and 185 MWh. The gap in performance between the two abovementioned glazing systems (SC and SR) and the rest of the systems becomes less significant (Figure 6.18, A to F) due to the change in d/l ratio. In other words, when more daylighting is admitted into the spaces, the effect on the dimming system decreases, hence the optical properties of the glazing systems becomes less influential.

While combinations with both SC and DC glazing showed an increase in cooling load, this was significantly higher for SC compared to DC. This means that both glazing types have some negative impact due to increased solar gain which adds to the cooling load for both cases, suggesting a preference of double-glazing over single-glazing. This happens because in double glazing the gap between the two glass panes plays a significant role in the reduction of solar heat gain and hence reduces the cooling load which eventually decreases energy consumption.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.18 Cooling loads figures

Depth analysis

When comparing all cases based on the depth of the PVSDs, it is evident that the depth has the lowest impact on cooling loads as the pattern of cooling load is similar in both 400mm and 600mm depths. This is a useful finding because this parameter, being the depth of PVSD, can be excluded from the analysis of a study where IFS would be considered and shift the focus of that study towards more influential parameters, such as d/l ratio or glazing system, or this could help make decisions of considering some increased depths of some PV panels and ensuring that this increase will not affect the performance of IFS combinations where other parameters are considered without any compromise when it comes to solar gain or lighting gain.

The best glazing system out of the six examined systems seems to be DL glazing for all scenarios, followed by DR, SL, SR, DC and the worst by far is SC. The reason could be because of the poor thermal characteristics of SC glazing (U-value=6.437, SHGC=0.812). This makes SC glazing less capable of controlling the amount of solar heat gain, resulting in an increase in cooling loads.

Overall cross-sectional analysis

There is a wide range of change in the performance of combinations with different glazing systems where annual cooling load is considered. Overall, it can be observed that the differences in performance between glazing systems increase when the d/l ratio increases, suggesting a positive correlation between them. This could be because the amount of solar gain penetrating into the building increases, due to the increased distance between PVSDs, and that puts most of the solar control task directly on the glazing systems of the façade. In other words, when d/l increases, the space between the PVSDs becomes much more exposed to outdoor conditions, reducing the effect of the PVSDs configurations on the cooling loads.

It was shown in the solar gain analysis that the more the angle is inclined, the less the solar gain is penetrated into the indoor spaces. Whereas for lighting gain, inclining the angle downwards from 20° to 60° shows a considerable increase in the lighting gain. To be able to justify how the contribution of solar gain to cooling loads could be less than the contribution of lighting gain to cooling loads, it is therefore important to use the factors’ dependency diagram (explained in section 4.14, CHAPTER 4). this will allow cooling load to be looked into in conjunction with both solar gain and lighting gain as they both contribute to the cooling loads.

This is one of the important, yet overlooked, aspects in the literature this research is covering, as it provides a detailed and an in-depth analysis of the contributing factors to energy/daylighting performance figures.

To summarise, using HPG integrated with PVSD is not a straightforward task or a rule of thumb, and needs careful consideration of the detailed performance of the resultant IFS to be able to make informed decisions on what, how, and when IFS can be used and whether they can improve the thermal and visual performance of buildings with highly- to fully-glazed façades. A practical application of this will be discussed in the next phase of the analysis (Phase two: Decisional synopses) in this chapter.

- *PV-generated electricity*

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for PV-generated electricity analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.19 shows the PV-generated electricity of those combinations. The base-case (BC) scenario does not incorporate ant PVSDs hence the combinations were compared to each other, since the PV-generated electricity is zero.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (PV-generated electricity) for different glazing systems and with different inclination angles, as presented in Figure 6.19 A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

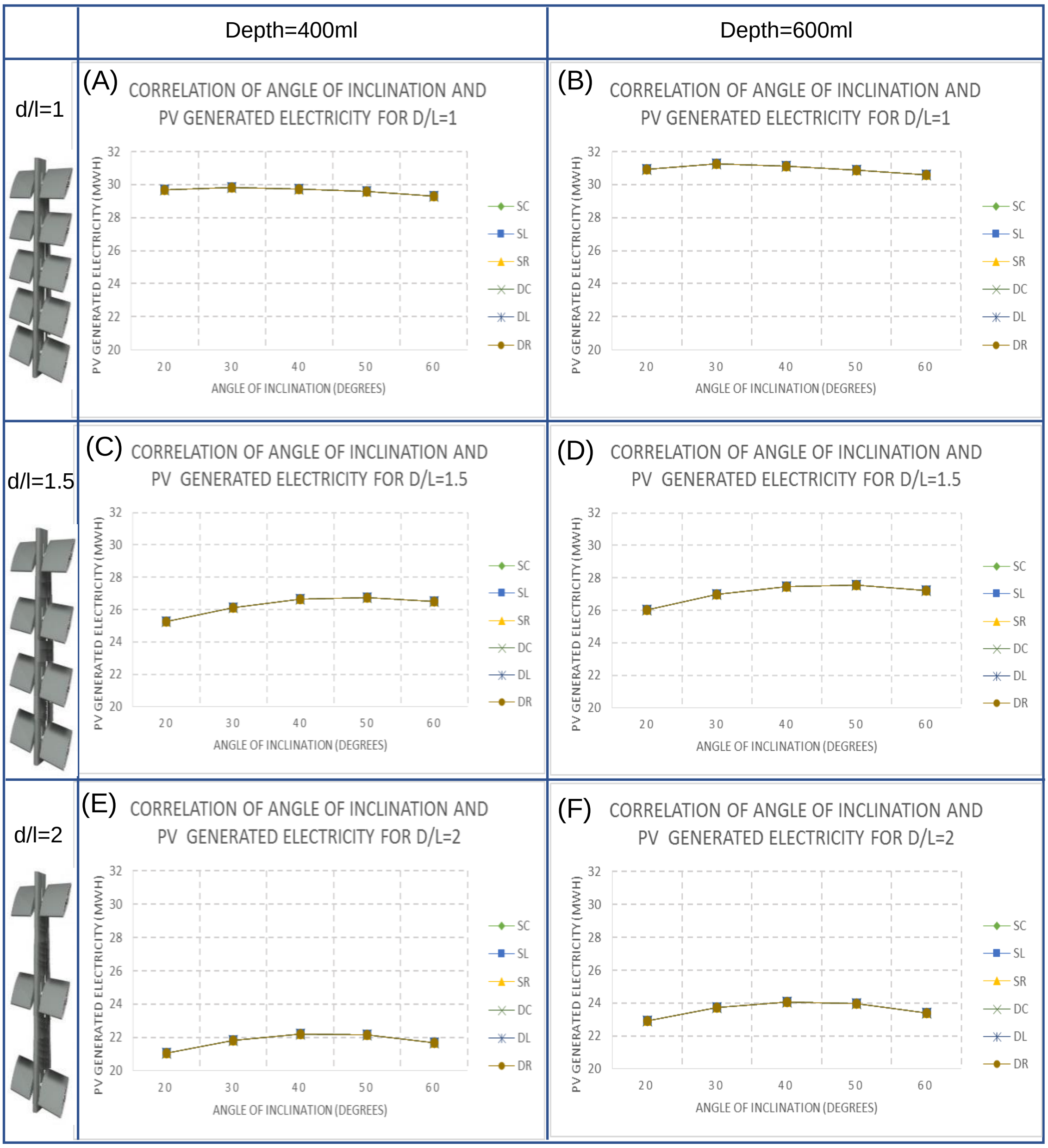
d/l analysis:

In all scenarios on the south façade, the amount of generated electricity varies from 21.06 MWh to 31.25 MWh. The graphs in the figure show that all the different glazing systems follow a single line, meaning that statistically there is no correlation between glazing systems and the PV-generated electricity. Identical results were also observed between different WWR (Appendix 10). This is simply because all the photovoltaic cells are integrated with the PVSDs on the outer skin of the building whereas the glazing systems and WWR are actually within the main building façade, behind the PVSDs and do not interfere with the panels.

Another important fact the figure shows is that the inclination angle has a considerable impact on the output of PVSDs. For d/l=1, for both depths (400mm and 600mm), 30° seems to be the optimum angle, whereas for d/l=1.5, the optimum angle is 50° and for d/l=2 the optimum angle is 40° for both depths.

When inclining the angle downwards from 20° to 30°, for d/l=1, a steady increase is observed in PV-generated electricity, starting from around 29.68 MWh to 29.85 MWh for the depth of 400mm and from about 30.91 MWh to 31.25 MWh for the depth of 600mm. Beyond that point, inclining the angle from 30° to 60° will negatively affect the PV output. This could be because the more inclined the angle downward the more the effect of self-shading between the panels (creating shades on the panel below), which has a negative impact on the electricity generation of the PV. Another reason for that being the angle of inclination also corresponds to the sun azimuth and altitude of the specific geographical location, in this study, Iraq, which affects the electricity generation. This is one of the important findings of this research and will be discussed and contextualised within the previous studies in detail in the discussion of findings in Chapter 7.

It can be concluded that the impact of the inclination angle of the PVSDs cannot be analysed in isolation without the combined effect of the distance between PVSDs (d/l ratio), as this distance shows a much more influential role on the output of the PVSDs, hence the need for careful attention to interrelationships between different influential parameters/factors, as discussed here.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l)

Figure 6.19 PV-generated electricity figures

Similarly changing the d/l ratio from 1 to 1.5 then 2 can considerably reduce the total PV output and bring it down from around 30 MWh to 21 MWh. The reason for that is that when the distance between the PVSDs increases, the number of panels is reduced which means reducing the available area for the PV cells and hence a significant reduction in the electricity output. This is because there is an interrelated effect between d/l ratio and the depth. For example, when the depth is 400mm and d/l=1 (Figure 6.19, A), the number of PVSDs is 41, whereas when d/l=1.5, the number of panels is reduced to 28. This reduction in the number of blades (PVSDs) is because they are governed by the same height of the façade. It can also be noticed that when the depth is 600mm, the distance between PVSDs is even more, resulting in a lower number of PVSDs for the same ratio d/l. Figure 6.20 shows the impact of change of d/l ratio on the number of PVSDs, the change of the actual distance between blades, the total number of PVSDs and the area available in each scenario.

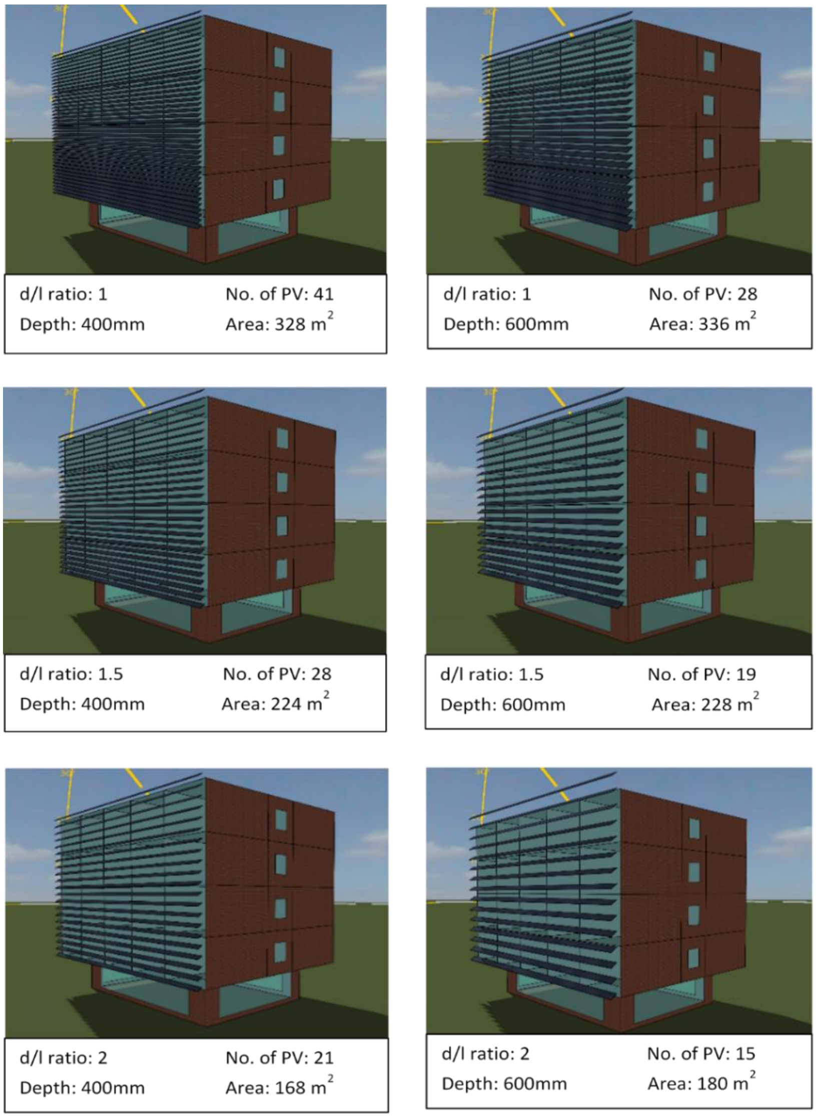


Figure 6.20 Number of PV panels and available area for each group of configurations

Therefore, increasing the distance between PVSDs might seem to be a solution to solve the self-shading effect but it is again not a straightforward task and needs special attention, mainly because it not only changes the pattern of the performance based on the change of the inclination angle but it also affects the total electricity output of the PV due to the available net area of PV cells.

Depth analysis:

It is evident that the depth of the PVSDs has a significant impact on the PV-generated electricity. With 600mm depth, the generated electricity ranges between 22.9 MWh and 31.25 MWh, outperforms the the generated electricity of 400mm depth, which ranges between 21.06 MWh and 29.83 MWh. This difference in the PV output is because the depth of the PVSDs also correlates to the area in which the PV cells are integrated. This means that an increase in one of the panels dimensions (i.e. the depth) will result in increasing the area. It is not difficult to conclude that the more area available for PV integration, the more electricity is generated. In other words, the depth of 600mm provides a bigger area to integrate more PV cells compared to the depth of 400mm, the electricity generated from 600mm exceeds that of 400mm within the same d/l group.

Overall cross-sectional analysis:

It can be concluded that PV-generated electricity is a function of d/l ratio, meaning that an increase in this ratio will negatively affect the PV-generated electricity. In addition to this, it was found that the change in the inclination angle also considerably affects the PV-generated electricity and both d/l and the inclination angle need to be considered inseparably so that optimum solution can be achieved when applying IFS into the façade design of a project.

Furthermore, no impact of both WWR or glazing systems on PV-generated electricity were observed, hence, those two variables can be frozen when PV-generated electricity is targeted. However, this is not a realistic scenario as other aspects of IFS (i.e. energy consumption or daylighting) are highly affected by those two variables. A net energy figure could be of great help as it integrates both energy consumption and energy generation in one figure. This figure therefore can be used, besides daylighting, for optimisation. This variable (net energy) will be discussed in the following section.

- *Net energy*

Net energy is a measure in which both total annual electricity consumption (energy consumption) and any renewables – electricity generated by the PVSDs in this study – are considered. It is simply calculated by subtracting the amount of electricity generated by PVSDs from the total electricity consumption. The base-case (BC) scenario is assumed to have zero renewable energy, therefore its net energy is equal to its energy consumption value and therefore all scenarios of interventions (IFS configurations) are considered improvements and assessed against the BC energy consumption results.

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for net energy analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.21 shows the annual net energy of those combinations on the left y-axis. The dotted red line on each of the graphs on the right y-axis represents the BC scenario net energy that is 204.4 MWh.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (net energy) for different glazing systems and with different inclination angles, as presented in Figure 6.21 A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

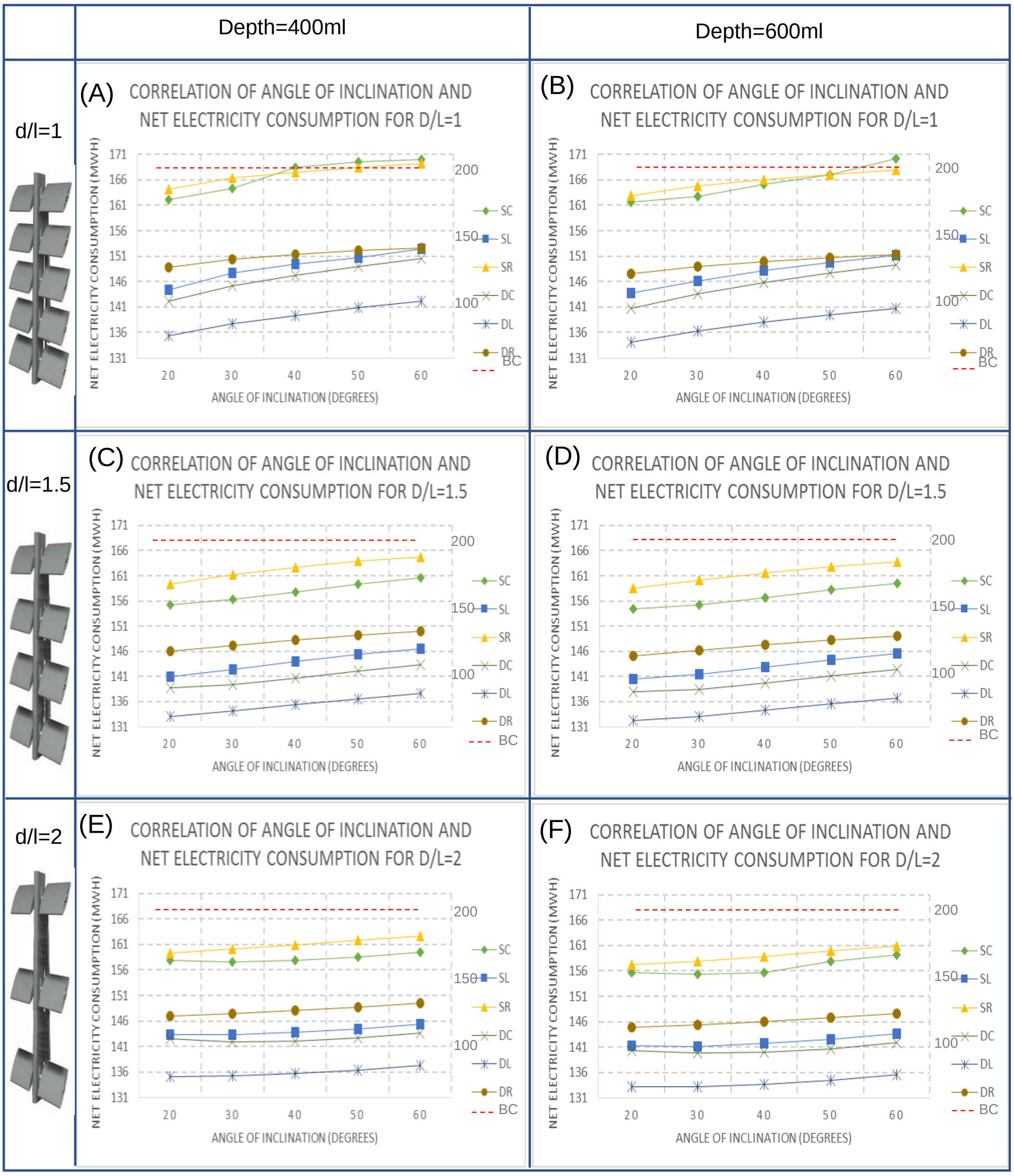
d/l analysis:

In all scenarios, considerable improvements have been observed when applying IFS configurations in comparison to the BC scenario results. SC and SR configurations at d/l=1 with inclination angles varying from 20° to 60°, have shown a slight improvement compared to combinations with the rest of the glazing systems (Figure xx, A and B), regardless of the depth. The improvements start with 16.7% (170.17 MWh) - for the combination with SC glazing, with 600mm depth and d/l=1 and at inclination angle of 60° Figure 6.21, B). the improvements then increase as the net energy performance go up to 35% with the final figure of

132.25 MWh for the combination with DL glazing, with 600mm depth and d/l=1.5 and at inclination angle of 20° (Figure 6.21, D). While both SC and SR showed the least improved combinations, it can be observed that both SC and SR exchange the rank of being the worst-case scenario or the least improved scenarios, compared to other glazing systems, by far, but that depends on the angle of inclination and the depth of PVSD. What makes SR a little more energy efficient compared to SC where combinations with angle of inclination higher than 40°, is that although SR adds to the need for artificial lighting (which in return adds to the electricity consumption), the higher solar gain in SC (compared to SR) adding to cooling load , seems to outweigh the extra load for artificial lighting in which is higher in SR than in SC glazing type.

A noticeable pattern can be observed, looking at glazing systems' performance changes between different d/l ratios. The glazing systems show a wide range of net energy performances, starting with DL at a range of 132.25 MWh to 142.11 MWh, followed by DC which ranges between 138 MWh and 150.57 MWh, then SL which varies from 140.47 MWh to 152.45 MWh, and DR varying from 144.95 MWh to 152.61 MWh, SC which fluctuates between 154.4 MWh and 170.17 MWh and SR which increases 157.24 MWh to 169.24 MWh. This suggests that there is a gap in performance between SC and SR on one side and the rest of the glazing systems on the other side. The gap in performance between the two abovementioned glazing systems (SC and SR) and the rest of the systems becomes less significant (Figure 6.21, A to F) due to the change in d/l ratio. In other words, when more daylighting is admitted into the spaces, the effect on the dimming system decreases, hence the optical properties of the glazing systems becomes less influential.

It can be concluded that net energy is a function of d/l ratio, meaning that an increase in this ratio will improve the net energy.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.21 Net energy figures

Depth analysis:

It can be seen that the depth of the PVSDs has the least influence on the net energy results. Although the combinations vary in value, based on the configuration under investigation, the trend is nearly similar for both 400mm and 600mm. In addition, the graphs show that there is a shift in the values, which is actually more influenced by the PV electricity generation outputs.

It is evident from the graphs of the net energy that PVSDs inclination angle of 20° scores the best in almost all the scenarios when it comes to net energy figures. Apart from SC and SR, the rest of the glazing systems positively correlates to the angle of inclination as far as the net energy is concerned. However, when d/l=1, SC combinations show better results than SR at 20° and 30°. Also, when increasing the angle to 40°, 50° and 60°, SR combinations outperform SC combinations. This fact does not apply to combinations at d/l=1.5 and 2. This is because the results of net energy are highly influenced by the amount of the generated electricity of the PVSDs.

Overall cross-sectional analysis:

It can also be noticed that the bigger the distance between blades (d/l ratio), the less the impact of change of the inclination angle on the net energy. This is justifiable because in scenarios where d/l=2, the distance between PVSDs is big enough to allow natural daylighting in, which means there is less lighting gain and hence a decreased energy consumption.

This is an interesting finding because it shows that with d/l=2, net energy figures improve, whereas this is the opposite situation with the PV electricity generation; therefore, it really depends on the design targets of a project and the aspect that needs to be investigated and analysed. In some cases a designer might consider PV electricity generation as a prime objective, while in others it might be electricity consumption. In both cases an in-depth and detailed systematic analysis should be conducted to support the decisions for the design of the façade and its associated shading devices integrated with PV panels (PVSDs).

- *Energy savings*

Another way of showing improvements as a result of the use of IFS is to indicate how much saving is expected when implementing a certain scenario. This will allow for a clearer understanding of the impact of each intervention in the configurations and will provide a better insight of where such interventions in the design are most influential. Furthermore, this measure help quantify the effect of the intervention in the design of IFS in form of a percentage of energy saving. Saving was calculated in Microsoft Excel (as seen in Figure 6.22) for all of the combinations based on the following equation:

fx=+(100-((Q4/O4)*100))/100

Where *fx* is the energy saving (percentage), Q4 is the net energy of combination x, and O4 is the energy consumption of combination x.

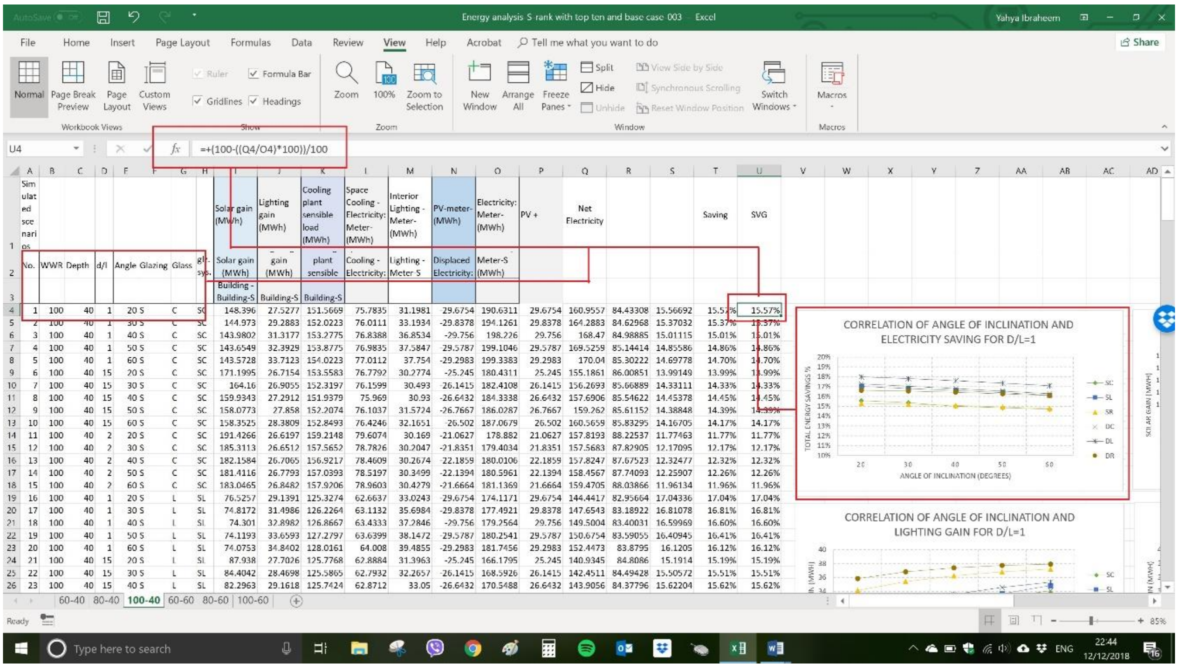


Figure 6.22 Calculation of energy savings in Microsoft Excel

A main north south orientation building model representing typical office buildings in Iraq, with 100% WWR, was used for energy saving analysis. IFS configurations are set up on the south-facing façade of the model. For two depths of 400mm and 600mm, inclination angle of the blades (PVSDs) varied from 20° to 60° with 10° intervals. These settings were probed for d/l ratios of 1, 1.5 and 2. The configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.23 shows the annual energy saving of those combinations. Since the base case (BC) does not have any PVSDs installed as an external skin of the building, which means that there is no PV-generated electricity, the saving is therefore considered zero for the BC and the savings are compared against the energy consumption figure of the BC (195.6702 MWh).

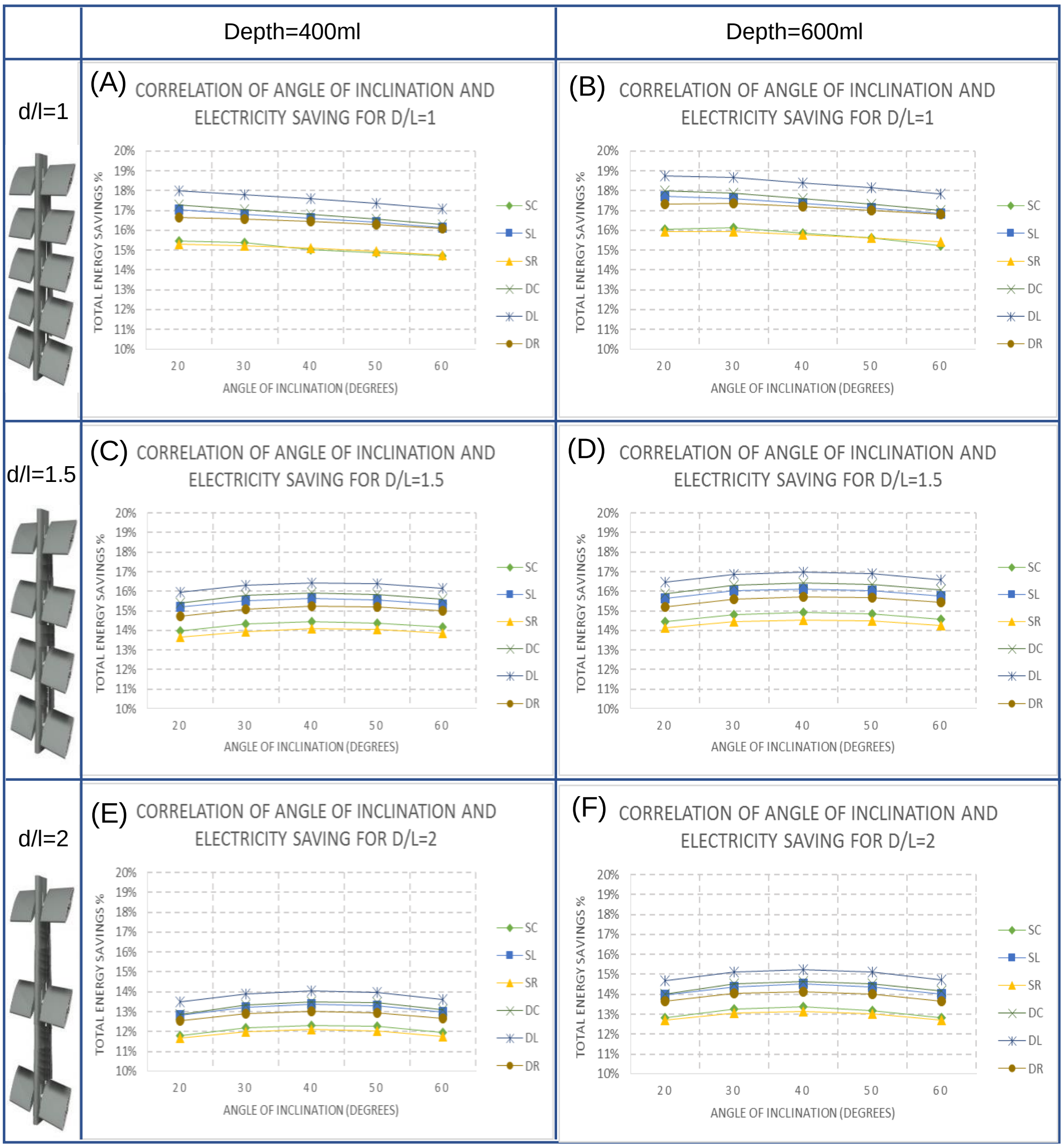
based on the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (energy saving) for the six above-mentioned glazing systems and with the range of inclination angles, as presented in Figure 6.23, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

The graphs in Figure 6.23 show that scenarios within different d/l ratios show that IFS has helped save energy. Varied patterns of energy saving were observed. For example, for combinations with d/l=1 and at both depths (Figure 6.23 A and B), all glazing systems showed similar pattern as the energy saving negatively correlates with the inclination angle. In other words, a decrease in the energy saving is observed when the angle of inclination increases from 20° to 60°. This is partially influenced by PV-generated electricity but mostly by the solar gain and lighting gain. This is because within the same d/l group, increasing the angle of inclination will result in decreasing the PV-generated electricity but in the same time it reduces solar gain and subsequent cooling loads, which seems to outweigh the the contribution of the generated electricity. However, different energy savings result from different glazing systems.

The situation is slightly different when increasing the d/l ratio to 1.5 and 2, as for both d/l=1.5 and d/l=2 a steady increase is observed in all glazing systems, starting from 20° until it reaches the peak at 40°. From 40° onward to 60°, a steady decrease is then observed. It can be concluded that the 20° inclination angle is optimum when the distance between blades is at its lowest (d/l=1) whereas it shifts to 40° when the distance between PVSDs increases to 1.5 and 2. This is justified by the influence of the generated electricity figures, which considerably changes when it comes to different d/l ratios, as discussed previously in PV-generated electricity section (please see Figure 6.19).

It can be concluded that energy consumption is a function of d/l ratio, meaning that an increase in this ratio will improve the energy consumption.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l)

Figure 6.23 Energy saving figures

Depth analysis:

A noticeable pattern can be observed, looking at glazing systems’ energy saving changes between different depths. For example, the energy saving starts with 11.68% for combinations with SL glazing, with d/l=2, and with 400mm depth and with angle of inclination of 20°, to 17.98% with combinations with DL glazing, and d/l=1 and with inclination angle of 20° (Figure 6.23, E). Whereas when the depth is increased to 600mm, the range of energy saving improves to start from 12.69% for combinations with SL glazing, with d/l=2 for inclination angle of 20° (Figure 6.23, F) to 18.73% for combinations with DL glazing, and d/l=1 and with inclination angle of 20° (Figure 6.23, A). In other words, the decrease in d/l will substantially increase the energy saving. This is because with lower d/l ratio, higher number of PVSDs is introduced, as discussed before in PV-generated electricity section, hence more saving is achievable due to the increased number of PVSD panels.

Energy saving of glazing types can be ranked at both depths from the best to the worst across different combinations as follows: DL, DC, SL, and DR, with SC and SR being the worst by far. This suggests that glazing with improved thermal characteristics, such as DL, have a noticeable positive impact on the energy saving, whereas for the glazing systems where optical properties are improved – e.g. SR– a negative effect on energy saving is observed.

To conclude it seems that the energy saving is a function of the depth.

Overall cross-sectional analysis:

In all interventions, considerable energy savings are observed, starting from about 12% to about 19%. These savings confirm the previous findings of the optimum scenarios regarding the energy performance aspect of this study. In all scenarios, DL glazing shows the best energy saving, ranging from 13.5% to 19%, whereas DC, SL and DR follow and show close ranges of energy saving. The least savings were observed in scenarios with SC and SR (11.76% to 16%).

Therefore, a cross comparison between different d/l ratio groups is imperative and of great help for making decisions about IFS strategies, and at a practical level for designers. For example, a designer might not be able to use DL glazing for financial reasons (i.e. initial cost of HPG) so instead they use SC glazing, which has the least thermal characteristics. A saving of 14% can be achieved in both cases. However, when using DL, the inclination angle is 60° and d/l=2, meaning that less artificial lighting is needed due to the sufficient distance between the PVSDs (d/l=2). In order to properly switch to SC glazing, while trying to achieve the same saving, the designer should decrease the distance between PVSDs (d/l) to 1 and rotate the angle to 40°. In that case, reducing the distance between the PVSDs not only reduces solar gain but also increases the number of PVSDs, meaning that the increased surface will allow for more PV panels to be integrated and to produce more electricity. That generated electricity can then improve the saving.

It can be concluded that pattern of the impact of changing the inclination angle varies within different d/l ratios, which suggests that this needs to be assessed against other rather influential factors, such as PV-generated electricity or solar gain to be able to make a decision about which out of the 90 combinations would perform best if saving was used as an optimisation output variable.

To summarise this far, the energy aspect analysis of the building under investigation has been discussed. All other influential factors that contribute to energy consumption have also been discussed and analysed based on their dependency. Improvements and optimum scenarios have been highlighted and links between different aspects have been made to facilitate the design strategies that aim at improving energy performance with and without inclusion of renewable energy integration.

There is still a third aspect that needs to be analysed and discussed to close the loop of trade-offs between the triad of energy consumption, energy generation and daylight provision. The next section will cover the daylight analysis as the third aspect.

6.5.2 Daylight analysis

As explained in CHAPTER 4, section 4.13.2, the indicators that will be evaluated in the analysis of the daylight performance are Useful Daylight Illuminance (UDI) ranges. The ranges that will be discussed in the following sections are $UDI_{\textit{less than 300 lux}}$, $UDI_{\textit{300 to 3000 lux}}$, and $UDI_{\textit{more than 3000 lux}}$. Before elaborating on UDI, Annual Daylight Illuminance (ADI) – a cumulative value of all daylight at a certain point, that occurred throughout the working hours of a whole year – will also be discussed and analysed. However, ADI could probably be useful only when assessing exposure, such as for museums or art galleries, where the showcased objects and art works are sensitive to a certain amount of light and could be damaged (Brembilla et al., 2017).

Although this value does not provide sufficient information that can be quantified and used in the analyses, it can still indicate the yearly amount of daylight received, which can be used in the current study as a secondary indicator to provide a general idea of how much light is expected in the interior spaces yearly.

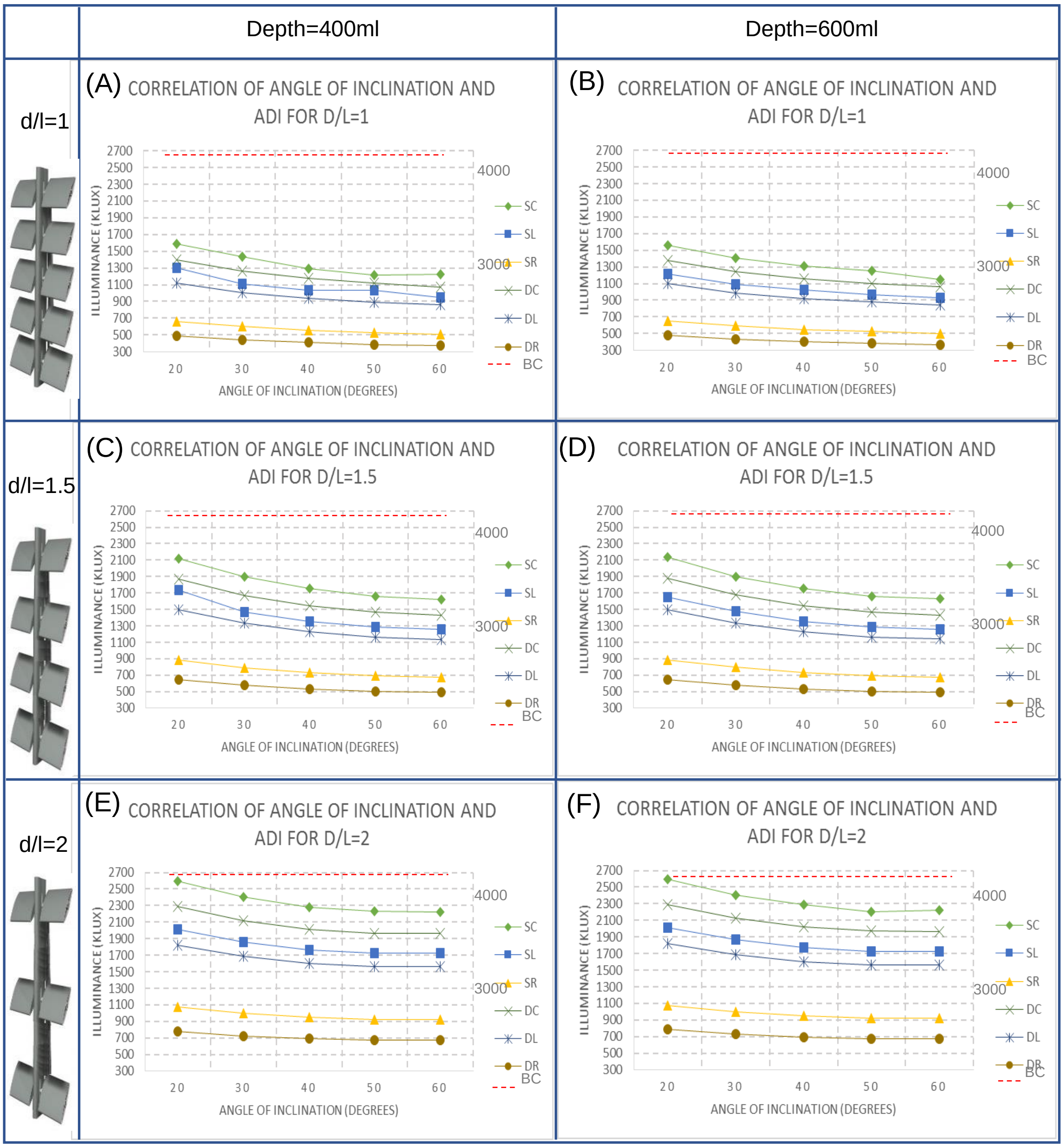
- *Annual Daylight Illuminance ADI*

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for ADI analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for daylighting simulation to 90. Figure 6.24 shows the annual ADI in Klux for those combinations on the left y-axis. The dotted red line on each of the graphs represents the base-case (BC) scenario ADI that is 4013.9 Klux on the right y-axis.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (ADI) for different glazing systems and with different inclination angles, as presented in Figure 6.24, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

In all scenarios, a significant decrease of ADI is observed compared to the BC scenario, starting with 35.3% (2596 Klux hrs) to 90% (366 Klux hrs) as a final figure. This decrease clearly proves the noticeable impact of the application of IFS on the amount of usable natural daylight during office working hours for a nominal year. The graphs prove that there is a strong positive correlation between d/l ratio and ADI. This is evident from the variation of the results in the figure. For example, The range of ADI within d/l=1 group varies between 366 Klux hrs for combinations with DR glazing, with 60° inclination angle, with 600mm depth and 1563 Klux hrs for combinations with SC glazing, with inclination angle of 20°. When d/l is increased to 1.5, ADI for the above-mentioned combinations range increases to vary from 493 Klux hrs to 2134 Klux hrs. a further increase in d/l ratio, i.e. 2, shifts the range up to vary from 672 Klux hrs to 2596 Klux hrs for the same two combinations.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.24 Annual Daylight Illuminance (ADI)

While combinations with both DR and SR showed a considerable decrease in the ADI, this was slightly higher for DR compared to SR. This means that both glazing types have some negative impact due to decreased ADI. What makes SR a little more efficient in terms of ADI compared to SR, is that T_{vis} of SR is slightly higher than that of DR (0.4 for SR and 0.3 for DR). The higher T_{vis} in SR (compared to DR) adding to ADI.

it can be concluded that ADI is a function of d/l ratio.

Depth analysis:

The graphs in the Figure 6.24, A to F suggest that there is no notable difference between the two depths, as similar trends with nearly similar results, are observed in the curves. However, there is surely a recognisable impact due to the change in the d/l ratio. Furthermore, there is a wide range change of ADI between combinations with different glazing systems. The combinations can be ranked based on ADI from the highest to the lowest as follows: SC comes first with the highest range of ADI (between 2596 Klux hrs and 1149 Klux hrs), followed by DC (2287 Klux hrs to 1062 Klux hrs), then SL (2010 Klux hrs to 968 Klux hrs), and DL (1563 Klux hrs to 845 Klux hrs). By far the lowest two ranges are for the two remaining two glazing systems; SR (1077 Klux hrs to 501 Klux hrs) and finally DR (783 Klux hrs to 366 Klux hrs).

Overall cross-sectional analysis:

Overall, different inclination angles have different effects on the annual ADI. A nearly steady decrease can be observed as the inclination angle of the PVSDs is increased from 20°. This suggests that there is a negative correlation between the angle of inclination and ADI, with some exceptions. This is justifiable because the bigger the angle of inclination, the more substantial the shade it creates. Needless to say, ADI is only an indicator of the quantity of the total annual daylight. It does not indicate the quality of the daylight, which is what this chapter will shed some light on in the following sections, using UDI ranges as the main daylight quality measure.

- *Useful daylight illuminance $UDI_{less\ than\ 300\ lux}$*

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for $UDI_{less\ than\ 300\ lux}$ range analysis. This range refers to the time where the useful level of illuminance falls below 300lux, which is below the minimum acceptable level for carrying out office tasks according to CIBSE LG7 and LG10 standards. Below this level a need for artificial lighting will arise in order to compensate for the lack of natural lighting.

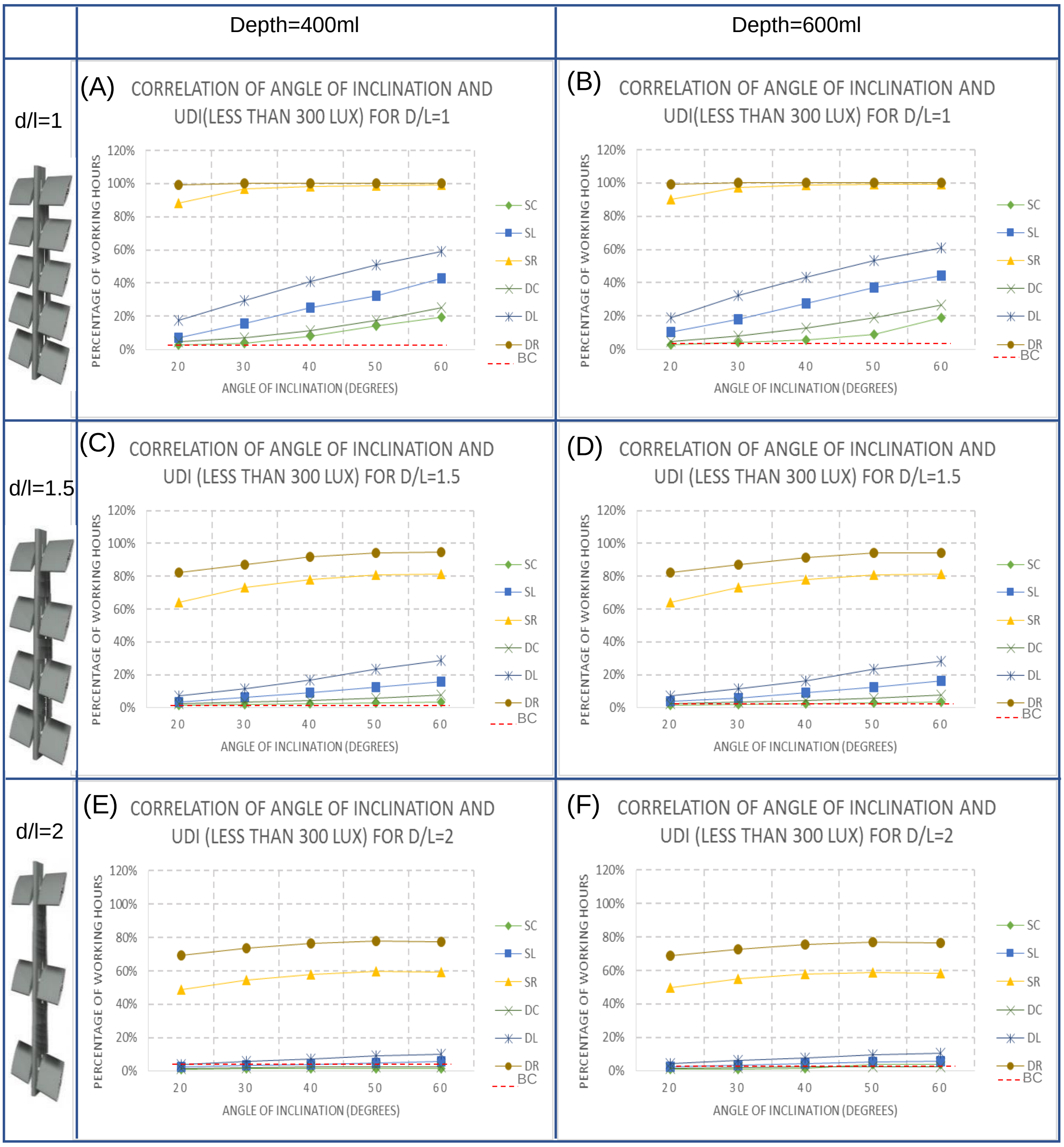
IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.25 shows the percentage of the total annual working hours, where UDI falls below 300lux, ($UDI_{\text{less than 300 lux}}$) of those combinations. The dotted red line on each of the graphs represents the base-case (BC) scenario $UDI_{\text{less than 300 lux}}$ that is 0.98%.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output ($UDI_{\text{less than 300 lux}}$) for different glazing systems and with different inclination angles, as presented in Figure 6.25, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

In all scenarios, a considerable increase has been observed when applying IFS in comparison to the BC results. These increases start as low as 4.7% and in some cases, go up to 99%. Clearly, all IFS configurations are considered as obstacles to daylight but to different extents. Therefore, they are expected to increase the percentage of hours where daylight illuminance falls under the minimum acceptable range when compared to the BC results.

It is evident that the d/l ratio has a significant impact on increasing the percentage of time where UDI is less than 300lux. The highest drop percentages are observed within d/l=1 combinations, whereas better results are observed when increasing the distance between PVSDs to d/l=1.5. The overall ranges of $UDI_{\textit{less than 300 lux}}$ are even more improved when d/lis further increased to 2. This was anticipated because the greater the distance between the PVSDs, the more daylight is permitted into the indoor spaces. However, the impact of change of the angle of inclination of the PVSDs varies between different d/l ratios. For example, at d/l=1 group for both depths (Figure 6.25, A and B), a steady increase in $UDI_{\textit{less than 300 lux}}$ is observed, starting from 4% for combinations with SC with inclination angle 20° then levelling up to 60% for combinations with DL with inclination angle 60°.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.25 Useful daylight illuminance UDI: less than 300 lux

This indicates that $UDI_{less\ than\ 300\ lux}$ positively correlates with the angle of inclination. The outliers, being combinations with SR and DR perform far different from the rest of the glazing types when it comes to different inclination angles within the same depth and d/l group. For instance, in d/l=1 group (Figure 6.25, A and B), combinations with SR and DR only improve when the angle of inclination is low (i.e. 20° and 30°).

Depth analysis:

Tilting the angle downwards from 30° to 60° will result in nearly 99% of time where the illuminance level in the indoor spaces fall under 500 lux during the working hours, which put further pressing need for artificial lightings. What makes combinations with SR performing slightly better at angles 20° and 30° within the same d/l and depth is that SL optical properties is slightly improved compared to DR. this makes the effect of larger angles, blocking the sunlight more influential on $UDI_{less\ than\ 300\ lux}$.

For d/l=1.5, the change of the angle of inclination becomes less influential compared to d/l=1. This is evident from the pattern of the graphs of the six glazing systems examined. The effect of the increase of the distance between PVSDs allows for more light to penetrate into the building. Another interesting observation in this series is that there is a clear difference in the $UDI_{less\ than\ 300\ lux}$ between single- and DR glazing systems, where SR glazing outperforms DR. However, both types are still poor in terms of daylight provision compared to other HPG systems.

In the third series where d/l=2, the effect of the change of angle becomes even less substantial compared to its effect within the other two series (d/l=1 and d/l=1.5). This is justifiable because the distance between PVSDs becomes very large, allowing much more daylight than the change of inclination angle can effectively control, leaving all the HPG types within a limited range from 1% to 10%, which also means that the effect of the change of HPGs becomes less impactful.

Overall cross-sectional analysis:

Overall, different inclination angles have different effects on the annual $UDI_{less\ than\ 300\ lux}$. A nearly steady increase can be observed as the inclination angle of the PVSDs is increased from 20°. Although tilting the PVSDs downward reduces the $UDI_{less\ than\ 300\ lux}$, it affects the dimming of the internal artificial lights which in turn results in additional internal heat gain, as explained previously in lighting gain section in this chapter. In all cases (Figure 6.25, A to F), the angle of inclination of 20° seems to be the optimum combination but this is only valid when considering the daylighting performance on its own, regardless of other output variables, i.e.

energy consumption, hence those outputs need to be considered together when IFS optimisation is aimed at.

The pattern of improving $UDI_{less\ than\ 300\ lux}$ due to tilting down the inclination angle and increasing d/l ratio of combinations with SC, DC, SL, and DL is similar across the board. However, this does not mean that the similarity is rooted in the same cause or achieved through the same route, meaning that, for example, if combinations with DC and DR are to be compared, DC glazing introduces better u-value than DR, which suggests improved energy performance, as explained in energy performance analysis section in this chapter. However, the compromise is the reduction of daylight due to lower T_{vis} of DR. This depends on the design target of the specific project where different or equal weights are given to daylight and energy performance. Practical examples wil be elaborated on in the phase of the analysis.

- *Useful daylight illuminance $UDI_{300\text{-}3000\ lux}$*

The building model that achieved 300lux for at least half of the analysis hours (50%) counts as meeting the daylighting threshold (Wymelenberg and Mahić, 2016).

A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for $UDI_{300\text{-}3000\ lux}$ analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.26 shows the annual $UDI_{300\text{-}3000\ lux}$ of those combinations. The dotted red line on each of the graphs represents the base-case (BC) scenario $UDI_{300\text{-}3000\ lux}$ that is 98.8%.

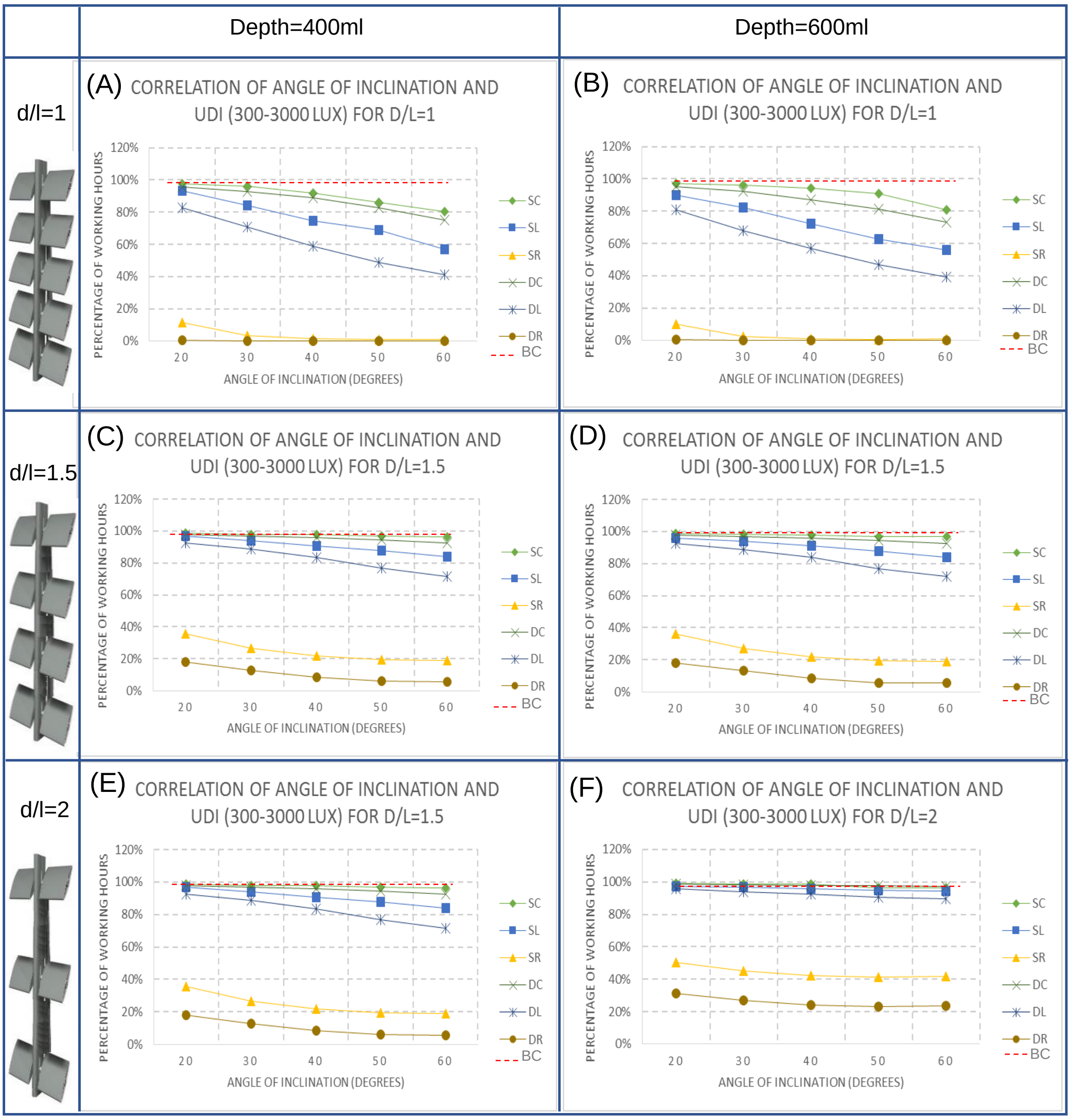
According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output ($UDI_{300\text{-}3000\ lux}$) for different glazing systems and with different inclination angles, as presented in Figure 6.26, A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

Clearly most of the interventions of IFS configurations on the south-facing façade have significantly decreased $UDI_{300\text{-}3000\ lux}$ compared to the BC scenario results.

In comparison to the BC, SR combinations at d/l=1 with inclination angle of 20° have shown a slight improvement whereas 30°, 40°, 50° and 60° with this glazing system have proven to be irresponsive to the change in the inclination angle beyond 30°. These decreases start with 1% for scenarios with SR and can go up to over 95% with some specific glazing systems, i.e SC. This is because all IFS configurations are obstructing the daylight. Therefore, they eventually increase the percentage of hours during which the daylight illuminance falls under the minimum acceptable level of 300lux, leaving most of the hours under a pressing need for artificial lighting. This situation worsens with combinations where DR glazing is considered. This is seen in Figure 6.26, A and B where no change in $UDI_{300\text{-}3000\ lux}$ was observed regardless of the change in the angle, leaving 99% of the working hours within $UDI_{less\ than\ 300\ lux}$. This means that both SR and DR glazing types have some negative impact due to decreased $UDI_{300\text{-}3000\ lux}$ which adds to the internal lighting gain for both cases.

A noticeable pattern can be observed, looking at glazing systems' performance changes between different d/l ratios. For example, when d/l=1 (Figure 6.26, A and B), apart from reflective glazing systems (SR and DR), a wide range of variation of $UDI_{300\text{-}3000\ lux}$ is observed, starting from 97.36% for combinations with SC glazing, with angle of inclination of 20° to 41.03% for combinations with DL glazing and inclination angle of 60°. Those results are regardless of the depth. A shorter range of $UDI_{300\text{-}3000\ lux}$ is observed when increasing d/l to 1.5, indicating that the change in the inclination angle becomes less influential. This is because increasing d/l results in increasing the space between the PVSDs. This space becomes too big and it allows for a high illuminance.



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.26 Useful daylight illuminance UDI: 300-3000 lux

Therefore, the shade strips created due to the PVSDs rotate and become too narrow compared to the large distance between the blades, making the inclination angle of the PVSDs less impactful. This also justifies the further improvements observed in reflective glazing systems, but they are yet to meet the threshold. With the increase of the distance between PVSDs to d/l=2, all combinations of all glazing systems show a less negative impact, especially those with poor visual characteristics, such as reflective glazing systems. Interestingly, configurations with single-reflective glazing can overcome the poor visible light transmittance of reflective glass, providing $UDI_{300\text{-}3000\ lux}$ just above the threshold of 50% of the time, as required.

It can be concluded that energy consumption is a function of d/l ratio, meaning that an increase in this ratio will improve the energy consumption.

Depth analysis:

A similar pattern of performance of the glazing types can be spotted at both depths (400mm and 600mm) for all the scenarios. When d/l=1 (Figure 6.26, A and B), for instance, a nearly similar result can be observed between combinations with SC and SR, regardless of the angle or depth. Glazing systems can be ranked based on their $UDI_{300\text{-}3000\ lux}$ as follows: combinations with SC glazing show the least affected cases with $UDI_{300\text{-}3000\ lux}$ between 92.5% and 97%; DC comes second with a range of variation between 73.22% and 98.37%. The third system in the ranking is SL which varies between 55.96% and 97.47%, followed by DL where a range of $UDI_{300\text{-}3000\ lux}$ is observed between 39.11% and 95.62%. The worst case by far, are the combinations with both SR and DR glazing where any scenario could barely achieve just above 50% but with large d/l ratio. This suggests that glazing systems with improved optical properties, such as DC, have a noticeable positive impact on $UDI_{300\text{-}3000\ lux}$, whereas for the glazing systems where thermal properties are improved but with the compromised optical properties – e.g. DL – a negative effect on $UDI_{300\text{-}3000\ lux}$ is observed.

In general, most of the HPG with improved visual characteristics performed reasonably well in terms of the provision of useful daylight, leaving a wider space for trade-offs with other factors, i.e. energy generation and energy consumption.

in both depths, it is evident that increasing the angle from 20° to 60° reduces the $UDI_{300\text{-}3000\ lux}$. This is because when the PVSDs are inclined downwards, they close down and the space between the panels decreases, allowing less light to penetrate into the building. However, this effect becomes less significant when it comes to different d/l scenarios, as was explained previously in d/l analysis in this section.

Overall cross-sectional analysis:

Overall, the graphs in the figure show the considerable influence of the angle of inclination on the $UDI_{300\text{-}3000\ lux}$. In most of the scenarios, an inclination angle of 20°

results in the optimum daylight performance, but with some exceptions. From 20° to 60°, a steady decrease is observed and the level of $UDI_{300\text{-}3000\ lux}$ goes below the threshold of 50%. This suggests a clear negative correlation between $UDI_{300\text{-}3000\ lux}$ and the angle of inclination.

The pattern of decreased $UDI_{300\text{-}3000\ lux}$ due to tilting down the inclination angle and increasing d/l ratio of combinations with SC, DC, SL, and DL is similar across the board. The similarity is rooted in the same cause and achieved through the same route, which is the reduction of daylight due to lower T_{vis}. However, this introduces a more pressing need for artificial lighting which emits more lighting into the spaces resulting in higher lighting gains and also adds up to electricity required to operate those artificial lightings, both of which eventually contribute to additional energy consumption. So while cooling load is reduced due to better u-value of glazing, there will still be a need for more artificial lighting. The decision therefore depends on the design targets of the specific project.

- *Useful daylight illuminance $UDI_{more\ than\ 3000\ lux}$*

When the illuminance level exceeds the maximum limit of 3000 lux, glare occurs. In the base-case (BC) results, the percentage of $UDI_{more\ than\ 3000\ lux}$ exceeds the maximum limit of 3000lux for only around 1.3% of the time, meaning that there is 1.3% of the working time where glare occurs. The fact that this percentage is already low lies in the correspondence of illuminance levels in the indoor spaces to the sun altitude in the context of the study, which is quite high during the working hours (i.e. between 8 am and 4 pm), as shown in section 5.2.3 in data generation chapter.

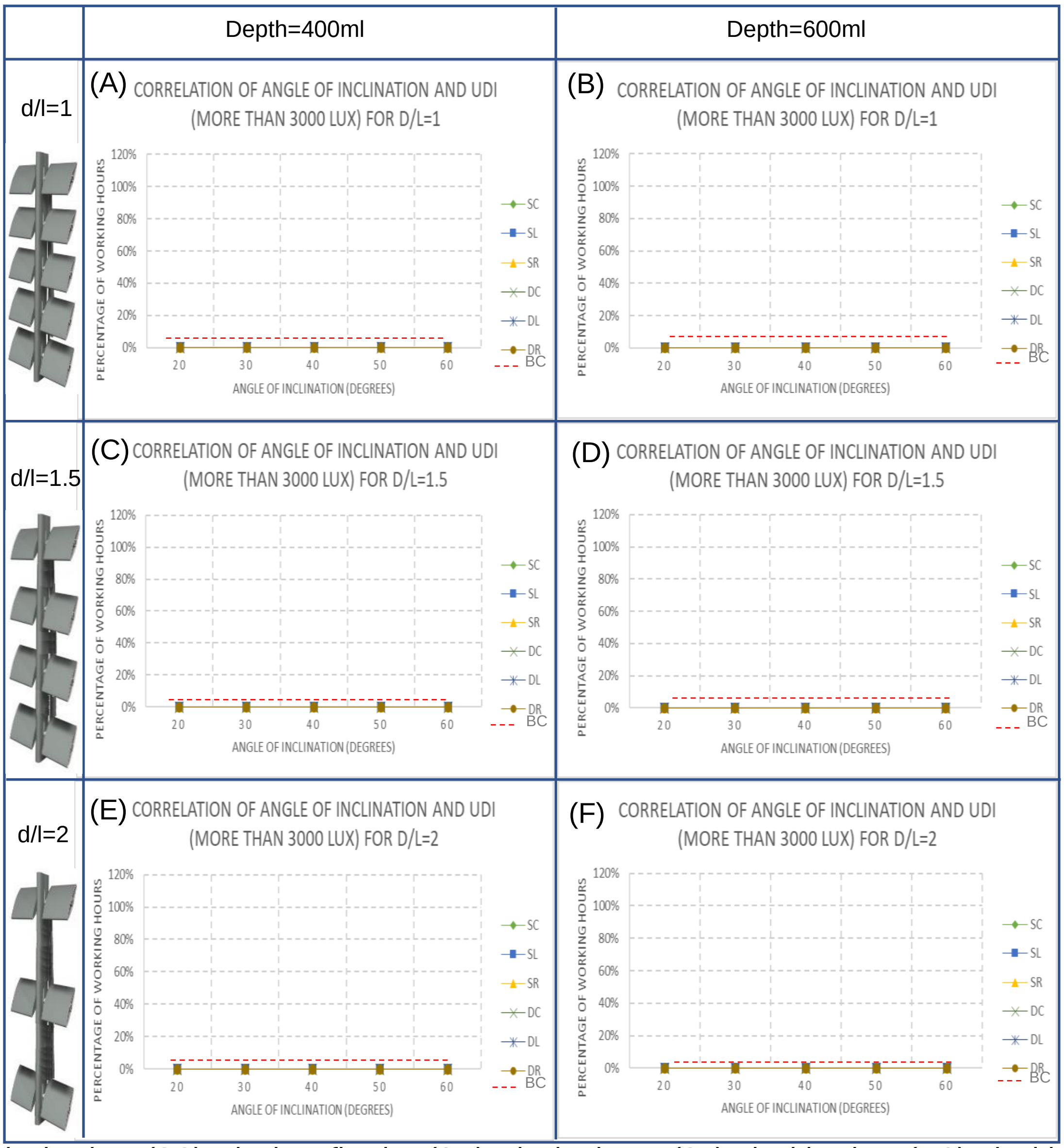
A building model representing typical office buildings in Iraq, with a main north south orientation with 100% WWR, was used for $UDI_{more\ than\ 3000\ lux}$ range analysis. IFS configurations are set up on the south-facing façade. The inclination angle of the blades (PVSDs) vary from 20° to 60° inclusive with 10° intervals for two depths of 400mm and 600mm. These settings were probed for d/l ratios of 1, 1.5 and 2. These configurations are presented for the six glazing systems under investigations; namely single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), and double-low e (DL), bringing the total number of possible combinations for energy simulation to 90. Figure 6.27 shows the percentage of the total annual working hours, where UDI exceeds 3000lux (the annual UDI*more than 3000 lux*) of those combinations. The dotted red line on each of the graphs represents the base-case (BC) scenario UDI*more than 3000 lux* that is 1.3%.

According to the systemic approach developed for this study, d/l=1 to 2, and depth 400mm and 600mm were investigated in a group for studying the output (UDI*more than 3000 lux*) for different glazing systems and with different inclination angles, as presented in Figure 6.27 A to F. The outliers, best-case scenario and worst-case scenario are discussed vertically (for different depths in each d/l ratio), horizontally (for different d/l ratios in each depth), and in a cross-sectional overall comparison of all combinations, as follows:

d/l analysis:

Clearly most of the interventions of IFS configurations on the south-facing façade have shown that none of the combinations exceeded the UDI*more than 3000 lux* on the south-facing façade. This suggests that no risk of glare is likely to happen at all. This might look unrealistic. However, it can be substantiated in two ways. Firstly the literature, on many occasions, suggests that when shading devices are properly set up, they could provide some view to the outside and at the same time they could efficiently prevent glare, especially when the shading device type is horizontal louvres, such as in this study. This finding conforms to the findings of González and Fiorito (2015) where an office building model with horizontal louvres was simulated for Australia and the illuminance levels never exceeded the upper threshold of 3000lux. Torreggiani et al. (2012) also studied similar cases which did not exceed that threshold either. Another example is a study conducted by Atzeri et al. (2014) where simulations were performed for an office building in Rome's climatic conditions and it was found that the shading typology used makes the hours of discomfort nil, no matter if they are internal or external. Secondly, the sun azimuth is higher in the working hours during each single day than it is in the early morning or late evening, making the occurrence of discomfort glare less likely.

It can therefore be concluded that no effect was recorded in the UDI*more than 3000 lux* when d/l ratio is changed where IFS configurations are to be used in the façade design in the context of the study. Hence, no correlation between d/l ratio and UDI*more than 3000 lux.*



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), base-case (BC), ratio of the depth to the distance between blades (d/l)

Figure 6.27 Useful daylight illuminance UDI: more than 3000 lux

Depth analysis:

A similar pattern of performance of the glazing types can be spotted at both depths (400mm and 600mm) for all the scenarios. This pattern does not change when the angle of inclination is changed or the depth. This also means that no effect was observed in UDI$_{\textit{more than 3000 lux}}$ due to the change in the angle of inclination or the depth.

Overall cross-sectional analysis:

To conclude, the effect of an increase of the distance between PVSDs is the most influential factor when it comes to daylight availability in indoor spaces where $UDI_{more\ than\ 3000\ lux}$ is to be evaluated. This conclusion needs to be examined statistically and proven valid, which what phase three of the analysis intends, where the Sensitivity Analysis (SA) will be conducted to highlight the importance of each variable and the percentage of the effect the change of each of the influential variables would have on the output variables.

6.6 Phase two: decisional synopsis

This phase elaborates on the conjoint performance of different combinations of parameters, especially when some parameters from an upper systemic level, such as orientation or WWR, are considered. This is crucially important in this research because it is where one of the most important contributions lie and it is important because the non-reductionist of this research advocates that no defendable, reasonable, realistic, justifiable and objective decision can be made unless such comprehensive consideration of all involved factors and parameters are taken into account. Therefore, all the results of the simulations have been grouped systematically and ranked in the form of decisional synopses tables. A ranking is a relationship between a set of items such that, for any two items, the first is either 'ranked higher than', 'ranked lower than' or 'ranked equal to' the second. This was carried out for each orientation and for the three main WWR percentages. Within each group, sub-groups of d/l ratio are presented, with six glazing systems and five inclination angles. In each group, 90 combinations have been ranked for all assessment indicators, such as solar gain, lighting gain, cooling load, PV electricity output, energy consumption, net energy, energy saving and daylighting (UDI range). In each table, actual simulation results values were ranked from 1 (minimum) to 90 (maximum) and the top ten ranks then highlighted in red.

The ranking was conducted in Microsoft Excel as per following steps (Figure 6.28):

- Simulation results of each group have been imported from VestaPro- the IES-VE module where the simulation results are manages, organised and stored- to Microsoft Excel. Each combination of variables has been given a unique code (for details on how the coding has been used in this research please refer to section 5.5).

- The simulation results have been ranked using the 'RANK' function in Microsoft Excel as follows:

RANK(NUMBER, REF, [ORDER])

In Microsoft Excel, the RANK function syntax has the following arguments:

NUMBER: the number whose rank is to be found (the simulation result of the specific combination under investigation).

Ref: an array of, or a reference to, a list of numbers (the range of combinations in which the ranking is conducted).

Order: a number (0 or 1) specifying how to rank. If order is 0, Microsoft Excel ranks the number as if ref were a list sorted in descending order. If order is 1, Microsoft Excel the ranks number as if ref were a list sorted in ascending order.

- The usual practice in ranking is to consider the top three, four or five. However, for the comprehensiveness of the analysis of the synopses, to ensure that no two items exactly or closely match, the decision was made to consider the top ten in the rank. The top ten combinations in the rank are then highlighted in red to show the most improved options out of each 90 combinations.

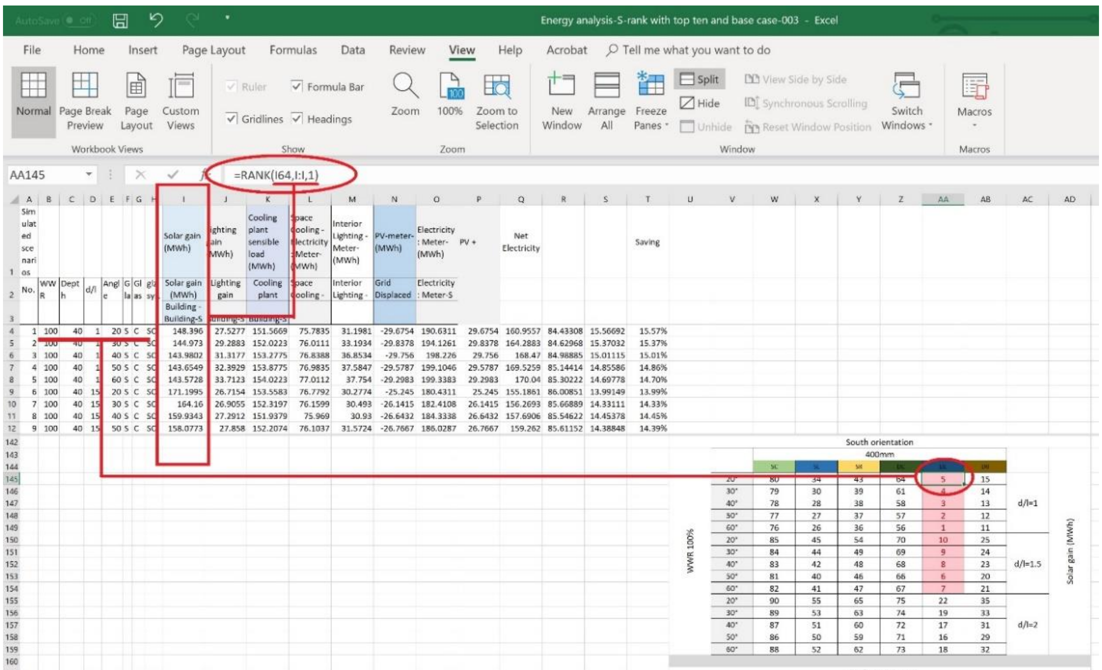


Figure 6.28 Screenshot of Microsoft Excel showing the RANK function

These synopses can be useful in different ways. For instance, if IFS were chosen and applied to a south-facing façade in a fully-glazed office building (WWR=100%), the synopses in each table will indicate how the best choices are spread over the possible variations within this combination category or table and show which of those options are more appropriate for the specific design intent or the project aspirations. For example, Table 6.1 indicates that the top ten options for reducing energy consumption are those with DL and DC glazing systems at both d/l=1.5 and 2. If, instead, the angle of inclination were chosen as the first concern[21], where the designer's target is to optimise energy consumption and PV electricity generation, then the best range of angles can be identified, i.e. 20° and 30° for energy consumption. The ranking of this range can then be compared to other parameters, such as cooling loads or PV-generated electricity for trade-off purposes, depending on the factors' dependency diagram (please see section 4.14 for details). Alternatively, if a glazing system were to be chosen for a building with IFS, while the other parameters, such as the orientation or WWR are kept constant, the synopses can confirm if this was the best glazing system for the design intent, i.e. maximising daylighting. Practical examples for each of the following sub-sections will be demonstrated in detail.

These synopses can also be used as a practical design tool for design decision making or environmentally-concerned designs to help reduce the number of configurations that can be chosen for further investigation within the specific constraints of the project under design. For example, take two combinations, X and Y. Combination X could be ranked as the 5th for net energy while combination Y ranks the 1st. However, when comparing the actual numerical value of those two combinations, X could outperform Y (please see Appendix 6 which contains all the simulation results for cross-comparison).

6.6.1 Energy performance decisional synopses

An overview on how 540 simulated models are ranked on the south-facing façade of the building model is presented and discussed first using energy performance, followed by a detailed analysis of the ranking of the combinations based on the

[21] In the hypothetical example that is being reviewed, it was assumed that the angle is the first priority hence we have started at that point.

solar gain, lighting gain, cooling load, PV-generated electricity, net energy and energy savings.

- *Energy consumption*

Table 6.1 shows the decisional synopses for the energy consumption of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Combinations with DL glazing seem to be scoring very well in the ranking across all WWR groups. Generally, combinations with coated glass (i.e. DL) are preferred over clear alternatives, although there are a few exceptions.

for WWR=100% (Table 6.1, A), there are 9 out of 10 top ranks in combinations with DL, suggesting that combinations with DL are the best solutions for lower energy consumption. This is mainly due to the improved thermal properties of DL (U-value=1.64, SHGC=0.28). When WWR decreases to 80% (Table 6.1, B), 8 out of 10 top ranks are between combinations with DL and 2 out of the 10 top ranks are in combinations with DC. When WWR is further decreased to 60% (Table 6.1, C), the number of the top ten ranks in combinations with DC increases to 3. This means that reducing the WWR will spread the best options across different glazing types due to various reasons. On one hand, this is because glazing systems with better optical properties (i.e. clear glass) can help provide more daylight and improve energy consumption much more than those with improved thermal properties (i.e. DL glazing). In other words, the effect of controlling solar gain becomes less influential compared to the effect of controlling daylighting. This will be further detailed in the next sections. On the other hand, when WWR is high, the level of daylight in the interior spaces is likely to be either at or above the threshold of 500 lux and hence the need for artificial lighting decreases. This means the contribution of additional artificial lighting to both the internal heat gains and the operational electricity for those artificial lighting decreases, which eventually improves the energy consumption.

This variation of options between DC and DL combinations gives a wider spectrum of options to the designers especially when trade-offs between energy consumption and daylighting is the design intent of a specific project.

Depth analysis:

Overall, Table 6.1 shows that there is no preference for the depth as far as energy consumption is concerned. This is because similar trends have been observed in both 400mm and 600mm depths. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential in energy consumption. This is a helpful finding that shows where design and investigation of IFS should be focused on.

d/l analysis:

The synopsis in Table 6.1 indicates that none of the combinations with d/l=1 scored in the top ten ranks. The top ten combinations are always found where d/l=1.5 and 2. This suggests a clear preference for wider distance between the blades (PVSDs). This preference comes from the fact that the wider the space between the blades the more daylight is allowed into the interior spaces but at the same time more solar gain as a result. However, solar gain can be controlled by the glazing system. Therefore, alternatives with DL glazing are preferred but with higher d/l so that acceptable levels of daylighting are provided as well. This can help make decisions about where the optimum combinations are likely to occur. A practical application of the synopses will be elaborated on in the following sections.

Inclination angle analysis:

The synopsis shows that lower inclination angles outperform higher inclination angles (Table 6.1, A) in terms of energy consumption. This trend is true for different WWR (Table 6.1, B, C). The reason is that although lower angles allow more solar gain, they also allow more daylight so that the lighting gain and the electricity needed for artificial lights are kept lower, thereby lower energy consumption. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3). The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings, the best scenario is DL at 20 degree for d/l=2 for WWR=60%.

For instance, if a decision is to be made to optimise daylighting in an office building at a south-facing façade, then the distance between the blades should be increased to 1.5 and 2. The next step is to decide which d/l is optimum and at which angle of inclination. To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed to be compared. The fourth best option, for example, in Table 6.1, B, is that with WWR=80%, depth=600mm, d/l=1.5, at 20° with DL glazing. Based on the coding system in this study this option will be referred to as S-80-60-15-20-DL. Whereas the fourth best option in Table 6.1, C is that with WWR=60%, depth=600mm, d/l=2, at 50° with DL glazing (S-60-60-2-50-DL). The actual numerical value of the annual energy consumption of the former option is 157.8095 MWh and the latter option is 157.7902. Since the difference in energy consumption between the two numbers is negligible, this will give the designer alternative options to choose from, based on other functions such as PV-generated electricity. Appendix 7 which contains all the numerical results of simulation outputs will be used for this purpose. For option S-80-60-15-20-DL, the annual PV generated electricity is 26.0091 MWh and for option S-60-60-2-50-DL is 23.9467 MWh. Therefore, the decision will be to go for the option with the higher PV electricity generation that is S-80-60-15-20-DL.

The next sections will discuss the decisional synopses of those assessed indicators in more details.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for energy consumption on its own are not sufficient to indicate the performance, but rather the consumption needs to be assessed in accordance with other influential factors, such as solar gain, cooling load and lighting gain, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influence each other please refer to section 4.14).

Table 6.1 Decisional synopses for energy consumption

A

WWR

100%

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	80	44	82	40	17	51	80	44	82	40	18	51	
30°	83	50	84	46	26	58	83	50	84	46	26	59	
40°	87	54	85	49	30	63	85	55	86	49	31	62	d/l=1
50°	89	59	86	52	34	65	87	61	88	52	35	63	
60°	90	66	88	56	39	67	90	65	89	57	39	66	
20°	61	22	74	12	4	38	60	22	74	14	4	38	
30°	69	28	77	20	7	43	68	28	77	20	7	43	
40°	72	35	78	25	8	45	72	34	78	25	8	45	d/l=1.5
50°	75	41	79	29	9	47	75	41	79	29	9	47	
60°	76	42	81	32	14	48	76	42	81	32	12	48	
20°	53	15	60	10	1	27	53	15	58	10	1	27	
30°	55	18	68	11	2	31	54	17	64	11	2	30	
40°	57	21	70	13	3	33	56	21	70	13	3	33	d/l=2
50°	62	23	71	16	5	36	67	23	71	16	5	36	
60°	64	24	73	19	6	37	69	24	73	19	6	37	

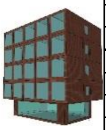
B

WWR

80%

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	79	44	82	40	21	54	79	44	82	39	20	53	
30°	83	51	84	45	26	61	83	51	84	45	26	60	
40°	85	57	86	49	30	63	85	56	86	49	30	64	d/l=1
50°	89	62	87	55	34	65	88	62	87	54	34	65	
60°	90	67	88	60	38	66	90	67	89	59	38	66	
20°	58	23	74	12	5	39	58	23	74	12	4	40	
30°	68	28	77	19	7	43	68	28	77	19	7	43	
40°	73	36	78	25	10	46	71	35	78	25	10	46	d/l=1.5
50°	75	41	80	29	15	47	75	41	80	29	14	47	
60°	76	42	81	32	18	48	76	42	81	32	17	48	
20°	50	14	64	8	1	27	50	13	63	8	1	27	
30°	52	17	69	9	2	31	52	18	69	9	2	31	
40°	53	20	70	11	3	33	55	21	70	11	3	33	d/l=2
50°	56	22	71	13	4	35	57	22	72	15	5	36	
60°	59	24	72	16	6	37	61	24	73	16	6	37	

C



WWR

60%

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	79	44	82	38	20	54	79	44	82	39	21	55	
30°	83	52	84	45	25	60	83	52	84	45	25	61	
40°	85	56	86	50	28	62	85	56	86	50	29	63	d/l=1
50°	89	61	87	53	32	65	89	62	87	54	32	65	
60°	90	66	88	58	34	64	90	66	88	58	34	64	
20°	57	22	74	11	4	40	59	23	74	12	5	40	
30°	68	29	77	19	8	43	68	27	77	19	8	43	
40°	71	36	78	26	13	46	73	36	78	26	11	46	d/l=1.5
50°	75	41	80	30	15	48	75	41	80	30	16	48	
60°	76	42	81	33	18	49	76	42	81	33	18	49	
20°	47	12	67	7	1	27	47	14	67	7	1	28	
30°	51	17	69	9	2	31	51	17	69	9	2	31	
40°	55	21	70	10	3	35	53	20	70	10	3	35	d/l=2
50°	59	23	72	14	5	37	57	22	71	13	4	37	
60°	63	24	73	16	6	39	60	24	72	15	6	38	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Generally, a clear preference of combinations with DL glazing over combinations with other glazing systems was demonstrated/evidenced/documented. It can also be observed that there are a few instances in which combinations with DC glazing are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. energy consumption, the best scenario for energy consumption is the combination with DL glazing at 20 degrees for d/l=2 for WWR=60%. Whereas if optimised energy, daylight and PV generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-80-60-15-20-DL or combination S-60-60-2-50-DL.

- *Solar gain*

Table 6.2 shows the decisional synopses for solar gain of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Combinations with DL glazing system outperform almost entirely all other HPG systems in terms of reducing solar gain across all WWR groups. In general, combinations with coated glass (i.e. DL) are preferred over clear alternatives. This is evident, for example, when WWR=100% (Table 6.2, A), the top ten ranks are those with DL glazing. This is mainly due to the improved SHGC of DL (0.28), which substantially cuts down solar gain. When WWR decreases to 80% (Table 6.2, B), the top ten ranks stay within the same combinations. Further reduction in WWR to 60% will also result in the same ranks, especially the top ten combinations. It seems that WWR has a slight influence on the ranking. For example, there is only one case where a combination with DR glazing outperforms a combination with DL glazing. Apart from the top ten options, the rankings of the rest of the combinations are ranked slightly differently when compared based on WWR, i.e. options number 20 in the ranks. However, this is not conclusive because with the decrease of WWR, the need for more artificial lighting will arise hence increased lighting gain which in turn contributes to cooling loads and eventually energy consumption. Therefore, the contribution of solar gain to energy consumption need to be assessed alongside with lighting gain to be able to have a general idea about which gain would be more influential when it comes to improving energy consumption.

Depth analysis:

Overall, Table 6.2 shows that the depth of the PVSDs seems to be the variable that least affects solar gain as the combinations in both 400mm and 600mm groups are ranked nearly similarly, suggesting no preference for the depth as far as solar gain is concerned. This is because similar trends have been observed in both 400mm and 600mm depths in the ranking. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential in solar gain. This is one of the finding that shows where design and investigation of IFS should be focused on.

d/l analysis:

The synopsis in Table 6.2, E and F indicates that none of the combinations with d/l=2 scored in the top ten ranks. The top ten combinations are always found where d/l=1 and 1.5. This suggests a clear preference for narrow space between the blades (PVSDs). This preference comes from the fact that the narrower the space between the blades the less solar radiation is allowed into the indoor spaces but at the same time less daylighting as a result. However, solar gain can be controlled by the glazing system. Therefore, alternatives with DL glazing are preferred especially with higher d/l ratio so that acceptable levels of daylighting are provided as well. This can help make decisions about where the optimum combinations are likely to occur. A practical application of the synopses will be elaborated on in the following sections.

Inclination angle analysis:

The synopsis shows that higher inclination angles outperform lower inclination angles (Table 6.2, A) in terms of solar gain. This trend, however, slightly changes when it comes to different WWR (Table 6.1, B, C). With WWR=100%, the preference of the angles starts with 60°, followed by 50°, 40°, 30°, then 20° as the least preferred angle. When WWR is decreased to 80% or 60%, the rank changes to be 50°, 60°, 40°, 30°, and then 20°. The reason is that with the decrease of WWR, the overall solar gain is decreased, leaving some space for slightly higher angles to perform similarly to that of higher angle. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3). So in order for the designers to effectively use the tables that show a variety of choices when they want to design PVSD for their IFS for office buildings by cutting down solar gain, the best scenario is to use DL glazing at 60 degree for d/l=1 for WWR=60%.

For instance, if a decision is to be made to optimise solar gain in an office building at a south-facing façade to reduce energy consumption while increasing PV-generated electricity, then the distance between the blades should be decreased to 1. The next step is to decide which WWR is optimum and at which angle of inclination. To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed for the cross-comparison. Table 6.2, A suggests that the third best option, for example, is that with WWR=100%, depth=400mm, d/l=1, at 40° with DL glazing. Based on the coding system in this study (please see section 5.5 for further details on the coding system) this option will be referred to as S-100-40-1-20-DL. Whereas the third best option in Table 6.2, C is that with WWR=60%, depth=400mm, d/l=1, at 50° with DL glazing (S-60-60-1-50-DL). Appendix 7 which contains all the numerical results of simulation outputs was used for this purpose. The actual numerical value of the annual solar gain of the former option is 49.75 MWh and the latter option is 38.99 MWh. For the same two options, PV-generated electricity for the combination S-100-40-1-20-DL is 29.7 MWh and for S-60-60-1-50-DL it is 29.6 MWh.

Table 6.2 Decisional synopses for solar gain

A

WWR 100%

	South orientation 400mm						South orientation 600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	80	34	43	64	5	15	80	33	42	63	5	15	d/l=1
30°	79	30	39	61	4	14	79	29	39	60	4	14	
40°	78	28	38	58	3	13	78	28	38	58	3	13	
50°	77	27	37	57	2	12	77	27	37	57	2	11	
60°	76	26	36	56	1	11	76	26	36	56	1	10	
20°	85	45	54	70	10	25	85	45	54	70	12	25	d/l=1.5
30°	84	44	49	69	9	24	84	44	49	69	9	24	
40°	83	42	48	68	8	23	83	43	48	68	8	23	
50°	81	40	46	66	6	20	81	40	46	66	6	20	
60°	82	41	47	67	7	21	82	41	47	67	7	21	
20°	90	55	65	75	22	35	90	55	65	75	22	35	d/l=2
30°	89	53	63	74	19	33	89	53	64	74	19	34	
40°	87	51	60	72	17	31	87	51	61	72	17	31	
50°	86	50	59	71	16	29	86	50	59	71	16	30	
60°	88	52	62	73	18	32	88	52	62	73	18	32	



B

WWR 80%

	400mm						600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	80	34	43	65	5	15	80	34	43	64	5	15	d/l=1
30°	79	32	41	63	4	14	79	32	39	63	4	14	
40°	78	30	38	62	3	13	78	30	38	61	3	13	
50°	76	28	36	59	1	11	76	28	36	59	1	11	
60°	77	29	37	60	2	12	77	29	37	60	2	12	
20°	85	45	54	70	10	25	85	45	54	70	10	25	d/l=1.5
30°	84	44	49	69	9	24	84	44	49	69	9	24	
40°	83	42	48	68	8	23	83	42	48	68	8	23	
50°	81	39	46	66	6	21	81	40	46	66	6	21	
60°	82	40	47	67	7	22	82	41	47	67	7	22	
20°	90	55	64	75	20	35	90	55	65	75	20	35	d/l=2
30°	88	52	58	73	18	31	89	53	62	74	19	33	
40°	86	50	56	71	16	26	87	51	57	72	17	27	
50°	87	51	57	72	17	27	86	50	56	71	16	26	
60°	89	53	61	74	19	33	88	52	58	73	18	31	



C

WWR 60%

	400mm						600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	80	35	43	65	5	18	80	35	43	65	5	18	d/l=1
30°	79	33	42	64	4	14	79	34	42	64	4	14	
40°	77	31	39	61	2	12	77	32	39	62	2	12	
50°	76	30	38	60	1	11	76	31	38	61	1	11	
60°	78	32	40	62	3	13	78	33	40	63	3	13	
20°	85	45	54	70	10	25	85	45	55	70	10	25	d/l=1.5
30°	84	44	50	69	9	24	84	44	51	69	9	24	
40°	83	41	48	68	8	23	83	41	48	68	8	23	
50°	81	36	46	66	6	21	81	36	46	66	6	21	
60°	82	37	47	67	7	22	82	37	47	67	7	22	
20°	90	55	63	75	20	34	90	54	60	75	20	30	d/l=2
30°	89	53	59	74	19	29	89	53	59	74	19	29	
40°	87	51	57	72	16	27	87	50	57	72	16	27	
50°	86	49	56	71	15	26	86	49	56	71	15	26	
60°	88	52	58	73	17	28	88	52	58	73	17	28	



single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Since the difference in PV-generated electricity between the two numbers is negligible, this will give the designer alternative options to choose from, based on other functions such as solar gain. Therefore, the decision will be to go for the option with the lower solar gain that is S-60-60-1-50-DL.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for solar gain can be used for optimisation purposes in accordance with other variables, such as PV-generated electricity, depending on design specifics of a project.

Generally, a clear preference of combinations with DL glazing over combinations with other glazing systems was demonstrated and substantiated with evidence. It can also be observed that all combinations vary over all WWR, d/l ratio and angle, meaning that there is quite a space for trade-offs if other assessment indicators are considered simultaneously. The trend of higher inclination angle performing better than lower angles was found slightly different but mostly true for all WWR and both depths. Table 6.2 confirms the fact that no angle is always preferred over the others but rather they first change according to the orientation, then the d/l ratio of the PVSDs and the variation of the other parameters, for example the WWR.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. controlling solar gain, the best scenario for energy consumption is the combination with DL glazing at 50° for d/l=1 for WWR=60%. Whereas if optimised solar gain control and PV generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-100-40-1-40-DL or combination S-60-40-1-50-DL.

- *Lighting gain*

Table 6.3 shows the decisional synopses for lighting gain of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination’s simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Combinations with SC glazing seem to be scoring very well in the ranking across all WWR groups, followed by DC. Generally, combinations with clear glass (i.e. SC) are preferred over other reflective or coated alternatives. For WWR=100% (Table 6.3, A), there are 8 out of 10 top ranks in combinations with SC, suggesting that combinations with SC are the best solutions for lower lighting gain. This is mainly due to the high visual transmittance SC (T_{vis}=0.88). When WWR decreases to 80% (Table 6.3, B), the number of the top ten ranks in combinations with DC increases to 3. This is also true when WWR is further decreased to 60% (Table 6.3, C). This means that reducing the WWR will spread the best options across different glazing types due to various reasons. On one hand, this is because glazing systems with better optical properties (i.e. clear glass) can help provide more daylight. On the other hand, when WWR is high, the level of daylight in the interior spaces is likely to be either at or above the threshold of 500 lux and hence the need for artificial lighting decreases. This means the contribution of additional artificial lighting to the internal heat gains decreases, which eventually improves the energy consumption.

This variation of options between SC and DC combinations gives a wider spectrum of options to the designers especially when trade-offs between energy consumption and daylighting is the design intent of a specific project.

Depth analysis:

Overall, Table 6.3 shows that there is no preference for the depth as far as lighting gain is concerned. This is because mostly similar trends have been observed in both 400mm and 600mm depths, with little exceptions. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential on lighting gain. This finding can help identify where design and investigation of IFS should be focused on.

d/l analysis:

The synopsis in Table 6.3, A and B indicates that none of the combinations with d/l=1 scored in the top ten ranks. The top ten combinations are always found where d/l=1.5 and 2. This suggests a clear preference for wider distance between the blades (PVSDs). This preference comes from the fact that the wider the space between the blades the more daylight is allowed into the interior spaces, though more solar gain as a result. Alternatives with clear glazing are preferred (i.e. SC and DC) regardless of WWR, d/l ratio or the angle. This is due to high T_{vis} of clear glass compared to other types. With higher d/l, acceptable levels of daylighting can be provided. However, this needs to be assessed with a specific inclination angle, which will be further detailed in the following sub-section. This can help make decisions about where the optimum combinations are likely to occur. Furthermore, a practical application of the lighting gain synopsis will be elaborated on in the following sections.

Inclination angle analysis:

The synopsis shows that lower inclination angles outperform higher inclination angles (Table 6.3, A) in terms of lighting gain. This trend is true for different WWR (Table 6.3, B, C). The reason is that although lower angles (i.e. 20°) allow more daylight so that the lighting gain is kept lower.

The decisional synopses of the combinations based on lighting gain confirms the trends identified earlier in the energy consumption or solar gain, suggesting a fairly wide range of optimum options when it comes to deciding about the angle of inclination. For example, in series d/l=2, regardless of the WWR, the first three best options scored at 20° then 30° then 40°. Generally speaking, the optimum angles for improved (reduced) lighting gain are those with a small inclination; however, this decision should be made with the d/l ratio, which governs the distance between the PVSDs. This because increasing the d/l ratio will minimise the impact of change in the angle. The best option for IFS in this case is therefore SC glazing at 20° for d/l=2 for any WWR. Moreover, the tables can be used as a practical decision tool to make design decisions based on the design targets to achieve optimum solutions when trade-oof between different outputs is aimed at.

For instance, if a decision is to be made to optimise daylighting in an office building at a south-facing façade, the two most reasonable options are to either go for a lower d/l (i.e. 1.5) with lower angle (i.e. 20°) or higher d/l (i.e. 2) with higher angle (i.e. 40°). To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed for the comparison.

Table 6.3 Decisional synopses for lighting gain

A — WWR 100%



South orientation

	Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR
d/l=1	20°	14	36	73	29	43	83	12	39	72	29	43	83
d/l=1	30°	38	50	80	44	55	85	37	51	80	44	57	86
d/l=1	40°	57	60	84	54	69	88	47	61	84	55	68	88
d/l=1	50°	63	70	85	62	76	89	56	70	85	64	75	89
d/l=1	60°	65	77	87	72	79	90	76	77	87	73	79	90
d/l=1.5	20°	4	18	51	11	31	68	3	19	52	9	30	67
d/l=1.5	30°	7	28	58	16	35	75	5	28	59	14	35	74
d/l=1.5	40°	10	37	64	24	41	78	8	36	63	23	41	78
d/l=1.5	50°	20	40	71	33	45	81	16	40	69	33	45	81
d/l=1.5	60°	27	42	74	39	47	82	26	42	71	38	48	82
d/l=2	20°	1	17	46	8	22	56	1	15	46	6	22	58
d/l=2	30°	2	19	48	9	25	59	2	17	49	7	25	60
d/l=2	40°	3	21	49	12	30	61	4	20	50	10	31	62
d/l=2	50°	5	23	52	13	32	66	18	24	53	11	32	65
d/l=2	60°	6	26	53	15	34	67	21	27	54	13	34	66

B — WWR 80%



South orientation

	Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR
d/l=1	20°	20	41	75	33	46	83	18	40	75	33	45	83
d/l=1	30°	38	54	80	45	59	86	38	54	80	46	58	86
d/l=1	40°	50	63	84	56	69	88	49	62	84	55	69	88
d/l=1	50°	58	71	85	66	76	89	59	72	85	67	76	89
d/l=1	60°	68	77	87	72	79	90	68	77	87	74	79	90
d/l=1.5	20°	4	21	53	11	28	67	3	19	52	10	27	66
d/l=1.5	30°	8	29	57	17	35	74	7	29	57	16	35	73
d/l=1.5	40°	14	36	65	26	40	78	13	36	63	26	41	78
d/l=1.5	50°	23	39	70	34	44	81	22	39	70	34	44	81
d/l=1.5	60°	30	42	73	37	48	82	30	42	71	37	48	82
d/l=2	20°	1	13	43	7	18	55	1	14	43	8	20	56
d/l=2	30°	2	16	47	9	24	60	2	17	47	9	24	60
d/l=2	40°	3	19	49	10	27	61	4	21	50	11	28	61
d/l=2	50°	5	22	51	12	31	62	5	23	51	12	31	64
d/l=2	60°	6	25	52	15	32	64	6	25	53	15	32	65

C — WWR 60%



South orientation

	Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR
d/l=1	20°	24	42	75	35	49	83	25	41	75	35	48	83
d/l=1	30°	39	54	80	46	60	87	40	54	80	46	60	87
d/l=1	40°	52	64	84	56	69	88	51	63	84	56	69	88
d/l=1	50°	59	72	85	66	76	89	58	72	85	65	76	89
d/l=1	60°	65	77	86	71	78	90	67	77	86	71	78	90
d/l=1.5	20°	4	20	53	11	27	68	4	20	53	11	29	68
d/l=1.5	30°	9	30	58	19	34	74	9	26	57	18	34	74
d/l=1.5	40°	17	36	67	28	40	79	16	36	66	28	39	79
d/l=1.5	50°	25	38	70	33	44	81	24	38	70	33	44	81
d/l=1.5	60°	32	43	73	37	47	82	31	42	73	37	47	82
d/l=2	20°	1	12	41	5	16	55	1	12	43	5	17	55
d/l=2	30°	2	15	45	8	21	57	2	15	45	8	22	59
d/l=2	40°	3	18	48	10	26	61	3	19	49	10	27	61
d/l=2	50°	6	22	50	13	29	62	6	21	50	13	30	62
d/l=2	60°	7	23	51	14	31	63	7	23	52	14	32	64

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).
Red cells represent the top ten ranks in each combination group.

Based on the coding system in this study, the two combinations that are going to be used for this comparison are S-100-40-15-20-SC and S-100-40-2-40-SC (Table 6.3, A). The actual numerical value of the lighting gain of the former option is 26.72 MWh and the latter option is 26.70 MWh. The exact same UDI 300-300 lux is achieved for each of them, meaning that the same daylight level is available using both combinations. Since the difference in lighting gain between the two numbers is negligible, this will give the designer alternative options to choose from, based on other functions such as PV-generated electricity. Appendix 7 which contains all the numerical results of simulation outputs will be used for this purpose. For the first option, the annual PV-generated electricity is 25.25 MWh, whereas for the second it is 22.19 MWh. Therefore, the decision will be to go for the option with the higher PV electricity generation that is S-100-40-15-20-SC.

Overall analysis:

Generally, a clear preference of combinations with SC glazing over combinations with other glazing systems was demonstrated and documented. It can also be observed that there are a few instances in which better performing combinations with DC glazing are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. lighting gain, the best scenario therefore is the combination with SC glazing at 20 degrees for d/l=2 for WWR=60%. Whereas if optimised daylight and PV generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-100-40-15-20-SC or combination S-100-40-2-40-SC.

The ranking of combinations based on lighting gain slightly differs when changing the depth of the PVSDs from 400mm to 600mm, except for WWR=60%, where they are the same.

The trend of the accumulation of the top ten combinations does not change when changing WWR. Table 6.3 shows that there is a correlation between d/l and inclination angle when it comes to lighting gain. In other words, increasing the angle results in the need for a bigger distance between PVSDs (d/l) and vice versa.

It is worth mentioning that although the tables show the ranking of combinations only, there is still a need to compare the ranking against the actual values of the combinations in order to have a clear and detailed idea about the performance trends within a certain assessed indicator, to be able to strike a balance between the trade-offs based on the objective of the design project.

Needless to say, if two combinations are to be compared between two different groups of WWR or depth, the actual numerical values of lighting gain should be checked to be able to tackle the intended energy saving accurately, rather than depending solely on the score in the ranking tables.

- *Cooling load*

Table 6.4 shows the decisional synopses for the annual cooling load of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

A clear preference for combinations with DL over all other types of HPG is observed as the top ten configurations are gathered around this glazing system in the ranking across all WWR groups. Generally, combinations with coated glass (i.e. DL) are preferred over clear alternatives. This is mainly due to the improved thermal properties of DL (U-value=1.64, SHGC=0.28).

The ranking of combinations based on cooling load slightly changes across different WWRs but generally no significant variation in the synopses is noticed when comparing different WWR combinations for cooling loads, with some exceptions. For WWR=100% (Table 6.4, A), there are 5 out of 10 top ranks in combinations with d/l=1.5, suggesting that combinations with the distance between blades that is 1.5 times the depth of the blades is preferable over smaller distances (i.e. d/l=1) and larger distances (i.e. d/l=2) and they are the best solutions for lower cooling load hence improved energy consumption. The reason for this is that d/l=1.5 is a balanced ratio between the lower one which increases the lighting gain and also the larger one which increases the solar gain. When WWR decreases to 80% (Table 6.4, B), both d/l=1.5 and 2 have 4 out of 10 top ranks in each of them. When WWR is further decreased to 60% (Table 6.4, C), similar results are achieved. This means that reducing the WWR will spread the best options across different d/l ratio due to various reasons. On one hand, this is because increased d/l can help provide more daylight, and improve energy consumption by reducing cooling load much more than lower d/l. In other words, the effect of controlling solar gain becomes less influential compared to the effect of controlling daylighting with low d/l (1) and vice versa with large d/l (2). On the other hand, when WWR is high, the level of daylight in the interior spaces is likely to be either at or above the threshold of 500 lux and hence the need for artificial lighting decreases. This means the contribution of additional artificial lighting to the internal heat gains and thereby cooling load improves energy consumption.

This variation of options of combinations with d/l at different WWR groups gives a wider spectrum of options to the designers especially when trade-offs between energy consumption and daylighting is the design intent of a specific project.

Depth analysis:

Overall, Table 6.4 shows that there is no preference for the depth as far as cooling load is concerned. This is because only little change in the ranking of combinations is observed as a result of changing the depth of the PVSDs from 400mm to 600mm. For example, a combination of WWR=60%, depth=400mm, d/l=2, angle=50° scores the tenth best combination, whereas it shifts up to the eighth best combination when the depth changes to 600mm.

similar trends have been observed in both 400mm and 600mm depths. This is probably because the other parameters, such as the angle of inclination, d/l ratio, glazing and WWR, are much more influential in cooling load.

d/l analysis:

The synopsis in Table 6.4 indicates no preference for the ratio d/l as the top ten combinations are fairly scattered around different d/l ratios. However, this needs to be assessed in accordance with WWR. As explained in the previous sub-section, it seems that the decrease in WWR will result in making combinations with higher d/l better options. Moreover, solar gain can be controlled by the glazing system. Therefore, alternatives with DL glazing are preferred but with higher d/l so that acceptable levels of daylighting are provided as well. This can help make decisions about where the optimum combinations are likely to occur. A practical application of the synopses will be elaborated on in the following sections.

Inclination angle analysis:

Clearly Table 6.4 indicates that smaller inclination angles seem to be better, i.e. 20° and 30°. The angle of inclination has a noticeable influence on the cooling loads but varies depending on different d/l ratios. For example, when d/l=1, both 50° and 60° did not score a ranking within the top five combinations, whereas when d/l=1.5, all angles could score within the top five rankings. When d/l=2, a lower number of combinations score within the top five, with some exceptions, such as 40° and 30° for WWR=100%, where they scored ninth and tenth respectively.

This should also be assessed in accordance with the actual numerical values of the cooling loads of that specific combination, in order to be able to conclude which are the best preferences (All numerical values of the simulation results are presented in Appendix 7).

For example, for both WWR=80% and 60%, with d/l=1.5, the trend slightly changes, rendering the combination with a 20° inclination angle to be the best in both 400mm and 600mm depths. The reason is that although lower angles allow more solar gain, they also allow more daylight so that the lighting gain and the electricity needed for artificial lights are kept lower, thereby lower energy consumption. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3).

The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design IFS for office buildings, the best scenario is a combination with DL glazing, at 20 degree for d/l=1.5 for WWR=60%.

Whereas if optimised daylighting in an office building at a south-facing façade is aimed at, then the distance between the blades should be increased to 1.5 and 2. The next step is to decide which d/l is optimum and at which angle of inclination. To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed to be compared.

the same option, for example the sixth best option, is to be compared over different WWR percentages. This option is that with WWR=100, depth 400mm, d/l=1, at 30° with DL glazing. Based on the coding system in this study this option will be referred to as S-100-40-1-30-DL (Table 6.4, A). The sixth option with WWR=80% is that with WWR=80, depth 400mm, d/l=1.5, at 50° with DL glazing (S-80-40-15-50-DL) (Table 6.4, B). option six with WWR=60 is that with depth 400mm, d/l=2, at 20 with DL glazing (S-60-40-2-20-DL) (Table 6.4, C). The actual numerical value of the annual cooling load for those combinations are as follows:

S-100-40-1-30-DL = 114.35 MWh
S-80-40-15-50-DL = 111.9 MWh
S-60-40-2-20-DL = 109.29 MWh

Clearly option 3 is best as far as cooling load is concerned. Since the difference in cooling load between any two numbers is not so significant, this will give the designer alternative options to choose from, based on other functions such as PV electricity generation. Appendix 7 which contains all the numerical results of simulation outputs will be used for this purpose. PV-generated electricity for those options are as follows:

S-100-40-1-30-DL = 29.84 MWh
S-80-40-15-50-DL = 26.77 MWh
S-60-40-2-20-DL = 21.06 MWh

Therefore, and depending on the design target of the specific project, the decision will be to go for either the option with the higher PV electricity generation that is S-100-40-1-30-DL.

Table 6.4 Decisional synopses of cooling loads

A

WWR

100%

South orientation

	400mm						600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	77	31	47	61	3	16	76	31	46	61	1	16	
30°	79	36	51	62	6	19	77	35	50	62	5	17	
40°	84	38	52	66	8	22	80	38	52	66	8	22	d/l=1
50°	76	39	54	69	13	24	83	39	54	68	13	23	
60°	85	41	55	70	15	25	85	41	55	70	15	25	
20°	83	34	48	68	2	20	84	34	48	69	3	20	
30°	81	32	46	64	1	17	81	32	47	64	2	18	
40°	78	33	49	63	4	18	78	33	49	63	4	19	d/l=1.5
50°	80	35	50	65	5	21	79	36	51	65	6	21	
60°	82	37	53	67	7	23	82	37	53	67	7	24	
20°	90	45	59	75	12	29	90	44	59	75	12	29	
30°	88	42	57	73	10	27	87	42	57	73	10	27	
40°	86	40	56	71	9	26	86	40	56	71	9	26	d/l=2
50°	87	43	58	72	11	28	88	43	58	72	11	28	
60°	89	44	60	74	14	30	89	45	60	74	14	30	

B

WWR

80%

South orientation

	400mm						600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	76	33	47	61	3	16	76	31	46	61	3	16	
30°	79	36	50	64	8	20	78	35	50	63	7	18	
40°	82	38	52	67	12	22	81	38	52	67	12	22	d/l=1
50°	84	43	54	69	14	24	84	43	54	69	14	23	
60°	85	44	57	70	15	25	85	44	56	70	15	24	
20°	81	32	48	66	1	19	82	33	47	65	1	20	
30°	78	31	46	62	2	17	79	32	48	62	2	17	
40°	77	34	49	63	4	18	77	34	49	64	4	19	d/l=1.5
50°	80	35	51	65	6	21	80	36	51	66	6	21	
60°	83	37	53	68	11	23	83	37	53	68	11	25	
20°	90	42	58	74	9	28	90	42	58	75	9	28	
30°	88	39	55	72	5	26	88	40	55	72	5	26	
40°	86	40	56	71	7	27	86	39	57	71	8	27	d/l=2
50°	87	41	59	73	10	29	87	41	59	73	10	29	
60°	89	45	60	75	13	30	89	45	60	74	13	30	

C

WWR

60%

South orientation

	400mm						600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	76	33	46	61	3	16	76	33	46	61	3	16	
30°	80	35	50	65	9	18	80	35	50	65	9	17	
40°	82	41	52	67	13	22	82	42	52	67	13	21	d/l=1
50°	84	43	54	69	14	24	84	44	55	69	14	24	
60°	85	45	55	72	15	23	85	45	57	72	15	23	
20°	79	31	48	63	1	20	79	32	47	63	1	19	
30°	77	32	47	62	2	17	77	31	48	62	2	18	
40°	78	34	49	64	4	19	78	34	49	64	6	20	d/l=1.5
50°	81	36	51	66	8	21	81	37	51	66	10	22	
60°	83	39	53	68	11	25	83	40	53	68	12	25	
20°	89	40	58	74	6	28	89	39	58	74	5	28	
30°	87	37	56	71	5	26	87	36	54	71	4	26	
40°	86	38	57	70	7	27	86	38	56	70	7	27	d/l=2
50°	88	42	59	73	10	29	88	41	59	73	8	29	
60°	90	44	60	75	12	30	90	43	60	75	11	30	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for cooling load on its own are not sufficient to indicate the performance, but rather the consumption needs to be assessed in accordance with other influential factors, such as solar gain, lighting gain and PV electricity generation, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influences each other please refer to section 4.14).

Generally, the cooling load decisional synopses conform to the main trend found in solar gain performance, which highlights the influence of the HPG used. A clear preference of combinations with DL glazing over combinations with other glazing systems was demonstrated. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths. This, however, depends on the variation of other variables, such as d/l ratio.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. cooling load, the best scenario for improved energy consumption is therefore the combination S-60-40-2-20-DL. Whereas if optimised energy and PV-generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-100-40-1-30-DL or S-80-40-15-50-DL.

- *PV-generated electricity*

Table 6.5 shows the decisional synopses for PV-generated electricity of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

The decisional synopses of PV-generated electricity show identical results for all WWR groups and all HPG systems; this is common sense because it is independent of glazing systems and WWR. Those variables are part of the main façade and are located behind the PVSDs so they have no influence on or create obstacles to the PV cells, whereas the distance between the PVSDs, the depth of the PVSDs and the angle of inclination of the PVSDs, are the variables with a direct impact on PV-generated electricity, which will be discussed next.

Depth analysis:

Overall, Table 6.5 shows that there is no significant preference of depth of the PVSD as the rankings in each group are similar, with some small exceptions, e.g. angle of inclination of 20˚ shows the fourth preference when the depth is 600mm, while it is the third for the depth=400mm. This could be because of the self-shading effect that the wider depth would cause. Needless to say, the synopses are used as a design decision tool and the ranking is done for each group of 90 combinations and they do not indicate the actual values of the PV-generated electricity because the results in phase one prove that the greater the depth the more electricity is generated. For more specific details on the actual numerical values of PV-generated electricity, please see Appendix 7.

d/l analysis:

The synopsis in Table 6.5 indicates that none of the combinations with d/l=2 scored in the top ten ranks. The top ten combinations are always found where d/l=1 and 1.5. This suggests a clear preference for narrow distance between the blades (PVSDs). This preference comes from fact that narrow space (low d/l ratio) provides higher number of blades hence more PV cells, thereby increased PV-generated electricity.

Inclination angle analysis:

The synopsis shows that mostly lower inclination angles outperform higher inclination angles (Table 6.5) in terms of PV-generated electricity. This trend is true for different WWR (Table 6.5, A, B and C). The reason is that although lower inclination angle will cause more shading on the PV panels, the increased number of the panels will help overcome this issue. This has been simulated and checked in IES-VE as explained in section 5.3.6. Combinations with d/l=1 are those that score the top five combinations, varying from 30° as the top option, followed by 40°, 20°, 50° and 60°. When the d/l ratio is increased to 1.5, options 6-10 are still achievable. For example, 50° comes out as the best angle for PV output, although it is sixth out of all 15 combinations. The following best option would be 40° followed by 60° then 30° and 20°. All combinations within the series of d/l=2 are the worst in terms of electricity generation.

As the tables are going to be used by designers to help make decisions based on their design targets, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings, the best scenario for optimum PV-generated electricity is that with 30 degree for d/l=1 with 600mm depth, for any WWR or glazing system.

Alternatively, if a decision is to be made to optimise daylighting as well as PV-generated electricity in an office building at a south-facing façade, then both actual numerical numbers should be considered alongside with the synopses. The next step is to decide which angle is optimum for each optimisation function (output), in this example, they are lighting gain and PV-generated electricity. To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed to be compared. The third best option, for example, in Table 6.5, A, is that with WWR=100%, depth=400mm, d/l=1, at 20° with DL glazing (as explained earlier in the previous sub-sections, no preference for glazing when PV-generated is aimed at, therefore it is reasonable to use a glazing with improved thermal properties and reasonable optical properties, such as DL). Based on the coding system in this study this option will be referred to as S-100-40-1-20-DL. Whereas the third best option in Table 6.5, A is that with WWR=100%, depth=600mm, d/l=1, at 50° with DL glazing (S-100-60-1-50-DL). The actual numerical value of PV-generated electricity of the former option is 29.68 MWh and the latter option is 30.89 MWh. For the former option, the annual lighting gain is 30.4 MWh and for the latter option is 34.5 MWh. The improvement in MWh due to optimised PV-generated electricity is 1.21 MWh. Whereas it is 4.1 MWh due to optimised lighting gain. Therefore, if the design target is a multi-objective design, the decision would then be to go for S-100-40-1-20-DL. However, if improving PV-generated electricity is the aim of a design project, then the decision would be to go for S-100-60-1-50-DL.

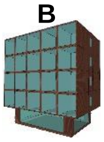
Table 6.5 Decisional synopses of PV-generated electricity

A

WWR 100%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	South orientation 600mm SC	SL	SR	DC	DL	DR	
20°	3	3	3	3	3	3	4	4	4	4	4	4	d/l=1
30°	1	1	1	1	1	1	1	1	1	1	1	1	
40°	2	2	2	2	2	2	2	2	2	2	2	2	
50°	4	4	4	4	4	4	3	3	3	3	3	3	
60°	5	5	5	5	5	5	5	5	5	5	5	5	
20°	10	10	10	10	10	10	10	10	10	10	10	10	d/l=1.5
30°	9	9	9	9	9	9	9	9	9	9	9	9	
40°	7	7	7	7	7	7	7	7	7	7	7	7	
50°	6	6	6	6	6	6	6	6	6	6	6	6	
60°	8	8	8	8	8	8	8	8	8	8	8	8	
20°	15	15	15	15	15	15	15	15	15	15	15	15	d/l=2
30°	13	13	13	13	13	13	13	13	13	13	13	13	
40°	11	11	11	11	11	11	11	11	11	11	11	11	
50°	12	12	12	12	12	12	12	12	12	12	12	12	
60°	14	14	14	14	14	14	14	14	14	14	14	14	

B



WWR 80%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	South orientation 600mm SC	SL	SR	DC	DL	DR	
20°	3	3	3	3	3	3	4	4	4	4	4	4	d/l=1
30°	1	1	1	1	1	1	1	1	1	1	1	1	
40°	2	2	2	2	2	2	2	2	2	2	2	2	
50°	4	4	4	4	4	4	3	3	3	3	3	3	
60°	5	5	5	5	5	5	5	5	5	5	5	5	
20°	10	10	10	10	10	10	10	10	10	10	10	10	d/l=1.5
30°	9	9	9	9	9	9	9	9	9	9	9	9	
40°	7	7	7	7	7	7	7	7	7	7	7	7	
50°	6	6	6	6	6	6	6	6	6	6	6	6	
60°	8	8	8	8	8	8	8	8	8	8	8	8	
20°	15	15	15	15	15	15	15	15	15	15	15	15	d/l=2
30°	13	13	13	13	13	13	13	13	13	13	13	13	
40°	11	11	11	11	11	11	11	11	11	11	11	11	
50°	12	12	12	12	12	12	12	12	12	12	12	12	
60°	14	14	14	14	14	14	14	14	14	14	14	14	

C

WWR 60%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	South orientation 600mm SC	SL	SR	DC	DL	DR	
20°	3	3	3	3	3	3	4	4	4	4	4	4	d/l=1
30°	1	1	1	1	1	1	1	1	1	1	1	1	
40°	2	2	2	2	2	2	2	2	2	2	2	2	
50°	4	4	4	4	4	4	3	3	3	3	3	3	
60°	5	5	5	5	5	5	5	5	5	5	5	5	
20°	10	10	10	10	10	10	10	10	10	10	10	10	d/l=1.5
30°	9	9	9	9	9	9	9	9	9	9	9	9	
40°	7	7	7	7	7	7	7	7	7	7	7	7	
50°	6	6	6	6	6	6	6	6	6	6	6	6	
60°	8	8	8	8	8	8	8	8	8	8	8	8	
20°	15	15	15	15	15	15	15	15	15	15	15	15	d/l=2
30°	13	13	13	13	13	13	13	13	13	13	13	13	
40°	11	11	11	11	11	11	11	11	11	11	11	11	
50°	12	12	12	12	12	12	12	12	12	12	12	12	
60°	14	14	14	14	14	14	14	14	14	14	14	14	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for PV-generated electricity on its own are not sufficient to indicate the performance, but rather the consumption needs to be assessed in accordance with other influential factors, such as solar gain, cooling load and lighting gain, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influence each other please refer to section 4.14).

Generally, a clear preference of combinations with d/l=1 over other ratios was demonstrated and backed up with evidence. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths, although a few instances in which combinations with higher angles are found. This, however, depends on the variation of other variables, such as d/l and depth.

Finally, when it comes to PV-generated electricity, the optimum solution might not be the same ones which are optimum for energy performance. Therefore, a balance is needed and that comes from a comprehensive and holistic approach to analysing the most influential variables and their contributing factors.

- *Net energy*

As explained earlier, in phase one of the analysis, the net energy is the amount of electricity used by the building, subtracting the electricity generated by the photovoltaics. Table 6.6 shows the decisional synopses for the net energy of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination’s simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

The ranking of the combinations varies as a result of different WWR. Combinations with a DL glazing system show a clear advantage over other HPG systems. Generally, combinations with coated glass (i.e. DL) are preferred over clear alternatives. This confirms that HPG has a significant influence on the outcomes. However, this needs to be quantified in order to ensure that design decisions are accurately justified. This will be discussed in the next phase of the analysis where Sensitivity Analysis are conducted.

When WWR is decreased to 80%, no clear influence on the ranks is observed. However, when WWR if further reduced to 60%, the top ten ranks slightly change. This could be because of the reduced transparent parts of the façade compared to the opaque parts which in turn increases the overall U-value of the building façade hence improved energy consumption, thereby improving the net energy.

Depth analysis:

Overall, the decisional synopses in Table 6.6 show no preference for the depth as far as net energy is concerned. This is because similar trends have been observed in both 400mm and 600mm depths. However, some differences arise when comparing the two depths, such as top ninth combination and top tenth, which swap their rank across different WWR. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential in net energy. This finding could help improve where design and investigation of IFS should be focused on.

d/l analysis:

The combinations at different d/l ratios show a preference for larger d/l over smaller ones. This also varies between different WWR. For example, combinations with WWR=100% show only one out of the top ten combinations within d/l=1 and the rest are within d/l=1.5 and 2. The same pattern occurs with WWR=80%. When WWR=60%, the top ten options are evenly distributed around d/l=1. For d/l=1.5 and depth=400mm, four out of the top ten combinations are found, whereas for depth=600mm, only three combinations score in the top ten. For d/l=2, a slightly different pattern is found, i.e. half of the top ten are found around the depth of 400mm and only four out ten are around 600mm. This preference comes from the fact that the wider the space between the blades the more daylight is allowed into the interior spaces but at the same time more solar gain as a result. However, solar gain can be controlled by the glazing system. Therefore, alternatives with DL glazing are preferred but with higher d/l so that acceptable levels of daylighting are provided as well. This can help make decisions about where the optimum combinations are likely to occur. A practical application of the synopses will be elaborated on in the following paragraph.

For instance, when a decision is made to choose WWR=100% and the aim is to strike a balance between energy consumption and generation, the net energy synopses table can help in deciding about whether increasing the distance between blades in the aim of providing more daylighting is a better option than using greater number of PVSDs but with more generated electricity. For example, if option 5 is to be compared between two different groups, the first group is the combination where d/l=2, depth=400mm and the inclination angle=20°, whereas option 5 in the second group is found with the combinations of d/l=2, depth=600mm and the inclination angle=40˚.

No decision can be made up to this point until the actual numerical value of each option is compared. The actual numerical value of option 5 with depth=400mm is 135.33 MWh whereas option 5 with depth=600mm is 134.1 MWh. In this case the decision would then be to go for increasing the distance to be double the depth – as d/l=2 suggests – which is a better option than the first one.

Inclination angle analysis:

The synopsis shows that lower inclination angles outperform higher inclination angles (Table 6.6, A) in terms of net energy. It can be seen that the optimum combination in terms of net energy is achieved at the 20° angle, regardless of the WWR, d/l ratio and depth. However, this needs to be assessed in accordance with d/l ratio. For example, within d/l=1 group, the only one out of the top ten combinations is found at the angle of 20° as the fifth combination, whereas d/l increasing to 1.5 results in four more top-ranked combinations, ranging between 20° and 50°. A further increase of d/l=2 will result in having a wider range of variation of the optimum angle of inclination (20° to 60°). The general observation in this synopses is that there is no preferable d/l ratio and the optimum solutions could be found across all ranges of the d/l ratio. This depends on the project objectives.

Table 6.6 Decisional synopses for net energy

A

WWR 100%

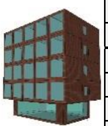
	South orientation 400mm						South orientation 600mm							
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR		
20°	74	33	81	21	5	48	75	35	82	23	6	48	d/l=1	
30°	82	44	84	35	11	54	80	45	84	34	11	53		
40°	87	52	85	42	14	57	85	51	86	42	13	57		
50°	89	56	86	49	17	58	87	56	88	49	16	58		
60°	90	59	88	55	23	60	90	59	89	55	24	60		
20°	61	18	70	13	1	38	61	21	71	14	1	39	d/l=1.5	
30°	62	24	76	15	2	41	62	28	77	15	2	44		
40°	64	32	78	16	6	46	66	33	79	17	7	47		
50°	68	36	80	22	9	50	70	37	81	25	10	52		
60°	73	39	83	29	12	53	74	41	83	31	12	54		
20°	65	27	69	25	3	40	64	27	67	20	3	38	d/l=2	
30°	63	28	72	19	4	43	63	26	69	18	4	40		
40°	66	31	75	20	7	45	65	29	72	19	5	43		
50°	67	34	77	26	8	47	68	32	76	22	8	46		
60°	71	37	79	30	10	51	73	36	78	30	9	50		

B

WWR 80%

	South orientation 400mm						South orientation 600mm							
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR		
20°	72	34	80	24	5	47	72	35	81	23	6	46	d/l=1	
30°	81	41	84	35	11	53	80	42	84	34	11	53		
40°	85	50	86	40	15	57	85	50	86	38	14	57		
50°	88	56	87	48	17	58	88	56	87	48	19	58		
60°	90	60	89	55	23	59	90	60	89	54	24	59		
20°	61	21	70	12	1	38	61	22	73	13	1	40	d/l=1.5	
30°	62	27	76	14	2	42	64	29	77	15	4	45		
40°	67	33	79	18	7	46	67	33	79	20	8	49		
50°	69	37	82	25	9	51	70	37	82	28	10	52		
60°	74	39	83	31	13	54	75	41	83	32	12	55		
20°	64	28	71	20	3	43	63	25	69	17	2	39	d/l=2	
30°	63	29	73	16	4	44	62	26	71	16	3	43		
40°	65	30	75	19	6	45	65	30	74	18	5	44		
50°	66	32	77	22	8	49	66	31	76	21	7	47		
60°	68	36	78	26	10	52	68	36	78	27	9	51		

C



WWR 60%

	South orientation 400mm						South orientation 600mm							
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR		
20°	70	33	78	23	3	42	69	34	79	23	4	43	d/l=1	
30°	79	39	83	32	8	48	78	39	83	31	9	49		
40°	85	45	86	37	14	53	85	44	86	37	13	54		
50°	89	54	87	43	16	56	89	53	87	42	18	56		
60°	90	59	88	50	19	58	90	60	88	50	20	58		
20°	61	22	71	11	1	41	61	24	73	12	1	41	d/l=1.5	
30°	64	27	75	15	2	44	65	28	76	17	5	46		
40°	67	34	77	21	6	47	68	35	81	22	8	51		
50°	69	36	81	25	9	51	70	38	82	29	11	55		
60°	73	40	84	30	12	55	74	40	84	33	14	59		
20°	62	26	72	17	4	46	62	26	71	16	2	45	d/l=2	
30°	63	28	74	18	5	49	63	27	72	15	3	47		
40°	65	31	76	20	7	52	64	30	75	19	6	48		
50°	66	35	80	24	10	57	66	32	77	21	7	52		
60°	68	38	82	29	13	60	67	36	80	25	10	57		

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).
Red cells represent the top ten ranks in each combination group.

Overall analysis:

To summarise, as was shown in the previous sub-sections where a practical application of the synopses was attempted on, the decisional synopses for net energy on its own are not sufficient to indicate the performance, but rather the consumption needs to be assessed in accordance with other influential factors, such as solar gain, cooling load and lighting gain, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influences each other please refer to section 4.14).

Generally, a clear preference of combinations with DL glazing over combinations with other glazing systems was documented. Lower angles also showed a preference over higher ones. It can also be observed that there are a few instances in which combinations with slightly higher angles are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for both depths.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. net energy, the best scenario for net energy is the combination with DL glazing at 20 degrees for d/l=1.5 for WWR=60%. Whereas if optimised energy and daylight form the design target of a specific project, multiple options can be chosen, such as combination S-100-60-2-20-DL or combination S-100-40-2-40-DL.

- *Energy savings*

As explained in section 6.5.1 in phase one of the analysis, energy savings are calculated as the percentage of the net energy to the energy consumption, so that it accounts for PV-generated electricity. Table 6.7 shows the decisional synopses for the energy savings of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination’s simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Table 6.7 shows that there is no preference for WWR as far as energy savings is concerned. This is because similar trends have been observed in all WWR groups. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential in energy savings. This suggests that design and investigation of IFS should focus on those parameters rather than WWR when it comes to energy savings.

Depth analysis:

Similarly to WWR, the table shows that in all groups, there is no preference regarding the depth. This also confirms that other parameters are much more influential, such as d/l, angle of inclination and glazing system. These parameters will be discussed in the following sub-sections.

d/l analysis:

The synopsis in Table 6.7 indicates that none of the combinations with d/l=2 scored in the top ten ranks. The top ten combinations are always found where d/l=1 and 1.5. This suggests a clear preference for narrow distance between the blades (PVSDs). This preference comes from the fact that with d/l=1 the highest amount of electricity can be generated by the integrated PVSDs, which will result in the highest energy saving, hence is the best option if energy saving is the intended objective of the design project. Within d/l=1, the top four combinations are always observed with a DL glazing system as the best preferred HPG. In addition, the synopses also show a possibility that combinations with different glazing systems can also score within the top ten when it comes to energy savings.

Combinations with DC glazing have a share of the top ten ranks, but with some specific inclination angles, in addition to some other combinations with SL. This gives a wider range of options to the designers if they aim at energy savings but also want to consider some significant savings on the cost of materials and glazing systems, i.e. when they have life-cycle cost on their design agenda.

Inclination angle analysis:

Table 6.7 also indicates that combinations with smaller angle of inclination, such as 20° and 30°, are likely to be optimum options with regard to energy savings. This trend is true for different WWR (Table 6.7, B, C). The reason is that although lower angles allow more solar gain, they also allow more daylight so that the lighting gain and the electricity needed for artificial lights are kept lower, thereby lower energy consumption. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as PV-generated electricity (Table 6.5) and lighting gain (Table 6.3). The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings, the best scenario is DL at 20 degree for d/l=1 for WWR=60%.

For instance, if a decision is to be made to optimise daylighting in an office building at a south-facing façade, while achieving best possible energy saving, both the ranking in the synopses and the numerical values from Appendix 7 are needed. The best option in Table 6.7, A is that with WWR=100%, inclination angle 20, with d/l=1, with DL glazing and for 400mm depth. Based on the coding system in this study this option will be referred to as S-100-40-1-20-DL. Whereas the best option in Table 6.7, C is that with WWR=60%, depth=600mm, d/l=1, at 30° with DL glazing (S-60-60-1-30-DL). The actual numerical value of the annual energy saving of the former option is 17.89% and the latter option is 18.87. Since the difference in energy saving between the two numbers is negligible (less than 1%), this will give the designer alternative options to choose from, based on other functions such $UDI_{300\text{-}3000\ lux}$. Appendix 7 which contains all the numerical results of simulation outputs will be used for this purpose. For option S-100-40-1-20-DL, the annual $UDI_{300\text{-}3000\ lux}$ is 82.75% of the annual working hours and for option S-60-60-1-30-DL is 47.53%. Therefore, the decision will be to go for the option with the higher $UDI_{300\text{-}3000\ lux}$ that is S-100-40-1-20-DL.

Table 6.7 Decisional synopses for energy saving

A

WWR 100%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	31	8	37	5	1	11	29	8	35	5	1	13	d/l=1
30°	35	9	40	7	2	14	31	9	36	6	2	12	
40°	45	12	42	10	3	16	38	11	39	10	3	15	
50°	47	17	46	13	4	21	44	16	45	14	4	17	
60°	50	23	48	20	6	24	50	22	48	18	7	23	
20°	58	41	63	34	25	49	67	43	73	37	25	51	d/l=1.5
30°	53	33	60	28	19	43	56	33	66	28	21	46	
40°	51	29	55	26	15	38	54	30	62	26	19	41	
50°	52	32	57	27	18	39	55	34	65	27	20	42	
60°	54	36	62	30	22	44	60	40	70	32	24	47	
20°	88	78	90	77	66	80	87	78	89	76	58	80	d/l=2
30°	83	71	86	69	61	76	82	68	85	64	52	74	
40°	81	68	84	65	56	73	81	63	84	59	49	72	
50°	82	70	85	67	59	75	83	69	86	61	53	75	
60°	87	74	89	72	64	79	88	77	90	71	57	79	

B

WWR 80%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	29	8	36	5	1	11	27	8	33	5	1	14	d/l=1
30°	33	9	37	7	2	13	30	9	32	6	2	11	
40°	39	12	40	10	3	15	37	12	38	10	3	15	
50°	45	16	44	14	4	17	42	16	40	13	4	17	
60°	49	23	48	18	6	21	48	20	46	18	7	19	
20°	57	43	63	35	26	50	65	45	72	39	26	51	d/l=1.5
30°	53	34	58	28	22	46	55	36	67	28	23	47	
40°	51	30	55	25	19	41	54	31	61	25	21	43	
50°	52	32	56	27	20	42	56	35	64	29	22	44	
60°	54	38	60	31	24	47	59	41	70	34	24	49	
20°	88	78	90	75	67	80	88	78	90	73	60	80	d/l=2
30°	83	71	87	68	62	77	83	68	85	63	52	77	
40°	81	69	84	65	59	73	81	66	84	57	50	74	
50°	82	70	86	66	61	76	82	69	86	62	53	75	
60°	85	74	89	72	64	79	87	76	89	71	58	79	

C

WWR 60%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	26	8	31	5	1	11	24	8	31	5	2	14	d/l=1
30°	30	9	32	7	2	13	26	9	28	6	1	12	
40°	36	12	37	10	3	15	33	11	34	10	3	15	
50°	42	16	40	14	4	17	40	16	36	13	4	17	
60°	48	20	45	18	6	19	45	20	42	18	7	19	
20°	57	46	62	39	29	50	61	48	72	41	32	50	d/l=1.5
30°	53	38	58	28	23	49	53	37	64	30	23	47	
40°	51	33	55	25	21	44	52	35	59	27	21	44	
50°	52	35	56	27	22	43	54	38	60	29	22	46	
60°	54	41	59	34	24	47	57	43	67	39	25	49	
20°	88	77	90	73	68	81	88	78	90	73	66	81	d/l=2
30°	83	71	87	67	63	78	82	70	87	63	56	77	
40°	80	69	84	64	60	74	80	68	84	58	51	74	
50°	82	70	86	66	61	76	83	69	86	62	55	76	
60°	85	75	89	72	65	79	85	75	89	71	65	79	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for energy savings on its own are not sufficient to indicate the performance, but rather the it needs to be assessed in accordance with other influential factors, such as solar gain, cooling load or lighting gain, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influes each other please refer to section 4.14).

Generally, a clear preference of combinations with DL glazing over combinations with other glazing systems was documented. It can also be observed that there are a few instances in which combinations with DC glazing are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design their IFS for office buildings. For instance, if a single output is targeted i.e. optimised energy, the best scenario for energy savings is the combination with DL glazing at 30 degrees for d/l=1 for WWR=60%. Whereas if optimised energy, daylight and PV- generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-100-40-1-20-DL or combination S-60-60-1-30-DL.

6.6.2 Daylight performance decisional synopses

An overview about how all the 540 simulated models on the south-facing façade of the building model have been ranked is presented and discussed first using ADI to indicate the potential exposure to the daylight, followed by a detailed analysis of the ranking of the combinations based on the UDI ranges. As discussed in section 6.5.2, when applying IFS, none of the 1620 simulated models exceeded the maximum threshold of 3000 lux where glare occurs. Therefore, decisional synopses will only include $UDI_{less\ than\ 300lux}$ and $UDI_{300\text{-}3000lux}$.

- *Annual daylight illuminance (ADI)*

These synopses can provide general information about the total annual cumulative amount of daylight received in the interior spaces. It also provides a general idea about the exposure to natural light. However, it does not give any indicator on the daylight quality therefore it will not be used in the optimisation. UDI ranges will be used for this purpose and will be discussed in the following sections.

Table 6.8 shows the decisional synopses for ADI of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination’s simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Combinations with SC and DC glazing seem to be scoring very well in the ranking across all WWR groups. Generally, the highest illuminance is more likely to occur within the glazing systems with high visual light transmittance, such as SC and DC glazing, although there are a few exceptions. In some cases, combinations with SL scored better in the ranks. However, this only happens in scenarios with low inclination angles compared to combinations with SC or DC but with high inclination angles. This is because low angles will allow more daylight to penetrate the indoor spaces much more than high inclination angles. Furthermore, when WWR is decreased i.e. from 80% to 60%, some combinations change their rank. For example, the tenth best combination with SC glazing, for WWR=80%, with d/l=2, at inclination angle of 60° and 400mm depth (Table 6.8, B) changes its rank to be the combination with SL glazing, for WWR=60%, with d/l=2 at inclination angle of 20° at the same depth (Table 6.8, C). this means that if WWR is reduced, then the angle needs to be adjusted to a lower one, with the possibility of changing the glazing, so that sufficient daylight is still achievable.

This variation of options between SC and DL combinations gives a wider spectrum of options to the designers especially when trade-offs between energy consumption and daylighting is the design intent of a specific project.

Depth analysis:

Overall, Table 6.8 shows that there is no preference for the depth as far as ADI is concerned. This is because similar trends have been observed in both 400mm and 600mm depths. This is probably because the other parameters, such as the angle of inclination, d/l ratio and glazing system, are much more influential in energy consumption. This is a helpful finding that shows where design and investigation of IFS should be focused on.

d/l analysis:

The synopsis in Table 6.8 indicates that none of the combinations with d/l=1 scored in the top ten ranks. The top ten combinations are mostly found where d/l=2, with few at d/l=1.5. This suggests a clear preference for wider distance between the blades (PVSDs). This preference comes from the fact that the wider the space between the blades the more daylight is allowed into the interior spaces. However, when the angle of inclination changes, d/l ratio preference will change accordingly. This will be discussed in the following sub-section.

Inclination angle analysis:

The synopsis shows that lower inclination angles outperform higher inclination angles in terms of ADI. This trend is true for different WWR (Table 6.8, A, B, and C). The reason is that lower angles allow more daylight. However, it will allow more solar gain. Therefore, this needs to be assessed in accordance with other outputs, such as lighting gain and the electricity needed for artificial lights, thereby energy consumption. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3). The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings, the scenario that allows the highest ADI is SC at 20 degree for d/l=2 for WWR=100%.

Overall analysis:

Generally, a clear preference of combinations with SC glazing, and some DC, over combinations with other glazing systems was demonstrated. It can also be observed that there are a few instances in which combinations with SL glazing are found. This, however, depends on the variation of other variables, such as WWR or d/l. The trend of lower inclination angle performing better than higher angles was found true for all WWR and both depths.

Table 6.8 Annual Daylight Illuminance decisional synopses

A

WWR 100%

	South orientation 400mm						South orientation 600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	27	39	76	36	51	86	28	45	76	36	51	86	
30°	34	52	78	42	57	87	35	52	78	43	57	87	
40°	40	55	80	47	61	88	39	55	80	47	63	88	d/l=1
50°	46	56	82	50	64	89	42	58	82	50	65	89	
60°	45	60	83	54	66	90	48	60	84	54	66	90	
20°	7	19	65	14	31	77	7	24	64	14	31	77	
30°	13	32	67	23	38	79	13	32	67	22	38	79	
40°	18	37	69	30	44	81	18	37	69	30	44	81	d/l=1.5
50°	24	41	71	33	48	84	23	40	71	33	46	83	
60°	25	43	73	35	49	85	25	41	73	34	49	85	
20°	1	10	53	3	16	68	1	10	53	4	16	68	
30°	2	15	58	8	22	70	2	15	56	8	21	70	
40°	4	17	59	9	26	72	3	17	59	9	26	72	d/l=2
50°	5	20	62	12	28	74	6	19	61	11	27	74	
60°	6	21	63	11	29	75	5	20	62	12	29	75	

B

WWR 80%

	South orientation 400mm						South orientation 600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	27	46	76	36	52	86	27	46	76	36	52	86	
30°	34	51	78	42	56	87	35	51	78	43	56	87	
40°	37	54	80	47	60	88	38	55	80	47	60	88	d/l=1
50°	40	57	81	49	64	89	41	57	81	50	64	89	
60°	44	59	83	53	65	90	44	59	83	53	65	90	
20°	7	25	66	14	32	77	7	25	66	14	32	77	
30°	13	33	67	22	39	79	13	33	67	22	39	79	
40°	18	38	69	30	45	82	17	37	69	30	45	82	d/l=1.5
50°	21	41	71	31	48	84	21	40	71	31	48	84	
60°	24	43	73	35	50	85	24	42	72	34	49	85	
20°	1	11	55	4	16	68	1	10	54	4	16	68	
30°	2	15	58	8	23	70	2	15	58	8	23	70	
40°	3	17	61	9	26	72	3	18	61	9	26	73	d/l=2
50°	6	20	63	12	29	75	6	20	63	12	29	75	
60°	5	19	62	10	28	74	5	19	62	11	28	74	

C

WWR 60%

	South orientation 400mm						South orientation 600mm						
Angle	SC	SL	SR	DC	DL	DR	SC	SL	SR	DC	DL	DR	
20°	25	45	73	36	53	86	25	46	73	36	53	86	
30°	31	52	77	41	56	87	33	52	78	43	56	87	
40°	37	54	79	46	59	88	37	54	79	45	59	88	d/l=1
50°	38	55	81	48	61	89	39	55	81	48	60	89	
60°	40	57	82	50	62	90	40	57	82	51	62	90	
20°	7	26	66	14	35	78	7	26	66	14	35	77	
30°	13	34	67	23	42	80	12	29	67	23	41	80	
40°	16	39	69	28	47	83	16	38	68	27	47	83	d/l=1.5
50°	19	43	70	32	49	84	20	42	70	32	49	84	
60°	22	44	72	33	51	85	22	44	71	34	50	85	
20°	1	10	58	4	17	68	1	13	58	6	18	69	
30°	2	15	60	8	24	71	2	15	61	8	24	72	
40°	3	18	63	9	27	74	3	17	63	9	28	74	d/l=2
50°	5	20	64	11	29	75	5	21	65	11	31	76	
60°	6	21	65	12	30	76	4	19	64	10	30	75	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

Finally, this synopsis, being ADI, can help provide a general idea of the choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. annual daylight illuminance (ADI), the best scenario for ADI is the combination with SC glazing at 20 degrees for d/l=2 for WWR=100%.

- *$UDI_{300\text{-}3000\ lux}$*

Table 6.9 shows the decisional synopses for $UDI_{300\text{-}3000\ lux}$ of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

Combinations with SC and DC glazing seem to be scoring very well in the ranking across all WWR groups. Generally, combinations with higher T_{vis} (i.e. SC) are preferred over other alternatives when it comes to $UDI_{300\text{-}3000\ lux}$. For WWR=100% (Table 6.9, A), there are some combinations that score exactly the same in the ranking although they have different configurations. For example, within the same WWR group (100%), combination with SC glazing with d/l=1.5 at inclination angle of 20°, for 400mm depth scores the third best combination. Whereas combination with the same glazing system but with d/l=2 and at inclination angle of 40° scores the third as well. This suggests that they both provide the same $UDI_{300\text{-}3000\ lux}$. This means that in order to provide the same percentage of $UDI_{300\text{-}3000\ lux}$, two options can do so, meaning that the designer should either increase the d/l ratio and further tilt the blades downwards (reducing the angle) or decreasing the d/l ratio but increasing the angle to be tilted more upwards (i.e. 20°).

The scenario is slightly different when it comes to different WWRs. This is noticeable as there is a shift in the top ten combinations towards a specific type of glazing and a range of inclination angles, meaning that there is no clear preference for WWR. Hence, optimisation and trade-off should focus on varying other variables.

Depth analysis:

Overall, Table 6.9 little difference can be seen between the two depths, suggesting that depth has no significant impact on $UDI_{300\text{-}3000\ lux}$. This is because similar trends have been observed in both 400mm and 600mm depths, suggesting that other parameters, such as d/l, angle of inclination or glazing, are much more influential on $UDI_{300\text{-}3000\ lux}$.

d/l analysis:

The synopses in Table 6.9 show a clear preference for the distance between PVSDs, indicating that none of the combinations with d/l=1 scored in the top ten ranks. The top ten combinations are always found where d/l=1.5 and 2. This suggests a clear preference for wider distance between the blades (PVSDs). This preference comes from the fact that the wider the space between the blades the more daylight is allowed into the interior spaces but at the same time more solar gain as a result. Therefore, this parameter needs to be assessed together with the angle of inclination, and glazing system. Glazing system can regulate solar gain, as was demonstrated in the previous sections in phase two and daylighting can be controlled with the inclination angle in order to achieve reasonable results.

For example, when comparing d/l ratios effects, the number of combinations that are within the top ten options appear more around d/l=2. The second is d/l=1.5 while none of the top ten options are recorded within d/l=1. This suggests a preference for a greater distance between PVSDs in order to allow more daylight into the interior spaces, which is quite expected. However, it is still possible to score some of the top ten options on a smaller value of d/l but that needs to be looked at in accordance with the angle of inclination. For instance, some combinations are observed within the top ten rankings with d/l=1.5 rather than 2, but in this case the inclination angle should not be more than 40°.

This can help make decisions about where the optimum combinations are likely to occur. A practical application of the synopses will be elaborated on in the following sections.

Inclination angle analysis:

The synopsis shows that lower inclination angles outperform higher inclination angles (Table 6.9, A) in terms of $UDI_{300\text{-}3000\ lux}$. This trend is true for different WWR

(Table 6.9, B, C). however, when the d/l is decreased, some higher angles outperform lower ones. The reason is that lower angles allow more daylight, but within high d/l ratio. When the distance between the blades (d/l) decreases, the inclination angle becomes more effective, thereby they need to be tilted downwards so that they allow the same level of daylighting. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3). The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings with improved daylighting, the best scenario is SC at 20 degree for d/l=2 for WWR=100%.

For instance, if a decision is to be made to optimise daylighting in an office building at a south-facing façade, then the distance between the blades should be increased to 1.5 and 2. The next step is to decide which d/l is optimum and at which angle of inclination. To make this decision, both the ranking in the synopses and the numerical values from Appendix 7 are needed to be compared. The fifth best option, for example, in Table 6.9, A, is that with WWR=100%, depth=400mm, d/l=1.5, at 50° with SC glazing. Based on the coding system in this study this option will be referred to as S-100-40-2-50-SC. Whereas the fifth best option in Table 6.9, B is that with WWR=80%, depth=400mm, d/l=1.5, at 20° with SC glazing (S-80-40-15-20-SC). The optimisation will attempt at PV-generated electricity and energy consumption, which together are accounted for by the net energy figure, in addition to daylight availability. The actual numerical value of the annual percentage of $UDI_{300\text{-}3000\ lux}$ of the former option is 98.63% and the latter option is 98.12%. Since the difference in energy consumption between the two numbers is negligible, this will give the designer alternative options to choose from, based on other functions such as net energy. Using Appendix 7, for option S-10-40-2-50-SC, the annual net energy 158.46 MWh and for option S-80-40-15-20-SC is 152.15 MWh. Therefore, the decision will be to go for the option with the higher net energy that is S-100-40-2-50-SC.

Table 6.9 Decisional synopses for UDI 300-3000 lux

A

WWR 100%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	600mm SC	SL	SR	DC	DL	DR	
20°	16	32	78	26	49	86	14	40	78	26	49	86	d/l=1
30°	22	44	82	33	56	87	21	47	82	35	55	87	
40°	37	53	83	41	57	87	29	53	83	44	57	87	
50°	47	54	84	48	60	87	37	56	85	48	60	87	
60°	50	58	85	52	63	87	50	58	84	52	65	87	
20°	3	19	66	11	34	76	3	21	66	8	33	76	d/l=1.5
30°	9	31	68	19	42	77	7	31	69	16	42	77	
40°	13	39	73	25	46	79	10	38	73	23	46	79	
50°	17	43	74	28	51	80	15	43	74	28	51	80	
60°	21	45	75	36	55	81	18	45	75	34	54	80	
20°	1	13	59	6	24	67	1	12	59	5	25	67	d/l=2
30°	2	18	61	8	30	69	2	17	61	6	32	68	
40°	3	23	62	10	35	70	3	23	62	8	36	70	
50°	5	27	65	12	38	72	19	27	64	10	39	72	
60°	6	29	64	15	40	71	20	30	63	13	41	71	

B

WWR 80%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	600mm SC	SL	SR	DC	DL	DR	
20°	14	41	78	26	50	86	13	40	78	25	50	86	d/l=1
30°	21	48	82	34	55	86	21	47	82	35	55	86	
40°	28	53	83	43	58	86	28	54	83	44	58	86	
50°	35	56	84	47	60	86	37	56	84	49	61	86	
60°	42	57	85	51	65	86	42	57	85	52	65	86	
20°	5	24	66	11	37	76	4	22	66	11	34	76	d/l=1.5
30°	9	32	68	18	44	77	8	31	68	18	43	77	
40°	11	39	71	23	49	79	12	38	72	23	48	79	
50°	17	45	74	30	52	80	17	45	74	29	51	80	
60°	19	46	75	33	54	81	19	46	75	33	53	81	
20°	1	15	59	7	25	67	1	16	59	7	26	67	d/l=2
30°	2	20	61	8	31	69	2	20	60	9	32	69	
40°	3	22	62	10	36	70	3	24	62	10	35	70	
50°	4	27	64	13	38	73	5	27	64	14	39	73	
60°	6	29	63	16	40	72	6	30	63	15	41	71	

C

WWR 60%

Angle	South orientation 400mm SC	SL	SR	DC	DL	DR	600mm SC	SL	SR	DC	DL	DR	
20°	11	41	78	23	51	86	11	43	78	25	51	86	d/l=1
30°	19	48	80	32	55	86	20	48	80	35	55	86	
40°	25	53	83	42	58	86	26	53	83	42	58	86	
50°	31	56	84	47	60	86	33	56	85	47	60	86	
60°	36	57	85	50	62	86	37	57	84	50	62	86	
20°	4	26	66	13	38	76	4	24	66	12	38	76	d/l=1.5
30°	8	34	68	18	45	77	8	27	68	19	45	77	
40°	10	39	70	22	49	79	10	39	70	22	49	79	
50°	15	44	74	29	52	81	16	44	74	30	52	82	
60°	20	46	75	33	54	81	18	46	75	32	54	81	
20°	1	17	59	7	27	67	1	17	59	7	29	67	d/l=2
30°	2	21	61	9	35	69	2	21	61	9	34	69	
40°	3	24	63	12	37	71	3	23	63	12	36	72	
50°	5	28	65	14	40	72	4	28	65	14	40	73	
60°	6	30	64	16	43	73	6	31	64	15	41	71	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).
Red cells represent the top ten ranks in each combination group.

Overall analysis:

To summarise, as was shown in the previous sub-section where a practical application of the synopses was attempted on, the decisional synopses for UDI$_{300\text{-}3000\ lux}$ can either be used for optimal daylighting or in accordance with other influential factors, such as net energy, solar gain, cooling load and lighting gain, based on design specifics of a project. These influential factors are to be analysed according to the dependency of the factors involved (for details on how these factors influences each other please refer to section 4.14).

Generally, a clear preference of combinations with SC glazing over combinations with other glazing systems was documented. It can also be observed that there are a few instances in which combinations with DC glazing are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for both depths.

Finally, the synopses alongside with the actual numerical values in the relevant appendices provide a variety of choices when designers want to design PVSD for their IFS for office buildings. For instance, if a single output is targeted i.e. $UDI_{300\text{-}3000\ lux}$, the best scenario is the combination with SC glazing at 20 degrees for d/l=2 for WWR=100%. Whereas if optimised energy, daylight and PV generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-100-40-2-50-SC or combination S-80-40-15-20-SC.

This limitation of options to only SC and DC might suggest that there is no space for other glazing systems. However, trade-offs need to be aimed at using other glazing systems to improve energy consumption as well, and not daylighting only, as those two types of glazing (SC and DC) have the worst thermal properties compared to other types, such as DL RS to name a few. This variation gives a wider spectrum of options to the designers especially when trade-offs between energy consumption and daylighting is the design intent of a specific project.

- *$UDI_{less\ than\ 300\ lux}$*

Table 6.10 shows the decisional synopses for $UDI_{less\ than\ 300\ lux}$ of combinations on a south-facing façade of a building model. Combinations are grouped according to their systemic levels; horizontally based on their WWR (100%, 80% and 60%) and vertically based on the depth of the PVSD (400mm and 600mm). Within each group, d/l ratio is sub-grouped for the six examined glazing systems; single-clear (SC), single-low e (SL), single-reflective (SR), double-clear (DC), double -low e (DL), double -reflective (DR), and five inclination angles. The numbers in these synopses represent the rank of each combination's simulation result and calculated as explained in section 6.6. The synopses will be analysed horizontally based on WWR and vertically based on the depth. In each group, d/l ratio, glazing systems and inclination angles are discussed also vertically, horizontally and overall as follows:

WWR analysis:

The decisional synopses of the $UDI_{less\ than\ 300\ lux}$ in Table 6.10 conform to the trends already identified for $UDI_{300\text{-}3000\ lux}$, such as the advantage of clear glazing over low-e and reflective. Combinations with SC and DC glazing seem to be scoring very well in the ranking across all WWR groups. As expected, combinations with improved optical properties (higher T_{vis}), such as SC, are preferred over other alternatives when it comes to $UDI_{300\text{-}3000\ lux}$. For WWR=100% (Table 6.10, A), there are some combinations that score similarly to the same ranking of other combinations although they have different configurations. Those configurations are explained in the previous section ($UDI_{300\text{-}3000\ lux}$).

Depth analysis:

The synopses confirm the fact that there is no single depth that is preferable over another. This is because similar trends have been observed in both 400mm and 600mm depths, suggesting that other parameters, such as d/l, angle of inclination or glazing, are much more influential on $UDI_{less\ than\ 300\ lux}$.

d/l analysis:

Similar to $UDI_{300\text{-}3000\ lux}$, the synopses of $UDI_{less\ than\ 300\ lux}$ show a preference of wide distance between the blades (PVSDs), meaning that higher d/l ratio is preferable. This evident in Table 6.10 as none of the combinations with d/l=1 scored in the top ten ranks. The top ten combinations are only found where d/l ratio is either 1.5 or 2. This is because the wider the space between the blades the more daylight is admitted into the indoor spaces. However, it is possible to found some of the top ten options scoring at a smaller d/l but that needs to be looked at in accordance with the angle of inclination. For instance, some combinations are observed within the top ten rankings with d/l=1.5 rather than 2, but in this case the inclination angle should not be more than 40°.

Inclination angle analysis:

The synopsis shows a preference of lower inclination angles over higher ones (Table 6.10, A) in terms of $UDI_{less\ than\ 300\ lux}$. This trend is found true for different WWR (Table 6.10, B, C). However, when the d/l decreases, some of the higher angles outperform lower ones. The reason is that lower angles allow more daylight, but within high d/l ratio. When the distance between the blades (d/l) decreases, the inclination angle becomes more influential so they need to be tilted downwards in order for them to allow the same level of daylighting. However, this does not mean that the combinations with a specific angle are the best also when it comes to other assessed indicators, such as electricity generation (Table 6.5) and lighting gain (Table 6.3). The tables are going to be used by designers, meaning that if they have a variety of choices when they want to design PVSD for their IFS for office buildings with reduced $UDI_{\textit{less than 300 lux}}$, the best scenario is SC at 20 degree for d/l=2 for WWR=100%.

Overall analysis:

To summaries, the synopses for $UDI_{\textit{less than 300 lux}}$ showed a clear preference of combinations with SC glazing over combinations with other glazing systems. It can also be observed that there are a few instances in which combinations with DC glazing are found. This, however, depends on the variation of other variables, such as WWR. The trend of lower inclination angle performing better than higher angles was found true for both depths.

It is worth mentioning that those synopses of UDI should be used in conjunction with the actual numerical values of the options under investigation. In addition, when trade-off is intended, other output variables should also be evaluated side-by-side. For instance, a decision was made in a project to go for a fully-glazed façade (WWR=100%) and option 5 was chosen for the comparison. It was assumed that the task was to choose between two PVSD products, i.e. 400mm and 600mm, the combination which scores the fifth option on the other side (600mm) is 100-60-2-50-SC, with an actual value of 96.4%, whereas for the fifth option with depth=400mm, which is 100-40-2-20-SC, the actual numerical value of $UDI_{\textit{300-3000 lux}}$ = 98.97%. Clearly the option with depth=400mm provides more $UDI_{\textit{300-3000 lux}}$; however, the same option provides less energy saving (11.77%) compared to 100-60-2-50-SC, which provides 13.17% energy saving. Hence a compromise is necessary in order to make the decision. (For details of actual values, please see Appendix 7: daylighting).

Table 6.10 Decisional synopses for UDI less than 300 lux

A

WWR 100%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	16	32	78	26	49	86	14	40	78	26	49	86	d/l=1
30°	22	44	82	33	56	87	21	47	82	35	55	87	
40°	37	53	83	41	57	87	29	53	83	44	57	87	
50°	47	54	84	48	60	87	37	56	85	48	60	87	
60°	50	58	85	52	63	87	50	58	84	52	65	87	
20°	3	19	66	11	34	76	3	21	66	8	33	76	d/l=1.5
30°	9	31	68	19	42	77	7	31	69	16	42	77	
40°	13	39	73	25	46	79	10	38	73	23	46	79	
50°	17	43	74	28	51	80	15	43	74	28	51	80	
60°	21	45	75	36	55	81	18	45	75	34	54	80	
20°	1	13	59	6	24	67	1	12	59	5	25	67	d/l=2
30°	2	18	61	8	30	69	2	17	61	6	32	68	
40°	3	23	62	10	35	70	3	23	62	8	36	70	
50°	5	27	65	12	38	72	19	27	64	10	39	72	
60°	6	29	64	15	40	71	20	30	63	13	41	71	

B

WWR 80%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	14	41	78	26	50	86	13	40	78	25	50	86	d/l=1
30°	21	48	82	34	55	86	21	47	82	35	55	86	
40°	28	53	83	43	58	86	28	54	83	44	58	86	
50°	35	56	84	47	60	86	37	56	84	49	61	86	
60°	42	57	85	51	65	86	42	57	85	52	65	86	
20°	5	24	66	11	37	76	4	22	66	11	34	76	d/l=1.5
30°	9	32	68	18	44	77	8	31	68	18	43	77	
40°	11	39	71	23	49	79	12	38	72	23	48	79	
50°	17	45	74	30	52	80	17	45	74	29	51	80	
60°	19	46	75	33	54	81	19	46	75	33	53	81	
20°	1	15	59	7	25	67	1	16	59	7	26	67	d/l=2
30°	2	20	61	8	31	69	2	20	60	9	32	69	
40°	3	22	62	10	36	70	3	24	62	10	35	70	
50°	4	27	64	13	38	73	5	27	64	14	39	73	
60°	6	29	63	16	40	72	6	30	63	15	41	71	

C

WWR 60%

South orientation

Angle	400mm SC	400mm SL	400mm SR	400mm DC	400mm DL	400mm DR	600mm SC	600mm SL	600mm SR	600mm DC	600mm DL	600mm DR	
20°	11	41	78	23	51	86	11	43	78	25	51	86	d/l=1
30°	19	48	80	32	55	86	20	48	80	35	55	86	
40°	25	53	83	42	58	86	26	53	83	42	58	86	
50°	31	56	84	47	60	86	33	56	85	47	60	86	
60°	36	57	85	50	62	86	37	57	84	50	62	86	
20°	4	26	66	13	38	76	4	24	66	12	38	76	d/l=1.5
30°	8	34	68	18	45	77	8	27	68	19	45	77	
40°	10	39	70	22	49	79	10	39	70	22	49	79	
50°	15	44	74	29	52	81	16	44	74	30	52	82	
60°	20	46	75	33	54	81	18	46	75	32	54	81	
20°	1	17	59	7	27	67	1	17	59	7	29	67	d/l=2
30°	2	21	61	9	35	69	2	21	61	9	34	69	
40°	3	24	63	12	37	71	3	23	63	12	36	72	
50°	5	28	65	14	40	72	4	28	65	14	40	73	
60°	6	30	64	16	43	73	6	31	64	15	41	71	

single-clear (SC), single-reflective (SR), single- low e (SL), double-clear (DC), double-reflective (DR), double-low e (DL), ratio of the depth to the distance between blades (d/l).

Red cells represent the top ten ranks in each combination group.

In the following section, the influence of each input variable is quantified using sensitivity analysis (SA) techniques.

6.7 Phase three: Sensitivity analysis (SA)

As explained in the methodology chapter, SA helps investigate the influence of the variation of different parameters that are used as inputs to the models on the final outcomes. SA has been run for all the outputs that are being evaluated, such as energy and daylighting assessment indicators.

To run SA, the results of all **1620** dynamic simulation models have been imported from Microsoft Excel™ into IBM-SPSS™ (version 22). This software has been used as the analysis tool for this phase due to its advanced analytical capabilities and the statistical methods integrated within it.

The nature of the data and the findings of the SA literature review suggest that Global SA methods (please see section 4.12.2) are the most applicable for quantifying how sensitive the outcomes are to the variation of the inputs. Furthermore, the range of the variation of each input parameter (Independent Variables (IV)) is fully controlled and no element of randomness is involved (i.e. predefined variations of depths, d/l, angle, etc.). Therefore, IV are considered to be categorical variables. In addition to that, the outputs (Dependent Variables (DV)) are measured on a continuous measurement scale. Hence, linear regression modelling is the appropriate Global Sensitivity technique for this study for the above-mentioned reasons.

This phase of the analysis will follow the same sequence as the analysis of the assessment indicators of the previous phases, meaning that it will start with the analysis of energy performance indicators, such as energy consumption, solar gain, lighting gain, cooling load, PV electricity generated, net energy and saving. In addition, both $UDI_{less\ than\ 300\ lux}$ and $UDI_{300\text{-}3000\ lux}$ will be analysed as daylighting performance indicators.

6.7.1 Sensitivity Analysis in SPSS

Having imported the data from Microsoft Excel™, the first step that was conducted in SPSS was preparing the data for the SA analysis. To do so, the data have been inserted and the input variables specified as Independent Variables (IV) and the output variables as Dependent Variables (DV). The measurement level of each variable was also specified (i.e. nominal, continuous and scale). In this study, the IV are considered to be nominal variables and the DV are considered to be scale variables. This is due to the nature of the input and output data (Norušis, 2006). Figure 6.29 shows the variables and the measurement level assigned to each of them in SPSS.

Having prepared the data for the analysis, the linear regression modelling method was chosen to run the analysis (Figure 6.30), followed by calculating the model fit and accuracy of prediction. This method was used as it is the most applicable method for continuous data (input variables) where the values of the inputs are already known – with a specific controlled variation – and randomness of values are not expected. Assumptions of linear regression have been checked and verified using the most appropriate statistical tests for the checks, i.e. test of normality of all DV and P-P plots, and are presented in details in Appendix 10.

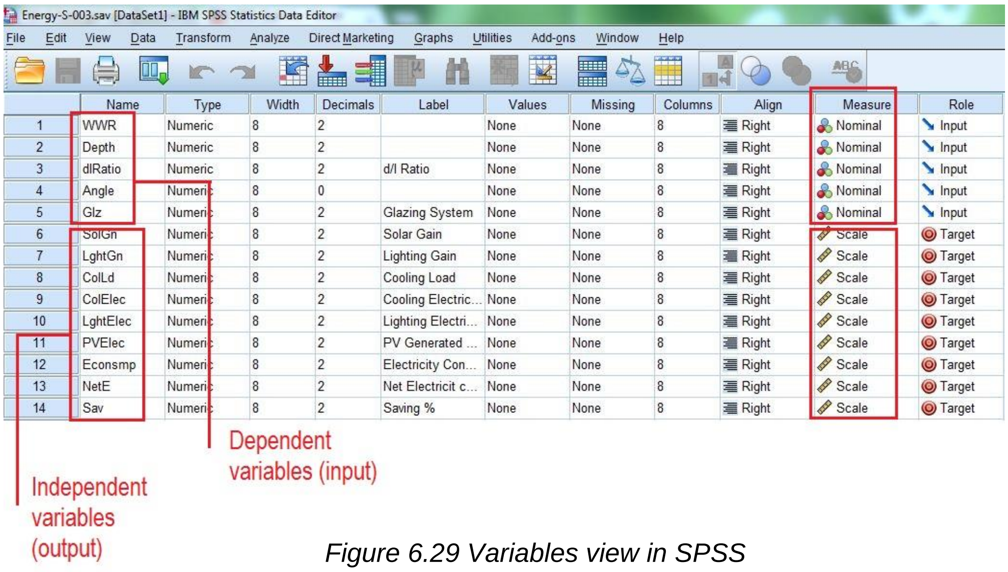


Figure 6.29 Variables view in SPSS

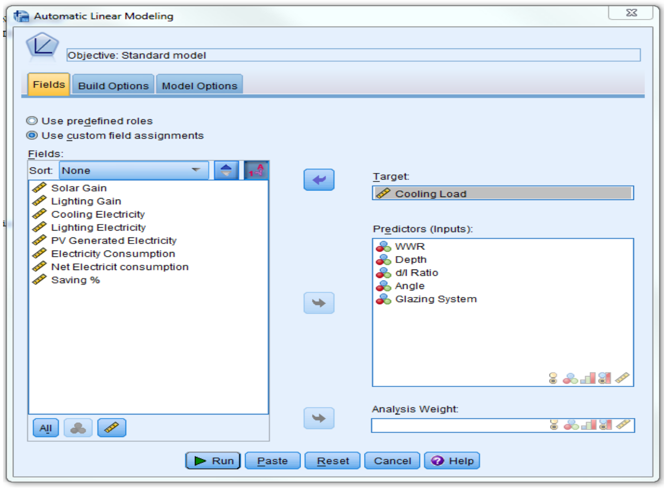


Figure 6.30 Linear regression modelling in SPSS

The input variables represent the predictors for which an Importance graph is generated; this was done for all the assessed indicators. This is based on the sensitivity of the change of each input, taking into consideration the change of other inputs simultaneously, on the output variables. A Predictor Importance view is then generated. This view shows the predictors in the final model in ranked order of importance. For linear models, the importance of a predictor is the residual sum of squares with the predictor removed from the model, normalized so that the importance values sum up to 1 (Norušis, 2012). The results were analysed using linear regression modelling with a 95% confidence interval. To check that the assumption of linearity is correct, and the model can predict the output, a plot of the predicted[22] results based on the regression model vs. the observed[23] results – that were extracted from the simulations – is produced. The closer the scatter of the plots to 45°, the more accurate the model will be (Norušis, 2012).

In order to account for the reliability and validity of the models and results in this study, a verification process needs to be followed to ensure that the method of analysis can accurately predict the results and that the models are also fairly accurate. This was followed within the SA by examining the model accuracy which is deemed to be a high-level summary of the model and its fit. The value of the displayed accuracy on the model summary chart is 100 × the adjusted R^2. The Model Summary view is a snapshot, at-a-glance summary of the model and its fit. Models with R^2 of less than 0.5 are considered no better than random models (Norušis, 2012).

Finally, One-At-Time (OAAT) analysis of the mean values of variations of each parameter were presented and analysed in order to zoom in on each of the parameters and to demonstrate the changes that correspond to each of their variations. The results were plotted with 95% confidence interval and error bars[24]. Figure 6.31 shows the procedure followed to carry out the SA.

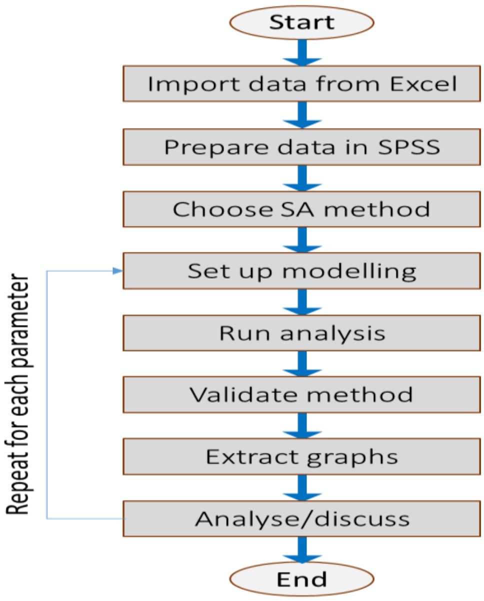


Figure 6.31 Sensitivity analysis workflow

[22] Predicted: Refers to the mean values calculated from the estimated regression model.

[23] Observed: Refers to the results generated through the dynamic simulation modelling.

[24] Error bars are graphical representations of the variability of data and used on graphs to indicate the error or uncertainty in a reported measurement. They represent the 95% confidence interval in this study.

6.7.2 Sensitivity analysis of energy performance assessment indicators

- *Energy consumption*

The results of energy consumption from all the 1620 dynamic simulation models were analysed in SPSS using a linear regression modelling with 95% confidence interval. Figure 6.32 shows the predicted vs. observed graph in which mean values calculated from the estimated regression (predicted) were plotted against those assessed through the dynamic simulation modelling (observed).

Figure 6.32 shows well-aligned values around a 45° line, indicating the high accuracy of the model. This was confirmed by the model summary in Figure 6.33 which also shows a highly accurate model as the adjusted R^2 coefficient is 0.979.

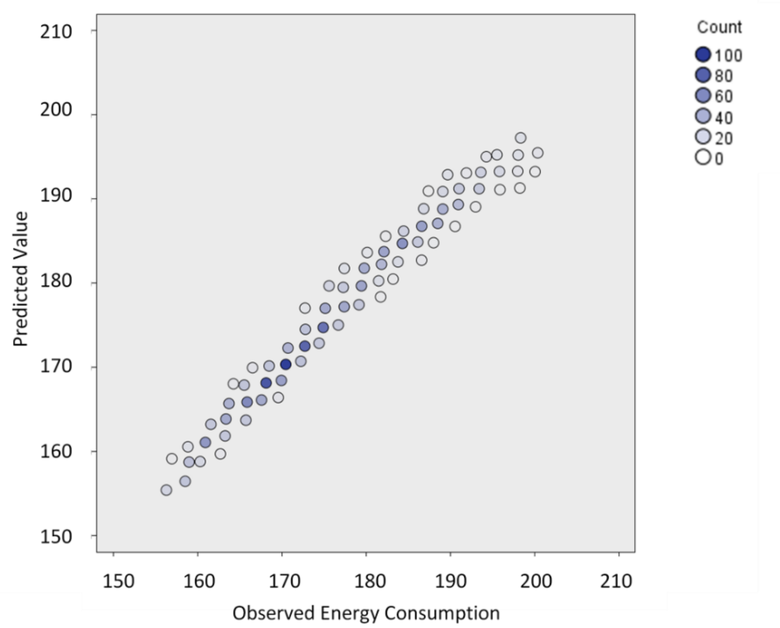


Figure 6.32 Predicted by observed plot for mean energy consumption

The overall influence on energy consumption as a result of variations in each of the parameters considered in this study is shown in Figure 6.34 where the importance of the parameters is quantified and ranked.

It is evident that HPG integrated in IFS is the most influential parameter because its variation has the most influence (more than 80%) on energy consumption figures, followed by the second important parameter, which is d/l ratio, with nearly 13%.

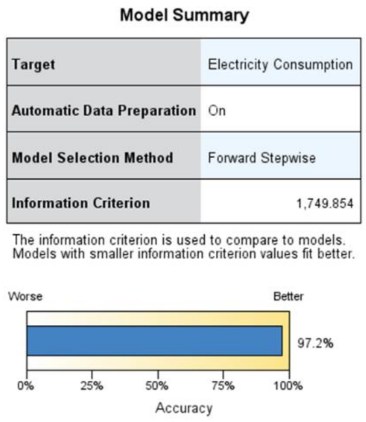


Figure 6.33 Model summary and accuracy of energy consumption

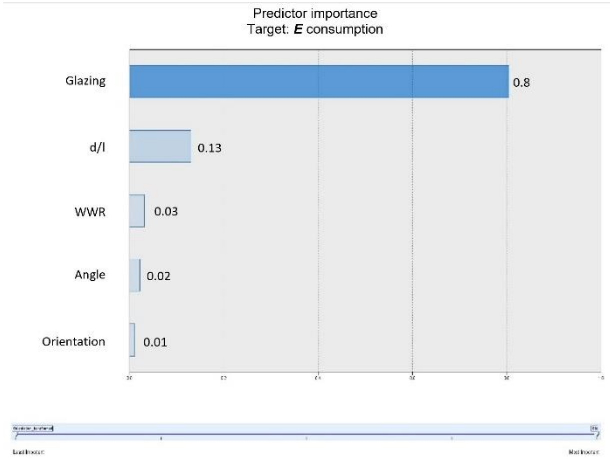


Figure 6.34 Predictor importance for energy consumption

The third is WWR with 3% of influence, followed by the angle of inclination (2%) and the least influential one is orientation (1%). It can be seen that the depth of the PVSDs has no effect on the energy figures as it did not score in the SA.

Figure 6.35 shows the OAAT figures of energy consumption. On the x-axis, the variations of each parameter are shown and their influence on the energy consumption is shown on the y-axis. It can be seen that the depth has extremely insignificant influence, as the red line that connects the mean values of the two different depths (400mm and 600mm) is almost horizontal.

In contrast, glazing is extremely significantly influential and this is evident from the fluctuation of the mean values of each type of glazing system combinations included in the analysis of this study. In addition, the figure shows that d/l ratio, followed by angle, WWR and orientation do have some impact but definitely less influence. The findings of the analysis of the graphs in the figure confirm the findings from the SA.

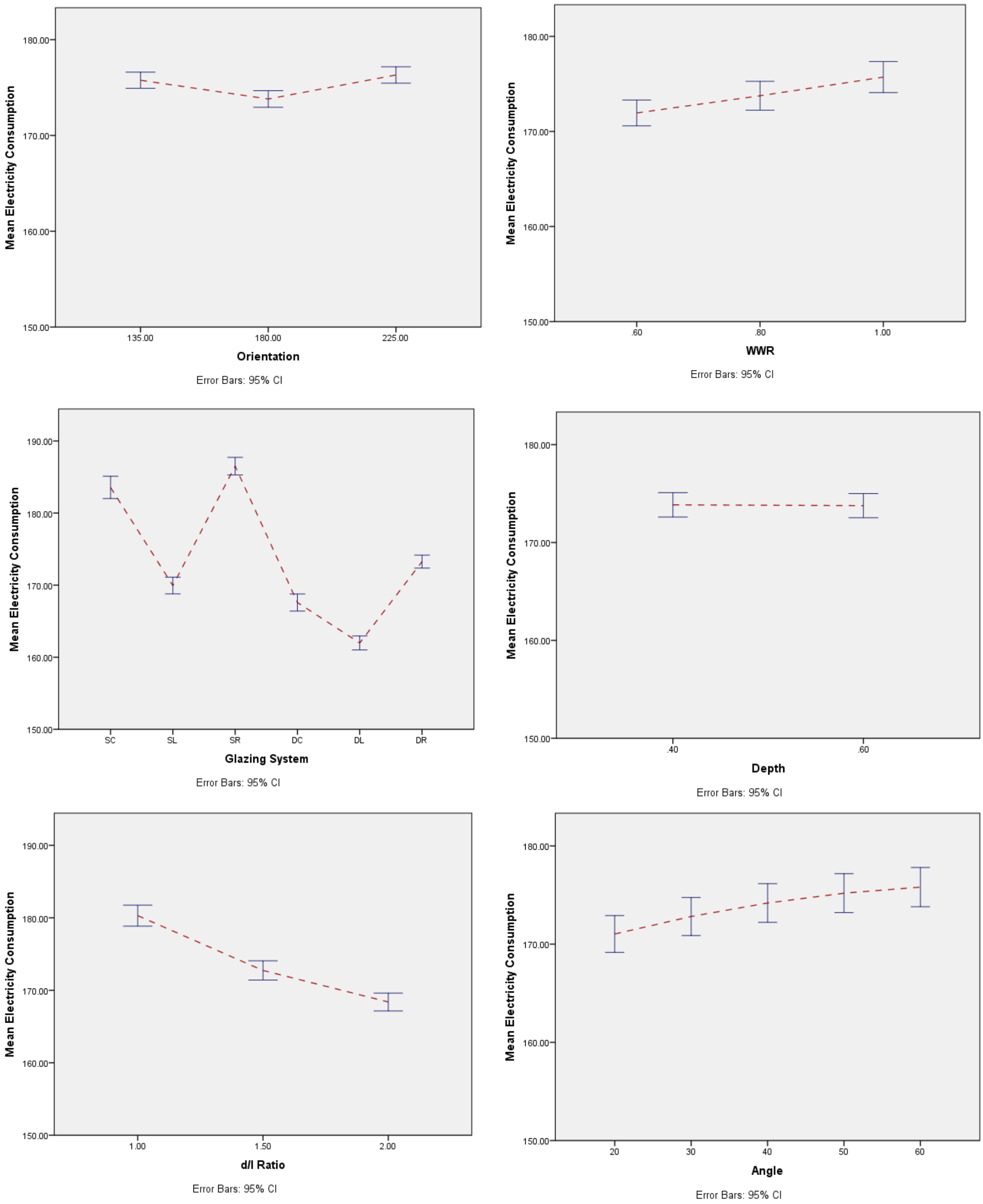


Figure 6.35 OAAT parameter of mean energy consumption

- *Solar gain*

Solar gain results have been inputted into SPSS and analysed using linear regression modelling with 95% confidence interval. Figure 6.36 shows data points of predicted vs. assessed results plotted for solar gain. It indicates that a reasonably high accuracy of the models is observed. The predicted vs. assessed values of solar gain plots the values calculated from the estimated regression equation (the predicted values) against those actual values extracted from the dynamic simulation models.

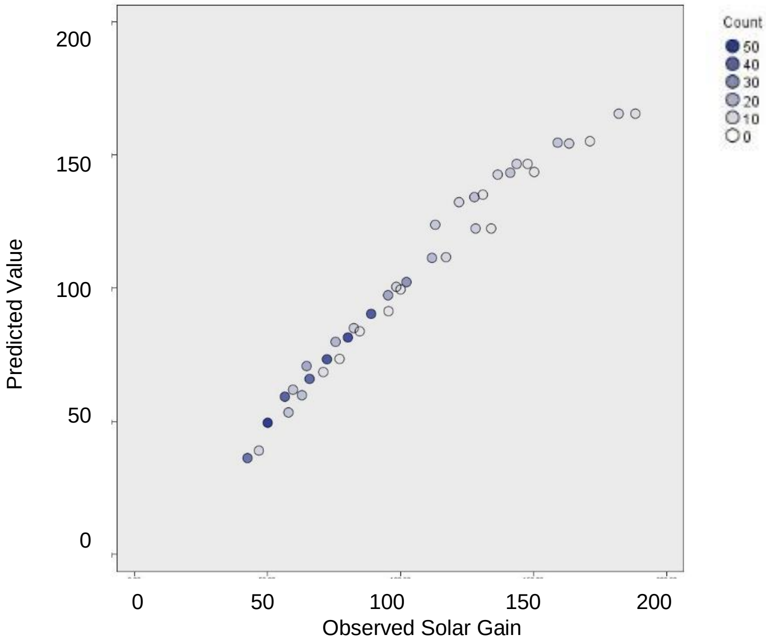


Figure 6.36 Predicted by observed plot for mean solar gain

The accuracy of the model is then verified through the model summary tested in SPSS to check whether the model used is any better than random models or not. Figure 6.37 confirms that the model is of high accuracy regarding solar gain (adjusted R^2 is 0.977).

The results of the SA in Figure 6.38 shows the overall influence of the variations of each of the parameters on solar gain. It can be seen that the most influential parameter is the glazing system with 87% influence, which means varying glazing systems has a significant impact on solar gain control, whereas WWR comes second in the line with 6% effect on solar gain. d/l ratio proves to be not so important with only 4%. The least influence comes from orientation (2%) and angle of inclination (1%). It can also be noticed that the depth has not scored in the SA of solar gain, which means it is negligible when it comes to solar gain.

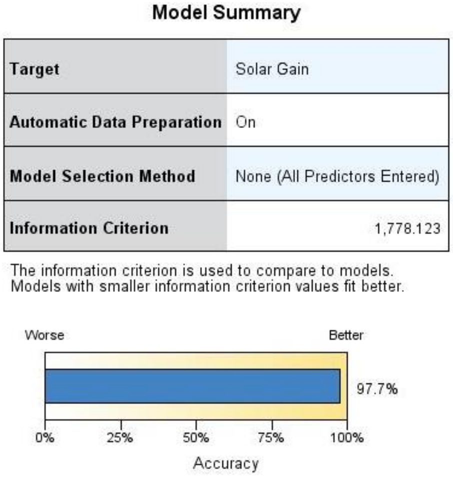


Figure 6.37 Model summary and accuracy of solar gain

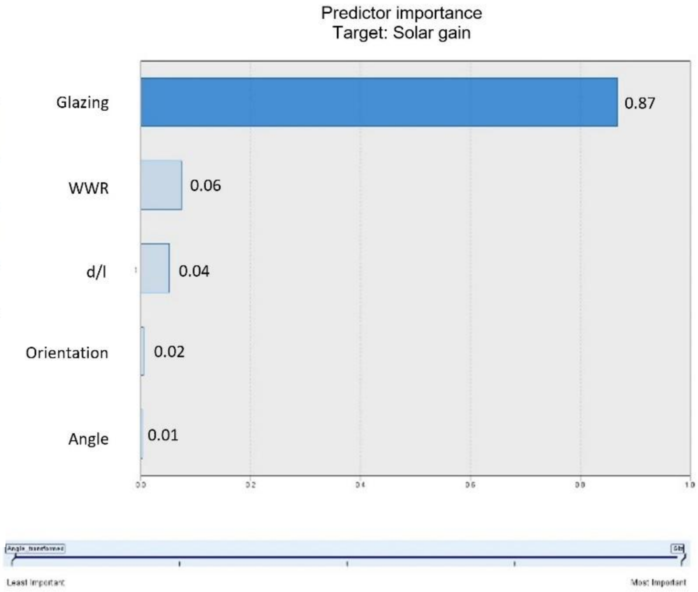


Figure 6.38 Predictor importance for solar gain

The graphs in Figure 6.39 show the OAAT analysis of the influence of variation of each parameter on solar gain. The x-axes are the different options for the parameters used, in order to show their influence on solar gain. It might be unexpected that glazing systems have such a significant influence in determining how much solar gain is received in the indoor environment compared to other parameters. However, what is really interesting is that the angle of inclination does not have a recognisable influence on solar gain. Both d/l ratio and WWR have an insignificant impact on solar gain.

These findings confirm what has been discussed and analysed in the previous two phases. Although the angle of inclination and orientation do have some influence on solar gain, as well as energy consumption (as discussed in phase 1), they score the least influential variables in the SA for solar gain and energy consumption, although they exchange their ranks from being fourth to fifth.

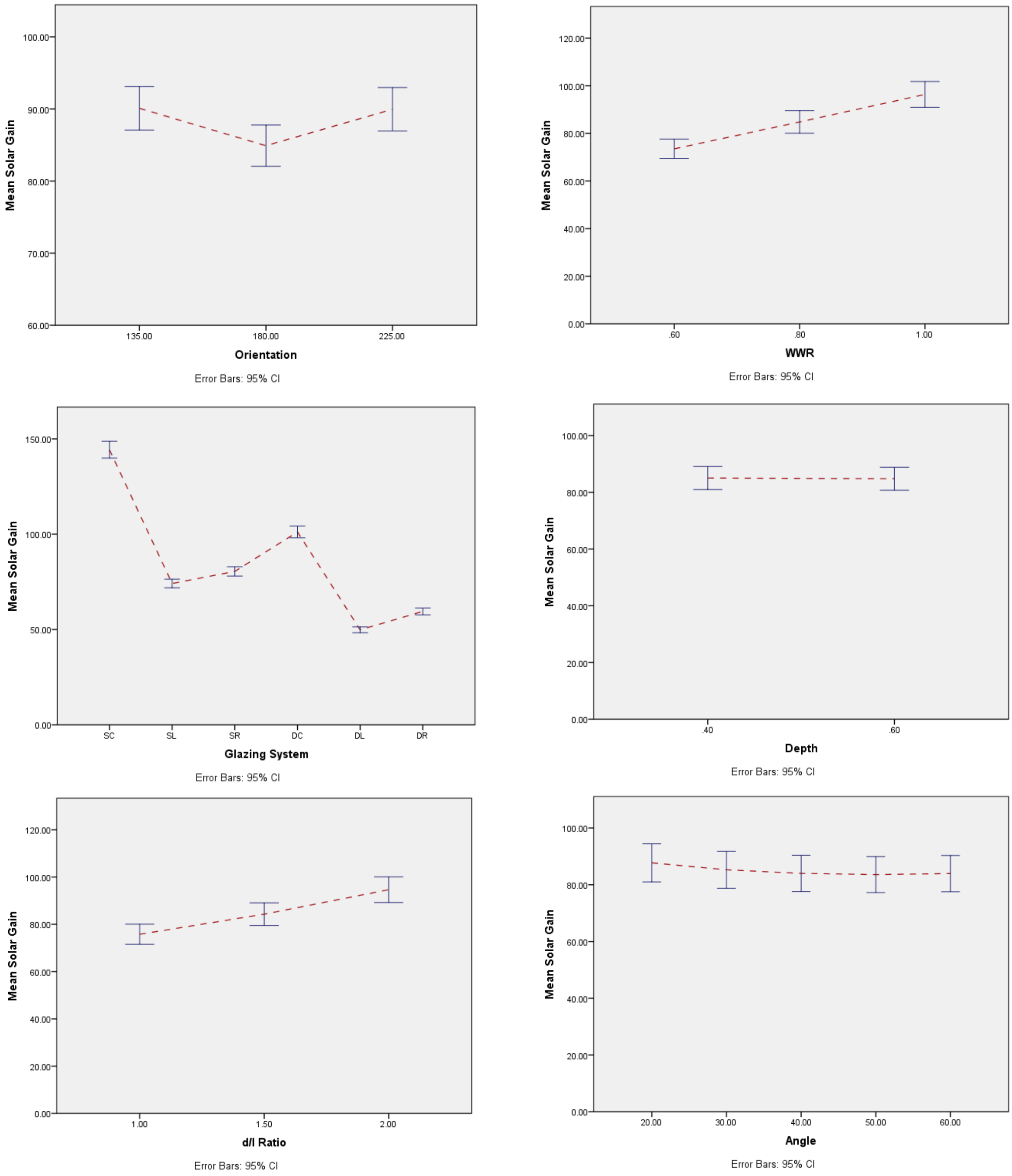


Figure 6.39 OAAT parameter of mean solar gain

The depth graph in the figure is almost horizontal. This means that the change from depth=400mm to 600mm does not have any impact on solar gain. The graph of the inclination angle shows an almost similar trend, meaning there is no significant change in the mean value of solar gain as a result of variation in the inclination angle.

It can be concluded that solar gain is mostly controlled by the glazing systems, hence other parameters becomes less effective, such as the depth of the PVSD, which means that their effect within the global influence on solar gain will then be either limited or negligible.

- *Lighting gain*

Figure 6.40 shows a fairly scattered accumulation of both predicted and observed values around the regression model for lighting gain. This is very well explained by the model accuracy of the adjusted R^2 equals 0.954, as shown in Figure 6.41.

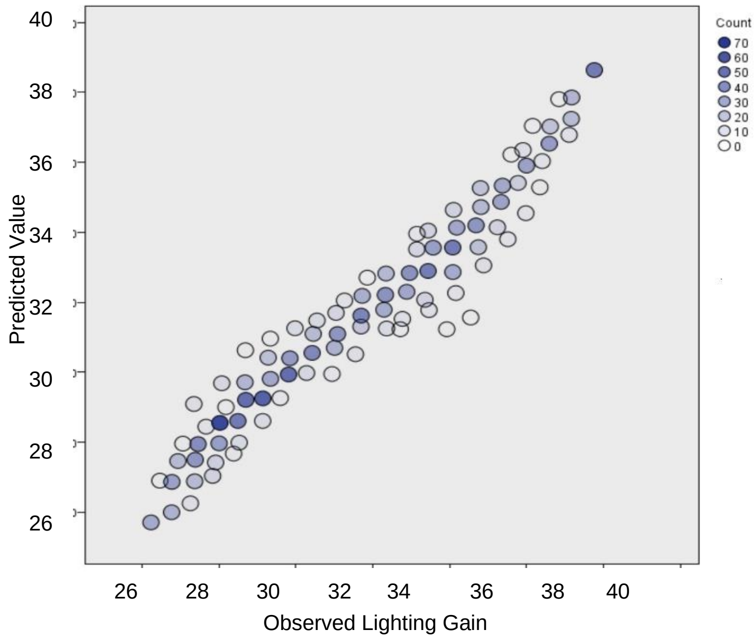


Figure 6.40 Predicted by observed plot for mean lighting gain

Figure 6.42 shows that the influence of the variation of each parameter on lighting gain is evident as the figure demonstrates a high predictor importance of glazing systems of nearly 57%, followed by d/l ratio as the second most influential parameter on the lighting gain with 31% of influence.

The angle of inclination has also scored in the SA, but less significantly than the first two parameters mentioned above, at 8%. The least influence on lighting gain comes from WWR (with only around 3%) and finally orientation with nearly 1%. The depth has one more time proved to be insignificant in terms of lighting gain.

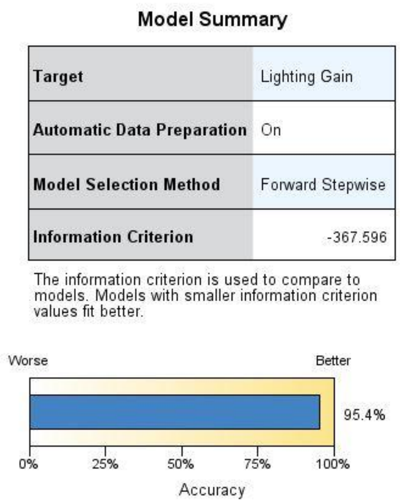


Figure 6.41 Model summary and accuracy of lighting gain

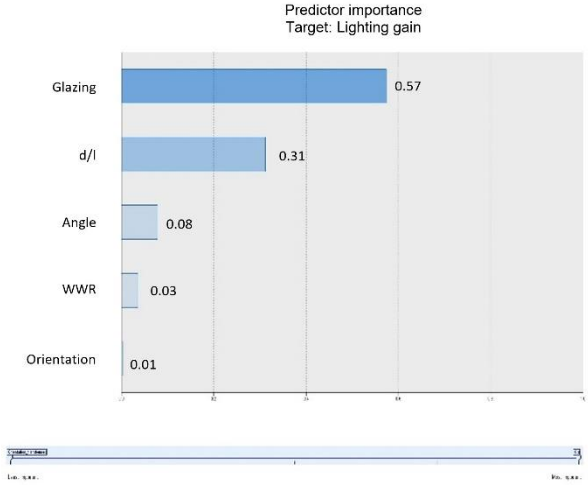


Figure 6.42 Predictor importance for lighting gain

When analysing parameters separately, one at a time, the graphs in Figure 6.43 prove the previously mentioned findings, where the trends vary from one parameter to another. The most fluctuating mean value of lighting gain is the glazing system, which means varying this parameter results in most of the variation of the output. The rest of the variation of the output (lighting gain) is influenced by the d/l ratio, followed by the angle of the inclination and finally WWR. No effect of the depth is recorded in the SA of the lighting gain, which confirms the previous findings (see SA of energy consumption and solar gain in the previous sections).

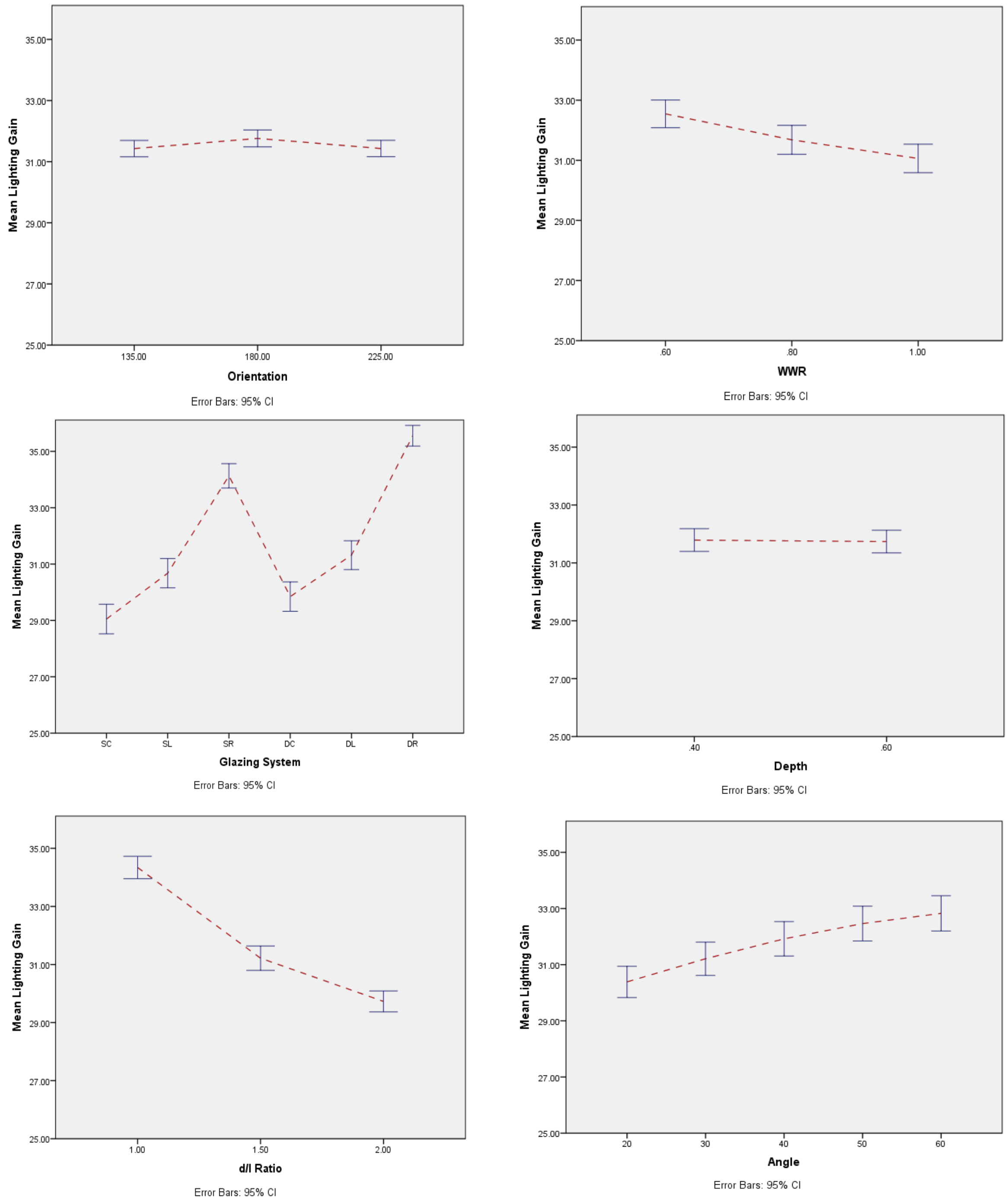


Figure 6.43 OAAT parameter for mean lighting gain

- *Cooling load*

The results of cooling loads calculated by the dynamic simulation models have been plotted against the predicted values that have been estimated by the regression equation, known as predicted, as shown in Figure 6.44. In the model summary shown in Figure 6.45, a high accuracy of the model is evident. The accuracy is extremely high as indicated by the adjusted R^2 coefficient (98.3%).

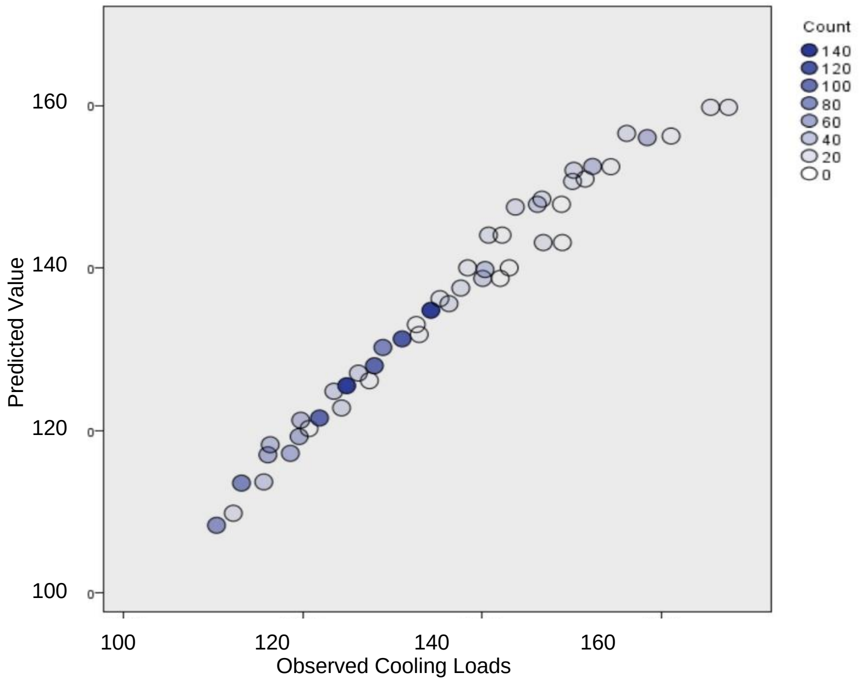
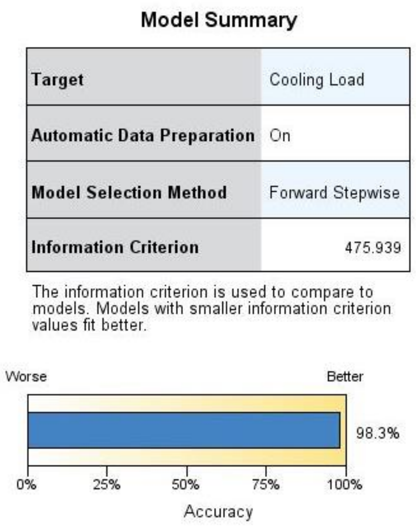


Figure 6.44 Predicted by observed plot for mean cooling loads

It is possible to see, in Figure 6.46, that glazing systems (HPG) is the most important parameter whose variations influence the cooling load as high as 89%. The second most influential parameter on cooling load is WWR which is already noted graphically in the results presented so far, with a limited influence of around 8%.



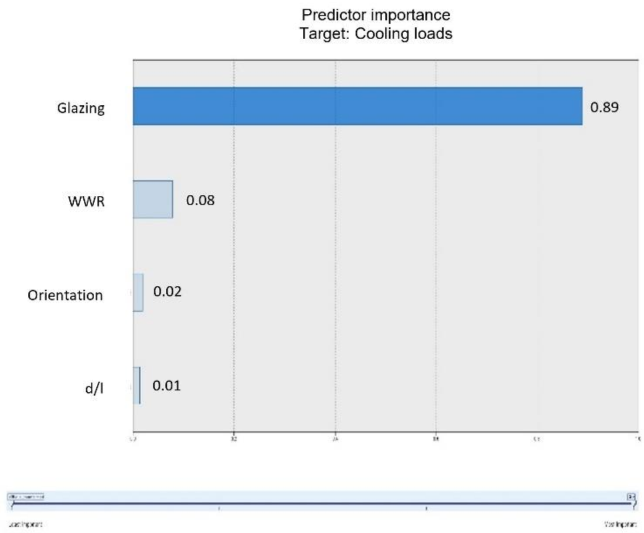


Figure 6.45 Model summary and accuracy of cooling loads

Figure 6.46 Predictor importance for cooling loads

The least influential were found to be orientation (almost 2%) and d/l ratio (around 1%). The rest of the parameters did not even score in the SA because their influence was insignificant on the cooling load figures.

In order to visualise the findings of the SA of cooling load results, line graphs of the mean values of each parameter, with error bars and 95% confidence interval, are presented in Figure 6.47

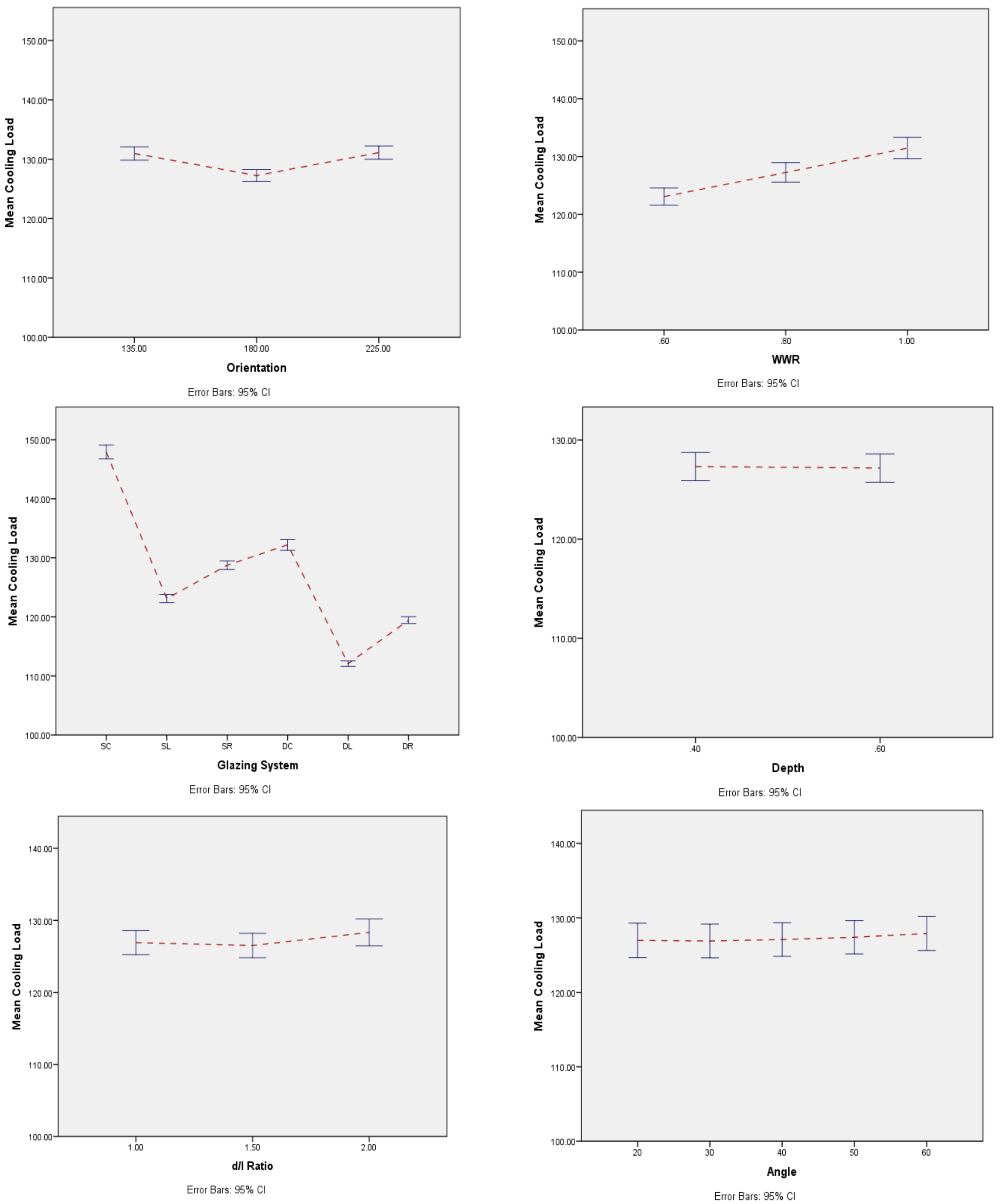


Figure 6.47 OAAT parameter of mean cooling loads

It can be seen from

the fluctuation of the dotted red lines that glazing types are more influential than other parameters, followed by WWR. The other three parameters' line graphs show nearly linear tendency which reads as being less influential. In other words, the change or variation in those two parameters has a very limited effect on the results.

- *PV electricity generation*

The SA of the generated electricity by the PVSDs shows a fairly high level of accuracy of the model, as the reasonable plot of predicted vs. observed in Figure 6.48 shows, and confirmed by the adjusted R^2 at 0.987, as shown in Figure 6.49.

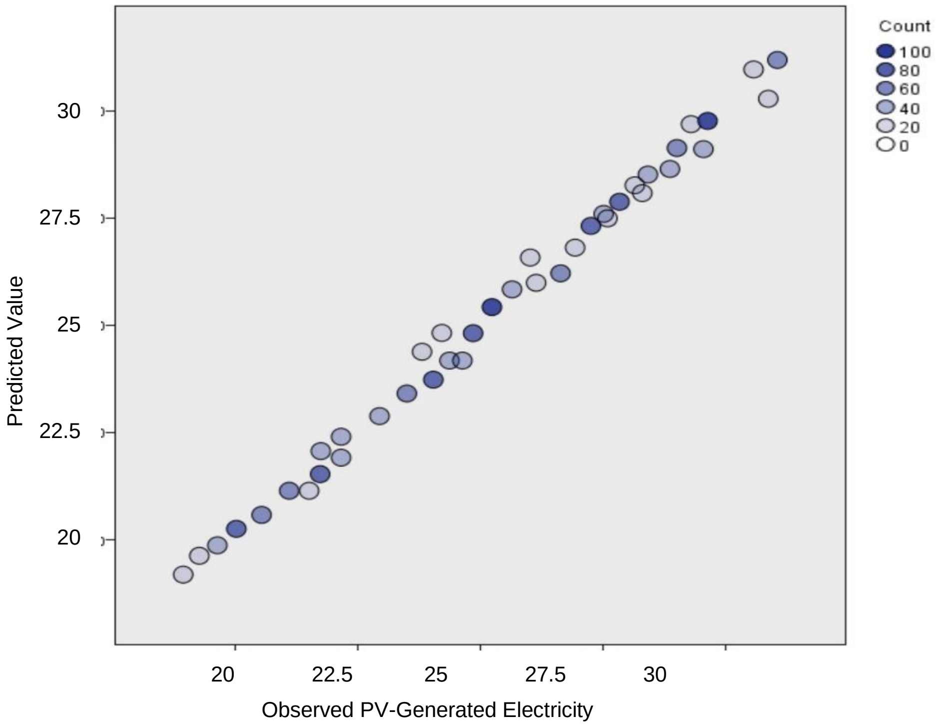


Figure 6.48 Predicted by observed plot of mean PV-generated electricity

The predictor importance analysis did not include any parameter that has proved to be irrelevant or not associated with the results at all, such as glazing systems (HPG) and the percentage of glass (WWR), simply because those two parameters are located behind the PVSDs within the main building skin (main façade), whereas the PV cells are integrated within the external building skin (PVSDs). This however, was proven statistically (please see section 6.5.1/PV-generated electricity) where the results were visualised. Therefore, only orientation, d/l ratio, depth of the PVSDs and the angle of inclination, which all have a direct influence on the PV output, are included in the sensitivity test for PV-generated electricity.

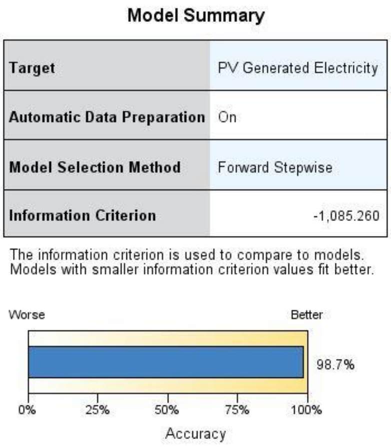


Figure 6.49 Model summary and accuracy for PV-generated electricity

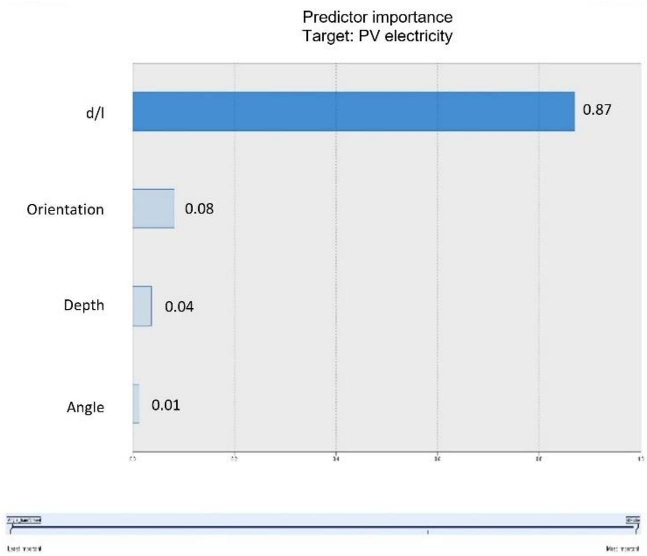


Figure 6.50 Predictor importance for PV-generated electricity

Figure 6.50 shows the predictor importance of these four parameters. It is noted that most of the influence of the variation of the input parameters is addressed by the d/l ratio. The influence of the d/l ratio on PV-generated electricity is as high as 87% and this confirms the findings from phases one and two of the analysis of this study which highlight that this ratio is particularly important because it mainly determines the space in which all the PVSDs are located. In other words, the greater this ratio, the lower the number of PV shading devices, which means less electricity is generated.

In addition to the d/l ratio, the orientation of the building scores the second with 8% of importance on the generated electricity. This is justifiable as the generated electricity is highly influenced by the sunbeam, which is determined by the sun azimuth and altitude. The depth comes next with 4% and finally the angle of inclination with around 1%. This fact also confirms the findings of the previous phases in the analysis and it is justified because the depth also determines the available area of each PVSD to which the PV cells are integrated. In other words, the bigger the depth of each PVSD the more area is available for the integration of the PV cells, hence more electricity will be generated.

To visualise these findings, OAAT parameter graphs have been plotted in Figure 6.51 where each of the parameters is shown on the x-axis against their corresponding mean value of the PV-generated electricity. The red dotted line that links those values shows different trends and indicates how much influence they have on the output.

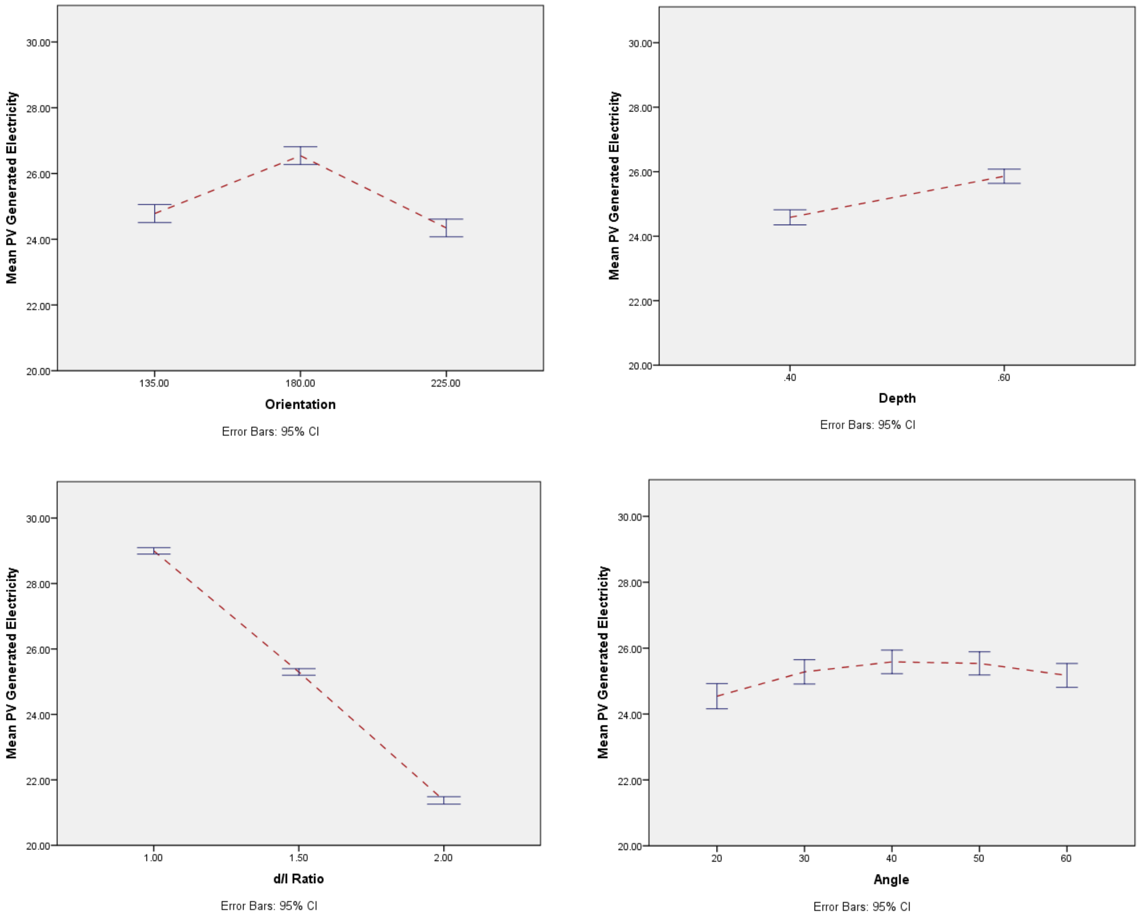


Figure 6.51 OAAT parameter for mean PV-generated electricity

- *Net energy*

The plot of the assessed vs. predicted values of net energy shown in Figure 6.52 is fairly scattered. That indicates a highly accurate model is observed. This is confirmed by the model summary in Figure 6.53 as the adjusted R^2 is 0.968.

The impact of change of each parameter on the net energy is visualised in Figure 6.54, which shows the predictor importance. It is interesting that all the parameters have no negligible influence on the results and could all score in the SA. However, the influence significantly varies among these parameters.

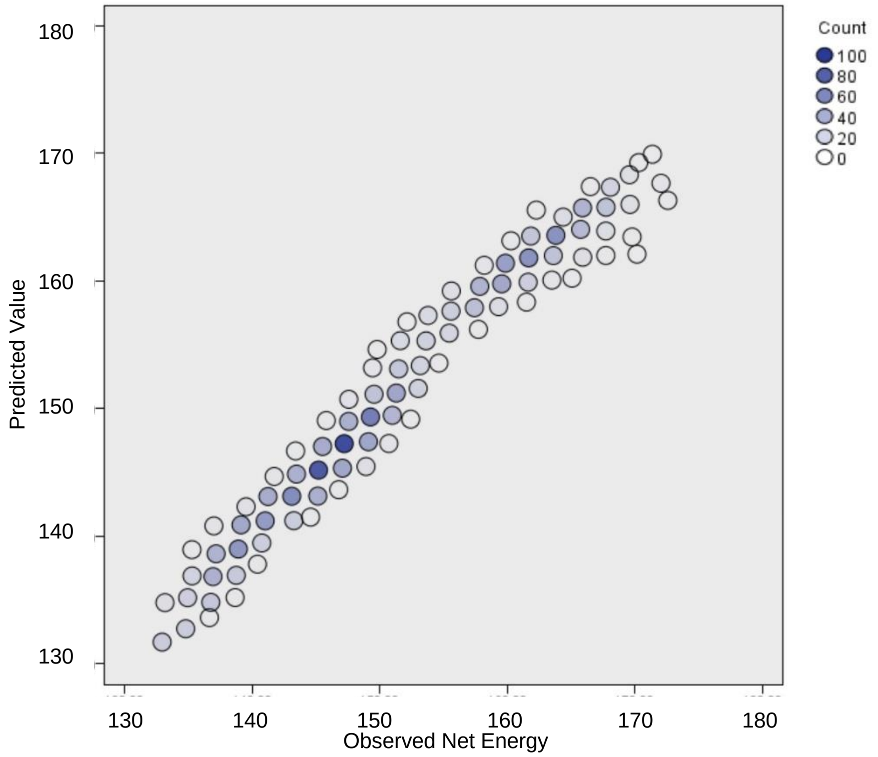


Figure 6.52 Predicted by observed plot for mean net energy

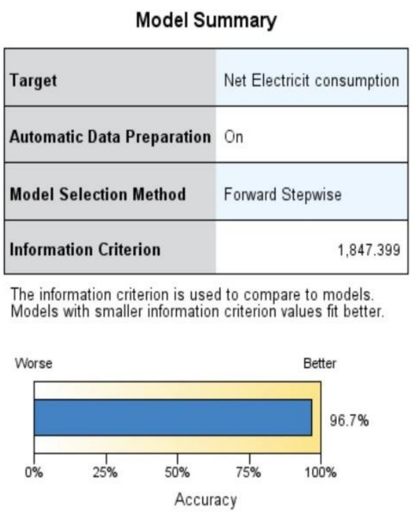


Figure 6.53 Model summary and accuracy for net energy

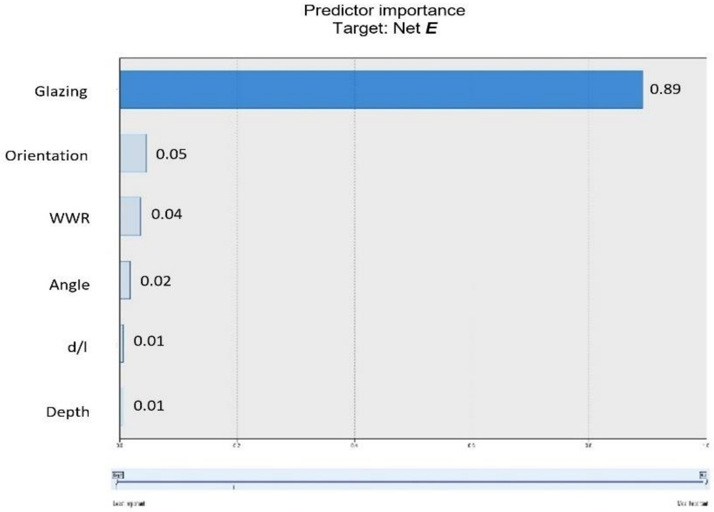


Figure 6.54 Predictor importance for net energy

Starting with the most influential parameter, once more the glazing system has scored the highest (89%) towards the final results. The second is orientation with 5% of influence, followed by WWR with 4%, angle of inclination 2%, and the least seem to be the d/l ratio and the depth at about 1%. The net energy measure is a very useful measure as it comprises both the energy that could have been consumed if IFS integration had been excluded and the energy consumption as a result of including IFS. Therefore, it can be seen that all the contributing parameters of both targets (energy consumption and PV electricity output) are influencing the results simultaneously. To be able to visualise these effects, OAAT graphs are presented in Figure 6.55.

The graph of glazing systems shows the most fluctuating trend, proving that this parameter highly influences the results. The depth shows a nearly straight line between the means of the two depths, meaning that they do have some influence but much less of an impact on the results. The rest of the parameters vary between the above-mentioned two parameters.

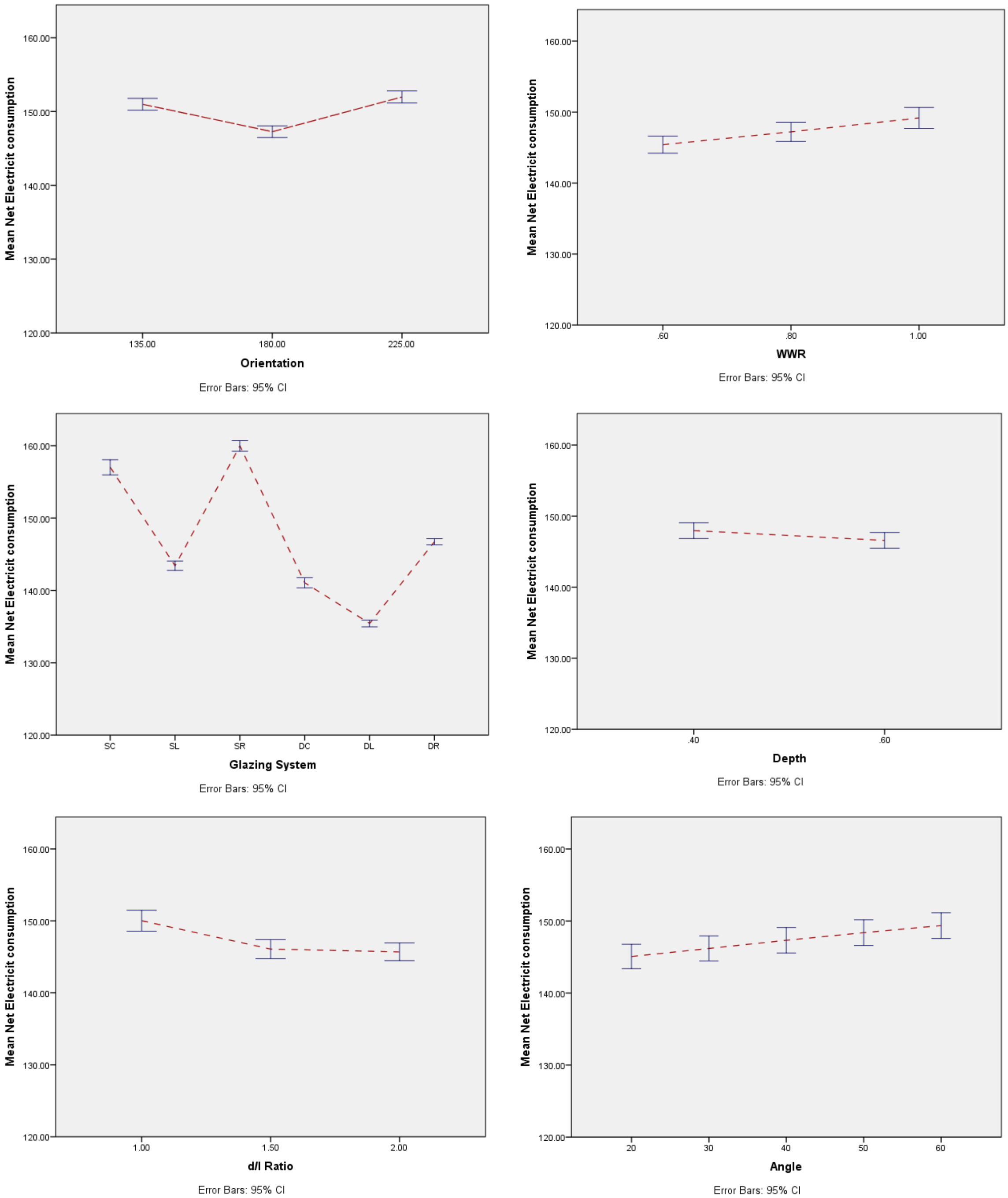


Figure 6.55 OAAT parameter of mean net energy

- *Energy savings*

As explained previously, this measure gives an idea about how much energy could be saved as a result of integrating IFS. The predicted vs. observed plot in Figure 6.56 shows a fair scatter of the predicted and observed values.

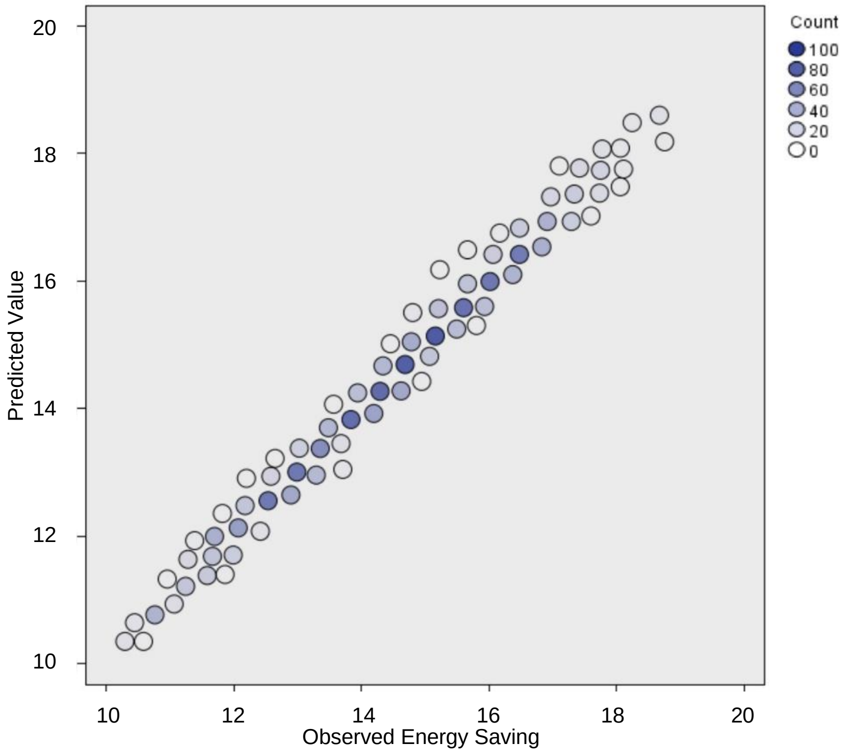


Figure 6.56 Predicted vs. Observed plot for energy saving

In the SA of energy saving percentage, the model's accuracy has proved to be quite high (96.5%), as seen in Figure 6.58. The importance of each influential parameter is ranked based on its scoring in SA towards the final figures, as shown in Figure 6.57.

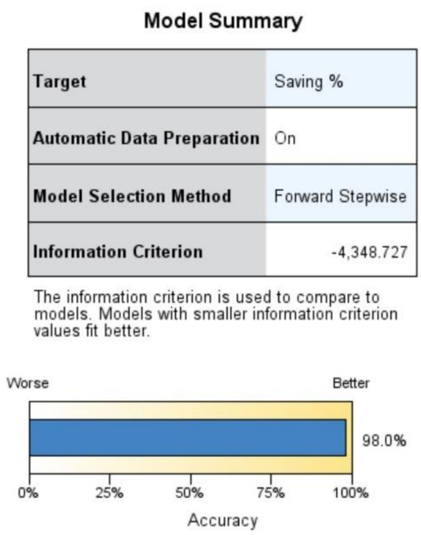


Figure 6.58 Model summary and accuracy for energy saving

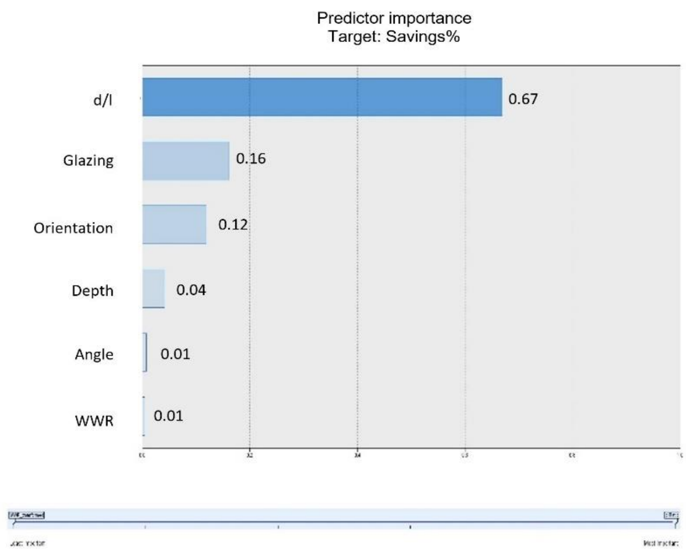


Figure 6.57 Predictor importance for energy saving

The SA of the saving has highlighted an interesting finding which is that the d/l ratio is the parameter that scores the highest, unlike in all the previous measures. This is justifiable because it results from both energy consumption figures and PV-generated electricity figures. The latter did not experience any influence by the glazing system nor from WWR, as explained earlier in the SA of PV-generated electricity), which means if the saving percentage figures are considered, the parameters that should be considered are those shown in Figure 6.57 and the focus should be more on those which scored the highest. The highest scoring parameter in the SA of savings is the d/l ratio with 67% of influence, the glazing system comes second with 16%, followed by orientation (12%), depth (4%) and finally the angle of inclination, which seems to have the least influence on the savings results (barely 1%). WWR did score in the SA but just above 0, which suggests that its influence on the savings is negligible. This is because of its overall limited influence on the other contributing factors, especially its null impact on PV-generated electricity.

Figure 6.59 illustrates those findings where the OAAT parameters are analysed. The red dotted line connects the mean values of each parameter variation, showing the trends when changing from one value to another. The trends in the graphs confirm the findings of the SA and show that although a variation in glazing systems has proved to have a significant influence on the previously analysed factors, when it comes to savings, the d/l ratio shows a more fluctuated trend, hence a higher impact. This means that it does have the highest influence on the savings figures. Other parameters also have some influence, but not as much.

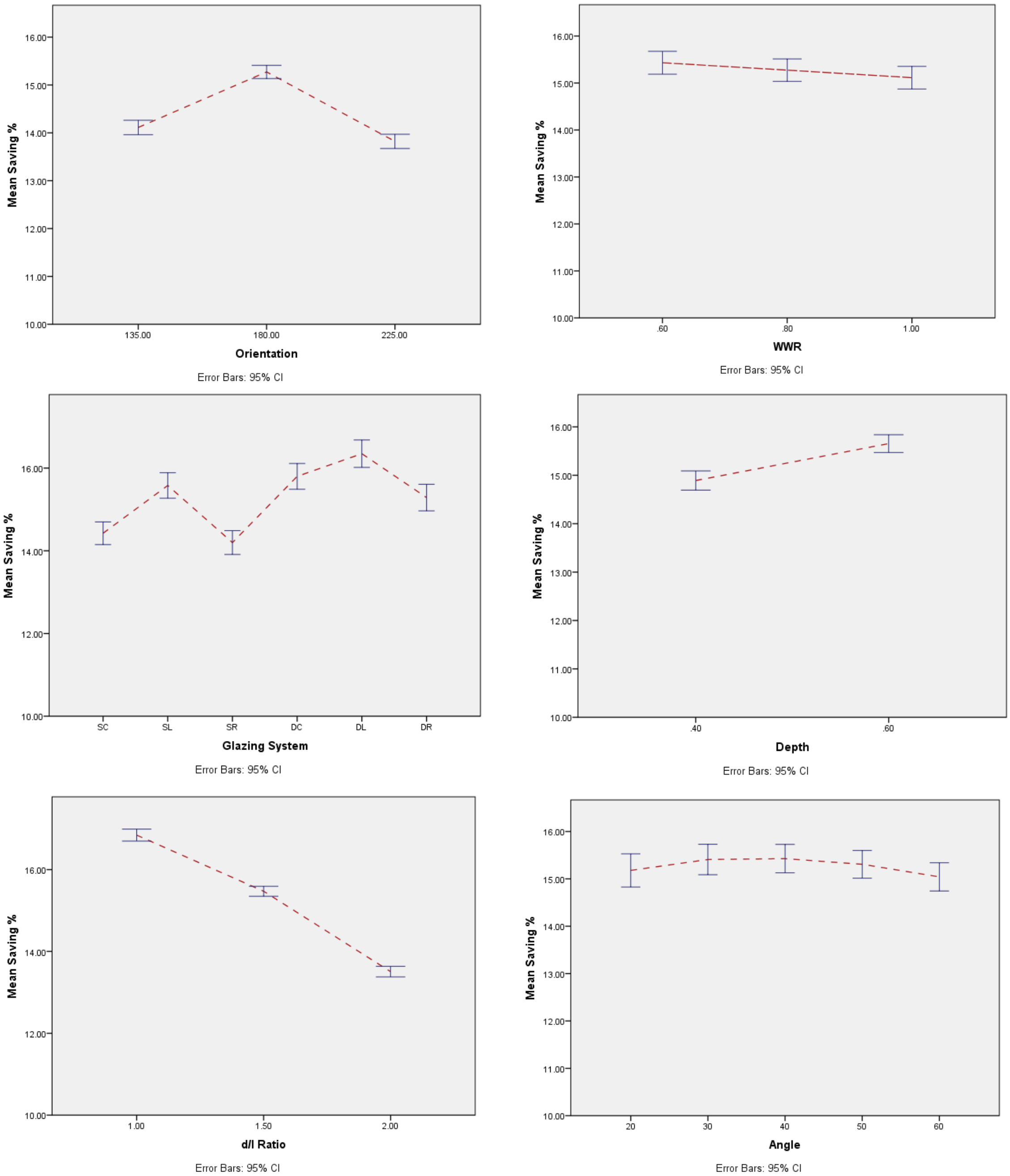


Figure 6.59 OAAT parameter of mean energy saving

6.7.3 Sensitivity analysis of daylighting performance

In this section, the SA of daylight performance indicators is presented and discussed. The main findings of the SA are highlighted. As explained in section 6.6.2, two indicators are analysed. These are: the range where the useful daylight illuminance level falls below the minimum threshold (less than 300lux) and the range where the need for artificial lights is limited or not needed at all and this range allows for tolerable and comfortable illumination in the indoor environment, i.e. between 300lux and 3000lux. In each of the following sections, the accuracy of the model is presented and verified against other methods used in the SA (i.e. the plot of predicted vs. observed values). The predictor importance of the influential parameters will be presented and parameters will be illustrated individually in order to visualise that importance.

- *$UDI_{less\ than\ 300\ lux}$*

The plot of the predicted values of $UDI_{less\ than\ 300\ lux}$ against those values resulting from the dynamic energy and lighting simulation models in Figure 6.60, shows a reasonable plot of the values and a trend of linearity of around 45°; this confirms both the accuracy of the model and the compatibility of the method used in the analysis with the data. In addition, the model summary, shown in Figure 6.61, confirms that the accuracy is high due to the adjusted R^2 being 0.962.

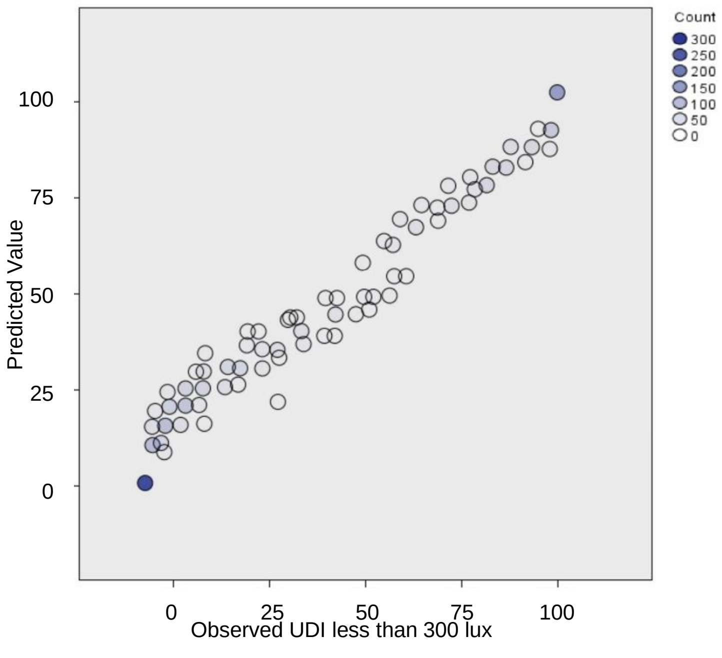


Figure 6.60 Predicted by observed plot of mean useful daylight illuminance for UDI less than 300 lux

It is evident that varying the glazing system has the highest influence on the results with 90% importance, as shown in Figure 6.62.

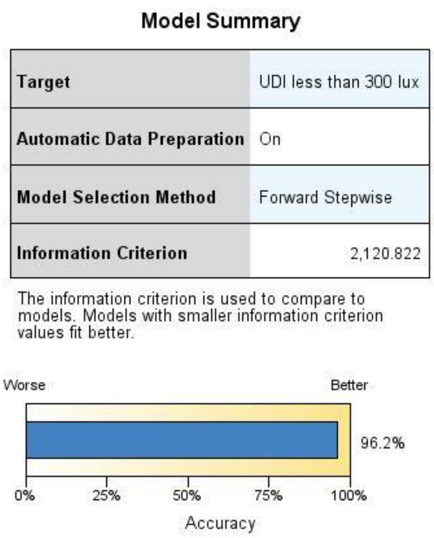


Figure 6.61 Model summary and accuracy of useful daylight illuminance for UDI less than 300 lux

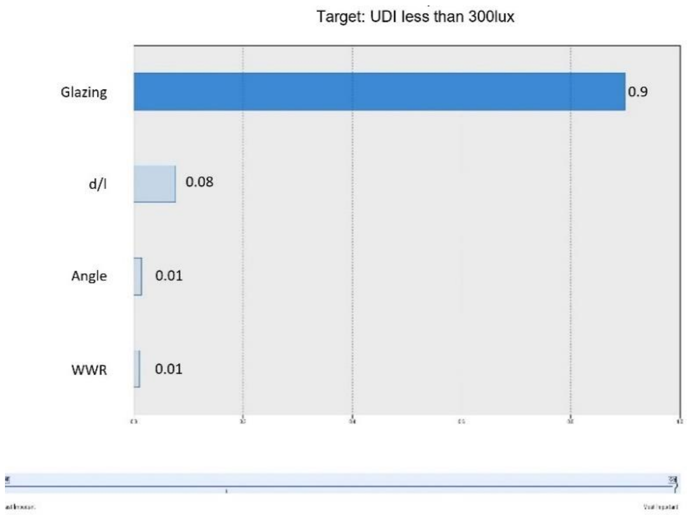


Figure 6.62 Predictor importance for useful daylight illuminance for UDI less than 300 lux

The second influential parameter on the UDI *less than 300 lux* that scores in the SA is the d/l ratio with an influence of around 8%. The angle of inclination comes third in the ranking with around 1% influence. Finally, WWR comes last with barely 1%. Clearly, this is due to the range in the variation of the optical characteristics of the glazing systems used in this study (t_{vis}) which highly impacts on the penetration of daylight into the interior spaces. It also seems reasonable that the d/l ratio has a significant influence as it determines the distance between the PVSDs, which in turn determines the façade surface area through which light penetrates into the indoor environment. The depth did not score in the SA; interestingly, neither did the orientation. This is justifiable because the illuminance is mainly governed by the sun azimuth and altitude. On each of the orientations examined (South, South-east and South-west), the time of the day where the sensors read the illuminance in the interior spaces is for a specific period (8 am to 4 pm) and during this period, the sun altitude for all of these three orientations is similar and only at the very beginning of the day and in the late evening a difference in the sunbeam occurs, and that is outside the analysis hours of UDI ranges.

Figure 6.63 shows the OAAT parameters and visualises the influence of each parameter on UDI*less than 300 lux*. The graphs in the figure confirm what has been concluded from the SA. Clearly, the glazing system is the most impactful parameter on the daylight performance as the mean varies considerably from one type to another; d/l, angle of inclination and WWR seem less influential. The straight line that links the mean values of different orientations suggests that there is no influence by varying the orientation on $UDI_{less\ than\ 300\ lux}$.

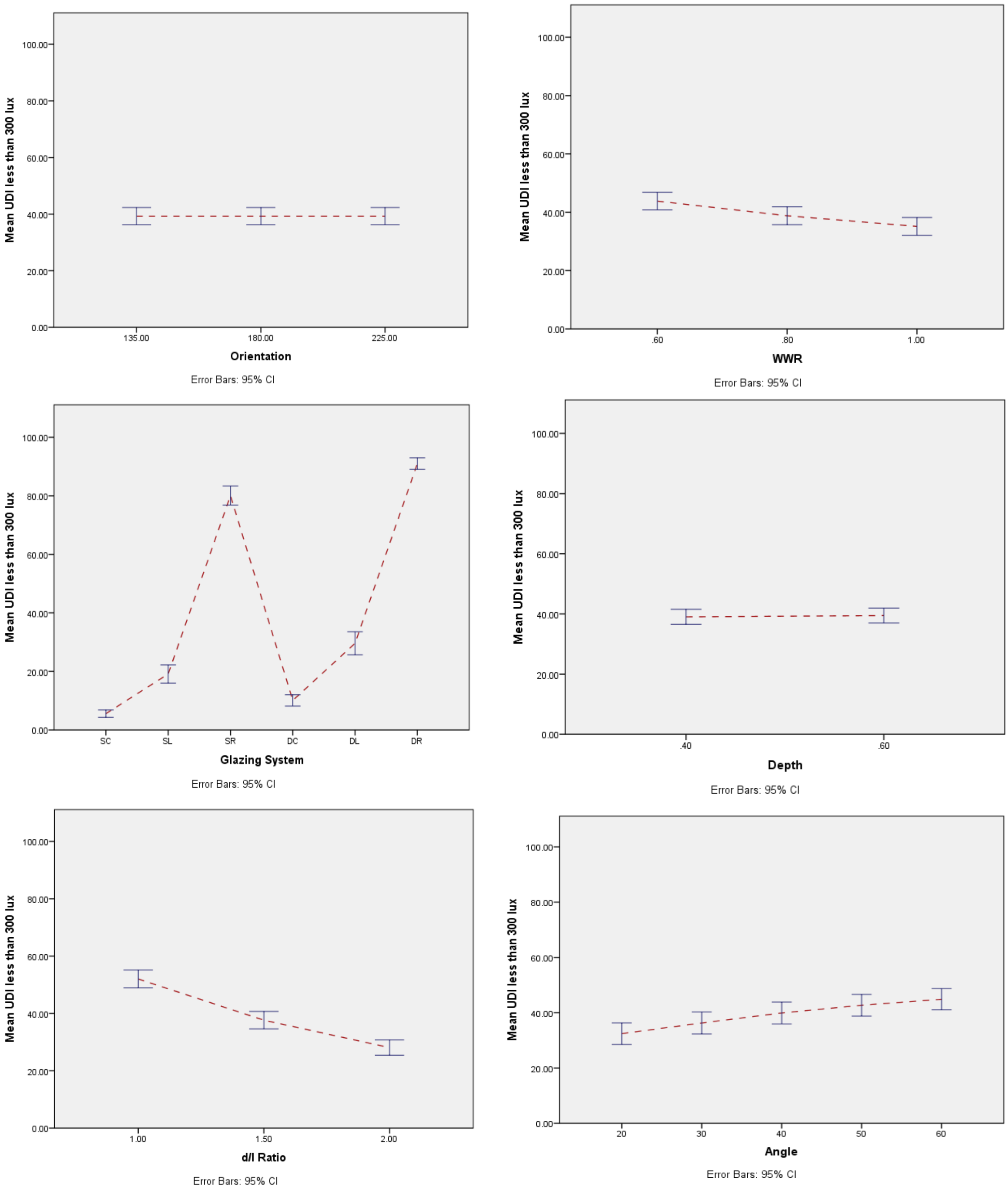


Figure 6.63 OAAT parameter of mean useful daylight illuminance for UDI less than 300 lux

- *$UDI_{300\ to\ 3000\ lux}$*

For this range, the model shows a high level of accuracy, as can be seen in Figure 6.64, where values of both assessed and predicted $UDI_{300\text{-}3000\ lux}$ are fairly scattered around the linear regression. This is also proven by the model summary where the adjusted R^2 is 0.962, as seen in Figure 6.65.

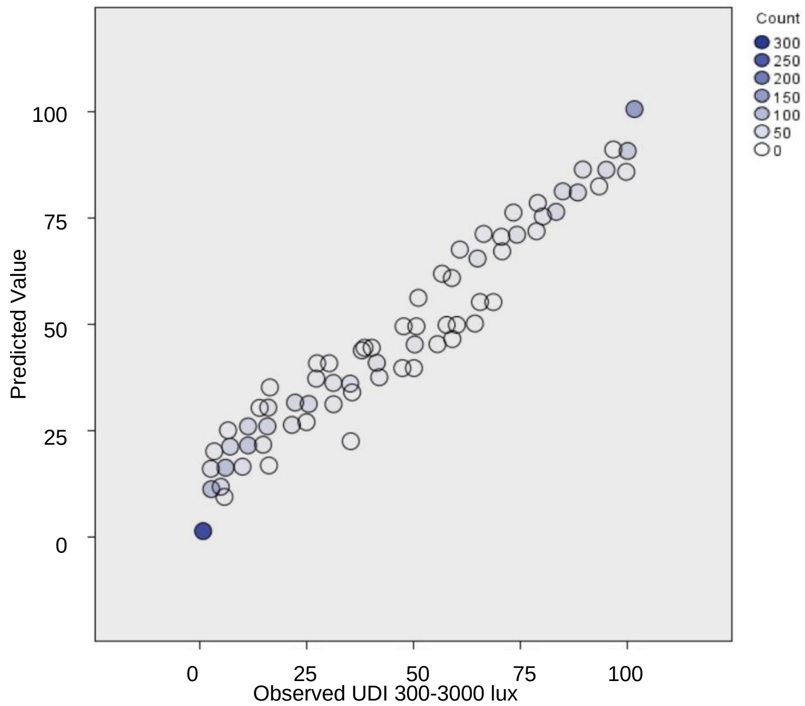


Figure 6.64 Predicted by observed plot of mean useful daylight illuminance for UDI 300 to 3000 lux

Figure 6.66 shows that variation of glazing type is again the most influential parameter (90%). The second parameter that scores in the SA is the d/l ratio with only 8% influence. The angle of inclination scores third in the ranking (1%) then WWR is the least influential with nearly 1% of importance. The orientation did not score in the SA for the reasons explained in the previous section.

Model Summary

Target	UDI 300-3000 lux
Automatic Data Preparation	On
Model Selection Method	Forward Stepwise
Information Criterion	2,120.822

The information criterion is used to compare to models. Models with smaller information criterion values fit better.

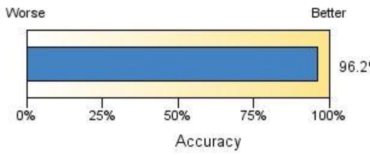


Figure 6.65 Model summary and accuracy of useful daylight illuminance for UDI 300 to 3000 lux

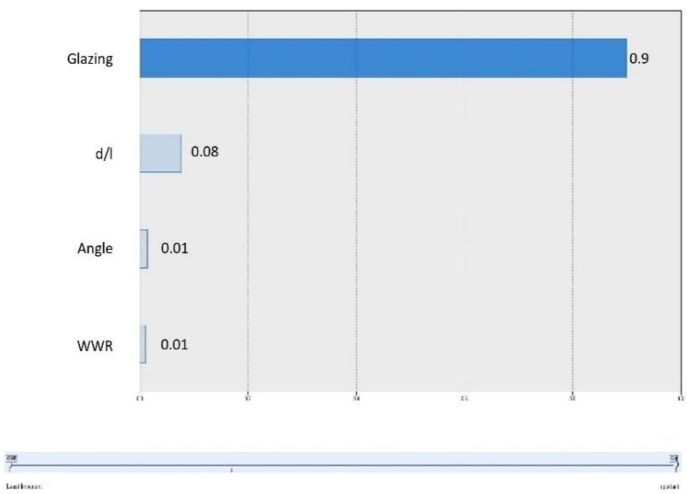


Figure 6.66 Predictor importance for useful daylight illuminance for UDI 300 to 3000 lux

An OAAT parameter analysis is presented in Figure 6.67. The trends of the variations are, as expected, the opposite of the previous assessment indicator. In other words, take WWR for example, when the trend increases between 60% and 100% for the mean values of UDI$_{300 \text{ to } 3000 \text{ lux}}$, the trend of the same parameter variation decreases in the range of UDI$_{\text{less than } 300 \text{ lux}}$.

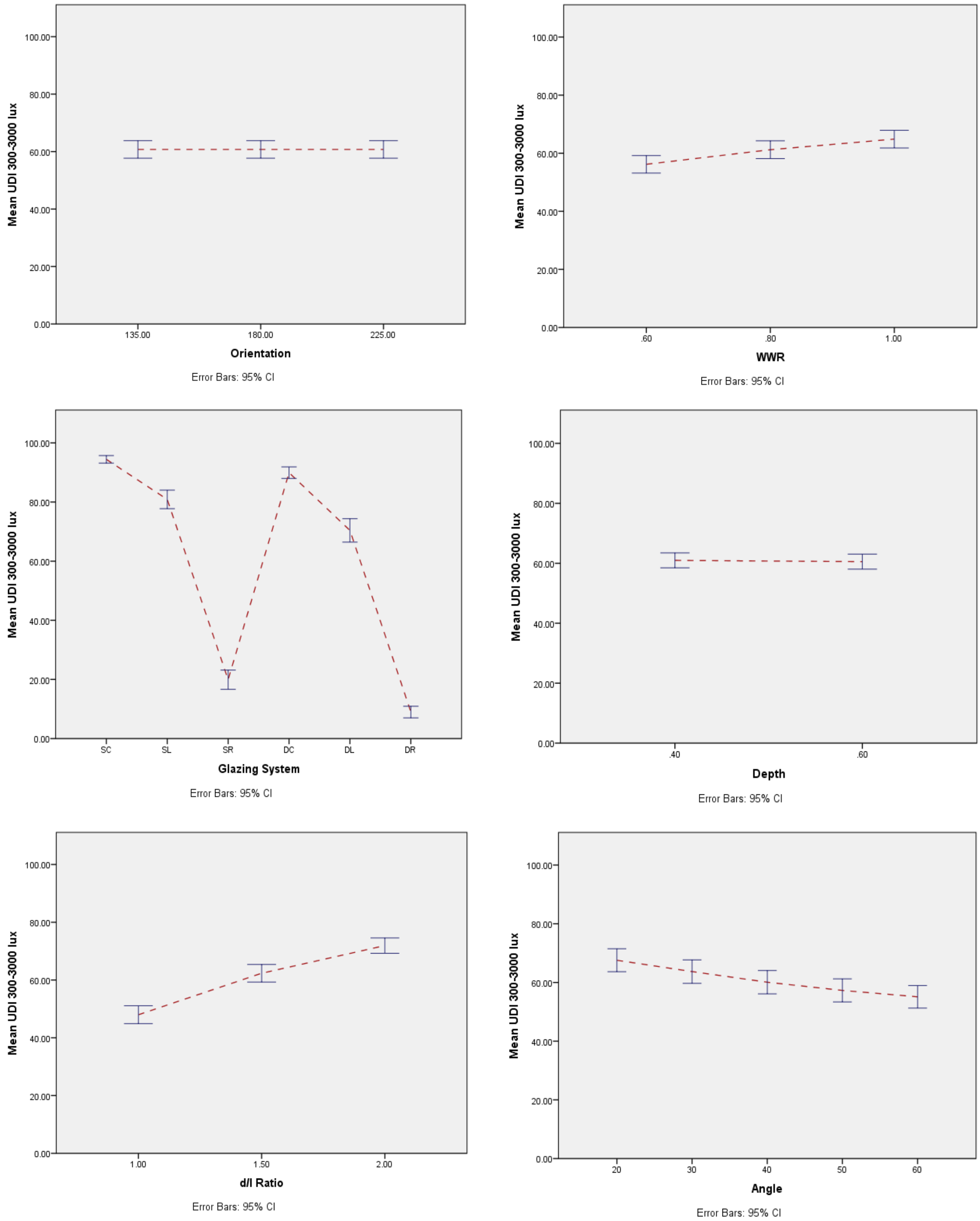


Figure 6.67 OAAT parameter of mean useful daylight illuminance for UDI 300 to 3000 lux

Neither the depth nor the orientation scored in the SA, proving that they have insignificant influence on the results, which is evident from the straight dotted red line that connects both variations of the depth.

6.8 Chapter summary

This chapter presented and discussed the analysis of the results of both the proof-of-concept stage and then the detailed **1620** combinations of all the parameters that were developed in this study. The first part of this chapter has presented the proof-of-concept model and simulations where two rounds of simulations were carried out for one scenario considering a single variable. The inclination angle was picked up to be modified and compared to a preliminary base-case while the rest of the parameters were kept fixed. It was found that there were satisfactory results, which suggests that there is a considerable influence of the change of the inclination angle on solar gain, cooling load and natural daylighting. Concluding comments detailing the findings of this stage were discussed in section 6.2.8. These findings showed that the approach and the expected outcomes were in line with what this research has set out to achieve in its aim and objectives, which in turn showed it was possible to carry on with full-scale investigations.

In the second part of this chapter, the results of **1620** combination models were presented and analysed. The results showed that when the focus switches to a more holistic assessment approach, the assessment indicators, such as energy consumption or cooling loads, would miss out some important information that may affect the interpretation of the results and thus taking accurate conclusions from the assessment unless a systemic method is utilised.

Over all, the vast majority of the configurations perform significantly better than the base-case with the same orientation. This means that all the IFS combinations proved to improve the base-case but to different extents. In addition, it was found that when IFS is integrated properly, considering all the influential factors in a systemic way, the impact of building orientation becomes much less significant and optimum combinations at a certain orientation can achieve a satisfactorily reduced energy demand with a reasonable daylight availability in the indoor spaces.

The numerical values of the simulation results in the inferential analysis phase have been clustered at the south orientation and, according to the two main depths, d/l ratios, angles of inclination and the glazing systems combinations, which are the parameters used.

As a general trend, combinations with double- and single- low-e glazing resulted in lower cooling loads than the other types. It was also found that the d/l ratio plays a significant role, with models where d/l=2 showed lower cooling loads and solar gain than d/l=1.5 or d/l=1. The opposite was instead found for lighting gain and useful daylight illuminance, which suggests trade-offs between the minimisation of cooling loads and the maximisation of daylight, or minimisation of lighting gain and maximisation of PV-generated electricity. This depends on the design agenda of a certain project. UDI results were also presented, indicating very promising results for highly- to fully-glazed office buildings with IFS, whilst providing good indoor conditions with less energy demand.

In the second phase, decisional synopses were presented in form of ranking tables of all combinations on a south-facing façade. The ranking was based on the numerical values of each of the assessment indicators investigated in this study. The synopses were generated as a form of design guidelines to help address the most sensible IFS combinations, given specific constraints or a particular design scenario.

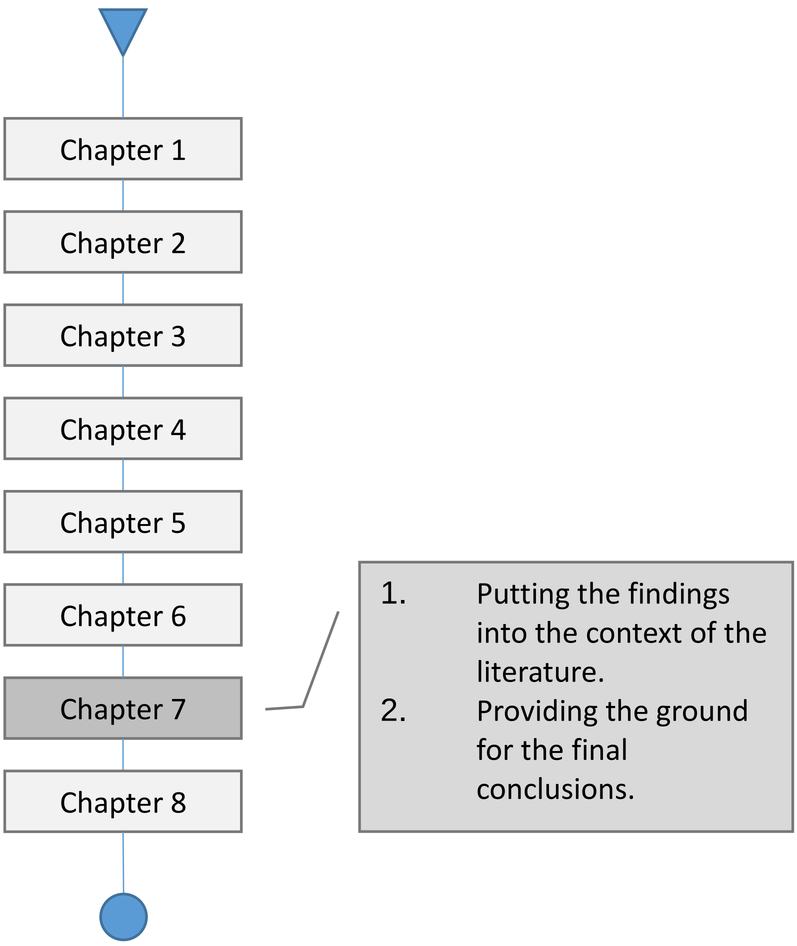
It was concluded that each glazing system could be preferable over the other types according to the variation of the other parameters.

Such parameters have also all been used for the SA, aiming at understanding which of the parameters are most influential on energy consumption, cooling loads, lighting gain and PV-generated electricity, in addition to daylight availability in the indoor spaces. Glazing system, d/l ratio and WWR have the most significant influence on the cooling loads, lighting gain and electricity consumption, whereas the inclination angle scored with less significance. The very same parameters have been found either much less significant or irrelevant when assessing the results of the SA for PV-generated electricity, net energy and energy savings, whereas d/l was found to be the most dominant parameter for these assessment indicators. Generally, the depth proved to be the least impactful parameter on the assessed indicators, except for PV-generated electricity. In order to facilitate visualising the impact of each input variable on each of the output variables, all Predictor Importance graphs are coupled in Appendix 13.

The next chapter will focus on the findings of this research within the context of the related literature to be able to then compare to, and discuss within, similar existing research wherever available and/or applicable. Commonalities and differences will be highlighted and explained.

Chapter Seven

Discussion of Findings



CHAPTER 7. Discussion of findings

7.1 Introduction

This chapter will put the findings of this research back into the context of the study and triangulate them with the review of the state-of-the-art literature where available, providing the ground for the final conclusions of the study. In the analysis, the aim is to look at output variables and trace them back to their causes (input variables), whereas in the discussion of findings, the investigations are set out to help understand how the output variables are impacted on by the input variables in order to have a clear pattern of the changes and the impacts that these will sustain from any of the input variables (Figure 7.1). This will help in devising a decision support system which means that any of these inputs can be chosen where the extent, range and depth of the impact of any them on the output variables can be scrutinised, analysed, prioritised – for a decision – or investigated in a parametric manner. This will be established following the systemic approach developed in this study which provides a customisable and modular system. Hence, all the influential variables analysed in the previous chapter will be organised as per their systemic level and will be discussed according to their impact on both energy (consumption and generation) and daylighting assessment indicators.

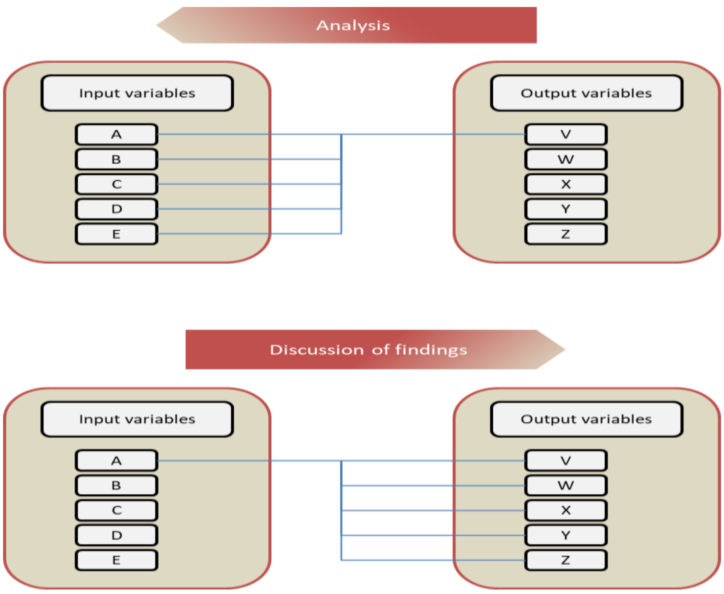


Figure 7.1 Workflow of discussion of findings vs. analysis

This chapter starts with the system level variables, namely orientation and window-to-wall ratio (WWR). The findings related to those two system level parameters will be highlighted and triangulated with the relevant literature wherever applicable. The same procedure is then followed with the sub-system level variables, i.e. PVSD variables including depth, d/l ratio, and inclination angle; and HPG variables including glazing systems with their corresponding glass types. Bases for the final conclusions will be established throughout the discussion presented in this chapter.

7.2 System level variables

The system level variables included in the investigations of this study are the building orientation and WWR. The findings from those two parameters are discussed in the following sections:

7.2.1 Orientation

In the current study where a systemic approach is followed, the influence of orientation seems to be insignificant. This can clearly be seen in Figure 7.2 for example, where the straight dotted line that links the mean values of the combinations on the three orientations under investigation is very close to a horizontal line. This was also confirmed by the SA as orientation did not score in the SA at all.

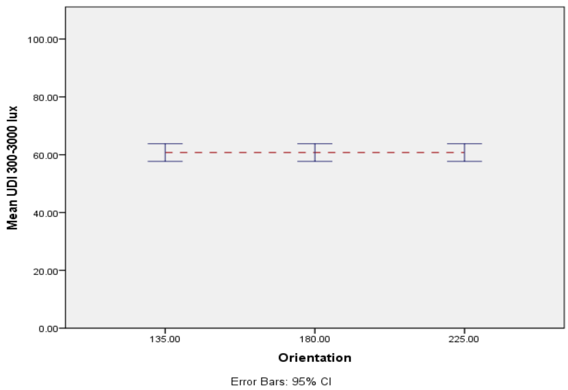


Figure 7.2 Mean UDI 300-3000 lux for different orientations

This has been achieved thanks to the thoroughness of the current study which provides a full account of the possible influential parameters and at the same time analyses a set of interrelated outputs based on their dependency. Therefore, the impact of any of the variables, such as lighting gain and how the use of a dimming profile contributes to a more stable visual condition, will not be missed out. In addition, variation in other parameters, such as HPG or d/l ratio, was found to be of much more importance. This leaves the other parameters, such as orientation's impact on daylighting quality almost irrelevant.

When analysing the extent of the impact of change of the orientation on each of the output variables, it is evident that in the presence of other variables, orientation seems to be one of the least impactful variables within the IFS settings. This is because the outputs are much more influenced by the variation of other variables, especially variables at the sub-system level. This is a significant finding because it provides a wide spectrum for design decisions to be made when there is a high level of constraints. For instance, one of the constraints could be a fixed orientation where the land plot is facing a certain orientation and cannot be rotated to improve the desired outputs. In that case, IFS provide a space for integrating a set of variables that can help overcome the orientation constraint by varying other variables at the sub-system level and maintaining the desired performance, be it thermal, visual or combined, in addition to optimum PV electricity generation. This finding, however, both contradicts and is in line with the findings of the literature, where orientation was found to be either a significant parameter (AlAnzi et al., 2009; Huang et al., 2014) or an insignificant parameter (Carlo and Lamberts, 2008; Poirazis et al., 2008).

The following paragraphs will elaborate on this in more detail and will show how using the systemic approach helps in clarifying this contradiction and provides robust justification based on the dependency and interdependency relationship of the variables.

Combinations at the south orientation are less energy intensive compared to those at the south-east and south-west (Figure 7.3). This is related to the variations from due south to other orientations which does not indicate a major difference in heat gains. The SA confirms that, as orientation was found to be the least influential variable compared to other parameters as demonstrated in section 6.7.2. This suggests that other variables, namely variables at the sub-system level, where interventions on the building envelope are conducted with the aim of improving the electricity consumption, are more influential on the output. However, when a full account of all influential parameters is taken, with multiple objectives, such as in the current study, the extent of the impact of the building orientation can be reduced.

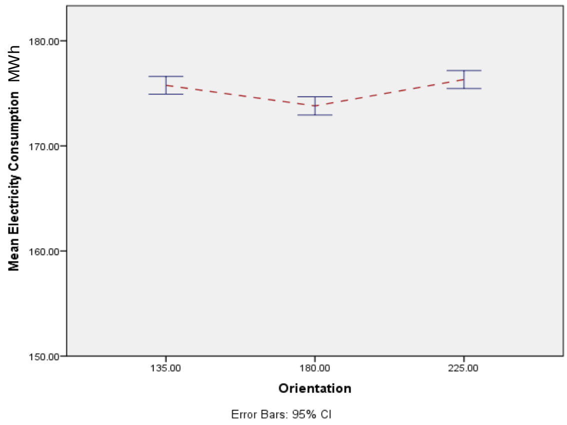


Figure 7.3 Mean electricity consumption for different orientations

Similar findings in the literature were identified, such as Carlo and Lamberts (2008) and Poirazis et al. (2008), where orientation was found to be of little importance; however, their focus was solely on energy consumption and they did not account for the full set of the influential parameters. Their findings therefore are exclusive to energy consumption and the dependency and interdependency of the factors were not accounted for. Hence it was not possible for them to identify the extent of the importance of orientation as a result of its relation to other variables.

On the other hand, other studies such as Fasi and Budaiwi (2015) and Huang et al. (2014) found that varying the building orientation can have a considerable impact on the daylighting performance; however, when analysing the impact of change of orientation in greater depth, such as the systemic approach of this study, and with a number of objectives, such as PV electricity generation or daylighting improvement, the influence of orientation can be reduced and its impact on daylighting for example can be controlled by other parameters at the sub-system level. Furthermore, the dependency of the output variables can be looked into in order to account for the impact of those variables on each other. To elaborate on this, for instance, when analysing the impact of change of orientation on lighting gain, it is evident, as shown in Figure 7.4, that more gain was found on the south compared to the south-east and south-west. Using the factors' dependency diagram (Figure 4.15), only then it is possible to investigate in detail, the influence of change of a system level variable, such as orientation, on lighting gain and to analyse how this gain is interrelated to other variables, such as cooling loads, solar gain and subsequent energy consumption.

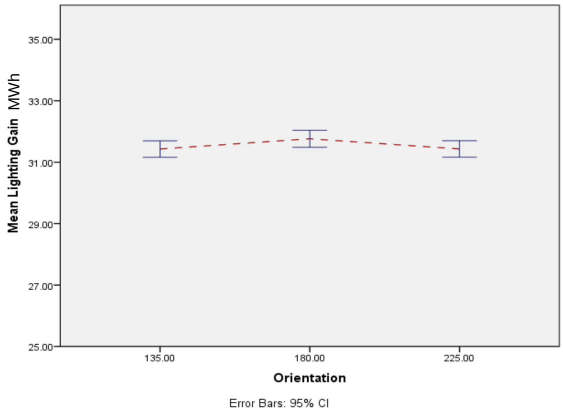


Figure 7.4 Mean lighting gain for different orientations

Figure 7.5 shows solar gain at different orientations. The figure shows that both south-east and south-west produce higher solar gain compared to south. This is due to high solar irradiance on both south-east and south-west as the solar beam is more influential on those orientations. This, in turn, will influence the cooling loads (Figure 7.6) and therefore the total energy is subsequently influenced.

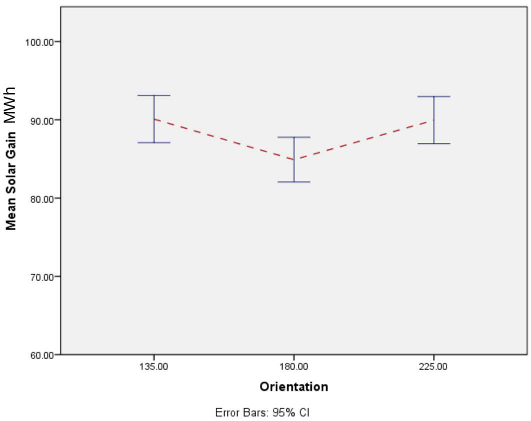


Figure 7.5 Mean solar gain for different orientations

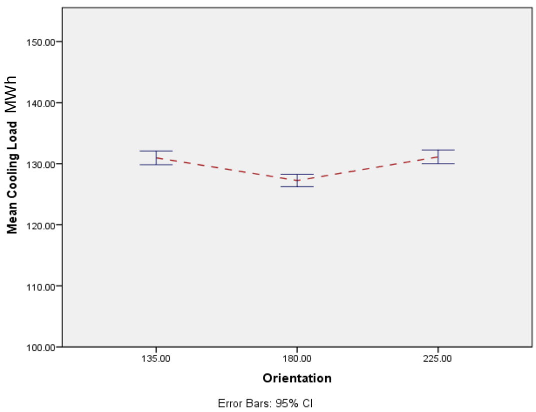


Figure 7.6 Mean cooling loads for different orientations

Figure 7.6 shows that cooling loads were found to be higher on south-west, followed by south-east and then south. The SA showed that orientation is the third most impactful parameter on cooling loads. This finding is in line with the findings of Sun et al. (2015) where the total cooling load reduction of a south-facing window was found to be smaller than that of a south-west facing window because the latter can receive more solar gain. On the other hand, contradictory findings were seen in the literature where cooling loads were reduced more on the south-east and south-west façades (Tongtuam et al., 2011; Zhang, 2014). Such contradiction could be because they did not account for lighting gain in the interior spaces (Figure 7.4) whose impact would influence the cooling loads. Lack of a systemic approach in those studies is also a contributing factor, which means those studies probably missed the opportunity to systemically analyse the contributing factors to be able to account fully and comprehensively for the influence of these factors on each other.

Combinations of PVSDs on south façades generate more electricity, followed by south-east then south-west (Figure 7.7), which is in line with what has been found by Zhang (2014).

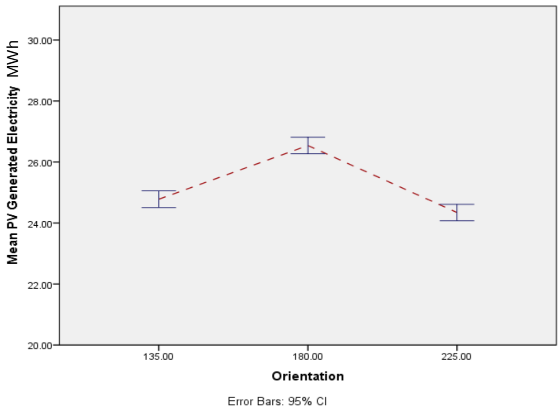


Figure 7.7 Mean PV-generated electricity for different orientations

The influence of orientation was found to be important in the SA where it scores as the second most important parameter – with 8% of importance – when it comes to PV electricity generation. In contrast, Sun et al. (2015) found that electricity generation per unit of PV area was more on the south-west than south. Whereas in an earlier study, Sun et al. (2012) suggest that the maximum electricity generation per unit of PV area is achieved when the PV modules are installed on south façades at a tilt angle of 10°. Such contradiction could be because Sun et al. (2015) analysed the impact of orientation on building elements in isolation (cladding elements only) without considering the self-shading impact of the PVSDs that can affect the PV efficiency and hence its electricity generation, and also the other influential parameters on different systemic levels. Another contradiction was found where the maximum power generation of the BIPV is not gained at exact south, but at south-east 50° or south-west 50° on a particular day in the building (Yoo, 2011). This clearly suggests that there is no general conclusion that can be reached in this regard and it highlights the importance of the necessity of using a holistic and comprehensive approach, in a systemic manner, to be able to clarify why there have been discrepancies in findings in the literature.

As a result of combining electricity consumption and PV-generated electricity, the net energy is therefore best on the south, followed by south-east, then finally on south-west facing façades, as can be seen in Figure 7.8. The SA showed that orientation is also the second most influential parameter. Hence, more saving is expected to happen on combinations at south then south-east then south-west, as can be seen in Figure 7.9. The SA shows that orientation is the third in the list of the influential parameters on energy savings.

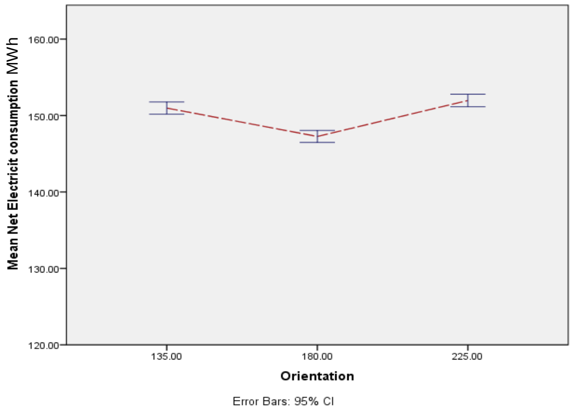


Figure 7.8 Mean net energy for different orientations

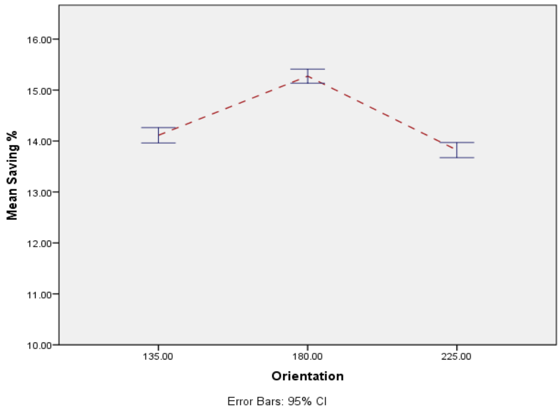


Figure 7.9 Mean energy saving for different orientations

7.2.2 Window-to-wall ratio

The variation of WWR was analysed for the main three values: 60%, 80% and 100%, which were chosen as representatives of highly- to fully-glazed façades. The trend of the mean electricity consumption shows that the bigger the WWR, the more energy intensive the combinations will be, reflecting a quite significant variation in the range of mean values. This can be seen in Figure 7.10 where the mean values of combinations at each of the WWR investigated are plotted. The SA substantiated the finding that WWR is significant in its effect on energy consumption but as a second most impactful parameter.

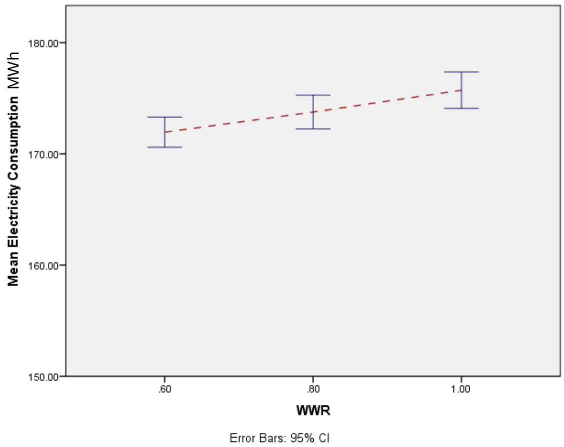


Figure 7.10 OAAT of mean electricity consumption for different WWR

This finding is in line with the general trends identified in the literature, such as Bellia et al. (2013) and Athalye et al. (2013). Certainly this correlates to the amount of the solar gain and its influence on increasing the cooling loads, thereby an increase in the electricity consumption. However, Carmody (2004) believes that increasing WWR could reduce energy use only if daylight potential is optimised. This can be justified using the factors' dependency, which means that the building envelope should incorporate elements that can help in enhancing the daylighting which reduces the need for artificial lighting and subsequently reduces the energy consumption.

Therefore, it is no surprise to find some of the combinations with lower energy use and higher WWR because the impact of daylighting is considered. An example of this could be when choosing a combination with a double-low-e glazing system in WWR=80% which is much more energy efficient compared to a combination with lower WWR but with reflective glazing. Hence, trade-offs can be achieved at almost any WWR, depending on the design intents and environmental sustainability agenda. Furthermore, increasing WWR resulted in a steady increase in the amount of solar gain, from around 75 MWh for WWR=60% to almost 75 MWh for WWR=80% and up to around 95 MWh for WWR=100%, as seen in Figure 7.11. This was expected because increasing the percentage of glass will result in allowing more solar irradiance to penetrate into the building, resulting in more solar gain. The SA confirmed that WWR is the second important parameter affecting solar gain.

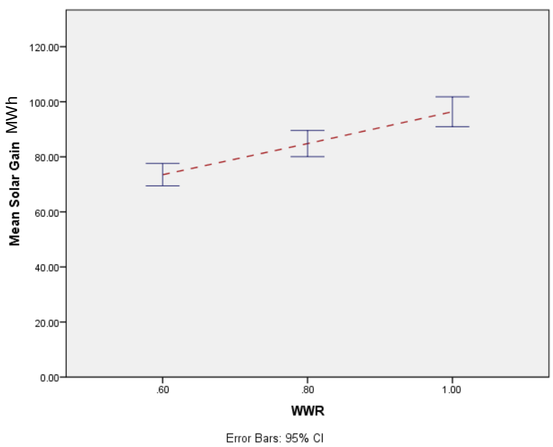


Figure 7.11 OAAT of mean solar gain for different WWR

Huang et al. (2014) assert that large window areas can ensure a considerable saving of lighting energy via daylighting strategies, meaning that larger WWR allows more daylighting, hence the need for artificial lights is reduced. However, Huang et al. (2014) are missing an important contributor to energy consumption because they did not account for factors' dependency, whereas in this study where a systemic approach is utilised, alongside factors' dependency, it was found that the lighting gain is significantly reduced but the solar gain due to the larger glass area contributed to cooling loads, which in turn influenced energy consumption, much more than lighting gain did. This is shown in Figure 7.12 where the mean value of lighting gain significantly decreases when increasing WWR, whereas increasing WWR results in increasing the cooling loads, as seen in Figure 7.13.

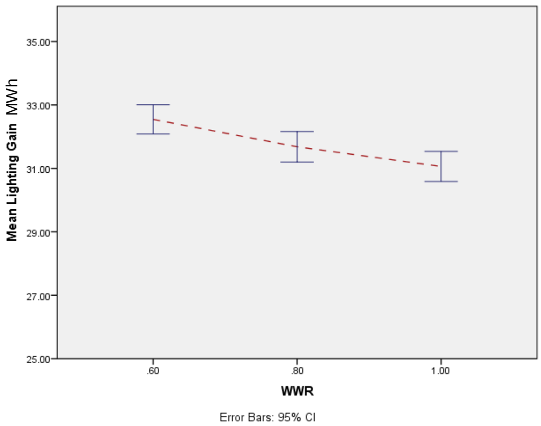


Figure 7.12 OAAT of mean lighting gain for different WWR

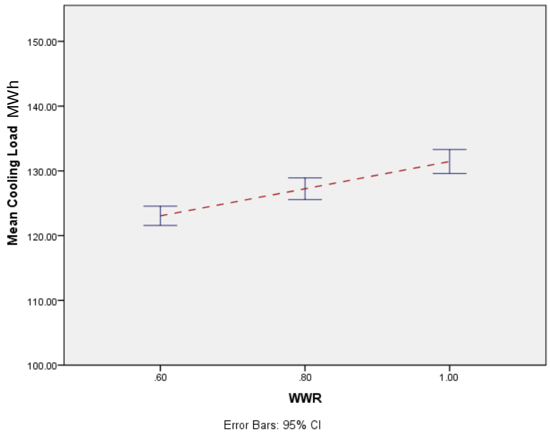


Figure 7.13 OAAT of mean cooling loads for different WWR

This finding was confirmed by the SA where the WWR has an insignificant impact on lighting gain (only 3%), but is still relevant, whereas the SA for the WWR proved that this parameter is highly important and the changes in this parameter will significantly affect the resultant cooling loads.

This finding is in line with what has generally been found in the literature. For instance Sun et al. (2015) studied WWR in a variation of 25%, 50% and 75% respectively and found that a smaller WWR leads to better cooling loads, which also confirms the findings of another study conducted by Poirazis et al. (2008) where cooling demand increases in the highly glazed building. However, it is not sufficient to say that smaller WWR leads to smaller cooling loads when a number of other contributing parameters are simultaneously accounted for, such as in the current study where daylight harvesting is considered. This affects the cooling load that results from the share of the lighting gain. In addition to that, the impact of some parameters changes when other combined parameters are included in the analysis, i.e. the impact of change of the inclination angle within a certain d/l ratio (this will be further discussed in section 7.3). This shows the importance of following a systemic and comprehensive methodology that can lead to more robust conclusions where a full account is taken of all the contributory factors and the combined impact of the variation of each one can be quantified and appropriately assessed.

The mean values of PV-generated electricity are shown in Figure 7.14 where identical results are found, suggesting that, statistically, there is no influence of the change of WWR on the generated electricity. In addition, WWR did not score in the SA. Therefore, WWR is irrelevant when it comes to PV-generated electricity.

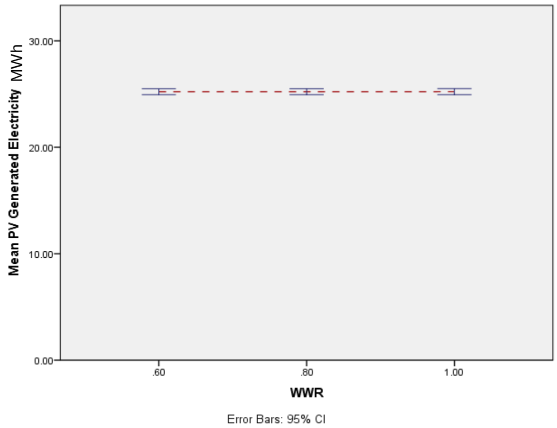


Figure 7.14 OAAT of mean PV-generated electricity for different WWR

The mean value of the expected energy saving varies between the three different values of WWR examined in this study. Generally, the results of OAAT analysis show that the less the WWR is the more saving is expected, as shown in Figure 7.15. However, the SA shows that the WWR is the least influential parameter compared to other parameters.

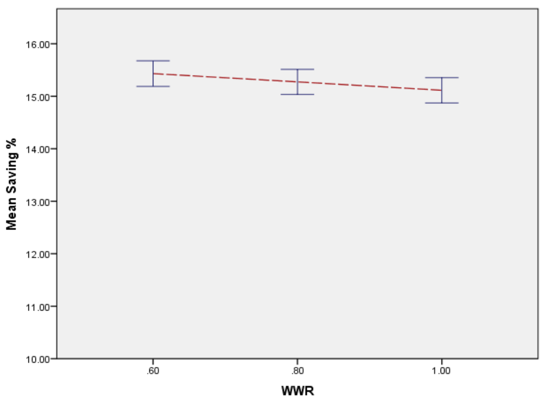


Figure 7.15 OAAT of mean savings for different WWR

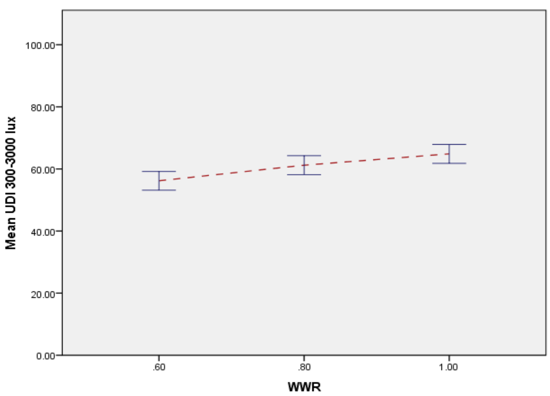


Figure 7.16 OAAT of mean UDI 300-3000 lux for different WWR

More daylighting is admitted when WWR is increased. This is evident in the OAAT figure of UDI shown in Figure 7.16, which confirms what was generally found in the literature (e.g. Athalye et al., 2013; Berardi and Anaraki, 2016; Jin and Overend, 2014). However, this impact seems to be insignificant compared to other parameters because it only accounts for 1% of the results, being the least influential parameter on UDI, as the SA suggests.

7.3 Sub-system level variables

The sub-system level variables are the depth of the PVSDs, the ratio between the depth and the distance between the PVSDs (d/l), the angle of inclination of the PVSDs, and the glazing systems (HPG). The following sections will discuss each of the parameters' findings and triangulate them with what has been found in the literature in order to set the foundation for the final conclusions.

7.3.1 Depth

The effect of the variation in the depth of the PVSDs was evaluated not only in terms of its influence on the three main objectives (energy consumption, energy generation and daylighting), but also in terms of the other influential factors such as cooling load, and lighting gain. This was achieved with the help of the systemic approach and based on the factors' dependency in order to comprehensively evaluate how the three main functionalities of IFS are affected by those interrelated factors, and how these functionalities influence each other. This methodology therefore enables both evaluating the impact of parameters and facilitating the studying of those parameters when a full account of all influential variables is being taken, and also is able to conclude and make informed decisions for the design of a project and to strike a balance between these rather contradictory functions.

It was found that the depth has the minimal effect in terms of electricity consumption, as can be seen in Figure 7.17 where the change of the depth from 400mm to 600mm has a negligible influence on energy consumption. The SA supports this finding as the depth did not score in the SA analysis. However, it contradicts a study conducted by Kang et al. (2012) where the depth of the panels was found to be more effective compared to other variables, such as the length. The justification would be that Kang et al. (2012) only focused on the electricity production of the PV panels and not the other aspects, such as cooling loads or daylighting that contribute to electricity consumption, and their focus was exclusively on the comparison of the results to check whether the length of the panels is more important than the depth. In that sense, the depth can be more effective than the length when considering the effect of self-shading of the panels. The SA also proves that the depth is the least effective parameter in most of the assessed indicators – with some variables it did not even score in the SA.

On the other hand, the only recognisable effect of the depth of the PVSD is found on the PV-generated electricity figures. This is because increasing the depth will result in allowing more area for the integration of the PV cells, which means increased electricity generation. This confirms what has generally been found in the literature, especially by those who focused on the PV electricity generation and with a variation of PVSD dimensions (see among others: Hwang et al., 2012; Sun and Yang, 2010; Sun et al., 2015). The width of a photovoltaic module, in addition to other parameters such as the angle of inclination, has a significant influence on the shading phenomenon and electric energy harvesting (Kang et al., 2012). The SA shows that the depth scores as the third most important parameter, conforming to the findings of previous studies.

Similarly to energy consumption, there has been a negligible influence of the depth on solar gain compared to other parameters. Figure 7.18 shows a straight line linking the two different mean values of 400mm and 600mm depths. The depth did not score in the SA. This suggests that other configurational variations are much more influential and those are the ones that designers should be focusing on when designing buildings with IFS.

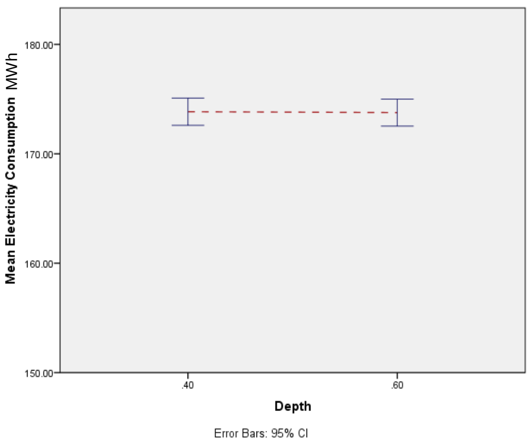


Figure 7.17 OAAT of mean electricity consumption for different depths

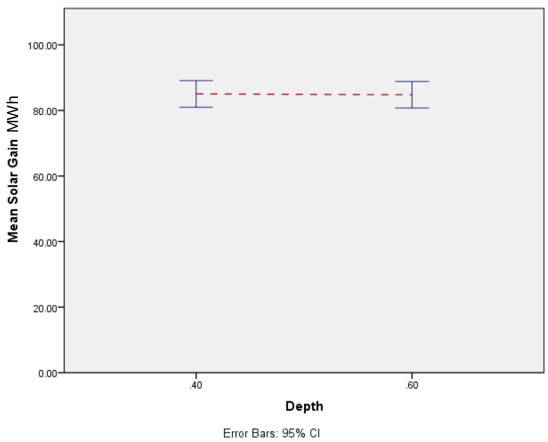


Figure 7.18 OAAT of mean solar gain for different depths

The same finding was observed with lighting gain (Figure 7.20), and supported by the SA as the depth also did not score in the SA. Moreover, a straight dotted line in Figure 7.19 linking the two depths, suggests that there is no considerable effect of the change of the depth on cooling loads. No scoring was recorded for depth in the SA of cooling loads. This confirms that this parameter is insignificant when it comes to cooling loads.

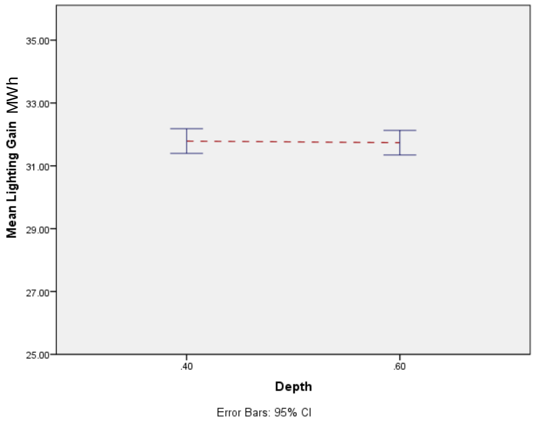


Figure 7.20 OAAT of mean lighting gain for different depths

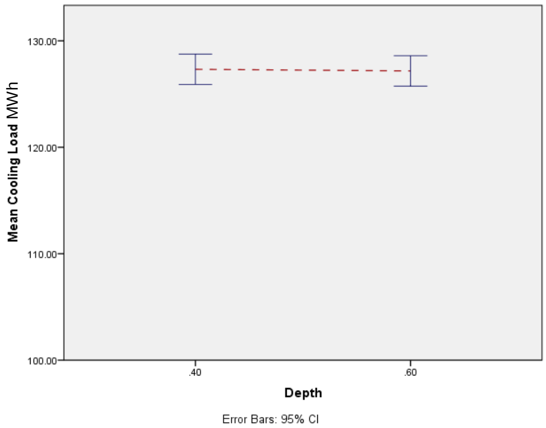


Figure 7.19 OAAT of mean cooling loads for different depths

Interestingly Sun and Yang (2010) suggest otherwise, asserting that deeper overhangs result in greater cooling loads reduction. The reason could be because their study is in a milder climate and they only modelled construction elements rather than including the whole building in the analysis. In addition, they calculated the potential cooling loads reduction as a result of varying the depth, whereas in the current study, a full account of all the influential variables and the dynamic impact of contextual and operational factors was accounted for by using a systemic approach. On the other hand, the depth was found to be significant when it comes to PV-generated electricity (Figure 7.21), which was expected because varying the depth from 400mm to 600mm will allow for more area of PV cells, hence, more energy is produced.

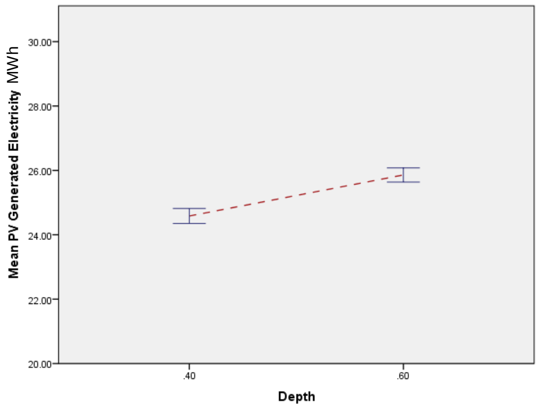


Figure 7.21 Mean PV-generated electricity for different depths

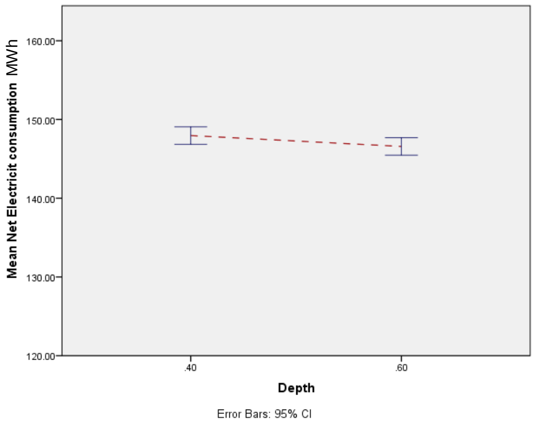


Figure 7.22 Mean net energy consumption for different depths

Clearly there is a noticeable impact of depth when assessing the net energy figures. This impact is mainly influenced by the PV output figures. Overall, the mean value of the net energy is improved when using a depth of 600mm for PVSDs compared to 400mm (Figure 7.22), although the depth comes last in importance compared to other parameters in the SA of net energy. This means that when taking electricity consumption and generation together as the net energy figures, only then can a meaningful impact of varying the depth of PVSDs be observed. This is also reflected in the energy saving figures (Figure 7.23). The SA showed that the depth is the third most influential parameter for savings.

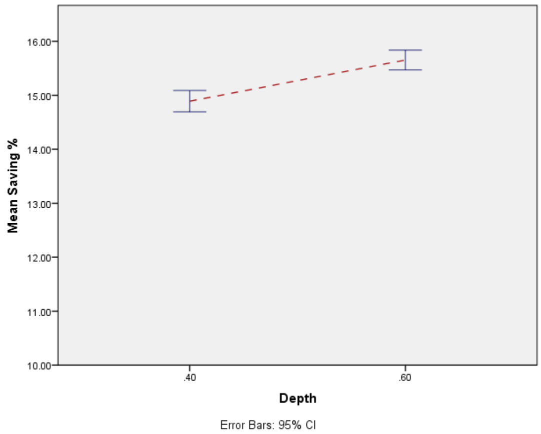


Figure 7.23 OAAT of mean savings for different depths

Varying the depth was also found to be insignificant when it comes to assessing $UDI_{300\text{-}3000\ lux}$. From a systemic point of view, this is because the other variables are much more influential, such as HPG, d/l ratio, and angle of inclination – HPG for its improved optical properties, d/l for its significant impact on allowing for different distances between the blades, and the angle for its impact on varying the distance between the blades as well. This means that the allowance of the daylight is controlled by those variables and did not leave any role for the depth. This can be seen in Figure 7.24 where a straight line between the two mean values of depth is shown. It also did not score in the SA. This is a useful finding as it helps in eliminating this factor when IFS is assessed systematically and it also helps in focusing on variables at different systemic levels that have a significant impact on $UDI_{300\text{-}3000\ lux}$.

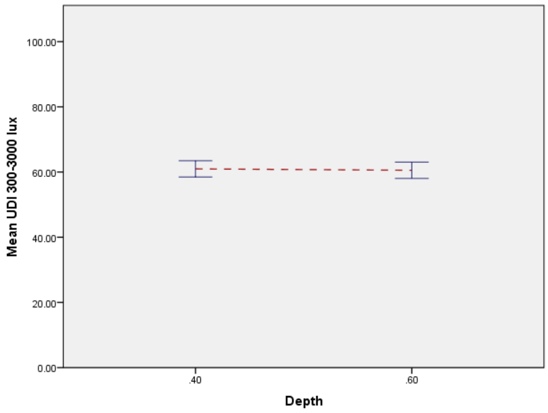


Figure 7.24 Mean UDI 300-3000 lux for different depths

7.3.2 d/l ratio

The distance between PVSDs is governed by the depth of the panel. This is represented by the d/l ratio where d is the depth of the PVSD and l represents the distance between the panels. The literature has occasionally studied this parameter, with its possible and effective range of variation (Bahr, 2009, 2013; Hwang et al., 2012; Kang et al., 2012; Mandalaki et al., 2014a).

Before conducting the comprehensive analysis and during the literature review of this study, some discrepancies were flagged in the findings of different studies where d/l was one of the parameters under investigation. For example, Bahr (2013) found that there is a significant impact of changing the d/l ratio but that specific study did not show to what extent that change affects the results. Another reason could be because Bahr (2013) studied the implication of that change on the daylight factor, which is a less detailed indicator, whereas in the current study, it was proved that there is a significant impact of the d/l ratio on daylighting performance and it also shows how significant that impact is, using UDI. Bahr's study has also missed out an important factor, which is the dependency of the factors, especially when a full parametric analysis of variables at different systemic levels is accounted for. This shows that when a systemic approach is in place, such as in the current study, a full account of the parameter is taken and the extent of the effect of change on each parameter can be studied and analysed systematically while taking into consideration the influence of the output variables on each other.

The current study has proved that the d/l ratio is one of the main influential parameters on all of the outputs under investigation, such as solar gain, lighting gain, cooling loads, energy consumption and UDI. However, its influence varies, depending on the influence of other parameters that are being varied at the same time. This influence was quantified and measured as a result of the SA for all the outputs. Furthermore, the systemic approach has helped in considering the full account of variables and assisted in the analysis where changes in one parameter was looked into with an eye on other parameters at different systemic levels.

In terms of electricity consumption, it was found that the mean value of electricity consumption negatively correlates to the ratio d/l, as shown in Figure 7.25. The SA shows that d/l ratio is the second most influential parameter on electricity consumption. Furthermore, solar gain was found to be positively correlated to the d/l ratio, as shown in Figure 7.26.

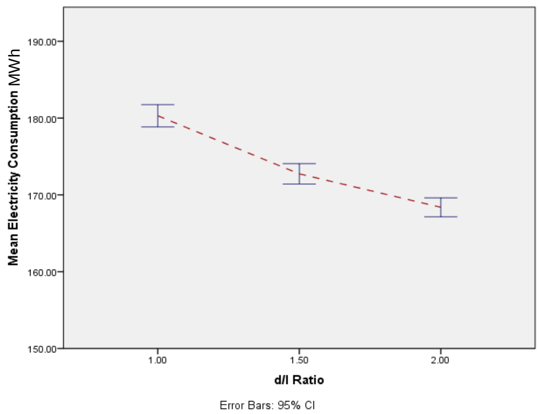


Figure 7.25 Mean electricity consumption for different d/l ratio

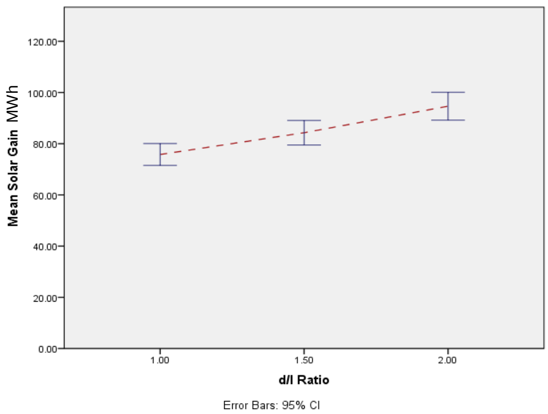


Figure 7.26 Mean solar gain for different d/l ratio

The SA of variables for solar gain showed that d/l is the third most influential parameter. This was anticipated as increasing the distance between the PVSDs (i.e. the greater the d/l) will allow more sunbeam to penetrate into the interior spaces and result in higher solar gains, hence adding more to the cooling loads.

Moreover, the mean lighting gain is significantly reduced as a result of increasing the d/l ratio (Figure 7.27). The SA of lighting gain showed that this is the second most significant parameter.

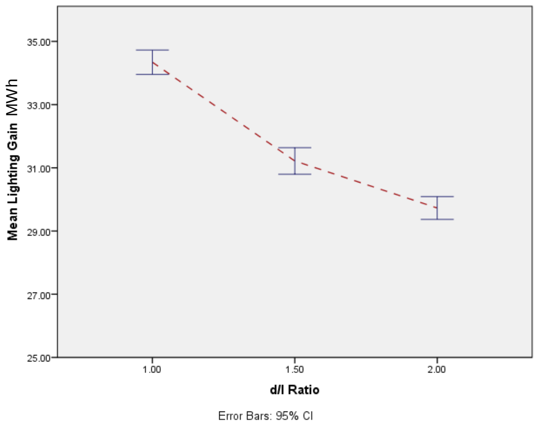


Figure 7.27 Mean lighting gain for different d/l ratio

Interestingly the difference between the mean values of the cooling loads does not significantly change when increasing the d/l from 1 to 1.5. However, it slightly increases as a result of increasing d/l to 2, as can be seen in Figure 7.28. The SA shows that this parameter is the least impactful parameter when it comes to cooling loads, suggesting that cooling loads are mostly influenced by other parameters.

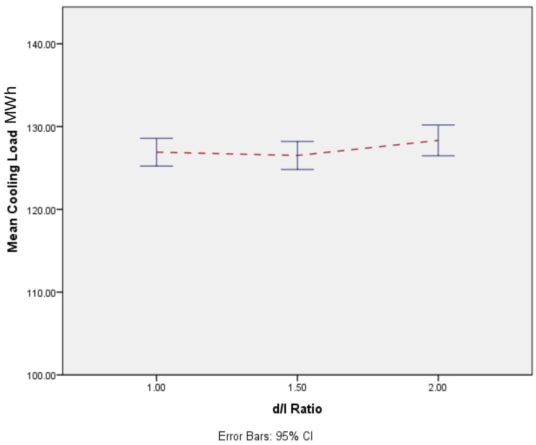


Figure 7.28 Mean cooling loads for different d/l ratios

From the aforementioned findings, it seems that designing IFS with a greater d/l ratio will be beneficial due to the daylight harvesting and the corresponding reduction in the artificial lighting gains. However, this will result in an increased solar gain that needs attention, which conforms to the findings of previous studies, such as Bahr (2014) and Hwang et al. (2012). Bahr (2014) suggests that the optimal design solution he claims they found entails the application of fewer blinds with more spacing between the PV panels in order to minimize the shading effect. On the other hand, Bahr (2014) goes further to conclude that increasing the number of the blinds (lower d/l ratios) contributes to an increase in PV output and a reduction in cooling loads. These two propositions are contradictory; however, this depends on the design goals of the project and whether or not trade-off is intended. For example, in the current study, when taking full account of all influential variables and aimed at a balance between energy and daylighting, a number of outputs need to be assessed. In order to effectively do that, factors' dependency needs to be considered so that it helps avoiding double counting of some variables or missing others.

To elaborate on this, for example, the current study found that reducing the d/l ratio will result in a reduction of solar gain, hence a reduction in cooling loads, but when accounting for the daylight harvesting and PV electricity generation, it was found that, in this case, the variations in this ratio will result in a significant impact on PV electricity generation (Figure 7.29) to vary from 29 MWh for d/l=1 to 25 MWh for d/l=1.5 and then to 22 MWh for d/l=2, which was proved in the SA where this parameter was found to be the most influential parameter for PV-generated electricity. The findings of previous research in this area are not in full accord with each other and seem to have been controversial. For instance, unlike what Bahr (2014) found, Hwang et al. (2012) suggest that a greater d/l ratio will result in a greater amount of sunlight, but it is not proportionate to the amount of power generated due to a decrease in the area of power generation. The use of the systemic approach showed that such variation in the findings regarding the d/l ratio is influenced by many other parameters, such as internal heat gains, building fabric thermal characteristics, the percentage of glazed area, and the inclusion of dimming systems to harvest daylighting, to name a few. In addition to that, none of those studies accounted for lighting gain in the interior spaces and daylight harvesting that remarkably influences both the cooling loads and electricity for artificial lighting. Therefore, discrepancies between those studies are expected because they are not seeing the whole picture and are not as comprehensive and holistic as the current study, hence, no generalisation can be made in this regard.

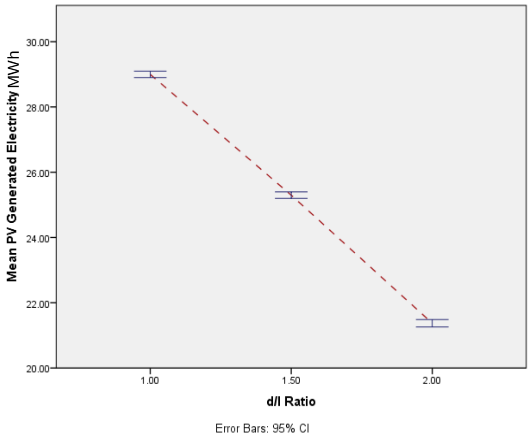


Figure 7.29 Mean PV-generated electricity for different d/l ratio

The mean values of net energy, shown in Figure 7.30, indicate that the increase in the d/l ratio from 1 to 1.5 will significantly reduce the net energy. However, increasing the ratio from 1.5 to 2 will not result in a significant change in the net energy, suggesting that the net energy is less influenced by this parameter within this particular interval (from 1.5 to 2). Therefore, it is no surprise to see that, in the SA, the d/l ratio scored as one of the least influential parameters compared to other parameters, such as HPG, orientation and angle of inclination. On the other hand, the energy saving, which is highly influenced by the PV area, as explained earlier in section 6.5.1, seems to be mostly dominated by the d/l ratio, as the SA proved. Figure 7.31 shows that the lower the d/l ratio, the more energy saving is expected. It is worth mentioning that no accounts of saving figures were found in the literature where energy saving is calculated as a result of subtracting the energy use of a building without IFS and energy use of a building with IFS (net energy figure), which was proved in this study to be a useful function when a decision is made in this regard. Only one study was carried out by Bahr (2013) where energy saving was accounted for but as a result of reduction in cooling loads. This method of calculating energy saving is not sufficient as the current systemic study showed. When a full account of the influential variables is considered and the factors' dependency of those variables is taken in consideration, cooling load is only one of the functions that cannot be considered in isolation from other outputs that have an interdependent relationship with each other, i.e. cooling load with solar gain and lighting gain.

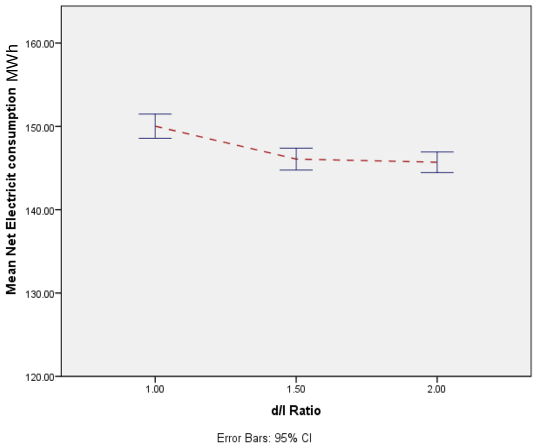


Figure 7.30 Mean net energy for different d/l ratio

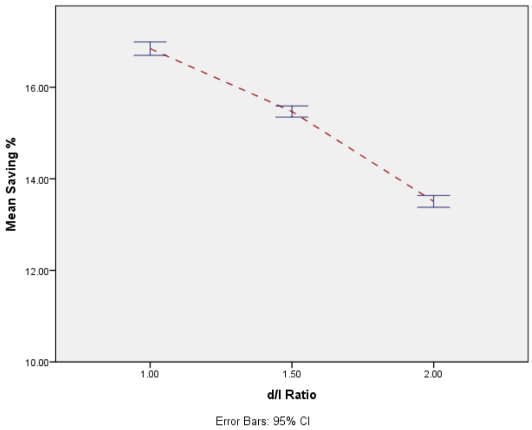


Figure 7.31 Mean energy saving for different d/l ratio

Finally, it was found that the greater the d/l ratio, the more daylight penetrates into the interior spaces (Figure 7.32). The figure suggests that combinations with d/l ratio =1.5 and 2 provide acceptable amounts of daylighting during working hours as they range from 60% to 75% of the time, which is well above the threshold of 50%. It was also proved in section 6.5.2 that all IFS combinations were successful in preventing glare as none of them exceeded 3000lux. This contradicts the findings of some of the literature, such as Bahr (2014), who found that the daylight factor is high for those ratios and glare could possibly occur. This finding can only be true for the settings of that study, because the measure used DF does not consider the sky condition and the building orientation, unlike UDI in the current study. Therefore, that finding cannot be generalised to a greater number of combinations, such as in the current study. The SA showed that the d/l ratio is the second most influential parameter for UDI ranges.

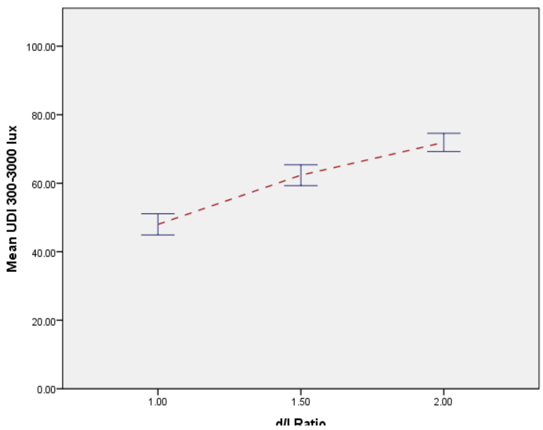


Figure 7.32 OAAT of mean UDI 300-3000 lux for different d/l ratios

7.3.3 Inclination angle

Different inclination angles have different effects on the thermal and visual performance of IFS configurations as well as electricity generated by the PVSDs. The angle of inclination is one of the most studied yet most controversial parameters. This was evident from the inconsistencies between many studies, in which the optimum angle of inclination was suggested to be either equal to latitude (Bahr, 2013) or low angles to be preferable, as suggested by Sun et al. (2012), over high angles, as suggested by Kang et al. (2012) and Hong et al. (2016). The following paragraphs will elaborate more on these within the findings of the current study and will justify why there have been such discrepancies.

The impact of change of the angle of inclination on energy consumption was found to be influential as a nearly steady increase in the electricity consumption can be observed while the angle of inclination increases, as shown in Figure 7.33. This can be justified in the sense of the inter-dependency of the contributing factors, as increasing the inclination angle of the PVSDs reduces the solar gain, and negatively affects the dimming of the internal artificial lights which in turns results in additional internal heat gain that contributes to cooling loads, hence an increase in the electricity consumption.

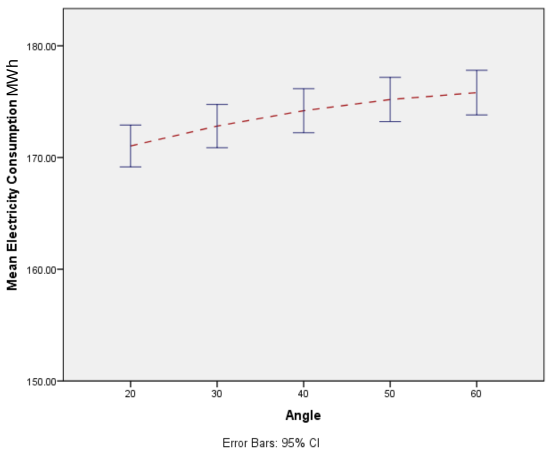


Figure 7.33 Mean electricity consumption for different inclination angles

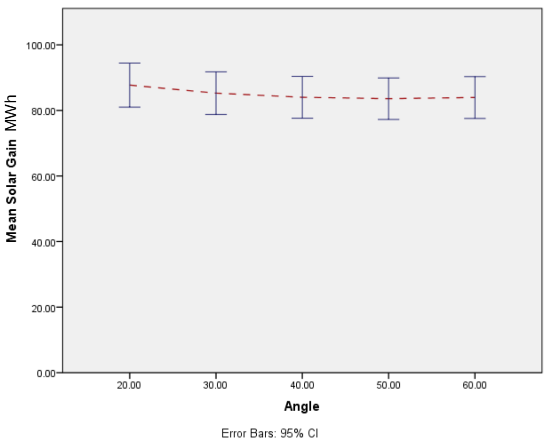


Figure 7.34 OAAT of mean solar gain for different inclination angles

In all cases, it was found that 20° was the optimum inclination angle, but that is only true when the electricity consumption figures were considered on their own, without considering the other objectives (daylighting and PV-generated electricity). The SA shows that the angle is the third most influential parameter on electricity consumption, whereas for solar gain (Figure 7.34), the angle has a minimal influence compared to other parameters, such as WWR or glazing, but it is still relevant. This concludes that the solar gain is mainly influenced by other parameters, much more than the change of angle. Additionally, lighting gain positively correlates to the angle of inclination and the SA showed that the angle of inclination is the third most influential parameter on lighting gain.

On the other hand, the mean values of cooling loads indicate that there is barely any effect on cooling loads when varying the angle of inclination, which is also confirmed by the SA of cooling loads where the angle did not even score. This finding contradicts the finding of Bahr (2013); however, this can be justified using the factors' dependency, as increasing the angle will result in lower solar gain but at the same time higher lighting gains are incurred but the two influence the cooling loads differently, resulting in nearly steady loads regardless of the angle, as shown in Figure 7.35 and Figure 7.36.

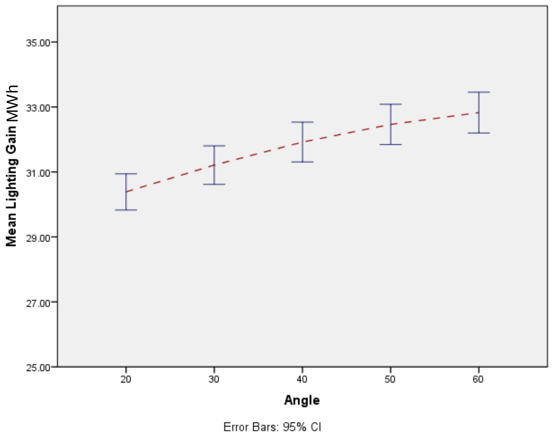


Figure 7.35 Mean lighting gain for different inclination angles

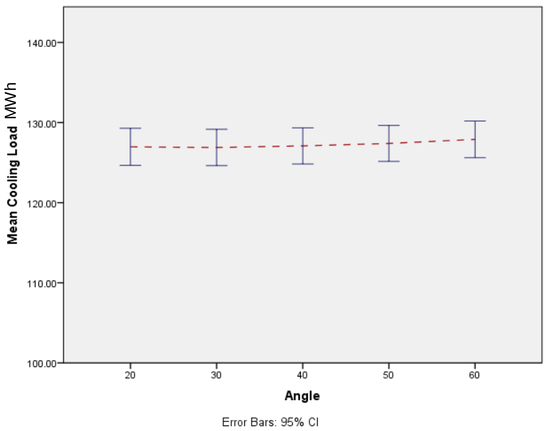


Figure 7.36 Mean cooling loads for different inclination angles

The angle of inclination has a varying effect on the PV output. This specific variable (PV-generated electricity) has been the focus of many studies; however, this is where most of the controversies occurred. The PV-generated electricity figure shows that inclining the angle from 20° to 40° improves the PV output, as shown in Figure 7.37. However, inclining the angle more (i.e. 40° to 60°) will negatively affect the PV-generated electricity.

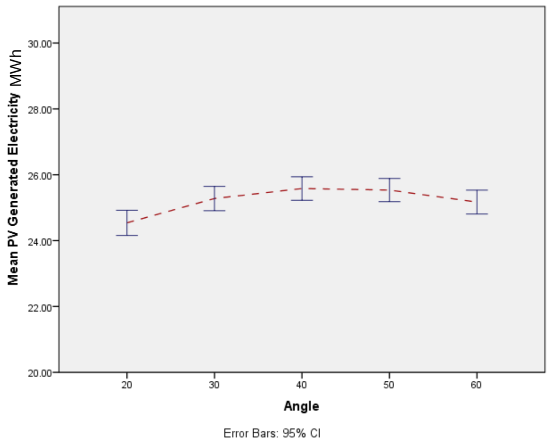


Figure 7.37 OAAT of mean PV-generated electricity for different inclination angles

This is because the angle corresponds to the solar beam due to the angle of incidence, geographical location, building orientation and the sun azimuth changes. Therefore, there is no single definite answer to the question: which angle is the best? This needs to be looked into within the other influential parameters – where factors' dependencies are considered – and within a given context. The SA shows that the angle has some effect though it appears to be the least impactful parameter compared to the others.

It can be concluded that the importance of the angle of inclination changes when the goal shifts from solar gain to cooling load or to daylighting. With the help of the SA, that effect can be quantified to allow for a more accurate conclusion when a decision needs to be made for optimum designs. Putting the findings of the current study regarding the impact of the change of the angle of inclination into the context of the state-of-the-art literature, some findings of the literature confirm what has been found in the current study, while others contradict it.

Hwang et al. (2012) found that 60° is the optimum angle which maximises electricity production; however, they did account for other influential parameters, i.e. geographical location, building orientation and other input variables. While they analysed PV output and the solar insulation of the system, they did not take into account their influence on the building's cooling loads, heat gain and solar gain, which has been covered comprehensively in the current study. They go further to conclude that this is the optimum angle for any setting and they recommend that a decision should be made according to other factors as well, such as visual elements, which seems to have hardly any relevance to the focus of their research and with very limited to no scope to be concluded. This clearly suggests that when integrating other factors, there is no conclusion that can be made based on one single factor, such as PV output. Hence there is a need for a systemic and comprehensive analysis that takes into consideration those effects in a more in-depth manner to account for all the performance aspects and to enable and facilitate the trade-offs.

Another study conducted by Kim et al. (2010) asserts that tilting the louvres downward from the horizontal position will increase the electricity production but at the same time it will decrease the interior daylight levels. However, the data in that study were collected from an experimental room during a short period of time where the daylight availability was measured without taking into consideration the impact of the daylight on the artificial lighting and the resultant lighting gain. Moreover, the seasonal variation of the sun path can significantly affect these results. Furthermore, that research was based in a cold climate whereas the current study is based in a hot and dry climate. A study was conducted by Sun et al. (2012) where inclining the angle to 20° was found to be optimum instead of local latitude, unlike what Bahr (2013) suggested for PV output. Moreover, Bahr (2013) concluded that when combining cooling load reduction and PV output for a variation of orientations, the optimum angle is then 30°-50°, because according to his study, increasing the angle reduces the cooling loads. In contrast, much higher angles were found in the literature to be more beneficial regarding PV electricity generation, such as 60° (Hwang et al., 2012), 75° (Kang et al., 2012), and 80° (Hong et al., 2016).

Such variations are, however, influenced by many factors (orientation, geographical location, altitude and sun azimuth, latitude, and distance between the panels [self-shading effect] – to name but a few) and therefore discrepancies can be expected so no global generalisation can be made in this regard. Moreover, when conducting a holistic and comprehensive assessment, other parameters can affect the impact of change of the angle, such as the d/l ratio. This effect comes from the impact of the self-shading influence which affects the efficiency of the PV cells.

Furthermore, when combining other aspects alongside the PV electricity generation, such as cooling loads or daylighting, even more variations in the results are likely to happen. For instance, Sun et al. (2012) combined cooling load reduction and PV output and found that on a south-facing façade, inclining the angle to 10° results in maximum power output but that is exclusive to a fixed WWR, orientation and depth. Sun et al. (2012) go on to further explain that a range between 30° and 50° is the optimum for both cooling load reduction and PV output, which agrees with another similar study conducted by Tongtuam et al. (2011). In the current study, this range was found to be optimum but only for PV-generated electricity, regardless of cooling loads. The reason why there is a difference between the findings of the current study and the study of Sun et al. (2012) is that in their study, the focus was not on the implementation of such systems on the overall performance of a building model but rather on a cladding element and therefore solar gain or internal gains were not taken into account. This suggests that the measures in that study could miss out some important information that affects the conclusions.

Increasing the angle was found to be disadvantageous when it comes to lighting gain; however, the SA showed that the change in the angle only accounts for 1% of the results of lighting gain compared to other parameters, which were found to be much more influential. Generally, it was expected that – with the same WWR and depth – a bigger angle leads to better PV output (Sun et al., 2015) and the optimum angle for PV output is, at the same time, the worst for daylighting (Kim et al., 2014), as shown in Figure 7.38/A, whereas in the current study, as explained earlier, increasing the angle of inclination does not necessarily result in increasing the PV-generated electricity. It was also proved that although increasing the angle will negatively affect the daylight performance of the IFS combinations, using UDI was more beneficial as it shows that there is more than one angle where acceptable levels of illuminance are achievable for more than 50% of the time during daily working hours. Therefore, the "solution space"[25] can expand to include more optimum combinations, as shown in Figure 7.38/B.

[25] The solution space is a representation of the set of all feasible solutions that satisfies a particular problem framing (Sosa et al., 2017)

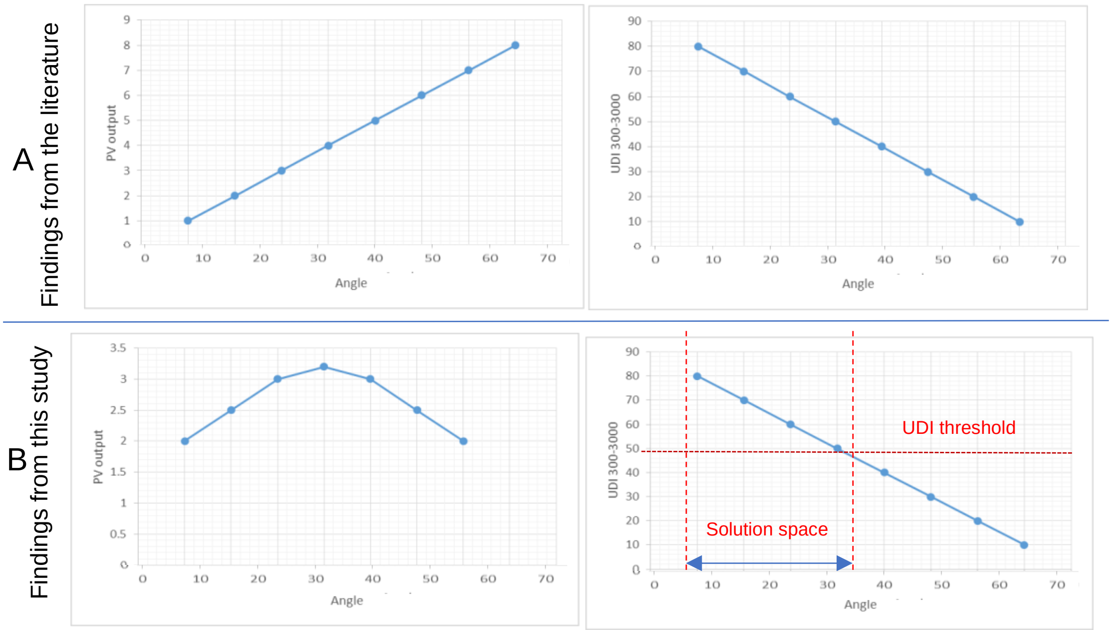


Figure 7.38 Solution space of inclination angle according to the findings of this study and the findings of the literature

The net energy figure – which combines both electricity consumption and PV-generated electricity figures – can be used either separately (i.e. as an energy optimisation function), or in conjunction with the $UDI_{300\text{-}3000\ lux}$ figure in order to account for the ultimate functionalities of IFS and to achieve trade-off. The mean values of the net energy shown in Figure 7.39 prove that there is a positive correlation between the angle of inclination of PVSD and the net energy. However, the SA shows that the angle is one of the least influential parameters on net energy as it scored fourth with a 2% influence on the results.

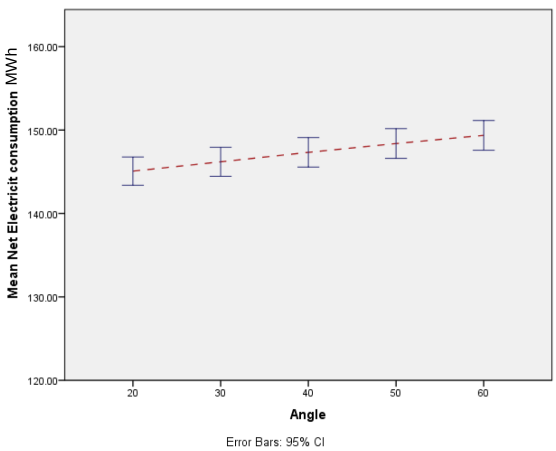


Figure 7.39 Mean net energy for different inclination angles

Similarly to the PV-generated electricity figure, increasing the angle from 20° to 40° results in an increase in energy saving, as shown in Figure 7.40, and then less energy saving is obtained as the inclination is increased from 40° to 60° yet the angle only scored 1% as a third important parameter in the SA for energy savings.

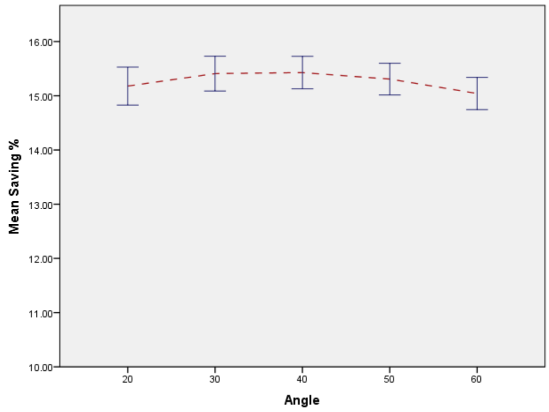


Figure 7.40 Mean savings for different inclination

In all cases, it was found that increasing the inclination angle results in a steady decrease in $UDI_{300\text{-}3000lux}$ (Figure 7.41), yet the angle is one of the least influential variables as it scored 1% of importance in the SA for lighting gain. This was generally expected as when the PVSDs close down, the space for the sunbeam to penetrate into the internal spaces will be reduced. This was previously suggested by other researchers, such as Huang et al. (2014).

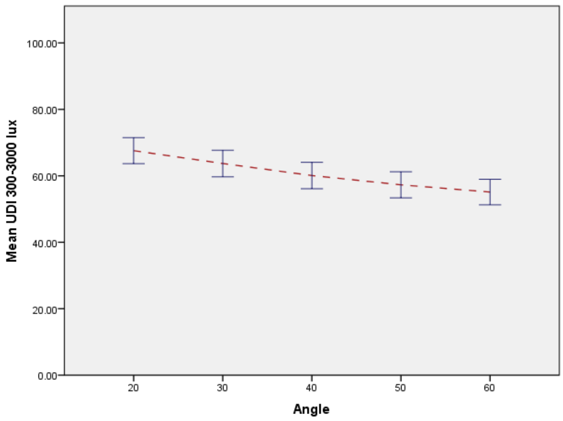


Figure 7.41 Mean UDI 300-3000 lux for different inclination

The variation in the results of previous research have shown that in the absence of a holistic and systemic assessment methodology, assessing the indicators in isolation of other inter-dependent variables, such as PV output or daylighting provision, could miss out important information that may influence the interpretation of the results and hence produce less reliable conclusions.

The findings of Kim et al. (2010) for the inclination angle indicate that increasing the angle would increase the PV output and decrease the daylighting levels.

However, in the case of angles higher than 40°, instead, the PV output starts decreasing but the daylight availability is still improving. There is a general preference for angles lower than 40°, but that needs to be analysed alongside other rather influential variables, such as the d/l ratio. To elaborate on this, when evaluating lighting gain, it can be seen that the trend of the impact of change of the angle varies in accordance with the change in d/l ratio. This is because when the distance between the PVSDs increases, so the impact of the change of the angle becomes less significant. Therefore, it is recommended that these two parameters should be assessed jointly to account for their combined effect on the specific output variables (Figure 7.42).

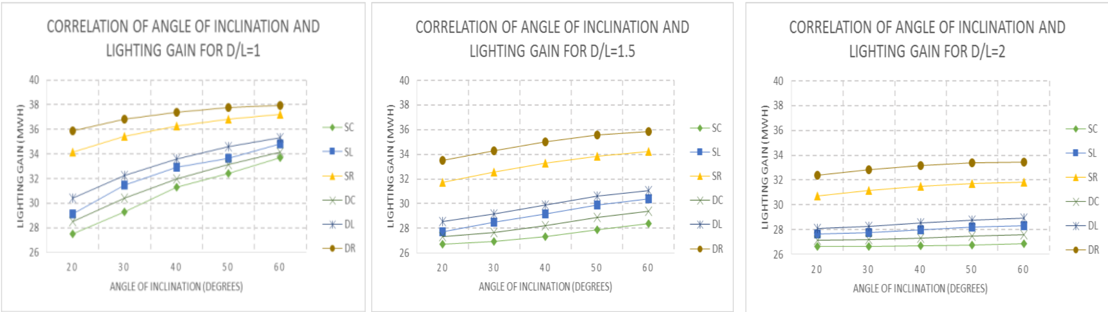


Figure 7.42 Correlation of the inclination angle and lighting gain for different d/l ratios

The use of a systemic holistic methodology also indicates that more attention should be paid to other parameters and that they should be assessed comprehensively based on the inter-dependency of the influential assessment variables, rather than focusing solely on one output variable in isolation, such as optimising the PV output, which seems to be where research in the field is still mostly focused.

7.3.4 Glazing systems (HPG)

Having conducted all the phases of the analysis, it has become evident that the most dominant parameter that influences energy consumption and daylighting in the context of IFS is HPG. This is due to its major influence on solar gain, cooling load, and lighting gain, in addition to daylighting. Although most of the literature, where the performance of fenestration systems has been the focus of their investigation, was in line with this finding of the current study, the research in this field seems to be mostly focusing on the glazing systems solely and missing out on an important element, which is the integration with other building envelope elements, such as shading devices, especially when they are integrated with PV. The current research concludes that in the presence of a holistic and comprehensive study that takes into account all the influential parameters, in a systemic manner, a specific glazing system would perform completely differently, especially in the context of IFS. To elaborate on this, the following paragraphs will triangulate the findings of this research to its contextual literature, where evidence is available, and justify any agreement or contradiction.

The current study has shown that the most obvious observation for energy consumption (Figure 7.43) is the wide range of variation in energy consumption due to different HPG systems, starting from around 165 MWh to around 185 MWh. Single-clear (SC) and Single-reflective (SR) glazing systems are the most energy intensive glazing systems; SC for being the system with the least improved thermal properties and SR for being the system with the poorest optical properties. Low-e glazing seems to be a better choice for energy-efficient purposes than double-clear (DC), especially in cooling-dominant climates, as Hutchins (2013) suggested, which is in line with the current study; however, this needs to be carefully investigated where other elements, such as PVSDs, are considered, which is what the current study has done. Double-low-e (DL) shows the most improved combinations for energy consumption, which is in line with a study conducted by Fasi and Budaiwi (2015) in closely similar climatic conditions where substantial reductions were observed when reflective tinted and low-e glazing are used. The rest of the systems (SC, SL, DC, DR) vary between those two types. The SA confirmed that the glazing system plays the most significant role in IFS regarding energy consumption and suggests that the HPG parameter is by far the most important as the variation in this parameter accounts for 80% of influence on energy consumption. Although similar findings in hot and arid climate were found in the literature, they do not necessarily apply to similar climates. For instance, the extent of the influence of HPG was not found as significant in Assem and Al-Mumin (2010) as in the current study. This is because although that study considered solar gain, it overlooked an important influence that results from the integration of artificial lighting control, where dimming is used to account for daylight harvesting. With the use of the inter-dependency of the variables, it was shown that this results in variation in lighting gain which influences the cooling loads and consequently affects the total energy consumption. Hence, low-e glazing might not be the best glazing if other aspects are included and analysed systematically.

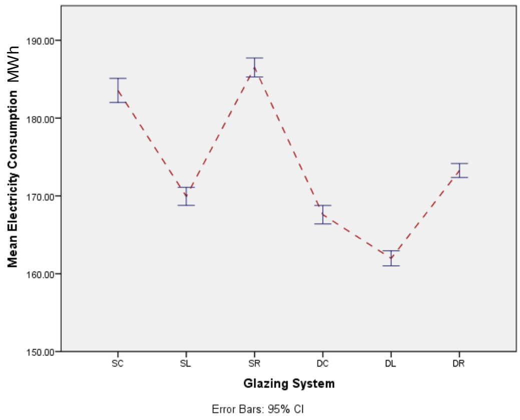


Figure 7.43 Mean electricity consumption for different glazing systems

In terms of solar gain, the current study found that solar gain increases when SC and DC glazing systems are used, as shown in Figure 7.44. This is because those two types have the highest SHGC.

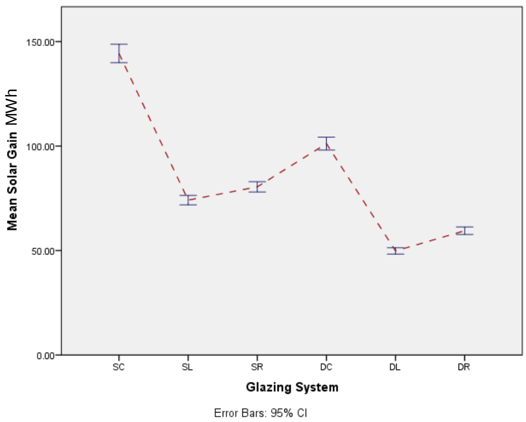


Figure 7.44 Mean solar gain for different glazing systems

Expectedly, the most improved combinations regarding solar gain control are those with DL and DR glazing due to their low SHGC, which is consistent with the findings of Awadh and Abuhijleh (2013). The SA showed that glazing systems account for 87% of the resultant solar gain as the most influential parameter of all (Figure 7.44).

The impact of daylight harvesting in the current study was assessed not only for daylight availability but also for lighting gain effects. It was suggested that using dimming to harvest daylighting would further reduce the internal heat gain thereby decreasing cooling loads. Although there exists some research on this area, it is scarce and with limited scope (Fasi and Budaiwi, 2015; Poirazis et al., 2008).

Therefore, in the absence of previous work in the literature regarding the implementation of lighting gain in the interior spaces and how it influences other variables, which was seen as interesting, the current research carries on with expanding more on the findings of lighting gain using the direct outcomes of this research because there is no precedent or other work for this to be compared to. The lighting gain effect was further investigated in more detail in the current study to account not only for varying glazing systems but also the combined effect of IFS and it proved to be significant. The highest lighting gains are observed with glazing systems that have the lowest T_{vis} (Figure 7.45), which is also consistent with what was generally expected from such glazing systems (Carmody, 2004; Cuce and Riffat, 2015). In the SA, the glazing system scored the highest influential parameter when it comes to lighting gain as it accounts for 57% of the importance.

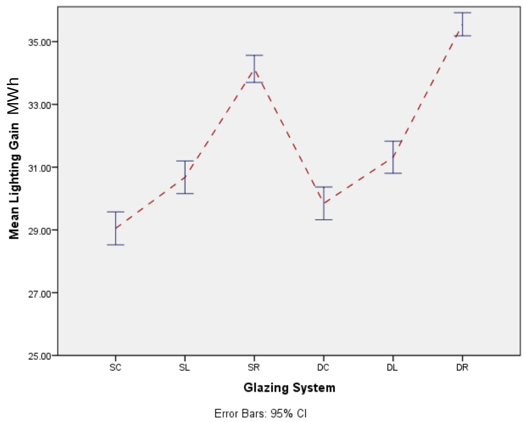


Figure 7.45 OAAT of mean lighting gain for different glazing systems

Cooling loads also vary greatly as a result of different HPG. It can be seen that a nearly similar pattern is observed in cooling loads (Figure 7.46) to that of solar gain (Figure 7.44), confirming that cooling loads highly correspond to solar gain. This is because of the flow of the heat through the glazing which results in heat gain due to solar radiation incidence, which consequently increases the cooling loads. Findings from Fasi and Budaiwi (2015) and Assem and Al-Mumin (2010) were in line with what has been found in the current study. However, their studies did not account for the full set of influential parameters and therefore missed the chance to qualify, and quantify, the impact of change of glazing systems systematically, and simultaneously with other variables, due to the absence of factors' inter-dependency in their studies, which the current study covers.

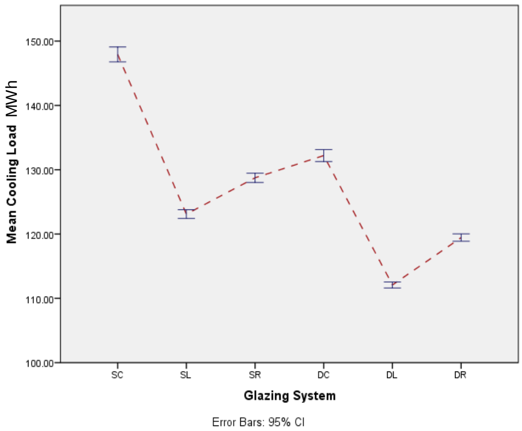


Figure 7.46 Mean cooling loads for different glazing systems

The SA in Chapter 6 showed that HPG has its highest influence on cooling loads (89%). This indicates that the thermal and optical properties of the glazing systems are significantly influential (probably the most), and they need careful attention when similar studies/research are to be carried out in different contexts using the systemic approach, and also when a design decision is to be made in a project.

It can also be noticed that DL and DR have the least mean value of cooling loads for all combinations. Fasi and Budaiwi (2015) and Awadh and Abuhijleh (2013) suggest that both low-e and reflective glazing systems are very effective in reducing the annual cooling loads compared to clear glass, which conforms to the findings of the current study. However, the current study came up with a rather different finding which is: combinations with single-reflective (SR) glazing can result in less cooling loads than those with double-clear (DC), although clear glass was proved to permit higher solar gain. This is because although the study of Fasi and Budaiwi (2015) took into account the daylight harvesting, it used a dimming profile that corresponds to either ON or OFF switching of artificial lights based on meeting a specific lux level (400 lux), whereas in the current study, a varying dimming of the artificial lighting has been set up by considering an equation that corresponds to a range of acceptable lighting levels ($UDI_{300\ to\ 3000\ lux}$) and varies within that range rather than switching on or off based on one single lux level. This is deemed more reliable and more realistic as the possibility of having 400 lux and above is a less desirable and rather outdated and unrealistic method, as was explained in the UDI analysis (please refer to section 5.3.5 for more details).

In addition to what was mentioned before regarding the location of glazing systems behind the PVSDs and the fact that they have no impact on the electricity generation of the integrated PV cells, statistically, no influence on PV-generated electricity was observed as a result of varying HPG, as shown in Figure 7.47. No scoring in the SA of glazing system regarding PV-generated electricity was observed.

On the other hand, there is a significant influence of the change of the glazing systems on the resultant net energy figures, as shown in Figure 7.48, where combinations with DL are the least energy intensive combinations.

The SA of net energy suggests that glazing is by far the most influential parameter of all IFS parameters (67%).

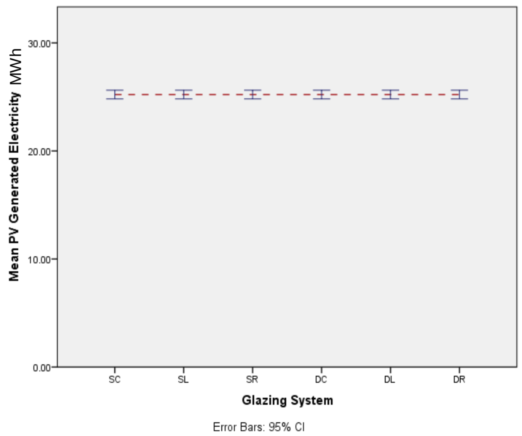


Figure 7.47 Mean PV-generated electricity for different glazing systems

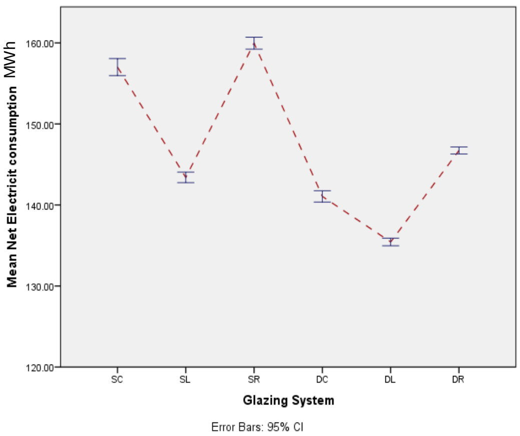


Figure 7.48 Mean net energy for different glazing systems

Similarly, reviewing mean values of energy saving for different glazing systems, as shown in Figure 7.49, suggests a possible saving of between 13% and 18% as a result of varying HPG. The SA of energy saving showed that glazing system scores the second most influential parameter with 36% of influence on the results.

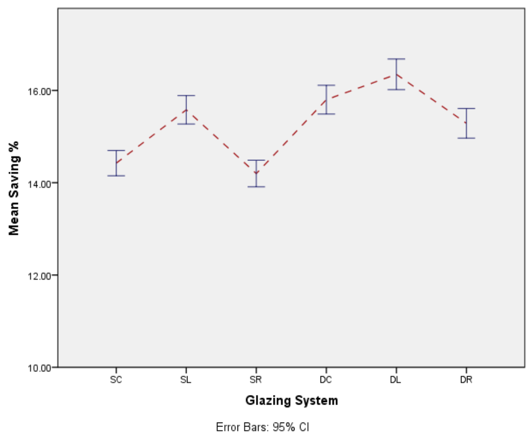


Figure 7.49 Mean savings for different glazing systems

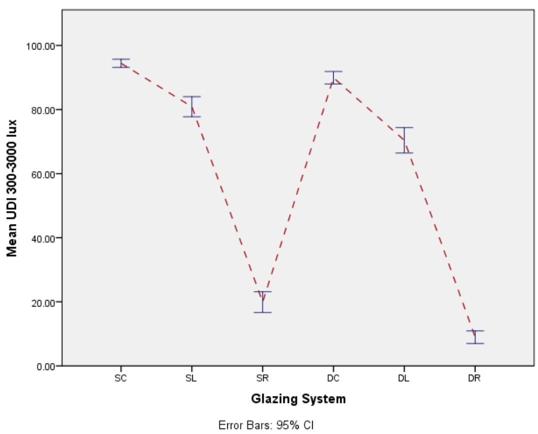


Figure 7.50 Mean UDI 300-3000 lux for different glazing systems

Different glazing systems reflect a rather wide range of variation of the mean value of $UDI_{300\text{-}3000lux}$ between the six HPGs under investigation, suggesting a quite significant influence of the variation of HPG on the daylight performance of IFS (Figure 7.50). The SA of $UDI_{300\text{-}3000lux}$ substantiates this finding as the glazing system scores the highest influential parameter by far (90%).

There have been some inconsistencies in the literature where some studies confirm the findings of the current study, such as Fasi and Budaiwi (2015), whereas others contradict, such as Huang et al. (2014). It was expected that SC and DC glazing systems provide the highest DF according to Fasi and Budaiwi (2015), which confirms the findings of the current study where the percentages of useful daylight illuminance in most of the working hours have been found the highest (Figure 7.50). This is justified as clear glass holds the highest visible light transmittance (please see Table 5.3 in section5.3.5).

On the other hand, single- and double-low-e glazing (SL and DL) show a significant difference in their daylight performance in the current study, whereas in some studies, such as Huang et al. (2014), daylighting performance of the low-e glazing was found to be almost the same as that of the DC glazing. This variation in the findings of the current study and that of Huang et al. (2014) was mainly because their study was not a full parametric study and hence missed out on some contributory factors on daylighting, such as WWR. In addition, an important implication of utilising factors' inter-dependency in their study resulted in missing out on the dynamic daylighting effect and the other relevant variables, such as lighting gain. Moreover, the measure used in that study was the annual electric lighting energy consumption under a certain illumination level set-point (i.e. <500lux). This measure does not give any value of the quality of the daylighting, especially when they did not account for a realistic daylight harvesting, which can be done using dimming systems rather than a fixed value of lux and an 'ON/OFF' artificial lighting profile. In contrast, the current study has analysed the daylight performance through UDI, which provides reasonable evidence that enables an in-depth assessment of the quality of daylighting. In addition to that, the current study implemented daylight harvesting using a dynamic response to the variation in dimming profile. Hence, a difference can exist. Moreover, the impact of any little difference in the glazing system's T_{vis} can result in variations in the daylight availability and the corresponding lighting gain.

7.4 Chapter summary

In this chapter, the discussion of the findings has been put into the context of the existing state-of-the-art literature where available. The discussion was presented for each of the influential parameters examined in this study. These findings have been mapped to highlight the state of the knowledge where the gaps were found. The discussion of the findings of this study within its contextual literature showed how this research contributed to the existing body of knowledge by the systemic methodology developed in this research and by the findings which were demonstrated to be rightly challenging some of the previous research findings in this area of research. This chapter creates foundations upon which conclusions will be built in the next chapter as a result of the research.

Some findings of the literature confirmed what has been found in the current study whereas others were contradictory. It seems that when IFS is holistically assessed within its context and following a systemic approach, some parameters will be found to be more influential than others, depending on the output parameter under investigation.

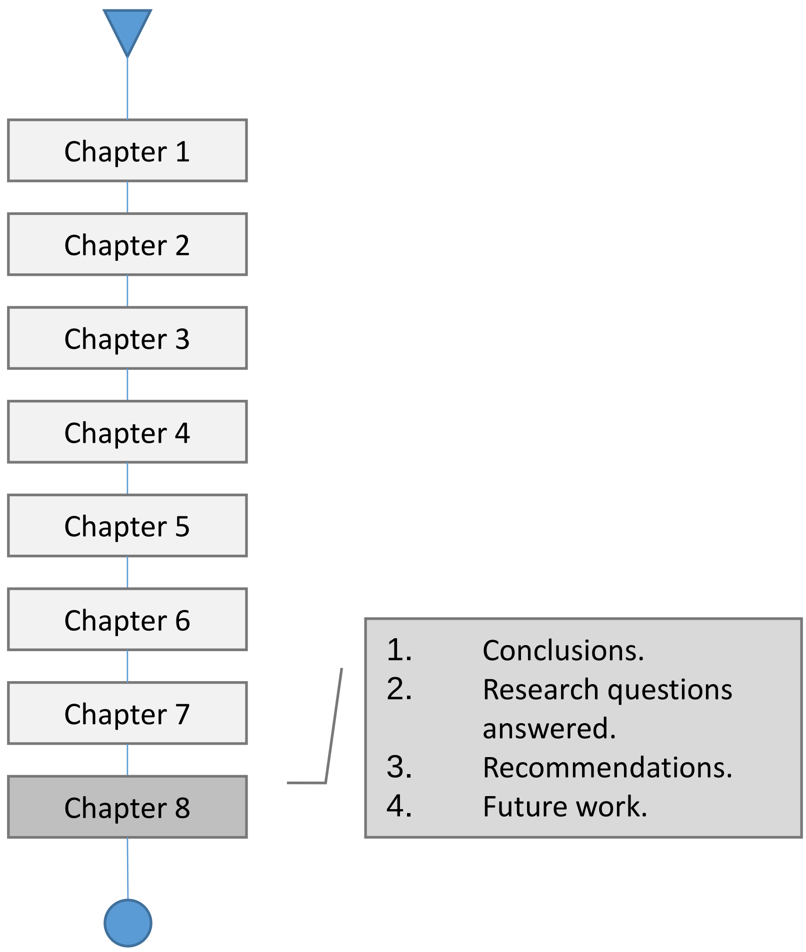
Results from the SA showed that parameters at the sub-system level have a higher influence on the outcome than those at the system level. These results help to understand where design efforts should be heading if a successful application of IFS is intended. For instance, under the assumption that the orientation may be a constraint, the HPG and d/l ratio are the elements on which to focus. Such results, combined with the decisional synopses introduced in the previous chapter, can be of great help in the design stage to narrow down the possible number of configurations to a meaningful number that can then be evaluated and decided upon. Furthermore, utilising the factors' inter-dependency showed that it is of paramount importance to consider the inter-dependency of all the influential output variables when a systemic and comprehensive analysis is intended to ensure accurate and reliable results.

The discussion highlighted the fact that energy performance measures depend highly on the glazing systems. In addition, the discussion also elaborated on the variations of the results between this study and other studies in the field. Such variations are, however, influenced by many parameters – such as occupancy profiles, internal heat gains, geometrical configurations of the combinations, the heat transfer in the building envelope and materials, dimming profiles, to name a few – and therefore discrepancies could result.

The chapter also highlighted the fact that adopting the systemic approach that is developed in this study will help further the understanding of some phenomena and justify how the contributory elements would behave when combined effects are under investigation. The discussion in this chapter has paved the way towards the final conclusions that will be presented in the next chapter.

Chapter Eight

Conclusions and Recommendations for Future Research



CHAPTER 8. Conclusions and Recommendations for Future Research

8.1 Introduction

This thesis presents a fundamental study for improved energy performance – at both consumption and generation ends – and daylight performance of integrated façade systems (IFS) for highly- to fully-glazed office buildings in hot and arid climates. This research is motivated by the lack of comprehensive and systemic studies concerned with office buildings where IFS is integrated both generally and more specifically in the specific climatic conditions of this study. It therefore aims to map out different determinants of highly- to fully-glazed façades (HGFs/FGFs) in hot and arid climates, utilising a systemic approach especially devised to investigate the effects of different configurations of IFS elements on energy and daylighting performance to contribute to the theory and practice of designing HGFs/FGFs for office buildings in hot and arid climates.

The study identified and evaluated three groups of highly influential parameters affecting the thermal and visual performance of buildings with IFS, in addition to PV generated electricity. Using a reference model of an office building that was developed based on a professional remote survey and informed by common practice, the influence of each key parameter on the building's energy and daylighting performance was studied with the aid of computational simulation. As a result of this, an approach was developed systematically that explores and uses combinations of solutions to maximise the building energy and daylight performance. The effects of the influential parameters – based on their systemic level – were also evaluated in order to provide references for improving the main three functions of the IFS: energy consumption, energy generation and daylighting.

To deliver the aim, this study set out seven objectives that will be reviewed and discussed in the next section. In addition to that, this chapter will demonstrate how the research question has been answered. The contribution of the research and the impact on the design of highly- to fully-glazed office buildings with IFS in hot and arid climates are also presented in this chapter. Furthermore, the limitations of the research and possible future directions for research in this field which were pointed out by this research, will be elaborated on.

8.2 Discussion and review of the research objectives

Objective one: *To establish the boundaries of this research by setting the contextual conditions of the study, the climate, the building type, simulation prerequisites and tools.*

In order to achieve this objective, an overview of the context of the study was presented in Chapter 2, where the climatic parameters were discussed and analysed so that possible contributory work that delivers desirable outcomes within this context could be established. This part of the study was presented with links to the situation in the country of the study, which was presented in 0. Conclusions from the analysis of the context and climate suggest that the minimisation of solar gain, maximisation of natural daylighting, in addition to the possibility of further maximising the benefits of the adopted strategies by harvesting the sunlight, is one of the best approaches for improving the built environment due to its positive contribution to reduce energy consumption, GHG and wider environmental impacts of the built environment.

Objective two: *To evaluate the working principles and establish the thermal and illuminance performance of IFS.*

The key fields that form the scope of this research are identified and grouped as Venn diagrams presented in CHAPTER 3 to show the interrelation between the main elements of IFS and to highlight the gaps in the existing knowledge in this field. The literature therefore was grouped under each of those key elements then critically and thoroughly reviewed with the aim of concluding a set of prerequisites for the design of IFS in highly- to fully-glazed office buildings, investigating the main elements that form the idea of IFS, with both PVSD and HPG in hot and arid climates, and also reviewing experimental, mathematical and computational simulation studies concerned with the energy and daylighting performance of those elements. Key parameters which contributed to the development of the building model and the identification of the key parameters affecting the building energy and daylighting performance – in addition to renewable energy generation – were then established.

Objective three: *To identify suitable IFS configurations and establish their physical and operational characteristics that may affect the building's energy and daylight performance.*

The most influential factors and parameters that are expected to have a significant impact on the performance of IFS in highly- to fully-glazed office buildings were identified in CHAPTER 5. They include site parameters, building parameters and IFS components' parameters. Conclusions indicated that there was a need to develop a systemic approach in order to be able to systematically and holistically study the influence of those factors and to enable navigating through those factors and differentiate the impact of each of them at different systemic levels. A development of this systemic approach that was informed by Systems Theory was therefore proposed and presented in CHAPTER 4.

Objective four: *To develop configurable simulation models of highly- to fully-glazed office buildings with combinations of the identified influential IFS components.*

To demonstrate the fundamental energy and daylighting performance of highly- to fully-glazed office buildings with IFS, a reference model was developed and simulated as a base-case scenario. The characteristics of the virtual base-case model are presented in Chapter 4. The building geometry, internal layout, heat gains, and construction elements and materials are identified based on the outcome of the remote questionnaire survey. This survey was devised and data were collected and analysed. This part was presented in the data generation in Chapter 5. This was deemed to be an alternative method where data and archives of office buildings are neither available nor sufficient to support development of the base-case model. Even though it was possible to develop a representative model solely for this research, the aim was, however, to provide a global tool that can be used by other researchers to serve other objectives related to their studies or projects, hence a systemic, modifiable and customisable methodology was developed for this research. So to fulfil this promise, a review of the literature on developing representative models and benchmarks was conducted and the research concluded that alternative methods such as questionnaire surveys can be a sufficient tool to help in devising models. The research therefore developed a representative model and provided the method as one of the plug-ins of the customisable methodology. Those plug-ins are the units that can be customised to suit any combination of conditions, depending on the research targets. The plug-ins are categorised based on their systemic levels, as seen in Figure 8.1.

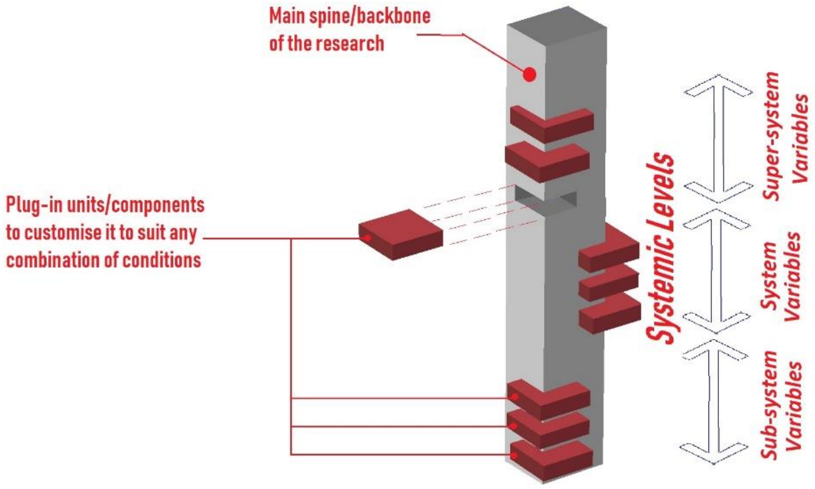


Figure 8.1 The systemic customisable methodology and its plug-ins

One of the main outcomes of this study is that due to the very specific approach which started early on using System Theory, the study facilitated devising a very modular, customisable, flexible and adjustable structure in its methodology which can be used not only for office buildings in the hot and arid climate of Iraq but also for other types of buildings in other climatic conditions and with different types of façade elements or design elements. The reason for that is because the whole structure, as shown in Figure 8.1, is modular, meaning that the spine of the structure can adopt packages and modules which can be plugged-in, based on the personalised study or the methodology, to the specifics of the context of similar studies like the current one. This is not just because of the design of the study but also because of the structure of the selected simulation package (IES-VE). This tool is a very powerful and flexible tool and with the simulations the current study has developed, there are elements that can be manipulated and changed to easily accommodate the design specifics of the building types and typologies of any similar study with a similar or the same scope, aim and objectives.

Objective five: *To simulate the building performance under different settings and combinations of parameters as determined in objective one and to monitor and evaluate the effect of change in those variables on the building performance.*

Based on the discussion and justification presented in CHAPTER 4, simulation tools seem to be the most appropriate method to conduct such a comprehensive and detailed parametric study. IES-VE is the tool that was selected after providing relevant justifications. The simulations were carried out in two stages: 1) the proof-of-concept stage, and 2) the full factorial parametric study and design configurations, which form the detailed simulations, as elaborated on in CHAPTER 5. The results of the simulated base-case model revealed the building energy and daylighting performance indicators and constraints. This model was used as a baseline or base-case scenario that represents the worst-case scenario. The impacts of all interventions have then been applied, simulated and assessed against this model to evaluate the improvements made both to the thermal and lighting aspects of this research. The detailed characteristics of the model are presented in CHAPTER 5. The results of the simulation are presented and analysed in CHAPTER 6. Simplified models have been developed and used as a tool for data quality checks and to verify and validate the simulation processes.

Objective six: *To develop an approach to systematically investigate the influential factors in the design and configuration of façade systems.*

Since this study aims to evaluate all the influential parameters through presenting a systemic methodology that leads to make design decisions about the trade-offs between three rather contradictory functionalities – improving energy consumption, maximising *in situ* energy generation and maximising daylighting – it was of great importance to assess and evaluate all the inter-dependent factors so that the influence of those inter-dependent variables is fully and completely accounted for and that the methodology will then lead to making informed decisions with a clear and comprehensive understanding of the combined impacts. Furthermore, it helped with the development of the methodology, such that it can be adopted, adapted and adjusted to the specifics of similar studies but in different contexts.

The Systems Theory, which was reviewed in CHAPTER 4/section 4.2, was then developed to include the contextual determinants in order to facilitate a global systematic approach for the investigations to help in navigating through all the influential parameters and to be able to plug-in/plug-out those parameters in a systemic manner. In doing so a systemic approach was adopted so that the study can be used as a point of reference for future research where interventions at different systemic levels can be justified and recommended. This study takes the building level as 'the system'. The upper level, 'the super-system', includes the context where the building is located (e.g. site, geographical location, climate, etc.) and the lower level, 'the sub-system', involves the façade components. This triad systemic classification can, and may, be expanded further into the next lower level which includes the façade components if, and when, a closer, more detailed investigation would be needed. The systemic approach not only helped with the organisation and processing of the parameters, but also with managing and organising the analysis phases in a systemic manner. In addition, this approach formed the methodological basis for a decision support system when design decisions are to be made in practice.

Objective seven: *To evaluate and optimise the operational energy and daylighting of highly- to fully-glazed office buildings with IFS.*

The individual influence of the key design parameters – at systemic levels – on the building energy and daylighting performance were evaluated through parametric analysis and presented in CHAPTER 6. Energy consumption/generation and UDI levels of the internal spaces of the building indicated the improvements of the alternative combination of scenarios in comparison to the base-case scenario. Influential parameters that maximise the building's electricity generation were defined and the significance of PVSDs' and HPGs' selections and design decisions were investigated. The contributing factors to the main assessed indicators (output variables), such as cooling loads and lighting gains, were also evaluated and the influence of PVSD and HPG parameters were established and comprehensively analysed based on their inter-dependency, which was discussed, established and developed in section 4.14.

The results of the simulations were then grouped systematically and ranked in the form of decisional synopses tables to be used as a practical design tool to help in reducing the number of configurations that can be chosen for further investigation, within the specific priorities, preferences, limitations and design intents of the project under design.

In order to quantify and verify the simulation results, sensitivity analysis (SA) was conducted on all of the output variables where all input variables were changed simultaneously so that the extent of the effect of the variation of each of them could be measured and evaluated. This was done using IBM SPSS™ as the core analysis tool and the regression technique was conducted as a Global Sensitivity Analysis method to fulfil this task.

In order to highlight the novelty of the current study and its position in its field of research, the findings were then discussed and contextualised within the relevant literature, where available, in CHAPTER 7.

8.3 Responding to the research questions

This thesis set out to answer the research questions formulated in 0 as a result of the work conducted in this study, as follows:

- **First research question:** *Can IFS have an impact on a more environmentally-concerned approach to the design of buildings in hot and arid climates?*

The answer to this research question lies in the thorough and comprehensive analysis of the three main elements of IFS: shading devices design, high-performance glazing (HPG) systems and integration of photovoltaics (PV). All the influential parameters involved in these elements have been identified, listed and comparatively analysed. In order to manage and navigate through all the influential parameters, a comprehensive and holistic methodology was developed based on the System Theory. This methodology is customisable and flexible so that it can help organise and manage the parameters, in a systemic manner, under three systemic levels: 1) *'super-system level'*, where all the parameters at the context level were listed and grouped as a larger level of influence; 2) *'system level'*, where parameters pertaining to the whole building were considered; and 3) *'sub-system level'*, where parameters at the element level were investigated.

A table of around 15000 possible combinations of variables was first composed, to which comprehensive inclusion and exclusion criteria were applied through a systemic process to help scale down the number of variables. The inclusion and exclusion processes were mainly informed by the literature related to the topic, the practice and the standards. The variables at the super-system level were excluded from the scope of this research as discussed and justified in CHAPTER 5, section 5.4. The variables at the system level that have been included in the investigations were: building orientation, with the main three orientations (south, south-east and south-west) and window-to-wall ratio (WWR) with three variations representing a highly- to fully-glazed façade (60%, 80% and 100%). Variables at the sub-system level were those related to HPG, such as the glazing system (single- and double-glazing) and glass type (clear, low-e and reflective) and those that are related to

PVSD, such as the depth (400mm and 600mm), the ratio between the depth and the distance between PVSDs (d/l=1, 1.5 and 2) and the angle of the inclination of PVSDs (20°, 30°, 40°, 50° and 60°). The table of variables was finalised and included **1620** unique combinations.

Furthermore, a remote questionnaire survey was devised in order to collect sufficient data, informed by practising architects, to be able to develop a representative model which would then be used in the dynamic simulations and analysis of the base-case scenario and the comparative analysis of the intended interventions with all the possible combinations. Those combinations were applied to the base-case model and each new combination was simulated using three integrated tools as follows: SunCast, which was run to generate solar energy data, shading and PV calculations; Radiance, which was then used to run a full year's radiance calculation for daylight harvesting; and finally Apache, which was utilised for integrated thermal, shading and dynamic daylighting simulation. The results were generated, extracted and analysed and the study concluded with some valuable findings to suggest that IFS can actually enhance the energy and daylighting performance, in addition to generating renewable energy.

The improvements were analysed and discussed to answer the second research question:

- **Second research question:** *If IFS prove to have some level of impact on the approach to a more environmentally-concerned design of buildings, then how can some of the performance criteria pertaining to IFS be adopted and adapted such that, while the energy consumption of the building is kept under control, other major indoor comfort conditions can be improved so that a reasonable balance can be struck in the design and specifications of highly- to fully-glazed façades?*

The second research question is chiefly a 'how' question with no single right or wrong answer but a range of 'if-then' answers. The results from both the energy assessment – be it consumption or generation – and daylighting assessment indicated that when IFS is used under Iraq's climatic conditions, almost all of the cases have shown significant improvements.

The results of the current full factorial parametric study revealed significant, and rather different and unexpected, influences of some parameters, and proved that others are negligible, with the possibility of considering trade-offs between the main triad functionalities of IFS. Starting from the system level variables, orientation was unexpectedly found to have a rather limited influence in general; however, it is still relevant and plays a role in cooling loads and solar gain. This is one of the significant findings of this research, which proves that when an IFS is set up in such a way, that it can help overcome building orientation, as a constraint, by deploying the functionalities to the other IFS components and hence have a limited effect on orientation. While WWR was found to have some influence on energy consumption, this influence is, however, mainly coming from the impact of WWR on solar gain and subsequent cooling loads. On the other hand, when trade-off is aimed at, WWR can be excluded from the daylighting optimisation list of influential variables as it does not have a significant impact on daylight availability. This is because daylight highly depends on the variations of other variables much more than on WWR. Scaling down to sub-system level variables, the two depths investigated did not show a considerable influence on the energy consumption and daylighting figures, whereas they were proved to have a considerable influence on the PV electricity generation figures. In other words, there is no difference in the depth of PVSD that can be considered better than others. The SA confirmed the findings of the first two phases of the analysis of this research by which the depth was shown to be the least scoring parameter.

The quantification of the above-mentioned influences of those input variables on each of the output variables would not have been achieved without the thorough utilisation of the SA methods, in addition to the SA's help in verifying the results of the simulations. SA was one of the powerful tools that significantly contributed to the comprehensiveness of this research.

Due to the advanced optical and thermal characteristics of HPG, the angle of inclination was found to have an unexpectedly minimum influence on the figures. In addition, it was found that an inclination angle can be preferable but only in accordance with the variation of other parameters, such as glazing system and glass types and orientation. The SA indicated that regardless of the orientation, the glazing system – as an integral part of the IFS – was the most important parameter. It also unveiled an interesting trade-off between other PVSD parameter combinations. Indeed, the d/l ratio was found to be the second most influential parameter on cooling loads, solar gain, lighting gain and subsequently the energy consumption. When accounting for trade-offs between daylighting, energy generation and energy consumption, combinations with the least d/l showed they were less energy intensive than the others. However, with the help of the factors inter-dependency relationship matrix developed in this research, the daylight assessment showed a more day-lit indoor environment in options with higher value of d/l ratio (1.5 and 2). This somehow suggests that the preferred IFS configurations in any given case may not be those which minimise cooling loads, nor are necessarily those which maximise daylighting, but rather those which score very highly (but not necessarily the highest) in both sensitivity analyses. For this reason, the same results have been ranked in the form of decisional synopses tables to present the findings for comparison purposes, but when actual numerical values are needed for a detailed and accurate conclusive decisions, both the graphs in phase one and spreadsheets representing the detailed results produced through the process of analysis, can be referred to/utilised.

While orientation played an important role in cooling loads and solar gain, with south-east and south-west orientations performing generally better than others on a global level, the south orientation also indicated considerable energy savings but relatively these were less. It was then concluded that, within a given orientation, there are IFS configurations that outperformed other alternatives in terms of cooling loads but not necessarily in terms of lighting and PV electricity generation. This finding motivates further research to challenge the commonly agreed upon rules of thumb that IFS should be facing south. It seems that a PVSD, when combined with HPG to form an IFS configuration, has a much more determining role on the energy performance of, and the daylight control in, an office building with highly- to fully-glazed façades.

Finally, amongst the parameters considered in this research, those related to the dimensions of the external building skin showed a less important role than what has been found in the existing literature, in which the focus tends to be on the PVSD and HPG as separate elements of the building. In addition, those parameters are treated as if they were somehow independent from other influential parameters with combined effects. As such, research on IFS should take this into account and incorporate the assessment into the broader context of the building where IFS is intended as a design solution.

- **Third research question:** *If IFS show they are capable of contributing to a more environmentally-concerned design of buildings with their components or pertaining criteria, then can a systemic approach be developed so that all potential significant variables can be accounted for, and evaluated proportionally, to be able to systematically contain, manage and configure different elements and parameters of IFS in order to strike a balance between the impacts that IFS might have on the environmental performance of the building in question?*

The results of this research indicated that IFS configurations proved to be feasible solutions to suit contextual conditions for highly- to fully-glazed office buildings in hot and arid climates, such as the context of this study (Iraq) because in most of the cases they have a positive impact on the building energy performance. This is true for the majority of combinations investigated and examined, although there are also some exceptions. In combinations with d/l=2 at a south orientation, only 33% of the 90 assessed scenarios are more efficient in terms of the electricity generated by the PV. In this case, when looking at the overall energy consumption as a net energy figure, it seems that they perform better, although they have the least electricity generation results. Such exceptions would not be revealed by the overall net energy figures only but must be assessed through probing/exploring the bigger picture of the triad functionalities more closely because other parameters, such as some glazing systems (e.g. low-e or reflective), will have a rather significant impact on the energy figures. Whilst there is a strong linear correlation between solar gain and cooling loads for all the combinations, there are still some variations in combinations with one glazing system and another and therefore the sole energy assessment would be misleading, suggesting that all the influential factors contributing to the energy and daylighting assessment should simultaneously be investigated. In other words, some preferable options may not be so in terms of one output indicator or another in isolation but may prove to be enhanced and hence a preferred option when combining the results of two or more output indicators. Although there has been some literature that looked into the combined effects of solutions, the findings of the current study confirm the continuing need to carry out comprehensive and holistic assessments that were identified to be missing in the previous literature.

The sensitivity analyses for net energy, energy saving and PV-generated electricity revealed a significant influence of fewer parameters than those resulting from the same analysis of the daylighting performance. Such diversity between energy consumption, daylighting and PV-generated electricity indicates a different role that certain parameters play according to the assessment indicator under consideration. This means that a certain parameter could sometimes be significant but in other occasions maybe less so. These findings confirm the need for a holistic and rather systemic approach to avoid making uninformed decisions, which in turn may negatively affect the other functions of IFS, i.e. what has been advocated for, evidenced, devised, applied, analysed and proved to be key to any all-inclusive research in this area if and when an ultimate conclusive and evidence-based outcome/result is intended.

8.4 The research contribution to the existing knowledge

While the aim of designers – in extreme climate conditions such as the one considered in this research – is to minimise solar gain and cooling loads and to maximise renewable energy while simultaneously maintaining a visually and thermally comfortable indoor environment, the literature review shows that there is a need to investigate and evaluate techniques where different solutions can be integrated to help reduce the negative impact of the intensive use of energy in buildings in such climates. One effective strategy in integrated design is what is known as the Integrated Façade System (IFS), namely façades where different technological solutions are incorporated to improve the performance. Some of the strategies in designing IFSs include incorporating:1) High-Performance Glazing (HPG); 2) Shading Devices (SD); and 3) Integrated Photovoltaics (PV).

However, knowledge on the combined effects of IFS's elements and a holistic and systemic evaluation of the impacts of all the possible influential parameters did not exist prior to conducting this doctorate. The methodological approach developed in this research should not only be accounted for as a holistic and comprehensive assessment but also one to benefit researchers and designers alike at both theory and practice levels. In addition to its contribution to both methodological and practical levels, this research has a wider and longer-term impact as it also contributes to policy level. The following sections will elaborate, in more details, on how this novel methodology with its systemic approach contributes to the existing knowledge at different levels.

8.4.1 Methodological contribution

This research comprises an original comprehensive analysis of the application of IFS under hot and arid climatic conditions in Baghdad city in Iraq, presenting and discussing the fundamental principles of IFS design, its operation and applicability to highly- to fully-glazed office buildings. The findings of this research have helped not only with identification of the most influential design parameters to maximise the triad functionalities of this system, but also with evaluation of those key factors affecting the building’s thermal and visual performance in a comprehensive, parametric and systemic manner. It has laid a solid foundation for systematic studies of topics related to those of this research, and also helped classify their impacts and further provided a decision support system for the course of intervention/action when it comes to the proposition of solutions for practical applications in building façade design.

Although this methodology is formulated using particular context-specifics of Iraq, its modular design allows for the highest level of customisability and its flexibility permits for it to be used globally to suit different contextual conditions, buildings and façade elements; what can be altered as different plug-ins in its modular methodological construct. These plug-ins are compatible and will work with the main structure of its methodological platform (see Figure 8.1).

This systemic methodology has resulted in some interesting findings. To name but one example, reducing the impact of one variable (e.g. the inclination angle of the PVSDs) due to its correlation with another variables (e.g. the ratio between the depth of PVSD and the distance between them) to overcome one or more of design constraints (e.g. building orientation). This has helped provide a multitude of design options for trade-offs between rather contradictory functions, such as reducing energy use, improving daylighting and increasing energy generation, which may not have the very much expected result as the common sense may lead one to believe or expect it and even as concluded by some precedent researches.

Furthermore, the methodology developed in this research, the data generated, the full factorial parametric analysis, the survey that led to the development of the model, the factors inter-dependency analysis, the use of decisional synopses and the unique development and deployment of SA, can all be applied to any comparative, parametric and holistic analytical study or evaluation in or for academic research, and also get used by architects or façade designers as a practical design decision support system. This will be further elaborated on in the following section.

The preference of one combination over any other(s) can be justified with the help of both the factors inter-dependency matrix that has been developed in this study, and through the sensitivity analysis (SA). The factor inter-dependency matrix has facilitated the study of those factors, helped trace back the origins of the cause and the causal-effect relationships between input and output parameters, which in turn helped highlight some interesting findings. For instance, combinations with SC glazing and SL glazing were found to have some negative impact on energy consumption due to increased solar gain which adds to the cooling load for both cases. What makes combinations with SR a little bit more energy efficient compared to those with SC, is that although SR adds to the need for artificial lighting (which in return adds to the electricity consumption), the higher solar gain in SC (compared to SR) – adding to cooling load – seems to outweigh the extra load for artificial lighting which is higher for SR than SC glazing type. Both combinations have significant influence on energy consumption. This finding can be confirmed by the SA which quantifies the effect of change of each of the variables at different output variable. This in turn helps make the decision about the combination, or a set of combinations, where particular changes can be made on the most influential variables to meet the requirements of the specific design intents. This is where the use of the decisional synopses helps with making those decisions, based on the ranking of the performance of the combinations as per different output variables (see section 8.4.2 and section 6.6 for details on practical application of this tool).

8.4.2 Practical contribution

The methodology in general and the systemic approach specifically have proved that the application of IFS in highly- to fully-glazed office buildings in Iraq can be optimised to help improve energy use, maximise electricity generation while maintaining the level of daylighting within satisfactory standard levels. The application of IFS has also shown to have helped reduce energy consumption in this type of buildings by up to 16% compared to the base-case scenario, while the electricity produced by the PVSDs can provide up to 31.25 MWh. These improvements were due to reduction in solar gain by up to 82.7%, reduction in cooling loads by up to 44.5% and regulating lighting gain in the indoor spaces in order to harvest daylighting. The energy saving as a result of reducing energy use and generating in-situ electricity can be increased by up to 18% while the useful daylight illuminance (UDI) levels in the indoor spaces vary between 1% and 95% during the working hours of the year. This wide range of variation in UDI can give a wide range of options depending on the priorities of the specific design intents and its set aesthetic aspirations and/or technical and environmental performance targets.

The decisional synopses can be used as a tool to assist with decisions about which combination(s) of IFS components is/are preferred over the other(s) when it comes to optimisation of the façade functions. The ranking in the synopses tables alongside with the simulation results can help make this decision. In addition, the coding system which was developed in this study can also help identify the exact components of each unique combination under investigation. For instance, if a single output is targeted e.g. energy consumption for south-facing façade, the best scenario for energy consumption is the combination with DL glazing at 20 degrees for d/l=2 for WWR=60%. Whereas if optimised energy, daylight and PV generated electricity form the design target of a specific project, multiple options can be chosen, such as combination S-80-60-15-20-DL or combination S-60-60-2-50-DL (refer to section 5.5 for details on the source codes). The decision on how any of those combinations is preferable over the others lies with the priority of the design intents, which can at the number of options which are near or at a single value of the design targets (i.e. similar results of energy consumption. So, for the above-mentioned example, the actual numerical value of the annual energy consumption of the former option (S-80-60-15-20-DL) is 157.8095 MWh and that of the latter option (S-60-60-2-50-DL) is 157.7902 MWh. Since the difference in energy consumption between the two numbers is negligible, this will give the designer alternative options to choose from, based on other functions such as PV-generated electricity. Appendix 7 contains all the numerical results of simulation outputs and can help serve this purpose. For option S-80-60-15-20-DL, the annual PV generated electricity is 26.0091 MWh and for option S-60-60-2-50-DL is 23.9467 MWh. Therefore, the decision will be to go for the option with the higher PV electricity generation that is S-80-60-15-20-DL. Other examples of how this tool can help the designers decide about the preferable combination or a set of combinations are provided under each of the output variables in Chapter 6 (section 6.6).

Not only does this methodology help designers keep their designs without radical changes, such as reducing the glazed parts of the façade, it does also help the designers throughout the country keep up the pace with technical and technological advancements as well as architectural movements throughout the world. Furthermore, the practical contribution and findings of this research help improve the relationship between designers and clients as of its contribution to saving energy at building level, making them greener, more sustainable and more environmentally-friendly by lowering their impact on shortage of resources as it is at the moment, help cut back on blackouts and electricity shortage, reduce their impact on immediate and wider environment by reducing the demand on mechanical cooling during peak times, which reduces the contribution to increased urban heat island (UHI) effects.

The results that have been demonstrated above are for one single building with IFS. The contribution of this methodology and the outcomes of this research at the practice level can potentially be further result in wider contribution at city level. This will be discussed in section 8.5.1.

8.5 The wider impact of this research

This section concludes the findings of this research not necessarily in the light of the research questions it aimed to answer but in its wider context, i.e. national building codes, legislations and policies and the ongoing research efforts in the built environment. The following sections will elaborate more on this wider impact:

8.5.1 Contribution to legislations and building codes

The long-term impact of the research which is on building codes and legislations, and built environment and urban policies. Although deemed to be a subsidiary contribution, this research provides original and up-to-date data and findings, which can inform the formation of green and sustainable policies, energy regulations, building codes and a best practice guide for office building design in Iraq. This is of paramount importance to the country as it is experiencing rapid developments in a post-conflict era after several wars, which lasted for more than 30 years. Due to several conflicts in the country, the latest building codes were updated back in 1980 and are now in desperate need for refinement and updating.

Although there has been some attempts to update them in the last few years (and the researcher has been a member of two of the teams involved in such attempts), one of the problems in that area is the lack of local data to back the decisions up. It has been observed that what has been done in this respect has been based on codes appropriated or adopted from neighbouring countries where there have been well-established institutions with testing facilities. Therefore, the research also aimed at contributing to the change of this trend by providing data that is based on the national practice in the country. This research is one of, if not, the first foundations to move that trend of borrowing from other legislative codes into a good practice of home-grown codes and legislations which are well-founded on research-base, tailored, created and provided according to and for the context-specifics of the country of their origin. Although the study is heavily reliant on the simulation, it uses this method with reference to Iraq weather, climate, location, and building industry specifically for the context of the country and as such is one of the first of its kind throughout the country.

When designing IFS for buildings, choosing one combination over the other(s) will affect the professional practice. For example, the decisional synopses, alongside with the excel spreadsheets of simulation results, can offer an optimisation tool (refer to section 6.6 for details) that helps make decision about which combination of variables can offer energy saving of, for example, 15%; this methodology is providing some options for designers. However, to make sure that they are complying with what are much needed design strategies for or approaches to highly- to fully-glazed facades, this needs to be enforced through legal and legislative channels, such as the Ministry of Construction and Housing or National Buildings Directorate. This is where the research furnishes some grounds for those legislative contributions to be made.

8.5.2 Contribution to policy

The current research has targeted one of the most controversial areas in the codes and legislations, namely highly- to fully-glazed buildings, proving that in this area, significant savings can be made. The research has targeted and proved that this is possible and doable against the worst-case scenarios, which will have some significant promises for the less problematic sectors in the building industry to follow.

The findings of this research can help designers acting as an easy-to-use design decision tool releasing them from the need to master simulation software packages; what seems to be challenging throughout the country but more so for small- to medium-sized design practices.

First and foremost, a great portion of the data generated in this study is useful to a much broader spectrum of research in fully- to highly-glazed buildings, given that IFS data were the most important missing dataset in the existing databases. Therefore, this research will made all the raw data freely available to all interested design, engineering and legislative bodies in the form of Excel spreadsheets, graphs and decisional synopses. This form for data-sharing comes from the awareness that many software tools are available on the market but not all practices, especially small- to medium-sized practices, can afford to purchase or invest in specialised training to effectively utilise them. A raw, openly accessible dataset (e.g. in *.csv format) will therefore allow users to benefit from the data regardless of the tools.

The focus of this research is on an extremely detailed assessment of IFS combinations but to fully understand the potential practical implications of the findings, a nation-wide numerical assessment would be helpful. For example, in Baghdad city on its own, nearly 100 office buildings are built yearly. If each building saves energy by up to 18% which is equivalent of 37.18 MWh per building per year, this means that if this methodology were to be followed for all these 100 buildings, then a total of 3718 MWh of energy could have possibly been saved. This significant saving can be used to secure lighting energy for nearly 200 primary schools in the country a year[26].

8.5.3 Contribution to the current research efforts in the built environment

In achieving its aim, this research has also reinforced some research trend and confirmed some very important themes currently being undertaken in the research areas associated with integrated design and integrated façade system in particular and in the built environment research in general. These themes' focuses vary from

[26] These calculations are merely based on available yet limited statistical data and do not take into account many other parameters which can potentially contribute to adopting IFS in buildings, e.g. costs. Therefore, care should be taken before making bold claims or generalisation in any shape or form. This thesis has indicated that the use of IFS in highly-to fully-glazed is one viable and promising solution. However, still more statistical analysis needs to be done to pin down the factual benefits this research will be able to offer at large scale up to national scales.

the potential of using solar energy in buildings in Iraq (with a wider scope for application of IFS for non-residential buildings in hot and arid climates), to the importance of avoiding, as much as possible, or otherwise knowingly and admittedly setting the boundaries and acknowledging the limitations, applications and scopes of, carrying out a 'single-impact category' study concerned with improving energy in buildings. This has been demonstrated through the evaluation, optimisation and SA processes of the triad functionalities of the IFS's impacts assessed through the analysis phases of this study and have all contributed to a broader and more in-depth holistic interpretation of the findings, and more importantly to more careful, more realistic yet much better-informed conclusions; what might easily challenge some over-claims or the claims made previously but are subject to more speculations due to positive bias associated with deterministic positivist approach underlying such studies. Therefore, future research on IFS should steadily grow in this direction and try to abandon the tendency to make bold claims based on single-category impact assessments (e.g. energy consumption).

Furthermore, as a product of the previous point, was also reinforcing and demonstrating the role of the decisional synopses as a technical design decision support tool. This is what was demonstrated to be capable of holding a sensibly higher value when combined with sensitivity analysis so that findings are not simply represented through single deterministic results but rather offering broader set of results which will lead to a higher choices from a spectrum of environmentally equivalent or comparable decisions, for instance with respect to the choice of a combination of glazing system and PVSD over the other(s).

8.6 Limitations of this research

Dynamic energy simulation was the only viable option for a full factorial parametric research as its main method. However, the lack of experimental data for IFS with its various applications forms the main limitation of this research. The fact that it is nearly impossible to build two identical office buildings with and without IFS, and it might not be feasible and viable to build a multi-storey testbed to mimic an office building with all its complexities, makes building up a test cell of IFS and applying it to a real office building a possible option to overcome this limitation. Further research could provide experimental validation of the performance of IFS combinations.

Moreover, assumptions had to be made for the modelling and simulation process, such as irregular occupancy and utilisation of lighting. As internal gains, some dynamic factors such as the varying use of the equipment (e.g. computers and printers) throughout the day, and people's heat gain into the rooms, were not considered in the simulations. Instead, uniform gains for each of them were inputted into the simulation settings. These are dynamic dependent variables that may have some effects on the internal gains and the interactions between the building and the façade. However, as the research design for the current study was structured around a comparative analysis method, this did not have any impact on the results of the research.

Furthermore, the cooling loads may also be affected by the increase of the use of mechanical air-conditioning systems, especially during the hottest days where peaks are expected. This would also possibly impact on the thermal behaviour of the system itself.

Another aspect that can be addressed as a limitation, and an interesting area for further research, is the prototype model, which was developed based on a remote questionnaire survey to account for a 'close to reality' model. Although still a necessary step to collect/generate data, a thorough survey of real buildings could help further the knowledge and understanding of a representative building so that more evidence-based generalisations could have been rolled out.

It is worth mentioning that the lack of national building regulations has resulted in using international standards and that may have had implications for some local requirements. As mentioned before, due to the comparative analytical nature of the research design for this doctoral thesis, the negative impacts have been eliminated or kept at a minimum as worst-case scenarios.

8.7 Recommendations for further research

This research has covered an area in order to provide valuable outcomes for a field of study on building performance, where IFSs are intended to be used in architectural design in hot and arid climates. However, due to complex issues related to the topic, some areas of research that could further contribute to the understanding of the applicability of IFS and its integrated technologies and configurations to help reduce energy consumption and encourage the implementation of low carbon solutions, technologies and techniques, are as follows:

Modelling: Detailing the computational models is necessary in order to provide reliable and better representative performance of buildings. The thermal zones need to be more detailed so that a finer zoning approach is followed to match accurate architectural designs. Furthermore, positioning of the PVSDs away from the main façade could enhance the air movement around the panels and that can have a positive impact on the electricity generation, considering the fact that the air movement can reduce the surface temperature of the PVSD – where the PV cells are placed – and that can help increase the efficiency of the PV panels and improve electricity generation. This involves further research in fluid dynamics and can enhance the understanding of the air movement implications on the outer skin of buildings where there is a combination of IFS elements installed.

Although this study indicates some design strategies to control daylighting and to prevent glare, detailed zone/room glare analysis may contribute to enhancing the daylight performance of buildings with IFS.

Software development: Some limitations of the software tool used in this research have been addressed and alternative strategies put in place to overcome those shortcomings. Those limitations were reported, consulted and discussed in detail with the IES-VE support team; parametrisation of the variables, PV electricity generation vs. accuracy of the geometric PV representation, automation of conversion of some Radiance values are just a few of them.

Experimental measurements: Comparisons between simulations and experimental measurements would increase the reliability of the results provided by the simulation software. Needless to say, this area has gained momentum recently, commonly known as the ‘performance gap’ in general, which can be specifically zoomed in on to investigate its implications for the current research.

Extending this study to other building types: It may be worth furthering this study in the future to study and explore the application of IFS on different building types, such as schools and hospitals, and incorporate all the related internal/external gains, base-case model, specifications of materials and construction, and different climate conditions using the systemic methodology developed in this research to verify its flexibility in adopting and adapting to different sets of plug-ins.

The interaction between the building and its occupants: In buildings with incorporated IFS, the modification of the windows and operability may have a significant effect on the HVAC and mechanical ventilation. Therefore, further research on the interaction between buildings with IFS and their occupants is still needed to investigate the impact of the user behaviour/preferences on the building's operational energy and control.

Urban Heat Island (UHI) phenomenon: A potential use of the methodology developed in this study is in the field of studying the UHI effect. This could be done either comparatively through scaling up to super-system level variables while freezing out all other inputs but the local microclimate conditions and study different areas or different climates from the carbon dioxide emission point of view, the increased energy required for air conditioning and refrigeration in cities, and the extent to which IFS could mitigate the UHI effect.

Climate Change and IFS: Investigating the potential impact of global climate change on buildings with IFS is also another potential area for future research. Possible changes in climate, such as wind, temperature and solar irradiation, can affect how buildings with IFS perform and how occupants may perceive thermal and visual comfort in their work spaces in the building.

Life cycle analysis/life cycle cost: Life cycle analyses of adopting new materials used as an integral part of this system, such as PV, may also be another path for future research. Assessment of the life cycle cost is gaining more attention and buildings with integrated IFS can provide room for further investigation in this regard.

Kinetic façades[27] and Biomimicry[28]: With the rapid developments in sensor technology, materials and building management technology, designers are

[27] A kinetic façade is one that changes dynamically rather than being static or fixed, allowing movement to occur on a building's surface to help create what is called a 'skin-like articulation' effect, and is an extension of the idea that a building's envelope is an active system rather than just a container (Brooks, 2017)

[28] Biomimicry is the application of recognised biological concepts to fields outside the discipline of biological science, such as Architecture, by demonstrating one analogical application which could be applied at some future point ibid.

increasingly able to consider kinetic components as design solutions. IFS can offer a kinetic façade solution that can be applied in a rather dynamic way so that rotating/sun-tracking blades are investigated as another future research of the current study. This could be a self-sufficient system that uses its very own PV-generated electricity. In addition, Biomimetics can also be one of the future fields of research of the current study where IFS can be utilised in such a way that the PVSDs employ sun-tracking sensors with slow-movement motors to mimic nature, similarly to the sunflower.

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Appendices

Appendices

Appendix 1: Publications during the course of this research

Peer-reviewed conference papers

1- Integrated Façade System for office buildings in hot and arid climates: A comparative analysis.

This paper was presented in SEEDS 2016 – International Conference on Sustainable Ecological Engineering Design for Society – in Leeds Beckett University, United Kingdom, 2016. This paper won '*SEEDS Award for Contribution to the Built Environment*'.

2- Embedding passive intelligence into building envelopes: a review of the state-of-the-art in integrated photovoltaic shading devices.

This paper was presented in SEB-16 – 8th International Conference on Sustainability in Energy and Buildings – in Turin, ITALY, 2016.

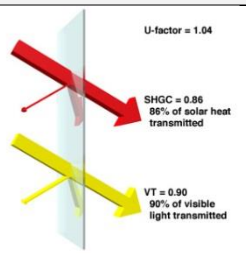
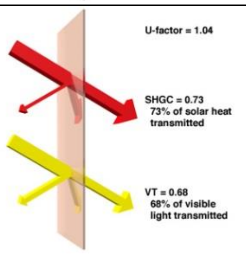
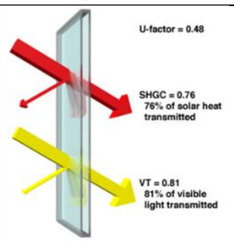
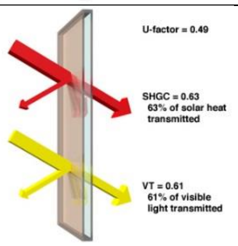
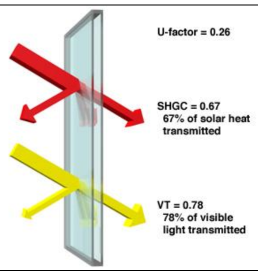
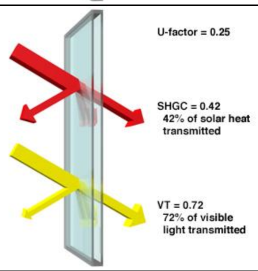
Peer-reviewed journal articles

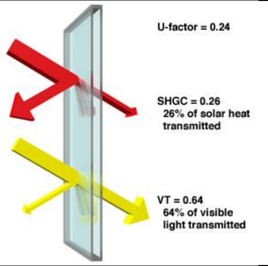
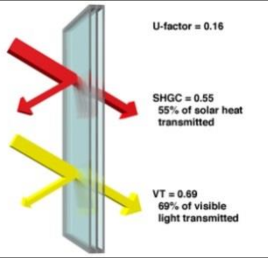
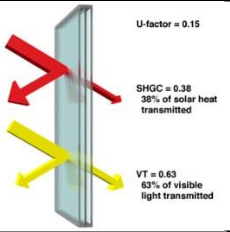
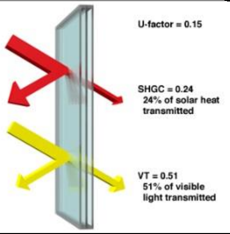
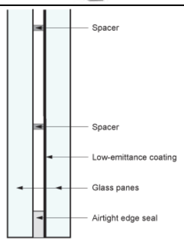
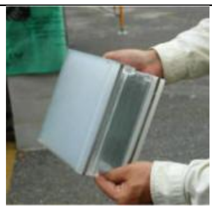
1- IBRAHEEM, Y., PIROOZFAR, A.E.P. & FARR, E.R.P. 2015. Embedding passive intelligence into building envelopes: a review of the state-of-the-art in integrated photovoltaic shading devices. Energy Procedia 111(2017) 964 – 973.

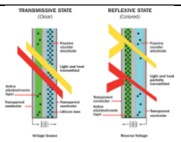
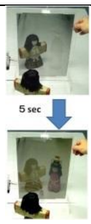
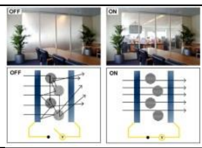
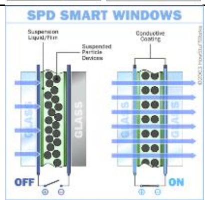
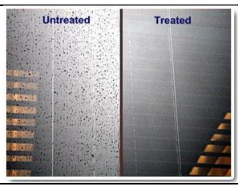
Peer-reviewed book chapters

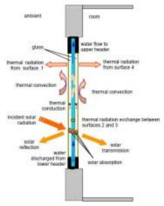
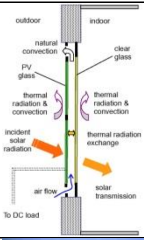
1- IBRAHEEM Y., PIROOZFAR P., FARR E.R.P. 2017. Integrated Façade System for Office Buildings in Hot and Arid Climates: A Comparative Analysis. In: Dastbaz M., Gorse C., Moncaster A. (eds) Building Information Modelling, Building Performance, Design and Smart Construction. Springer, Cham. ISBN: 978-3-319-50346-2. doi: https://doi.org/10.1007/978-3-319-50346-2_19

Appendix 2: summary of available HPGs and their best achieved performance

Glazing type	Brief description	Illustration	Best achieved performance		
			U-value	SHGC	VT
Single clear	- Highest transmittance of heat energy -highest transmittance of daylight		0.84	0.64	0.65
Single tint	-no effect on the U-factor -reduces solar heat gain(benefit in summer) -reduced visible light compared to clear glass		0.84	0.54	0.49
Double Clear	-high visible light -high solar heat gain.		0.49	0.56	0.59
Double Tint	- reduced solar heat gain - reduced visible light transmission (green/blue tints offer higher visible light transmission). - useful in controlling glare but solar heat gain and visible light transmission may be reduced compared to low-e low-low solar gain		0.49	0.47	0.44
Double High-Solar-Gain Low-E	- reduce heat loss but admit solar gain. - best for heating-dominated climates		0.37	0.53	0.54
Double Medium-Solar-Gain Low-E	- reduced solar heat gain - reduced heat loss -retaining high visible transmittance -suitable for both heating and cooling dominated climates		0.35	0.44	0.56

Glazing type	Brief description	Illustration	Best achieved performance		
			U-value	SHGC	VT
Double Low-Solar-Gain Low-E	- reduces heat loss in winter and summer - retaining high visible transmittance - ideal for cooling-dominated climates		0.34	0.30	0.51
Triple High-Solar-Gain Low-E	- low U-factor, high solar heat and visi ble light transmittance - suitable for very cold climates				
Triple Medium-Solar-Gain Low-E	-very low heat loss rate (low U-factor), high solar heat and visible light transmittance -suitable for very cold climates		0.29	0.38	0.47
Triple Low-Solar-Gain Low-E	-minimised solar heat gain - suitable for climates with both significant heating and cooling loads		0.28	0.25	0.4
Vacuum-insulated Glass	-2 panes of glass with a very small air space. - The vacuum eliminates conduction and convection but not radiation, so a low-E coating is necessary on the pane of glass. - thin (0.20–0.43 inch) and thus suitable for many facade designs. -The disadvantages of this type are; the structural requirement to resist air pressure and variable pressures caused by wind and vibration and the maintenance of an airtight seal around the unit edge.				
Insulation-Filled Glazing	Aerogel, honeycombs, and capillary tubes located between glazing panes. These materials provide diffuse light, not a clear view. Some of these materials are used in Europe for passive solar applications. Aerogel has received research attention for its ability to be both highly transparent and insulating, making it one of a number of materials that are generically referred to as transparent insulation. It is not yet widely manufactured. They do not				

Glazing type	Brief description	Illustration	Best achieved performance		
			U-value	SHGC	VT
	provide a view.				
Photochromic	Photochromic materials change their transparency in response to light intensity. They cut out excess sunlight that creates glare and overloads the cooling system. Cost-effective, large, durable glazings for windows are not yet commercially available.				
Thermochromics	Thermochromics adapt to changing sunlight intensity to reduce heat load in buildings. They change transmission continuously over a range of temperatures so they not only reduce heat loads (especially at times of peak demand), but they maximize daylighting and reducing glare. It is one the advanced technologies.				
Electrochromic	This glazing switches between a clear and transparent blue-gray tinted state with no degradation in view, similar in appearance to photochromic sunglasses. It is one the most promising technologies. The table shows examples of electrochromic glazing (Cuce and Riffat, 2015, Jelle et al., 2012, LIU, 2012)				
Gasochromic Windows	A similar effect to electrochromic windows, but to colour the window. The gas can be generated at the window in a system integrated into the facade. Gasochromic windows with an area of 2-by-3.5 feet are now undergoing accelerated durability tests and full-scale field tests and are expected to reach the market in the near future.				
Liquid Crystal Device	This material transmits most of the incident sunlight in a diffuse mode, thus its solar heat gain coefficient remains high. It is used for privacy glazing				
Suspended Particle Device (SPD) Windows	In its unpowered state, the particles are randomly oriented and partially block sunlight transmission and view. Transparent electrical conductors allow an electric field to be applied to the dispersed particle film, aligning the particles and raising the transmittance. In terms of durability and solar-optical properties have not been independently verified. Products are now entering the market, but cost remains an issue.				
Self-cleaning glazing	The glass surface can decompose organic contamination with the aid of ultraviolet light				

Glazing type	Brief description	Illustration	Best achieved performance		
			U-value	SHGC	VT
water-flow double-pane window	the idea is to remove the absorbed heat inside the cavity of the window via water flow from a feed water tank. Results indicate that the water flow in the system can efficiently decrease the glass pane temperatures, lower room heat gain, and thus the electricity consumption				
natural-ventilated PV double-pane window	This window is composed of two parallel glass sheets forming a channel through which air flows. The incident solar radiation and the temperature difference between the external and internal ambient induce an upward airflow				
Building Integrated Photovoltaics(BIPV)	Building Integrated Photovoltaics (BIPV) is integral to glass as a building component. Photovoltaic vision glass integrates a thin-film, semi-transparent photovoltaic panel with an exterior glass panel in an otherwise traditional double-pane window. All the PV types can be integrated or laminated in glass, but only thin-film photovoltaics will be translucent. BIPVs are receiving increased attention that is justified by the promise of a building envelope that can generate energy in addition to providing shelter				

Notes:

- Values on the photos are outdated; values in the table are from references which have been updated.
- Some values are not available in the literature.
- (Carmody, 2007; Cuce and Riffat, 2015; Jelle et al., 2012)

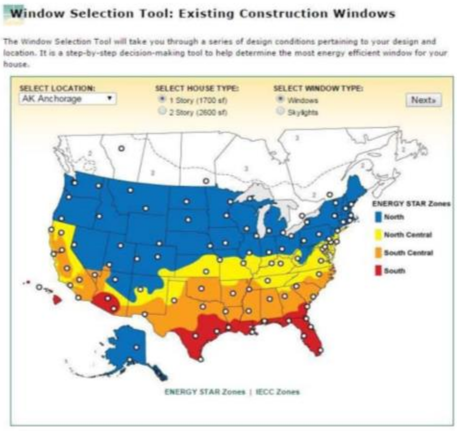
Appendix 3: summary and review of available façade assessment tools

Efficient Windows Collaborative

WST WINDOW SELECTION TOOL

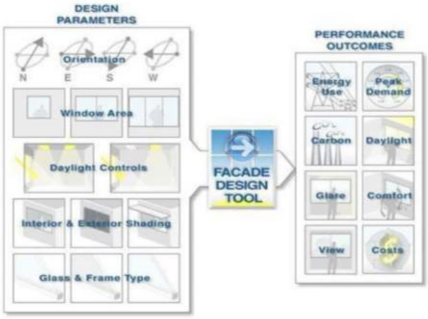
residential

1- Compare how various window or skylight types affect estimated energy cost for a typical *house* in *USA*.
2- Get general feedback on certain design conditions such as orientation, shading and window area.
3- Compare simple payback and cost savings compared to a base case window.



Office/ school

FACADE DESIGN TOOL



Efficient Window Collaborative™

Efficient Windows Collaborative

Selection Process for New Windows

1. Meet the Energy Code and look for the ENERGY STAR

Windows must meet the locally applicable energy code requirements. Windows that are ENERGY STAR qualified typically meet or exceed energy code requirements. A hoMe eMatand loeation deterMine the relative iMortanee of heatino and eoolino energy use, the applicable building energy code requirement:::, and the qualification criteria far ENERGY STAR windows.

ENERGY STAR

2. look for Efficient Properties on the NFRC abel

The Naticonal Fenestration Rating Council (NFRC) label is needed for verification of ener9y code compliance. The NFRC label di plays whole-windDw energy properties and appears on all fenestration productwhich are part of the ENERGY STAR program and provides the only reliable way to determine the window energy propertiesand to compare Dr'oducts.

3. Compare Annual Energy Costs for a Typical House

Use the Window Selection Tool to compare the annual energy performance of different-window tyDj!!> and dtsign conditions for a typical house. Find manufacturer' who offer windows and skylights within the generic results shown. Learn more about manufac:tlrers' spec:ific product options.

WST for New Windows

4. Customize Energy Use for a Specific House

A computer simulation progam, such as RESFEN, lets you compar't window performa nee optionby calculating performance based on utility rates for your climate, house de$ign options, and window design options.

S. Choose a Durable Product

,lake sUN- the design and workmanship of the window results in a durable product for your specific application. Window warranties can be an indicator of the reliability of the window and its manufacturer. Durability may vary with location. Aspects of window durability that deserve attention art, flame and ashes, insulating glass seals, weatherstripping, and local requirements for structural integrity.

6. Ensure Proper Installation

Proper installation is necessary for optimal window performance, to en!>ure an airtight fit and avoid water leakage. Always follow manufacturers installation guidelines and use tIained professionals for window installation.

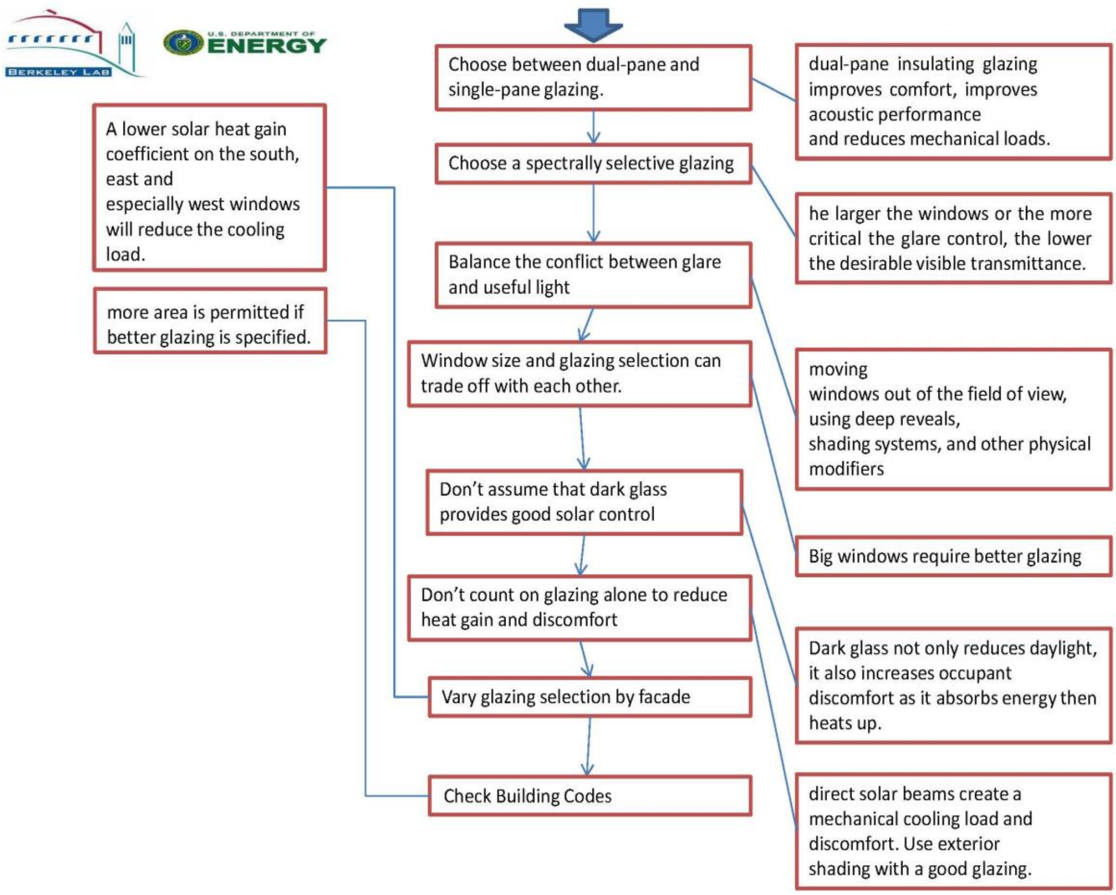
CHECKLIST

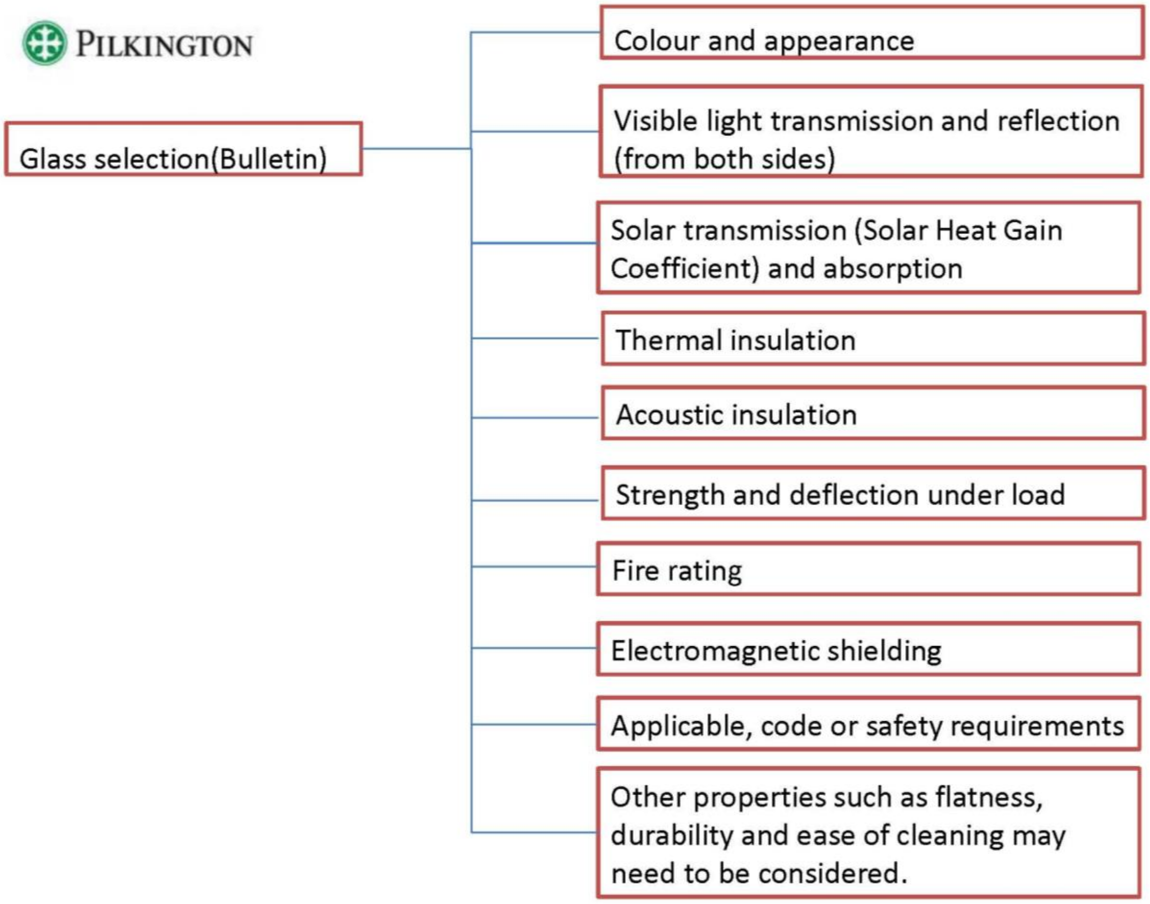
1. Review your fenestration decisions to date, as these will guide the glazing selection.
2. Use the effective aperture target as discussed to determine the range of desirable visible transmittances, based on your window-to-wall ratio.
3. Decide between insulating glazing options (or in some circumstances, single glazing). Mechanical engineer's calculations, comfort concerns, and construction budget data will help in this decision.
4. Identify to what extent colour, reflectance, UV transmittance, and sound will influence glazing selection.
5. Determine, via mechanical engineer or building code requirements, the desirable range of values for U-Value and solar heat gain coefficient. If the building has good exterior shading, glazing solar control becomes less critical.
6. Review product literature and select candidate glazing systems that meet the above criteria.
7. Evaluate glare potential, ideally with a physical model, and take preventive measures if necessary.
8. Contact manufacturer for assistance and pricing.

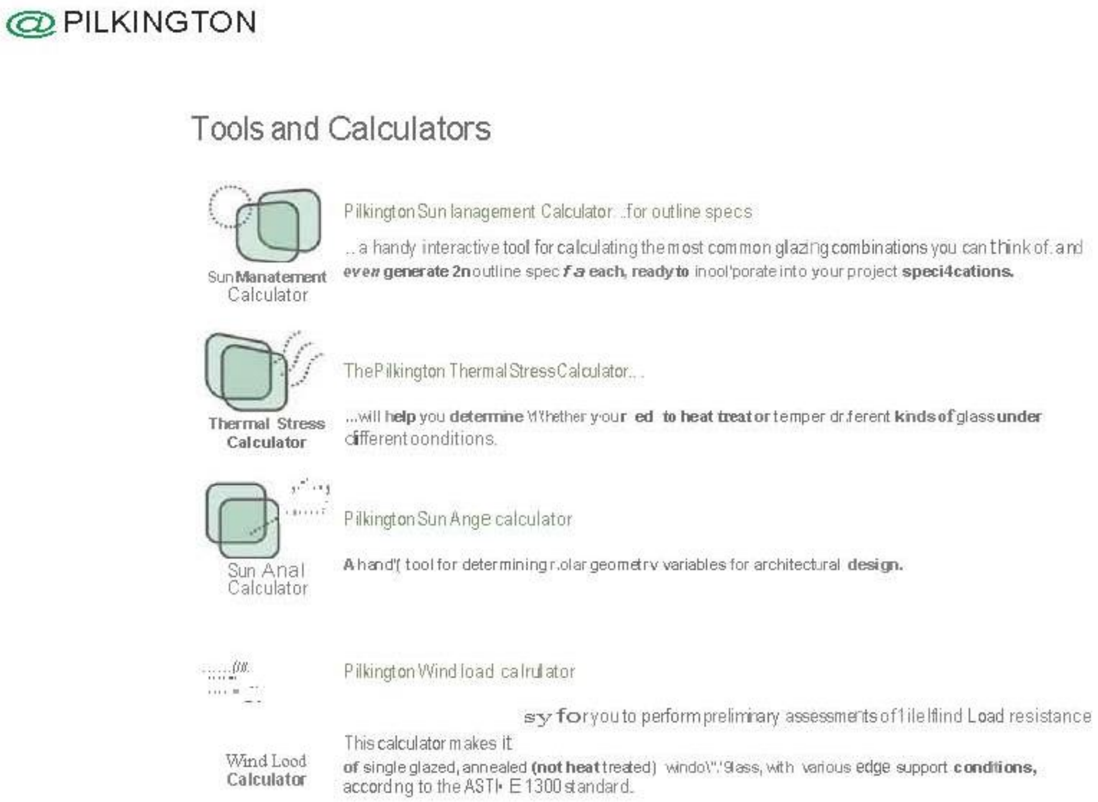
WinDat

Calculated properties

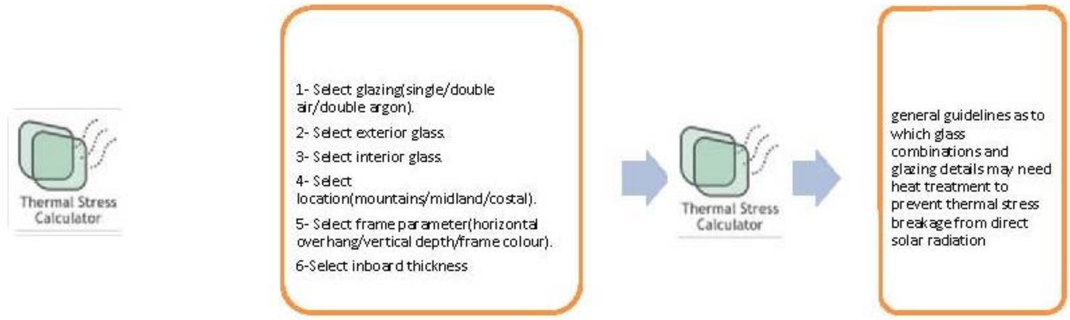
The main properties of windows system that are calculated in WIS are:
1-Geometric factors (Projected Frame Area, Visible Area Transparent System & Frame Perimeter Length)
2-U-value
3-g-value
4-solar direct transmittance, light transmittance and UV transmittance
5-Ray-tracing calculations are possible for blinds (such as Venetian blinds and louvers). Included 4 different types of scattering layers: Slatted type blinds (venetian and louvers), Pleated blinds, Roller blinds and screens.
6-Generic diffusing devices (such as diffusing panes and other scattering devices not belonging to one of the other categories




PILKINGTON
Glass selection(Bulletin)
Colour and appearance
Visible light transmission and reflection (from both sides)
Solar transmission (Solar Heat Gain Coefficient) and absorption
Thermal insulation
Acoustic insulation
Strength and deflection under load
Fire rating
Electromagnetic shielding
Applicable, code or safety requirements
Other properties such as flatness, durability and ease of cleaning may need to be considered.


PILKINGTON
Tools and Calculators
Sun Management Calculator
Pilkington Sun Management Calculator ...for outline specs
...a handy interactive tool for calculating the most common glazing combinations you can think of, and even generate an outline spec for each, ready to incorporate into your project specifications.
Thermal Stress Calculator
The Pilkington Thermal Stress Calculator...
...will help you determine whether your need to heat treat or temper different kinds of glass under different conditions.
Sun Angle Calculator
Pilkington Sun Angle calculator
A handy tool for determining solar geometry variables for architectural design.
Wind Load Calculator
Pilkington Wind load calculator
This calculator makes it easy for you to perform preliminary assessments of the Wind Load resistance of single glazed, annealed (not heat treated) window glass, with various edge support conditions, according to the ASTM E 1300 standard.

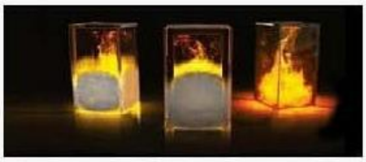
PILKINGTON



PILKINGTON

online specification tools

Pilkington Spectrum
A Windows-based glass performance model for the theoretical construction of Insulating Glass Units



Pilkington Specifire Online
Offering an easier way to select the correct Pilkington fire-resistant glass for your application.

Colour Swatch Performance Data
Interactive buildings to help you choose from our wide range of different glass colours.

Pilkington Sound Simulator
Our simulator aims to demonstrate the benefit of Pilkington **Optiphon**™ noise insulation product.

Pilkington Spectrum provides the following information:
-Light and solar properties (transmittance, reflectance, absorptance, g value, etc.) in accordance with EN 410
-Centre pane U-value in accordance with EN 673 (with an option to display the U-value to two decimal places)
-Sound insulation values in accordance with EN ISO 140-3 or generally accepted values from EN 12758
Ultra violet (UV) transmittance and colour rendering index (Ra) in accordance with EN 410
-Other properties (e.g. pendulum body impact resistance, fire resistance, resistance to manual attack, etc.),

SAINT-GOBAIN GLASS

Calumen

CALUMEN is a calculation tool enabling you to produce performance reports for numerous combinations of Saint-Gobain Glass products in single, double or triple glazing.

Download your free of charge copy here

Calumen II

Available on the App Store | GET IT ON Google play

Glass Compass - Window energy saving calculator for your home

Available from iTunes and the Play Store

SAINT-GOBAIN

GLASS Pro

Free

Description

GlassPro is an interactive software which simulates a realistic image synthesis of different glazing products on facades of buildings. GlassPro enables the user to visualize the rendering of a glazing product under a variety of lighting condition (overcast or sunny) and several interior design settings (with or without white/gray blinds).

Saint-Gobain Web Site · GlassPro Europe Support · ...More

What's New in Version 1.4.4

Bug fixing

- New images and product descriptions

Appendix 4: Review of methodologies and approaches to glazing selection

Study strategy/method of research previously undertaken by researchers was either by using simulation tools (Aboulnaga, 2006; Al-Tamimi and Qahtan, 2016; Liao and Xu, 2015), developing mathematical models (Chow et al., 2010; Ismail et al., 2009), or through experiments (Liu, 2012; Quyen et al., 2015; Thanachareonkit et al., 2005). Monitoring a real building is also considered as a method (Sun et al., 2014).

The variations in these methods were mostly depending on the goal of the research or even the nature of the research. When assessing glazing against standards or codes, simulation tools are more likely to be the option and when researchers are to investigate the effects of a specific component on the energy consumption of a building, they tend to keep other parameters fixed and just focus on the relationship between the variable and its target. In that case, any method will suffice; however, for interactions of various climates, and for whole buildings with patterns of use of inhabitants, simulation would also be the best scenario (Namini et al., 2014).

When considering simulation as a method in research, it is important to choose the right tool that matches the purpose of the study. There is a wide range of these tools which have widely been used. Some are location-specific and can exclusively be used in certain locations and climates with specific national building codes, regulations and legislations, such as HiPerWin, that is designed based on Turkish building codes (Çetiner et al., 2012; Tavil et al., 2006) and for Japan, the WUFI simulation tool is designed for the Japanese climate and building construction types (Ihara et al., 2015). In European climates such as Sweden, Finland and Switzerland, IDA ICE 3.0 was the tool used that is specifically designed for these regions (Poirazis et al., 2008). This tool clearly would not be the best choice in the case of buildings in hot, arid climates.

The building type was the core of some tools that have been particularly designed for a certain type of building, such as COMFEN that is for commercial buildings and RESFEN for residential buildings. These two tools are supported by leading institutions in the glazing industry, such as the National Renewable Energy Laboratory (NREL) and the Lawrence Berkley National Laboratory (LBNL); however, they use prototype models that have characteristics representing 80,000 buildings in the USA. These tools are reliable but exclusive to USA buildings and have been used widely within the States (Carmody and Haglund, 2012; Lee et al., 2013; Papaefthimiou et al., 2009).

The Façade Design Tool is another, alternative option but is also exclusive to American buildings in the United States (EWC, 2012). This tool allows the designer to choose from a limited number of window design options and will not allow changes in design parameters, locations or climate. In other words, it is fixed and limited. Some of the tools can provide a wider range of inputs but are still limited to 40 buildings only types (40 model) such as Ener-win (Stegou-Sagia et al., 2007).

When different and varied climate conditions, prototypes and materials are to be investigated using simulation tools, a more flexible tool in terms of these variables is needed.

To summarise, the above mentioned tools are not appropriate for other climates because their weather/climate parameters are fixed and cannot be adjusted for different climates. In other words some parameters of these tools are closed to the user and the user has no control over them.

Packages of detailed energy modelling are available for general use such as: EnergyPlus (Assem and Al-Mumin, 2010; Bojić and Yik, 2007; Huang et al., 2014; Liao and Xu, 2015; Ochoa et al., 2012; Warwick et al., 2014), TRNSYS (Bahaj et al., 2008; Singh and Garg, 2009, 2011), IES (Aboulnaga, 2006; Al-Tamimi and Qahtan, 2016; Tibi and Mokhtar, 2014), DesignBuilder (Fasi and Budaiwi, 2015; Macka and Yasar, 2011, Yaşar and Kalfa, 2012), DOE/DOE-2 (Farrar-Nagy et al., 2000b; Ihm et al., 2012) and ESP-r (Machniewics and Heim, 2013; Yun et al., 2007). It is also worth mentioning that some of the tools could be specific for lighting quality and control purposes, such as Radiance (Capeluto and Ochoa, 2006). These tools are based on a dynamic simulation building energy modelling approach (DSM).

Simplified tools are provided by companies or manufacturers that are concerned with, and exclusively related to their products. Those tools help in selecting appropriate glazing by calculating the results based on annual heating and cooling loads. Although those tools have been certified, however, they are not intended to replace whole-building performance simulation tools but rather facilitating early decision-making processes in the schematic design and development processes.

Those tools have been reviewed and assessed in this research and a summary of the review of these tools is presented in Appendix 3 with details about how they work, what purpose they are supposed to serve and to what extent can they be used for are also presented.

Methodologies and approaches

Several methodologies in the form of tools (Carmody, 2004), checklists (O'Connor et al., 2013), procedures (BSI, 2005), or rating schemes (NFRC, 2015), digests that identify performance requirements (BRE, 1992) and lists of specifications (CWCT, 2000), are designed to facilitate this task or to help designers and specifiers make an informed decision about the choice of glazing. On the other hand, some companies or manufacturers have also provided methodologies in the form of tools, checklists or procedures. Although they have rigorous tests and are certified, their work is exclusive to their own products and there are different weights between academic contributions, legislations, organisations or institutes, e.g. BSI[29], BRE[30], NFRC[31] or NREL. For further reading about these tools, please refer to Appendix 3.

Decision-making process for window design and selection

The methodology suggested by NREL and provided by Carmody (2004) is one of the most used tools in the USA. This methodology starts after having both climate and building type known, then going to smaller levels of orientation, daylighting control, window area, shading, then window types. This methodology has been used as the main framework for a number of selector tools in the United States: COMFEN, RESFEN, EWC Window Selection Tool and FAÇADE DESIGN TOOL. These tools are useful and can give both an estimation of annual energy use of typical buildings and a ranking of several glazing and window types. However, these tools are limited to the specific types of buildings and within the US states, as the prototypes used in those tools are designed based on a survey of 40,000

[29] The British Standards Institution BSI.

[30] Building Research Establishment BRE.

[31] The National Fenestration Rating Council NFRC

US buildings to represent them. On the other hand those tools are based on a methodology that is limited to a number of WWR possibilities and do not allow adjusting these WWRs, in another words, those tools do not apply to highly- or fully-glazed buildings for instance. Another important element that would make a huge difference in performance is the type of SD which, in this methodology and all related tools, is limited to overhang typology of SD only and only allow for limited modifications of SD.

Other parameters in this tool cannot be adjusted. In addition, numerical calculations of these tools are limited to an office cell that is supposed to represent an office room with a fixed pattern of use, number of occupants and equipment. In addition, climate is fixed to the local climatic and weather conditions of the different states. The results or the output of this tool are limited to annual energy cost and annual energy use. *Figure 0.1* shows this methodology.

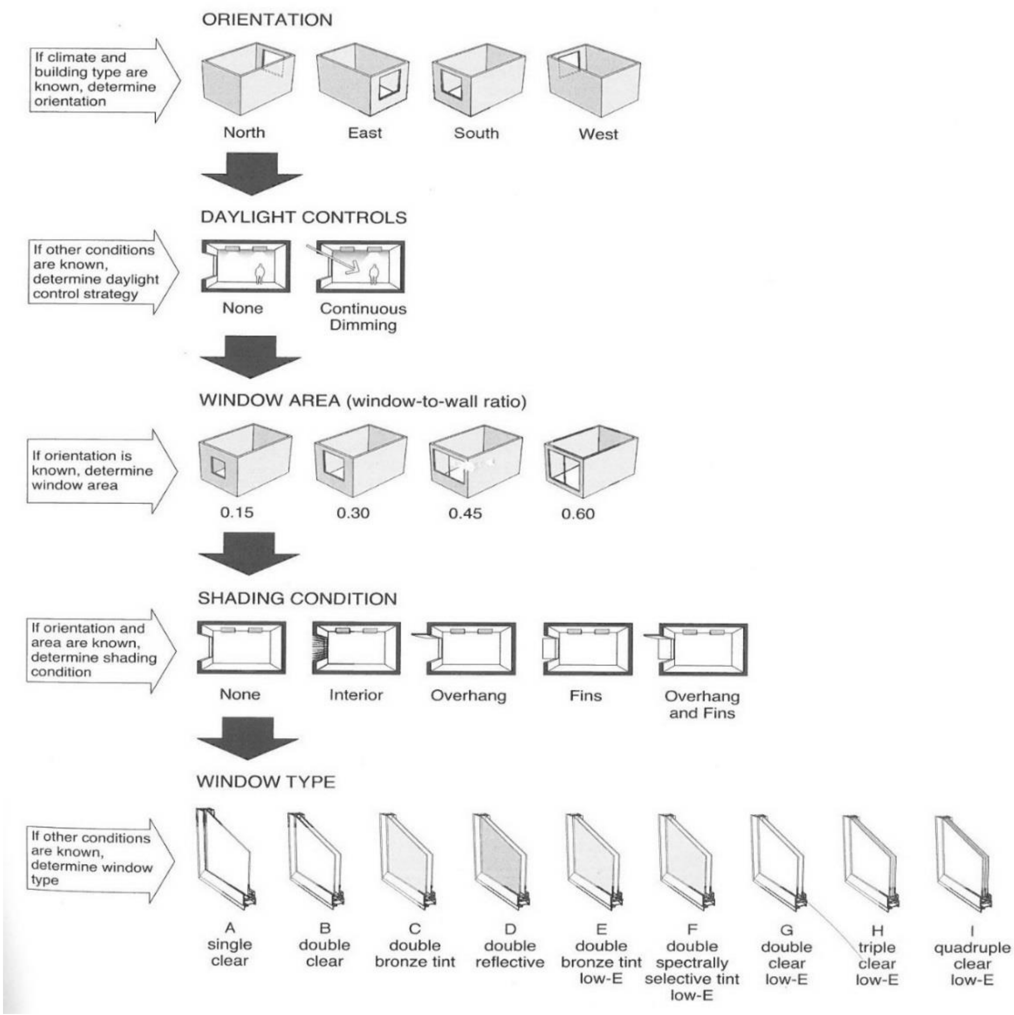


Figure 0.1 Decision-making process for window design and selection (Carmody, 2004)

BRE digest

BRE (1992) published a digest of performance aspects that need to be considered in choosing glazing. These aspects are: window size, window configuration, weather tightness, operation, strength, security, endurance, thermal insulation and condensation, sound insulation, duration and quality assurance. These requirements are summarised in a usable way in *Figure 0.2*.

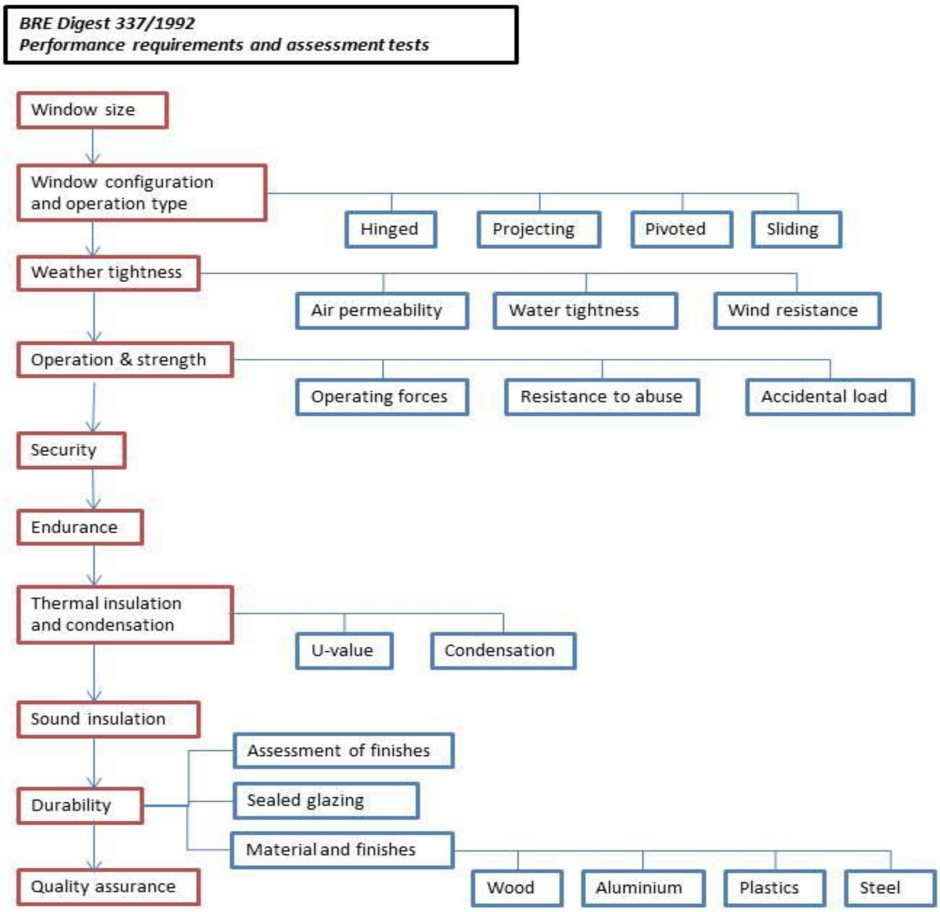


Figure 0.2 BRE Digest-performance requirements

Although this digest lists important performance aspects, it is, however, general and provides advice rather than details of how, for instance, different types would perform in relation to weather parameters, such as solar radiation or temperature, and lighting, or how and to what extent different types can affect energy usage in relation to glazing.

BSI general selection methodology

BSI (2005) presented a general methodology that incorporates these aspects to meet design and performance requirements, such as higher thermal insulation, amended acoustic performance, etc. for glass in order to provide information and recommendations about glazing with respect to its effects on the energy, light and sound in buildings. Figure 30 shows the steps of this methodology.

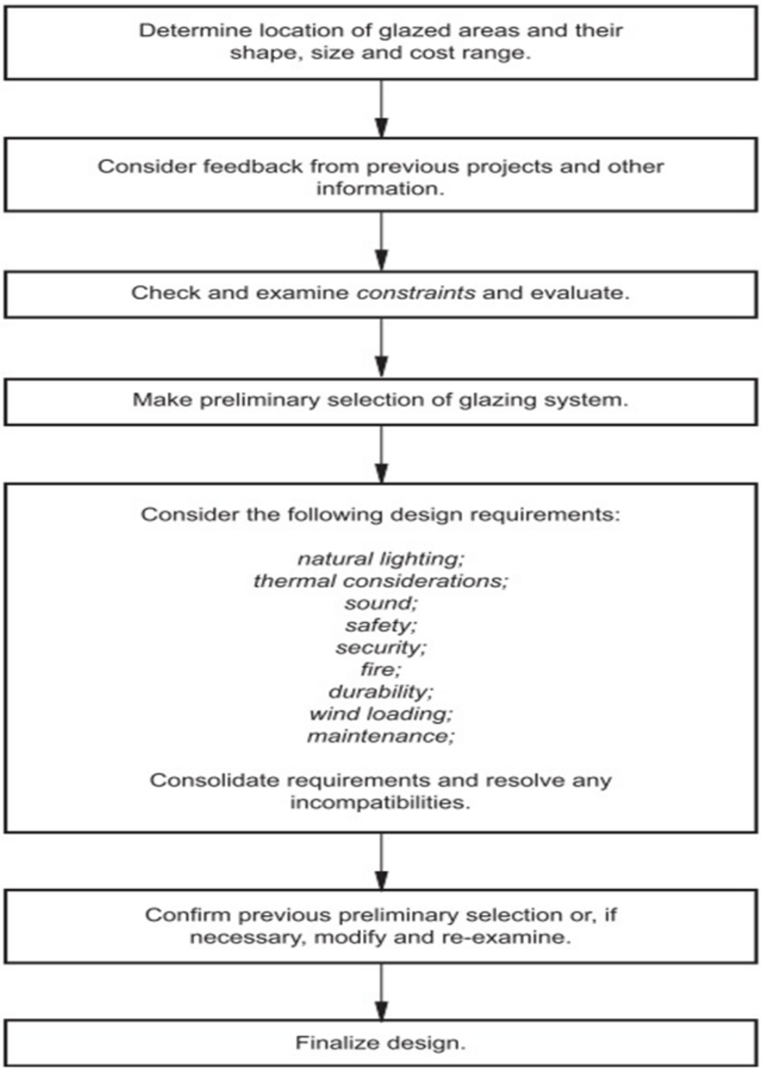


Figure 0.3 BSI methodology diagram (BSI, 2005)

BSI methodology works as follows:

- Within the cost range, location of glazed area, shape, and size are determined.
- Consideration of feedbacks from similar or identical previous projects is recommended.

- Constraints, such as design requirements, legislative requirements and effect on cost, should be considered.
- A preliminary decision can be made following the above to shortlist the glazing options to come up with what is called here the initial or preliminary selection.
- More detailed design requirements are to be considered next then an approval or disapproval of the preliminary decision can be made at this point in order to finalise the design.

The above mentioned points should be decided by the designer.

BSI methodology is designed for UK climate conditions so in the case of using it for different climates, more details about the influence of climatic parameters need to be incorporated. When considering different building types, such as office or residential buildings, specific design parameters (i.e. pattern of use or building construction type or façade construction) need to be clearly highlighted and incorporated too. In the case of highly- or fully-glazed façades, these façades can outperform normal walls with a 20% window area if appropriate glazing is selected (Aboulnaga, 2006; Bojić and Yik, 2007; Bouden, 2007).

The BSI methodology neglected another important aspect; aesthetic considerations (such as the view) and any specific client requirements, such as security and maintenance considerations, which should be considered.

The results of this review on methodologies of glazing selection, amendments and improvements to existing methodologies and legislations are given. The best model, based on the BSI model, is a model that can be improved and enhanced as shown in Figure 0.4. In addition, the final decision should be made based on detailed energy/lighting simulation.

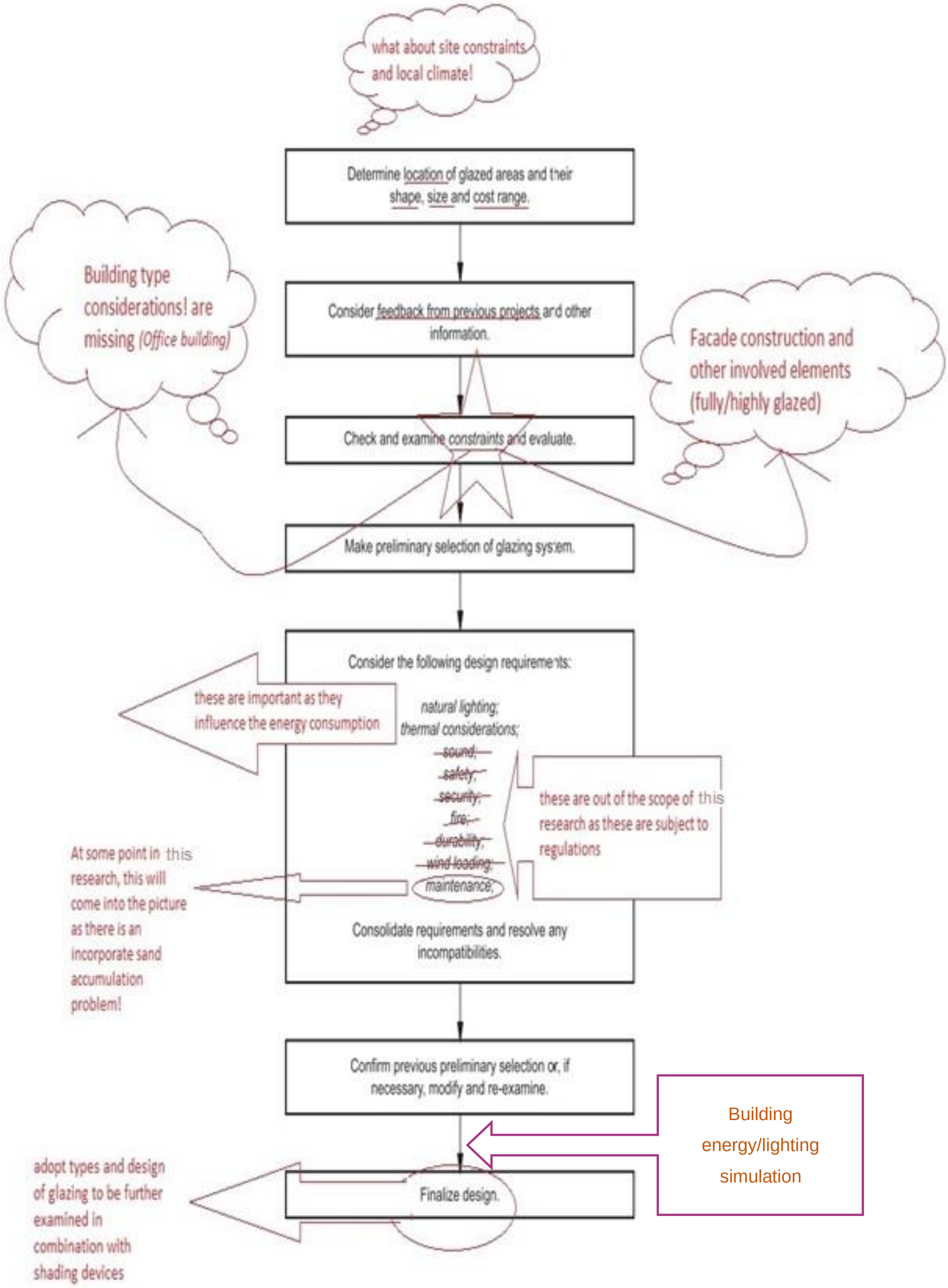


Figure 0.4 proposed amendments that needed to be done to improve BSI methodology

CWCT[32] checklist

The Centre for Window and Cladding Technology, in Bath/UK, (CWCT, 2000) provide a checklist in the form of a technical note. This note simply lists the items that a specifier might need to consider, possible alternatives and the role of relevant British Standards. Window specification may be divided into six key areas:

- Aesthetic needs
- Performance requirements
- Environmental concerns
- Health and safety issues
- Installation requirements
- Maintenance requirements

Each of these may be further sub-divided into several areas, sometimes depending upon the frame material. However, the note does not indicate any form of output. Much of this technical note is concerned with the specification of framing systems and materials used for windows, and of different glazing infill panels. It also deals with all aspects of window selection and covers each different framing material with reference to relevant British Standards.

Rating schemes

To simplify the specifications of building materials and components, standardised methods and methodologies have been applied by different national standard organisations, such as rating schemes.

These can be utilised to help when making a choice by evaluating window performance based on window properties (U-value, SHGC, etc.). The National Fenestration Rating Council (NFRC) in the USA, rates the properties of windows according to thermal transmittance (U-value), SHGC and air infiltration (NFRC, 2015). A sample of this rating scheme is shown in *Figure 0.5*.

[32] Centre for Window and Cladding Technology (CWCT)

Figure 0.5 A sample of rating scheme (NFRC, 2015)

Other similar rating schemes are used in different countries such as Canada’s Energy Rating (ER) Program by National Resources Canada, Window Energy Rating Scheme (WERS, 2010) by Australian Window Council (AWC) and the European Window Energy Rating Systems (EWERS) by British Fenestration Rating Council (BFRC). All these systems rate residential windows for energy performance in the same way as NFRC (Çetiner et al., 2012). All of them can be used as indicators of performance. However, these indicators have been achieved in controlled experiments under fixed or controlled conditions and can only be used as inputs in tests. Actual performance may vary.

Other criteria

Other performance aspects such as structural, acoustics, fire resistance, security etc., are not addressed here, although in any building, they may be critically important performance factors.

Appendix 5: Remote questionnaire survey form

Dear Participant,

Thank you for agreeing to take part in this important survey as a part of a PhD research entitled '*Integrated façade systems for highly-glazed office buildings in hot and arid climates with special reference to Iraq*'. This research will be seeking your thoughts and opinions in order to enhance the validity and reliability of its findings. This survey should not take more than 5 minutes. Please answer the questions to the best of your knowledge and professional experience. Needless to say that there are no right or wrong answers. The survey is not intended to gauge your level of knowledge of planning or building regulations but rather trying to use your professional view for this research. There are two versions of this survey; English and Arabic. Please feel free to respond using any of them.

In this research, there are three main stages that are not parallel but rather serial. This survey represents the first stage that helps build up some knowledge-base using professional survey of office building types through consultation with architectural professionals in Iraq to find out about the most prevailing types of office buildings. This survey, therefore, targets professionals and practitioners who have been designing office buildings in Iraq during the last two decades. It is worthwhile noting that the survey aims to capture data about mainstream office and although iconic office buildings (such as ministry of Higher education) are exemplar models of such buildings, they are NOT in the target sample of this study. The questions are grouped in three main categories: building form, building footprint & layout, building access & services and building structure & materials.

The outcome of the survey will be used to inform the development of the representative building model which will then be used for data generation through building modelling and simulation.

Suffice to say that your responses will be anonymised and treated in full confidentiality. No data, names or contacts will be shared with or revealed to anyone without your consent. If you have any questions or concerns regarding this research, please do NOT hesitate to contact me on Y.Ibraheem@brighton.ac.uk or yahyaalzuhairy@yahoo.com .

Thanks again,

Yahya Ibraheem

PhD student

School of Environment & Technology

Office building prototype survey

BUILDING FORM

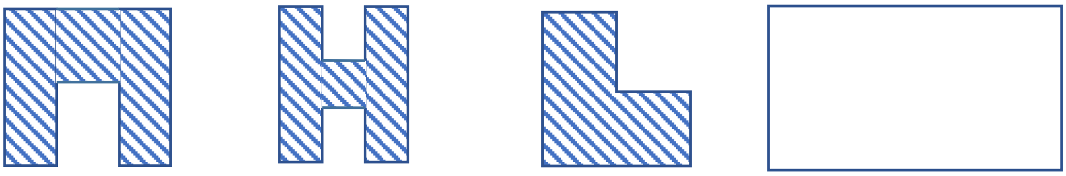
Q1: Overall **Building Form** (choose ONLY one of the following two options):
☐ Rectangular. If yes, please go to Q1.1
☐ Non-Rectangular. If yes, please go to Q1.2

Q1.1. If the building form is rectangular which form represents the building more closely: (then proceed to Q2)

Additional comments (if applicable)

☐ Square ☐ Near-Square Rectangle ☐ Rectangle

Q1.2. If the building form is non-rectangular which form represents the building more closely: (then proceed to Q3)



Additional comments (if applicable)

☐ C-shaped ☐ H-shaped ☐ L-shaped ☐ Other (please draw)

Q2: Does the building have any significant internal layout feature?

☐ Yes.

☐ No.

If yes, please indicate the feature:

☐ Central Courtyard (open).

☐ Central Atrium (covered).

☐ Other (please specify).

Additional comments (if applicable)

Q3: N**<u>umber of floors</u>**:

Additional comments (if applicable)

☐ 3-6 floors (low-rise). ☐ 7-14 floors (mid-rise). ☐ 15+ (high-rise).

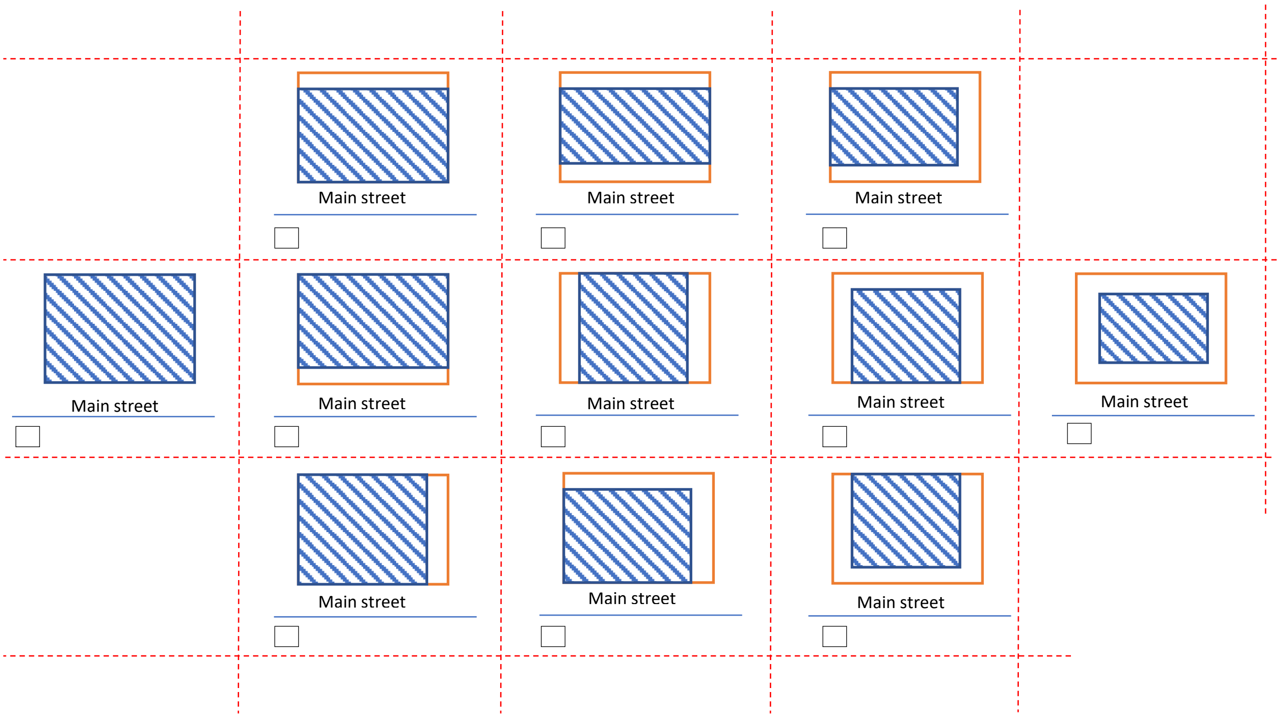
Q4: Is building **<u>footprint-to-land plot ratio</u>**:

☐ Up to 40%. ☐ 40%-60%. ☐ 60%-80%.

☐ 80%+. ☐ N/A (size of building footprint is independent of the land plot [i.e. building in a park]).

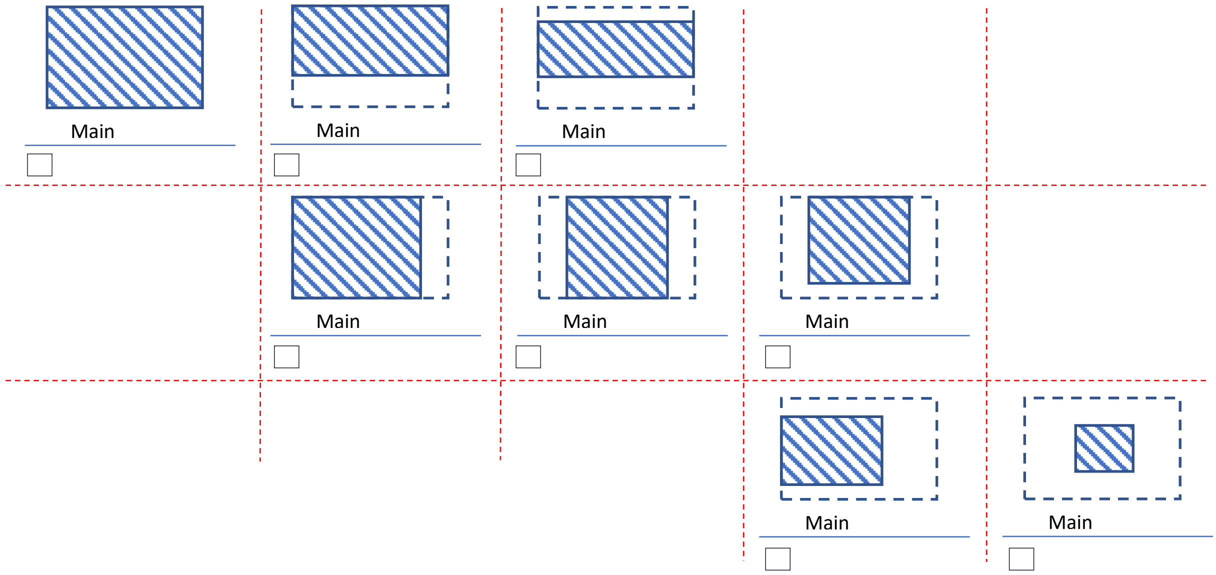
BUILDING FOOTPRINT & LAYOUT

Q5: What is the most typical representative for the **<u>Site plan</u>** of the building you have designed? (Please tick only one)



Additional comments (if applicable)

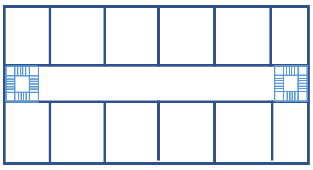
Q6: Which one of the following schematics resembles the **layout of the ground floor** most closely? (Please tick only one):



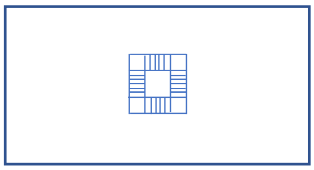
Additional comments (if applicable)

Q7: **Internal layout**:

☐ Cellular



☐ Open plan



Additional comments (if applicable)

Q8: If you have designed cellular office buildings, what has been the typical **dimensions of each office** (WxD)

where ? (Please tick only one):

Additional comments (if applicable)

☐ 3.5X5m. ☐ 4X6m. ☐ 4X8m. ☐ 5X8m. ☐ Other (please specify).

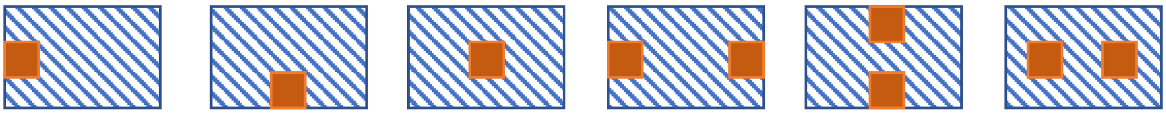
Q9: What has been the average typical **floor-to-floor height** of the buildings you have designed? (Please tick only one):

Additional comments (if applicable)

☐ 3m. ☐ 3.5m. ☐ 4m. ☐ 4.5m. ☐ Other (please specify).

BUILDING ACCESS & SERVICES

Q10: Which schematic represents the location of building's **wet zones** (kitchen, toilets, etc.) most closely (please tick only one)?



☐ ☐ ☐ ☐ ☐ ☐

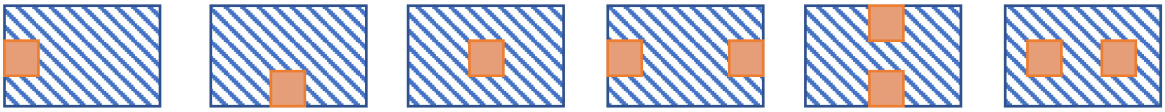
If not rectangular please sketch here:

Q11: Which schematic represents the location of building's **main entrance** most closely (please tick only one)?

☐ ☐ ☐ ☐

If not rectangular please sketch here:

Q12: Which schematic most closely represents the location of building's **vertical access** (staircase and lifts) (please tick only one)?



☐ ☐ ☐ ☐ ☐ ☐

If not rectangular please sketch here:

BUILDING STRUCTURE & MATERIALS

Q13: What is the main **structural system** of the building?

☐ Masonry (load bearing). ☐ Steel frame. ☐ Concrete frame. ☐ Other (please specify).

Additional comments (if applicable)

Q14: The prevailing material of the **opaque part of the façade** is:

☐ Concrete blocks. ☐ Thermo-stone. ☐ Brick. ☐ Other (please specify).

Additional comments (if applicable)

Q15: The prevailing material of the **finishing of external surface** of non-glazed part of the façade is:

☐ Alucobond. ☐ Cement render. ☐ Terraco render. ☐ Other (please specify).

Additional comments (if applicable)

Q16: The prevailing material of the **finishing of internal surface** of non-glazed part of the façade is:

☐ Gypsum & clay mix + plaster board ☐ Gypsum & clay mix + plaster. ☐ Terraco render. ☐ Other (please specify).

Additional comments (if applicable)

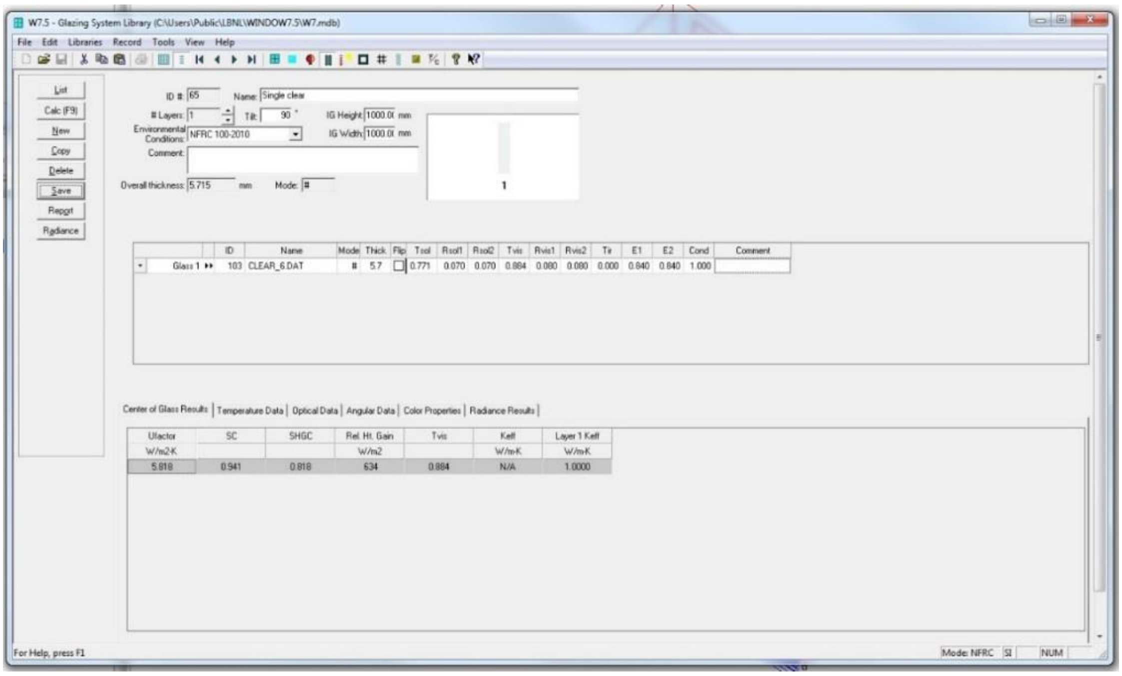
Q17: Can you please provide a rough sketch of the external (non-glazed) wall section of the building with all constituent layers of materials and their corresponding thicknesses: (optional)

Please draw here:

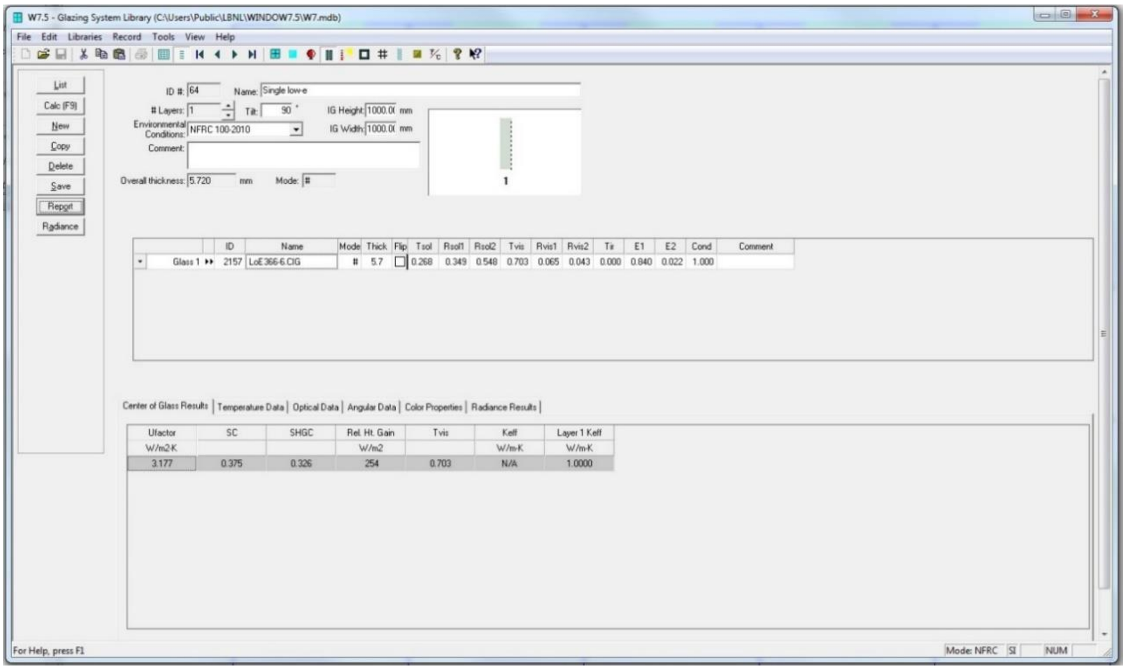
Appendix 6: Glazing systems generated in LBNL Windows 7.5

LBNL Windows 7.5 was used to generate the glazing systems to be used in the simulation tool. For a user-defined fenestration system and user-defined environmental conditions, WINDOW 7.5 calculates the U-value, solar heat gain coefficient, shading coefficient, and visible transmittance for the complete window system. The specific glazing systems were first created then the calculations were run. These glazing systems are:

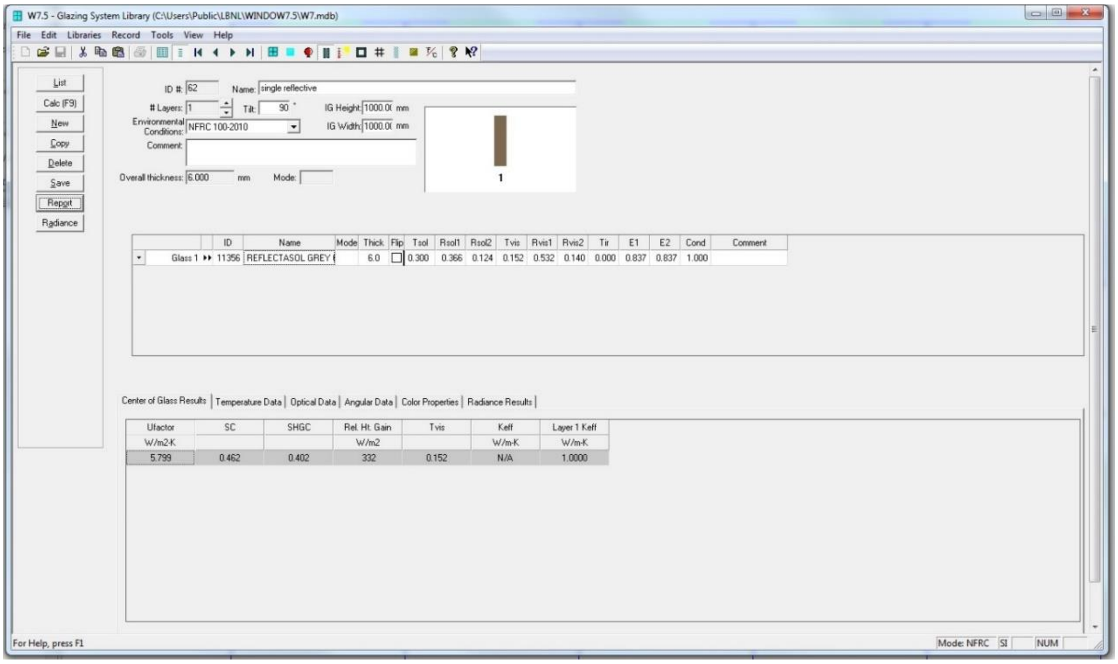
Single-clear:



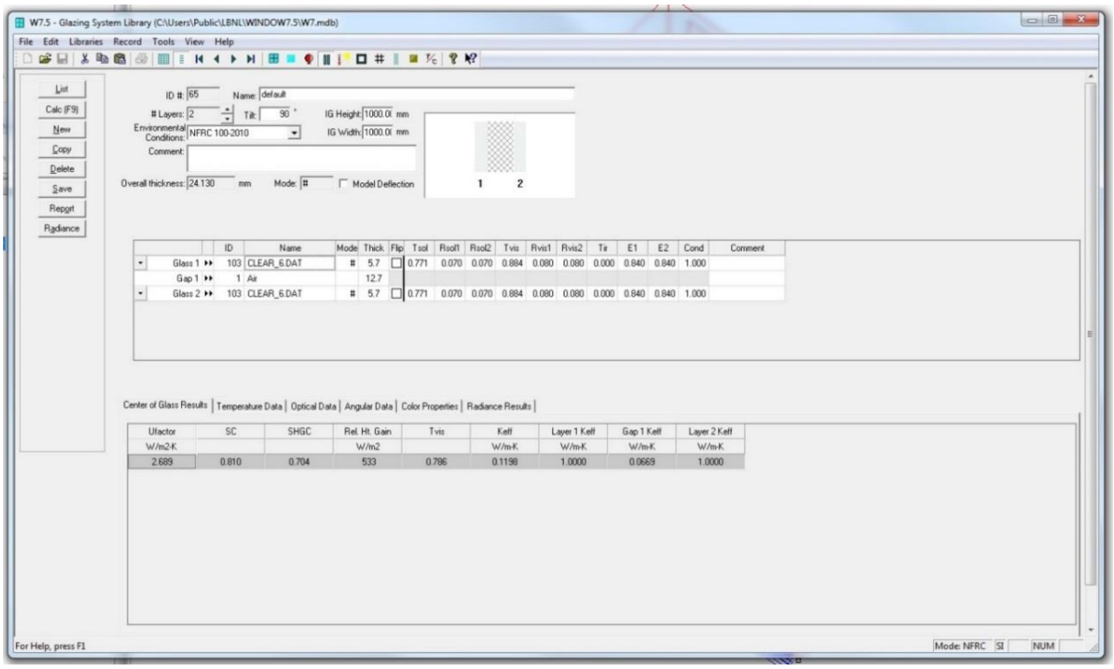
Single-low-e:



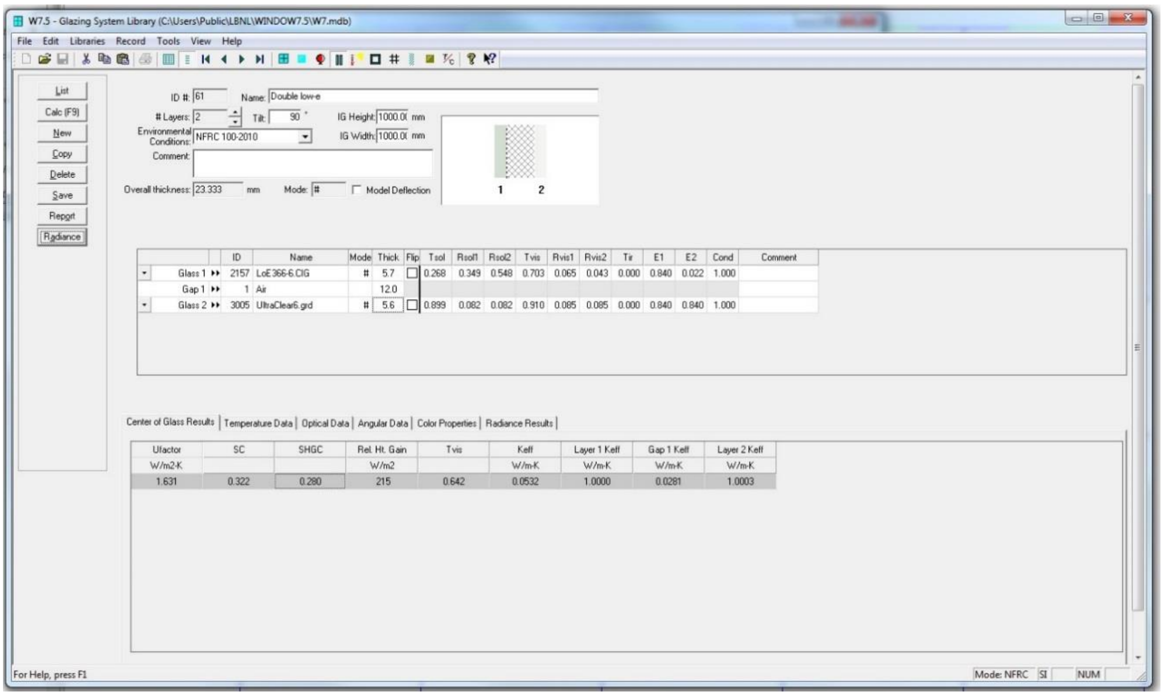
Single-reflective:



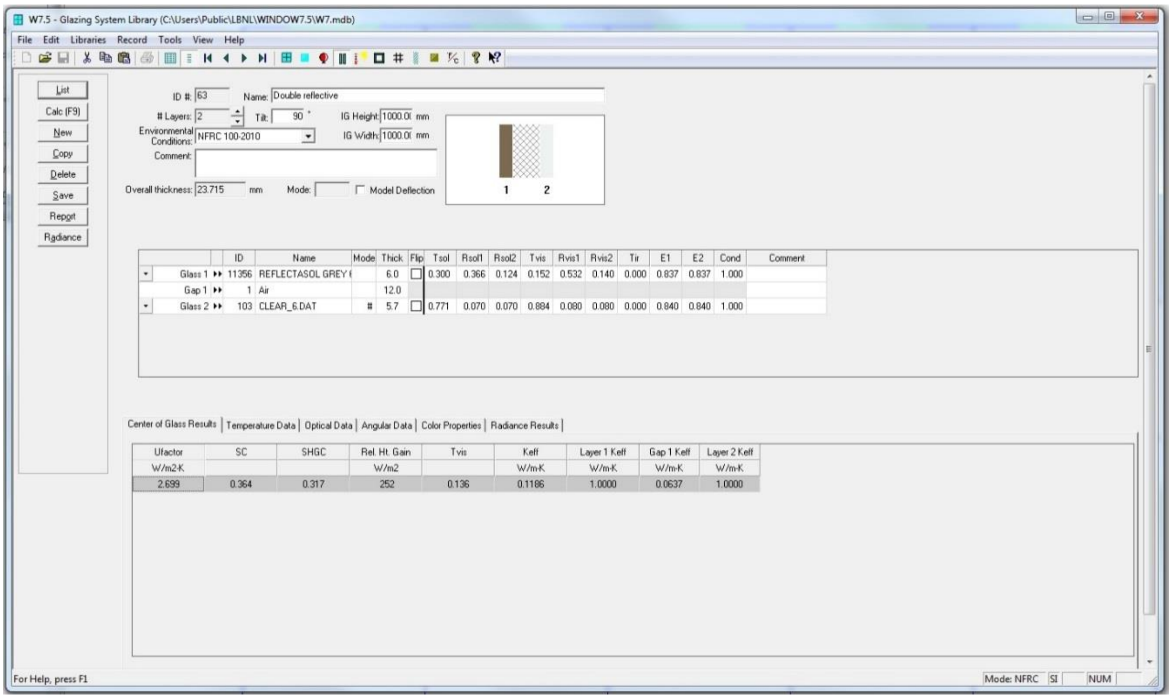
Double-clear:



Double-low-e:



Double-reflective:



Appendix 7: Dynamic simulation results

Energy assessment indicators

Combinations of south-facing façade

Simulated scenarios							Solar gain (MWh)	Lighting gain (MWh)	Cooling plant sensible load (MWh)	PV-generated electricity	Net Energy	Enrgy saving
No.	WWR	Depth	d/l	Angle	Glazing	Glass	South	South	South	South	South	South
1	100-	40-	1-	20-	S-	C	148.396	27.5277	151.5669	29.6754	160.9557	15.56692
2	100-	40-	1-	30-	S-	C	144.973	29.2883	152.0223	29.8378	164.2883	15.37032
3	100-	40-	1-	40-	S-	C	143.9802	32.5177	153.6775	29.756	168.47	15.01115
4	100-	40-	1-	50-	S-	C	143.6549	33.1629	149.508	29.5787	169.5259	14.85586
5	100-	40-	1-	60-	S-	C	143.5728	33.3123	154.0223	29.2983	170.04	14.69778
6	100-	40-	15-	20-	S-	C	171.1995	26.7154	153.5583	25.245	155.1861	13.99149
7	100-	40-	15-	30-	S-	C	164.16	26.9055	152.3197	26.1415	156.2693	14.33111
8	100-	40-	15-	40-	S-	C	159.9343	27.2912	151.9379	26.6432	157.6906	14.45378
9	100-	40-	15-	50-	S-	C	158.0773	27.858	152.2074	26.7667	159.262	14.38848
10	100-	40-	15-	60-	S-	C	158.3525	28.3809	152.8493	26.502	160.5659	14.16705
11	100-	40-	2-	20-	S-	C	191.4266	26.6197	159.2148	21.0627	157.8193	11.77463
12	100-	40-	2-	30-	S-	C	185.3113	26.6512	157.5652	21.8351	157.5683	12.17095
13	100-	40-	2-	40-	S-	C	182.1584	26.7065	156.9217	22.1859	157.8247	12.32477
14	100-	40-	2-	50-	S-	C	181.4116	26.7793	157.0393	22.1394	158.4567	12.25907
15	100-	40-	2-	60-	S-	C	183.0465	26.8482	157.9206	21.6664	159.4705	11.96134
16	100-	60-	1-	20-	S-	C	147.0577	27.4914	151.0553	30.9116	159.6551	16.22088
17	100-	60-	1-	30-	S-	C	143.9917	29.2707	151.572	31.2541	162.6948	16.11461
18	100-	60-	1-	40-	S-	C	143.0896	30.9305	152.2994	31.1155	165.0557	15.8614
19	100-	60-	1-	50-	S-	C	142.8118	32.2561	153.0282	30.8925	166.9987	15.61085
20	100-	60-	1-	60-	S-	C	142.7927	34.5494	154.4247	30.5749	170.1658	15.23104
21	100-	60-	15-	20-	S-	C	170.9879	26.6998	153.4994	26.0405	154.3971	14.43186
22	100-	60-	15-	30-	S-	C	164.4737	26.8841	152.3336	27.0025	155.219	14.8185
23	100-	60-	15-	40-	S-	C	160.2237	27.2457	151.9301	27.476	156.6378	14.92338
24	100-	60-	15-	50-	S-	C	158.2516	27.7897	152.1315	27.5585	158.2031	14.83541
25	100-	60-	15-	60-	S-	C	158.5767	28.3057	152.7638	27.232	159.531	14.58105
26	100-	60-	2-	20-	S-	C	190.7396	26.6189	158.6446	22.8962	155.6546	12.82335
27	100-	60-	2-	30-	S-	C	185.1391	26.6495	157.1735	23.7199	155.3407	13.24686
28	100-	60-	2-	40-	S-	C	181.7908	26.7067	156.5232	24.0441	155.6967	13.3771
29	100-	60-	2-	50-	S-	C	180.8401	27.8821	157.4077	23.9467	157.9405	13.16569
30	100-	60-	2-	60-	S-	C	182.3918	28.0159	158.3766	23.3882	159.2312	12.80707
31	100-	40-	1-	20-	S-	L	76.5257	29.1391	125.3274	29.6754	144.4417	17.04336
32	100-	40-	1-	30-	S-	L	74.8172	31.4986	126.2264	29.8378	147.6543	16.81078
33	100-	40-	1-	40-	S-	L	74.301	32.8982	126.8667	29.756	149.5004	16.59969
34	100-	40-	1-	50-	S-	L	74.1193	33.6593	127.2797	29.5787	150.6754	16.40945
35	100-	40-	1-	60-	S-	L	74.0753	34.8402	128.0161	29.2983	152.4473	16.1205
36	100-	40-	15-	20-	S-	L	87.938	27.7026	125.7768	25.245	140.9345	15.1914
37	100-	40-	15-	30-	S-	L	84.4042	28.4698	125.5865	26.1415	142.4511	15.50572
38	100-	40-	15-	40-	S-	L	82.2963	29.1618	125.7424	26.6432	143.9056	15.62204
39	100-	40-	15-	50-	S-	L	81.3486	29.8593	126.1667	26.7667	145.3342	15.55291
40	100-	40-	15-	60-	S-	L	81.4826	30.3694	126.7098	26.502	146.5072	15.31826
41	100-	40-	2-	20-	S-	L	98.0697	27.6501	128.8781	21.0627	143.2688	12.8172
42	100-	40-	2-	30-	S-	L	95.0049	27.7831	128.1075	21.8351	143.3111	13.22168

43	100-	40-	2-	40-	S-	L	93.4185	27.9753	127.9116	22.1859	143.752	13.37
44	100-	40-	2-	50-	S-	L	93.0456	28.1754	128.15	22.1394	144.4852	13.28699
45	100-	40-	2-	60-	S-	L	93.8601	28.3226	128.7779	21.6664	145.4536	12.96458
46	100-	60-	1-	20-	S-	L	75.8531	29.5359	125.2645	30.9116	143.6874	17.70434
47	100-	60-	1-	30-	S-	L	74.3158	31.4946	125.9583	31.2541	146.1859	17.6139
48	100-	60-	1-	40-	S-	L	73.8422	32.9044	126.6254	31.1155	148.1162	17.36049
49	100-	60-	1-	50-	S-	L	73.689	33.9756	127.2475	30.8925	149.7202	17.10428
50	100-	60-	1-	60-	S-	L	73.6705	34.8329	127.7772	30.5749	151.123	16.82733
51	100-	60-	15-	20-	S-	L	87.822	27.9411	125.9043	26.0405	140.4692	15.63903
52	100-	60-	15-	30-	S-	L	84.5523	28.4116	125.549	27.0025	141.4015	16.03436
53	100-	60-	15-	40-	S-	L	82.4192	29.0837	125.6822	27.476	142.867	16.12981
54	100-	60-	15-	50-	S-	L	81.4321	29.7712	126.0852	27.5585	144.3313	16.03266
55	100-	60-	15-	60-	S-	L	81.5885	30.2784	126.6188	27.232	145.5391	15.7619
56	100-	60-	2-	20-	S-	L	97.7034	27.6532	128.4702	22.8962	141.1976	13.95312
57	100-	60-	2-	30-	S-	L	94.8996	27.793	127.8084	23.7199	141.1791	14.3845
58	100-	60-	2-	40-	S-	L	93.2195	27.9854	127.6197	24.0441	141.7176	14.50522
59	100-	60-	2-	50-	S-	L	92.7417	28.1914	127.8691	23.9467	142.5903	14.37921
60	100-	60-	2-	60-	S-	L	93.5095	28.335	128.517	23.3882	143.707	13.99693
61	100-	40-	1-	20-	S-	R	82.9494	34.156	132.0588	29.6754	164.1475	15.31057
62	100-	40-	1-	30-	S-	R	81.0651	35.4467	132.4146	29.8378	166.3031	15.21243
63	100-	40-	1-	40-	S-	R	80.5051	36.2444	132.7246	29.756	167.5003	15.08494
64	100-	40-	1-	50-	S-	R	80.3137	36.8194	133.0221	29.5787	168.4498	14.93659
65	100-	40-	1-	60-	S-	R	80.2679	37.2059	133.2472	29.2983	169.2361	14.75729
66	100-	40-	15-	20-	S-	R	95.5271	31.7079	132.1222	25.2419	159.3835	13.67195
67	100-	40-	15-	30-	S-	R	91.6364	32.5319	132.0369	26.1415	161.1875	13.95486
68	100-	40-	15-	40-	S-	R	89.3158	33.262	132.1385	26.6432	162.6539	14.07481
69	100-	40-	15-	50-	S-	R	88.2793	33.8516	132.3923	26.7667	163.8475	14.04234
70	100-	40-	15-	60-	S-	R	88.425	34.2153	132.7565	26.502	164.7257	13.85887
71	100-	40-	2-	20-	S-	R	106.6129	30.7265	134.0127	21.0627	159.2991	11.67803
72	100-	40-	2-	30-	S-	R	103.2507	31.1328	133.5995	21.8351	160.1059	12.0012
73	100-	40-	2-	40-	S-	R	101.5101	31.4796	133.5928	22.1859	160.9664	12.11336
74	100-	40-	2-	50-	S-	R	101.0954	31.7394	133.88	22.1394	161.8419	12.03351
75	100-	40-	2-	60-	S-	R	101.9814	31.8433	134.4284	21.6664	162.6969	11.75201
76	100-	60-	1-	20-	S-	R	82.2192	34.1002	131.7686	30.9116	162.9238	15.94735
77	100-	60-	1-	30-	S-	R	80.5269	35.4093	132.1444	31.2541	164.8021	15.9414
78	100-	60-	1-	40-	S-	R	80.0141	36.221	132.4785	31.1155	166.082	15.77885
79	100-	60-	1-	50-	S-	R	79.853	36.803	132.7852	30.8925	167.0802	15.60442
80	100-	60-	1-	60-	S-	R	79.8372	37.1994	133.0195	30.5749	167.9123	15.40397
81	100-	60-	15-	20-	S-	R	95.3923	31.6074	132.0169	26.0405	158.4666	14.11355
82	100-	60-	15-	30-	S-	R	91.8028	32.423	131.9789	27.0025	160.0772	14.43369
83	100-	60-	15-	40-	S-	R	89.4601	33.146	132.0871	27.476	161.5977	14.5319
84	100-	60-	15-	50-	S-	R	88.3746	33.7397	132.3192	27.5585	162.8338	14.47459
85	100-	60-	15-	60-	S-	R	88.5466	34.0938	132.6835	27.232	163.7562	14.25847
86	100-	60-	2-	20-	S-	R	106.2361	30.7499	133.6483	22.8962	157.2439	12.71022
87	100-	60-	2-	30-	S-	R	103.158	31.1491	133.3195	23.7199	157.9497	13.05661
88	100-	60-	2-	40-	S-	R	101.3118	31.4848	133.314	24.0441	158.908	13.14229
89	100-	60-	2-	50-	S-	R	100.7818	31.711	133.5965	23.9467	159.8902	13.02606
90	100-	60-	2-	60-	S-	R	101.6174	31.7942	134.1613	23.3882	160.8831	12.69226
91	100-	40-	1-	20-	D-	C	104.0281	28.5104	134.7274	29.6754	142.0824	17.27747
92	100-	40-	1-	30-	D-	C	101.6379	30.4141	135.3306	29.8378	145.143	17.05204
93	100-	40-	1-	40-	D-	C	100.9574	31.9522	136.0417	29.756	147.2496	16.81077
94	100-	40-	1-	50-	D-	C	100.7429	33.1623	136.7546	29.5787	149.0254	16.56104

95	100-	40-	1-	60-	D-	C	100.6953	34.1229	137.3668	29.2983	150.5657	16.28914
96	100-	40-	15-	20-	D-	C	120.0899	27.3162	136.5702	25.245	138.8147	15.38769
97	100-	40-	15-	30-	D-	C	115.1534	27.6432	135.5641	26.1415	139.463	15.7855
98	100-	40-	15-	40-	D-	C	112.193	28.2056	135.3631	26.6432	140.6806	15.92314
99	100-	40-	15-	50-	D-	C	110.8996	28.8561	135.6949	26.7667	142.1029	15.85051
100	100-	40-	15-	60-	D-	C	111.1004	29.3971	136.3322	26.502	143.3928	15.59906
101	100-	40-	2-	20-	D-	C	134.2254	27.1325	141.5833	21.0627	142.4825	12.87882
102	100-	40-	2-	30-	D-	C	129.9494	27.2031	140.1084	21.8351	141.9245	13.33363
103	100-	40-	2-	40-	D-	C	127.7426	27.3171	139.5727	22.1859	142.0276	13.5104
104	100-	40-	2-	50-	D-	C	127.2143	27.4495	139.7217	22.1394	142.6181	13.43757
105	100-	40-	2-	60-	D-	C	128.3396	27.5634	140.5262	21.6664	143.6619	13.10508
106	100-	60-	1-	20-	D-	C	103.1077	28.47	134.3012	30.9116	140.7618	18.00605
107	100-	60-	1-	30-	D-	C	100.973	30.408	134.9783	31.2541	143.6041	17.87397
108	100-	60-	1-	40-	D-	C	100.3592	31.9597	135.7438	31.1155	145.8253	17.58526
109	100-	60-	1-	50-	D-	C	100.1806	33.1497	136.4538	30.8925	147.6252	17.30501
110	100-	60-	1-	60-	D-	C	100.1793	34.1104	137.0785	30.5749	149.2069	17.00667
111	100-	60-	15-	20-	D-	C	119.9329	27.2921	136.5137	26.0405	138.0095	15.87351
112	100-	60-	15-	30-	D-	C	115.3695	27.6089	135.5776	27.0025	138.4611	16.3193
113	100-	60-	15-	40-	D-	C	112.3962	28.1442	135.3571	27.476	139.6719	16.43814
114	100-	60-	15-	50-	D-	C	111.0243	28.7794	135.6405	27.5585	141.1082	16.33903
115	100-	60-	15-	60-	D-	C	111.264	29.3034	136.2608	27.232	142.4101	16.05262
116	100-	60-	2-	20-	D-	C	133.8121	27.1312	141.1298	22.8962	140.3966	14.02156
117	100-	60-	2-	30-	D-	C	129.8943	27.2049	139.822	23.7199	139.8103	14.5049
118	100-	60-	2-	40-	D-	C	127.5478	27.3145	139.2761	24.0441	139.9884	14.65813
119	100-	60-	2-	50-	D-	C	126.8738	27.4517	139.4276	23.9467	140.7066	14.54371
120	100-	60-	2-	60-	D-	C	127.9384	27.5716	140.2622	23.3882	141.9081	14.14926
121	100-	40-	1-	20-	D-	L	51.2386	30.3959	113.667	29.6754	135.3316	17.98433
122	100-	40-	1-	30-	D-	L	50.0805	32.2662	114.3475	29.8378	137.6814	17.81157
123	100-	40-	1-	40-	D-	L	49.7477	33.5691	114.988	29.756	139.3668	17.59432
124	100-	40-	1-	50-	D-	L	49.6401	34.5753	115.5897	29.5787	140.8288	17.35763
125	100-	40-	1-	60-	D-	L	49.6183	35.3427	116.094	29.2983	142.1099	17.09271
126	100-	40-	15-	20-	D-	L	59.1152	28.5285	113.6272	25.245	133.0841	15.94464
127	100-	40-	15-	30-	D-	L	56.7045	29.1386	113.5394	26.1415	134.0891	16.31492
128	100-	40-	15-	40-	D-	L	55.2626	29.8976	113.8271	26.6432	135.3617	16.44592
129	100-	40-	15-	50-	D-	L	54.6244	30.587	114.2688	26.7667	136.6141	16.38301
130	100-	40-	15-	60-	D-	L	54.7204	31.0756	114.7626	26.502	137.7135	16.13855
131	100-	40-	2-	20-	D-	L	65.9662	28.0709	115.5109	21.0627	135.1227	13.4857
132	100-	40-	2-	30-	D-	L	63.8884	28.2759	115.0753	21.8351	135.2075	13.90393
133	100-	40-	2-	40-	D-	L	62.8088	28.5231	115.038	22.1859	135.6504	14.05627
134	100-	40-	2-	50-	D-	L	62.5427	28.7554	115.2876	22.1394	136.3515	13.96888
135	100-	40-	2-	60-	D-	L	63.0712	28.9117	115.7809	21.6664	137.2622	13.63279
136	100-	60-	1-	20-	D-	L	50.8049	30.3636	113.4538	30.9116	134.1011	18.73286
137	100-	60-	1-	30-	D-	L	49.7681	32.2691	114.1751	31.2541	136.2571	18.65792
138	100-	60-	1-	40-	D-	L	49.4669	33.5604	114.8294	31.1155	138.0039	18.39854
139	100-	60-	1-	50-	D-	L	49.3792	34.547	115.4304	30.8925	139.495	18.13073
140	100-	60-	1-	60-	D-	L	49.3773	35.3228	115.9346	30.5749	140.8099	17.83991
141	100-	60-	15-	20-	D-	L	59.038	28.4878	113.573	26.0405	132.2492	16.45117
142	100-	60-	15-	30-	D-	L	56.8097	29.0753	113.5034	27.0025	133.0682	16.86911
143	100-	60-	15-	40-	D-	L	55.3573	29.8087	113.777	27.476	134.3562	16.97808
144	100-	60-	15-	50-	D-	L	54.689	30.4879	114.1971	27.5585	135.6395	16.88654
145	100-	60-	15-	60-	D-	L	54.8034	30.9667	114.6806	27.232	136.7724	16.60443

146	100-	60-	2-	20-	D-	L	65.7895	28.077	115.2446	22.8962	133.1299	14.6746
147	100-	60-	2-	30-	D-	L	63.8841	28.2911	114.8855	23.7199	133.1616	15.11963
148	100-	60-	2-	40-	D-	L	62.7359	28.5458	114.8577	24.0441	133.7005	15.24242
149	100-	60-	2-	50-	D-	L	62.3954	28.7737	115.1102	23.9467	134.512	15.11227
150	100-	60-	2-	60-	D-	L	62.8891	28.9235	115.615	23.3882	135.5498	14.7153
151	100-	40-	1-	20-	D-	R	61.2024	35.8732	121.9086	29.6754	148.7664	16.6303
152	100-	40-	1-	30-	D-	R	59.8108	36.8194	122.1792	29.8378	150.4118	16.5536
153	100-	40-	1-	40-	D-	R	59.4058	37.3817	122.4191	29.756	151.3473	16.4304
154	100-	40-	1-	50-	D-	R	59.2722	37.7557	122.6306	29.5787	152.071	16.28337
155	100-	40-	1-	60-	D-	R	59.2439	37.9436	122.7432	29.2983	152.6104	16.10605
156	100-	40-	15-	20-	D-	R	70.618	33.5065	122.1819	25.245	146.0013	14.74192
157	100-	40-	15-	30-	D-	R	67.7315	34.3058	122.0202	26.1415	147.2144	15.07967
158	100-	40-	15-	40-	D-	R	66.0053	35.026	122.0625	26.6432	148.2819	15.2312
159	100-	40-	15-	50-	D-	R	65.2373	35.5649	122.2476	26.7667	149.1855	15.21248
160	100-	40-	15-	60-	D-	R	65.3493	35.8711	122.55	26.502	149.9486	15.0195
161	100-	40-	2-	20-	D-	R	78.822	32.4036	123.943	21.0627	146.9497	12.5364
162	100-	40-	2-	30-	D-	R	76.3323	32.8213	123.5589	21.8351	147.4067	12.90172
163	100-	40-	2-	40-	D-	R	75.0386	33.1565	123.5259	22.1859	148.0094	13.03555
164	100-	40-	2-	50-	D-	R	74.7211	33.3729	123.7436	22.1394	148.6991	12.95926
165	100-	40-	2-	60-	D-	R	75.3568	33.446	124.1994	21.6664	149.4884	12.65895
166	100-	60-	1-	20-	D-	R	60.6822	35.846	121.6775	30.9116	147.5502	17.32113
167	100-	60-	1-	30-	D-	R	59.4347	36.8079	121.9645	31.2541	148.9416	17.34453
168	100-	60-	1-	40-	D-	R	59.0665	37.3772	122.2219	31.1155	149.951	17.18457
169	100-	60-	1-	50-	D-	R	58.9569	37.7502	122.4431	30.8925	150.7248	17.00967
170	100-	60-	1-	60-	D-	R	58.9515	37.9337	122.5541	30.5749	151.2927	16.81163
171	100-	60-	15-	20-	D-	R	70.5265	33.4202	122.1073	26.0405	145.1281	15.21336
172	100-	60-	15-	30-	D-	R	67.858	34.1953	121.984	27.0025	146.1574	15.59397
173	100-	60-	15-	40-	D-	R	66.1175	34.9174	122.0326	27.476	147.2804	15.72246
174	100-	60-	15-	50-	D-	R	65.3151	35.4531	122.1992	27.5585	148.2312	15.67697
175	100-	60-	15-	60-	D-	R	65.4483	35.7426	122.4967	27.232	149.0329	15.44947
176	100-	60-	2-	20-	D-	R	78.6014	32.422	123.6599	22.8962	144.9532	13.64092
177	100-	60-	2-	30-	D-	R	76.3193	32.824	123.3458	23.7199	145.3213	14.03202
178	100-	60-	2-	40-	D-	R	74.9444	33.1227	123.2927	24.0441	145.9689	14.14251
179	100-	60-	2-	50-	D-	R	74.5379	33.3221	123.5042	23.9467	146.7591	14.02805
180	100-	60-	2-	60-	D-	R	75.132	33.3787	123.9713	23.3882	147.6721	13.67249
181	80-	40-	1-	20-	S-	C	131.234	28.4972	145.7904	29.6703	157.8996	15.81826
182	80-	40-	1-	30-	S-	C	128.7355	30.5485	146.4869	29.8401	161.167	15.62251
183	80-	40-	1-	40-	S-	C	128.0557	32.1198	147.2131	29.7621	163.2972	15.41604
184	80-	40-	1-	50-	S-	C	127.8988	33.3089	147.8972	29.5777	165.0139	15.19989
185	80-	40-	1-	60-	S-	C	127.9187	34.2196	148.4597	29.2977	166.4484	14.96719
186	80-	40-	15-	20-	S-	C	150.3889	26.9213	147.056	25.2435	152.1461	14.23054
187	80-	40-	15-	30-	S-	C	144.553	27.3242	146.2405	26.1414	153.5426	14.54854
188	80-	40-	15-	40-	S-	C	141.1296	27.9836	146.2151	26.6436	155.2927	14.64447
189	80-	40-	15-	50-	S-	C	139.6309	28.7174	146.6398	26.7671	157.0075	14.56518
190	80-	40-	15-	60-	S-	C	139.8843	29.2893	147.2898	26.5024	158.3398	14.33785
191	80-	40-	2-	20-	S-	C	165.3658	26.6785	151.0142	21.0629	154.215	12.01686
192	80-	40-	2-	30-	S-	C	160.9846	26.76	149.8678	21.8347	154.0461	12.41449
193	80-	40-	2-	40-	S-	C	159.1704	26.8857	149.5629	22.1857	154.2659	12.57325
194	80-	40-	2-	50-	S-	C	159.2584	27.0465	149.8623	22.1389	154.8052	12.5118
195	80-	40-	2-	60-	S-	C	161.341	27.1804	150.8546	21.6666	155.7273	12.21384

196	80-	60-	1-	20-	S-	C	130.5865	28.3347	145.4554	30.845	156.534	16.46129
197	80-	60-	1-	30-	S-	C	128.175	30.3948	146.1723	31.198	159.5843	16.35267
198	80-	60-	1-	40-	S-	C	127.4972	32.0158	146.9298	31.0601	161.8542	16.10047
199	80-	60-	1-	50-	S-	C	127.3486	33.2464	147.6318	30.8684	163.6188	15.87169
200	80-	60-	1-	60-	S-	C	127.403	34.1885	148.2103	30.5748	165.0965	15.62559
201	80-	60-	15-	20-	S-	C	149.9718	26.8831	146.9924	26.0091	151.4519	14.65623
202	80-	60-	15-	30-	S-	C	144.682	27.2537	146.2282	27.002	152.5038	15.04241
203	80-	60-	15-	40-	S-	C	141.3158	27.8955	146.1695	27.4757	154.2037	15.12318
204	80-	60-	15-	50-	S-	C	139.8088	28.6122	146.5624	27.5582	155.9133	15.02043
205	80-	60-	15-	60-	S-	C	140.1225	29.1607	147.1976	27.2321	157.2563	14.76087
206	80-	60-	2-	20-	S-	C	165.6066	26.6828	150.9569	22.896	152.2873	13.06974
207	80-	60-	2-	30-	S-	C	161.1588	26.7696	149.8366	23.7197	152.1301	13.48861
208	80-	60-	2-	40-	S-	C	158.7323	26.9053	149.4397	24.0442	152.5566	13.615
209	80-	60-	2-	50-	S-	C	158.3308	27.0817	149.7254	23.9466	153.3867	13.50372
210	80-	60-	2-	60-	S-	C	159.8945	27.2088	150.6194	23.388	154.5265	13.14564
211	80-	40-	1-	20-	S-	L	67.608	30.8546	122.0525	29.6703	143.4228	17.14124
212	80-	40-	1-	30-	S-	L	66.3554	32.6809	122.719	29.8401	145.8077	16.9886
213	80-	40-	1-	40-	S-	L	66.0062	33.9332	123.3357	29.7621	147.4579	16.79387
214	80-	40-	1-	50-	S-	L	65.9146	34.857	123.8905	29.5777	148.8328	16.57845
215	80-	40-	1-	60-	S-	L	65.9227	35.5436	124.3409	29.2977	150.0008	16.34018
216	80-	40-	15-	20-	S-	L	77.1051	28.5009	121.9809	25.2435	139.9485	15.28131
217	80-	40-	15-	30-	S-	L	74.2059	29.2204	121.9123	26.1414	141.3149	15.61088
218	80-	40-	15-	40-	S-	L	72.5048	30.0445	122.221	26.6436	142.8048	15.72372
219	80-	40-	15-	50-	S-	L	71.7525	30.7709	122.6602	26.7671	144.1445	15.66137
220	80-	40-	15-	60-	S-	L	71.8765	31.2349	123.1498	26.5024	145.2241	15.43291
221	80-	40-	2-	20-	S-	L	84.549	27.8879	123.7842	21.0629	141.526	12.9547
222	80-	40-	2-	30-	S-	L	82.3753	28.1401	123.3503	21.8347	141.6548	13.35541
223	80-	40-	2-	40-	S-	L	81.4706	28.4266	123.3773	22.1857	142.0799	13.50599
224	80-	40-	2-	50-	S-	L	81.5166	28.6895	123.7076	22.1389	142.7068	13.43007
225	80-	40-	2-	60-	S-	L	82.5473	28.8536	124.3634	21.6666	143.5442	13.11452
226	80-	60-	1-	20-	S-	L	67.2704	30.6489	121.8129	30.845	142.0875	17.83644
227	80-	60-	1-	30-	S-	L	66.0727	32.5146	122.4865	31.198	144.269	17.77998
228	80-	60-	1-	40-	S-	L	65.7223	33.8315	123.1346	31.0601	146.0541	17.53676
229	80-	60-	1-	50-	S-	L	65.6331	34.8084	123.7162	30.8684	147.493	17.30666
230	80-	60-	1-	60-	S-	L	65.6537	35.5271	124.1773	30.5748	148.7006	17.05465
231	80-	60-	15-	20-	S-	L	76.8858	28.4124	121.892	26.0091	139.1549	15.74744
232	80-	60-	15-	30-	S-	L	74.251	29.0997	121.8352	27.002	140.2442	16.14506
233	80-	60-	15-	40-	S-	L	72.5824	29.9265	122.1452	27.4757	141.7512	16.23601
234	80-	60-	15-	50-	S-	L	71.8345	30.6433	122.5771	27.5582	143.1212	16.14618
235	80-	60-	15-	60-	S-	L	71.9871	31.1129	123.069	27.2321	144.2561	15.87987
236	80-	60-	2-	20-	S-	L	84.6432	27.9034	123.6876	22.896	139.6099	14.08933
237	80-	60-	2-	30-	S-	L	82.4341	28.1638	123.2828	23.7197	139.7541	14.50979
238	80-	60-	2-	40-	S-	L	81.2318	28.4645	123.28	24.0442	140.365	14.62461
239	80-	60-	2-	50-	S-	L	81.0326	28.7191	123.6012	23.9466	141.198	14.50038
240	80-	60-	2-	60-	S-	L	81.7998	28.8738	124.2001	23.388	142.2191	14.12258
241	80-	40-	1-	20-	S-	R	73.3098	35.0879	128.1499	29.6703	161.1179	15.55143
242	80-	40-	1-	30-	S-	R	71.9308	36.1245	128.4603	29.8401	162.8089	15.48936
243	80-	40-	1-	40-	S-	R	71.5506	36.7819	128.7532	29.7621	163.8271	15.37384
244	80-	40-	1-	50-	S-	R	71.4556	37.2381	129.0208	29.5777	164.6456	15.22871
245	80-	40-	1-	60-	S-	R	71.4661	37.4838	129.1819	29.2977	165.2595	15.05866

246	80-	40-	15-	20-	S-	R	83.8016	32.4537	128.181	25.2404	157.383	13.82101
247	80-	40-	15-	30-	S-	R	80.5984	33.2654	128.1398	26.1414	158.9028	14.12711
248	80-	40-	15-	40-	S-	R	78.7247	34.0045	128.2602	26.6436	160.1699	14.26214
249	80-	40-	15-	50-	S-	R	77.8981	34.6119	128.492	26.7671	161.2073	14.23976
250	80-	40-	15-	60-	S-	R	78.0331	34.9674	128.8185	26.5024	162.0195	14.058
251	80-	40-	2-	20-	S-	R	91.9602	31.3451	129.3356	21.0629	157.5993	11.78923
252	80-	40-	2-	30-	S-	R	89.5713	31.7677	129.0927	21.8347	158.174	12.1298
253	80-	40-	2-	40-	S-	R	88.5765	32.0934	129.1602	22.1857	158.7241	12.2634
254	80-	40-	2-	50-	S-	R	88.6235	32.3197	129.437	22.1389	159.2808	12.20314
255	80-	40-	2-	60-	S-	R	89.7516	32.3955	129.9762	21.6666	159.9135	11.93225
256	80-	60-	1-	20-	S-	R	72.9482	34.9293	127.9384	30.845	159.8305	16.1767
257	80-	60-	1-	30-	S-	R	71.6266	36.0353	128.269	31.198	161.3391	16.20363
258	80-	60-	1-	40-	S-	R	71.2457	36.7363	128.5831	31.0601	162.4753	16.0488
259	80-	60-	1-	50-	S-	R	71.1546	37.215	128.8596	30.8684	163.3242	15.89577
260	80-	60-	1-	60-	S-	R	71.1806	37.467	129.0222	30.5748	163.9547	15.71731
261	80-	60-	15-	20-	S-	R	83.5523	32.3174	128.0808	26.0091	156.5589	14.24625
262	80-	60-	15-	30-	S-	R	80.6549	33.138	128.0841	27.002	157.8485	14.60748
263	80-	60-	15-	40-	S-	R	78.8163	33.88	128.2098	27.4757	159.1363	14.72344
264	80-	60-	15-	50-	S-	R	77.9921	34.4545	128.4392	27.5582	160.2078	14.67689
265	80-	60-	15-	60-	S-	R	78.1592	34.7926	128.7641	27.2321	161.0614	14.46258
266	80-	60-	2-	20-	S-	R	92.0817	31.3372	129.2241	22.896	155.6053	12.8268
267	80-	60-	2-	30-	S-	R	89.6526	31.738	128.9937	23.7197	156.1738	13.18541
268	80-	60-	2-	40-	S-	R	88.3275	32.0719	129.0457	24.0442	156.9464	13.28478
269	80-	60-	2-	50-	S-	R	88.1041	32.2958	129.3335	23.9466	157.7576	13.17889
270	80-	60-	2-	60-	S-	R	88.943	32.3667	129.8327	23.388	158.6111	12.85061
271	80-	40-	1-	20-	D-	C	91.9758	29.688	130.1869	29.6703	140.6551	17.41977
272	80-	40-	1-	30-	D-	C	90.2411	31.6626	130.9268	29.8401	143.5189	17.21289
273	80-	40-	1-	40-	D-	C	89.7797	33.0747	131.644	29.7621	145.45	16.98633
274	80-	40-	1-	50-	D-	C	89.6811	34.1283	132.2952	29.5777	147.022	16.74844
275	80-	40-	1-	60-	D-	C	89.7035	34.9269	132.8335	29.2977	148.3609	16.49101
276	80-	40-	15-	20-	D-	C	105.4226	27.6708	131.2074	25.2435	137.0404	15.55515
277	80-	40-	15-	30-	D-	C	101.342	28.249	130.6682	26.1414	138.1179	15.91472
278	80-	40-	15-	40-	D-	C	98.9515	29.0185	130.7648	26.6436	139.6025	16.0266
279	80-	40-	15-	50-	D-	C	97.9122	29.7778	131.1979	26.7671	141.0974	15.94566
280	80-	40-	15-	60-	D-	C	98.0966	30.2937	131.7886	26.5024	142.3177	15.6986
281	80-	40-	2-	20-	D-	C	115.8457	27.2617	134.4817	21.0629	139.8082	13.09303
282	80-	40-	2-	30-	D-	C	112.7974	27.4123	133.5603	21.8347	139.4875	13.53484
283	80-	40-	2-	40-	D-	C	111.5351	27.6272	133.3886	22.1857	139.7035	13.70425
284	80-	40-	2-	50-	D-	C	111.5977	27.8544	133.7233	22.1389	140.2997	13.62909
285	80-	40-	2-	60-	D-	C	113.0397	28.0182	134.605	21.6666	141.2807	13.29669
286	80-	60-	1-	20-	D-	C	91.5348	29.5056	129.898	30.845	139.2781	18.13099
287	80-	60-	1-	30-	D-	C	89.8622	31.5041	130.6655	31.198	141.9638	18.01668
288	80-	60-	1-	40-	D-	C	89.4048	32.9671	131.4097	31.0601	144.019	17.74061
289	80-	60-	1-	50-	D-	C	89.3148	34.0611	132.0866	30.8684	145.6511	17.48725
290	80-	60-	1-	60-	D-	C	89.3633	34.9004	132.6385	30.5748	147.0289	17.21518
291	80-	60-	15-	20-	D-	C	105.1184	27.611	131.1307	26.0091	136.2895	16.02546
292	80-	60-	15-	30-	D-	C	101.4248	28.1573	130.6396	27.002	137.0895	16.45545
293	80-	60-	15-	40-	D-	C	99.0793	28.9165	130.7201	27.4757	138.5532	16.54875
294	80-	60-	15-	50-	D-	C	98.0361	29.6642	131.1374	27.5582	140.0677	16.4403
295	80-	60-	15-	60-	D-	C	98.2647	30.17	131.7189	27.2321	141.3177	16.15671

296	80-	60-	2-	20-	D-	C	116.0615	27.2651	134.4705	22.896	137.9527	14.23449
297	80-	60-	2-	30-	D-	C	112.961	27.43	133.5805	23.7197	137.6514	14.69885
298	80-	60-	2-	40-	D-	C	111.2685	27.6595	133.3263	24.0442	138.0162	14.83657
299	80-	60-	2-	50-	D-	C	110.9841	27.892	133.6315	23.9466	138.8138	14.71279
300	80-	60-	2-	60-	D-	C	112.0602	28.0393	134.4161	23.388	139.9432	14.31937
301	80-	40-	1-	20-	D-	L	45.3173	31.6888	111.3478	29.6703	134.7665	18.04359
302	80-	40-	1-	30-	D-	L	44.4736	33.3774	111.9948	29.8401	136.7703	17.91011
303	80-	40-	1-	40-	D-	L	44.2496	34.5121	112.5799	29.7621	138.2423	17.71507
304	80-	40-	1-	50-	D-	L	44.199	35.3419	113.1045	29.5777	139.5034	17.4932
305	80-	40-	1-	60-	D-	L	44.2104	35.969	113.5358	29.2977	140.612	17.2431
306	80-	40-	15-	20-	D-	L	51.8863	29.155	110.9618	25.2435	132.6333	15.98937
307	80-	40-	15-	30-	D-	L	49.901	29.9534	111.1144	26.1414	133.795	16.34487
308	80-	40-	15-	40-	D-	L	48.7363	30.7938	111.4791	26.6436	135.0268	16.4802
309	80-	40-	15-	50-	D-	L	48.2267	31.4674	111.904	26.7671	136.1662	16.42826
310	80-	40-	15-	60-	D-	L	48.3146	31.9181	112.342	26.5024	137.1724	16.19211
311	80-	40-	2-	20-	D-	L	56.9228	28.4203	112.032	21.0629	134.39	13.54938
312	80-	40-	2-	30-	D-	L	55.4508	28.7324	111.8373	21.8347	134.5212	13.96474
313	80-	40-	2-	40-	D-	L	54.8358	29.0524	111.9541	22.1857	134.9288	14.12072
314	80-	40-	2-	50-	D-	L	54.8616	29.3318	112.2715	22.1389	135.5442	14.04012
315	80-	40-	2-	60-	D-	L	55.5479	29.4841	112.7732	21.6666	136.3311	13.71324
316	80-	60-	1-	20-	D-	L	45.1081	31.486	111.1598	30.845	133.4354	18.77582
317	80-	60-	1-	30-	D-	L	44.2981	33.2398	111.8353	31.198	135.2917	18.7387
318	80-	60-	1-	40-	D-	L	44.0754	34.4247	112.4453	31.0601	136.8805	18.49469
319	80-	60-	1-	50-	D-	L	44.0289	35.2989	112.9874	30.8684	138.1916	18.25884
320	80-	60-	1-	60-	D-	L	44.0511	35.9478	113.4238	30.5748	139.3271	17.99556
321	80-	60-	15-	20-	D-	L	51.735	29.0514	110.8731	26.0091	131.8004	16.48133
322	80-	60-	15-	30-	D-	L	49.9359	29.8272	111.0406	27.002	132.7419	16.90331
323	80-	60-	15-	40-	D-	L	48.7961	30.6659	111.4102	27.4757	134.002	17.01517
324	80-	60-	15-	50-	D-	L	48.2889	31.3497	111.8333	27.5582	135.1839	16.93366
325	80-	60-	15-	60-	D-	L	48.3981	31.7814	112.2672	27.2321	136.233	16.65927
326	80-	60-	2-	20-	D-	L	57.0399	28.4444	111.9893	22.896	132.5269	14.73142
327	80-	60-	2-	30-	D-	L	55.5371	28.7525	111.8088	23.7197	132.6513	15.16886
328	80-	60-	2-	40-	D-	L	54.7139	29.0813	111.9006	24.0442	133.2039	15.29061
329	80-	60-	2-	50-	D-	L	54.5674	29.3516	112.2046	23.9466	133.979	15.16322
330	80-	60-	2-	60-	D-	L	55.0699	29.495	112.6635	23.388	134.9254	14.77323
331	80-	40-	1-	20-	D-	R	54.1257	36.5614	118.8112	29.6703	146.8471	16.80871
332	80-	40-	1-	30-	D-	R	53.109	37.3087	119.0492	29.8401	148.1187	16.76798
333	80-	40-	1-	40-	D-	R	52.8356	37.7517	119.2703	29.7621	148.8993	16.65838
334	80-	40-	1-	50-	D-	R	52.7713	38.0045	119.4364	29.5777	149.48	16.51853
335	80-	40-	1-	60-	D-	R	52.7832	38.0758	119.4802	29.2977	149.8587	16.35314
336	80-	40-	15-	20-	D-	R	61.9781	34.1783	119.0284	25.2435	144.9358	14.83347
337	80-	40-	15-	30-	D-	R	59.6016	34.9915	118.9306	26.1414	145.9605	15.18949
338	80-	40-	15-	40-	D-	R	58.2066	35.7029	118.9893	26.6436	146.8418	15.35783
339	80-	40-	15-	50-	D-	R	57.5937	36.1925	119.1512	26.7671	147.5996	15.35104
340	80-	40-	15-	60-	D-	R	57.6965	36.4515	119.4206	26.5024	148.2972	15.16159
341	80-	40-	2-	20-	D-	R	68.0132	33.0105	120.151	21.0629	146.0904	12.60095
342	80-	40-	2-	30-	D-	R	66.2487	33.4253	119.9252	21.8347	146.3814	12.98015
343	80-	40-	2-	40-	D-	R	65.5111	33.7343	119.9677	22.1857	146.7535	13.13236
344	80-	40-	2-	50-	D-	R	65.5417	33.9227	120.1894	22.1389	147.2101	13.07294
345	80-	40-	2-	60-	D-	R	66.3651	33.9724	120.6449	21.6666	147.8332	12.78267

346	80-	60-	1-	20-	D-	R	53.8735	36.4666	118.6486	30.845	145.6055	17.48082
347	80-	60-	1-	30-	D-	R	52.8988	37.2572	118.9032	31.198	146.6966	17.53735
348	80-	60-	1-	40-	D-	R	52.6263	37.729	119.139	31.0601	147.5768	17.38728
349	80-	60-	1-	50-	D-	R	52.5663	37.9979	119.3119	30.8684	148.1829	17.23998
350	80-	60-	1-	60-	D-	R	52.5901	38.0737	119.3582	30.5748	148.5796	17.06617
351	80-	60-	15-	20-	D-	R	61.7987	34.0591	118.9584	26.0091	144.1383	15.28622
352	80-	60-	15-	30-	D-	R	59.6439	34.8586	118.8958	27.002	144.9532	15.70293
353	80-	60-	15-	40-	D-	R	58.2782	35.5767	118.9582	27.4757	145.8644	15.85075
354	80-	60-	15-	50-	D-	R	57.6687	36.0707	119.1248	27.5582	146.6764	15.81672
355	80-	60-	15-	60-	D-	R	57.7965	36.3237	119.3828	27.2321	147.403	15.59372
356	80-	60-	2-	20-	D-	R	68.1459	32.9711	120.0636	22.896	144.126	13.70837
357	80-	60-	2-	30-	D-	R	66.3456	33.3752	119.8462	23.7197	144.4037	14.10851
358	80-	60-	2-	40-	D-	R	65.3598	33.6963	119.8658	24.0442	144.9495	14.22787
359	80-	60-	2-	50-	D-	R	65.1848	33.8982	120.0892	23.9466	145.615	14.12266
360	80-	60-	2-	60-	D-	R	65.788	33.9436	120.4962	23.388	146.4137	13.77371
361	60-	40-	1-	20-	S-	C	114.8763	30.0067	140.006	29.6777	154.7525	16.09156
362	60-	40-	1-	30-	S-	C	113.1754	31.9193	140.7295	29.8438	157.5291	15.92749
363	60-	40-	1-	40-	S-	C	112.7288	33.2798	141.4118	29.7569	159.3944	15.7318
364	60-	40-	1-	50-	S-	C	112.6729	34.2471	141.9987	29.5774	160.8297	15.53377
365	60-	40-	1-	60-	S-	C	112.7441	34.917	142.4339	29.2983	161.9642	15.31837
366	60-	40-	15-	20-	S-	C	129.715	27.6163	140.5297	25.2405	149.6193	14.43471
367	60-	40-	15-	30-	S-	C	125.257	28.3649	140.2321	26.1413	151.3376	14.72924
368	60-	40-	15-	40-	S-	C	122.7129	29.2636	140.4774	26.6434	153.1571	14.81831
369	60-	40-	15-	50-	S-	C	121.5936	30.0127	140.9103	26.7669	154.698	14.75046
370	60-	40-	15-	60-	S-	C	121.847	30.483	141.4589	26.5025	155.8355	14.53482
371	60-	40-	2-	20-	S-	C	142.7929	26.9859	143.726	21.0628	150.8613	12.25122
372	60-	40-	2-	30-	S-	C	138.7904	27.2562	142.9197	21.835	151.2286	12.61675
373	60-	40-	2-	40-	S-	C	136.6642	27.6017	142.8078	22.1858	152.0627	12.73228
374	60-	40-	2-	50-	S-	C	136.0184	27.8957	143.1228	22.1392	153.0993	12.63375
375	60-	40-	2-	60-	S-	C	136.9384	28.0659	143.8433	21.6663	154.2314	12.31756
376	60-	60-	1-	20-	S-	C	114.4815	29.9046	139.8172	30.8556	153.4698	16.73974
377	60-	60-	1-	30-	S-	C	112.6982	31.7946	140.4948	31.1985	156.0392	16.66251
378	60-	60-	1-	40-	S-	C	112.2625	33.1597	141.1833	31.0811	157.9516	16.44218
379	60-	60-	1-	50-	S-	C	112.1994	34.1455	141.7644	30.8621	159.4334	16.21799
380	60-	60-	1-	60-	S-	C	112.3265	34.8686	142.2388	30.5695	160.6379	15.98761
381	60-	60-	15-	20-	S-	C	129.281	27.5713	140.48	26.0092	148.9303	14.86754
382	60-	60-	15-	30-	S-	C	125.1396	28.282	140.1968	27.0021	150.3747	15.22302
383	60-	60-	15-	40-	S-	C	122.4843	29.1278	140.3925	27.474	152.2237	15.28901
384	60-	60-	15-	50-	S-	C	121.337	29.8456	140.7916	27.5583	153.7697	15.19804
385	60-	60-	15-	60-	S-	C	121.7177	30.3049	141.3123	27.2321	154.8573	14.95535
386	60-	60-	2-	20-	S-	C	140.5076	27.0008	143.0277	22.8959	149.2595	13.29955
387	60-	60-	2-	30-	S-	C	137.399	27.2652	142.4121	23.7196	149.3673	13.70387
388	60-	60-	2-	40-	S-	C	135.7559	27.5559	142.3189	24.0443	149.983	13.8164
389	60-	60-	2-	50-	S-	C	135.6146	27.8056	142.6432	23.9467	150.8024	13.70348
390	60-	60-	2-	60-	S-	C	137.0322	27.9429	143.4385	23.3881	151.8367	13.34748
391	60-	40-	1-	20-	S-	L	59.2102	32.2393	118.5496	29.6777	141.6559	17.32159
392	60-	40-	1-	30-	S-	L	58.3736	33.7597	119.1336	29.8438	143.5269	17.21387
393	60-	40-	1-	40-	S-	L	58.1408	34.8144	119.6902	29.7569	144.9551	17.03197
394	60-	40-	1-	50-	S-	L	58.1041	35.5513	120.1604	29.5774	146.1035	16.83587
395	60-	40-	1-	60-	S-	L	58.1418	36.0188	120.4883	29.2983	147.0033	16.61828

396	60-	40-	15-	20-	S-	L	66.512	29.535	118.2733	25.2405	139.1872	15.35052
397	60-	40-	15-	30-	S-	L	64.3129	30.4081	118.4348	26.1413	140.5081	15.68641
398	60-	40-	15-	40-	S-	L	63.0569	31.2567	118.7716	26.6434	141.759	15.82127
399	60-	40-	15-	50-	S-	L	62.5059	31.903	119.1433	26.7669	142.8483	15.78096
400	60-	40-	15-	60-	S-	L	62.6312	32.311	119.5429	26.5025	143.7695	15.5648
401	60-	40-	2-	20-	S-	L	72.9578	28.596	119.5861	21.0628	140.3221	13.05128
402	60-	40-	2-	30-	S-	L	70.989	29.0002	119.3774	21.835	140.8006	13.42572
403	60-	40-	2-	40-	S-	L	69.9344	29.3918	119.4871	22.1858	141.537	13.55083
404	60-	40-	2-	50-	S-	L	69.6184	29.6858	119.7926	22.1392	142.3997	13.4553
405	60-	40-	2-	60-	S-	L	70.0744	29.8206	120.2581	21.6663	143.3171	13.13241
406	60-	60-	1-	20-	S-	L	58.9966	32.1213	118.4106	30.8556	140.41	18.01623
407	60-	60-	1-	30-	S-	L	58.1231	33.6734	118.9732	31.1985	142.1013	18.00262
408	60-	60-	1-	40-	S-	L	57.8974	34.7218	119.5251	31.0811	143.5554	17.7976
409	60-	60-	1-	50-	S-	L	57.864	35.4834	120.0011	30.8621	144.7605	17.57297
410	60-	60-	1-	60-	S-	L	57.922	35.9933	120.355	30.5695	145.7192	17.34059
411	60-	60-	15-	20-	S-	L	66.2833	29.4577	118.2045	26.0092	138.424	15.81749
412	60-	60-	15-	30-	S-	L	64.239	29.9086	118.1077	27.0021	139.0421	16.262
413	60-	60-	15-	40-	S-	L	62.9324	31.1133	118.6812	27.474	140.8191	16.32509
414	60-	60-	15-	50-	S-	L	62.3713	31.7625	119.0443	27.5583	141.9453	16.25824
415	60-	60-	15-	60-	S-	L	62.5582	32.1531	119.4283	27.2321	142.8608	16.01013
416	60-	60-	2-	20-	S-	L	71.8137	28.611	119.1787	22.8959	138.73	14.16598
417	60-	60-	2-	30-	S-	L	70.2774	28.986	119.0313	23.7196	138.9345	14.58285
418	60-	60-	2-	40-	S-	L	69.4766	29.3299	119.1445	24.0443	139.5139	14.70076
419	60-	60-	2-	50-	S-	L	69.4081	29.5854	119.4344	23.9467	140.2291	14.58601
420	60-	60-	2-	60-	S-	L	70.1033	29.6975	119.9289	23.3881	141.1022	14.21853
421	60-	40-	1-	20-	S-	R	64.2055	35.8741	124.0551	29.6777	157.3254	15.87016
422	60-	40-	1-	30-	S-	R	63.2794	36.6894	124.3383	29.8438	158.614	15.8358
423	60-	40-	1-	40-	S-	R	63.027	37.2215	124.6135	29.7569	159.4971	15.72326
424	60-	40-	1-	50-	S-	R	62.9907	37.5077	124.8059	29.5774	160.1105	15.59267
425	60-	40-	1-	60-	S-	R	63.0322	37.5606	124.8398	29.2983	160.4545	15.44025
426	60-	40-	15-	20-	S-	R	72.2897	33.4195	124.1351	25.2404	155.176	13.99008
427	60-	40-	15-	30-	S-	R	69.8523	34.2244	124.1145	26.1413	156.3048	14.32823
428	60-	40-	15-	40-	S-	R	68.4668	34.9817	124.2318	26.6434	157.2598	14.48773
429	60-	40-	15-	50-	S-	R	67.8577	35.5131	124.425	26.7669	158.0695	14.4814
430	60-	40-	15-	60-	S-	R	67.9939	35.7934	124.6933	26.5025	158.7576	14.30556
431	60-	40-	2-	20-	S-	R	79.3664	32.2063	125.1116	21.0628	155.5535	11.92574
432	60-	40-	2-	30-	S-	R	77.1958	32.6202	124.9381	21.835	156.1869	12.26534
433	60-	40-	2-	40-	S-	R	76.0342	32.9658	125.0191	22.1858	156.9167	12.38721
434	60-	40-	2-	50-	S-	R	75.6813	33.1851	125.2529	22.1392	157.6739	12.31234
435	60-	40-	2-	60-	S-	R	76.1763	33.2411	125.6376	21.6663	158.4501	12.02905
436	60-	60-	1-	20-	S-	R	63.9794	35.8096	123.9352	30.8556	156.1162	16.50281
437	60-	60-	1-	30-	S-	R	63.0114	36.6456	124.2072	31.1985	157.235	16.55677
438	60-	60-	1-	40-	S-	R	62.7664	37.1849	124.4853	31.0811	158.1596	16.42411
439	60-	60-	1-	50-	S-	R	62.7318	37.4896	124.6815	30.8621	158.8275	16.26979
440	60-	60-	1-	60-	S-	R	62.7982	37.5586	124.7312	30.5695	159.2067	16.10818
441	60-	60-	15-	20-	S-	R	72.0293	33.3301	124.0739	26.0092	154.4272	14.41461
442	60-	60-	15-	30-	S-	R	69.7755	34.11	124.0791	27.0021	155.3593	14.80692
443	60-	60-	15-	40-	S-	R	68.3329	34.8505	124.188	27.474	156.3882	14.94271
444	60-	60-	15-	50-	S-	R	67.7121	35.3902	124.3672	27.5583	157.23	14.91344
445	60-	60-	15-	60-	S-	R	67.9178	35.6599	124.6245	27.2321	157.9202	14.70795

446	60-	60-	2-	20-	S-	R	78.1197	32.2045	124.7466	22.8959	154.022	12.94154
447	60-	60-	2-	30-	S-	R	76.4294	32.6078	124.6309	23.7196	154.3626	13.31947
448	60-	60-	2-	40-	S-	R	75.5425	32.9164	124.7117	24.0443	154.9273	13.4347
449	60-	60-	2-	50-	S-	R	75.4636	33.1011	124.9317	23.9467	155.5353	13.34212
450	60-	60-	2-	60-	S-	R	76.2252	33.1604	125.3545	23.3881	156.2858	13.01697
451	60-	40-	1-	20-	D-	C	80.5553	31.1759	125.7308	29.6777	139.258	17.56745
452	60-	40-	1-	30-	D-	C	79.3797	32.8849	126.4173	29.8438	141.5856	17.4088
453	60-	40-	1-	40-	D-	C	79.0795	34.0868	127.0689	29.7569	143.2529	17.19955
454	60-	40-	1-	50-	D-	C	79.0505	34.9424	127.6324	29.5774	144.5821	16.98294
455	60-	40-	1-	60-	D-	C	79.1079	35.5138	128.0334	29.2983	145.6207	16.74964
456	60-	40-	15-	20-	D-	C	90.9342	28.5752	126.1153	25.2405	136.1276	15.64157
457	60-	40-	15-	30-	D-	C	87.8278	29.4173	126.0147	26.1413	137.4827	15.97645
458	60-	40-	15-	40-	D-	C	86.0582	30.2929	126.2662	26.6434	138.9044	16.09408
459	60-	40-	15-	50-	D-	C	85.2845	30.991	126.6562	26.7669	140.1739	16.03377
460	60-	40-	15-	60-	D-	C	85.4673	31.438	127.1438	26.5025	141.2196	15.80144
461	60-	40-	2-	20-	D-	C	100.0118	27.7655	128.563	21.0628	137.9773	13.2437
462	60-	40-	2-	30-	D-	C	97.2316	28.1264	128.0149	21.835	138.2153	13.64259
463	60-	40-	2-	40-	D-	C	95.7528	28.5031	127.9967	22.1858	138.8914	13.7734
464	60-	40-	2-	50-	D-	C	95.2996	28.8106	128.312	22.1392	139.8086	13.67058
465	60-	40-	2-	60-	D-	C	95.9274	28.962	128.9121	21.6663	140.8444	13.33223
466	60-	60-	1-	20-	D-	C	80.2852	31.0653	125.5742	30.8556	137.9938	18.27404
467	60-	60-	1-	30-	D-	C	79.0526	32.792	126.2404	31.1985	140.1454	18.20812
468	60-	60-	1-	40-	D-	C	78.7621	33.9921	126.8897	31.0811	141.8438	17.97376
469	60-	60-	1-	50-	D-	C	78.7301	34.8485	127.4346	30.8621	143.1945	17.73107
470	60-	60-	1-	60-	D-	C	78.8274	35.4732	127.8774	30.5695	144.3091	17.48041
471	60-	60-	15-	20-	D-	C	90.6182	28.5037	126.0509	26.0092	135.3782	16.116
472	60-	60-	15-	30-	D-	C	87.736	29.3162	125.9698	27.0021	136.5168	16.51314
473	60-	60-	15-	40-	D-	C	85.8918	30.1484	126.178	27.474	137.9592	16.60731
474	60-	60-	15-	50-	D-	C	85.1014	30.8365	126.541	27.5583	139.2432	16.52161
475	60-	60-	15-	60-	D-	C	85.3754	31.273	127.0188	27.2321	140.2773	16.25706
476	60-	60-	2-	20-	D-	C	98.4428	27.792	128.0198	22.8959	136.3183	14.38056
477	60-	60-	2-	30-	D-	C	96.2846	28.1166	127.5965	23.7196	136.315	14.82154
478	60-	60-	2-	40-	D-	C	95.1433	28.4466	127.5915	24.0443	136.8298	14.94604
479	60-	60-	2-	50-	D-	C	95.0445	28.7063	127.9061	23.9467	137.5832	14.82493
480	60-	60-	2-	60-	D-	C	96.0224	28.8372	128.5733	23.3881	138.58	14.43994
481	60-	40-	1-	20-	D-	L	39.7244	32.9775	109.0258	29.6777	133.9738	18.13469
482	60-	40-	1-	30-	D-	L	39.1577	34.3489	109.5815	29.8438	135.5523	18.04384
483	60-	40-	1-	40-	D-	L	39.01	35.3059	110.1098	29.7569	136.84	17.86162
484	60-	40-	1-	50-	D-	L	38.9941	35.9735	110.5584	29.5774	137.9097	17.65951
485	60-	40-	1-	60-	D-	L	39.0237	36.3635	110.8447	29.2983	138.7207	17.43749
486	60-	40-	15-	20-	D-	L	44.7811	30.2472	108.5923	25.2405	132.7869	15.97223
487	60-	40-	15-	30-	D-	L	43.273	31.1275	108.8569	26.1413	133.7992	16.34439
488	60-	40-	15-	40-	D-	L	42.412	31.9232	109.1979	26.6434	134.7756	16.50574
489	60-	40-	15-	50-	D-	L	42.0354	32.5719	109.5589	26.7669	135.7253	16.47273
490	60-	40-	15-	60-	D-	L	42.1226	32.9535	109.9116	26.5025	136.5831	16.25067
491	60-	40-	2-	20-	D-	L	49.1608	29.2262	109.2896	21.0628	134.207	13.56529
492	60-	40-	2-	30-	D-	L	47.8179	29.655	109.2532	21.835	134.5825	13.95944
493	60-	40-	2-	40-	D-	L	47.0959	30.0506	109.4233	22.1858	135.2038	14.0961
494	60-	40-	2-	50-	D-	L	46.8693	30.335	109.6996	22.1392	135.9532	14.00396
495	60-	40-	2-	60-	D-	L	47.1609	30.4345	110.04	21.6663	136.7562	13.67628

496	60-	60-	1-	20-	D-	L	39.5941	32.8603	108.9315	30.8556	132.7584	18.85878
497	60-	60-	1-	30-	D-	L	39	34.2748	109.4697	31.1985	134.154	18.86787
498	60-	60-	1-	40-	D-	L	38.858	35.2342	109.9979	31.0811	135.4754	18.66099
499	60-	60-	1-	50-	D-	L	38.8439	35.9081	110.4344	30.8621	136.5726	18.43232
500	60-	60-	1-	60-	D-	L	38.8895	36.3298	110.7415	30.5695	137.4322	18.19595
501	60-	60-	15-	20-	D-	L	44.6246	30.157	108.5241	26.0092	131.9833	16.4623
502	60-	60-	15-	30-	D-	L	43.2239	31.0294	108.8067	27.0021	132.8513	16.89179
503	60-	60-	15-	40-	D-	L	42.3282	31.7919	109.1252	27.474	133.8485	17.03048
504	60-	60-	15-	50-	D-	L	41.9456	32.4199	109.471	27.5583	134.8157	16.97211
505	60-	60-	15-	60-	D-	L	42.0777	32.8061	109.8121	27.2321	135.69	16.7148
506	60-	60-	2-	20-	D-	L	48.4071	29.2416	109.0168	22.8959	132.5838	14.72597
507	60-	60-	2-	30-	D-	L	47.3633	29.6294	109.0063	23.7196	132.7119	15.16293
508	60-	60-	2-	40-	D-	L	46.812	29.9841	109.1667	24.0443	133.2133	15.28975
509	60-	60-	2-	50-	D-	L	46.7582	30.2201	109.4174	23.9467	133.8435	15.17629
510	60-	60-	2-	60-	D-	L	47.2181	30.3184	109.788	23.3881	134.6575	14.79832
511	60-	40-	1-	20-	D-	R	47.439	37.1289	115.629	29.6777	144.5135	17.03743
512	60-	40-	1-	30-	D-	R	46.7565	37.7018	115.841	29.8438	145.4617	17.02388
513	60-	40-	1-	40-	D-	R	46.5752	38.0128	116.0256	29.7569	146.0933	16.92173
514	60-	40-	1-	50-	D-	R	46.5532	38.0978	116.0854	29.5774	146.4331	16.80434
515	60-	40-	1-	60-	D-	R	46.5874	38.0982	116.0813	29.2983	146.7032	16.64662
516	60-	40-	15-	20-	D-	R	53.4857	35.062	115.8527	25.2405	143.9053	14.92233
517	60-	40-	15-	30-	D-	R	51.6799	35.8574	115.7878	26.1413	144.5938	15.31103
518	60-	40-	15-	40-	D-	R	50.648	36.4753	115.8473	26.6434	145.2075	15.50379
519	60-	40-	15-	50-	D-	R	50.1955	36.8682	115.9823	26.7669	145.785	15.51238
520	60-	40-	15-	60-	D-	R	50.2983	37.062	116.1929	26.5025	146.3718	15.3305
521	60-	40-	2-	20-	D-	R	58.7319	33.7987	116.83	21.0628	145.1823	12.66973
522	60-	40-	2-	30-	D-	R	57.1229	34.2172	116.6563	21.835	145.5123	13.04772
523	60-	40-	2-	40-	D-	R	56.2575	34.5574	116.6894	22.1858	146.0063	13.19075
524	60-	40-	2-	50-	D-	R	55.987	34.7535	116.8575	22.1392	146.6055	13.11994
525	60-	40-	2-	60-	D-	R	56.3387	34.8114	117.1701	21.6663	147.3346	12.82023
526	60-	60-	1-	20-	D-	R	47.282	37.0948	115.5424	30.8556	143.3369	17.71351
527	60-	60-	1-	30-	D-	R	46.5673	37.6854	115.7458	31.1985	144.1165	17.79568
528	60-	60-	1-	40-	D-	R	46.3926	38.0027	115.9301	31.0811	144.7836	17.6733
529	60-	60-	1-	50-	D-	R	46.373	38.1055	115.9993	30.8621	145.1856	17.53053
530	60-	60-	1-	60-	D-	R	46.4253	38.1071	115.9988	30.5695	145.4706	17.36508
531	60-	60-	15-	20-	D-	R	53.2998	34.958	115.809	26.0092	143.1422	15.37628
532	60-	60-	15-	30-	D-	R	51.6221	35.7589	115.7664	27.0021	143.6849	15.81966
533	60-	60-	15-	40-	D-	R	50.5486	36.3812	115.8169	27.474	144.3592	15.98876
534	60-	60-	15-	50-	D-	R	50.0891	36.7819	115.9405	27.5583	144.9706	15.97315
535	60-	60-	15-	60-	D-	R	50.245	36.9622	116.1412	27.2321	145.5665	15.75944
536	60-	60-	2-	20-	D-	R	57.8284	33.8374	116.5324	22.8959	143.605	13.75122
537	60-	60-	2-	30-	D-	R	56.5767	34.2309	116.4058	23.7196	143.6909	14.16853
538	60-	60-	2-	40-	D-	R	55.9167	34.5292	116.4439	24.0443	144.0656	14.30273
539	60-	60-	2-	50-	D-	R	55.8522	34.7106	116.6131	23.9467	144.5776	14.20964
540	60-	60-	2-	60-	D-	R	56.404	34.7409	116.957	23.3881	145.2928	13.86529

Combinations of south-east-facing façade

Simulated scenarios							Solar gain (MWh)	Lighting gain (MWh)	Cooling plant sensible load (MWh)	PV-generated electricity	Net Energy	Enrgy saving
No.	WWR	Depth	d/l	Angle	Glazing	Glass	South-east	South-east	South-east	South-east	South-east	South-east
1	100-	40-	1-	20-	S-	C	160.2832	27.2951	156.3394	27.4286	163.1604	14.39149
2	100-	40-	1-	30-	S-	C	154.8494	28.5253	155.6926	28.0837	165.2985	14.52238
3	100-	40-	1-	40-	S-	C	151.5923	31.7149	156.7127	28.2868	170.2156	14.2501
4	100-	40-	1-	50-	S-	C	150.1774	32.482	154.5622	28.1521	171.2778	14.11629
5	100-	40-	1-	60-	S-	C	149.6934	32.6917	156.9534	27.8887	172.309	13.93058
6	100-	40-	15-	20-	S-	C	180.861	26.3613	161.6505	23.4003	162.6439	12.57782
7	100-	40-	15-	30-	S-	C	173.9128	26.6968	159.5596	24.3459	162.7832	13.01022
8	100-	40-	15-	40-	S-	C	169.4681	27.1396	158.4891	24.8318	163.4612	13.18785
9	100-	40-	15-	50-	S-	C	166.8697	27.733	158.2933	24.9673	164.8696	13.15197
10	100-	40-	15-	60-	S-	C	166.5582	28.2732	158.7823	24.7555	166.2396	12.96133
11	100-	40-	2-	20-	S-	C	200.8524	26.0736	169.1708	19.2731	166.5725	10.37049
12	100-	40-	2-	30-	S-	C	195.1128	26.1975	167.1668	20.0709	166.0604	10.78319
13	100-	40-	2-	40-	S-	C	191.4952	26.3262	165.9601	20.4442	165.9551	10.96796
14	100-	40-	2-	50-	S-	C	190.2398	26.4807	165.8642	20.4165	166.7261	10.9096
15	100-	40-	2-	60-	S-	C	191.6602	26.6151	166.8004	19.9126	167.8981	10.60248
16	100-	60-	1-	20-	S-	C	159.4381	27.2624	155.8644	28.802	161.5116	15.13397
17	100-	60-	1-	30-	S-	C	154.0953	28.5423	155.2108	29.4256	163.5752	15.24636
18	100-	60-	1-	40-	S-	C	150.8564	30.1179	155.5337	29.6006	166.5099	15.09384
19	100-	60-	1-	50-	S-	C	149.4332	31.5898	156.0612	29.4075	168.8933	14.82974
20	100-	60-	1-	60-	S-	C	149.0112	33.8979	157.3717	29.0911	172.1538	14.45557
21	100-	60-	15-	20-	S-	C	181.1968	26.3131	161.7608	24.2153	161.7304	13.02278
22	100-	60-	15-	30-	S-	C	174.1602	26.6357	159.5342	25.1419	161.6768	13.45791
23	100-	60-	15-	40-	S-	C	169.6526	27.0872	158.5879	25.6125	162.7136	13.60008
24	100-	60-	15-	50-	S-	C	167.0519	27.655	158.2721	25.6872	163.9474	13.54563
25	100-	60-	15-	60-	S-	C	166.85	28.195	158.7967	25.4055	165.3757	13.31656
26	100-	60-	2-	20-	S-	C	200.6543	26.0554	168.9195	21.1057	164.5143	11.37038
27	100-	60-	2-	30-	S-	C	194.813	26.1733	166.8065	21.8823	163.8574	11.78116
28	100-	60-	2-	40-	S-	C	191.0122	26.313	165.7599	22.2229	164.2348	11.91847
29	100-	60-	2-	50-	S-	C	189.6371	27.7186	166.3421	22.104	166.5221	11.71842
30	100-	60-	2-	60-	S-	C	191.0352	27.8796	167.3255	21.4964	167.8837	11.35093
31	100-	40-	1-	20-	S-	L	82.5346	28.8102	127.6804	27.4286	146.1102	15.80546
32	100-	40-	1-	30-	S-	L	79.7648	30.6643	127.9513	28.0837	148.4257	15.9106
33	100-	40-	1-	40-	S-	L	78.0892	31.9249	128.2002	28.2868	150.1781	15.85006
34	100-	40-	1-	50-	S-	L	77.34	33.0379	128.6115	28.1521	151.8066	15.64364
35	100-	40-	1-	60-	S-	L	77.0654	34.252	129.3118	27.8887	153.669	15.36079
36	100-	40-	15-	20-	S-	L	93.024	27.5695	130.3694	23.4003	146.3031	13.78894
37	100-	40-	15-	30-	S-	L	89.5405	28.4098	129.5858	24.3459	146.93	14.21443
38	100-	40-	15-	40-	S-	L	87.2461	28.8101	129.1383	24.8318	147.5567	14.40456
39	100-	40-	15-	50-	S-	L	85.9095	29.7215	129.3216	24.9673	148.9346	14.35712
40	100-	40-	15-	60-	S-	L	85.7107	30.2311	129.7413	24.7555	150.0938	14.15819
41	100-	40-	2-	20-	S-	L	103.1227	27.4014	134.8031	19.2731	149.8868	11.39342
42	100-	40-	2-	30-	S-	L	100.1972	27.6277	133.7367	20.0709	149.6137	11.82836
43	100-	40-	2-	40-	S-	L	98.3527	27.6257	133.0898	20.4442	149.5855	12.0239
44	100-	40-	2-	50-	S-	L	97.686	28.0956	133.2091	20.4165	150.4194	11.95094

45	100-	40-	2-	60-	S-	L	98.3966	28.2596	133.8555	19.9126	151.4509	11.62009
46	100-	60-	1-	20-	S-	L	82.1461	29.2024	127.6413	28.802	145.0604	16.56597
47	100-	60-	1-	30-	S-	L	79.3871	30.443	127.6142	29.4256	146.7867	16.69895
48	100-	60-	1-	40-	S-	L	77.7144	32.1706	128.1123	29.6006	149.0787	16.56633
49	100-	60-	1-	50-	S-	L	76.9624	33.3649	128.6026	29.4075	150.9205	16.30778
50	100-	60-	1-	60-	S-	L	76.718	34.2446	129.0991	29.0911	152.4199	16.02718
51	100-	60-	15-	20-	S-	L	93.2054	27.8473	130.6172	24.2153	145.7857	14.24421
52	100-	60-	15-	30-	S-	L	89.661	28.1086	129.4728	25.1419	145.7744	14.71007
53	100-	60-	15-	40-	S-	L	87.3389	28.9883	129.2308	25.6125	146.8828	14.84823
54	100-	60-	15-	50-	S-	L	85.9993	29.6433	129.2787	25.6872	148.0572	14.78448
55	100-	60-	15-	60-	S-	L	85.8555	30.1436	129.7207	25.4055	149.2783	14.54371
56	100-	60-	2-	20-	S-	L	103.0513	27.396	134.6205	21.1057	147.8923	12.48873
57	100-	60-	2-	30-	S-	L	100.0663	27.3747	133.4246	21.8823	147.4234	12.92473
58	100-	60-	2-	40-	S-	L	98.1382	27.8572	133.0019	22.2229	147.9525	13.05882
59	100-	60-	2-	50-	S-	L	97.4159	28.0896	133.0114	22.104	148.6912	12.94182
60	100-	60-	2-	60-	S-	L	98.1074	28.2403	133.6614	21.4964	149.8362	12.54659
61	100-	40-	1-	20-	S-	R	89.5533	33.5715	134.392	27.4286	165.5483	14.21341
62	100-	40-	1-	30-	S-	R	86.4577	34.8051	134.2532	28.0837	167.1697	14.38321
63	100-	40-	1-	40-	S-	R	84.5889	35.408	134.131	28.2868	168.2462	14.3929
64	100-	40-	1-	50-	S-	R	83.7599	36.378	134.4816	28.1521	169.7837	14.22284
65	100-	40-	1-	60-	S-	R	83.463	36.7677	134.6715	27.8887	170.6678	14.04573
66	100-	40-	15-	20-	S-	R	101.2393	31.8737	136.5905	23.4004	164.6553	12.44333
67	100-	40-	15-	30-	S-	R	97.3274	32.586	135.8407	24.3459	165.3564	12.83374
68	100-	40-	15-	40-	S-	R	94.7852	32.8777	135.3771	24.8318	165.972	13.01431
69	100-	40-	15-	50-	S-	R	93.299	33.7038	135.498	24.9673	167.276	12.98734
70	100-	40-	15-	60-	S-	R	93.0827	34.043	135.7811	24.7555	168.203	12.82944
71	100-	40-	2-	20-	S-	R	112.3711	30.9267	140.1088	19.2731	166.5538	10.37153
72	100-	40-	2-	30-	S-	R	109.1314	31.3076	139.2837	20.0709	166.7437	10.74375
73	100-	40-	2-	40-	S-	R	107.0827	31.3058	138.7284	20.4442	166.8886	10.91331
74	100-	40-	2-	50-	S-	R	106.3386	31.8707	138.9324	20.4165	167.8974	10.84174
75	100-	40-	2-	60-	S-	R	107.1001	31.9515	139.4957	19.9126	168.7989	10.55187
76	100-	60-	1-	20-	S-	R	89.1246	33.5721	134.147	28.802	164.068	14.93337
77	100-	60-	1-	30-	S-	R	86.0526	34.4597	133.8551	29.4256	165.3878	15.10451
78	100-	60-	1-	40-	S-	R	84.1878	35.7292	134.0828	29.6006	167.2138	15.03985
79	100-	60-	1-	50-	S-	R	83.353	36.3673	134.2691	29.4075	168.4868	14.86021
80	100-	60-	1-	60-	S-	R	83.0896	36.7626	134.4717	29.0911	169.4255	14.65424
81	100-	60-	15-	20-	S-	R	101.414	31.7958	136.595	24.2153	163.6811	12.88758
82	100-	60-	15-	30-	S-	R	97.4655	32.1703	135.6568	25.1419	164.051	13.28903
83	100-	60-	15-	40-	S-	R	94.8917	33.1085	135.5027	25.6125	165.3535	13.41207
84	100-	60-	15-	50-	S-	R	93.4029	33.6018	135.4492	25.6872	166.3722	13.37461
85	100-	60-	15-	60-	S-	R	93.2477	33.9342	135.753	25.4055	167.3593	13.17953
86	100-	60-	2-	20-	S-	R	112.3006	30.9544	139.9613	21.1057	164.5964	11.36535
87	100-	60-	2-	30-	S-	R	108.9949	30.9957	138.9601	21.8823	164.4954	11.74084
88	100-	60-	2-	40-	S-	R	106.8475	31.6249	138.7154	22.2229	165.3783	11.84582
89	100-	60-	2-	50-	S-	R	106.0371	31.8319	138.7358	22.104	166.1502	11.74157
90	100-	60-	2-	60-	S-	R	106.7773	31.8929	139.2974	21.4964	167.1563	11.3947
91	100-	40-	1-	20-	D-	C	112.393	28.2418	138.557	27.4286	144.5139	15.95219
92	100-	40-	1-	30-	D-	C	108.5636	29.6103	138.1491	28.0837	146.3107	16.10356
93	100-	40-	1-	40-	D-	C	106.2709	30.9616	138.2795	28.2868	148.2849	16.02001
94	100-	40-	1-	50-	D-	C	105.2813	32.5415	138.9246	28.1521	150.558	15.75294
95	100-	40-	1-	60-	D-	C	104.9486	33.5287	139.4724	27.8887	152.168	15.48884

96	100-	40-	15-	20-	D-	C	126.9127	27.1072	143.2059	23.4003	145.3885	13.86366
97	100-	40-	15-	30-	D-	C	122.0228	27.5231	141.4235	24.3459	145.19	14.36032
98	100-	40-	15-	40-	D-	C	118.8974	27.8631	140.5379	24.8318	145.6227	14.56799
99	100-	40-	15-	50-	D-	C	117.0728	28.7249	140.4824	24.9673	146.9256	14.52492
100	100-	40-	15-	60-	D-	C	116.8558	29.2804	140.9674	24.7555	148.2123	14.3122
101	100-	40-	2-	20-	D-	C	140.9071	26.7158	149.5858	19.2731	149.875	11.39422
102	100-	40-	2-	30-	D-	C	136.8813	26.8911	147.903	20.0709	149.1833	11.85844
103	100-	40-	2-	40-	D-	C	134.3387	26.8626	146.8688	20.4442	148.913	12.07165
104	100-	40-	2-	50-	D-	C	133.4467	27.2851	146.8451	20.4165	149.637	12.00593
105	100-	40-	2-	60-	D-	C	134.4153	27.4438	147.6479	19.9126	150.7625	11.66696
106	100-	60-	1-	20-	D-	C	111.8165	28.187	138.158	28.802	142.8906	16.77533
107	100-	60-	1-	30-	D-	C	108.0549	29.3977	137.743	29.4256	144.6211	16.90673
108	100-	60-	1-	40-	D-	C	105.7761	31.1888	138.1349	29.6006	147.1431	16.74775
109	100-	60-	1-	50-	D-	C	104.7797	32.5319	138.6564	29.4075	149.2425	16.46096
110	100-	60-	1-	60-	D-	C	104.4887	33.5317	139.225	29.0911	150.9156	16.16112
111	100-	60-	15-	20-	D-	C	127.1451	27.0693	143.3029	24.2153	144.5088	14.35201
112	100-	60-	15-	30-	D-	C	122.197	27.2583	141.3764	25.1419	144.091	14.85639
113	100-	60-	15-	40-	D-	C	119.0303	28.0282	140.6599	25.6125	144.9463	15.01682
114	100-	60-	15-	50-	D-	C	117.2029	28.6532	140.4734	25.6872	146.0548	14.95685
115	100-	60-	15-	60-	D-	C	117.0612	29.1907	140.9814	25.4055	147.3941	14.70229
116	100-	60-	2-	20-	D-	C	140.8127	26.7066	149.3857	21.1057	147.8754	12.48998
117	100-	60-	2-	30-	D-	C	136.7102	26.6532	147.5758	21.8823	146.9976	12.95731
118	100-	60-	2-	40-	D-	C	134.034	27.0709	146.7298	22.2229	147.2428	13.11351
119	100-	60-	2-	50-	D-	C	133.0541	27.2661	146.5779	22.104	147.8646	13.00475
120	100-	60-	2-	60-	D-	C	133.9992	27.4138	147.3939	21.4964	149.1187	12.59935
121	100-	40-	1-	20-	D-	L	55.4457	29.9627	115.2429	27.4286	136.7895	16.70254
122	100-	40-	1-	30-	D-	L	53.4895	31.4465	115.4512	28.0837	138.398	16.86894
123	100-	40-	1-	40-	D-	L	52.3106	32.603	115.7376	28.2868	139.8547	16.82321
124	100-	40-	1-	50-	D-	L	51.7925	33.9613	116.3683	28.1521	141.7192	16.57261
125	100-	40-	1-	60-	D-	L	51.6117	34.7475	116.8335	27.8887	143.0407	16.31592
126	100-	40-	15-	20-	D-	L	62.7889	28.519	117.0673	23.4003	137.4685	14.5462
127	100-	40-	15-	30-	D-	L	60.3496	29.111	116.4279	24.3459	137.6338	15.03022
128	100-	40-	15-	40-	D-	L	58.7561	29.5356	116.1766	24.8318	138.1494	15.23599
129	100-	40-	15-	50-	D-	L	57.8222	30.4529	116.4538	24.9673	139.4276	15.18739
130	100-	40-	15-	60-	D-	L	57.6824	30.9383	116.8466	24.7555	140.4935	14.98073
131	100-	40-	2-	20-	D-	L	69.6823	27.9529	120.103	19.2731	140.671	12.0499
132	100-	40-	2-	30-	D-	L	67.6659	28.2078	119.3603	20.0709	140.385	12.50867
133	100-	40-	2-	40-	D-	L	66.3827	28.2105	118.8828	20.4442	140.2995	12.71851
134	100-	40-	2-	50-	D-	L	65.9036	28.7227	119.0605	20.4165	141.1232	12.63869
135	100-	40-	2-	60-	D-	L	66.3422	28.8881	119.5563	19.9126	142.089	12.29161
136	100-	60-	1-	20-	D-	L	55.1984	29.9725	115.0612	28.802	135.3427	17.54671
137	100-	60-	1-	30-	D-	L	53.2605	31.1924	115.1741	29.4256	136.7605	17.70641
138	100-	60-	1-	40-	D-	L	52.0834	32.8667	115.7332	29.6006	138.8008	17.57741
139	100-	60-	1-	50-	D-	L	51.5593	33.9487	116.2169	29.4075	140.4452	17.31353
140	100-	60-	1-	60-	D-	L	51.3991	34.7422	116.688	29.0911	141.8193	17.02126
141	100-	60-	15-	20-	D-	L	62.9144	28.4608	117.0927	24.2153	136.5581	15.06176
142	100-	60-	15-	30-	D-	L	60.4406	28.7925	116.2976	25.1419	136.473	15.55667
143	100-	60-	15-	40-	D-	L	58.8283	29.7191	116.2736	25.6125	137.5006	15.70229
144	100-	60-	15-	50-	D-	L	57.8926	30.349	116.4031	25.6872	138.5467	15.64062
145	100-	60-	15-	60-	D-	L	57.7911	30.8294	116.8105	25.4055	139.6767	15.38961

146	100-	60-	2-	20-	D-	L	69.6757	27.9456	119.9728	21.1057	138.7187	13.20556
147	100-	60-	2-	30-	D-	L	67.6134	27.9455	119.0931	21.8823	138.222	13.66753
148	100-	60-	2-	40-	D-	L	66.2634	28.4758	118.8682	22.2229	138.7385	13.80635
149	100-	60-	2-	50-	D-	L	65.7381	28.7154	118.9067	22.104	139.4109	13.68542
150	100-	60-	2-	60-	D-	L	66.159	28.8695	119.403	21.4964	140.4879	13.27067
151	100-	40-	1-	20-	D-	R	66.2172	35.3467	123.9609	27.4286	150.5006	15.41546
152	100-	40-	1-	30-	D-	R	63.8625	36.3463	123.7562	28.0837	151.5611	15.6329
153	100-	40-	1-	40-	D-	R	62.4414	36.6511	123.5305	28.2868	152.1581	15.67614
154	100-	40-	1-	50-	D-	R	61.813	37.4347	123.8287	28.1521	153.4528	15.50184
155	100-	40-	1-	60-	D-	R	61.5907	37.6199	123.9027	27.8887	154.0562	15.3281
156	100-	40-	15-	20-	D-	R	75.0508	33.7008	126.0557	23.4003	150.757	13.4363
157	100-	40-	15-	30-	D-	R	72.1195	34.3528	125.3497	24.3459	151.0884	13.8775
158	100-	40-	15-	40-	D-	R	70.1981	34.541	124.8394	24.8318	151.3186	14.09693
159	100-	40-	15-	50-	D-	R	69.0719	35.3371	124.9549	24.9673	152.4202	14.07501
160	100-	40-	15-	60-	D-	R	68.8993	35.6185	125.1755	24.7555	153.1888	13.91194
161	100-	40-	2-	20-	D-	R	83.3507	32.6749	129.1536	19.2731	153.2007	11.17451
162	100-	40-	2-	30-	D-	R	80.921	33.0712	128.4216	20.0709	153.185	11.58454
163	100-	40-	2-	40-	D-	R	79.3757	33.0228	127.8575	20.4442	153.0867	11.7813
164	100-	40-	2-	50-	D-	R	78.7974	33.5706	128.0413	20.4165	153.9863	11.70652
165	100-	40-	2-	60-	D-	R	79.3276	33.613	128.4922	19.9126	154.8052	11.39701
166	100-	60-	1-	20-	D-	R	65.9223	35.3381	123.7617	28.802	149.0429	16.19501
167	100-	60-	1-	30-	D-	R	63.5861	35.9732	123.3673	29.4256	149.7417	16.42353
168	100-	60-	1-	40-	D-	R	62.1665	37.0164	123.5536	29.6006	151.1975	16.37219
169	100-	60-	1-	50-	D-	R	61.5312	37.4415	123.656	29.4075	152.1738	16.19522
170	100-	60-	1-	60-	D-	R	61.3341	37.6236	123.7378	29.0911	152.8266	15.99135
171	100-	60-	15-	20-	D-	R	75.2039	33.6333	126.079	24.2153	149.8244	13.91366
172	100-	60-	15-	30-	D-	R	72.2294	33.9123	125.1462	25.1419	149.7694	14.37409
173	100-	60-	15-	40-	D-	R	70.2851	34.8192	125.0115	25.6125	150.7995	14.51857
174	100-	60-	15-	50-	D-	R	69.1569	35.2456	124.9229	25.6872	151.5613	14.4922
175	100-	60-	15-	60-	D-	R	69.031	35.5304	125.1668	25.4055	152.4057	14.28791
176	100-	60-	2-	20-	D-	R	83.3425	32.7045	129.0509	21.1057	151.2918	12.24246
177	100-	60-	2-	30-	D-	R	80.8577	32.7194	128.0928	21.8823	150.897	12.66489
178	100-	60-	2-	40-	D-	R	79.2335	33.3419	127.8795	22.2229	151.5993	12.78485
179	100-	60-	2-	50-	D-	R	78.6003	33.5101	127.8473	22.104	152.2032	12.68106
180	100-	60-	2-	60-	D-	R	79.1097	33.5346	128.2912	21.4964	153.1219	12.31051
181	80-	40-	1-	20-	S-	C	142.1885	28.1086	150.1257	27.4285	159.9255	14.63993
182	80-	40-	1-	30-	S-	C	138.0305	29.6826	149.9783	28.0836	162.2395	14.75575
183	80-	40-	1-	40-	S-	C	135.5435	31.1157	150.2291	28.2862	164.4893	14.67313
184	80-	40-	1-	50-	S-	C	134.5419	32.6089	150.8389	28.1511	166.6747	14.44937
185	80-	40-	1-	60-	S-	C	134.2481	33.5377	151.3496	27.8884	168.2011	14.22228
186	80-	40-	15-	20-	S-	C	159.3569	26.7338	154.4885	23.4002	159.3609	12.80371
187	80-	40-	15-	30-	S-	C	153.7587	27.2264	152.896	24.3458	159.6795	13.22959
188	80-	40-	15-	40-	S-	C	150.1846	27.6585	152.1649	24.8322	160.5084	13.39814
189	80-	40-	15-	50-	S-	C	148.1761	28.5715	152.1972	24.9678	162.0117	13.35323
190	80-	40-	15-	60-	S-	C	148.0083	29.1477	152.721	24.7558	163.3584	13.15998
191	80-	40-	2-	20-	S-	C	175.0308	26.2922	160.357	19.2734	162.6139	10.59634
192	80-	40-	2-	30-	S-	C	170.9745	26.4671	158.9222	20.0712	162.1866	11.01253
193	80-	40-	2-	40-	S-	C	168.6438	26.4711	158.1455	20.4446	162.1064	11.19939
194	80-	40-	2-	50-	S-	C	168.1788	26.8986	158.3307	20.4169	162.899	11.13755
195	80-	40-	2-	60-	S-	C	169.8349	27.0705	159.3678	19.9132	164.061	10.82391

196	80-	60-	1-	20-	S-	C	141.9117	27.9974	149.9093	28.8022	158.3132	15.39275
197	80-	60-	1-	30-	S-	C	137.7186	29.3497	149.6552	29.4258	160.4598	15.49659
198	80-	60-	1-	40-	S-	C	135.1938	31.2116	150.1114	29.59	163.2189	15.3468
199	80-	60-	1-	50-	S-	C	134.1227	32.5647	150.6269	29.4076	165.3275	15.10134
200	80-	60-	1-	60-	S-	C	133.8164	33.5193	151.1486	29.0909	166.9456	14.83953
201	80-	60-	15-	20-	S-	C	159.4924	26.6777	154.571	24.2154	158.4758	13.25483
202	80-	60-	15-	30-	S-	C	153.8715	26.9385	152.826	25.1418	158.5533	13.6867
203	80-	60-	15-	40-	S-	C	150.3484	27.7729	152.267	25.6124	159.7557	13.81705
204	80-	60-	15-	50-	S-	C	148.3011	28.4696	152.1716	25.6872	161.0962	13.7524
205	80-	60-	15-	60-	S-	C	148.1739	29.0261	152.697	25.4056	162.4866	13.52137
206	80-	60-	2-	20-	S-	C	175.201	26.285	160.4559	21.1058	160.8496	11.59944
207	80-	60-	2-	30-	S-	C	170.5954	26.2661	158.7455	21.8824	160.3104	12.01057
208	80-	60-	2-	40-	S-	C	167.7751	26.6862	158.0211	22.223	160.7543	12.14522
209	80-	60-	2-	50-	S-	C	166.9506	26.9078	157.9899	22.1041	161.4791	12.04037
210	80-	60-	2-	60-	S-	C	168.3537	27.0648	158.9163	21.4965	162.7194	11.66919
211	80-	40-	1-	20-	S-	L	73.1292	30.2746	124.1525	27.4285	144.9397	15.91274
212	80-	40-	1-	30-	S-	L	71.0052	31.7724	124.3615	28.0836	146.6373	16.07341
213	80-	40-	1-	40-	S-	L	69.7338	32.8885	124.6332	28.2862	148.1116	16.03546
214	80-	40-	1-	50-	S-	L	69.2014	34.1536	125.2145	28.1511	149.887	15.81184
215	80-	40-	1-	60-	S-	L	69.0291	34.8456	125.6275	27.8884	151.1043	15.58075
216	80-	40-	15-	20-	S-	L	81.8008	28.4703	126.0659	23.4002	144.8832	13.90523
217	80-	40-	15-	30-	S-	L	79.0008	29.1406	125.4312	24.3458	145.2699	14.35351
218	80-	40-	15-	40-	S-	L	77.1704	29.6424	125.1901	24.8322	145.9527	14.54004
219	80-	40-	15-	50-	S-	L	76.1408	30.5634	125.4556	24.9678	147.2668	14.49639
220	80-	40-	15-	60-	S-	L	76.0273	31.0369	125.8524	24.7558	148.3207	14.30339
221	80-	40-	2-	20-	S-	L	89.6392	27.7895	129.1892	19.2734	147.6677	11.54503
222	80-	40-	2-	30-	S-	L	87.5881	28.0678	128.4775	20.0712	147.4144	11.98384
223	80-	40-	2-	40-	S-	L	86.4157	28.1087	128.0908	20.4446	147.3699	12.18286
224	80-	40-	2-	50-	S-	L	86.1638	28.6305	128.3841	20.4169	148.2066	12.10798
225	80-	40-	2-	60-	S-	L	86.9688	28.801	129.054	19.9132	149.1957	11.77537
226	80-	60-	1-	20-	S-	L	72.9896	30.1305	123.9704	28.8022	143.3505	16.73061
227	80-	60-	1-	30-	S-	L	70.8418	31.3911	124.0596	29.4258	144.8593	16.88372
228	80-	60-	1-	40-	S-	L	69.552	33.0611	124.6031	29.59	146.9554	16.76056
229	80-	60-	1-	50-	S-	L	68.9884	34.1092	125.0613	29.4076	148.5672	16.52346
230	80-	60-	1-	60-	S-	L	68.8137	34.8321	125.4879	29.0909	149.8718	16.25529
231	80-	60-	15-	20-	S-	L	81.8596	28.3819	126.0648	24.2154	143.9548	14.39934
232	80-	60-	15-	30-	S-	L	79.0415	28.7896	125.272	25.1418	144.0793	14.85737
233	80-	60-	15-	40-	S-	L	77.2401	29.7662	125.2573	25.6124	145.2374	14.99118
234	80-	60-	15-	50-	S-	L	76.2024	30.4506	125.403	25.6872	146.3818	14.92843
235	80-	60-	15-	60-	S-	L	76.1091	30.9199	125.8066	25.4056	147.5	14.69334
236	80-	60-	2-	20-	S-	L	89.7374	27.7847	129.2139	21.1058	145.8528	12.64134
237	80-	60-	2-	30-	S-	L	87.3993	27.8196	128.2861	21.8824	145.4415	13.07787
238	80-	60-	2-	40-	S-	L	85.9848	28.3774	128.0771	22.223	146.0129	13.20943
239	80-	60-	2-	50-	S-	L	85.5493	28.6403	128.1754	22.1041	146.716	13.09329
240	80-	60-	2-	60-	S-	L	86.2372	28.7895	128.7818	21.4965	147.7858	12.69861
241	80-	40-	1-	20-	S-	R	79.3453	34.4078	130.3157	27.4285	162.5706	14.43612
242	80-	40-	1-	30-	S-	R	76.9726	35.4553	130.2144	28.0836	163.7566	14.63906
243	80-	40-	1-	40-	S-	R	75.5515	35.9122	130.1203	28.2862	164.5708	14.66693
244	80-	40-	1-	50-	S-	R	74.9622	36.7436	130.4596	28.1511	165.9051	14.50667
245	80-	40-	1-	60-	S-	R	74.7768	36.9872	130.5929	27.8884	166.5928	14.3399

246	80-	40-	15-	20-	S-	R	89.0272	32.5569	132.1357	23.4003	162.1233	12.61311
247	80-	40-	15-	30-	S-	R	85.8772	33.2421	131.5463	24.3458	162.6551	13.01908
248	80-	40-	15-	40-	S-	R	83.8449	33.5101	131.1641	24.8322	163.1072	13.21288
249	80-	40-	15-	50-	S-	R	82.699	34.3218	131.3273	24.9678	164.279	13.19325
250	80-	40-	15-	60-	S-	R	82.5751	34.6377	131.5925	24.7558	165.1059	13.03886
251	80-	40-	2-	20-	S-	R	97.6931	31.5186	134.7581	19.2734	163.9505	10.51904
252	80-	40-	2-	30-	S-	R	95.4195	31.9209	134.2153	20.0712	164.0254	10.90254
253	80-	40-	2-	40-	S-	R	94.1129	31.8955	133.8298	20.4446	163.987	11.08519
254	80-	40-	2-	50-	S-	R	93.8273	32.434	134.1288	20.4169	164.8501	11.02026
255	80-	40-	2-	60-	S-	R	94.7061	32.486	134.6907	19.9132	165.6468	10.73141
256	80-	60-	1-	20-	S-	R	79.199	34.292	130.1556	28.8022	161.0083	15.17419
257	80-	60-	1-	30-	S-	R	76.8014	35.0553	129.9012	29.4258	161.9409	15.37666
258	80-	60-	1-	40-	S-	R	75.3589	36.1968	130.1578	29.59	163.5384	15.32141
259	80-	60-	1-	50-	S-	R	74.7324	36.7328	130.3296	29.4076	164.6196	15.15643
260	80-	60-	1-	60-	S-	R	74.5428	36.9796	130.4631	29.0909	165.3695	14.95981
261	80-	60-	15-	20-	S-	R	89.0712	32.4428	132.1084	24.2154	161.1566	13.06314
262	80-	60-	15-	30-	S-	R	85.9287	32.8092	131.3453	25.1418	161.3676	13.48018
263	80-	60-	15-	40-	S-	R	83.9281	33.7341	131.2987	25.6124	162.5118	13.61462
264	80-	60-	15-	50-	S-	R	82.7697	34.2176	131.2891	25.6872	163.4062	13.5844
265	80-	60-	15-	60-	S-	R	82.668	34.5192	131.5573	25.4056	164.2892	13.39288
266	80-	60-	2-	20-	S-	R	97.7987	31.5084	134.7915	21.1058	162.1292	11.51843
267	80-	60-	2-	30-	S-	R	95.2076	31.5474	133.9654	21.8824	161.9176	11.90555
268	80-	60-	2-	40-	S-	R	93.6287	32.1839	133.8498	22.223	162.6886	12.01818
269	80-	60-	2-	50-	S-	R	93.1383	32.3915	133.9152	22.1041	163.3435	11.91932
270	80-	60-	2-	60-	S-	R	93.8826	32.4212	134.417	21.4965	164.2315	11.57418
271	80-	40-	1-	20-	D-	C	99.6431	29.2101	133.5798	27.4285	142.8033	16.11244
272	80-	40-	1-	30-	D-	C	96.7245	30.7727	133.5687	28.0836	144.6863	16.25491
273	80-	40-	1-	40-	D-	C	94.9807	32.0438	133.8094	28.2862	146.4621	16.18682
274	80-	40-	1-	50-	D-	C	94.2842	33.4059	134.414	28.1511	148.4204	15.94317
275	80-	40-	1-	60-	D-	C	94.0846	34.2226	134.9017	27.8884	149.8039	15.69477
276	80-	40-	15-	20-	D-	C	111.7163	27.5774	137.152	23.4002	143.2475	14.04172
277	80-	40-	15-	30-	D-	C	107.7904	28.1657	135.891	24.3458	143.3459	14.51819
278	80-	40-	15-	40-	D-	C	105.2837	28.6644	135.338	24.8322	143.9697	14.71085
279	80-	40-	15-	50-	D-	C	103.8778	29.5947	135.467	24.9678	145.3241	14.66177
280	80-	40-	15-	60-	D-	C	103.7632	30.1171	135.9364	24.7558	146.5117	14.45446
281	80-	40-	2-	20-	D-	C	122.6556	27.0257	141.9861	19.2734	146.9516	11.59477
282	80-	40-	2-	30-	D-	C	119.8236	27.2477	140.83	20.0712	146.4237	12.05514
283	80-	40-	2-	40-	D-	C	118.1935	27.2788	140.1942	20.4446	146.2525	12.26452
284	80-	40-	2-	50-	D-	C	117.8621	27.7538	140.4247	20.4169	147.0384	12.19245
285	80-	40-	2-	60-	D-	C	118.999	27.9331	141.3039	19.9132	148.1589	11.84801
286	80-	60-	1-	20-	D-	C	99.4618	29.0666	133.3762	28.8022	141.177	16.94454
287	80-	60-	1-	30-	D-	C	96.5167	30.4044	133.2536	29.4258	142.8921	17.07646
288	80-	60-	1-	40-	D-	C	94.7477	32.1791	133.7476	29.59	145.2563	16.92344
289	80-	60-	1-	50-	D-	C	94.0022	33.3705	134.2444	29.4076	147.1006	16.66076
290	80-	60-	1-	60-	D-	C	93.791	34.2036	134.7279	29.0909	148.5479	16.37643
291	80-	60-	15-	20-	D-	C	111.8041	27.5086	137.2082	24.2154	142.3643	14.53683
292	80-	60-	15-	30-	D-	C	107.8631	27.8428	135.7778	25.1418	142.1871	15.02538
293	80-	60-	15-	40-	D-	C	105.398	28.7788	135.4426	25.6124	143.2597	15.16674
294	80-	60-	15-	50-	D-	C	103.9659	29.4824	135.432	25.6872	144.4296	15.09974
295	80-	60-	15-	60-	D-	C	103.8757	30.0019	135.9084	25.4056	145.6812	14.84954

296	80-	60-	2-	20-	D-	C	122.7949	27.0149	142.0588	21.1058	145.1765	12.69275
297	80-	60-	2-	30-	D-	C	119.5729	27.019	140.6371	21.8824	144.474	13.15393
298	80-	60-	2-	40-	D-	C	117.5956	27.5147	140.1067	22.223	144.8536	13.30108
299	80-	60-	2-	50-	D-	C	117.0089	27.771	140.1189	22.1041	145.5217	13.18657
300	80-	60-	2-	60-	D-	C	117.9625	27.9279	140.8899	21.4965	146.6953	12.78094
301	80-	40-	1-	20-	D-	L	49.1378	31.0766	112.7249	27.4285	136.1238	16.77048
302	80-	40-	1-	30-	D-	L	47.6393	32.4848	113.0069	28.0836	137.4944	16.96095
303	80-	40-	1-	40-	D-	L	46.7421	33.486	113.2881	28.2862	138.7048	16.93876
304	80-	40-	1-	50-	D-	L	46.3738	34.66	113.8639	28.1511	140.33	16.70876
305	80-	40-	1-	60-	D-	L	46.2612	35.2835	114.259	27.8884	141.4528	16.46876
306	80-	40-	15-	20-	D-	L	55.2164	29.1649	113.919	23.4002	136.5583	14.62892
307	80-	40-	15-	30-	D-	L	53.2558	29.8817	113.5621	24.3458	136.8607	15.10224
308	80-	40-	15-	40-	D-	L	51.9806	30.3613	113.4456	24.8322	137.3797	15.30849
309	80-	40-	15-	50-	D-	L	51.2595	31.2608	113.7683	24.9678	138.576	15.26674
310	80-	40-	15-	60-	D-	L	51.1784	31.7042	114.1282	24.7558	139.5354	15.06824
311	80-	40-	2-	20-	D-	L	60.5955	28.3923	116.085	19.2734	139.3806	12.14807
312	80-	40-	2-	30-	D-	L	59.1838	28.7012	115.6207	20.0712	139.1226	12.60803
313	80-	40-	2-	40-	D-	L	58.3665	28.7568	115.3571	20.4446	139.0521	12.8182
314	80-	40-	2-	50-	D-	L	58.1775	29.2963	115.6636	20.4169	139.8719	12.73757
315	80-	40-	2-	60-	D-	L	58.6972	29.452	116.1712	19.9132	140.7851	12.39167
316	80-	60-	1-	20-	D-	L	49.0621	30.9133	112.5664	28.8022	134.5349	17.63359
317	80-	60-	1-	30-	D-	L	47.5466	32.1079	112.7416	29.4258	135.7438	17.81551
318	80-	60-	1-	40-	D-	L	46.6355	33.6702	113.3029	29.59	137.5816	17.70037
319	80-	60-	1-	50-	D-	L	46.2426	34.6268	113.7517	29.4076	139.033	17.45874
320	80-	60-	1-	60-	D-	L	46.1264	35.2698	114.1523	29.0909	140.2294	17.18099
321	80-	60-	15-	20-	D-	L	55.2591	29.0554	113.8958	24.2154	135.6113	15.15104
322	80-	60-	15-	30-	D-	L	53.2895	29.5037	113.3829	25.1418	135.6471	15.63653
323	80-	60-	15-	40-	D-	L	52.0363	30.5045	113.5267	25.6124	136.7074	15.77897
324	80-	60-	15-	50-	D-	L	51.3075	31.1442	113.7116	25.6872	137.6987	15.7218
325	80-	60-	15-	60-	D-	L	51.2392	31.5739	114.0732	25.4056	138.7196	15.4794
326	80-	60-	2-	20-	D-	L	60.6753	28.389	116.1006	21.1058	137.5743	13.30085
327	80-	60-	2-	30-	D-	L	59.0612	28.4414	115.4332	21.8824	137.1265	13.76175
328	80-	60-	2-	40-	D-	L	58.0698	29.0306	115.3749	22.223	137.6764	13.89811
329	80-	60-	2-	50-	D-	L	57.7491	29.2957	115.4866	22.1041	138.3264	13.77799
330	80-	60-	2-	60-	D-	L	58.1812	29.4348	115.9391	21.4965	139.3208	13.36703
331	80-	40-	1-	20-	D-	R	58.6761	35.9934	120.689	27.4285	148.5929	15.58248
332	80-	40-	1-	30-	D-	R	56.8694	36.8157	120.5303	28.0836	149.3153	15.83076
333	80-	40-	1-	40-	D-	R	55.7874	37.0002	120.3397	28.2862	149.7142	15.89109
334	80-	40-	1-	50-	D-	R	55.3397	37.6555	120.6126	28.1511	150.8092	15.73036
335	80-	40-	1-	60-	D-	R	55.2002	37.7162	120.6244	27.8884	151.2295	15.56986
336	80-	40-	15-	20-	D-	R	65.9887	34.287	122.4201	23.4002	149.2086	13.55678
337	80-	40-	15-	30-	D-	R	63.6306	34.904	121.8653	24.3458	149.4048	14.01192
338	80-	40-	15-	40-	D-	R	62.0929	35.0871	121.4442	24.8322	149.5269	14.24199
339	80-	40-	15-	50-	D-	R	61.2225	35.8677	121.6004	24.9678	150.5223	14.22747
340	80-	40-	15-	60-	D-	R	61.1216	36.1377	121.8046	24.7558	151.2128	14.06831
341	80-	40-	2-	20-	D-	R	72.4639	33.2606	124.742	19.2734	151.5965	11.27958
342	80-	40-	2-	30-	D-	R	70.7619	33.637	124.2522	20.0712	151.4787	11.69992
343	80-	40-	2-	40-	D-	R	69.7777	33.5483	123.8422	20.4446	151.2377	11.90839
344	80-	40-	2-	50-	D-	R	69.5491	34.0706	124.1227	20.4169	152.0379	11.83899
345	80-	40-	2-	60-	D-	R	70.1741	34.1022	124.5786	19.9132	152.7865	11.53054

346	80-	60-	1-	20-	D-	R	58.5843	35.914	120.5695	28.8022	147.088	16.3751
347	80-	60-	1-	30-	D-	R	56.7573	36.4116	120.2195	29.4258	147.4885	16.6328
348	80-	60-	1-	40-	D-	R	55.6585	37.3352	120.4284	29.59	148.7507	16.59184
349	80-	60-	1-	50-	D-	R	55.1816	37.6505	120.5024	29.4076	149.5343	16.43416
350	80-	60-	1-	60-	D-	R	55.0388	37.7195	120.5158	29.0909	150.0173	16.24208
351	80-	60-	15-	20-	D-	R	66.0406	34.1918	122.4105	24.2154	148.2785	14.03841
352	80-	60-	15-	30-	D-	R	63.6711	34.4576	121.6459	25.1418	148.1041	14.5122
353	80-	60-	15-	40-	D-	R	62.1593	35.3494	121.6152	25.6124	149.0145	14.66693
354	80-	60-	15-	50-	D-	R	61.281	35.7832	121.575	25.6872	149.6908	14.64676
355	80-	60-	15-	60-	D-	R	61.1963	36.0272	121.7744	25.4056	150.4288	14.44859
356	80-	60-	2-	20-	D-	R	72.5607	33.2287	124.7559	21.1058	149.7607	12.35222
357	80-	60-	2-	30-	D-	R	70.615	33.2343	123.9659	21.8824	149.2975	12.78328
358	80-	60-	2-	40-	D-	R	69.4222	33.8726	123.8861	22.223	149.9414	12.90801
359	80-	60-	2-	50-	D-	R	69.0351	34.0351	123.9078	22.1041	150.4681	12.80861
360	80-	60-	2-	60-	D-	R	69.5568	34.0446	124.3039	21.4965	151.2945	12.44075
361	60-	40-	1-	20-	S-	C	125.0752	29.3875	144.0858	27.4282	156.7448	14.89263
362	60-	40-	1-	30-	S-	C	122.107	30.9325	144.1775	28.0834	158.7129	15.03424
363	60-	40-	1-	40-	S-	C	120.2544	32.1852	144.4446	28.286	160.5499	14.97914
364	60-	40-	1-	50-	S-	C	119.5509	33.4366	144.9968	28.1519	162.4049	14.7735
365	60-	40-	1-	60-	S-	C	119.3856	34.118	145.4064	27.8891	163.6271	14.56227
366	60-	40-	15-	20-	S-	C	138.255	27.5386	147.2326	23.4003	156.2312	13.02684
367	60-	40-	15-	30-	S-	C	141.6393	27.9471	148.8565	24.346	158.0794	13.34573
368	60-	40-	15-	40-	S-	C	131.3267	28.8701	145.81	24.8321	157.6967	13.60448
369	60-	40-	15-	50-	S-	C	129.8705	29.7607	145.9502	24.9678	159.0505	13.56811
370	60-	40-	15-	60-	S-	C	129.7849	30.2363	146.3848	24.7558	160.1699	13.38689
371	60-	40-	2-	20-	S-	C	150.9638	26.8371	152.0934	19.2731	159.1991	10.79894
372	60-	40-	2-	30-	S-	C	147.2781	27.144	150.8746	20.0707	159.0511	11.20506
373	60-	40-	2-	40-	S-	C	144.9399	27.2915	150.2056	20.4445	159.2667	11.37631
374	60-	40-	2-	50-	S-	C	144.1345	27.7954	150.3269	20.4171	160.215	11.30314
375	60-	40-	2-	60-	S-	C	145.042	27.9486	151.0499	19.9132	161.3187	10.98769
376	60-	60-	1-	20-	S-	C	124.8369	29.3253	143.9819	28.8022	155.2726	15.64701
377	60-	60-	1-	30-	S-	C	121.7233	30.6357	143.893	29.426	157.0464	15.78035
378	60-	60-	1-	40-	S-	C	119.9146	32.2928	144.353	29.5902	159.3178	15.66382
379	60-	60-	1-	50-	S-	C	119.1804	33.3463	144.7849	29.4074	161.0194	15.44289
380	60-	60-	1-	60-	S-	C	119.0407	34.0775	145.2334	29.0909	162.3591	15.19504
381	60-	60-	15-	20-	S-	C	138.171	27.4873	147.2761	24.2154	155.3898	13.48257
382	60-	60-	15-	30-	S-	C	133.8201	27.9756	146.0589	25.1419	155.6984	13.90282
383	60-	60-	15-	40-	S-	C	131.1152	28.9359	145.7814	25.6124	156.9506	14.02935
384	60-	60-	15-	50-	S-	C	129.695	29.6138	145.8117	25.6872	158.1326	13.97412
385	60-	60-	15-	60-	S-	C	129.7813	30.0782	146.2882	25.4056	159.2885	13.7555
386	60-	60-	2-	20-	S-	C	149.7943	26.8355	151.6058	21.1058	157.3015	11.83012
387	60-	60-	2-	30-	S-	C	146.446	26.9246	150.385	21.8823	156.9235	12.23803
388	60-	60-	2-	40-	S-	C	144.5112	27.4295	149.9813	22.2231	157.4405	12.36928
389	60-	60-	2-	50-	S-	C	144.0783	27.6768	150.0488	22.1042	158.1101	12.26551
390	60-	60-	2-	60-	S-	C	145.4065	27.8271	150.884	21.4965	159.2171	11.89534
391	60-	40-	1-	20-	S-	L	64.3251	31.4378	120.5033	27.4282	143.1413	16.08037
392	60-	40-	1-	30-	S-	L	62.8257	32.7752	120.7601	28.0834	144.4353	16.27847
393	60-	40-	1-	40-	S-	L	61.8809	33.7149	121.0075	28.286	145.6001	16.26697
394	60-	40-	1-	50-	S-	L	61.5032	34.7668	121.5199	28.1515	147.1078	16.06277
395	60-	40-	1-	60-	S-	L	61.405	35.239	121.8294	27.8891	148.0568	15.85095

396	60-	40-	15-	20-	S-	L	70.9278	29.4904	121.7911	23.4003	143.4251	14.02682
397	60-	40-	15-	30-	S-	L	68.8038	30.2567	121.4446	24.346	143.8385	14.47577
398	60-	40-	15-	40-	S-	L	67.4575	30.7553	121.3357	24.8321	144.4059	14.67289
399	60-	40-	15-	50-	S-	L	66.7223	31.5906	121.6112	24.9678	145.514	14.64543
400	60-	40-	15-	60-	S-	L	66.6617	31.984	121.9433	24.7558	146.4087	14.46316
401	60-	40-	2-	20-	S-	L	77.2469	28.5549	124.2151	19.2731	146.0066	11.6609
402	60-	40-	2-	30-	S-	L	75.3993	28.94	123.6773	20.0707	145.9495	12.08931
403	60-	40-	2-	40-	S-	L	74.2253	29.0647	123.3632	20.4445	146.0662	12.27819
404	60-	40-	2-	50-	S-	L	73.7997	29.5914	123.5921	20.4171	146.9373	12.19992
405	60-	40-	2-	60-	S-	L	74.2452	29.705	124.0391	19.9132	147.8198	11.87196
406	60-	60-	1-	20-	S-	L	64.2027	31.3717	120.4096	28.8022	141.6879	16.89377
407	60-	60-	1-	30-	S-	L	62.6211	32.4536	120.497	29.426	142.7575	17.08991
408	60-	60-	1-	40-	S-	L	61.6987	33.882	120.9875	29.5902	144.458	17.00115
409	60-	60-	1-	50-	S-	L	61.3178	34.6991	121.368	29.4074	145.7665	16.78755
410	60-	60-	1-	60-	S-	L	61.2306	35.2066	121.7012	29.0909	146.8098	16.53825
411	60-	60-	15-	20-	S-	L	70.8739	29.417	121.7787	24.2154	142.5534	14.52034
412	60-	60-	15-	30-	S-	L	68.7108	29.545	121.0245	25.1419	142.2462	15.02012
413	60-	60-	15-	40-	S-	L	67.3487	30.8752	121.355	25.6124	143.7381	15.1239
414	60-	60-	15-	50-	S-	L	66.6292	31.4595	121.4993	25.6872	144.6427	15.08085
415	60-	60-	15-	60-	S-	L	66.6486	31.8496	121.8472	25.4056	145.5744	14.85881
416	60-	60-	2-	20-	S-	L	76.6443	28.5502	123.8996	21.1058	144.1514	12.77149
417	60-	60-	2-	30-	S-	L	74.9624	28.6621	123.2708	21.8823	143.8026	13.20718
418	60-	60-	2-	40-	S-	L	73.9995	29.2427	123.2295	22.2231	144.3501	13.34134
419	60-	60-	2-	50-	S-	L	73.7766	29.482	123.3545	22.1042	144.9471	13.23198
420	60-	60-	2-	60-	S-	L	74.4267	29.5761	123.8576	21.4965	145.8635	12.84447
421	60-	40-	1-	20-	S-	R	69.772	35.1393	126.1162	27.4282	158.8884	14.72129
422	60-	40-	1-	30-	S-	R	68.0906	36.0192	126.0789	28.0834	159.6822	14.95663
423	60-	40-	1-	40-	S-	R	67.0329	36.3177	126.0002	28.286	160.2497	15.00299
424	60-	40-	1-	50-	S-	R	66.6152	36.9815	126.2881	28.1515	161.3506	14.85551
425	60-	40-	1-	60-	S-	R	66.5091	37.0355	126.3084	27.8891	161.764	14.70532
426	60-	40-	15-	20-	S-	R	77.16	33.4166	127.5956	23.4003	159.2982	12.80815
427	60-	40-	15-	30-	S-	R	74.7587	34.0461	127.1407	24.346	159.5902	13.23611
428	60-	40-	15-	40-	S-	R	73.2629	34.2939	126.8483	24.8321	159.854	13.44557
429	60-	40-	15-	50-	S-	R	72.4409	35.0714	127.0346	24.9678	160.8449	13.43708
430	60-	40-	15-	60-	S-	R	72.3736	35.3478	127.2515	24.7558	161.542	13.28829
431	60-	40-	2-	20-	S-	R	84.143	32.3391	129.8036	19.2731	161.3902	10.66797
432	60-	40-	2-	30-	S-	R	82.0881	32.7091	129.3037	20.0707	161.4317	11.05809
433	60-	40-	2-	40-	S-	R	80.7788	32.6852	128.9116	20.4445	161.4219	11.24149
434	60-	40-	2-	50-	S-	R	80.3031	33.2046	129.1237	20.4171	162.2869	11.17496
435	60-	40-	2-	60-	S-	R	80.782	33.226	129.4924	19.9132	163.0327	10.88475
436	60-	60-	1-	20-	S-	R	69.64	35.0904	126.0434	28.8022	157.4618	15.46311
437	60-	60-	1-	30-	S-	R	67.8704	35.6628	125.8012	29.426	157.9646	15.70303
438	60-	60-	1-	40-	S-	R	66.838	36.6137	126.0572	29.5902	159.2498	15.66946
439	60-	60-	1-	50-	S-	R	66.412	36.9626	126.1742	29.4074	160.073	15.52002
440	60-	60-	1-	60-	S-	R	66.3188	37.0319	126.2082	29.0909	160.561	15.3391
441	60-	60-	15-	20-	S-	R	77.079	33.3398	127.5712	24.2154	158.4138	13.25933
442	60-	60-	15-	30-	S-	R	74.6617	33.6398	126.9348	25.1419	158.3929	13.69871
443	60-	60-	15-	40-	S-	R	73.1428	34.5275	126.9406	25.6124	159.326	13.84915
444	60-	60-	15-	50-	S-	R	72.3399	34.9763	126.9502	25.6872	160.016	13.83239
445	60-	60-	15-	60-	S-	R	72.3642	35.2418	127.1914	25.4056	160.7613	13.64668

446	60-	60-	2-	20-	S-	R	83.4881	32.3272	129.4964	21.1058	159.5332	11.68397
447	60-	60-	2-	30-	S-	R	81.6204	32.373	128.8699	21.8823	159.209	12.08357
448	60-	60-	2-	40-	S-	R	80.5431	32.9751	128.8524	22.2231	159.83	12.20693
449	60-	60-	2-	50-	S-	R	80.2879	33.1335	128.9142	22.1042	160.3207	12.11688
450	60-	60-	2-	60-	S-	R	80.9974	33.1554	129.3485	21.4965	161.1135	11.77181
451	60-	40-	1-	20-	D-	C	87.6538	30.4537	128.8434	27.4282	141.2527	16.26041
452	60-	40-	1-	30-	D-	C	85.5777	31.8897	128.9845	28.0834	142.777	16.43646
453	60-	40-	1-	40-	D-	C	84.2822	32.9758	129.2262	28.286	144.2104	16.39802
454	60-	40-	1-	50-	D-	C	83.7953	34.1322	129.7806	28.1515	145.8975	16.17447
455	60-	40-	1-	60-	D-	C	83.685	34.7075	130.1513	27.8891	146.9807	15.94849
456	60-	40-	15-	20-	D-	C	96.8854	28.5141	131.2939	23.4003	141.6355	14.17892
457	60-	40-	15-	30-	D-	C	93.8878	29.2779	130.5218	24.346	141.9553	14.63969
458	60-	40-	15-	40-	D-	C	92.0446	29.8462	130.2523	24.8321	142.617	14.82964
459	60-	40-	15-	50-	D-	C	91.0301	30.7167	130.4467	24.9678	143.8044	14.79379
460	60-	40-	15-	60-	D-	C	90.9716	31.1327	130.8272	24.7558	144.7864	14.60156
461	60-	40-	2-	20-	D-	C	105.724	27.6873	135.0998	19.2731	144.8511	11.743
462	60-	40-	2-	30-	D-	C	103.1563	28.0415	134.1744	20.0707	144.6135	12.18739
463	60-	40-	2-	40-	D-	C	101.5234	28.1798	133.642	20.4445	144.6775	12.38145
464	60-	40-	2-	50-	D-	C	100.9549	28.7033	133.8098	20.4171	145.5569	12.30138
465	60-	40-	2-	60-	D-	C	101.5699	28.8522	134.3988	19.9132	146.5717	11.96096
466	60-	60-	1-	20-	D-	C	87.4912	30.3851	128.7497	28.8022	139.7894	17.08401
467	60-	60-	1-	30-	D-	C	85.3122	31.5895	128.7115	29.426	141.1002	17.256
468	60-	60-	1-	40-	D-	C	84.0493	33.1226	129.1833	29.5902	143.0384	17.14096
469	60-	60-	1-	50-	D-	C	83.5396	34.0524	129.597	29.4074	144.529	16.90698
470	60-	60-	1-	60-	D-	C	83.4444	34.6648	129.9939	29.0909	145.71	16.64231
471	60-	60-	15-	20-	D-	C	96.8196	28.4532	131.3158	24.2154	140.7859	14.67588
472	60-	60-	15-	30-	D-	C	93.7799	28.9753	130.3809	25.1419	140.8704	15.1446
473	60-	60-	15-	40-	D-	C	91.8924	29.9327	130.245	25.6124	141.9041	15.28948
474	60-	60-	15-	50-	D-	C	90.9027	30.5629	130.3063	25.6872	142.8833	15.23825
475	60-	60-	15-	60-	D-	C	90.9624	30.9912	130.7312	25.4056	143.9319	15.00294
476	60-	60-	2-	20-	D-	C	104.919	27.6815	134.7006	21.1058	142.9527	12.8648
477	60-	60-	2-	30-	D-	C	102.5868	27.791	133.7298	21.8823	142.4601	13.31507
478	60-	60-	2-	40-	D-	C	101.2354	28.3345	133.4801	22.2231	142.918	13.45704
479	60-	60-	2-	50-	D-	C	100.9283	28.5903	133.5665	22.1042	143.5317	13.34505
480	60-	60-	2-	60-	D-	C	101.8335	28.7071	134.2266	21.4965	144.5489	12.94616
481	60-	40-	1-	20-	D-	L	43.2207	32.1474	110.2553	27.4282	135.2727	16.85805
482	60-	40-	1-	30-	D-	L	42.157	33.3956	110.5518	28.0834	136.3018	17.0839
483	60-	40-	1-	40-	D-	L	41.4875	34.2224	110.8006	28.286	137.2545	17.08706
484	60-	40-	1-	50-	D-	L	41.2259	35.2091	111.3098	28.1515	138.6541	16.87683
485	60-	40-	1-	60-	D-	L	41.1614	35.6046	111.58	27.8891	139.4946	16.66178
486	60-	40-	15-	20-	D-	L	47.8511	30.2118	111.0284	23.4003	136.0766	14.67316
487	60-	40-	15-	30-	D-	L	46.3602	30.9586	110.8553	24.346	136.3344	15.15182
488	60-	40-	15-	40-	D-	L	45.4215	31.4122	110.8224	24.8321	136.7316	15.36985
489	60-	40-	15-	50-	D-	L	44.9035	32.2377	111.1435	24.9678	137.7577	15.34351
490	60-	40-	15-	60-	D-	L	44.8574	32.5998	111.4328	24.7558	138.5625	15.15801
491	60-	40-	2-	20-	D-	L	52.183	29.2154	112.6372	19.2731	138.7075	12.19966
492	60-	40-	2-	30-	D-	L	50.9031	29.6126	112.3115	20.0707	138.604	12.64896
493	60-	40-	2-	40-	D-	L	50.0816	29.7188	112.0967	20.4445	138.6358	12.85169
494	60-	40-	2-	50-	D-	L	49.7744	30.2374	112.3317	20.4171	139.4321	12.77273
495	60-	40-	2-	60-	D-	L	50.0491	30.3283	112.6562	19.9132	140.2344	12.43428

496	60-	60-	1-	20-	D-	L	43.1464	32.0738	110.1855	28.8022	133.8359	17.70938
497	60-	60-	1-	30-	D-	L	42.027	33.0803	110.3147	29.426	134.6354	17.93597
498	60-	60-	1-	40-	D-	L	41.374	34.4238	110.8244	29.5902	136.1545	17.85288
499	60-	60-	1-	50-	D-	L	41.1052	35.1556	111.1902	29.4074	137.3336	17.63657
500	60-	60-	1-	60-	D-	L	41.0483	35.582	111.481	29.0909	138.2666	17.38249
501	60-	60-	15-	20-	D-	L	47.8161	30.1372	111.0118	24.2154	135.1994	15.19018
502	60-	60-	15-	30-	D-	L	46.3003	30.6169	110.6793	25.1419	135.2002	15.68016
503	60-	60-	15-	40-	D-	L	45.3469	31.5475	110.8582	25.6124	136.0851	15.8397
504	60-	60-	15-	50-	D-	L	44.8415	32.0978	111.0347	25.6872	136.8795	15.80102
505	60-	60-	15-	60-	D-	L	44.8534	32.4606	111.3437	25.4056	137.7456	15.57181
506	60-	60-	2-	20-	D-	L	51.7918	29.2124	112.4071	21.1058	136.8616	13.36086
507	60-	60-	2-	30-	D-	L	50.63	29.3154	111.961	21.8823	136.4502	13.82047
508	60-	60-	2-	40-	D-	L	49.9531	29.9038	112.0151	22.2231	136.9523	13.96139
509	60-	60-	2-	50-	D-	L	49.7834	30.1364	112.1354	22.1042	137.5007	13.84932
510	60-	60-	2-	60-	D-	L	50.2023	30.2056	112.4922	21.4965	138.3381	13.44922
511	60-	40-	1-	20-	D-	R	51.6005	36.5674	117.3894	27.4282	146.3247	15.78575
512	60-	40-	1-	30-	D-	R	50.3181	37.2012	117.2909	28.0834	146.7332	16.06449
513	60-	40-	1-	40-	D-	R	49.5101	37.2479	117.1034	28.286	146.9163	16.14477
514	60-	40-	1-	50-	D-	R	49.1912	37.7264	117.2904	28.1515	147.7478	16.00433
515	60-	40-	1-	60-	D-	R	49.1106	37.7237	117.2682	27.8891	148.0605	15.85062
516	60-	40-	15-	20-	D-	R	57.1722	35.0216	118.7776	23.4003	147.6047	13.68399
517	60-	40-	15-	30-	D-	R	55.3789	35.6083	118.3615	24.346	147.6272	14.15686
518	60-	40-	15-	40-	D-	R	54.2463	35.7656	118.0194	24.8321	147.591	14.40184
519	60-	40-	15-	50-	D-	R	53.6211	36.487	118.1977	24.9678	148.4409	14.39824
520	60-	40-	15-	60-	D-	R	53.5636	36.6938	118.3551	24.7558	149.0126	14.24643
521	60-	40-	2-	20-	D-	R	62.3893	33.9759	120.6966	19.2731	150.1675	11.37455
522	60-	40-	2-	30-	D-	R	60.8466	34.3226	120.2498	20.0707	150.0247	11.79967
523	60-	40-	2-	40-	D-	R	59.857	34.2458	119.8366	20.4445	149.8051	12.00855
524	60-	40-	2-	50-	D-	R	59.4856	34.77	120.0468	20.4171	150.6065	11.93818
525	60-	40-	2-	60-	D-	R	59.8174	34.8051	120.3494	19.9132	151.3262	11.62887
526	60-	60-	1-	20-	D-	R	51.511	36.5372	117.3352	28.8022	144.9218	16.57929
527	60-	60-	1-	30-	D-	R	50.1612	36.8411	117.0076	29.426	144.9883	16.87132
528	60-	60-	1-	40-	D-	R	49.3729	37.6017	117.2142	29.5902	145.9983	16.85201
529	60-	60-	1-	50-	D-	R	49.0466	37.7322	117.2025	29.4074	146.5005	16.7175
530	60-	60-	1-	60-	D-	R	48.9756	37.7307	117.1812	29.0909	146.8651	16.53305
531	60-	60-	15-	20-	D-	R	57.1305	34.9636	118.777	24.2154	146.7542	14.16357
532	60-	60-	15-	30-	D-	R	55.3065	35.2	118.1413	25.1419	146.4101	14.65556
533	60-	60-	15-	40-	D-	R	54.1574	36.0569	118.1593	25.6124	147.1474	14.82544
534	60-	60-	15-	50-	D-	R	53.5473	36.4199	118.1328	25.6872	147.6499	14.81922
535	60-	60-	15-	60-	D-	R	53.5596	36.6028	118.3079	25.4056	148.2664	14.6285
536	60-	60-	2-	20-	D-	R	61.9164	33.9958	120.4532	21.1058	148.3458	12.45536
537	60-	60-	2-	30-	D-	R	60.5158	34.341	120.0356	21.8823	148.1791	12.86729
538	60-	60-	2-	40-	D-	R	59.701	34.5843	119.8487	22.2231	148.3131	13.03131
539	60-	60-	2-	50-	D-	R	59.4964	34.7294	119.8842	22.1042	148.7324	12.9388
540	60-	60-	2-	60-	D-	R	60.0021	34.7441	120.2309	21.4965	149.4898	12.57206

Combinations of south-west-facing façade

Simulated scenarios							Solar gain (MWh)	Lighting gain (MWh)	Cooling plant sensible load (MWh)	PV-generated electricity	Net Energy	Enrgy saving
No.	WWR	Depth	d/l	Angle	Glazing	Glass	South-west	South-west	South-west	South-west	South-west	South-west
1	100-	40-	1-	20-	S-	C	160.3143	27.2858	156.8488	26.9348	164.6981	14.05542
2	100-	40-	1-	30-	S-	C	154.5718	28.5365	156.3332	27.5986	166.5427	14.21573
3	100-	40-	1-	40-	S-	C	151.7184	31.5286	157.6081	27.7482	170.1239	14.0233
4	100-	40-	1-	50-	S-	C	150.0787	32.5344	154.1763	27.6387	172.1215	13.83594
5	100-	40-	1-	60-	S-	C	149.6345	32.7445	157.7771	27.3607	172.5123	13.68904
6	100-	40-	15-	20-	S-	C	180.7092	26.1472	161.0087	23.0006	164.6216	12.259
7	100-	40-	15-	30-	S-	C	173.9938	26.6696	159.4789	23.9029	164.8168	12.66582
8	100-	40-	15-	40-	S-	C	169.302	26.9538	158.6091	24.4021	165.4431	12.85368
9	100-	40-	15-	50-	S-	C	166.7912	27.736	158.4501	24.5194	166.4893	12.8368
10	100-	40-	15-	60-	S-	C	166.4107	28.2797	158.8601	24.2847	167.6817	12.6505
11	100-	40-	2-	20-	S-	C	200.7118	25.8684	167.5252	18.9487	168.4997	10.10876
12	100-	40-	2-	30-	S-	C	194.958	26.1821	165.8869	19.6953	168.1256	10.48621
13	100-	40-	2-	40-	S-	C	191.3465	26.1372	164.9539	20.081	168.0818	10.67214
14	100-	40-	2-	50-	S-	C	189.9614	26.5021	164.8031	20.0473	168.5479	10.6298
15	100-	40-	2-	60-	S-	C	191.1729	26.6292	165.5697	19.586	169.4979	10.35836
16	100-	60-	1-	20-	S-	C	159.4333	27.2491	156.3719	28.3032	163.0645	14.78996
17	100-	60-	1-	30-	S-	C	153.8464	28.3269	155.9856	28.9354	165.0709	14.91467
18	100-	60-	1-	40-	S-	C	151.0096	30.157	156.3327	29.0565	167.437	14.78751
19	100-	60-	1-	50-	S-	C	149.4169	31.64	156.902	28.8836	169.7717	14.53956
20	100-	60-	1-	60-	S-	C	148.9515	33.9587	158.1989	28.5475	173.0153	14.16308
21	100-	60-	15-	20-	S-	C	181.0561	26.3313	161.1638	23.812	163.8886	12.68616
22	100-	60-	15-	30-	S-	C	174.3173	26.4563	159.5357	24.6926	163.9082	13.09252
23	100-	60-	15-	40-	S-	C	169.5791	27.1019	158.6142	25.1713	164.495	13.27136
24	100-	60-	15-	50-	S-	C	167.0063	27.6643	158.4214	25.231	165.5826	13.22285
25	100-	60-	15-	60-	S-	C	166.7171	28.194	158.8713	24.9292	166.857	12.99843
26	100-	60-	2-	20-	S-	C	200.5573	26.0619	167.3242	20.7671	166.6357	11.08153
27	100-	60-	2-	30-	S-	C	194.7174	25.9834	165.6105	21.5119	166.1179	11.46508
28	100-	60-	2-	40-	S-	C	190.9103	26.3316	164.6489	21.8452	166.1529	11.6199
29	100-	60-	2-	50-	S-	C	189.3495	27.7481	165.2507	21.7155	168.2538	11.43106
30	100-	60-	2-	60-	S-	C	190.5144	27.8971	166.0635	21.1473	169.3985	11.09828
31	100-	40-	1-	20-	S-	L	82.5697	28.5656	127.9953	26.9348	146.8923	15.49517
32	100-	40-	1-	30-	S-	L	79.6919	30.6597	128.3985	27.5986	149.2561	15.60524
33	100-	40-	1-	40-	S-	L	78.2333	32.1097	128.8459	27.7482	151.1464	15.51092
34	100-	40-	1-	50-	S-	L	77.4029	32.9907	129.15	27.6387	152.5044	15.34264
35	100-	40-	1-	60-	S-	L	77.1521	34.1957	129.8613	27.3607	154.3685	15.05575
36	100-	40-	15-	20-	S-	L	92.7544	27.3014	130.1962	23.0006	147.4866	13.4911
37	100-	40-	15-	30-	S-	L	89.3828	28.3902	129.7211	23.9029	148.2407	13.88544
38	100-	40-	15-	40-	S-	L	87.0422	29.0473	129.4473	24.4021	148.9656	14.07534
39	100-	40-	15-	50-	S-	L	85.7728	29.703	129.5598	24.5194	149.9917	14.05034
40	100-	40-	15-	60-	S-	L	85.5804	30.2153	129.9499	24.2847	151.0672	13.84912
41	100-	40-	2-	20-	S-	L	102.6542	27.1316	134.126	18.9487	151.1607	11.13913
42	100-	40-	2-	30-	S-	L	99.7702	27.5956	133.3022	19.6953	151.0494	11.53494
43	100-	40-	2-	40-	S-	L	97.9661	27.8348	132.8539	20.081	151.1372	11.72831
44	100-	40-	2-	50-	S-	L	97.2816	28.0674	132.8821	20.0473	151.6616	11.67517
45	100-	40-	2-	60-	S-	L	97.886	28.2389	133.4406	19.586	152.5637	11.37731

46	100-	60-	1-	20-	S-	L	82.157	29.1774	128.0534	28.3032	146.0638	16.23197
47	100-	60-	1-	30-	S-	L	79.3266	30.6933	128.2046	28.9354	147.9015	16.36276
48	100-	60-	1-	40-	S-	L	77.8747	32.11	128.6446	29.0565	149.7973	16.24595
49	100-	60-	1-	50-	S-	L	77.0612	33.3209	129.1682	28.8836	151.6404	15.99987
50	100-	60-	1-	60-	S-	L	76.8081	34.1868	129.656	28.5475	153.1359	15.71277
51	100-	60-	15-	20-	S-	L	92.9253	27.8133	130.5258	23.812	147.184	13.92547
52	100-	60-	15-	30-	S-	L	89.5304	28.3312	129.7202	24.6926	147.3298	14.35429
53	100-	60-	15-	40-	S-	L	87.1697	28.9778	129.418	25.1713	148.0475	14.53151
54	100-	60-	15-	50-	S-	L	85.8825	29.6312	129.522	25.231	149.132	14.47039
55	100-	60-	15-	60-	S-	L	85.7277	30.119	129.9205	24.9292	150.2573	14.23009
56	100-	60-	2-	20-	S-	L	102.58	27.3685	134.0376	20.7671	149.429	12.20187
57	100-	60-	2-	30-	S-	L	99.6537	27.5864	133.1025	21.5119	149.1034	12.60842
58	100-	60-	2-	40-	S-	L	97.7692	27.8242	132.6472	21.8452	149.2724	12.76619
59	100-	60-	2-	50-	S-	L	97.0121	28.0595	132.6782	21.7155	149.9293	12.65142
60	100-	60-	2-	60-	S-	L	97.582	28.2185	133.2424	21.1473	150.9562	12.28755
61	100-	40-	1-	20-	S-	R	89.5643	33.2404	134.6821	26.9348	166.4035	13.93144
62	100-	40-	1-	30-	S-	R	86.4247	34.7621	134.7779	27.5986	168.1269	14.10067
63	100-	40-	1-	40-	S-	R	84.844	35.6746	134.924	27.7482	169.3869	14.07573
64	100-	40-	1-	50-	S-	R	83.9411	36.3209	135.1168	27.6387	170.4979	13.94932
65	100-	40-	1-	60-	S-	R	83.6796	36.7122	135.3279	27.3607	171.3745	13.76742
66	100-	40-	15-	20-	S-	R	100.6455	31.5355	136.2772	23.0007	165.9679	12.1717
67	100-	40-	15-	30-	S-	R	96.9981	32.5751	135.957	23.9029	166.9293	12.52561
68	100-	40-	15-	40-	S-	R	94.4465	33.1859	135.7218	24.4021	167.7071	12.7022
69	100-	40-	15-	50-	S-	R	93.0679	33.6881	135.7407	24.5194	168.554	12.69952
70	100-	40-	15-	60-	S-	R	92.8547	34.0187	135.982	24.2847	169.3681	12.54033
71	100-	40-	2-	20-	S-	R	111.4213	30.594	139.1888	18.9487	168.0079	10.13535
72	100-	40-	2-	30-	S-	R	108.2906	31.3021	138.6905	19.6953	168.4303	10.46923
73	100-	40-	2-	40-	S-	R	106.3265	31.6211	138.4048	20.081	168.7744	10.633
74	100-	40-	2-	50-	S-	R	105.5723	31.8538	138.4761	20.0473	169.3696	10.58369
75	100-	40-	2-	60-	S-	R	106.2146	31.9426	138.9406	19.586	170.1369	10.32348
76	100-	60-	1-	20-	S-	R	89.1122	33.5453	134.5889	28.3032	165.2559	14.62251
77	100-	60-	1-	30-	S-	R	86.036	34.7497	134.5715	28.9354	166.7264	14.78848
78	100-	60-	1-	40-	S-	R	84.4628	35.6656	134.7196	29.0565	168.0179	14.74392
79	100-	60-	1-	50-	S-	R	83.5801	36.3102	134.9333	28.8836	169.223	14.57983
80	100-	60-	1-	60-	S-	R	83.3114	36.7116	135.1403	28.5475	170.1591	14.36666
81	100-	60-	15-	20-	S-	R	100.8482	31.7748	136.4383	23.812	165.3291	12.58954
82	100-	60-	15-	30-	S-	R	97.1648	32.4794	135.9327	24.6926	165.965	12.95128
83	100-	60-	15-	40-	S-	R	94.5911	33.0943	135.6835	25.1713	166.7601	13.11474
84	100-	60-	15-	50-	S-	R	93.1883	33.5875	135.6909	25.231	167.6635	13.08021
85	100-	60-	15-	60-	S-	R	93.0178	33.9106	135.9459	24.9292	168.5392	12.88541
86	100-	60-	2-	20-	S-	R	111.3483	30.9431	139.1749	20.7671	166.4013	11.09541
87	100-	60-	2-	30-	S-	R	108.1705	31.3192	138.5276	21.5119	166.5283	11.44005
88	100-	60-	2-	40-	S-	R	106.1114	31.6167	138.2241	21.8452	166.9347	11.57178
89	100-	60-	2-	50-	S-	R	105.2711	31.8229	138.2753	21.7155	167.6259	11.46897
90	100-	60-	2-	60-	S-	R	105.8773	31.8805	138.7339	21.1473	168.4918	11.15134
91	100-	40-	1-	20-	D-	C	112.4249	28.0006	138.8371	26.9348	145.2767	15.64054
92	100-	40-	1-	30-	D-	C	108.3555	29.6154	138.6093	27.5986	147.1784	15.79075
93	100-	40-	1-	40-	D-	C	106.3407	31.1435	138.9765	27.7482	149.2811	15.67435
94	100-	40-	1-	50-	D-	C	105.1847	32.4802	139.5034	27.6387	151.29	15.44677
95	100-	40-	1-	60-	D-	C	104.8794	33.4813	140.0899	27.3607	152.9551	15.17377

96	100-	40-	15-	20-	D-	C	126.8786	26.8595	142.7161	23.0006	146.3414	13.58234
97	100-	40-	15-	30-	D-	C	122.1347	27.5005	141.4141	23.9029	146.4087	14.0348
98	100-	40-	15-	40-	D-	C	118.8169	28.0734	140.7039	24.4021	146.9471	14.24115
99	100-	40-	15-	50-	D-	C	117.0457	28.7211	140.6312	24.5194	147.9447	14.2171
100	100-	40-	15-	60-	D-	C	116.7757	29.2601	141.0465	24.2847	149.112	14.00528
101	100-	40-	2-	20-	D-	C	140.9296	26.4759	148.4555	18.9487	150.6329	11.17379
102	100-	40-	2-	30-	D-	C	136.8743	26.863	147.0488	19.6953	150.2069	11.59214
103	100-	40-	2-	40-	D-	C	134.3247	27.0583	146.2493	20.081	150.1218	11.79828
104	100-	40-	2-	50-	D-	C	133.3383	27.2586	146.144	20.0473	150.5855	11.7488
105	100-	40-	2-	60-	D-	C	134.1659	27.4175	146.827	19.586	151.5581	11.44416
106	100-	60-	1-	20-	D-	C	111.8171	28.1878	138.5451	28.3032	143.8965	16.43627
107	100-	60-	1-	30-	D-	C	107.8649	29.6459	138.3566	28.9354	145.7772	16.56171
108	100-	60-	1-	40-	D-	C	105.8639	31.1459	138.7293	29.0565	147.9039	16.41978
109	100-	60-	1-	50-	D-	C	104.743	32.4818	139.2814	28.8836	150.0079	16.14588
110	100-	60-	1-	60-	D-	C	104.419	33.4748	139.8408	28.5475	151.703	15.83768
111	100-	60-	15-	20-	D-	C	127.1162	27.0405	142.8852	23.812	145.6674	14.05009
112	100-	60-	15-	30-	D-	C	122.3615	27.4538	141.4686	24.6926	145.5243	14.50655
113	100-	60-	15-	40-	D-	C	119.0168	28.0167	140.7182	25.1713	146.0376	14.7021
114	100-	60-	15-	50-	D-	C	117.2019	28.6508	140.6238	25.231	147.0907	14.6418
115	100-	60-	15-	60-	D-	C	116.9952	29.1688	141.0533	24.9292	148.3037	14.39057
116	100-	60-	2-	20-	D-	C	140.8616	26.6872	148.3386	20.7671	148.8544	12.2432
117	100-	60-	2-	30-	D-	C	136.7446	26.853	146.8324	21.5119	148.2415	12.67244
118	100-	60-	2-	40-	D-	C	134.0531	27.0399	146.0015	21.8452	148.2229	12.84497
119	100-	60-	2-	50-	D-	C	132.9381	27.2383	145.8764	21.7155	148.8079	12.73462
120	100-	60-	2-	60-	D-	C	133.7257	27.3995	146.5782	21.1473	149.9273	12.36145
121	100-	40-	1-	20-	D-	L	55.4573	29.7098	115.4863	26.9348	137.3316	16.39702
122	100-	40-	1-	30-	D-	L	53.4342	31.4342	115.8369	27.5986	139.0862	16.55736
123	100-	40-	1-	40-	D-	L	52.4202	32.8043	116.318	27.7482	140.7692	16.46607
124	100-	40-	1-	50-	D-	L	51.8412	33.9092	116.8266	27.6387	142.364	16.2578
125	100-	40-	1-	60-	D-	L	51.6799	34.6923	117.3118	27.3607	143.7155	15.99328
126	100-	40-	15-	20-	D-	L	62.572	28.2282	116.9035	23.0006	138.1258	14.27488
127	100-	40-	15-	30-	D-	L	60.2386	29.098	116.5668	23.9029	138.5554	14.71325
128	100-	40-	15-	40-	D-	L	58.6071	29.7873	116.4791	24.4021	139.2414	14.91174
129	100-	40-	15-	50-	D-	L	57.7236	30.4374	116.6693	24.5194	140.2011	14.88546
130	100-	40-	15-	60-	D-	L	57.5788	30.9105	117.03	24.2847	141.2048	14.67447
131	100-	40-	2-	20-	D-	L	69.3197	27.6681	119.5544	18.9487	141.3212	11.82299
132	100-	40-	2-	30-	D-	L	67.3374	28.1736	119.0392	19.6953	141.2768	12.23523
133	100-	40-	2-	40-	D-	L	66.0854	28.4463	118.7642	20.081	141.3943	12.43596
134	100-	40-	2-	50-	D-	L	65.5898	28.7071	118.8377	20.0473	141.9291	12.37668
135	100-	40-	2-	60-	D-	L	65.9617	28.8664	119.2648	19.586	142.7824	12.06269
136	100-	60-	1-	20-	D-	L	55.1915	29.9558	115.4099	28.3032	136.1164	17.21401
137	100-	60-	1-	30-	D-	L	53.213	31.4521	115.7092	28.9354	137.7434	17.35998
138	100-	60-	1-	40-	D-	L	52.2036	32.8062	116.1894	29.0565	139.4523	17.24331
139	100-	60-	1-	50-	D-	L	51.6373	33.8944	116.6986	28.8836	141.1083	16.99116
140	100-	60-	1-	60-	D-	L	51.4692	34.6874	117.1689	28.5475	142.5062	16.6892
141	100-	60-	15-	20-	D-	L	62.6909	28.4331	117.0378	23.812	137.4767	14.76359
142	100-	60-	15-	30-	D-	L	60.3485	29.0263	116.5585	24.6926	137.6494	15.21024
143	100-	60-	15-	40-	D-	L	58.7053	29.7089	116.45	25.1713	138.3364	15.39457
144	100-	60-	15-	50-	D-	L	57.8068	30.3484	116.6256	25.231	139.343	15.3311
145	100-	60-	15-	60-	D-	L	57.6899	30.8175	116.9967	24.9292	140.4119	15.07744

146	100-	60-	2-	20-	D-	L	69.3121	27.9147	119.5333	20.7671	139.6382	12.94664
147	100-	60-	2-	30-	D-	L	67.2968	28.1722	118.9007	21.5119	139.3742	13.37089
148	100-	60-	2-	40-	D-	L	65.9791	28.4483	118.62	21.8452	139.5749	13.53313
149	100-	60-	2-	50-	D-	L	65.4235	28.6866	118.6786	21.7155	140.2113	13.41069
150	100-	60-	2-	60-	D-	L	65.7692	28.8471	119.1108	21.1473	141.1923	13.02658
151	100-	40-	1-	20-	D-	R	66.2215	34.9766	124.1755	26.9348	151.0405	15.13401
152	100-	40-	1-	30-	D-	R	63.8346	36.3022	124.2161	27.5986	152.3787	15.33449
153	100-	40-	1-	40-	D-	R	62.6346	36.9652	124.2757	27.7482	153.3112	15.32547
154	100-	40-	1-	50-	D-	R	61.9499	37.3921	124.3776	27.6387	154.1487	15.20386
155	100-	40-	1-	60-	D-	R	61.7555	37.5752	124.4647	27.3607	154.751	15.02413
156	100-	40-	15-	20-	D-	R	74.6247	33.3425	125.7643	23.0006	151.4898	13.18158
157	100-	40-	15-	30-	D-	R	71.8642	34.355	125.4598	23.9029	152.1963	13.57354
158	100-	40-	15-	40-	D-	R	69.9366	34.8947	125.1997	24.4021	152.7108	13.77771
159	100-	40-	15-	50-	D-	R	68.8919	35.3223	125.1831	24.5194	153.3701	13.7835
160	100-	40-	15-	60-	D-	R	68.7225	35.5926	125.3699	24.2847	154.0735	13.61569
161	100-	40-	2-	20-	D-	R	82.6202	32.3392	128.3802	18.9487	153.9588	10.95887
162	100-	40-	2-	30-	D-	R	80.273	33.0847	127.9642	19.6953	154.2862	11.32034
163	100-	40-	2-	40-	D-	R	78.7928	33.3806	127.6731	20.081	154.4828	11.50353
164	100-	40-	2-	50-	D-	R	78.2105	33.5724	127.6937	20.0473	154.9535	11.45555
165	100-	40-	2-	60-	D-	R	78.6579	33.621	128.0666	19.586	155.657	11.17648
166	100-	60-	1-	20-	D-	R	65.9063	35.3222	124.1596	28.3032	149.9656	15.8767
167	100-	60-	1-	30-	D-	R	63.5686	36.3	124.0529	28.9354	150.9974	16.08123
168	100-	60-	1-	40-	D-	R	62.374	36.9683	124.1098	29.0565	151.9575	16.05207
169	100-	60-	1-	50-	D-	R	61.7038	37.4039	124.2338	28.8836	152.896	15.88935
170	100-	60-	1-	60-	D-	R	61.5027	37.5813	124.309	28.5475	153.542	15.67773
171	100-	60-	15-	20-	D-	R	74.7666	33.6315	125.9599	23.812	150.9421	13.626
172	100-	60-	15-	30-	D-	R	71.9938	34.2732	125.4493	24.6926	151.2727	14.03265
173	100-	60-	15-	40-	D-	R	70.0518	34.8141	125.1756	25.1713	151.8011	14.22329
174	100-	60-	15-	50-	D-	R	68.9903	35.2401	125.1486	25.231	152.5178	14.19475
175	100-	60-	15-	60-	D-	R	68.8532	35.5132	125.3578	24.9292	153.3043	13.98682
176	100-	60-	2-	20-	D-	R	82.6063	32.7197	128.4432	20.7671	152.4434	11.98952
177	100-	60-	2-	30-	D-	R	80.2204	33.0817	127.8281	21.5119	152.3886	12.37023
178	100-	60-	2-	40-	D-	R	78.6649	33.3455	127.5058	21.8452	152.6215	12.52113
179	100-	60-	2-	50-	D-	R	78.0138	33.5155	127.5033	21.7155	153.1833	12.41604
180	100-	60-	2-	60-	D-	R	78.4302	33.5383	127.8639	21.1473	153.9797	12.07541
181	80-	40-	1-	20-	S-	C	142.2286	27.9011	150.7196	26.934	161.0654	14.32664
182	80-	40-	1-	30-	S-	C	137.8131	29.7095	150.7479	27.5944	163.4095	14.44703
183	80-	40-	1-	40-	S-	C	135.6473	31.277	151.1843	27.7467	165.6072	14.35021
184	80-	40-	1-	50-	S-	C	134.4756	32.5713	151.7106	27.6383	167.5619	14.15895
185	80-	40-	1-	60-	S-	C	134.2007	33.486	152.2404	27.3606	169.0998	13.92678
186	80-	40-	15-	20-	S-	C	159.2321	26.5207	154.2115	23.0001	160.8693	12.50893
187	80-	40-	15-	30-	S-	C	153.7998	27.2053	153.0776	23.9025	161.3004	12.90612
188	80-	40-	15-	40-	S-	C	150.0663	27.8567	152.5325	24.4018	162.1542	13.08015
189	80-	40-	15-	50-	S-	C	148.0803	28.5761	152.5651	24.5193	163.3691	13.04993
190	80-	40-	15-	60-	S-	C	147.842	29.1404	153.0134	24.2863	164.5781	12.85912
191	80-	40-	2-	20-	S-	C	175.0126	26.077	159.3286	18.9363	164.1766	10.34132
192	80-	40-	2-	30-	S-	C	170.8779	26.4485	158.1517	19.6944	163.895	10.72742
193	80-	40-	2-	40-	S-	C	168.5326	26.6511	157.5835	20.0808	163.9178	10.91356
194	80-	40-	2-	50-	S-	C	167.9613	26.88	157.6975	20.0473	164.4615	10.86523
195	80-	40-	2-	60-	S-	C	169.4592	27.0516	158.5706	19.586	165.4287	10.58619

196	80-	60-	1-	20-	S-	C	141.9052	27.9882	150.5555	28.303	159.622	15.0608
197	80-	60-	1-	30-	S-	C	137.5187	29.5695	150.5313	28.9353	161.8425	15.16702
198	80-	60-	1-	40-	S-	C	135.3236	31.1688	150.9743	29.0563	164.1119	15.04197
199	80-	60-	1-	50-	S-	C	134.1591	32.5175	151.5493	28.8834	166.2333	14.80314
200	80-	60-	1-	60-	S-	C	133.8016	33.4667	152.0543	28.5476	167.8527	14.53542
201	80-	60-	15-	20-	S-	C	159.4593	26.6589	154.3681	23.812	160.1433	12.94445
202	80-	60-	15-	30-	S-	C	153.981	27.1248	153.1024	24.6925	160.3695	13.34283
203	80-	60-	15-	40-	S-	C	150.2763	27.7743	152.5377	25.1714	161.2147	13.50498
204	80-	60-	15-	50-	S-	C	148.2847	28.4723	152.55	25.2301	162.4581	13.44256
205	80-	60-	15-	60-	S-	C	148.124	29.0185	153.0206	24.9292	163.7298	13.21389
206	80-	60-	2-	20-	S-	C	175.1277	26.2683	159.4373	20.7671	162.5043	11.33134
207	80-	60-	2-	30-	S-	C	170.5176	26.4453	158.0625	21.5119	162.118	11.71481
208	80-	60-	2-	40-	S-	C	167.6894	26.6661	157.3844	21.8452	162.2784	11.86442
209	80-	60-	2-	50-	S-	C	166.7035	26.8834	157.3748	21.7155	162.9404	11.75998
210	80-	60-	2-	60-	S-	C	167.9212	27.0483	158.1588	21.1472	164.0295	11.42001
211	80-	40-	1-	20-	S-	L	73.2012	30.0149	124.5192	26.934	145.5757	15.61304
212	80-	40-	1-	30-	S-	L	70.9772	31.7446	124.8551	27.5944	147.4045	15.76833
213	80-	40-	1-	40-	S-	L	69.8761	33.0714	125.3116	27.7467	149.0718	15.69219
214	80-	40-	1-	50-	S-	L	69.2847	34.0871	125.7729	27.6383	150.5678	15.50918
215	80-	40-	1-	60-	S-	L	69.1262	34.786	126.2036	27.3606	151.8138	15.27037
216	80-	40-	15-	20-	S-	L	81.6112	28.2037	126.0476	23.0001	145.7742	13.62773
217	80-	40-	15-	30-	S-	L	78.8929	29.1315	125.6844	23.9025	146.3632	14.03835
218	80-	40-	15-	40-	S-	L	77.0431	29.8761	125.5959	24.4018	147.1614	14.22321
219	80-	40-	15-	50-	S-	L	76.0528	30.5587	125.7863	24.5193	148.1845	14.19731
220	80-	40-	15-	60-	S-	L	75.9318	31.0281	126.1543	24.2863	149.1808	14.00052
221	80-	40-	2-	20-	S-	L	89.3482	27.516	128.8075	18.9363	148.6627	11.29858
222	80-	40-	2-	30-	S-	L	87.2858	28.0438	128.2897	19.6944	148.6162	11.70122
223	80-	40-	2-	40-	S-	L	86.1224	28.3399	128.0769	20.0808	148.7469	11.89426
224	80-	40-	2-	50-	S-	L	85.8444	28.6088	128.2594	20.0473	149.2962	11.83825
225	80-	40-	2-	60-	S-	L	86.5741	28.7902	128.8517	19.586	150.1757	11.53735
226	80-	60-	1-	20-	S-	L	73.0338	30.1114	124.4365	28.303	144.2202	16.40533
227	80-	60-	1-	30-	S-	L	70.8262	31.6429	124.6996	28.9353	145.9141	16.5487
228	80-	60-	1-	40-	S-	L	69.7109	32.9899	125.1599	29.0563	147.6419	16.44403
229	80-	60-	1-	50-	S-	L	69.11	34.0504	125.6511	28.8834	149.2763	16.21208
230	80-	60-	1-	60-	S-	L	68.9251	34.7746	126.0732	28.5476	150.5951	15.93568
231	80-	60-	15-	20-	S-	L	81.6951	28.3493	126.1484	23.812	145.0641	14.10028
232	80-	60-	15-	30-	S-	L	78.966	29.0197	125.6419	24.6925	145.405	14.51667
233	80-	60-	15-	40-	S-	L	77.1307	29.7667	125.5504	25.1714	146.2235	14.6862
234	80-	60-	15-	50-	S-	L	76.1448	30.4419	125.7402	25.2301	147.3032	14.62332
235	80-	60-	15-	60-	S-	L	76.0573	30.9022	126.115	24.9292	148.3576	14.38609
236	80-	60-	2-	20-	S-	L	89.3981	27.7571	128.9061	20.7671	147.0505	12.3748
237	80-	60-	2-	30-	S-	L	87.1051	28.0423	128.2107	21.5119	146.8294	12.77874
238	80-	60-	2-	40-	S-	L	85.7164	28.3487	127.9434	21.8452	147.0787	12.93198
239	80-	60-	2-	50-	S-	L	85.2466	28.6178	128.06	21.7155	147.7458	12.81443
240	80-	60-	2-	60-	S-	L	85.8369	28.7816	128.5927	21.1472	148.729	12.44859
241	80-	40-	1-	20-	S-	R	79.4416	34.056	130.6932	26.934	163.2586	14.16143
242	80-	40-	1-	30-	S-	R	77.0205	35.4094	130.81	27.5944	164.6514	14.35371
243	80-	40-	1-	40-	S-	R	75.825	36.1696	130.9586	27.7467	165.69	14.34407
244	80-	40-	1-	50-	S-	R	75.1809	36.6898	131.1452	27.6383	166.6316	14.22675
245	80-	40-	1-	60-	S-	R	75.0166	36.9268	131.2849	27.3606	167.306	14.05511

246	80-	40-	15-	20-	S-	R	88.6117	32.2196	132.0151	23.0003	163.0945	12.35945
247	80-	40-	15-	30-	S-	R	85.6724	33.2313	131.801	23.9025	163.9322	12.72528
248	80-	40-	15-	40-	S-	R	83.6522	33.8277	131.6389	24.4018	164.5956	12.91118
249	80-	40-	15-	50-	S-	R	82.572	34.3002	131.681	24.5193	165.348	12.91391
250	80-	40-	15-	60-	S-	R	82.4373	34.6188	131.9115	24.2863	166.1093	12.7557
251	80-	40-	2-	20-	S-	R	97.0642	31.194	134.214	18.9363	165.055	10.29195
252	80-	40-	2-	30-	S-	R	94.8237	31.9049	133.9216	19.6944	165.3918	10.64066
253	80-	40-	2-	40-	S-	R	93.5553	32.2134	133.7712	20.0808	165.6226	10.81337
254	80-	40-	2-	50-	S-	R	93.2446	32.4205	133.9146	20.0473	166.1055	10.76927
255	80-	40-	2-	60-	S-	R	94.0313	32.4822	134.3849	19.586	166.7853	10.50913
256	80-	60-	1-	20-	S-	R	79.2654	34.2585	130.6778	28.303	162.0274	14.87046
257	80-	60-	1-	30-	S-	R	76.8615	35.3327	130.6783	28.9353	163.1946	15.06028
258	80-	60-	1-	40-	S-	R	75.6499	36.1294	130.834	29.0563	164.3036	15.02706
259	80-	60-	1-	50-	S-	R	75	36.6727	131.0389	28.8834	165.3589	14.86978
260	80-	60-	1-	60-	S-	R	74.8007	36.9204	131.1653	28.5476	166.0965	14.66656
261	80-	60-	15-	20-	S-	R	88.7291	32.4287	132.1666	23.812	162.4575	12.78363
262	80-	60-	15-	30-	S-	R	85.7585	33.1232	131.7677	24.6925	162.9809	13.15717
263	80-	60-	15-	40-	S-	R	83.7543	33.7244	131.6058	25.1714	163.6678	13.32954
264	80-	60-	15-	50-	S-	R	82.6759	34.2012	131.6484	25.2301	164.4854	13.29891
265	80-	60-	15-	60-	S-	R	82.5789	34.4895	131.8817	24.9292	165.2918	13.10539
266	80-	60-	2-	20-	S-	R	97.1204	31.4988	134.3486	20.7671	163.5045	11.26983
267	80-	60-	2-	30-	S-	R	94.6267	31.8688	133.8372	21.5119	163.5773	11.62245
268	80-	60-	2-	40-	S-	R	93.106	32.1801	133.6381	21.8452	163.9347	11.75865
269	80-	60-	2-	50-	S-	R	92.5807	32.3738	133.7185	21.7155	164.5408	11.65893
270	80-	60-	2-	60-	S-	R	93.2141	32.4173	134.1352	21.1472	165.3347	11.34008
271	80-	40-	1-	20-	D-	C	99.6684	28.9664	133.9626	26.934	143.4695	15.80601
272	80-	40-	1-	30-	D-	C	96.553	30.7607	134.1044	27.5944	145.5225	15.93975
273	80-	40-	1-	40-	D-	C	95.0286	32.2131	134.549	27.7467	147.4576	15.83677
274	80-	40-	1-	50-	D-	C	94.2062	33.361	135.0477	27.6383	149.1908	15.62995
275	80-	40-	1-	60-	D-	C	94.0198	34.1633	135.5509	27.3606	150.6025	15.37431
276	80-	40-	15-	20-	D-	C	111.6752	27.3363	136.9322	23.0001	144.0232	13.77059
277	80-	40-	15-	30-	D-	C	107.852	28.1559	136.06	23.9025	144.3833	14.20352
278	80-	40-	15-	40-	D-	C	105.2217	28.8756	135.6642	24.4018	145.1273	14.39387
279	80-	40-	15-	50-	D-	C	103.8246	29.5864	135.7447	24.5193	146.2153	14.36106
280	80-	40-	15-	60-	D-	C	103.6564	30.1073	136.1564	24.2863	147.3283	14.15165
281	80-	40-	2-	20-	D-	C	122.7271	26.778	141.2785	18.9363	147.65	11.36726
282	80-	40-	2-	30-	D-	C	119.8269	27.2232	140.3326	19.6944	147.362	11.78907
283	80-	40-	2-	40-	D-	C	118.18	27.4777	139.8914	20.0808	147.3833	11.99111
284	80-	40-	2-	50-	D-	C	117.7721	27.7346	140.0276	20.0473	147.9268	11.93476
285	80-	40-	2-	60-	D-	C	118.8046	27.9248	140.7994	19.586	148.9234	11.62309
286	80-	60-	1-	20-	D-	C	99.4515	29.0581	133.8524	28.303	142.0778	16.61161
287	80-	60-	1-	30-	D-	C	96.358	30.6425	133.9266	28.9353	143.9908	16.73275
288	80-	60-	1-	40-	D-	C	94.8128	32.1172	134.3719	29.0563	145.9885	16.59935
289	80-	60-	1-	50-	D-	C	93.9959	33.3182	134.9165	28.8834	147.8799	16.34016
290	80-	60-	1-	60-	D-	C	93.7491	34.1459	135.3924	28.5476	149.361	16.04622
291	80-	60-	15-	20-	D-	C	111.8278	27.4882	137.092	23.812	143.343	14.24546
292	80-	60-	15-	30-	D-	C	107.9746	28.0656	136.071	24.6925	143.4615	14.68446
293	80-	60-	15-	40-	D-	C	105.3673	28.7757	135.6567	25.1714	144.1975	14.86188
294	80-	60-	15-	50-	D-	C	103.9654	29.4819	135.7274	25.2301	145.3363	14.79195
295	80-	60-	15-	60-	D-	C	103.8521	29.9912	136.1565	24.9292	146.5132	14.54086

296	80-	60-	2-	20-	D-	C	122.8255	26.9941	141.4167	20.7671	146.0463	12.4493
297	80-	60-	2-	30-	D-	C	119.5885	27.2262	140.2676	21.5119	145.6024	12.87257
298	80-	60-	2-	40-	D-	C	117.5965	27.4922	139.7183	21.8452	145.7218	13.0367
299	80-	60-	2-	50-	D-	C	116.8941	27.7458	139.7433	21.7155	146.3702	12.9193
300	80-	60-	2-	60-	D-	C	117.7236	27.9143	140.42	21.1472	147.449	12.54311
301	80-	40-	1-	20-	D-	L	49.1793	30.7842	112.9887	26.934	136.557	16.4743
302	80-	40-	1-	30-	D-	L	47.6215	32.4569	113.4285	27.5944	138.1618	16.64758
303	80-	40-	1-	40-	D-	L	46.853	33.6806	113.8945	27.7467	139.6267	16.57772
304	80-	40-	1-	50-	D-	L	46.4392	34.5943	114.3436	27.6383	140.9744	16.39159
305	80-	40-	1-	60-	D-	L	46.3381	35.2222	114.7507	27.3606	142.1255	16.14327
306	80-	40-	15-	20-	D-	L	55.0643	28.8833	113.8825	23.0001	137.0873	14.36721
307	80-	40-	15-	30-	D-	L	53.183	29.8755	113.7806	23.9025	137.6613	14.79447
308	80-	40-	15-	40-	D-	L	51.8914	30.6187	113.8264	24.4018	138.3759	14.99087
309	80-	40-	15-	50-	D-	L	51.1979	31.2514	114.0449	24.5193	139.2725	14.9698
310	80-	40-	15-	60-	D-	L	51.1046	31.6839	114.3801	24.2863	140.1979	14.76513
311	80-	40-	2-	20-	D-	L	60.3644	28.1074	115.7625	18.9363	139.9093	11.9212
312	80-	40-	2-	30-	D-	L	58.9509	28.6804	115.4885	19.6944	139.9146	12.33915
313	80-	40-	2-	40-	D-	L	58.1442	28.9995	115.4013	20.0808	140.0675	12.53888
314	80-	40-	2-	50-	D-	L	57.9343	29.2833	115.5897	20.0473	140.6093	12.47835
315	80-	40-	2-	60-	D-	L	58.4044	29.444	116.0383	19.586	141.4313	12.16391
316	80-	60-	1-	20-	D-	L	49.0837	30.891	112.9558	28.303	135.2439	17.30574
317	80-	60-	1-	30-	D-	L	47.5361	32.3462	113.3051	28.9353	136.6827	17.47111
318	80-	60-	1-	40-	D-	L	46.7562	33.6001	113.7792	29.0563	138.2192	17.37033
319	80-	60-	1-	50-	D-	L	46.3385	34.5661	114.2592	28.8834	139.7037	17.13263
320	80-	60-	1-	60-	D-	L	46.2137	35.2118	114.6537	28.5476	140.9212	16.84534
321	80-	60-	15-	20-	D-	L	55.1299	29.0431	113.9864	23.812	136.4023	14.86259
322	80-	60-	15-	30-	D-	L	53.2397	29.7535	113.7347	24.6925	136.7121	15.29851
323	80-	60-	15-	40-	D-	L	51.9587	30.5018	113.7747	25.1714	137.4441	15.47909
324	80-	60-	15-	50-	D-	L	51.2656	31.1409	114.0004	25.2301	138.4145	15.41762
325	80-	60-	15-	60-	D-	L	51.1978	31.5629	114.3374	24.9292	139.395	15.17074
326	80-	60-	2-	20-	D-	L	60.4146	28.3665	115.8784	20.7671	138.3399	13.05229
327	80-	60-	2-	30-	D-	L	58.8358	28.6833	115.433	21.5119	138.1489	13.4735
328	80-	60-	2-	40-	D-	L	57.8637	29.0136	115.2979	21.8452	138.401	13.63227
329	80-	60-	2-	50-	D-	L	57.5138	29.282	115.4224	21.7155	139.0369	13.50866
330	80-	60-	2-	60-	D-	L	57.8848	29.4214	115.819	21.1472	139.9531	13.12673
331	80-	40-	1-	20-	D-	R	58.7448	35.6001	120.9649	26.934	149.0399	15.30568
332	80-	40-	1-	30-	D-	R	56.9036	36.7601	121.0412	27.5944	150.0924	15.5298
333	80-	40-	1-	40-	D-	R	55.994	37.3051	121.1134	27.7467	150.8463	15.53628
334	80-	40-	1-	50-	D-	R	55.5043	37.6034	121.1908	27.6383	151.4971	15.42872
335	80-	40-	1-	60-	D-	R	55.3819	37.6703	121.2126	27.3606	151.926	15.26082
336	80-	40-	15-	20-	D-	R	65.6977	33.9353	122.2897	23.0001	149.7715	13.31243
337	80-	40-	15-	30-	D-	R	63.4703	34.9058	122.0855	23.9025	150.3552	13.71675
338	80-	40-	15-	40-	D-	R	61.9436	35.4271	121.9005	24.4018	150.7771	13.92965
339	80-	40-	15-	50-	D-	R	61.1238	35.8409	121.9068	24.5193	151.3584	13.94111
340	80-	40-	15-	60-	D-	R	61.0148	36.0932	122.0896	24.2863	152.021	13.77498
341	80-	40-	2-	20-	D-	R	71.9763	32.9143	124.2543	18.9363	152.1776	11.06649
342	80-	40-	2-	30-	D-	R	70.3004	33.6442	124.0317	19.6944	152.4308	11.4419
343	80-	40-	2-	40-	D-	R	69.3459	33.9102	123.8697	20.0808	152.5286	11.63367
344	80-	40-	2-	50-	D-	R	69.1005	34.0753	123.9652	20.0473	152.916	11.59049
345	80-	40-	2-	60-	D-	R	69.6618	34.1169	124.3536	19.586	153.5683	11.3113

346	80-	60-	1-	20-	D-	R	58.6296	35.8787	121.0234	28.303	147.9188	16.06101
347	80-	60-	1-	30-	D-	R	56.8005	36.7266	120.9472	28.9353	148.6871	16.29034
348	80-	60-	1-	40-	D-	R	55.8775	37.2913	121.0192	29.0563	149.4924	16.2736
349	80-	60-	1-	50-	D-	R	55.3821	37.6069	121.1093	28.8834	150.2492	16.12403
350	80-	60-	1-	60-	D-	R	55.2333	37.6733	121.114	28.5476	150.7315	15.92355
351	80-	60-	15-	20-	D-	R	65.7747	34.1908	122.4676	23.812	149.2154	13.76198
352	80-	60-	15-	30-	D-	R	63.5372	34.817	122.0679	24.6925	149.4472	14.17971
353	80-	60-	15-	40-	D-	R	62.0226	35.3415	121.8825	25.1714	149.8931	14.37836
354	80-	60-	15-	50-	D-	R	61.2039	35.7553	121.8872	25.2301	150.5332	14.35459
355	80-	60-	15-	60-	D-	R	61.1246	35.9982	122.0746	24.9292	151.2523	14.14973
356	80-	60-	2-	20-	D-	R	72.0352	33.2418	124.4225	20.7671	150.6929	12.11192
357	80-	60-	2-	30-	D-	R	70.1648	33.6022	123.941	21.5119	150.5976	12.49896
358	80-	60-	2-	40-	D-	R	69.0166	33.874	123.7241	21.8452	150.7962	12.65351
359	80-	60-	2-	50-	D-	R	68.6071	34.0442	123.7698	21.7155	151.315	12.5501
360	80-	60-	2-	60-	D-	R	69.0517	34.0557	124.0958	21.1472	152.0509	12.20983
361	60-	40-	1-	20-	S-	C	125.0859	29.1698	144.7618	26.9339	157.684	14.589
362	60-	40-	1-	30-	S-	C	121.9126	30.919	144.9801	27.5937	159.7519	14.72877
363	60-	40-	1-	40-	S-	C	120.296	32.3157	145.4074	27.7476	161.6449	14.65084
364	60-	40-	1-	50-	S-	C	119.4547	33.3839	145.8755	27.6382	163.2984	14.47507
365	60-	40-	1-	60-	S-	C	119.3033	34.0648	146.2985	27.3604	164.5414	14.2575
366	60-	40-	15-	20-	S-	C	138.1429	27.3417	147.2829	22.9999	157.3635	12.75198
367	60-	40-	15-	30-	S-	C	134.0549	28.2544	146.6211	23.9024	158.065	13.13554
368	60-	40-	15-	40-	S-	C	131.2443	29.0764	146.3885	24.4018	159.0932	13.29835
369	60-	40-	15-	50-	S-	C	129.7898	29.7649	146.4836	24.5194	160.1834	13.27506
370	60-	40-	15-	60-	S-	C	129.6677	30.2304	146.8654	24.2862	161.2242	13.09156
371	60-	40-	2-	20-	S-	C	150.9045	26.6233	151.5203	18.9474	160.2676	10.57244
372	60-	40-	2-	30-	S-	C	147.1652	27.1294	150.5474	19.6943	160.2909	10.94218
373	60-	40-	2-	40-	S-	C	144.8773	27.4826	150.1074	20.0808	160.6253	11.11241
374	60-	40-	2-	50-	S-	C	143.9825	27.7865	150.1547	20.0472	161.3115	11.05389
375	60-	40-	2-	60-	S-	C	144.6935	27.9564	150.7594	19.5859	162.2801	10.76941
376	60-	60-	1-	20-	S-	C	124.8781	29.3116	144.7473	28.3029	156.3875	15.32451
377	60-	60-	1-	30-	S-	C	121.5898	30.8275	144.8191	28.9353	158.2771	15.45587
378	60-	60-	1-	40-	S-	C	120.0082	32.2222	145.2371	29.0561	160.1807	15.35436
379	60-	60-	1-	50-	S-	C	119.1909	33.2932	145.7207	28.8833	161.9296	15.13697
380	60-	60-	1-	60-	S-	C	118.994	34.0212	146.1417	28.5473	163.2793	14.88183
381	60-	60-	15-	20-	S-	C	138.1553	27.4717	147.4071	23.8119	156.6476	13.19515
382	60-	60-	15-	30-	S-	C	133.917	28.169	146.5789	24.6923	157.1641	13.57791
383	60-	60-	15-	40-	S-	C	131.0925	28.9429	146.2828	25.1711	158.1407	13.7313
384	60-	60-	15-	50-	S-	C	129.6855	29.6291	146.3748	25.2308	159.2804	13.6744
385	60-	60-	15-	60-	S-	C	129.7014	30.0653	146.767	24.9293	160.328	13.45658
386	60-	60-	2-	20-	S-	C	149.8131	26.8189	151.1919	20.767	158.5672	11.58006
387	60-	60-	2-	30-	S-	C	146.4522	27.1104	150.2258	21.5117	158.3582	11.95959
388	60-	60-	2-	40-	S-	C	144.4182	27.4154	149.7986	21.8451	158.6359	12.10382
389	60-	60-	2-	50-	S-	C	143.8906	27.6703	149.905	21.7154	159.3164	11.99535
390	60-	60-	2-	60-	S-	C	145.121	27.819	150.6353	21.1473	160.3182	11.65362
391	60-	40-	1-	20-	S-	L	64.4035	31.1746	120.8977	26.9339	143.6819	15.78629
392	60-	40-	1-	30-	S-	L	62.8256	32.7261	121.2678	27.5937	145.1399	15.97471
393	60-	40-	1-	40-	S-	L	62.008	33.8852	121.6942	27.7476	146.5533	15.91937
394	60-	40-	1-	50-	S-	L	61.58	34.6988	122.0881	27.6383	147.7959	15.75423
395	60-	40-	1-	60-	S-	L	61.4913	35.1772	122.4086	27.3604	148.7722	15.53398

396	60-	40-	15-	20-	S-	L	70.816	29.2421	121.9127	22.9999	144.1064	13.76363
397	60-	40-	15-	30-	S-	L	68.7768	30.2476	121.7932	23.9024	144.7367	14.1737
398	60-	40-	15-	40-	S-	L	67.3963	30.9928	121.8237	24.4018	145.4727	14.3646
399	60-	40-	15-	50-	S-	L	66.6797	31.5873	122.0045	24.5194	146.3095	14.35319
400	60-	40-	15-	60-	S-	L	66.6231	31.9587	122.3092	24.2862	147.1531	14.16606
401	60-	40-	2-	20-	S-	L	77.0176	28.2973	124.0267	18.9474	146.6825	11.4396
402	60-	40-	2-	30-	S-	L	75.1788	28.9232	123.6757	19.6943	146.849	11.82533
403	60-	40-	2-	40-	S-	L	74.0535	29.3037	123.5474	20.0808	147.1534	12.00759
404	60-	40-	2-	50-	S-	L	73.6229	29.5817	123.67	20.0472	147.7348	11.94836
405	60-	40-	2-	60-	S-	L	73.9729	29.7007	124.053	19.5859	148.5298	11.65025
406	60-	60-	1-	20-	S-	L	64.2848	31.3273	120.9031	28.3029	142.4306	16.57724
407	60-	60-	1-	30-	S-	L	62.6487	32.6632	121.1502	28.9353	143.7252	16.75849
408	60-	60-	1-	40-	S-	L	61.8481	33.8075	121.5608	29.0561	145.142	16.67992
409	60-	60-	1-	50-	S-	L	61.4331	34.6358	121.9624	28.8833	146.4701	16.47148
410	60-	60-	1-	60-	S-	L	61.3309	35.148	122.2896	28.5473	147.5382	16.21218
411	60-	60-	15-	20-	S-	L	70.7897	29.4024	122.0046	23.8119	143.437	14.2374
412	60-	60-	15-	30-	S-	L	68.6942	29.7707	121.4849	24.6923	143.3676	14.69256
413	60-	60-	15-	40-	S-	L	67.308	30.8644	121.7236	25.1711	144.5519	14.83069
414	60-	60-	15-	50-	S-	L	66.6185	31.4518	121.9004	25.2308	145.4319	14.78402
415	60-	60-	15-	60-	S-	L	66.6238	31.8195	122.2099	24.9293	146.3142	14.55781
416	60-	60-	2-	20-	S-	L	76.4648	28.5323	123.8607	20.767	145.0684	12.52266
417	60-	60-	2-	30-	S-	L	74.8049	28.8999	123.4273	21.5117	144.9445	12.92334
418	60-	60-	2-	40-	S-	L	73.8185	29.2281	123.2969	21.8451	145.2082	13.07672
419	60-	60-	2-	50-	S-	L	73.5731	29.4686	123.4409	21.7154	145.804	12.96292
420	60-	60-	2-	60-	S-	L	74.1721	29.5692	123.8883	21.1473	146.6464	12.60315
421	60-	40-	1-	20-	S-	R	69.9104	34.7627	126.546	26.9339	159.4505	14.45073
422	60-	40-	1-	30-	S-	R	68.1854	35.9538	126.7119	27.5937	160.5196	14.66866
423	60-	40-	1-	40-	S-	R	67.296	36.576	126.8587	27.7476	161.3654	14.6725
424	60-	40-	1-	50-	S-	R	66.831	36.9169	126.9827	27.6383	162.0761	14.56837
425	60-	40-	1-	60-	S-	R	66.7393	36.9714	127.0082	27.3604	162.4879	14.41172
426	60-	40-	15-	20-	S-	R	76.9092	33.0846	127.6393	23.0001	159.991	12.56897
427	60-	40-	15-	30-	S-	R	74.707	34.0334	127.5243	23.9024	160.6203	12.95364
428	60-	40-	15-	40-	S-	R	73.1955	34.5883	127.4255	24.4018	161.1293	13.1524
429	60-	40-	15-	50-	S-	R	72.4112	35.0317	127.4793	24.5194	161.7502	13.16339
430	60-	40-	15-	60-	S-	R	72.3452	35.3039	127.6729	24.2862	162.4155	13.00802
431	60-	40-	2-	20-	S-	R	83.7	32.0144	129.5003	18.9474	162.0987	10.46551
432	60-	40-	2-	30-	S-	R	81.693	32.7062	129.2461	19.6943	162.4439	10.81283
433	60-	40-	2-	40-	S-	R	80.4626	33.0033	129.0974	20.0808	162.7067	10.98587
434	60-	40-	2-	50-	S-	R	79.9839	33.1875	129.1526	20.0472	163.1786	10.94125
435	60-	40-	2-	60-	S-	R	80.3557	33.2225	129.4583	19.5859	163.846	10.67748
436	60-	60-	1-	20-	S-	R	69.787	35.0359	126.6303	28.3029	158.3405	15.16416
437	60-	60-	1-	30-	S-	R	67.9998	35.9217	126.6201	28.9353	159.1411	15.38486
438	60-	60-	1-	40-	S-	R	67.1293	36.545	126.7575	29.0561	160.0044	15.36868
439	60-	60-	1-	50-	S-	R	66.678	36.8978	126.8927	28.8833	160.8058	15.22665
440	60-	60-	1-	60-	S-	R	66.5675	36.9704	126.9171	28.5473	161.2954	15.03734
441	60-	60-	15-	20-	S-	R	76.9072	33.3169	127.7961	23.8119	159.4139	12.99593
442	60-	60-	15-	30-	S-	R	74.6217	33.9494	127.4765	24.6923	159.7351	13.38863
443	60-	60-	15-	40-	S-	R	73.1043	34.5038	127.3585	25.1711	160.2612	13.57428
444	60-	60-	15-	50-	S-	R	72.3482	34.9384	127.4041	25.2308	160.9204	13.55393
445	60-	60-	15-	60-	S-	R	72.3514	35.1921	127.6091	24.9293	161.6272	13.36287

446	60-	60-	2-	20-	S-	R	83.1069	32.3144	129.3873	20.767	160.5658	11.45242
447	60-	60-	2-	30-	S-	R	81.2988	32.6874	129.0227	21.5117	160.5578	11.8151
448	60-	60-	2-	40-	S-	R	80.2149	32.9611	128.8772	21.8451	160.7994	11.96045
449	60-	60-	2-	50-	S-	R	79.9371	33.1229	128.965	21.7154	161.3022	11.8652
450	60-	60-	2-	60-	S-	R	80.5823	33.1442	129.3309	21.1473	162.0066	11.54619
451	60-	40-	1-	20-	D-	C	87.6514	30.2063	129.2704	26.9339	141.8373	15.95882
452	60-	40-	1-	30-	D-	C	85.4205	31.8509	129.5377	27.5937	143.5554	16.12261
453	60-	40-	1-	40-	D-	C	84.2864	33.1373	129.9685	27.7476	145.2051	16.04346
454	60-	40-	1-	50-	D-	C	83.6985	34.0682	130.4099	27.6383	146.6592	15.85697
455	60-	40-	1-	60-	D-	C	83.5973	34.6443	130.7946	27.3604	147.7768	15.62227
456	60-	40-	15-	20-	D-	C	96.8333	28.2823	131.2962	22.9999	142.254	13.91792
457	60-	40-	15-	30-	D-	C	93.9648	29.2751	130.8593	23.9024	142.8483	14.33421
458	60-	40-	15-	40-	D-	C	91.9916	30.0571	130.7095	24.4018	143.6595	14.51958
459	60-	40-	15-	50-	D-	C	90.9735	30.7047	130.8264	24.5194	144.5941	14.49878
460	60-	40-	15-	60-	D-	C	90.8885	31.1233	131.1715	24.2862	145.5395	14.30066
461	60-	40-	2-	20-	D-	C	105.7371	27.4445	134.7042	18.9474	145.3704	11.53095
462	60-	40-	2-	30-	D-	C	103.1204	28.0267	133.992	19.6943	145.3896	11.92987
463	60-	40-	2-	40-	D-	C	101.5165	28.394	133.6679	20.0808	145.6459	12.11682
464	60-	40-	2-	50-	D-	C	100.8829	28.6957	133.7339	20.0472	146.2633	12.05408
465	60-	40-	2-	60-	D-	C	101.3634	28.8498	134.2348	19.5859	147.1711	11.74517
466	60-	60-	1-	20-	D-	C	87.504	30.3503	129.2796	28.3029	140.5763	16.75926
467	60-	60-	1-	30-	D-	C	85.1951	31.7859	129.4081	28.9353	142.1168	16.91607
468	60-	60-	1-	40-	D-	C	84.0872	33.0573	129.8254	29.0561	143.775	16.81185
469	60-	60-	1-	50-	D-	C	83.5165	33.9927	130.2729	28.8833	145.3087	16.5813
470	60-	60-	1-	60-	D-	C	83.3816	34.6141	130.6588	28.5473	146.5307	16.30548
471	60-	60-	15-	20-	D-	C	96.8299	28.4324	131.4249	23.8119	141.5863	14.39671
472	60-	60-	15-	30-	D-	C	93.8605	29.1879	130.8181	24.6923	141.9628	14.81641
473	60-	60-	15-	40-	D-	C	91.8809	29.9387	130.6127	25.1711	142.7333	14.99133
474	60-	60-	15-	50-	D-	C	90.8953	30.5579	130.7108	25.2308	143.6849	14.93692
475	60-	60-	15-	60-	D-	C	90.9062	30.9649	131.0745	24.9293	144.6733	14.69865
476	60-	60-	2-	20-	D-	C	104.9808	27.6644	134.4696	20.767	143.713	12.62585
477	60-	60-	2-	30-	D-	C	102.6316	27.9964	133.7154	21.5117	143.4588	13.03973
478	60-	60-	2-	40-	D-	C	101.2056	28.3277	133.4	21.8451	143.6809	13.19738
479	60-	60-	2-	50-	D-	C	100.8298	28.5853	133.512	21.7154	144.3125	13.07937
480	60-	60-	2-	60-	D-	C	101.6723	28.7113	134.1076	21.1473	145.2631	12.70792
481	60-	40-	1-	20-	D-	L	43.2728	31.86	110.5427	26.9339	135.6659	16.56453
482	60-	40-	1-	30-	D-	L	42.1612	33.3517	110.9843	27.5937	136.9435	16.77049
483	60-	40-	1-	40-	D-	L	41.5884	34.4076	111.412	27.7476	138.1796	16.72276
484	60-	40-	1-	50-	D-	L	41.289	35.1453	111.7985	27.6383	139.31	16.55501
485	60-	40-	1-	60-	D-	L	41.2319	35.5405	112.0767	27.3604	140.1751	16.33111
486	60-	40-	15-	20-	D-	L	47.7609	29.9448	111.0922	22.9999	136.4961	14.42036
487	60-	40-	15-	30-	D-	L	46.3481	30.9503	111.1448	23.9024	137.0322	14.85224
488	60-	40-	15-	40-	D-	L	45.3815	31.6477	111.2523	24.4018	137.6325	15.05965
489	60-	40-	15-	50-	D-	L	44.8775	32.2011	111.4568	24.5194	138.3715	15.05265
490	60-	40-	15-	60-	D-	L	44.8297	32.5693	111.736	24.2862	139.1701	14.85792
491	60-	40-	2-	20-	D-	L	52.0102	28.9445	112.4661	18.9474	139.0739	11.99041
492	60-	40-	2-	30-	D-	L	50.7394	29.6055	112.326	19.6943	139.2522	12.39052
493	60-	40-	2-	40-	D-	L	49.9542	29.9714	112.2859	20.0808	139.4988	12.58356
494	60-	40-	2-	50-	D-	L	49.638	30.2361	112.409	20.0472	140.0247	12.52387
495	60-	40-	2-	60-	D-	L	49.8498	30.3201	112.6801	19.5859	140.739	12.21638

496	60-	60-	1-	20-	D-	L	43.2011	32.0425	110.5978	28.3029	134.481	17.38679
497	60-	60-	1-	30-	D-	L	42.0503	33.294	110.8971	28.9353	135.5471	17.59173
498	60-	60-	1-	40-	D-	L	41.4901	34.3425	111.3084	29.0561	136.7899	17.51993
499	60-	60-	1-	50-	D-	L	41.1991	35.083	111.6971	28.8833	137.9953	17.30797
500	60-	60-	1-	60-	D-	L	41.1296	35.5142	111.9811	28.5473	138.9514	17.0433
501	60-	60-	15-	20-	D-	L	47.748	30.1169	111.1943	23.8119	135.8494	14.91401
502	60-	60-	15-	30-	D-	L	46.2939	30.8659	111.0977	24.6923	136.1563	15.35127
503	60-	60-	15-	40-	D-	L	45.3242	31.5448	111.1726	25.1711	136.7427	15.54599
504	60-	60-	15-	50-	D-	L	44.8385	32.0828	111.3649	25.2308	137.5127	15.50341
505	60-	60-	15-	60-	D-	L	44.8359	32.4351	111.6469	24.9293	138.353	15.26761
506	60-	60-	2-	20-	D-	L	51.6515	29.1962	112.387	20.767	137.4933	13.12205
507	60-	60-	2-	30-	D-	L	50.5092	29.5697	112.1354	21.5117	137.3559	13.54065
508	60-	60-	2-	40-	D-	L	49.817	29.9033	112.0914	21.8451	137.5897	13.70159
509	60-	60-	2-	50-	D-	L	49.6283	30.124	112.2162	21.7154	138.1271	13.5855
510	60-	60-	2-	60-	D-	L	50.0149	30.1929	112.531	21.1473	138.8972	13.21339
511	60-	40-	1-	20-	D-	R	51.7027	36.1575	117.7072	26.9339	146.7216	15.50996
512	60-	40-	1-	30-	D-	R	50.3895	37.1545	117.8346	27.5937	147.4945	15.75989
513	60-	40-	1-	40-	D-	R	49.7112	37.5565	117.8926	27.7476	148.049	15.78392
514	60-	40-	1-	50-	D-	R	49.3563	37.6786	117.881	27.6383	148.4441	15.69623
515	60-	40-	1-	60-	D-	R	49.2869	37.6765	117.8637	27.3604	148.766	15.53453
516	60-	40-	15-	20-	D-	R	57.0087	34.675	118.7834	22.9999	148.0295	13.44792
517	60-	40-	15-	30-	D-	R	55.3348	35.5872	118.6846	23.9024	148.4522	13.86815
518	60-	40-	15-	40-	D-	R	54.1919	36.0871	118.5714	24.4018	148.7678	14.09127
519	60-	40-	15-	50-	D-	R	53.5961	36.4444	118.5844	24.5194	149.2177	14.11293
520	60-	40-	15-	60-	D-	R	53.5408	36.6555	118.7273	24.2862	149.7831	13.95203
521	60-	40-	2-	20-	D-	R	62.0451	33.6345	120.4021	18.9474	150.5352	11.17955
522	60-	40-	2-	30-	D-	R	60.5403	34.3328	120.2106	19.6943	150.7744	11.55303
523	60-	40-	2-	40-	D-	R	59.6113	34.6069	120.0597	20.0808	150.9072	11.74398
524	60-	40-	2-	50-	D-	R	59.2401	34.7764	120.0915	20.0472	151.2991	11.69981
525	60-	40-	2-	60-	D-	R	59.4955	34.802	120.3325	19.5859	151.9277	11.41944
526	60-	60-	1-	20-	D-	R	51.6172	36.4833	117.8404	28.3029	145.6965	16.26609
527	60-	60-	1-	30-	D-	R	50.2569	37.1464	117.7642	28.9353	146.1428	16.52708
528	60-	60-	1-	40-	D-	R	49.5933	37.5473	117.8137	29.0561	146.719	16.53027
529	60-	60-	1-	50-	D-	R	49.2483	37.6814	117.8156	28.8833	147.2056	16.40268
530	60-	60-	1-	60-	D-	R	49.165	37.6844	117.7876	28.5473	147.5862	16.20776
531	60-	60-	15-	20-	D-	R	56.9932	34.95	118.9583	23.8119	147.5165	13.8984
532	60-	60-	15-	30-	D-	R	55.2711	35.5421	118.6576	24.6923	147.6179	14.33014
533	60-	60-	15-	40-	D-	R	54.1241	36.0386	118.5203	25.1711	147.9358	14.54078
534	60-	60-	15-	50-	D-	R	53.5501	36.3902	118.5303	25.2308	148.4337	14.52847
535	60-	60-	15-	60-	D-	R	53.5476	36.5681	118.679	24.9293	149.0319	14.33038
536	60-	60-	2-	20-	D-	R	61.618	34.0033	120.3741	20.767	149.0915	12.22606
537	60-	60-	2-	30-	D-	R	60.2636	34.3458	120.0342	21.5117	148.9292	12.62121
538	60-	60-	2-	40-	D-	R	59.4457	34.584	119.8784	21.8451	149.0368	12.78374
539	60-	60-	2-	50-	D-	R	59.2257	34.7366	119.9401	21.7154	149.4815	12.68446
540	60-	60-	2-	60-	D-	R	59.6876	34.7446	120.2344	21.1473	150.1641	12.34436

Daylighting assessment indicators (S, SE and SW)

Combinations scenarios							ADI (Klux)			UDI (lux)								
										S			SE			SW		
No.	WWR	Depth	d/l	Angle	Glazing	Glass	S	SE	SW	<300	300-3000	>3000	<300	300-3000	>3000	<300	300-3000	>3000
1	100-	40-	1-	20-	S-	C	1587.788	1783.341	1792.274	2.64%	97.36%	0.00%	2.43%	97.57%	0.00%	2.53%	97.47%	0.00%
2	100-	40-	1-	30-	S-	C	1431.134	1608.369	1615.182	3.80%	96.20%	0.00%	3.77%	96.23%	0.00%	3.56%	96.44%	0.00%
3	100-	40-	1-	40-	S-	C	1092.475	1266.448	1234.429	17.98%	82.02%	0.00%	12.95%	87.05%	0.00%	16.54%	83.46%	0.00%
4	100-	40-	1-	50-	S-	C	1118.972	1258.661	1265.229	16.99%	83.01%	0.00%	15.55%	84.45%	0.00%	15.65%	84.35%	0.00%
5	100-	40-	1-	60-	S-	C	1221.031	1371.552	1379.201	11.58%	88.42%	0.00%	10.86%	89.14%	0.00%	10.48%	89.52%	0.00%
6	100-	40-	15-	20-	S-	C	2120.848	2235.778	2270.162	1.34%	98.66%	0.00%	1.68%	98.32%	0.00%	1.51%	98.49%	0.00%
7	100-	40-	15-	30-	S-	C	1896.328	2034.183	2039.658	2.02%	97.98%	0.00%	1.95%	98.05%	0.00%	2.09%	97.91%	0.00%
8	100-	40-	15-	40-	S-	C	1751.282	1932.81	1904.512	2.47%	97.53%	0.00%	2.26%	97.74%	0.00%	2.64%	97.36%	0.00%
9	100-	40-	15-	50-	S-	C	1662.18	1805.81	1813.595	2.98%	97.02%	0.00%	2.84%	97.16%	0.00%	3.01%	96.99%	0.00%
10	100-	40-	15-	60-	S-	C	1621.149	1759.838	1764.356	3.53%	96.47%	0.00%	3.49%	96.51%	0.00%	3.42%	96.58%	0.00%
11	100-	40-	2-	20-	S-	C	2596.073	2679.269	2645.774	1.03%	98.97%	0.00%	1.27%	98.70%	0.03%	1.23%	98.77%	0.00%
12	100-	40-	2-	30-	S-	C	2401.481	2469.807	2468.439	1.20%	98.80%	0.00%	1.30%	98.70%	0.00%	1.30%	98.70%	0.00%
13	100-	40-	2-	40-	S-	C	2282.44	2398.134	2362.448	1.34%	98.66%	0.00%	1.44%	98.56%	0.00%	1.44%	98.56%	0.00%
14	100-	40-	2-	50-	S-	C	2227.594	2301.185	2306.54	1.37%	98.63%	0.00%	1.58%	98.42%	0.00%	1.58%	98.42%	0.00%
15	100-	40-	2-	60-	S-	C	2225.433	2299.132	2301.299	1.40%	98.60%	0.00%	1.64%	98.36%	0.00%	1.61%	98.39%	0.00%
16	100-	60-	1-	20-	S-	C	1562.648	1755.812	1763.479	2.84%	97.16%	0.00%	2.67%	97.33%	0.00%	2.77%	97.23%	0.00%
17	100-	60-	1-	30-	S-	C	1401.62	1624.787	1589.334	4.01%	95.99%	0.00%	3.70%	96.30%	0.00%	4.25%	95.75%	0.00%
18	100-	60-	1-	40-	S-	C	1313.297	1475.805	1483.154	5.62%	94.38%	0.00%	5.79%	94.21%	0.00%	5.58%	94.42%	0.00%
19	100-	60-	1-	50-	S-	C	1248.52	1402.572	1410.677	8.94%	91.06%	0.00%	8.29%	91.71%	0.00%	8.25%	91.75%	0.00%
20	100-	60-	1-	60-	S-	C	983.425	1109.961	1115.048	37.12%	62.88%	0.00%	32.36%	67.64%	0.00%	32.81%	67.19%	0.00%
21	100-	60-	15-	20-	S-	C	2134.235	2233.041	2235.951	1.27%	98.73%	0.00%	1.78%	98.22%	0.00%	1.54%	98.46%	0.00%
22	100-	60-	15-	30-	S-	C	1901.895	2068.419	2034.196	1.99%	98.01%	0.00%	1.82%	98.18%	0.00%	2.16%	97.84%	0.00%
23	100-	60-	15-	40-	S-	C	1750.24	1897.014	1896.552	2.47%	97.53%	0.00%	2.53%	97.47%	0.00%	2.60%	97.40%	0.00%
24	100-	60-	15-	50-	S-	C	1659.363	1806.181	1811.214	2.98%	97.02%	0.00%	2.74%	97.26%	0.00%	2.95%	97.05%	0.00%
25	100-	60-	15-	60-	S-	C	1627.166	1764.407	1771.053	3.42%	96.58%	0.00%	3.36%	96.64%	0.00%	3.32%	96.68%	0.00%
26	100-	60-	2-	20-	S-	C	2596.056	2643.085	2642.067	1.03%	98.97%	0.00%	1.23%	98.77%	0.00%	1.27%	98.70%	0.03%
27	100-	60-	2-	30-	S-	C	2407.83	2511.541	2477.928	1.16%	98.84%	0.00%	1.30%	98.70%	0.00%	1.30%	98.70%	0.00%
28	100-	60-	2-	40-	S-	C	2288.832	2364.695	2363.811	1.27%	98.73%	0.00%	1.54%	98.46%	0.00%	1.54%	98.46%	0.00%
29	100-	60-	2-	50-	S-	C	1822.359	1892.72	1892.8	3.60%	96.40%	0.00%	3.60%	96.40%	0.00%	3.53%	96.47%	0.00%
30	100-	60-	2-	60-	S-	C	1823.747	1891.209	1888.71	3.90%	96.10%	0.00%	4.01%	95.99%	0.00%	3.66%	96.34%	0.00%
31	100-	40-	1-	20-	S-	L	1297.099	1501.572	1457.352	6.99%	93.01%	0.00%	5.55%	94.45%	0.00%	7.05%	92.95%	0.00%
32	100-	40-	1-	30-	S-	L	1109.844	1255.418	1249.343	15.79%	84.21%	0.00%	15.58%	84.42%	0.00%	14.86%	85.14%	0.00%
33	100-	40-	1-	40-	S-	L	1036.717	1204.585	1170.638	25.17%	74.83%	0.00%	16.78%	83.22%	0.00%	22.71%	77.29%	0.00%
34	100-	40-	1-	50-	S-	L	1036.485	1164.03	1167.937	27.23%	72.77%	0.00%	23.84%	76.16%	0.00%	25.55%	74.45%	0.00%
35	100-	40-	1-	60-	S-	L	945.767	1063.882	1072.311	42.98%	57.02%	0.00%	38.15%	61.85%	0.00%	37.64%	62.36%	0.00%
36	100-	40-	15-	20-	S-	L	1735.925	1870.973	1831.181	3.25%	96.75%	0.00%	2.95%	97.05%	0.00%	3.39%	96.61%	0.00%
37	100-	40-	15-	30-	S-	L	1471.593	1584.809	1584.39	6.03%	93.97%	0.00%	6.44%	93.56%	0.00%	6.68%	93.32%	0.00%
38	100-	40-	15-	40-	S-	L	1357.565	1516.435	1481.166	9.18%	90.82%	0.00%	7.36%	92.64%	0.00%	9.08%	90.92%	0.00%
39	100-	40-	15-	50-	S-	L	1289.733	1405.891	1412.576	12.50%	87.50%	0.00%	12.91%	87.09%	0.00%	12.40%	87.60%	0.00%
40	100-	40-	15-	60-	S-	L	1256.17	1372.26	1373.296	15.99%	84.01%	0.00%	15.27%	84.73%	0.00%	15.62%	84.38%	0.00%
41	100-	40-	2-	20-	S-	L	2009.23	2092.991	2056.093	2.47%	97.53%	0.00%	2.53%	97.47%	0.00%	2.67%	97.33%	0.00%
42	100-	40-	2-	30-	S-	L	1857.905	1916.802	1919.067	3.12%	96.88%	0.00%	3.32%	96.68%	0.00%	3.49%	96.51%	0.00%
43	100-	40-	2-	40-	S-	L	1767.064	1873.493	1834.697	3.87%	96.13%	0.00%	3.49%	96.51%	0.00%	4.08%	95.92%	0.00%
44	100-	40-	2-	50-	S-	L	1724.564	1788.855	1791.859	4.79%	95.21%	0.00%	4.83%	95.17%	0.00%	4.59%	95.41%	0.00%
45	100-	40-	2-	60-	S-	L	1723.821	1784.509	1785.934	5.62%	94.38%	0.00%	5.31%	94.69%	0.00%	5.14%	94.86%	0.00%
46	100-	60-	1-	20-	S-	L	1210.598	1371.747	1374.021	10.14%	89.86%	0.00%	10.17%	89.83%	0.00%	9.86%	90.14%	0.00%
47	100-	60-	1-	30-	S-	L	1091.329	1273.716	1236.462	17.91%	82.09%	0.00%	12.81%	87.19%	0.00%	16.78%	83.22%	0.00%
48	100-	60-	1-	40-	S-	L	1018.868	1148.006	1154.297	27.60%	72.40%	0.00%	24.42%	75.58%	0.00%	24.79%	75.21%	0.00%
49	100-	60-	1-	50-	S-	L	968.237	1091.192	1097.066	37.16%	62.84%	0.00%	32.53%	67.47%	0.00%	33.39%	66.61%	0.00%
50	100-	60-	1-	60-	S-	L	932.347	1053.288	1059.417	44.04%	55.96%	0.00%	39.32%	60.68%	0.00%	39.28%	60.72%	0.00%
51	100-	60-	15-	20-	S-	L	1648.759	1740.395	1741.1	4.01%	95.99%	0.00%	4.38%	95.62%	0.00%	4.32%	95.68%	0.00%
52	100-	60-	15-	30-	S-	L	1475.215	1623.572	1585.862	5.99%	94.01%	0.00%	5.41%	94.59%	0.00%	6.47%	93.53%	0.00%
53	100-	60-	15-	40-	S-	L	1357.197	1475.84	1476.747	9.08%	90.92%	0.00%	9.62%	90.38%	0.00%	9.21%	90.79%	0.00%
54	100-	60-	15-	50-	S-	L	1288.983	1405.251	1409.757	12.43%	87.57%	0.00%	12.84%	87.16%	0.00%	12.47%	87.53%	0.00%
55	100-	60-	15-	60-	S-	L	1259.209	1371.491	1377.661	16.06%	83.94%	0.00%	15.45%	84.55%	0.00%	15.38%	84.62%	0.00%
56	100-	60-	2-	20-	S-	L	2010.259	2055.809	2051.085	2.53%	97.47%	0.00%	2.81%	97.19%	0.00%	2.77%	97.23%	0.00%
57	100-	60-	2-	30-	S-	L	1868.588	1962.505	1927.098	3.32%	96.68%	0.00%	3.18%	96.82%	0.00%	3.39%	96.61%	0.00%
58	100-	60-	2-	40-	S-	L	1772.374	1840.083	1839.25	4.21%	95.79%	0.00%	4.21%	95.79%	0.00%	4.18%	95.82%	0.00%
59	100-	60-	2-	50-	S-	L	1728.613	1798.638	1795.297	5.03%	94.97%	0.00%	4.83%	95.17%	0.00%	4.86%	95.14%	0.00%
60	100-	60-	2-	60-	S-	L	1728.429	1795.095	1794.754	5.72%	94.28%	0.00%	5.51%	94.49%	0.00%	5.21%	94.79%	0.00%
61	100-	40-	1-	20-	S-	R	664.251	795.333	753.154	88.39%	11.61%	0.00%	73.84%	26.16%	0.00%	77.53%	22.47%	0.00%
62	100-	40-	1-	30-	S-	R	598.638	680.752	678.15	96.85%	3.15%	0.00%	82.19%	17.81%	0.00%	82.50%	17.50%	0.00%
63	100-	40-	1-	40-	S-	R	559.073	671.866	633.453	98.39%	1.61%	0.00%	82.50%	17.50%	0.00%	84.93%	15.07%	0.00%
64	100-	40-	1-	50-	S-	R	529.538	597.944	600.87	99.01%	0.99%	0.00%	88.01%	11.99%	0.00%	86.78%	13.22%	0.00%
65	100-	40-	1-	60-	S-	R	509.488	576.591	577.993	99.14%	0.86%	0.00%	89.14%	10.86%	0.00%	88.29%	11.71%	0.00%

66	100-	40-	15-	20-	S-	R	885.961	984.779	945.845	64.28%	35.72%	0.00%	57.36%	42.64%	0.00%	62.19%	37.81%	0.00%
67	100-	40-	15-	30-	S-	R	792.263	860.562	859.651	73.36%	26.64%	0.00%	69.49%	30.51%	0.00%	68.77%	31.23%	0.00%
68	100-	40-	15-	40-	S-	R	731.539	842.091	803.481	78.15%	21.85%	0.00%	69.35%	30.65%	0.00%	73.56%	26.44%	0.00%
69	100-	40-	15-	50-	S-	R	693.027	762.606	765.266	80.82%	19.18%	0.00%	75.82%	24.18%	0.00%	76.10%	23.90%	0.00%
70	100-	40-	15-	60-	S-	R	676.089	741.816	744.367	81.20%	18.80%	0.00%	77.16%	22.84%	0.00%	76.95%	23.05%	0.00%
71	100-	40-	2-	20-	S-	R	1077.132	1152.414	1113.053	48.94%	51.06%	0.00%	42.19%	57.81%	0.00%	47.16%	52.84%	0.00%
72	100-	40-	2-	30-	S-	R	997.314	1039.915	1040.022	54.69%	45.31%	0.00%	53.94%	46.06%	0.00%	53.25%	46.75%	0.00%
73	100-	40-	2-	40-	S-	R	947.766	1032.863	992.662	57.67%	42.33%	0.00%	51.44%	48.56%	0.00%	57.91%	42.09%	0.00%
74	100-	40-	2-	50-	S-	R	922.255	967.439	968.509	59.59%	40.41%	0.00%	58.29%	41.71%	0.00%	59.49%	40.51%	0.00%
75	100-	40-	2-	60-	S-	R	920.36	964.63	965.856	59.32%	40.68%	0.00%	58.29%	41.71%	0.00%	58.46%	41.54%	0.00%
76	100-	60-	1-	20-	S-	R	655.167	743.928	746.593	90.03%	9.97%	0.00%	78.01%	21.99%	0.00%	78.22%	21.78%	0.00%
77	100-	60-	1-	30-	S-	R	589.066	710.671	671.536	97.50%	2.50%	0.00%	80.21%	19.79%	0.00%	82.91%	17.09%	0.00%
78	100-	60-	1-	40-	S-	R	550.034	622.658	625.281	98.90%	1.10%	0.00%	86.20%	13.80%	0.00%	85.48%	14.52%	0.00%
79	100-	60-	1-	50-	S-	R	522.655	591.959	594.524	99.28%	0.72%	0.00%	88.46%	11.54%	0.00%	87.40%	12.60%	0.00%
80	100-	60-	1-	60-	S-	R	501.487	571.024	572.895	99.21%	0.79%	0.00%	89.52%	10.48%	0.00%	88.56%	11.44%	0.00%
81	100-	60-	15-	20-	S-	R	888.254	945.242	947.056	63.87%	36.13%	0.00%	62.05%	37.95%	0.00%	62.36%	37.64%	0.00%
82	100-	60-	15-	30-	S-	R	795.36	901.867	861.736	73.01%	26.99%	0.00%	63.84%	36.16%	0.00%	69.52%	30.48%	0.00%
83	100-	60-	15-	40-	S-	R	731.143	800.383	802.309	78.08%	21.92%	0.00%	73.63%	26.37%	0.00%	73.77%	26.23%	0.00%
84	100-	60-	15-	50-	S-	R	694.195	761.844	765.606	80.65%	19.35%	0.00%	76.06%	23.94%	0.00%	75.82%	24.18%	0.00%
85	100-	60-	15-	60-	S-	R	677.144	744.061	745.87	81.23%	18.77%	0.00%	76.75%	23.25%	0.00%	76.78%	23.22%	0.00%
86	100-	60-	2-	20-	S-	R	1077.337	1112.566	1111.7	49.62%	50.38%	0.00%	47.50%	52.50%	0.00%	49.11%	50.89%	0.00%
87	100-	60-	2-	30-	S-	R	1000.885	1082.187	1043.034	54.93%	45.07%	0.00%	47.40%	52.60%	0.00%	54.18%	45.82%	0.00%
88	100-	60-	2-	40-	S-	R	949.751	995.566	994.44	57.71%	42.29%	0.00%	56.16%	43.84%	0.00%	57.19%	42.81%	0.00%
89	100-	60-	2-	50-	S-	R	926.31	972.643	969.627	58.77%	41.23%	0.00%	57.29%	42.71%	0.00%	58.32%	41.68%	0.00%
90	100-	60-	2-	60-	S-	R	925.296	968.21	969.377	58.29%	41.71%	0.00%	57.02%	42.98%	0.00%	57.23%	42.77%	0.00%
91	100-	40-	1-	20-	D-	C	1400.808	1614.851	1571.445	4.38%	95.62%	0.00%	3.87%	96.13%	0.00%	4.38%	95.62%	0.00%
92	100-	40-	1-	30-	D-	C	1259.913	1424.841	1419.791	7.05%	92.95%	0.00%	7.09%	92.91%	0.00%	7.19%	92.81%	0.00%
93	100-	40-	1-	40-	D-	C	1178.108	1359.33	1326.96	11.30%	88.70%	0.00%	8.66%	91.34%	0.00%	10.96%	89.04%	0.00%
94	100-	40-	1-	50-	D-	C	1117.692	1254.332	1261.862	17.40%	82.60%	0.00%	15.58%	84.42%	0.00%	16.03%	83.97%	0.00%
95	100-	40-	1-	60-	D-	C	1074.672	1209.053	1216.855	25.14%	74.86%	0.00%	22.26%	77.74%	0.00%	22.47%	77.53%	0.00%
96	100-	40-	15-	20-	D-	C	1872.076	2009.861	1970.426	2.36%	97.64%	0.00%	2.29%	97.71%	0.00%	2.43%	97.57%	0.00%
97	100-	40-	15-	30-	D-	C	1672.362	1800.411	1794.412	3.25%	96.75%	0.00%	3.42%	96.58%	0.00%	3.29%	96.71%	0.00%
98	100-	40-	15-	40-	D-	C	1544.87	1713.561	1681.24	4.14%	95.86%	0.00%	3.94%	96.06%	0.00%	4.35%	95.65%	0.00%
99	100-	40-	15-	50-	D-	C	1464.027	1596.86	1599.046	5.58%	94.42%	0.00%	5.89%	94.11%	0.00%	5.68%	94.32%	0.00%
100	100-	40-	15-	60-	D-	C	1428.539	1554.334	1557.247	7.60%	92.40%	0.00%	7.26%	92.74%	0.00%	7.02%	92.98%	0.00%
101	100-	40-	2-	20-	D-	C	2289.689	2373.069	2335.728	1.40%	98.60%	0.00%	1.58%	98.42%	0.00%	1.68%	98.32%	0.00%
102	100-	40-	2-	30-	D-	C	2117.66	2182.083	2180.679	1.71%	98.29%	0.00%	2.02%	97.98%	0.00%	1.99%	98.01%	0.00%
103	100-	40-	2-	40-	D-	C	2010.102	2121.791	2082.002	2.19%	97.81%	0.00%	2.09%	97.91%	0.00%	2.43%	97.57%	0.00%
104	100-	40-	2-	50-	D-	C	1960.656	2031.115	2032.377	2.43%	97.57%	0.00%	2.47%	97.53%	0.00%	2.53%	97.47%	0.00%
105	100-	40-	2-	60-	D-	C	1961.168	2026.997	2027.797	2.53%	97.47%	0.00%	2.43%	97.57%	0.00%	2.77%	97.23%	0.00%
106	100-	60-	1-	20-	D-	C	1377.262	1553.848	1561.378	4.73%	95.27%	0.00%	4.83%	95.17%	0.00%	4.76%	95.24%	0.00%
107	100-	60-	1-	30-	D-	C	1240.063	1438.509	1402.004	7.74%	92.26%	0.00%	6.51%	93.49%	0.00%	8.05%	91.95%	0.00%
108	100-	60-	1-	40-	D-	C	1156.836	1301.512	1309.914	12.81%	87.19%	0.00%	12.43%	87.57%	0.00%	12.50%	87.50%	0.00%
109	100-	60-	1-	50-	D-	C	1101.382	1239.915	1246.68	18.87%	81.13%	0.00%	17.29%	82.71%	0.00%	17.84%	82.16%	0.00%
110	100-	60-	1-	60-	D-	C	1061.754	1197.285	1202.645	26.78%	73.22%	0.00%	23.97%	76.03%	0.00%	24.04%	75.96%	0.00%
111	100-	60-	15-	20-	D-	C	1875.988	1973.296	1975.704	2.26%	97.74%	0.00%	2.33%	97.67%	0.00%	2.47%	97.53%	0.00%
112	100-	60-	15-	30-	D-	C	1675.347	1837.138	1798.083	3.18%	96.82%	0.00%	3.05%	96.95%	0.00%	3.49%	96.51%	0.00%
113	100-	60-	15-	40-	D-	C	1542.52	1670.243	1676.16	4.21%	95.79%	0.00%	4.59%	95.41%	0.00%	4.52%	95.48%	0.00%
114	100-	60-	15-	50-	D-	C	1466.835	1595.461	1597.474	5.58%	94.42%	0.00%	5.89%	94.11%	0.00%	5.68%	94.32%	0.00%
115	100-	60-	15-	60-	D-	C	1430.724	1558.101	1564.084	7.50%	92.50%	0.00%	7.02%	92.98%	0.00%	7.05%	92.95%	0.00%
116	100-	60-	2-	20-	D-	C	2286.873	2335.086	2330.015	1.40%	98.60%	0.00%	1.68%	98.32%	0.00%	1.71%	98.29%	0.00%
117	100-	60-	2-	30-	D-	C	2123.208	2222.495	2183.881	1.88%	98.12%	0.00%	1.88%	98.12%	0.00%	2.12%	97.88%	0.00%
118	100-	60-	2-	40-	D-	C	2018.577	2089.117	2088.99	2.26%	97.74%	0.00%	2.29%	97.71%	0.00%	2.43%	97.57%	0.00%
119	100-	60-	2-	50-	D-	C	1969.584	2041.204	2038.402	2.47%	97.53%	0.00%	2.47%	97.53%	0.00%	2.64%	97.36%	0.00%
120	100-	60-	2-	60-	D-	C	1966.105	2039.277	2035.461	2.60%	97.40%	0.00%	2.67%	97.33%	0.00%	2.81%	97.19%	0.00%
121	100-	40-	1-	20-	D-	L	1115.825	1298.752	1255.451	17.43%	82.57%	0.00%	12.74%	87.26%	0.00%	16.95%	83.05%	0.00%
122	100-	40-	1-	30-	D-	L	1006.209	1141.408	1135.861	29.25%	70.75%	0.00%	26.47%	73.53%	0.00%	25.51%	74.49%	0.00%
123	100-	40-	1-	40-	D-	L	941.314	1094.006	1061.755	41.03%	58.97%	0.00%	28.49%	71.51%	0.00%	35.99%	64.01%	0.00%
124	100-	40-	1-	50-	D-	L	891.404	1004.002	1007.873	51.13%	48.87%	0.00%	43.97%	56.03%	0.00%	44.21%	55.79%	0.00%
125	100-	40-	1-	60-	D-	L	858.392	966.825	970.61	58.97%	41.03%	0.00%	52.26%	47.74%	0.00%	50.96%	49.04%	0.00%
126	100-	40-	15-	20-	D-	L	1492.481	1617.876	1578.662	7.29%	92.71%	0.00%	6.03%	93.97%	0.00%	7.71%	92.29%	0.00%
127	100-	40-	15-	30-	D-	L	1331.4	1438.241	1436.861	11.47%	88.53%	0.00%	11.88%	88.12%	0.00%	12.29%	87.71%	0.00%
128	100-	40-	15-	40-	D-	L	1229.164	1379.297	1344.696	16.68%	83.32%	0.00%	12.88%	87.12%	0.00%	16.85%	83.15%	0.00%
129	100-	40-	15-	50-	D-	L	1165.933	1273.759	1280.192	23.49%	76.51%	0.00%	21.88%	78.12%	0.00%	22.64%	77.36%	0.00%
130	100-	40-	15-	60-	D-	L	1137.942	1241.574	1246.543	28.70%	71.30%	0.00%	26.34%	73.66%	0.00%	27.09%	72.91%	0.00%

131	100-	40-	2-	20-	D-	L	1819.535	1903.003	1863.376	4.01%	95.99%	0.00%	3.53%	96.47%	0.00%	4.59%	95.41%	0.00%
132	100-	40-	2-	30-	D-	L	1685.61	1741.136	1742.657	5.72%	94.28%	0.00%	5.62%	94.38%	0.00%	5.96%	94.04%	0.00%
133	100-	40-	2-	40-	D-	L	1600.427	1704.398	1663.255	7.36%	92.64%	0.00%	5.82%	94.18%	0.00%	6.85%	93.15%	0.00%
134	100-	40-	2-	50-	D-	L	1560.896	1622.196	1624.171	9.04%	90.96%	0.00%	9.21%	90.79%	0.00%	8.32%	91.68%	0.00%
135	100-	40-	2-	60-	D-	L	1558.786	1616.636	1620.678	10.00%	90.00%	0.00%	9.76%	90.24%	0.00%	9.08%	90.92%	0.00%
136	100-	60-	1-	20-	D-	L	1099.432	1243.229	1248.907	19.01%	80.99%	0.00%	18.22%	81.78%	0.00%	18.08%	81.92%	0.00%
137	100-	60-	1-	30-	D-	L	987.291	1157.778	1121.876	32.09%	67.91%	0.00%	21.92%	78.08%	0.00%	29.35%	70.65%	0.00%
138	100-	60-	1-	40-	D-	L	922.692	1039.318	1046.567	43.25%	56.75%	0.00%	38.97%	61.03%	0.00%	38.39%	61.61%	0.00%
139	100-	60-	1-	50-	D-	L	878.09	990.255	994.761	53.25%	46.75%	0.00%	46.13%	53.87%	0.00%	45.96%	54.04%	0.00%
140	100-	60-	1-	60-	D-	L	844.694	956.113	960.784	60.89%	39.11%	0.00%	53.15%	46.85%	0.00%	52.05%	47.95%	0.00%
141	100-	60-	15-	20-	D-	L	1495.666	1577.025	1581.277	7.33%	92.67%	0.00%	7.88%	92.12%	0.00%	7.23%	92.77%	0.00%
142	100-	60-	15-	30-	D-	L	1335.285	1475.174	1438.48	11.37%	88.63%	0.00%	9.25%	90.75%	0.00%	11.64%	88.36%	0.00%
143	100-	60-	15-	40-	D-	L	1229.691	1339.031	1340.737	16.30%	83.70%	0.00%	16.61%	83.39%	0.00%	17.02%	82.98%	0.00%
144	100-	60-	15-	50-	D-	L	1166.687	1276.376	1280.672	23.42%	76.58%	0.00%	21.40%	78.60%	0.00%	21.99%	78.01%	0.00%
145	100-	60-	15-	60-	D-	L	1139.967	1244.678	1247.551	28.12%	71.88%	0.00%	26.16%	73.84%	0.00%	26.61%	73.39%	0.00%
146	100-	60-	2-	20-	D-	L	1821.815	1864.891	1861.029	4.38%	95.62%	0.00%	4.76%	95.24%	0.00%	4.52%	95.48%	0.00%
147	100-	60-	2-	30-	D-	L	1689.207	1784.628	1744.995	6.16%	93.84%	0.00%	5.10%	94.90%	0.00%	5.96%	94.04%	0.00%
148	100-	60-	2-	40-	D-	L	1603.915	1665.903	1666.408	7.77%	92.23%	0.00%	8.05%	91.95%	0.00%	7.23%	92.77%	0.00%
149	100-	60-	2-	50-	D-	L	1565.746	1627.662	1626.477	9.45%	90.55%	0.00%	9.73%	90.27%	0.00%	8.60%	91.40%	0.00%
150	100-	60-	2-	60-	D-	L	1562.528	1624.957	1624.829	10.55%	89.45%	0.00%	9.79%	90.21%	0.00%	9.52%	90.48%	0.00%
151	100-	40-	1-	20-	D-	R	485.029	593.641	551.337	99.35%	0.65%	0.00%	91.10%	8.90%	0.00%	91.58%	8.42%	0.00%
152	100-	40-	1-	30-	D-	R	436.525	498.851	496.604	100.00%	0.00%	0.00%	94.69%	5.31%	0.00%	94.45%	5.55%	0.00%
153	100-	40-	1-	40-	D-	R	407.914	503.185	463.726	100.00%	0.00%	0.00%	96.13%	3.87%	0.00%	96.47%	3.53%	0.00%
154	100-	40-	1-	50-	D-	R	386.968	438.22	439.321	100.00%	0.00%	0.00%	97.29%	2.71%	0.00%	97.26%	2.74%	0.00%
155	100-	40-	1-	60-	D-	R	371.053	421.851	424.727	100.00%	0.00%	0.00%	97.43%	2.57%	0.00%	97.33%	2.67%	0.00%
156	100-	40-	15-	20-	D-	R	644.924	732.946	691.349	82.19%	17.81%	0.00%	81.82%	18.18%	0.00%	83.39%	16.61%	0.00%
157	100-	40-	15-	30-	D-	R	578.135	630.565	628.862	87.12%	12.88%	0.00%	86.71%	13.29%	0.00%	85.41%	14.59%	0.00%
158	100-	40-	15-	40-	D-	R	533.34	628.415	588.063	91.61%	8.39%	0.00%	86.75%	13.25%	0.00%	87.67%	12.33%	0.00%
159	100-	40-	15-	50-	D-	R	505.095	557.686	559.836	94.08%	5.92%	0.00%	89.04%	10.96%	0.00%	88.46%	11.54%	0.00%
160	100-	40-	15-	60-	D-	R	491.811	543.548	545.027	94.52%	5.48%	0.00%	89.42%	10.58%	0.00%	88.70%	11.30%	0.00%
161	100-	40-	2-	20-	D-	R	782.541	852.897	814.197	69.11%	30.89%	0.00%	71.82%	28.18%	0.00%	73.77%	26.23%	0.00%
162	100-	40-	2-	30-	D-	R	724.638	759.776	761.348	73.56%	26.44%	0.00%	77.50%	22.50%	0.00%	76.30%	23.70%	0.00%
163	100-	40-	2-	40-	D-	R	688.963	766.864	726.091	76.71%	23.29%	0.00%	75.96%	24.04%	0.00%	79.11%	20.89%	0.00%
164	100-	40-	2-	50-	D-	R	672.004	707.327	707.915	77.84%	22.16%	0.00%	78.87%	21.13%	0.00%	80.17%	19.83%	0.00%
165	100-	40-	2-	60-	D-	R	669.209	704.114	704.838	77.43%	22.57%	0.00%	78.39%	21.61%	0.00%	79.49%	20.51%	0.00%
166	100-	60-	1-	20-	D-	R	477.995	544.854	547.04	99.45%	0.55%	0.00%	91.78%	8.22%	0.00%	92.43%	7.57%	0.00%
167	100-	60-	1-	30-	D-	R	430.263	531.827	492.096	100.00%	0.00%	0.00%	94.14%	5.86%	0.00%	94.62%	5.38%	0.00%
168	100-	60-	1-	40-	D-	R	401.157	455.591	457.441	100.00%	0.00%	0.00%	96.75%	3.25%	0.00%	96.71%	3.29%	0.00%
169	100-	60-	1-	50-	D-	R	380.859	432.47	433.961	100.00%	0.00%	0.00%	97.88%	2.12%	0.00%	97.47%	2.53%	0.00%
170	100-	60-	1-	60-	D-	R	365.982	417.589	419.888	100.00%	0.00%	0.00%	97.98%	2.02%	0.00%	97.60%	2.40%	0.00%
171	100-	60-	15-	20-	D-	R	647.952	692.339	693	82.16%	17.84%	0.00%	83.32%	16.68%	0.00%	83.46%	16.54%	0.00%
172	100-	60-	15-	30-	D-	R	579.503	671.718	631.098	86.82%	13.18%	0.00%	84.45%	15.55%	0.00%	86.64%	13.36%	0.00%
173	100-	60-	15-	40-	D-	R	532.688	585.847	587.641	91.51%	8.49%	0.00%	87.84%	12.16%	0.00%	87.67%	12.33%	0.00%
174	100-	60-	15-	50-	D-	R	504.949	559.343	559.918	94.32%	5.68%	0.00%	89.04%	10.96%	0.00%	88.60%	11.40%	0.00%
175	100-	60-	15-	60-	D-	R	492.97	544.578	544.75	94.32%	5.68%	0.00%	89.32%	10.68%	0.00%	88.84%	11.16%	0.00%
176	100-	60-	2-	20-	D-	R	783.285	813.9	812.473	68.66%	31.34%	0.00%	73.87%	26.13%	0.00%	74.21%	25.79%	0.00%
177	100-	60-	2-	30-	D-	R	728.192	803.348	762.686	72.81%	27.19%	0.00%	74.18%	25.82%	0.00%	76.85%	23.15%	0.00%
178	100-	60-	2-	40-	D-	R	692.44	728.704	728.915	75.75%	24.25%	0.00%	77.33%	22.67%	0.00%	78.63%	21.37%	0.00%
179	100-	60-	2-	50-	D-	R	673.204	710.153	709.337	77.02%	22.98%	0.00%	77.84%	22.16%	0.00%	79.32%	20.68%	0.00%
180	100-	60-	2-	60-	D-	R	671.603	707.343	707.654	76.51%	23.49%	0.00%	77.57%	22.43%	0.00%	79.01%	20.99%	0.00%
181	80-	40-	1-	20-	S-	C	1464.677	1704.596	1657.881	3.56%	96.44%	0.00%	3.22%	96.78%	0.00%	3.70%	96.30%	0.00%
182	80-	40-	1-	30-	S-	C	1343.468	1527.538	1518.25	4.90%	95.10%	0.00%	5.48%	94.52%	0.00%	5.51%	94.49%	0.00%
183	80-	40-	1-	40-	S-	C	1261.825	1468.591	1435.488	8.18%	91.82%	0.00%	6.30%	93.70%	0.00%	8.29%	91.71%	0.00%
184	80-	40-	1-	50-	S-	C	1209.515	1368.029	1376.731	11.64%	88.36%	0.00%	11.44%	88.56%	0.00%	11.23%	88.77%	0.00%
185	80-	40-	1-	60-	S-	C	1169.961	1327.633	1335.822	15.62%	84.38%	0.00%	14.86%	85.14%	0.00%	15.21%	84.79%	0.00%
186	80-	40-	15-	20-	S-	C	1939.281	2095.839	2055.605	1.88%	98.12%	0.00%	1.92%	98.08%	0.00%	1.99%	98.01%	0.00%
187	80-	40-	15-	30-	S-	C	1747.076	1891.443	1886.52	2.60%	97.40%	0.00%	2.77%	97.23%	0.00%	2.67%	97.33%	0.00%
188	80-	40-	15-	40-	S-	C	1618.188	1810.775	1776.988	3.22%	96.78%	0.00%	2.98%	97.02%	0.00%	3.29%	96.71%	0.00%
189	80-	40-	15-	50-	S-	C	1546.184	1698.731	1703.793	3.87%	96.13%	0.00%	4.04%	95.96%	0.00%	4.25%	95.75%	0.00%
190	80-	40-	15-	60-	S-	C	1511.846	1659.217	1666.054	4.79%	95.21%	0.00%	4.62%	95.38%	0.00%	4.90%	95.10%	0.00%
191	80-	40-	2-	20-	S-	C	2338.278	2451.007	2412.471	1.23%	98.77%	0.00%	1.30%	98.70%	0.00%	1.47%	98.53%	0.00%
192	80-	40-	2-	30-	S-	C	2184.946	2275.048	2273.605	1.37%	98.63%	0.00%	1.64%	98.36%	0.00%	1.64%	98.36%	0.00%
193	80-	40-	2-	40-	S-	C	2092.974	2224.577	2188.832	1.58%	98.42%	0.00%	1.78%	98.22%	0.00%	1.71%	98.29%	0.00%
194	80-	40-	2-	50-	S-	C	2051.192	2144.618	2144.049	1.78%	98.22%	0.00%	1.95%	98.05%	0.00%	1.99%	98.01%	0.00%
195	80-	40-	2-	60-	S-	C	2060.998	2150.799	2150.464	1.92%	98.08%	0.00%	2.02%	97.98%	0.00%	2.05%	97.95%	0.00%
196	80-	60-	1-	20-	S-	C	1453.574	1648.935	1653.167	3.49%	96.51%	0.00%	3.70%	96.30%	0.00%	3.77%	96.23%	0.00%
197	80-	60-	1-	30-	S-	C	1322.663	1545.004	1512.405	5.55%	94.45%	0.00%	4.66%	95.34%	0.00%	5.68%	94.32%	0.00%
198	80-	60-	1-	40-	S-	C	1242.577	1412.46	1420.396	8.66%	91.34%	0.00%	8.53%	91.47%	0.00%	8.80%	91.20%	0.00%
199	80-	60-	1-	50-	S-	C	1192.188	1352.689	1359.371	12.67%	87.33%	0.00%	12.19%	87.81%	0.00%	11.95%	88.05%	0.00%
200	80-	60-	1-	60-	S-	C	1152.175	1310.963	1320.093	17.50%	82.50%	0.00%	15.86%	84.14%	0.00%	16.30%	83.70%	0.00%

201	80-	60-	15-	20-	S-	C	1935.597	2054.187	2060.295	1.78%	98.22%	0.00%	1.95%	98.05%	0.00%	2.02%	97.98%	0.00%
202	80-	60-	15-	30-	S-	C	1746.354	1923.285	1888.563	2.57%	97.43%	0.00%	2.36%	97.64%	0.00%	2.67%	97.33%	0.00%
203	80-	60-	15-	40-	S-	C	1623.094	1770.849	1774.542	3.22%	96.78%	0.00%	3.32%	96.68%	0.00%	3.39%	96.61%	0.00%
204	80-	60-	15-	50-	S-	C	1546.206	1697.817	1703.751	3.97%	96.03%	0.00%	4.04%	95.96%	0.00%	4.11%	95.89%	0.00%
205	80-	60-	15-	60-	S-	C	1521.386	1662.391	1670.505	4.83%	95.17%	0.00%	4.62%	95.38%	0.00%	4.97%	95.03%	0.00%
206	80-	60-	2-	20-	S-	C	2331.453	2400.355	2397.541	1.27%	98.73%	0.00%	1.51%	98.49%	0.00%	1.37%	98.63%	0.00%
207	80-	60-	2-	30-	S-	C	2174.812	2296.693	2262.331	1.44%	98.56%	0.00%	1.61%	98.39%	0.00%	1.61%	98.39%	0.00%
208	80-	60-	2-	40-	S-	C	2078.432	2172.69	2171.356	1.71%	98.29%	0.00%	1.92%	98.08%	0.00%	1.75%	98.25%	0.00%
209	80-	60-	2-	50-	S-	C	2037.383	2127.806	2128.783	1.88%	98.12%	0.00%	2.05%	97.95%	0.00%	2.16%	97.84%	0.00%
210	80-	60-	2-	60-	S-	C	2042.34	2134.549	2133.514	2.02%	97.98%	0.00%	2.05%	97.95%	0.00%	2.05%	97.95%	0.00%
211	80-	40-	1-	20-	S-	L	1138.427	1338.092	1292.3	15.51%	84.49%	0.00%	11.75%	88.25%	0.00%	14.55%	85.45%	0.00%
212	80-	40-	1-	30-	S-	L	1039.983	1190.465	1183.883	24.97%	75.03%	0.00%	22.71%	77.29%	0.00%	22.43%	77.57%	0.00%
213	80-	40-	1-	40-	S-	L	980.398	1152.352	1117.668	35.62%	64.38%	0.00%	23.84%	76.16%	0.00%	32.12%	67.88%	0.00%
214	80-	40-	1-	50-	S-	L	937.325	1065.998	1070.49	42.95%	57.05%	0.00%	38.63%	61.37%	0.00%	38.63%	61.37%	0.00%
215	80-	40-	1-	60-	S-	L	908.153	1030.052	1036.475	49.18%	50.82%	0.00%	44.38%	55.62%	0.00%	43.87%	56.13%	0.00%
216	80-	40-	15-	20-	S-	L	1504.898	1641.492	1603.555	6.71%	93.29%	0.00%	5.31%	94.69%	0.00%	6.95%	93.05%	0.00%
217	80-	40-	15-	30-	S-	L	1353.55	1474.365	1470.848	10.00%	90.00%	0.00%	10.14%	89.86%	0.00%	10.55%	89.45%	0.00%
218	80-	40-	15-	40-	S-	L	1258.224	1419.85	1384.937	14.35%	85.65%	0.00%	11.20%	88.80%	0.00%	14.38%	85.62%	0.00%
219	80-	40-	15-	50-	S-	L	1197.654	1320.124	1324.82	19.49%	80.51%	0.00%	18.87%	81.13%	0.00%	19.08%	80.92%	0.00%
220	80-	40-	15-	60-	S-	L	1173.309	1290.171	1296.316	23.97%	76.03%	0.00%	22.33%	77.67%	0.00%	22.57%	77.43%	0.00%
221	80-	40-	2-	20-	S-	L	1814.816	1912.028	1876.146	3.60%	96.40%	0.00%	3.22%	96.78%	0.00%	3.77%	96.23%	0.00%
222	80-	40-	2-	30-	S-	L	1694.388	1767.421	1767.823	4.86%	95.14%	0.00%	4.97%	95.03%	0.00%	5.03%	94.97%	0.00%
223	80-	40-	2-	40-	S-	L	1624.427	1741.007	1703.033	6.44%	93.56%	0.00%	4.93%	95.07%	0.00%	5.92%	94.08%	0.00%
224	80-	40-	2-	50-	S-	L	1591.725	1667.396	1672.168	7.53%	92.47%	0.00%	7.77%	92.23%	0.00%	6.71%	93.29%	0.00%
225	80-	40-	2-	60-	S-	L	1597.503	1669.028	1672.13	8.32%	91.68%	0.00%	8.15%	91.85%	0.00%	7.60%	92.40%	0.00%
226	80-	60-	1-	20-	S-	L	1131.6	1284.048	1291.436	15.92%	84.08%	0.00%	15.62%	84.38%	0.00%	15.82%	84.18%	0.00%
227	80-	60-	1-	30-	S-	L	1031.285	1211.746	1177.132	25.89%	74.11%	0.00%	18.29%	81.71%	0.00%	24.38%	75.62%	0.00%
228	80-	60-	1-	40-	S-	L	966.74	1100.061	1106.659	37.43%	62.57%	0.00%	32.40%	67.60%	0.00%	32.88%	67.12%	0.00%
229	80-	60-	1-	50-	S-	L	924.139	1051.466	1058.057	45.21%	54.79%	0.00%	39.86%	60.14%	0.00%	39.90%	60.10%	0.00%
230	80-	60-	1-	60-	S-	L	893.582	1021.557	1025.969	51.88%	48.12%	0.00%	44.93%	55.07%	0.00%	45.24%	54.76%	0.00%
231	80-	60-	15-	20-	S-	L	1504.042	1598.46	1604.258	6.61%	93.39%	0.00%	6.99%	93.01%	0.00%	6.37%	93.63%	0.00%
232	80-	60-	15-	30-	S-	L	1357.925	1510.943	1475.168	9.90%	90.10%	0.00%	8.08%	91.92%	0.00%	10.07%	89.93%	0.00%
233	80-	60-	15-	40-	S-	L	1258.068	1381.066	1384.923	14.25%	85.75%	0.00%	14.45%	85.55%	0.00%	14.42%	85.58%	0.00%
234	80-	60-	15-	50-	S-	L	1200.583	1320.466	1328.349	19.38%	80.62%	0.00%	18.66%	81.34%	0.00%	18.70%	81.30%	0.00%
235	80-	60-	15-	60-	S-	L	1179.033	1293.141	1300.599	23.80%	76.20%	0.00%	22.36%	77.64%	0.00%	22.05%	77.95%	0.00%
236	80-	60-	2-	20-	S-	L	1804.119	1866.213	1863.839	3.94%	96.06%	0.00%	4.04%	95.96%	0.00%	3.77%	96.23%	0.00%
237	80-	60-	2-	30-	S-	L	1685.218	1798.037	1756.431	5.14%	94.86%	0.00%	4.14%	95.86%	0.00%	5.34%	94.66%	0.00%
238	80-	60-	2-	40-	S-	L	1613.884	1689.635	1689.836	6.88%	93.12%	0.00%	6.61%	93.39%	0.00%	6.23%	93.77%	0.00%
239	80-	60-	2-	50-	S-	L	1578.187	1655.816	1658.154	7.98%	92.02%	0.00%	7.81%	92.19%	0.00%	7.12%	92.88%	0.00%
240	80-	60-	2-	60-	S-	L	1580.699	1658.02	1660.582	8.90%	91.10%	0.00%	8.77%	91.23%	0.00%	7.77%	92.23%	0.00%
241	80-	40-	1-	20-	S-	R	613.923	745.95	702.508	93.63%	6.37%	0.00%	77.91%	22.09%	0.00%	81.06%	18.94%	0.00%
242	80-	40-	1-	30-	S-	R	563.076	646.388	643.709	98.12%	1.88%	0.00%	83.90%	16.10%	0.00%	84.25%	15.75%	0.00%
243	80-	40-	1-	40-	S-	R	530.424	644.093	607.861	99.04%	0.96%	0.00%	84.76%	15.24%	0.00%	85.92%	14.08%	0.00%
244	80-	40-	1-	50-	S-	R	507.072	577.293	579.807	99.32%	0.68%	0.00%	89.01%	10.99%	0.00%	87.91%	12.09%	0.00%
245	80-	40-	1-	60-	S-	R	488.788	560.38	563.353	99.49%	0.51%	0.00%	89.83%	10.17%	0.00%	88.73%	11.27%	0.00%
246	80-	40-	15-	20-	S-	R	812.122	913.877	872.696	71.06%	28.94%	0.00%	63.53%	36.47%	0.00%	67.19%	32.81%	0.00%
247	80-	40-	15-	30-	S-	R	731.889	801.771	800.245	77.81%	22.19%	0.00%	73.39%	26.61%	0.00%	73.63%	26.37%	0.00%
248	80-	40-	15-	40-	S-	R	680.043	791.116	752.664	81.71%	18.29%	0.00%	73.42%	26.58%	0.00%	76.92%	23.08%	0.00%
249	80-	40-	15-	50-	S-	R	646.66	718.738	719.786	83.90%	16.10%	0.00%	78.22%	21.78%	0.00%	78.90%	21.10%	0.00%
250	80-	40-	15-	60-	S-	R	631.839	701.439	702.45	84.42%	15.58%	0.00%	79.21%	20.79%	0.00%	79.49%	20.51%	0.00%
251	80-	40-	2-	20-	S-	R	975.797	1056.9	1017.515	56.64%	43.36%	0.00%	50.75%	49.25%	0.00%	55.48%	44.52%	0.00%
252	80-	40-	2-	30-	S-	R	910.083	960	958.553	60.92%	39.08%	0.00%	60.79%	39.21%	0.00%	60.31%	39.69%	0.00%
253	80-	40-	2-	40-	S-	R	871.996	963.743	925.189	63.60%	36.40%	0.00%	58.39%	41.61%	0.00%	63.18%	36.82%	0.00%
254	80-	40-	2-	50-	S-	R	854.491	902.495	905.319	64.76%	35.24%	0.00%	64.55%	35.45%	0.00%	64.52%	35.48%	0.00%
255	80-	40-	2-	60-	S-	R	856.193	902.502	904.361	64.62%	35.38%	0.00%	63.73%	36.27%	0.00%	64.08%	35.92%	0.00%
256	80-	60-	1-	20-	S-	R	609.396	698.34	702.698	94.14%	5.86%	0.00%	81.30%	18.70%	0.00%	80.58%	19.42%	0.00%
257	80-	60-	1-	30-	S-	R	555.955	678.072	639.67	98.36%	1.64%	0.00%	82.43%	17.57%	0.00%	84.45%	15.55%	0.00%
258	80-	60-	1-	40-	S-	R	521.795	596.679	599.772	99.55%	0.45%	0.00%	88.05%	11.95%	0.00%	87.09%	12.91%	0.00%
259	80-	60-	1-	50-	S-	R	499.057	569.638	573.003	99.66%	0.34%	0.00%	89.49%	10.51%	0.00%	88.49%	11.51%	0.00%
260	80-	60-	1-	60-	S-	R	482.897	553.674	556.633	99.76%	0.24%	0.00%	90.41%	9.59%	0.00%	89.49%	10.51%	0.00%
261	80-	60-	15-	20-	S-	R	809.667	869.972	872.427	71.20%	28.80%	0.00%	67.40%	32.60%	0.00%	67.77%	32.23%	0.00%
262	80-	60-	15-	30-	S-	R	729.712	839.589	802.448	77.98%	22.02%	0.00%	69.59%	30.41%	0.00%	73.32%	26.68%	0.00%
263	80-	60-	15-	40-	S-	R	678.494	750.656	752.829	81.99%	18.01%	0.00%	76.37%	23.63%	0.00%	76.88%	23.12%	0.00%
264	80-	60-	15-	50-	S-	R	647.378	718.632	720.122	83.73%	16.27%	0.00%	78.29%	21.71%	0.00%	78.90%	21.10%	0.00%
265	80-	60-	15-	60-	S-	R	634.387	702.854	704.435	84.01%	15.99%	0.00%	79.08%	20.92%	0.00%	79.28%	20.72%	0.00%
266	80-	60-	2-	20-	S-	R	969.405	1011.234	1011.615	56.47%	43.53%	0.00%	55.27%	44.73%	0.00%	56.40%	43.60%	0.00%
267	80-	60-	2-	30-	S-	R	906.106	995.71	954.588	60.48%	39.52%	0.00%	54.35%	45.65%	0.00%	60.68%	39.32%	0.00%
268	80-	60-	2-	40-	S-	R	866.43	914.862	914.921	63.18%	36.82%	0.00%	63.08%	36.92%	0.00%	63.18%	36.82%	0.00%
269	80-	60-	2-	50-	S-	R	847.238	896.38	897.252	64.66%	35.34%	0.00%	63.97%	36.03%	0.00%	64.25%	35.75%	0.00%
270	80-	60-	2-	60-	S-	R	849.08	899.014	898.605	64.18%	35.82%	0.00%	62.98%	37.02%	0.00%	63.42%	36.58%	0.00%

271	80-	40-	1-	20-	D-	C	1291.757	1508.773	1461.682	7.02%	92.98%	0.00%	5.92%	94.08%	0.00%	7.50%	92.50%	0.00%
272	80-	40-	1-	30-	D-	C	1182.65	1349.927	1342.865	11.47%	88.53%	0.00%	11.03%	88.97%	0.00%	11.27%	88.73%	0.00%
273	80-	40-	1-	40-	D-	C	1115.218	1298.743	1269.386	16.99%	83.01%	0.00%	12.71%	87.29%	0.00%	16.30%	83.70%	0.00%
274	80-	40-	1-	50-	D-	C	1064.48	1206.411	1213.205	24.79%	75.21%	0.00%	22.53%	77.47%	0.00%	23.32%	76.68%	0.00%
275	80-	40-	1-	60-	D-	C	1030.043	1172.974	1178.684	31.99%	68.01%	0.00%	28.12%	71.88%	0.00%	29.04%	70.96%	0.00%
276	80-	40-	15-	20-	D-	C	1711.397	1855.706	1819.251	3.22%	96.78%	0.00%	3.01%	96.99%	0.00%	3.39%	96.61%	0.00%
277	80-	40-	15-	30-	D-	C	1540.523	1674.471	1666.795	4.32%	95.68%	0.00%	4.79%	95.21%	0.00%	4.97%	95.03%	0.00%
278	80-	40-	15-	40-	D-	C	1430.787	1605.9	1569.939	6.47%	93.53%	0.00%	5.31%	94.69%	0.00%	6.58%	93.42%	0.00%
279	80-	40-	15-	50-	D-	C	1363.505	1498.961	1505.734	8.87%	91.13%	0.00%	8.94%	91.06%	0.00%	8.73%	91.27%	0.00%
280	80-	40-	15-	60-	D-	C	1332.062	1464.722	1470.234	11.44%	88.56%	0.00%	11.30%	88.70%	0.00%	10.72%	89.28%	0.00%
281	80-	40-	2-	20-	D-	C	2061.075	2167.429	2130.205	2.09%	97.91%	0.00%	1.95%	98.05%	0.00%	2.05%	97.95%	0.00%
282	80-	40-	2-	30-	D-	C	1928.841	2006.127	2006.854	2.53%	97.47%	0.00%	2.67%	97.33%	0.00%	2.67%	97.33%	0.00%
283	80-	40-	2-	40-	D-	C	1848.802	1972.163	1933.262	2.91%	97.09%	0.00%	2.77%	97.23%	0.00%	3.08%	96.92%	0.00%
284	80-	40-	2-	50-	D-	C	1811.458	1895.73	1896.281	3.42%	96.58%	0.00%	3.46%	96.54%	0.00%	3.36%	96.64%	0.00%
285	80-	40-	2-	60-	D-	C	1817.893	1896.732	1895.982	3.66%	96.34%	0.00%	3.46%	96.54%	0.00%	3.53%	96.47%	0.00%
286	80-	60-	1-	20-	D-	C	1281.11	1457.267	1463.543	7.29%	92.71%	0.00%	7.60%	92.40%	0.00%	7.23%	92.77%	0.00%
287	80-	60-	1-	30-	D-	C	1169.07	1365.873	1338.366	12.36%	87.64%	0.00%	9.49%	90.51%	0.00%	11.58%	88.42%	0.00%
288	80-	60-	1-	40-	D-	C	1096.147	1246.656	1256.552	18.70%	81.30%	0.00%	17.16%	82.84%	0.00%	17.19%	82.81%	0.00%
289	80-	60-	1-	50-	D-	C	1050.493	1192.419	1202.016	26.51%	73.49%	0.00%	23.56%	76.44%	0.00%	23.87%	76.13%	0.00%
290	80-	60-	1-	60-	D-	C	1017.709	1158.647	1167.351	33.32%	66.68%	0.00%	29.18%	70.82%	0.00%	29.55%	70.45%	0.00%
291	80-	60-	15-	20-	D-	C	1710.129	1815.697	1815.635	3.18%	96.82%	0.00%	3.39%	96.61%	0.00%	3.39%	96.61%	0.00%
292	80-	60-	15-	30-	D-	C	1541.821	1705.53	1667.342	4.28%	95.72%	0.00%	4.49%	95.51%	0.00%	4.79%	95.21%	0.00%
293	80-	60-	15-	40-	D-	C	1428.347	1565.859	1569.092	6.68%	93.32%	0.00%	6.75%	93.25%	0.00%	6.51%	93.49%	0.00%
294	80-	60-	15-	50-	D-	C	1366.798	1498.886	1504.395	8.73%	91.27%	0.00%	9.11%	90.89%	0.00%	8.60%	91.40%	0.00%
295	80-	60-	15-	60-	D-	C	1338.662	1467.323	1473.446	11.30%	88.70%	0.00%	11.13%	88.87%	0.00%	10.58%	89.42%	0.00%
296	80-	60-	2-	20-	D-	C	2054.64	2118.5	2113.032	2.05%	97.95%	0.00%	2.16%	97.84%	0.00%	2.26%	97.74%	0.00%
297	80-	60-	2-	30-	D-	C	1918.717	2036.509	1996.426	2.60%	97.40%	0.00%	2.40%	97.60%	0.00%	2.84%	97.16%	0.00%
298	80-	60-	2-	40-	D-	C	1834.237	1918.83	1916.641	3.08%	96.92%	0.00%	3.18%	96.82%	0.00%	3.05%	96.95%	0.00%
299	80-	60-	2-	50-	D-	C	1794.953	1879.852	1880.071	3.53%	96.47%	0.00%	3.49%	96.51%	0.00%	3.46%	96.54%	0.00%
300	80-	60-	2-	60-	D-	C	1802.329	1885.468	1883.789	3.80%	96.20%	0.00%	3.63%	96.37%	0.00%	3.60%	96.40%	0.00%
301	80-	40-	1-	20-	D-	L	1032.44	1218.304	1173.794	28.90%	71.10%	0.00%	20.07%	79.93%	0.00%	25.62%	74.38%	0.00%
302	80-	40-	1-	30-	D-	L	945.625	1080.369	1072.271	40.34%	59.66%	0.00%	35.75%	64.25%	0.00%	36.99%	63.01%	0.00%
303	80-	40-	1-	40-	D-	L	887.549	1049.82	1016.36	51.54%	48.46%	0.00%	37.84%	62.16%	0.00%	43.84%	56.16%	0.00%
304	80-	40-	1-	50-	D-	L	852.598	965.619	971.278	59.25%	40.75%	0.00%	52.12%	47.88%	0.00%	50.72%	49.28%	0.00%
305	80-	40-	1-	60-	D-	L	823.108	937.426	942.318	65.45%	34.55%	0.00%	56.64%	43.36%	0.00%	55.21%	44.79%	0.00%
306	80-	40-	15-	20-	D-	L	1361.337	1498.383	1454.775	12.50%	87.50%	0.00%	9.35%	90.65%	0.00%	12.53%	87.47%	0.00%
307	80-	40-	15-	30-	D-	L	1228.784	1338.726	1333.188	18.63%	81.37%	0.00%	18.49%	81.51%	0.00%	18.39%	81.61%	0.00%
308	80-	40-	15-	40-	D-	L	1140.454	1291.103	1254.346	26.03%	73.97%	0.00%	18.63%	81.37%	0.00%	25.55%	74.45%	0.00%
309	80-	40-	15-	50-	D-	L	1086.326	1197.775	1202.4	32.50%	67.50%	0.00%	30.21%	69.79%	0.00%	30.55%	69.45%	0.00%
310	80-	40-	15-	60-	D-	L	1061.244	1172.807	1174.462	36.03%	63.97%	0.00%	33.25%	66.75%	0.00%	33.80%	66.20%	0.00%
311	80-	40-	2-	20-	D-	L	1641.128	1739.115	1701.88	6.85%	93.15%	0.00%	5.27%	94.73%	0.00%	7.19%	92.81%	0.00%
312	80-	40-	2-	30-	D-	L	1536.529	1606.446	1604.665	9.42%	90.58%	0.00%	8.49%	91.51%	0.00%	9.52%	90.48%	0.00%
313	80-	40-	2-	40-	D-	L	1471.461	1584.562	1547.199	11.85%	88.15%	0.00%	8.36%	91.64%	0.00%	10.92%	89.08%	0.00%
314	80-	40-	2-	50-	D-	L	1442.473	1513.551	1515.591	13.77%	86.23%	0.00%	13.12%	86.88%	0.00%	12.88%	87.12%	0.00%
315	80-	40-	2-	60-	D-	L	1447.023	1513.33	1513.015	15.10%	84.90%	0.00%	14.14%	85.86%	0.00%	13.49%	86.51%	0.00%
316	80-	60-	1-	20-	D-	L	1023.491	1165.12	1170.822	29.76%	70.24%	0.00%	26.47%	73.53%	0.00%	27.40%	72.60%	0.00%
317	80-	60-	1-	30-	D-	L	933	1104.109	1069.201	42.02%	57.98%	0.00%	28.87%	71.13%	0.00%	36.92%	63.08%	0.00%
318	80-	60-	1-	40-	D-	L	875.986	997.503	1003.602	52.88%	47.12%	0.00%	45.75%	54.25%	0.00%	45.38%	54.62%	0.00%
319	80-	60-	1-	50-	D-	L	837.053	953.722	958.817	61.75%	38.25%	0.00%	53.46%	46.54%	0.00%	52.12%	47.88%	0.00%
320	80-	60-	1-	60-	D-	L	810.459	926.45	931.656	66.88%	33.12%	0.00%	57.57%	42.43%	0.00%	56.06%	43.94%	0.00%
321	80-	60-	15-	20-	D-	L	1363.806	1452.908	1455.833	11.99%	88.01%	0.00%	12.29%	87.71%	0.00%	12.05%	87.95%	0.00%
322	80-	60-	15-	30-	D-	L	1229.229	1374.934	1338.592	18.46%	81.54%	0.00%	13.90%	86.10%	0.00%	18.49%	81.51%	0.00%
323	80-	60-	15-	40-	D-	L	1140.264	1253.375	1255.67	26.27%	73.73%	0.00%	24.38%	75.62%	0.00%	24.76%	75.24%	0.00%
324	80-	60-	15-	50-	D-	L	1088.172	1201.163	1203.33	32.95%	67.05%	0.00%	29.86%	70.14%	0.00%	30.41%	69.59%	0.00%
325	80-	60-	15-	60-	D-	L	1070.492	1175.914	1179.759	35.99%	64.01%	0.00%	33.42%	66.58%	0.00%	33.70%	66.30%	0.00%
326	80-	60-	2-	20-	D-	L	1633.779	1694.053	1691.343	7.43%	92.57%	0.00%	7.23%	92.77%	0.00%	7.02%	92.98%	0.00%
327	80-	60-	2-	30-	D-	L	1527.112	1632.901	1593.754	10.10%	89.90%	0.00%	7.16%	92.84%	0.00%	8.94%	91.06%	0.00%
328	80-	60-	2-	40-	D-	L	1460.356	1530.738	1532.159	12.36%	87.64%	0.00%	11.54%	88.46%	0.00%	11.27%	88.73%	0.00%
329	80-	60-	2-	50-	D-	L	1428.979	1501.744	1502.437	14.62%	85.38%	0.00%	13.22%	86.78%	0.00%	13.08%	86.92%	0.00%
330	80-	60-	2-	60-	D-	L	1436.129	1503.228	1502.852	15.96%	84.04%	0.00%	14.25%	85.75%	0.00%	13.90%	86.10%	0.00%
331	80-	40-	1-	20-	D-	R	448.824	557.672	514.791	100.00%	0.00%	0.00%	92.81%	7.19%	0.00%	92.53%	7.47%	0.00%
332	80-	40-	1-	30-	D-	R	410.796	473.488	471.608	100.00%	0.00%	0.00%	95.21%	4.79%	0.00%	95.07%	4.93%	0.00%
333	80-	40-	1-	40-	D-	R	386.905	482.959	444.159	100.00%	0.00%	0.00%	96.47%	3.53%	0.00%	96.85%	3.15%	0.00%
334	80-	40-	1-	50-	D-	R	369.89	421.47	424.587	100.00%	0.00%	0.00%	97.71%	2.29%	0.00%	97.43%	2.57%	0.00%
335	80-	40-	1-	60-	D-	R	357.589	410.663	411.306	100.00%	0.00%	0.00%	97.88%	2.12%	0.00%	97.53%	2.47%	0.00%
336	80-	40-	15-	20-	D-	R	591.672	680.351	639.039	85.27%	14.73%	0.00%	84.69%	15.31%	0.00%	84.59%	15.41%	0.00%
337	80-	40-	15-	30-	D-	R	533.255	587.828	587.001	90.51%	9.49%	0.00%	87.60%	12.40%	0.00%	87.23%	12.77%	0.00%
338	80-	40-	15-	40-	D-	R	495.678	590.86	551.302	94.69%	5.31%	0.00%	88.70%	11.30%	0.00%	88.97%	11.03%	0.00%
339	80-	40-	15-	50-	D-	R	472.026	525.827	528.316	97.29%	2.71%	0.00%	90.62%	9.38%	0.00%	89.97%	10.03%	0.00%
340	80-	40-	15-	60-	D-	R	461.347	512.912	515.613	97.53%	2.47%	0.00%	91.03%	8.97%	0.00%	90.41%	9.59%	0.00%

341	80-	40-	2-	20-	D-	R	707.806	785.922	744.265	75.86%	24.14%	0.00%	76.51%	23.49%	0.00%	77.05%	22.95%	0.00%
342	80-	40-	2-	30-	D-	R	663.13	702.107	701.605	79.69%	20.31%	0.00%	80.86%	19.14%	0.00%	80.03%	19.97%	0.00%
343	80-	40-	2-	40-	D-	R	634.669	716.207	676.221	81.68%	18.32%	0.00%	79.69%	20.31%	0.00%	82.05%	17.95%	0.00%
344	80-	40-	2-	50-	D-	R	622.774	661.33	663.936	82.12%	17.88%	0.00%	82.40%	17.60%	0.00%	82.36%	17.64%	0.00%
345	80-	40-	2-	60-	D-	R	623.112	660.477	659.926	81.78%	18.22%	0.00%	81.61%	18.39%	0.00%	82.05%	17.95%	0.00%
346	80-	60-	1-	20-	D-	R	444.967	511.888	513.985	100.00%	0.00%	0.00%	92.53%	7.47%	0.00%	93.39%	6.61%	0.00%
347	80-	60-	1-	30-	D-	R	406.419	508.872	468.394	100.00%	0.00%	0.00%	95.00%	5.00%	0.00%	95.21%	4.79%	0.00%
348	80-	60-	1-	40-	D-	R	381.508	437.645	439.004	100.00%	0.00%	0.00%	97.43%	2.57%	0.00%	96.92%	3.08%	0.00%
349	80-	60-	1-	50-	D-	R	364.64	418.203	419.93	100.00%	0.00%	0.00%	98.29%	1.71%	0.00%	97.77%	2.23%	0.00%
350	80-	60-	1-	60-	D-	R	352.576	405.725	407.172	100.00%	0.00%	0.00%	98.49%	1.51%	0.00%	97.77%	2.23%	0.00%
351	80-	60-	15-	20-	D-	R	591.188	637.582	639.246	85.38%	14.62%	0.00%	84.76%	15.24%	0.00%	85.99%	14.01%	0.00%
352	80-	60-	15-	30-	D-	R	533.502	627.947	586.921	90.65%	9.35%	0.00%	86.23%	13.77%	0.00%	87.67%	12.33%	0.00%
353	80-	60-	15-	40-	D-	R	495.164	549.744	551.712	94.66%	5.34%	0.00%	89.52%	10.48%	0.00%	88.94%	11.06%	0.00%
354	80-	60-	15-	50-	D-	R	472.115	525.74	527.686	96.95%	3.05%	0.00%	90.62%	9.38%	0.00%	90.03%	9.97%	0.00%
355	80-	60-	15-	60-	D-	R	461.991	515.628	516.966	97.43%	2.57%	0.00%	90.89%	9.11%	0.00%	90.34%	9.66%	0.00%
356	80-	60-	2-	20-	D-	R	707.503	739.852	740.608	74.35%	25.65%	0.00%	76.85%	23.15%	0.00%	78.08%	21.92%	0.00%
357	80-	60-	2-	30-	D-	R	660.28	738.017	697.437	79.28%	20.72%	0.00%	77.47%	22.53%	0.00%	80.68%	19.32%	0.00%
358	80-	60-	2-	40-	D-	R	630.552	668.726	669.93	81.47%	18.53%	0.00%	81.99%	18.01%	0.00%	82.05%	17.95%	0.00%
359	80-	60-	2-	50-	D-	R	617.701	656.353	655.964	82.26%	17.74%	0.00%	82.40%	17.60%	0.00%	82.47%	17.53%	0.00%
360	80-	60-	2-	60-	D-	R	617.723	656.522	654.909	81.92%	18.08%	0.00%	81.47%	18.53%	0.00%	82.12%	17.88%	0.00%
361	60-	40-	1-	20-	S-	C	1368.333	1604.377	1555.151	4.90%	95.10%	0.00%	4.52%	95.48%	0.00%	5.27%	94.73%	0.00%
362	60-	40-	1-	30-	S-	C	1265.795	1454.195	1448.7	7.98%	92.02%	0.00%	8.39%	91.61%	0.00%	8.05%	91.95%	0.00%
363	60-	40-	1-	40-	S-	C	1200.513	1412.66	1383.451	12.02%	87.98%	0.00%	9.01%	90.99%	0.00%	11.51%	88.49%	0.00%
364	60-	40-	1-	50-	S-	C	1157.288	1323.279	1332.228	16.75%	83.25%	0.00%	15.27%	84.73%	0.00%	15.31%	84.69%	0.00%
365	60-	40-	1-	60-	S-	C	1127.834	1292.76	1301.686	21.27%	78.73%	0.00%	19.14%	80.86%	0.00%	19.21%	80.79%	0.00%
366	60-	40-	15-	20-	S-	C	1735.142	1904.522	1863.338	2.84%	97.16%	0.00%	2.74%	97.26%	0.00%	2.77%	97.23%	0.00%
367	60-	40-	15-	30-	S-	C	1586.43	1739.8	1786.476	3.66%	96.34%	0.00%	3.87%	96.13%	0.00%	3.36%	96.64%	0.00%
368	60-	40-	15-	40-	S-	C	1487.417	1678.141	1648.122	4.79%	95.21%	0.00%	4.28%	95.72%	0.00%	5.03%	94.97%	0.00%
369	60-	40-	15-	50-	S-	C	1427.146	1582.005	1588.743	6.54%	93.46%	0.00%	6.75%	93.25%	0.00%	6.71%	93.29%	0.00%
370	60-	40-	15-	60-	S-	C	1402.308	1555.469	1564.905	8.05%	91.95%	0.00%	7.74%	92.26%	0.00%	7.57%	92.43%	0.00%
371	60-	40-	2-	20-	S-	C	2086.501	2198.367	2160.657	1.75%	98.25%	0.00%	1.78%	98.22%	0.00%	1.92%	98.08%	0.00%
372	60-	40-	2-	30-	S-	C	1959.478	2045.4	2041.017	2.23%	97.77%	0.00%	2.36%	97.64%	0.00%	2.33%	97.67%	0.00%
373	60-	40-	2-	40-	S-	C	1872.176	1998.639	1966.08	2.64%	97.36%	0.00%	2.40%	97.60%	0.00%	2.71%	97.29%	0.00%
374	60-	40-	2-	50-	S-	C	1828.891	1923.578	1928.551	2.95%	97.05%	0.00%	2.77%	97.23%	0.00%	2.88%	97.12%	0.00%
375	60-	40-	2-	60-	S-	C	1825.934	1924.025	1926.746	3.15%	96.85%	0.00%	2.88%	97.12%	0.00%	2.98%	97.02%	0.00%
376	60-	60-	1-	20-	S-	C	1340.445	1532.547	1544.378	5.41%	94.59%	0.00%	5.89%	94.11%	0.00%	5.62%	94.38%	0.00%
377	60-	60-	1-	30-	S-	C	1245.288	1466.918	1435.94	8.60%	91.40%	0.00%	6.58%	93.42%	0.00%	9.25%	90.75%	0.00%
378	60-	60-	1-	40-	S-	C	1183.431	1355.408	1366.672	12.74%	87.26%	0.00%	12.36%	87.64%	0.00%	12.02%	87.98%	0.00%
379	60-	60-	1-	50-	S-	C	1144.29	1308.509	1316.642	17.36%	82.64%	0.00%	15.82%	84.18%	0.00%	15.89%	84.11%	0.00%
380	60-	60-	1-	60-	S-	C	1115.013	1285.338	1289.456	22.23%	77.77%	0.00%	19.55%	80.45%	0.00%	19.62%	80.38%	0.00%
381	60-	60-	15-	20-	S-	C	1726.172	1845.117	1853.638	2.91%	97.09%	0.00%	2.88%	97.12%	0.00%	2.95%	97.05%	0.00%
382	60-	60-	15-	30-	S-	C	1576.513	1758.275	1725.476	3.73%	96.27%	0.00%	3.60%	96.40%	0.00%	4.01%	95.99%	0.00%
383	60-	60-	15-	40-	S-	C	1477.621	1635.307	1636.113	4.90%	95.10%	0.00%	5.24%	94.76%	0.00%	5.10%	94.90%	0.00%
384	60-	60-	15-	50-	S-	C	1422.077	1577.997	1584.599	6.58%	93.42%	0.00%	6.64%	93.36%	0.00%	6.44%	93.56%	0.00%
385	60-	60-	15-	60-	S-	C	1405.087	1557.939	1562.142	7.84%	92.16%	0.00%	7.47%	92.53%	0.00%	7.33%	92.67%	0.00%
386	60-	60-	2-	20-	S-	C	2026.196	2114.579	2116.044	1.88%	98.12%	0.00%	1.99%	98.01%	0.00%	2.02%	97.98%	0.00%
387	60-	60-	2-	30-	S-	C	1913.361	2051.96	2013.484	2.40%	97.60%	0.00%	1.99%	98.01%	0.00%	2.43%	97.57%	0.00%
388	60-	60-	2-	40-	S-	C	1846.954	1950.94	1952.744	2.67%	97.33%	0.00%	2.64%	97.36%	0.00%	2.74%	97.26%	0.00%
389	60-	60-	2-	50-	S-	C	1822.159	1927.13	1926.244	2.91%	97.09%	0.00%	2.74%	97.26%	0.00%	2.84%	97.16%	0.00%
390	60-	60-	2-	60-	S-	C	1835.875	1938.423	1939.19	3.12%	96.88%	0.00%	2.74%	97.26%	0.00%	2.95%	97.05%	0.00%
391	60-	40-	1-	20-	S-	L	1062.328	1257.433	1211.812	24.66%	75.34%	0.00%	17.95%	82.05%	0.00%	22.50%	77.50%	0.00%
392	60-	40-	1-	30-	S-	L	982.384	1133.769	1127.815	35.34%	64.66%	0.00%	31.64%	68.36%	0.00%	30.62%	69.38%	0.00%
393	60-	40-	1-	40-	S-	L	933.924	1108.951	1075.294	43.56%	56.44%	0.00%	31.27%	68.73%	0.00%	38.56%	61.44%	0.00%
394	60-	40-	1-	50-	S-	L	898.788	1031.356	1037.058	51.23%	48.77%	0.00%	44.01%	55.99%	0.00%	43.60%	56.40%	0.00%
395	60-	40-	1-	60-	S-	L	878.866	1007.036	1013.617	55.55%	44.45%	0.00%	48.87%	51.13%	0.00%	47.74%	52.26%	0.00%
396	60-	40-	15-	20-	S-	L	1346.682	1494.991	1452.328	12.29%	87.71%	0.00%	9.01%	90.99%	0.00%	12.29%	87.71%	0.00%
397	60-	40-	15-	30-	S-	L	1233.054	1352.946	1349.88	17.53%	82.47%	0.00%	17.29%	82.71%	0.00%	16.99%	83.01%	0.00%
398	60-	40-	15-	40-	S-	L	1155.661	1316.392	1283.727	23.73%	76.27%	0.00%	16.88%	83.12%	0.00%	22.47%	77.53%	0.00%
399	60-	40-	15-	50-	S-	L	1109.25	1234.412	1239.971	29.45%	70.55%	0.00%	26.30%	73.70%	0.00%	27.40%	72.60%	0.00%
400	60-	40-	15-	60-	S-	L	1091.699	1210.998	1217.71	32.47%	67.53%	0.00%	29.62%	70.38%	0.00%	29.93%	70.07%	0.00%
401	60-	40-	2-	20-	S-	L	1621.456	1716.606	1679.867	7.40%	92.60%	0.00%	5.31%	94.69%	0.00%	6.95%	93.05%	0.00%
402	60-	40-	2-	30-	S-	L	1519.508	1593.24	1590.317	9.83%	90.17%	0.00%	8.66%	91.34%	0.00%	9.42%	90.58%	0.00%
403	60-	40-	2-	40-	S-	L	1452.815	1569.672	1531.325	11.99%	88.01%	0.00%	8.32%	91.68%	0.00%	10.86%	89.14%	0.00%
404	60-	40-	2-	50-	S-	L	1418.713	1497.37	1502.209	13.90%	86.10%	0.00%	12.57%	87.43%	0.00%	12.53%	87.47%	0.00%
405	60-	40-	2-	60-	S-	L	1418.57	1492.983	1495.463	15.07%	84.93%	0.00%	13.53%	86.47%	0.00%	13.18%	86.82%	0.00%
406	60-	60-	1-	20-	S-	L	1042.65	1197.626	1206.086	27.23%	72.77%	0.00%	24.18%	75.82%	0.00%	23.90%	76.10%	0.00%
407	60-	60-	1-	30-	S-	L	967.228	1153.604	1118.237	37.29%	62.71%	0.00%	24.86%	75.14%	0.00%	33.12%	66.88%	0.00%
408	60-	60-	1-	40-	S-	L	921.074	1054.849	1062.043	44.59%	55.41%	0.00%	40.21%	59.79%	0.00%	40.00%	60.00%	0.00%
409	60-	60-	1-	50-	S-	L	886.944	1020.298	1026.594	52.53%	47.47%	0.00%	44.97%	55.03%	0.00%	44.69%	55.31%	0.00%
410	60-	60-	1-	60-	S-	L	867.125	997.849	1003.423	57.64%	42.36%	0.00%	49.86%	50.14%	0.00%	48.90%	51.10%	0.00%

411	60-	60-	15-	20-	S-	L	1339.004	1439.237	1444.06	12.43%	87.57%	0.00%	12.60%	87.40%	0.00%	12.16%	87.84%	0.00%
412	60-	60-	15-	30-	S-	L	1291.159	1448.522	1414.624	12.88%	87.12%	0.00%	10.03%	89.97%	0.00%	12.74%	87.26%	0.00%
413	60-	60-	15-	40-	S-	L	1150.24	1270.443	1277.476	24.25%	75.75%	0.00%	22.64%	77.36%	0.00%	22.71%	77.29%	0.00%
414	60-	60-	15-	50-	S-	L	1103.19	1231.108	1236.432	29.76%	70.24%	0.00%	26.51%	73.49%	0.00%	27.36%	72.64%	0.00%
415	60-	60-	15-	60-	S-	L	1089.993	1211.319	1217.572	32.02%	67.98%	0.00%	29.66%	70.34%	0.00%	29.76%	70.24%	0.00%
416	60-	60-	2-	20-	S-	L	1573.118	1647.973	1648.669	7.74%	92.26%	0.00%	7.50%	92.50%	0.00%	7.05%	92.95%	0.00%
417	60-	60-	2-	30-	S-	L	1480.938	1606.343	1569.883	10.41%	89.59%	0.00%	7.05%	92.95%	0.00%	9.11%	90.89%	0.00%
418	60-	60-	2-	40-	S-	L	1431.286	1519.301	1523.004	12.19%	87.81%	0.00%	11.30%	88.70%	0.00%	10.68%	89.32%	0.00%
419	60-	60-	2-	50-	S-	L	1411.535	1498.521	1499.098	13.70%	86.30%	0.00%	12.53%	87.47%	0.00%	12.05%	87.95%	0.00%
420	60-	60-	2-	60-	S-	L	1422.15	1508.364	1507.379	14.76%	85.24%	0.00%	12.88%	87.12%	0.00%	12.64%	87.36%	0.00%
421	60-	40-	1-	20-	S-	R	574.049	703.714	660.605	96.68%	3.32%	0.00%	80.31%	19.69%	0.00%	83.39%	16.61%	0.00%
422	60-	40-	1-	30-	S-	R	532.837	616.603	612.707	99.01%	0.99%	0.00%	85.27%	14.73%	0.00%	86.47%	13.53%	0.00%
423	60-	40-	1-	40-	S-	R	504.314	622.053	584.574	99.66%	0.34%	0.00%	86.34%	13.66%	0.00%	87.36%	12.64%	0.00%
424	60-	40-	1-	50-	S-	R	486.104	559.881	562.923	99.76%	0.24%	0.00%	89.76%	10.24%	0.00%	88.80%	11.20%	0.00%
425	60-	40-	1-	60-	S-	R	473.942	546.441	549.461	99.86%	0.14%	0.00%	90.10%	9.90%	0.00%	89.69%	10.31%	0.00%
426	60-	40-	15-	20-	S-	R	727.622	831.42	791.641	77.77%	22.23%	0.00%	70.27%	29.73%	0.00%	73.32%	26.68%	0.00%
427	60-	40-	15-	30-	S-	R	664.483	736.659	734.234	82.57%	17.43%	0.00%	77.71%	22.29%	0.00%	77.47%	22.53%	0.00%
428	60-	40-	15-	40-	S-	R	623.19	735.166	699.259	85.38%	14.62%	0.00%	77.05%	22.95%	0.00%	79.62%	20.38%	0.00%
429	60-	40-	15-	50-	S-	R	598.665	670.594	673.254	87.50%	12.50%	0.00%	80.89%	19.11%	0.00%	80.82%	19.18%	0.00%
430	60-	40-	15-	60-	S-	R	588.128	656.874	661.078	87.77%	12.23%	0.00%	81.78%	18.22%	0.00%	81.44%	18.56%	0.00%
431	60-	40-	2-	20-	S-	R	871.081	950.57	910.964	63.77%	36.23%	0.00%	59.90%	40.10%	0.00%	63.63%	36.37%	0.00%
432	60-	40-	2-	30-	S-	R	817.345	863.584	863.772	68.05%	31.95%	0.00%	66.54%	33.46%	0.00%	66.16%	33.84%	0.00%
433	60-	40-	2-	40-	S-	R	780.607	870.708	831.415	70.58%	29.42%	0.00%	64.79%	35.21%	0.00%	68.29%	31.71%	0.00%
434	60-	40-	2-	50-	S-	R	761.753	812.015	813.848	71.68%	28.32%	0.00%	69.42%	30.58%	0.00%	69.59%	30.41%	0.00%
435	60-	40-	2-	60-	S-	R	760.837	810.074	809.97	71.03%	28.97%	0.00%	69.11%	30.89%	0.00%	68.97%	31.03%	0.00%
436	60-	60-	1-	20-	S-	R	564.865	651.357	654.625	97.47%	2.53%	0.00%	83.80%	16.20%	0.00%	83.25%	16.75%	0.00%
437	60-	60-	1-	30-	S-	R	523.611	645.54	608.046	99.32%	0.68%	0.00%	84.73%	15.27%	0.00%	86.40%	13.60%	0.00%
438	60-	60-	1-	40-	S-	R	496.902	573.462	577.048	99.86%	0.14%	0.00%	89.35%	10.65%	0.00%	88.42%	11.58%	0.00%
439	60-	60-	1-	50-	S-	R	479.421	553.237	557.705	99.93%	0.07%	0.00%	90.48%	9.52%	0.00%	89.90%	10.10%	0.00%
440	60-	60-	1-	60-	S-	R	468.778	541.554	544.314	99.90%	0.10%	0.00%	90.72%	9.28%	0.00%	90.55%	9.45%	0.00%
441	60-	60-	15-	20-	S-	R	721.588	782.305	785.987	78.05%	21.95%	0.00%	74.01%	25.99%	0.00%	73.56%	26.44%	0.00%
442	60-	60-	15-	30-	S-	R	660.31	769.733	729.987	82.91%	17.09%	0.00%	74.76%	25.24%	0.00%	78.08%	21.92%	0.00%
443	60-	60-	15-	40-	S-	R	619.6	692.28	694.014	85.79%	14.21%	0.00%	79.49%	20.51%	0.00%	79.73%	20.27%	0.00%
444	60-	60-	15-	50-	S-	R	595.955	668.615	670.901	87.95%	12.05%	0.00%	80.99%	19.01%	0.00%	80.82%	19.18%	0.00%
445	60-	60-	15-	60-	S-	R	586.688	658.01	660.271	88.15%	11.85%	0.00%	81.75%	18.25%	0.00%	81.44%	18.56%	0.00%
446	60-	60-	2-	20-	S-	R	846.708	892.303	894.411	64.93%	35.07%	0.00%	64.59%	35.41%	0.00%	64.38%	35.62%	0.00%
447	60-	60-	2-	30-	S-	R	798.643	891.351	851.417	69.32%	30.68%	0.00%	63.29%	36.71%	0.00%	67.47%	32.53%	0.00%
448	60-	60-	2-	40-	S-	R	771.045	825.054	825.131	71.27%	28.73%	0.00%	68.56%	31.44%	0.00%	69.25%	30.75%	0.00%
449	60-	60-	2-	50-	S-	R	760.073	812.925	812.575	71.99%	28.01%	0.00%	69.55%	30.45%	0.00%	69.97%	30.03%	0.00%
450	60-	60-	2-	60-	S-	R	762.041	815.656	815.77	71.37%	28.63%	0.00%	69.35%	30.65%	0.00%	69.01%	30.99%	0.00%
451	60-	40-	1-	20-	D-	C	1202.191	1419.94	1373.721	11.75%	88.25%	0.00%	8.84%	91.16%	0.00%	11.40%	88.60%	0.00%
452	60-	40-	1-	30-	D-	C	1118.48	1288.324	1278.49	16.95%	83.05%	0.00%	16.40%	83.60%	0.00%	16.64%	83.36%	0.00%
453	60-	40-	1-	40-	D-	C	1060.733	1250.412	1219.949	24.86%	75.14%	0.00%	17.23%	82.77%	0.00%	22.91%	77.09%	0.00%
454	60-	40-	1-	50-	D-	C	1019.209	1169.535	1173.691	32.71%	67.29%	0.00%	28.36%	71.64%	0.00%	29.08%	70.92%	0.00%
455	60-	40-	1-	60-	D-	C	994.92	1141.638	1148.044	36.92%	63.08%	0.00%	32.88%	67.12%	0.00%	33.05%	66.95%	0.00%
456	60-	40-	15-	20-	D-	C	1529.862	1685.207	1648.357	5.55%	94.45%	0.00%	4.62%	95.38%	0.00%	5.68%	94.32%	0.00%
457	60-	40-	15-	30-	D-	C	1399.781	1535.538	1532.265	7.91%	92.09%	0.00%	7.88%	92.12%	0.00%	8.12%	91.88%	0.00%
458	60-	40-	15-	40-	D-	C	1310.991	1490.313	1454.26	11.30%	88.70%	0.00%	8.63%	91.37%	0.00%	11.16%	88.84%	0.00%
459	60-	40-	15-	50-	D-	C	1259.265	1396.888	1404.085	14.18%	85.82%	0.00%	14.04%	85.96%	0.00%	13.53%	86.47%	0.00%
460	60-	40-	15-	60-	D-	C	1237.566	1373.55	1378.094	17.36%	82.64%	0.00%	16.27%	83.73%	0.00%	16.10%	83.90%	0.00%
461	60-	40-	2-	20-	D-	C	1840.305	1943.089	1906.515	3.18%	96.82%	0.00%	2.88%	97.12%	0.00%	3.39%	96.61%	0.00%
462	60-	40-	2-	30-	D-	C	1724.133	1807.296	1803.051	4.11%	95.89%	0.00%	4.04%	95.96%	0.00%	4.04%	95.96%	0.00%
463	60-	40-	2-	40-	D-	C	1649.933	1776.405	1739.872	5.31%	94.69%	0.00%	4.01%	95.99%	0.00%	4.86%	95.14%	0.00%
464	60-	40-	2-	50-	D-	C	1611.769	1699.785	1702.808	6.40%	93.60%	0.00%	5.89%	94.11%	0.00%	5.75%	94.25%	0.00%
465	60-	40-	2-	60-	D-	C	1611.485	1699.814	1697.502	6.75%	93.25%	0.00%	6.16%	93.84%	0.00%	6.37%	93.63%	0.00%
466	60-	60-	1-	20-	D-	C	1184.143	1355.981	1363.897	12.71%	87.29%	0.00%	12.67%	87.33%	0.00%	12.29%	87.71%	0.00%
467	60-	60-	1-	30-	D-	C	1097.276	1300.893	1267.088	18.77%	81.23%	0.00%	13.60%	86.40%	0.00%	17.60%	82.40%	0.00%
468	60-	60-	1-	40-	D-	C	1045.15	1196.367	1203.956	26.20%	73.80%	0.00%	23.60%	76.40%	0.00%	24.11%	75.89%	0.00%
469	60-	60-	1-	50-	D-	C	1009.397	1157.067	1163.446	33.49%	66.51%	0.00%	29.55%	70.45%	0.00%	29.83%	70.17%	0.00%
470	60-	60-	1-	60-	D-	C	984.133	1132.249	1140.452	38.12%	61.88%	0.00%	33.80%	66.20%	0.00%	33.36%	66.64%	0.00%
471	60-	60-	15-	20-	D-	C	1523.136	1629.572	1639.381	5.45%	94.55%	0.00%	6.10%	93.90%	0.00%	5.51%	94.49%	0.00%
472	60-	60-	15-	30-	D-	C	1387.832	1556.376	1520.649	8.18%	91.82%	0.00%	6.68%	93.32%	0.00%	8.22%	91.78%	0.00%
473	60-	60-	15-	40-	D-	C	1305.198	1444.891	1448.192	11.47%	88.53%	0.00%	11.40%	88.60%	0.00%	11.27%	88.73%	0.00%
474	60-	60-	15-	50-	D-	C	1256.685	1396.071	1400.366	13.84%	86.16%	0.00%	13.63%	86.37%	0.00%	13.29%	86.71%	0.00%
475	60-	60-	15-	60-	D-	C	1236.269	1376.718	1381.994	16.75%	83.25%	0.00%	15.89%	84.11%	0.00%	15.72%	84.28%	0.00%
476	60-	60-	2-	20-	D-	C	1787.077	1870.485	1867.157	3.46%	96.54%	0.00%	3.42%	96.58%	0.00%	3.42%	96.58%	0.00%
477	60-	60-	2-	30-	D-	C	1690.188	1816.416	1780.353	4.32%	95.68%	0.00%	3.63%	96.37%	0.00%	4.14%	95.86%	0.00%
478	60-	60-	2-	40-	D-	C	1629.209	1724.644	1727.176	5.45%	94.55%	0.00%	5.24%	94.76%	0.00%	4.97%	95.03%	0.00%
479	60-	60-	2-	50-	D-	C	1601.269	1702.013	1700.218	6.27%	93.73%	0.00%	5.89%	94.11%	0.00%	5.58%	94.42%	0.00%
480	60-	60-	2-	60-	D-	C	1618.959	1709.829	1710.325	6.44%	93.56%	0.00%	5.96%	94.04%	0.00%	6.16%	93.84%	0.00%

481	60-	40-	1-	20-	D-	L	960.517	1145.914	1100.088	39.73%	60.27%	0.00%	28.87%	71.13%	0.00%	35.72%	64.28%	0.00%
482	60-	40-	1-	30-	D-	L	895.241	1030.086	1025.105	49.49%	50.51%	0.00%	43.25%	56.75%	0.00%	43.42%	56.58%	0.00%
483	60-	40-	1-	40-	D-	L	847.749	1011.397	977.076	59.86%	40.14%	0.00%	44.01%	55.99%	0.00%	50.38%	49.62%	0.00%
484	60-	40-	1-	50-	D-	L	815.142	935.457	939.172	66.06%	33.94%	0.00%	56.61%	43.39%	0.00%	55.07%	44.93%	0.00%
485	60-	40-	1-	60-	D-	L	796.04	912.747	918.302	69.01%	30.99%	0.00%	60.00%	40.00%	0.00%	58.01%	41.99%	0.00%
486	60-	40-	15-	20-	D-	L	1221.818	1358.323	1317.683	22.84%	77.16%	0.00%	16.06%	83.94%	0.00%	21.20%	78.80%	0.00%
487	60-	40-	15-	30-	D-	L	1115.683	1230.662	1226.051	30.34%	69.66%	0.00%	28.80%	71.20%	0.00%	27.88%	72.12%	0.00%
488	60-	40-	15-	40-	D-	L	1048.704	1198.927	1165.296	36.64%	63.36%	0.00%	26.82%	73.18%	0.00%	34.32%	65.68%	0.00%
489	60-	40-	15-	50-	D-	L	1003.284	1120.495	1126.478	42.53%	57.47%	0.00%	37.64%	62.36%	0.00%	37.95%	62.05%	0.00%
490	60-	40-	15-	60-	D-	L	989.194	1098.268	1103.522	44.93%	55.07%	0.00%	40.62%	59.38%	0.00%	40.58%	59.42%	0.00%
491	60-	40-	2-	20-	D-	L	1467.748	1563.625	1524.321	13.39%	86.61%	0.00%	8.94%	91.06%	0.00%	12.57%	87.43%	0.00%
492	60-	40-	2-	30-	D-	L	1377.387	1442.127	1443.605	17.77%	82.23%	0.00%	15.99%	84.01%	0.00%	16.06%	83.94%	0.00%
493	60-	40-	2-	40-	D-	L	1314.035	1427.036	1391.331	21.82%	78.18%	0.00%	14.35%	85.65%	0.00%	19.32%	80.68%	0.00%
494	60-	40-	2-	50-	D-	L	1283.081	1357.737	1360.083	24.59%	75.41%	0.00%	21.82%	78.18%	0.00%	21.44%	78.56%	0.00%
495	60-	40-	2-	60-	D-	L	1282.883	1357.964	1359.736	25.82%	74.18%	0.00%	22.53%	77.47%	0.00%	21.47%	78.53%	0.00%
496	60-	60-	1-	20-	D-	L	946.62	1086.811	1091.866	41.71%	58.29%	0.00%	37.50%	62.50%	0.00%	37.40%	62.60%	0.00%
497	60-	60-	1-	30-	D-	L	877.139	1048.648	1014.337	52.47%	47.53%	0.00%	39.01%	60.99%	0.00%	44.93%	55.07%	0.00%
498	60-	60-	1-	40-	D-	L	831.356	957.991	964.224	62.16%	37.84%	0.00%	52.77%	47.23%	0.00%	51.95%	48.05%	0.00%
499	60-	60-	1-	50-	D-	L	806.609	925.363	931.571	66.99%	33.01%	0.00%	57.71%	42.29%	0.00%	55.62%	44.38%	0.00%
500	60-	60-	1-	60-	D-	L	786.136	905.025	910.073	70.48%	29.52%	0.00%	60.41%	39.59%	0.00%	58.97%	41.03%	0.00%
501	60-	60-	15-	20-	D-	L	1214.762	1307.82	1309.598	22.98%	77.02%	0.00%	21.54%	78.46%	0.00%	22.09%	77.91%	0.00%
502	60-	60-	15-	30-	D-	L	1107.659	1255.599	1218.128	31.30%	68.70%	0.00%	22.19%	77.81%	0.00%	29.18%	70.82%	0.00%
503	60-	60-	15-	40-	D-	L	1042.017	1154.23	1158.371	37.71%	62.29%	0.00%	33.94%	66.06%	0.00%	34.45%	65.55%	0.00%
504	60-	60-	15-	50-	D-	L	1000.952	1116.983	1121.007	42.23%	57.77%	0.00%	38.05%	61.95%	0.00%	38.05%	61.95%	0.00%
505	60-	60-	15-	60-	D-	L	988.015	1101.211	1103.127	44.90%	55.10%	0.00%	40.41%	59.59%	0.00%	40.68%	59.32%	0.00%
506	60-	60-	2-	20-	D-	L	1425.92	1494.532	1492.117	13.80%	86.20%	0.00%	13.01%	86.99%	0.00%	13.12%	86.88%	0.00%
507	60-	60-	2-	30-	D-	L	1344.623	1462.006	1423.988	18.42%	81.58%	0.00%	11.95%	88.05%	0.00%	16.30%	83.70%	0.00%
508	60-	60-	2-	40-	D-	L	1299.262	1381.592	1380.351	21.61%	78.39%	0.00%	19.14%	80.86%	0.00%	19.04%	80.96%	0.00%
509	60-	60-	2-	50-	D-	L	1277.695	1360.315	1360.081	24.38%	75.62%	0.00%	21.30%	78.70%	0.00%	21.20%	78.80%	0.00%
510	60-	60-	2-	60-	D-	L	1288.208	1369.219	1368.814	25.38%	74.62%	0.00%	21.68%	78.32%	0.00%	21.13%	78.87%	0.00%
511	60-	40-	1-	20-	D-	R	418.929	527.288	483.705	100.00%	0.00%	0.00%	93.94%	6.06%	0.00%	93.84%	6.16%	0.00%
512	60-	40-	1-	30-	D-	R	388.909	451.891	449.757	100.00%	0.00%	0.00%	95.79%	4.21%	0.00%	96.06%	3.94%	0.00%
513	60-	40-	1-	40-	D-	R	368.036	467.107	427.867	100.00%	0.00%	0.00%	96.75%	3.25%	0.00%	97.05%	2.95%	0.00%
514	60-	40-	1-	50-	D-	R	355.348	409.334	411.322	100.00%	0.00%	0.00%	98.05%	1.95%	0.00%	97.67%	2.33%	0.00%
515	60-	40-	1-	60-	D-	R	346.136	400.174	402.292	100.00%	0.00%	0.00%	98.15%	1.85%	0.00%	97.64%	2.36%	0.00%
516	60-	40-	15-	20-	D-	R	531.972	620.411	579.943	89.73%	10.27%	0.00%	86.88%	13.12%	0.00%	86.71%	13.29%	0.00%
517	60-	40-	15-	30-	D-	R	486.285	540.315	539.013	94.90%	5.10%	0.00%	89.18%	10.82%	0.00%	89.76%	10.24%	0.00%
518	60-	40-	15-	40-	D-	R	455.484	551.836	511.725	98.70%	1.30%	0.00%	90.65%	9.35%	0.00%	91.13%	8.87%	0.00%
519	60-	40-	15-	50-	D-	R	436.456	492.067	493.616	99.35%	0.65%	0.00%	92.26%	7.74%	0.00%	91.99%	8.01%	0.00%
520	60-	40-	15-	60-	D-	R	428.99	482.014	483.987	99.35%	0.65%	0.00%	92.23%	7.77%	0.00%	92.53%	7.47%	0.00%
521	60-	40-	2-	20-	D-	R	635.517	707.883	667.722	80.72%	19.28%	0.00%	80.00%	20.00%	0.00%	80.89%	19.11%	0.00%
522	60-	40-	2-	30-	D-	R	595.558	631.966	632	84.04%	15.96%	0.00%	83.77%	16.23%	0.00%	83.60%	16.40%	0.00%
523	60-	40-	2-	40-	D-	R	568.339	647.991	608.08	86.03%	13.97%	0.00%	83.63%	16.37%	0.00%	85.31%	14.69%	0.00%
524	60-	40-	2-	50-	D-	R	554.948	594.14	594.419	87.16%	12.84%	0.00%	85.31%	14.69%	0.00%	86.06%	13.94%	0.00%
525	60-	40-	2-	60-	D-	R	554.397	592.613	593.265	87.19%	12.81%	0.00%	85.38%	14.62%	0.00%	85.89%	14.11%	0.00%
526	60-	60-	1-	20-	D-	R	413.392	477.155	480.66	100.00%	0.00%	0.00%	94.04%	5.96%	0.00%	94.25%	5.75%	0.00%
527	60-	60-	1-	30-	D-	R	383.339	483.838	446.013	100.00%	0.00%	0.00%	96.13%	3.87%	0.00%	95.99%	4.01%	0.00%
528	60-	60-	1-	40-	D-	R	363.672	420.489	422.755	100.00%	0.00%	0.00%	97.64%	2.36%	0.00%	97.19%	2.81%	0.00%
529	60-	60-	1-	50-	D-	R	350.261	405.744	407.989	100.00%	0.00%	0.00%	98.53%	1.47%	0.00%	97.95%	2.05%	0.00%
530	60-	60-	1-	60-	D-	R	341.635	396.736	398.595	100.00%	0.00%	0.00%	98.56%	1.44%	0.00%	97.88%	2.12%	0.00%
531	60-	60-	15-	20-	D-	R	527.837	573.77	574.959	90.17%	9.83%	0.00%	87.23%	12.77%	0.00%	87.64%	12.36%	0.00%
532	60-	60-	15-	30-	D-	R	482.597	575.63	535.289	95.34%	4.66%	0.00%	89.25%	10.75%	0.00%	89.69%	10.31%	0.00%
533	60-	60-	15-	40-	D-	R	453.168	507.205	508.124	98.94%	1.06%	0.00%	91.64%	8.36%	0.00%	91.71%	8.29%	0.00%
534	60-	60-	15-	50-	D-	R	436.185	489.49	491.651	99.52%	0.48%	0.00%	92.40%	7.60%	0.00%	92.57%	7.43%	0.00%
535	60-	60-	15-	60-	D-	R	430.205	483.141	484.995	99.42%	0.58%	0.00%	92.43%	7.57%	0.00%	92.53%	7.47%	0.00%
536	60-	60-	2-	20-	D-	R	615.178	653.946	653.962	82.50%	17.50%	0.00%	82.91%	17.09%	0.00%	83.18%	16.82%	0.00%
537	60-	60-	2-	30-	D-	R	582.822	624.068	624.194	85.24%	14.76%	0.00%	84.45%	15.55%	0.00%	85.14%	14.86%	0.00%
538	60-	60-	2-	40-	D-	R	561.772	605.61	606.504	86.88%	13.12%	0.00%	85.14%	14.86%	0.00%	86.03%	13.97%	0.00%
539	60-	60-	2-	50-	D-	R	553.422	597.11	595.818	87.43%	12.57%	0.00%	85.48%	14.52%	0.00%	86.34%	13.66%	0.00%
540	60-	60-	2-	60-	D-	R	557.061	597.116	597.106	86.82%	13.18%	0.00%	85.27%	14.73%	0.00%	86.10%	13.90%	0.00%

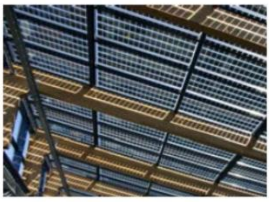
Appendix 8: Summary of PVSD product specifications and dimensions

Shadovoltaic

Shadovoltaic describes a fixed or controllable external solar shading system that incorporates glass louvres with photovoltaic cells integrated into the glass so as to generate electricity at the same time as providing shading. The louvres are available in various colours, surface finishes, patterns and coatings to meet specific design requirements.

Both monocrystalline and polycrystalline cells may be used. The photovoltaic cells may be integrated into the glass, either by attaching them onto the reverse side of the glass panels or by laminating them between two sheets of glass.

- Combines the functions of solar shading with the generation of electrical power.
- Available in widths of up to 600mm.
- Available in supported spans of up to 4m (depending on windloads and other criteria).
- Wide range of colours, surface finishes, cell patterns and coatings.
- All principal support components manufactured from corrosion-resistant extruded aluminium alloy with stainless steel fixings
- Fixed or controllable.



Hotel de Ville, Montepellier.
Colt installed a solar shading solution to the new Hotel de Ville designed by Architect Jean Nouvel.
The building is very eco-friendly and hosts a photovoltaic power generation array of 1,400 m², one of the largest in France.

GLASS PARAMETERS TABLE

Dimensions	LS3
A mm (max)	4000
B mm	600
C mm	60
D mm	5
Angle of rotation°	0 - 100

The new multi-million pound headquarters development for HML in Skipton, brings together more than 800 of its staff into a BREEAM 'Very Good' rated building, equipped with a revolutionary Levolux Solar Shading system, which actually generates its own electricity.

The development for HML, a subsidiary of Skipton Building Society, to the west of Skipton, consolidates its local business operations from four sites in the town centre, into a single site. The 10,000m2 development comprises two buildings, linked by a central atrium, with accommodation arranged over three and four floors.

Locally based, Bowman Riley Architects, created an ambitious design, incorporating a raft of energy saving features. These include rainwater harvesting, solar hot water panels and a comprehensive Solar Shading system from Levolux. As a result, the buildings are much less dependent on energy-sapping artificial lighting and air conditioning.

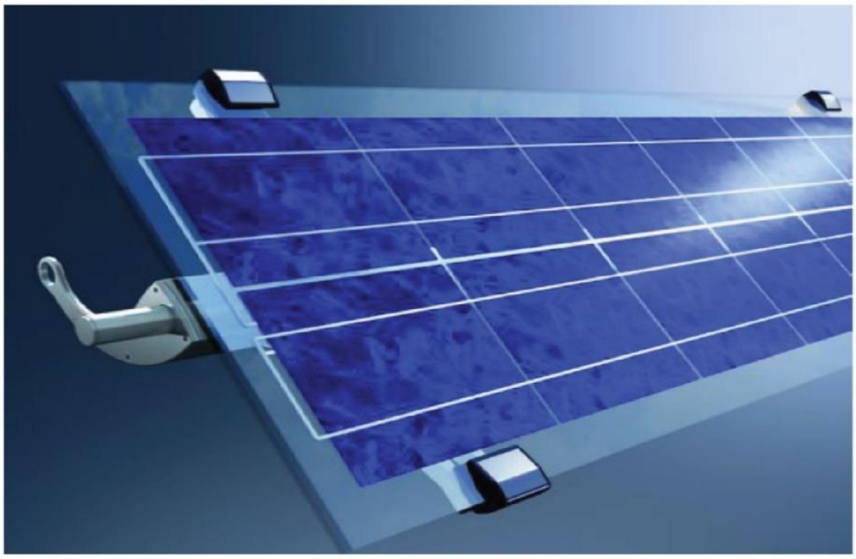
As the UK's leading Solar Shading specialist, Levolux was chosen to design, fabricate, install and commission a bespoke Solar Shading solution, incorporating its external Glass Fins with integral photovoltaic cells and its Internal 760SX Roller Blinds.

The external, motorised Glass Fin PV Solar Shading system, incorporates 210 horizontal Glass Fins, each measuring 535mm wide by 18mm thick and spanning up to 1937mm. Each Glass Fin is laminated, with two layers of clear glass sandwiching an inter layer which includes mono-crystalline photovoltaic cells. The underside of each Glass Fin has been screen printed with a silver dot matrix effect, creating an attractive opaque finish.

The Glass Fins, arranged in a series of vertical stacks, provide shade to windows on south facing elevations of each building at each level. The motorised Glass Fins are linked to a stand-alone controller, which automatically rotates them, following the movement of the sun overhead. This maintains them at the optimum angle for effective shading, reducing unwanted solar heat gain and allows the photovoltaic cells to operate efficiently, contributing 11kWp of renewable electricity.

The Glass Fins are fixed to vertical extruded aluminium support posts, 1150mm in front of the glazed facade. All aluminium components have been given an attractive silver grey powder coated finish.

Elsewhere, Levolux installed its 760SX Internal Roller Blinds throughout both buildings to control light and glare levels on each floor. In total, more than 347 individual, manually operated Roller Blinds were applied, in widths of up to 2870mm and lengths of up to 3570mm. All Blinds feature an attractive white



Characteristics

- Material:

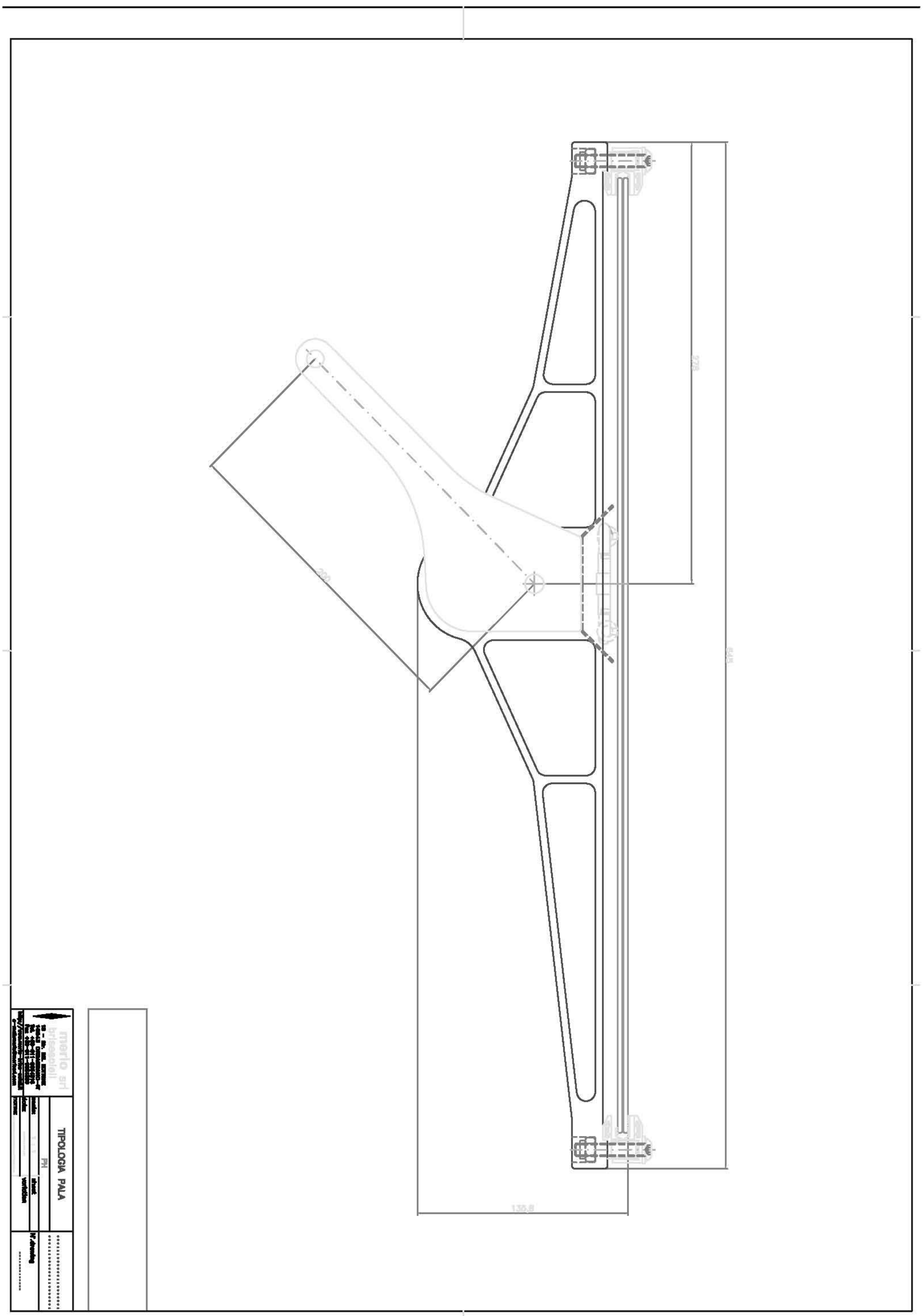
  glass
- Applications:

  for facades
- Other characteristics:

  PV

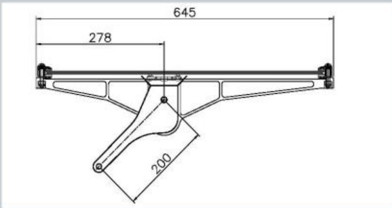
Description

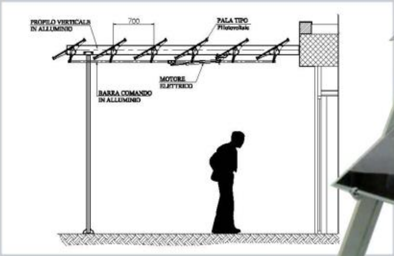
PV blade
Optimised cable guide for PV modules
Glazing clip in a new design
Surface area optimisation with larger PV modules
Polycrystalline solar cells 156 mm x 156 mm, integrated in 2 series in the glazed unit
400 mm blade width
Max. blade length 2600 mm
Rotation angle of louvre blades 0° to 110°
PV blade output: 100 watts
PV blade open-circuit voltage: 18.3 Volt DC
PV blade MPP voltage: 14.7 Volt DC

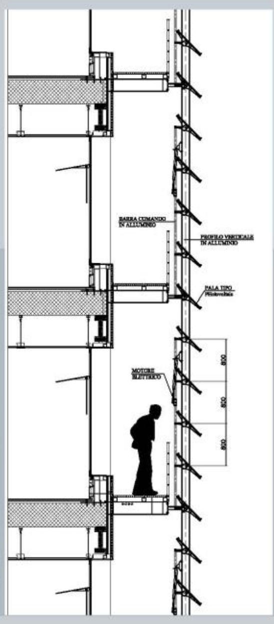

TIPOLOGIA PALA

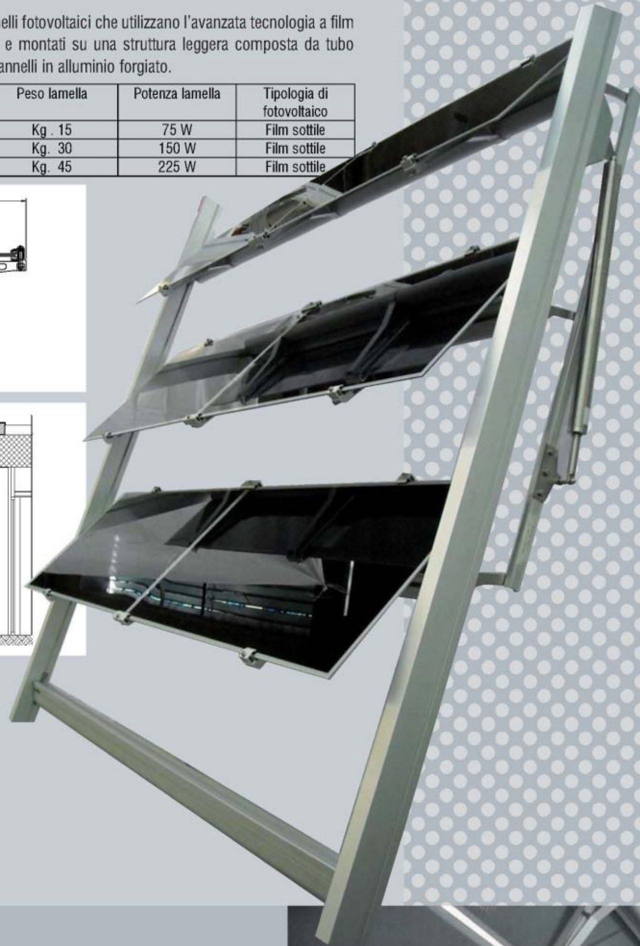
Pale **PH 600** mm di larghezza costituita da pannelli fotovoltaici che utilizzano l'avanzata tecnologia a film sottile inserito in vetro stratificato antigrandine e montati su una struttura leggera composta da tubo centrale in alluminio estruso e supporti porta pannelli in alluminio forgiato.

Lunghezze lamella mm	N° pannelli fotovoltaici/lamella	Peso lamella	Potenza lamella	Tipologia di fotovoltaico
1300	1	Kg . 15	75 W	Film sottile
2500	2	Kg. 30	150 W	Film sottile
3700	3	Kg. 45	225 W	Film sottile









COSTI. L'installazione del frangisole fotovoltaico richiede un investimento iniziale; i costi di gestione sono ridotti al minimo in quanto la fonte di energia rinnovabile (l'irraggiamento solare) è gratuita; anche i costi di manutenzione solo limitati sia che si tratti di lamelle fisse che di lamelle orientabili le quali possono essere inoltre dotate di impianto ad "inseguimento" per una maggiore efficienza . I costi di esercizio e manutenzione annui sono abitualmente stimati in circa 0,5 - 1% del costo dell'impianto.

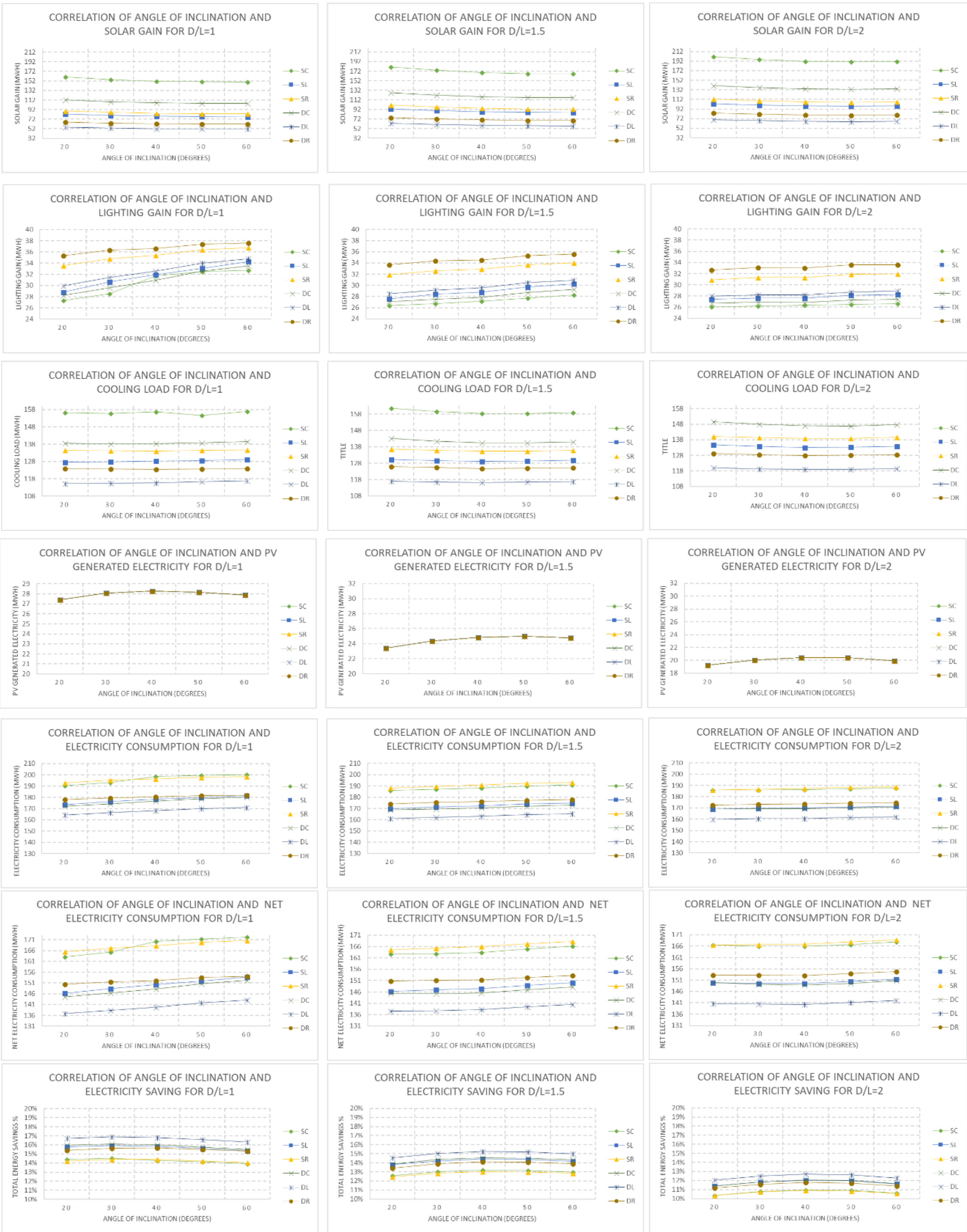
FINANZIAMENTO. Numerosi istituti di credito, compresi i principali operatori italiani, hanno ideato dei prodotti specifici per finanziare l'acquisto di impianti fotovoltaici. Il GSE, al fine di facilitare il finanziamento degli impianti, permette al soggetto responsabile la cessione dei crediti derivanti dall'ammissione alle tariffe incentivanti al soggetto finanziatore. Il GSE a tal fine ha sottoscritto un accordo quadro con quasi tutti gli istituti di credito che consente loro di avvalersi di modalità semplificate per la cessione del credito.

GARANZIE. Il frangisole fotovoltaico è realizzato secondo le normative tecniche previste nell'allegato 1 al DM 19 febbraio 2007. In particolare i moduli in film sottile utilizzati nel frangisole fotovoltaico sono conformi alla norma CEI EN 61646; inoltre il produttore dei moduli, oltre a fornire garanzia su eventuali difetti del materiale o di fabbricazione, garantisce una potenza nominale non inferiore all'80% di quella iniziale nei primi 25 anni di funzionamento. L'impianto elettrico rispetta tutte le norme di sicurezza e protezione previste per gli impianti elettrici.

Appendix 9: Phase one graphs for south-east and south-west combinations

Energy assessment indicators

Orientation=south-east, WWR=100, depth=400mm



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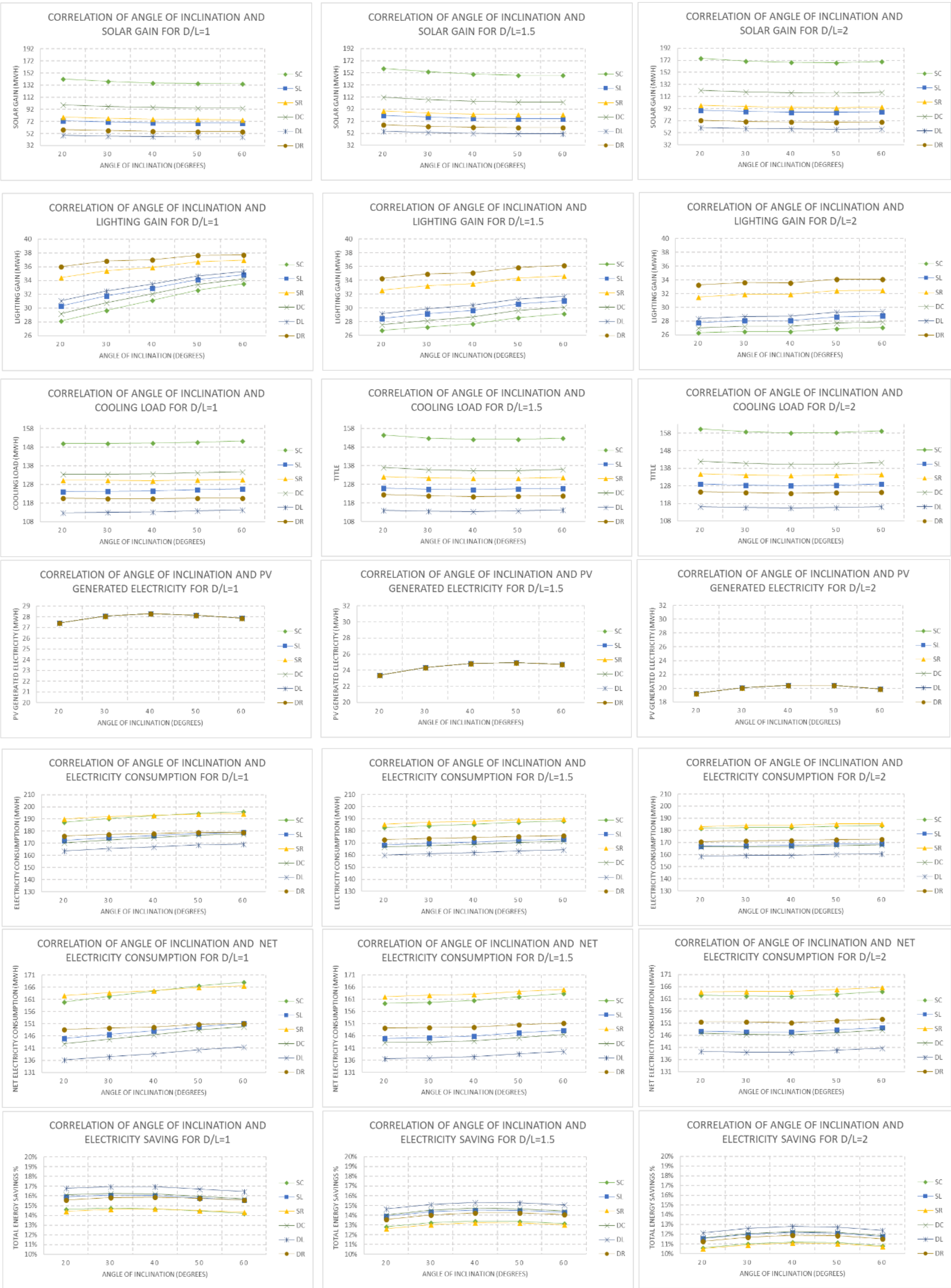
Orientation=south-east, WWR=80, depth=400mm



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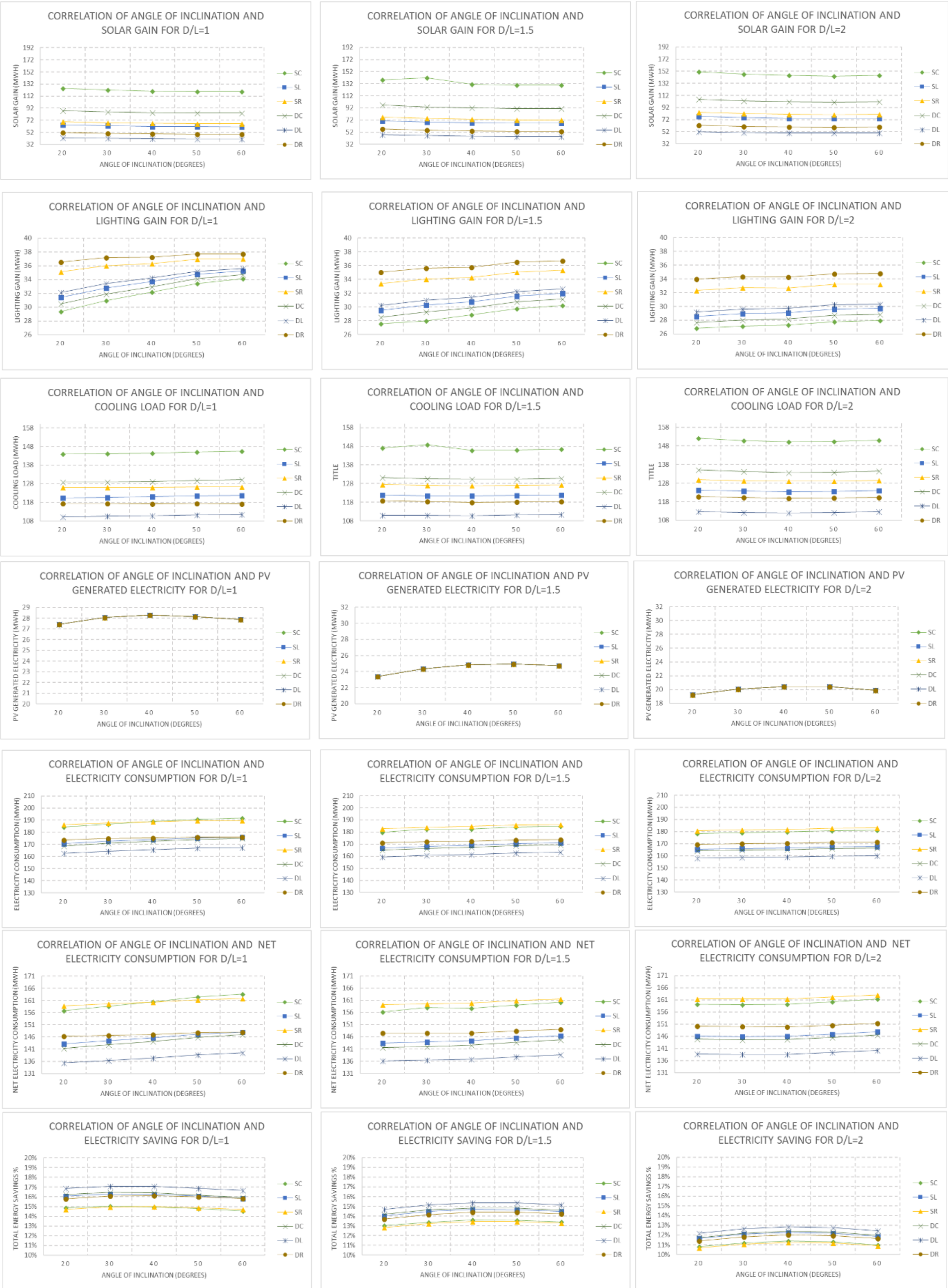

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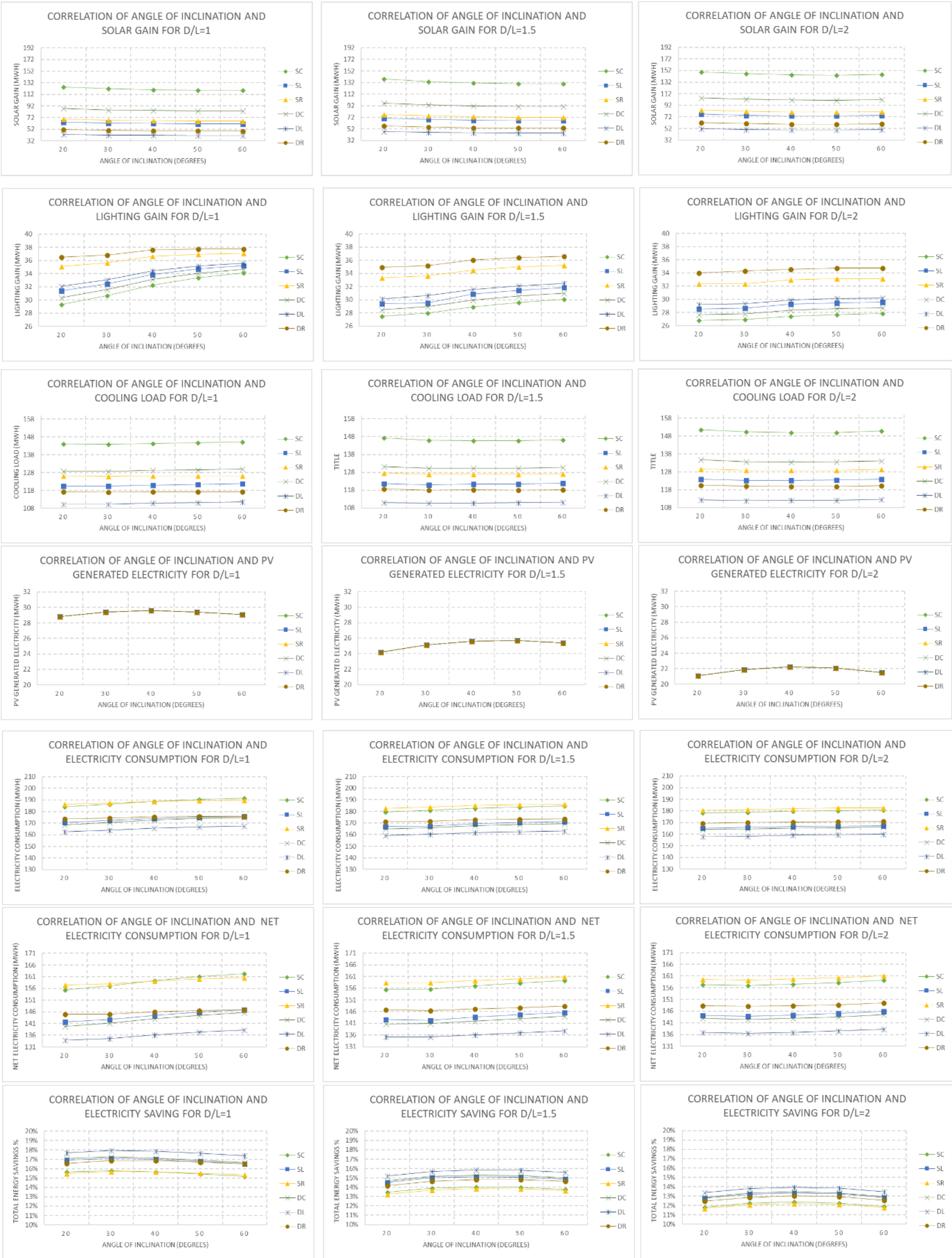

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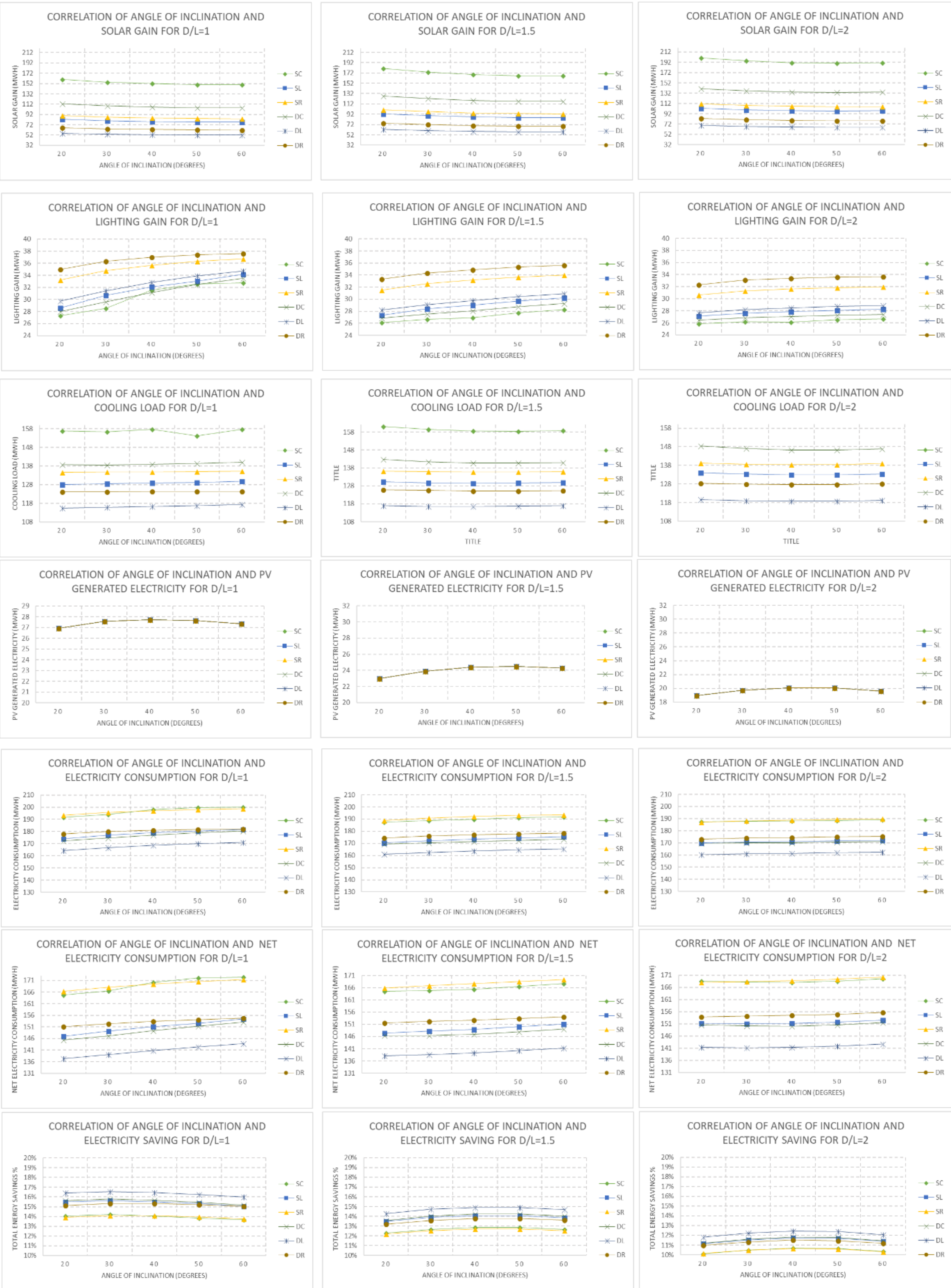

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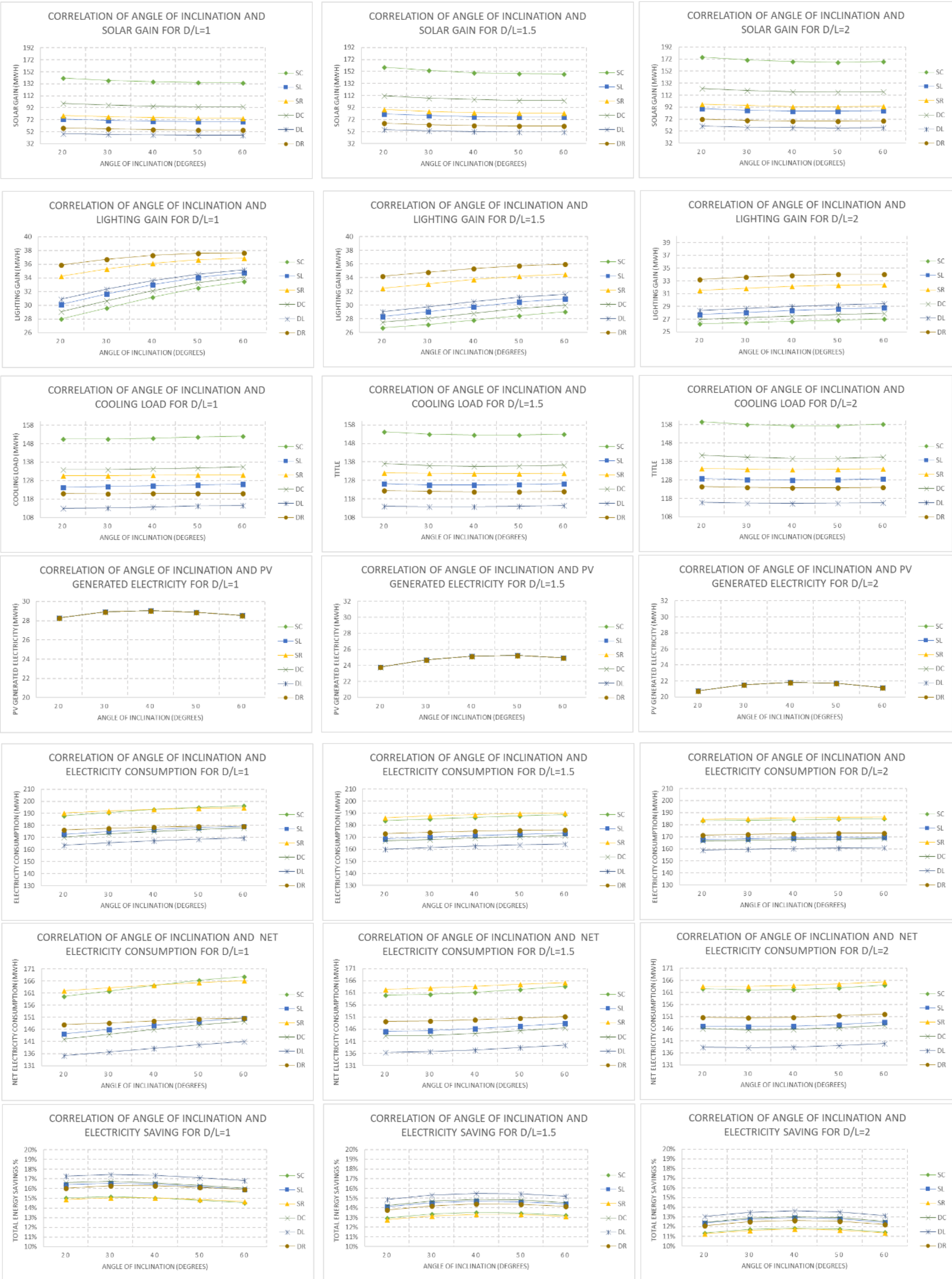
Orientation=south-west, WWR=80, depth=400mm

Orientation=south-west, WWR=80, depth=600mm



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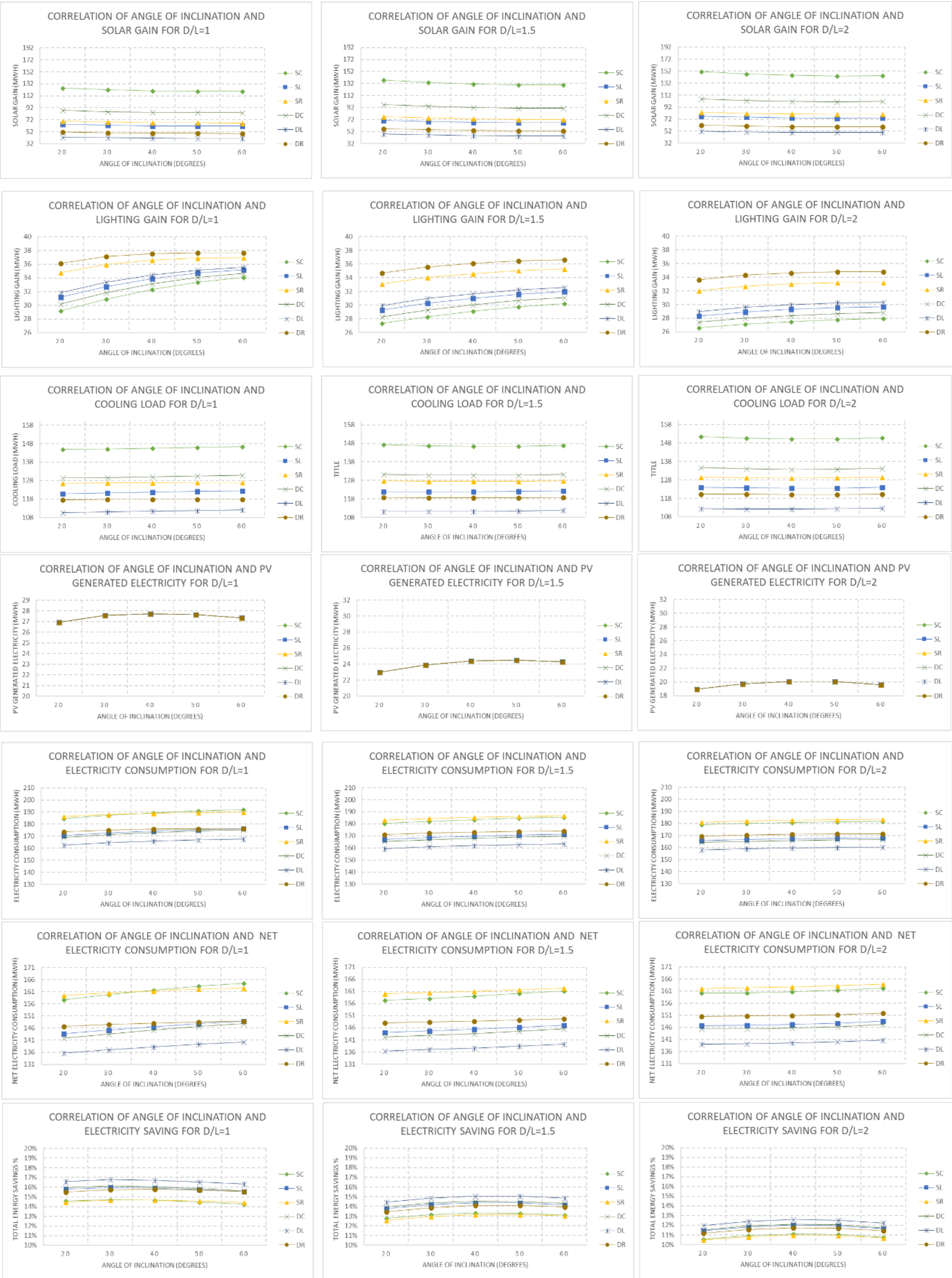
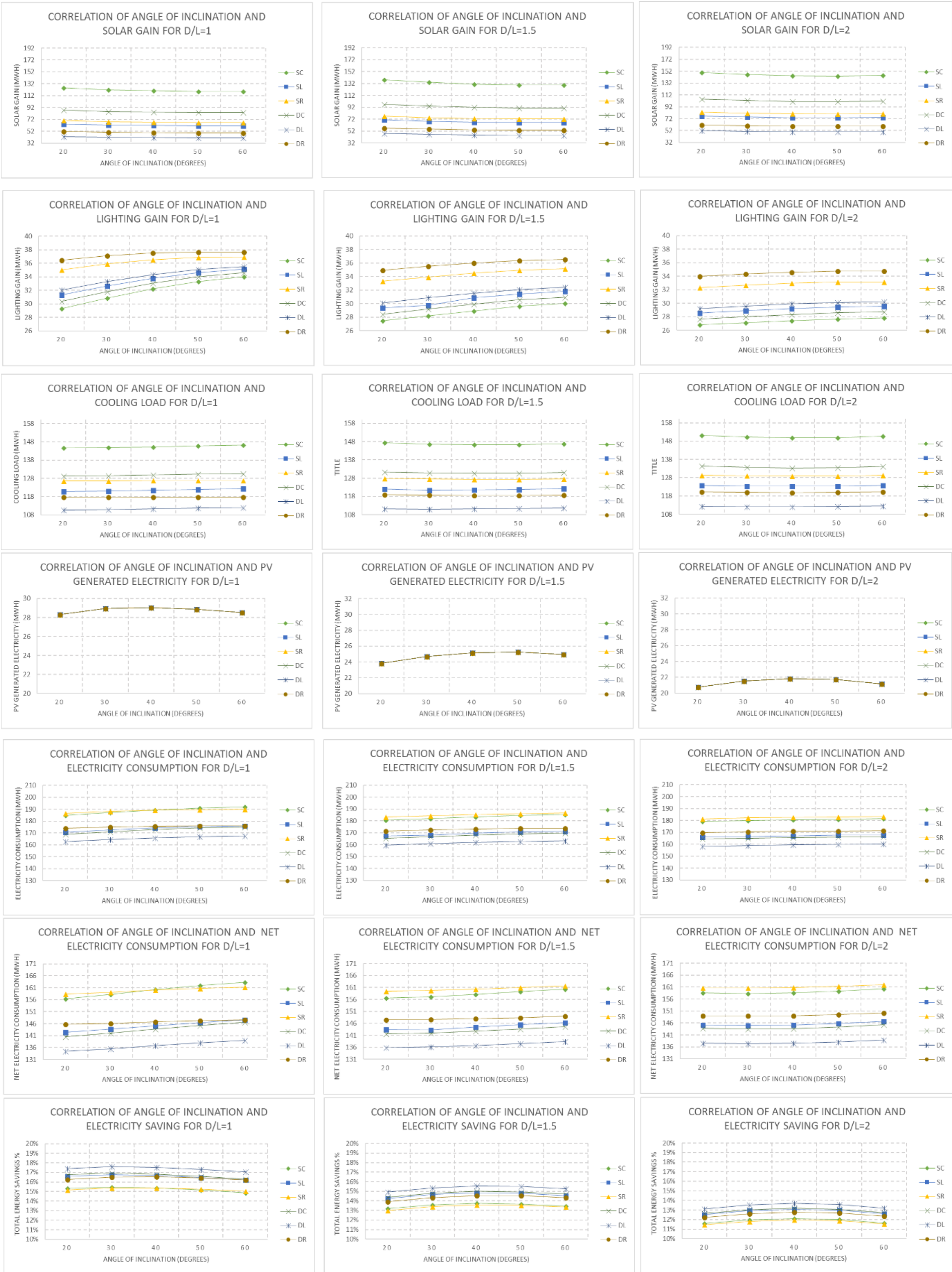
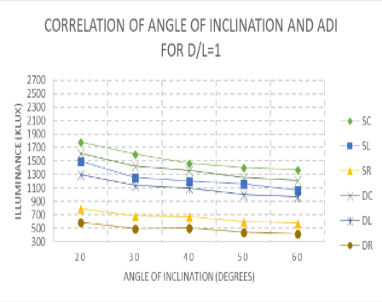


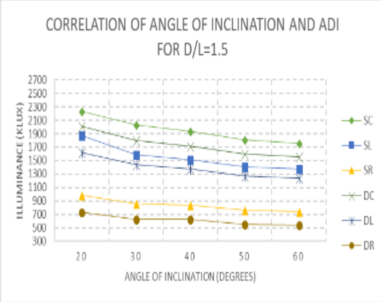
Orientation=south-west, WWR=60, depth=600mm

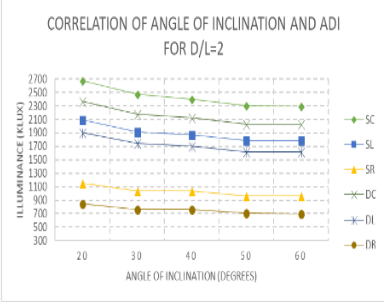


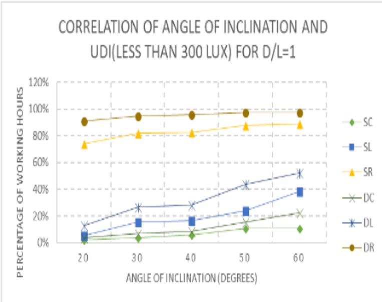
Daylighting assessment indicators

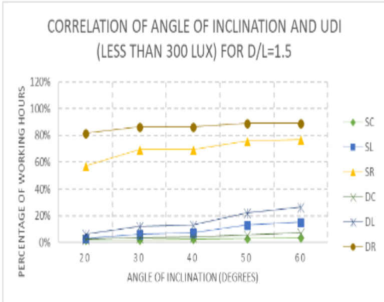
Orientation=south-east, WWR=100, depth=400mm

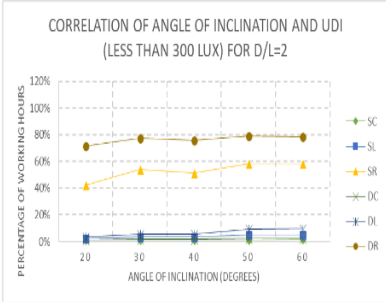


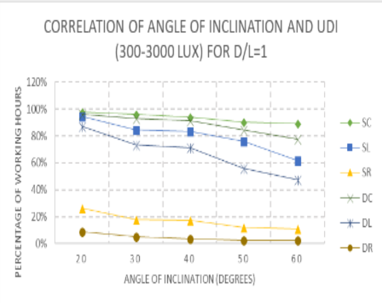


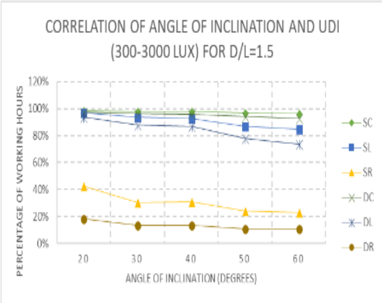


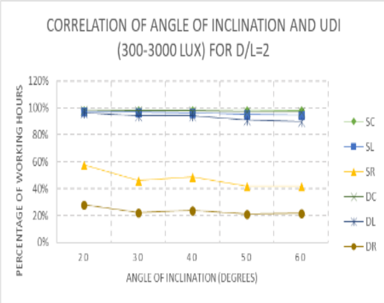


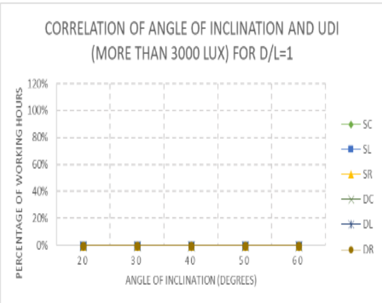


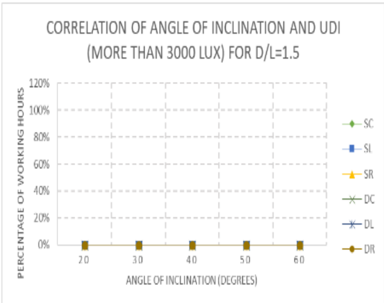


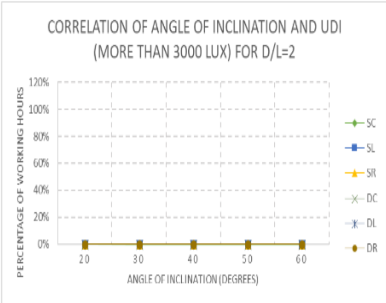












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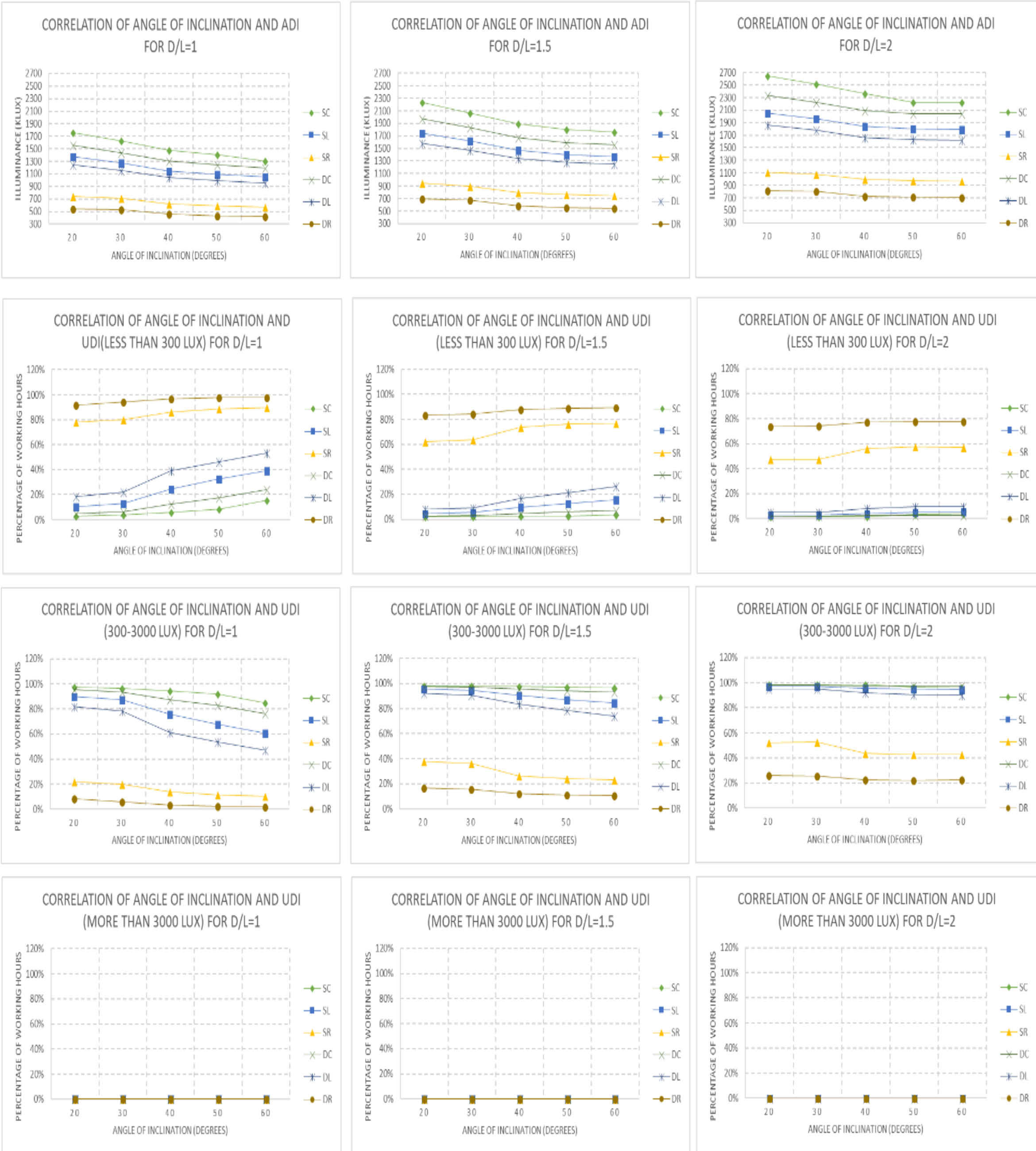

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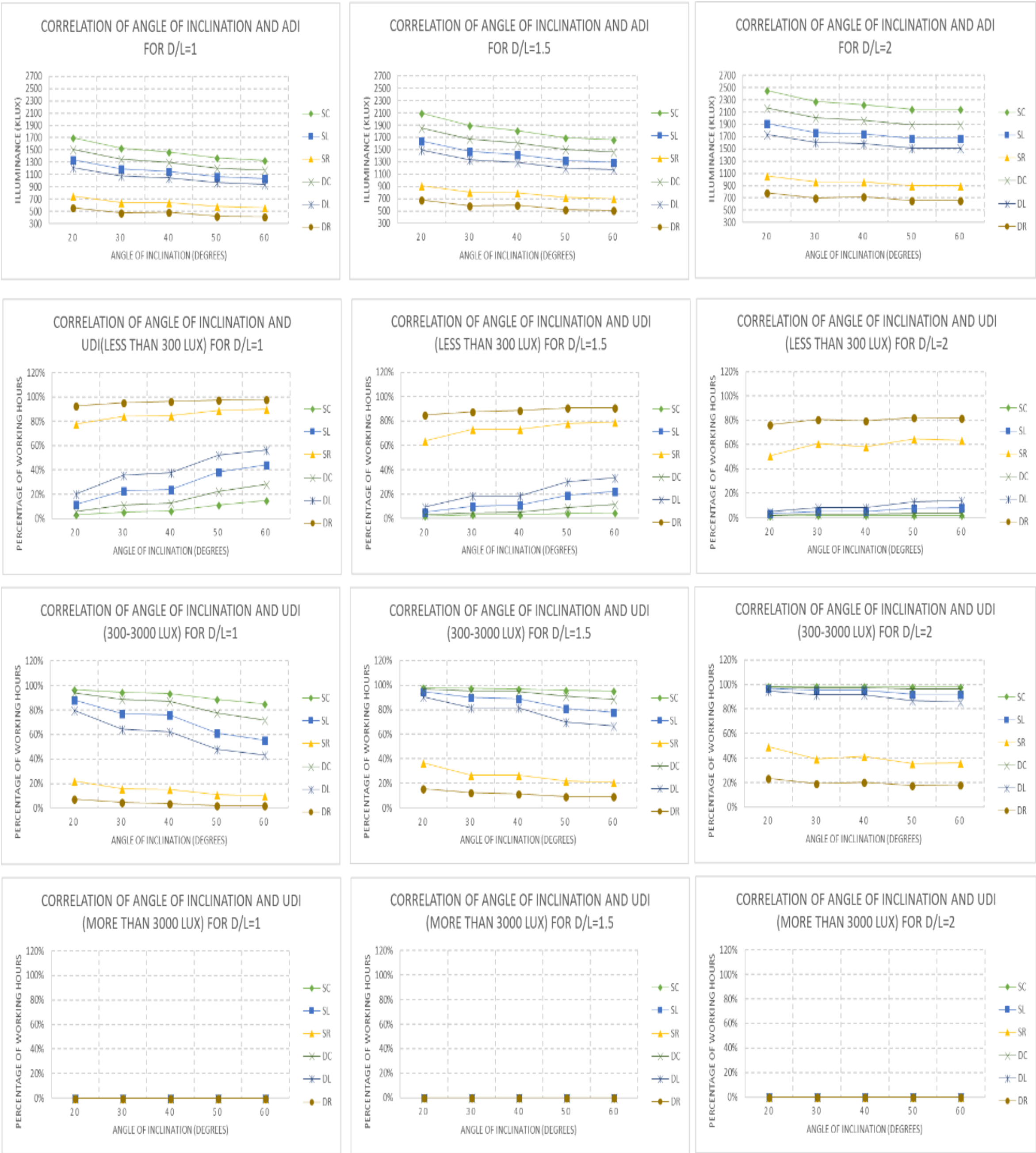

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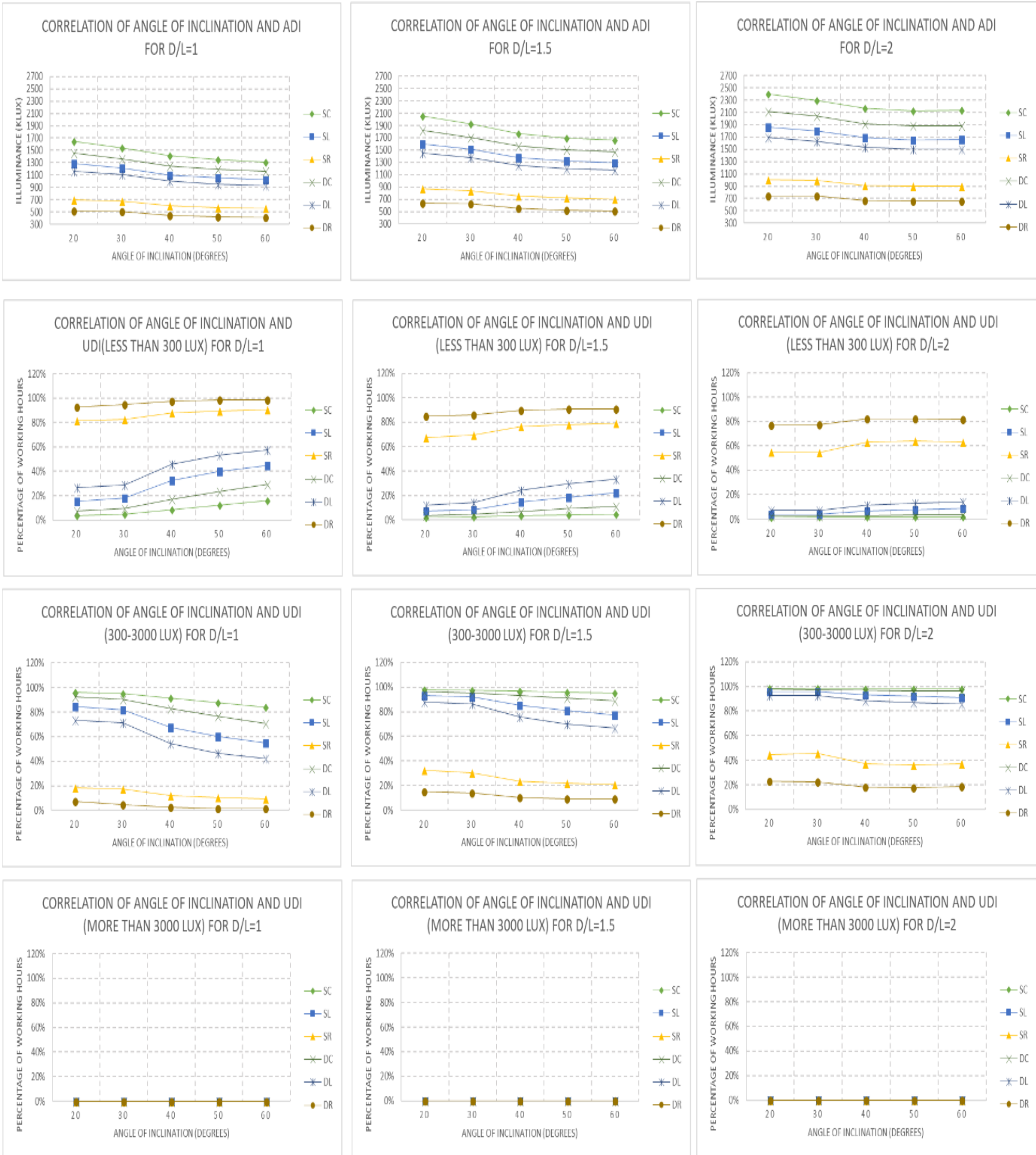

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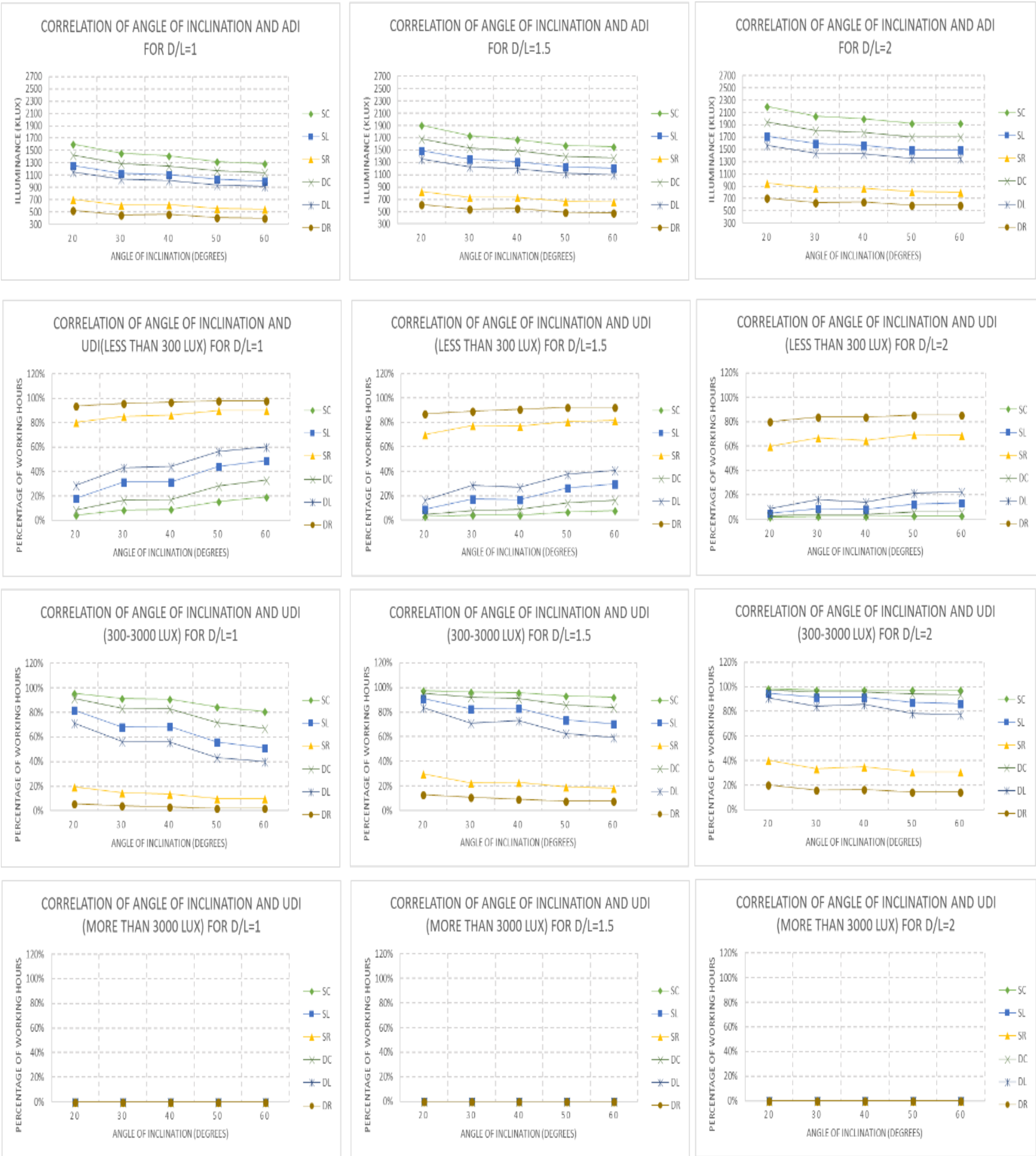

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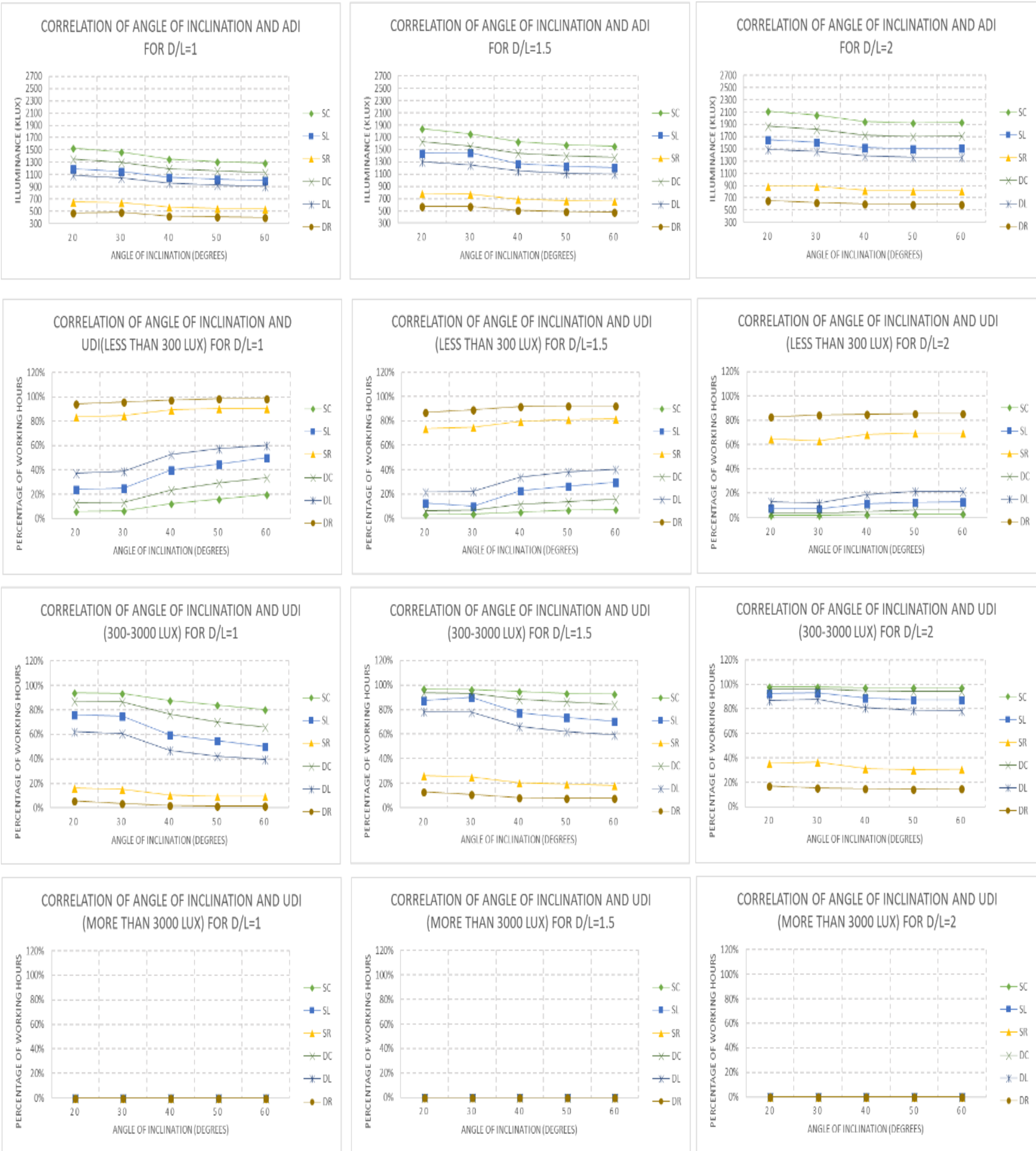

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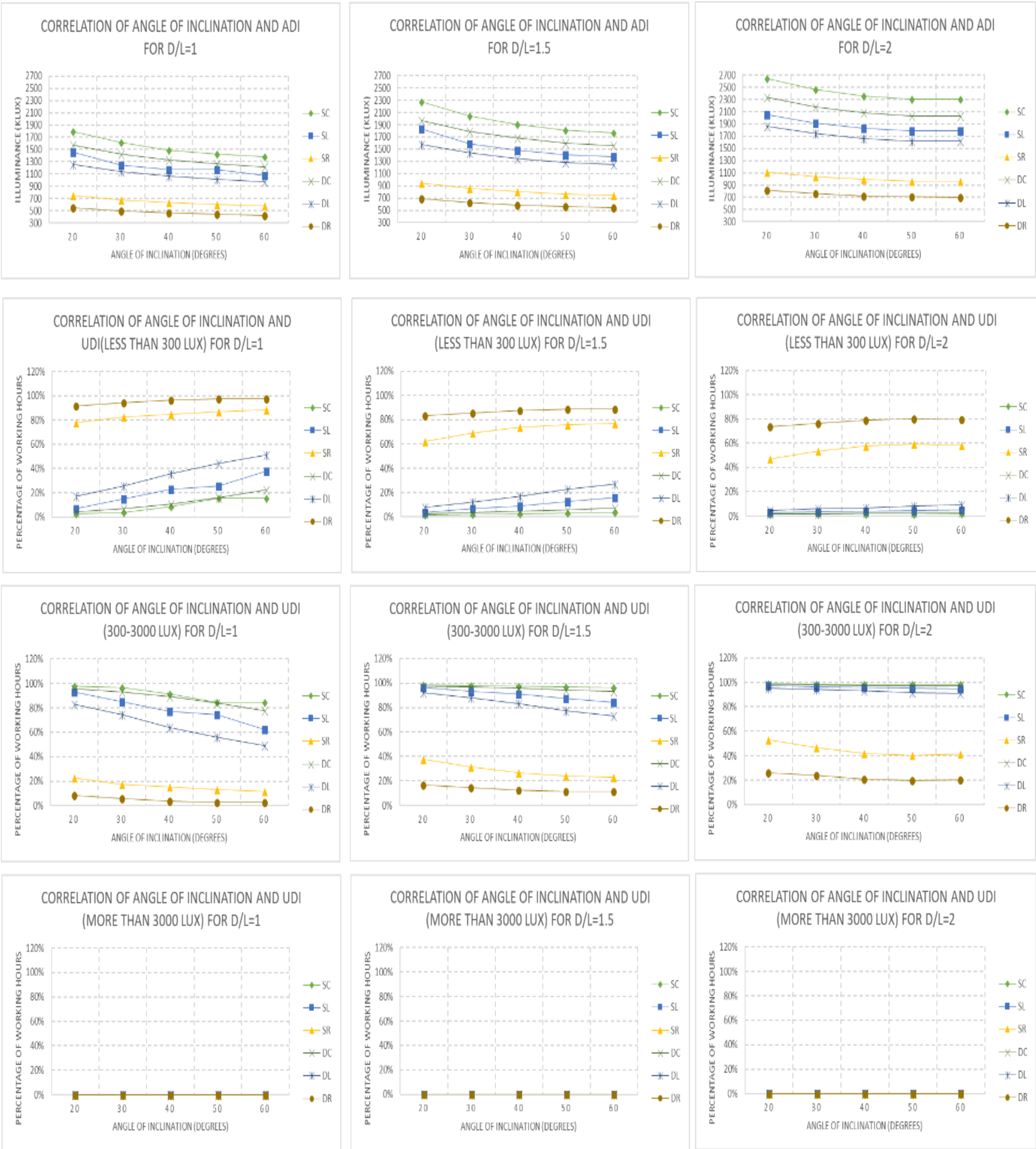

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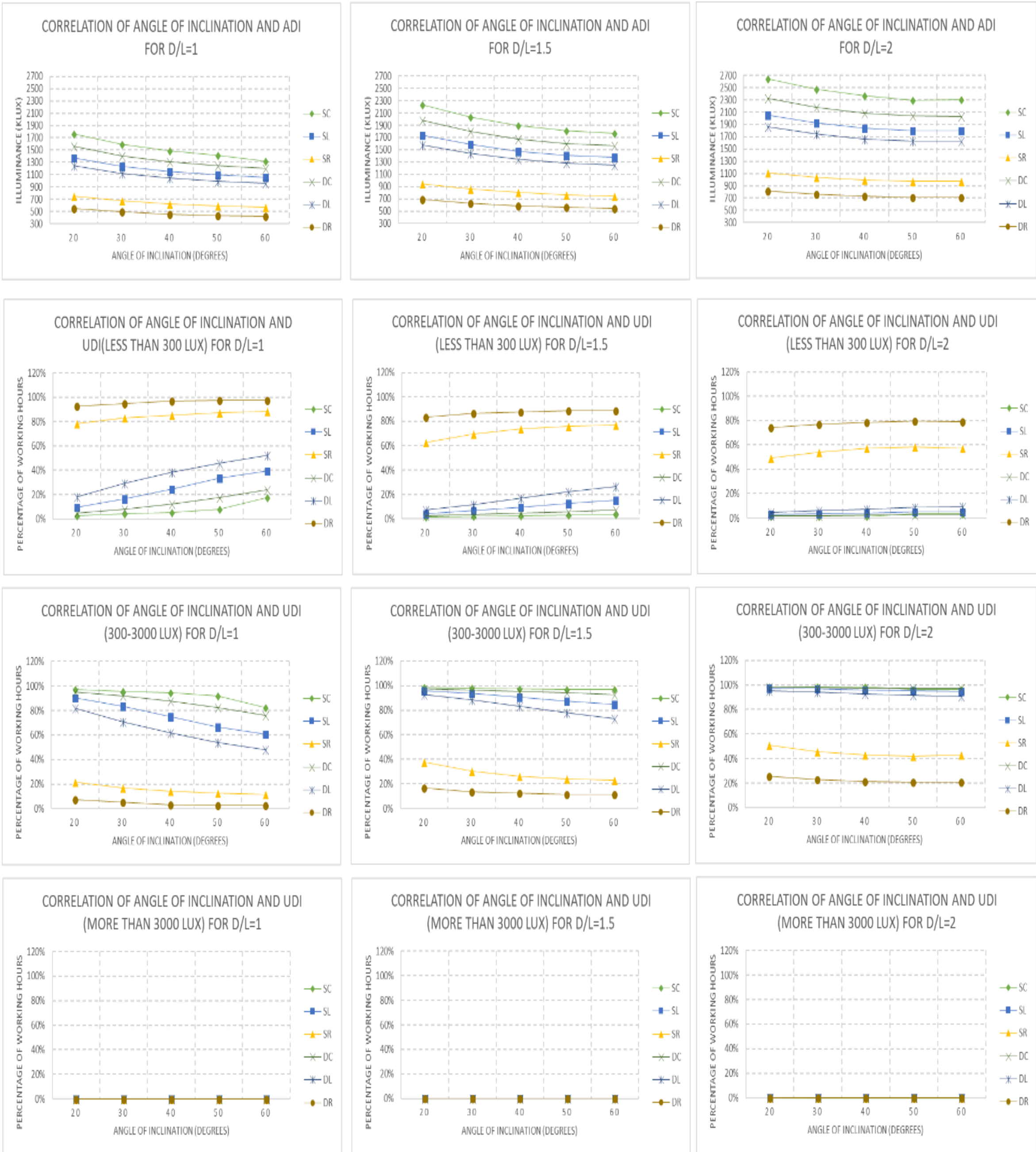

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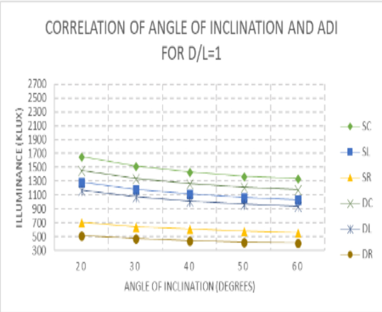
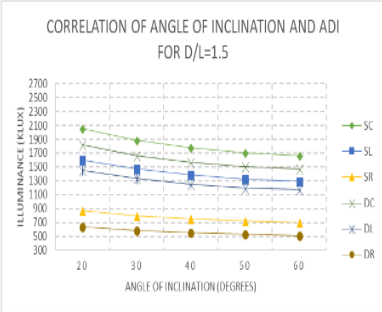
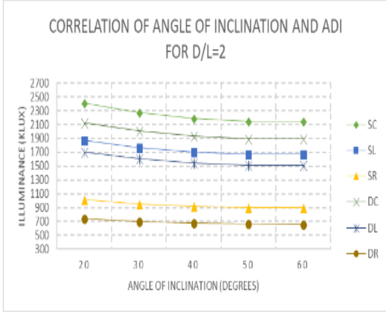
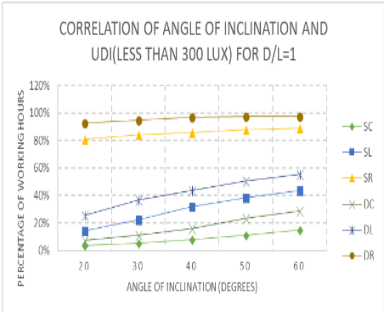
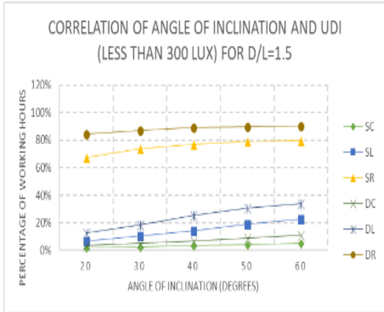
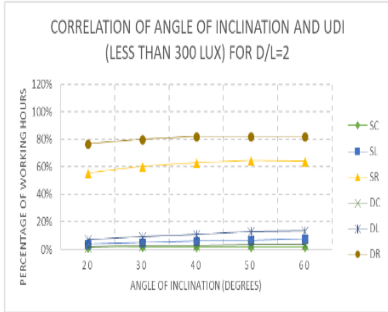


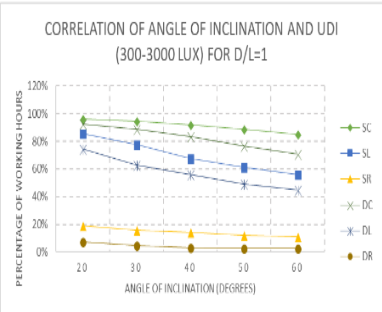


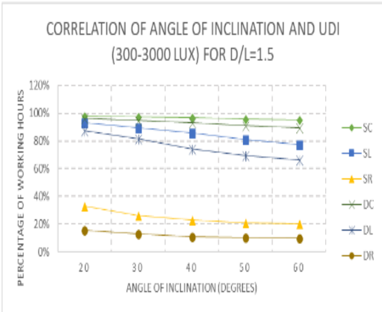


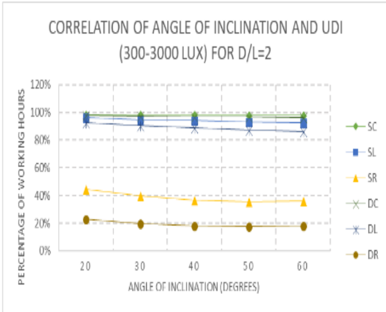


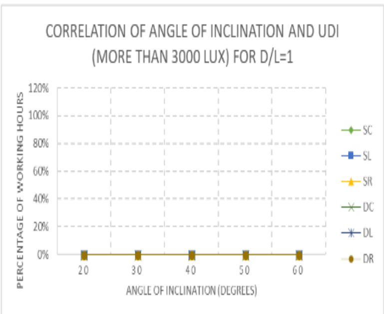


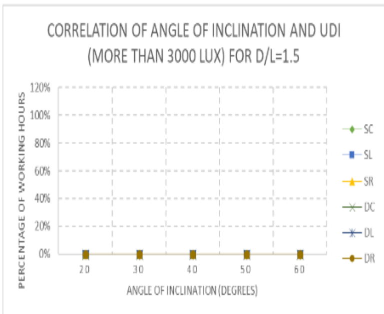


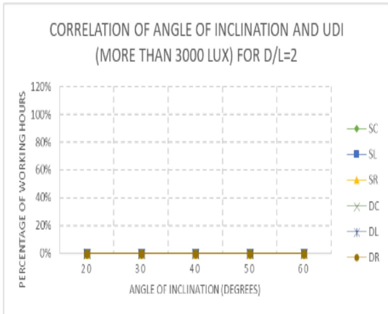




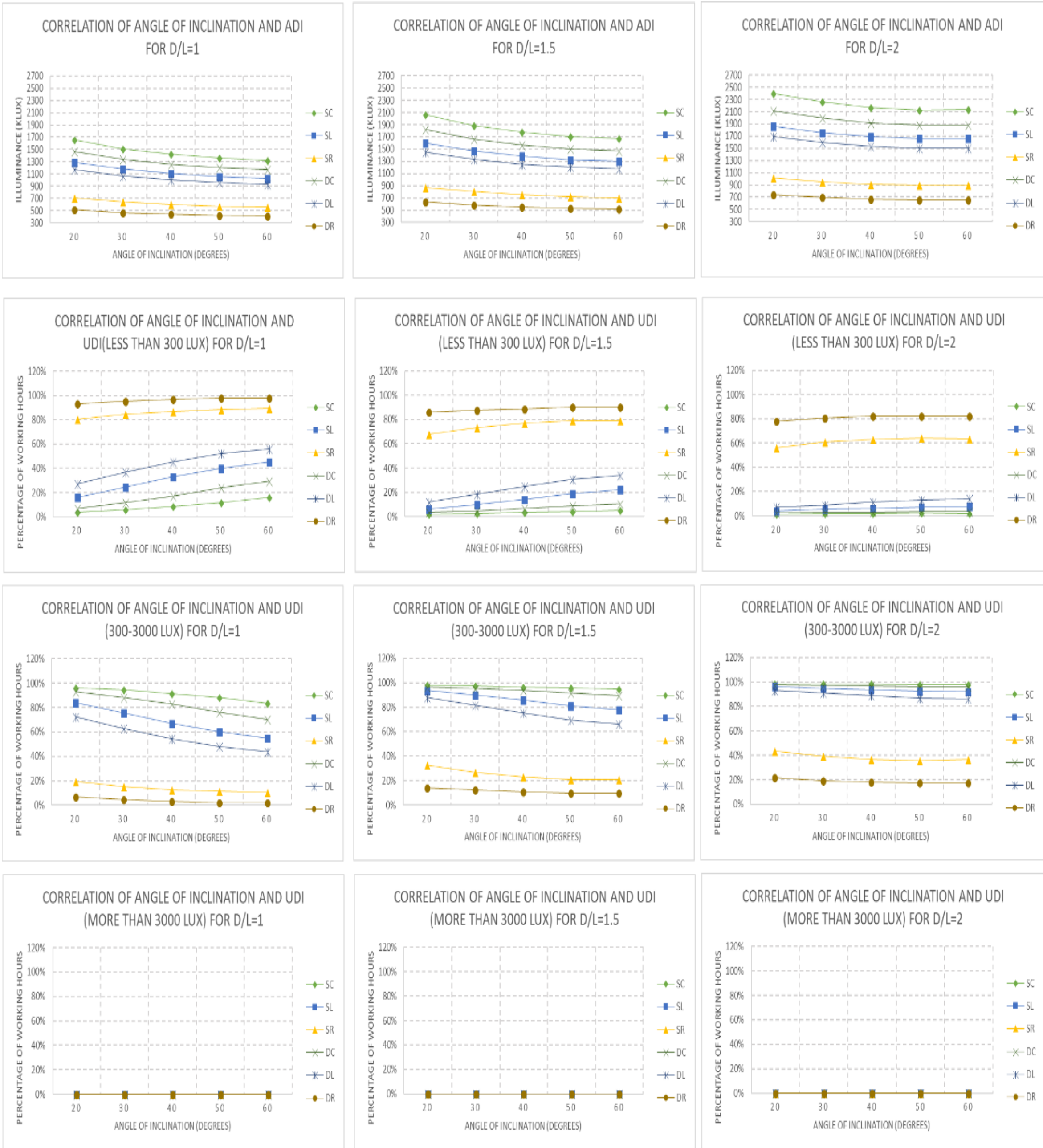




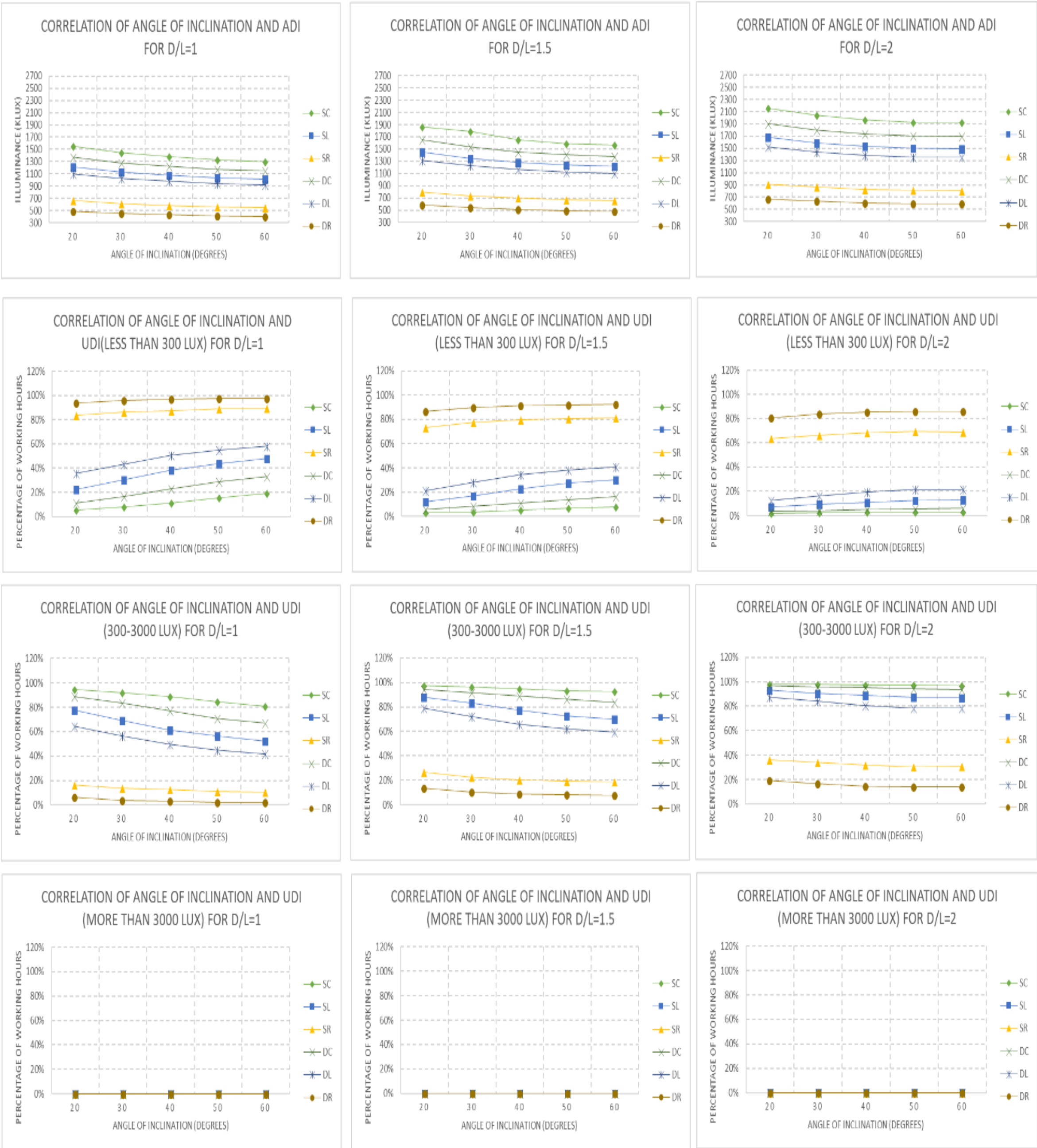




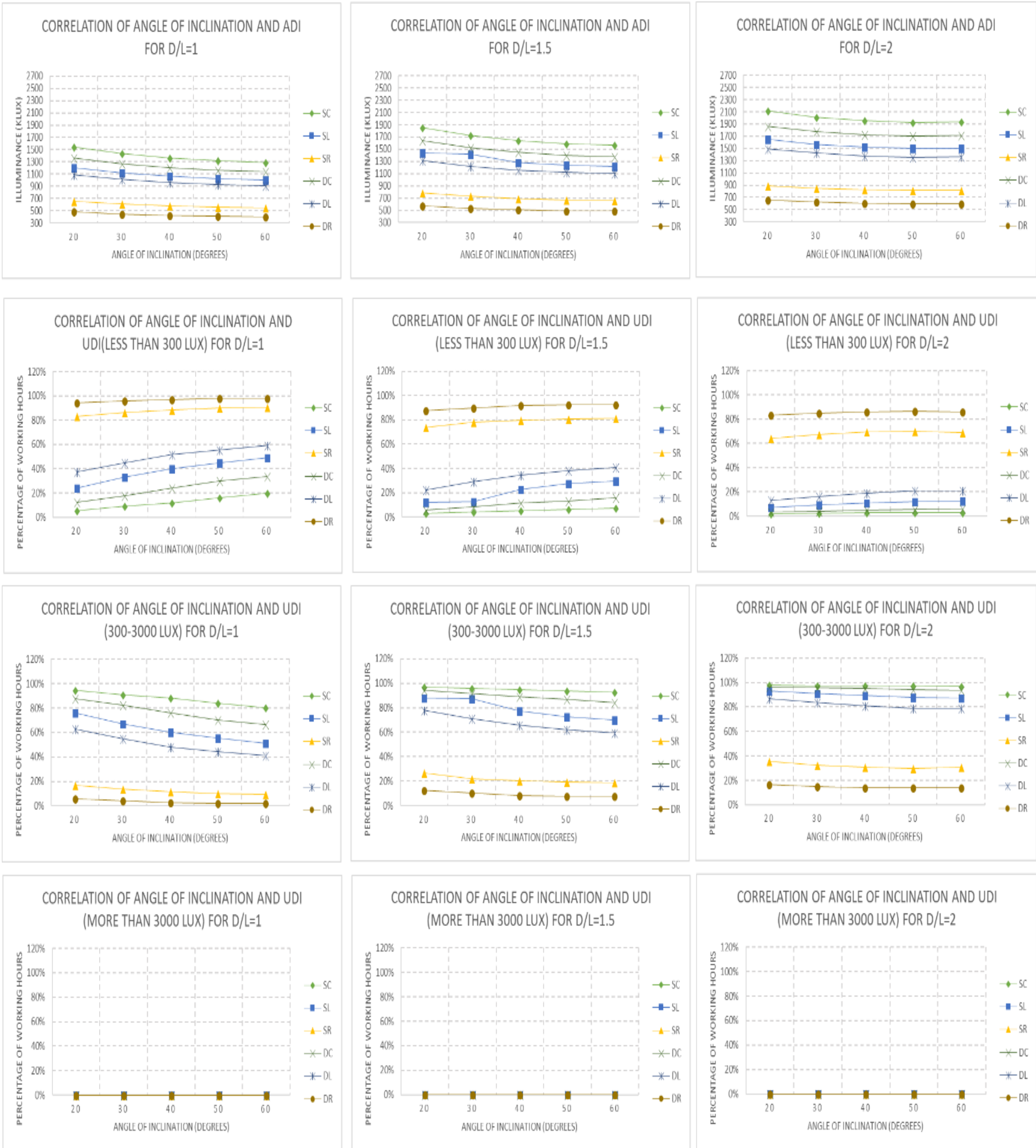
Orientation=south-west, WWR=80, depth=600mm



Orientation=south-west, WWR=60, depth=400mm

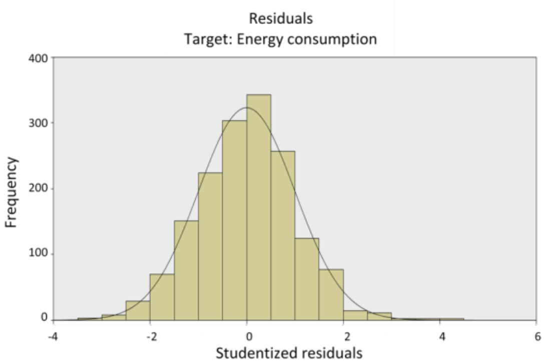


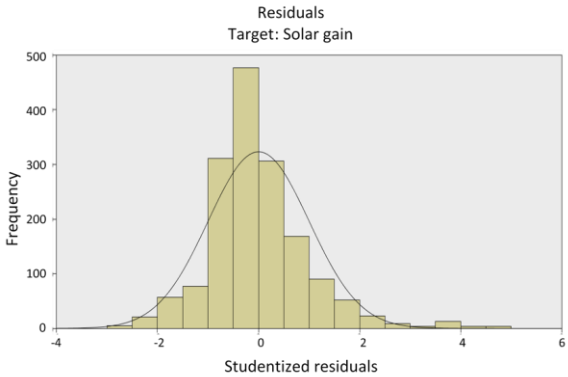
Orientation=south-west, WWR=60, depth=600mm

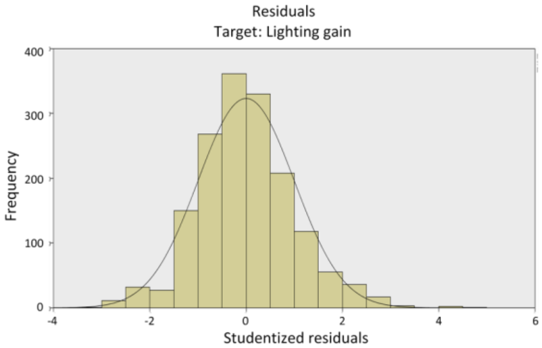


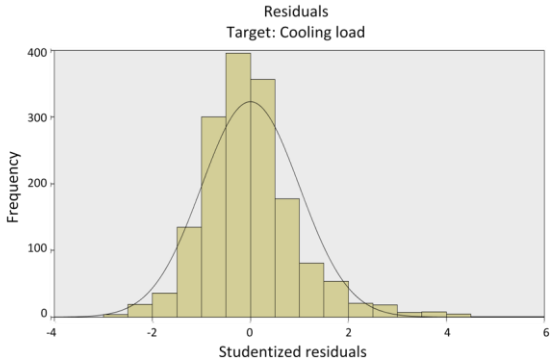
Appendix 10: Assumptions of linear regression analysis

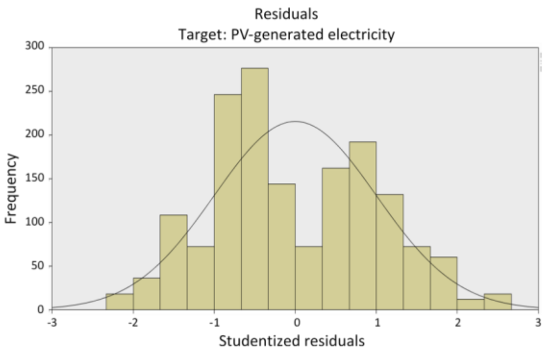
A: Normality test

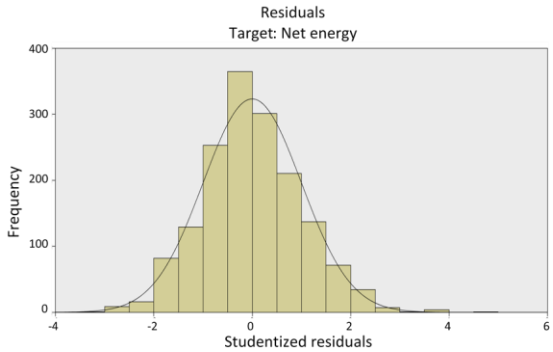


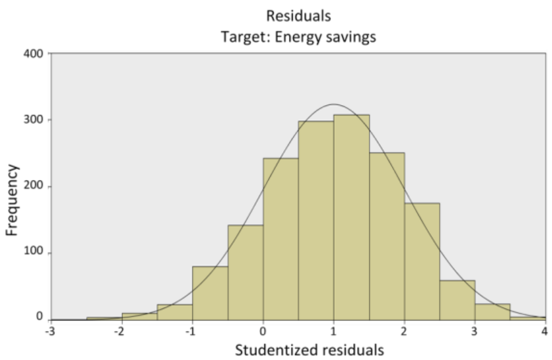


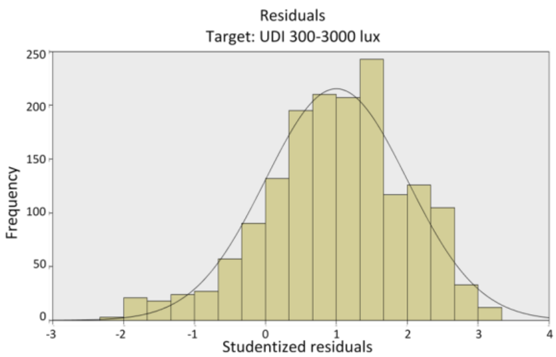




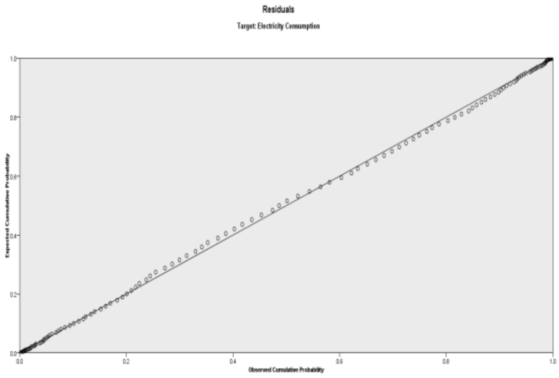




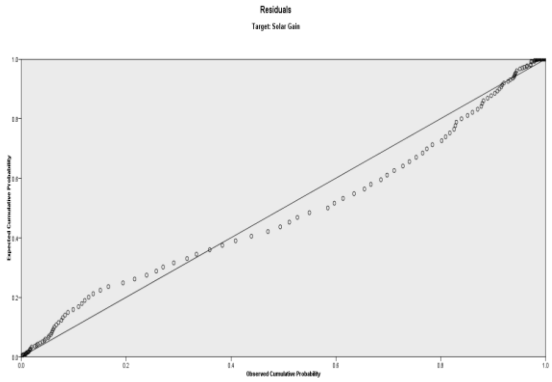




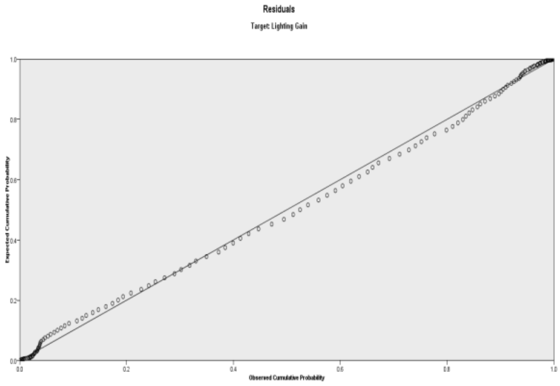
B: Normal P-P plot



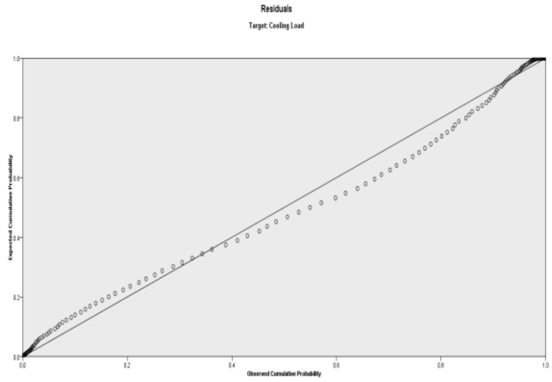
The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



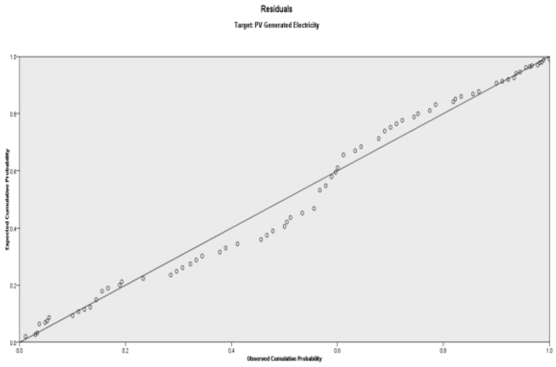
The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



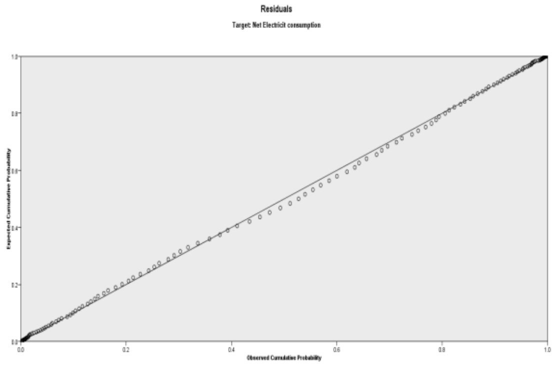
The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



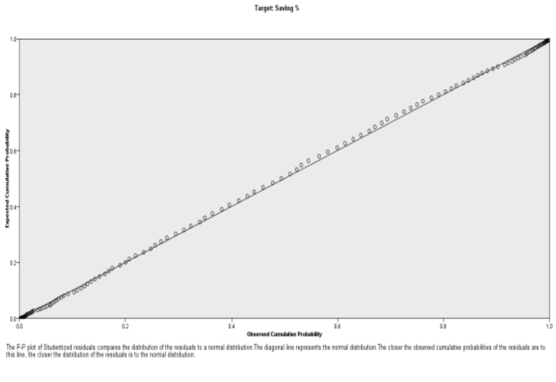
The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



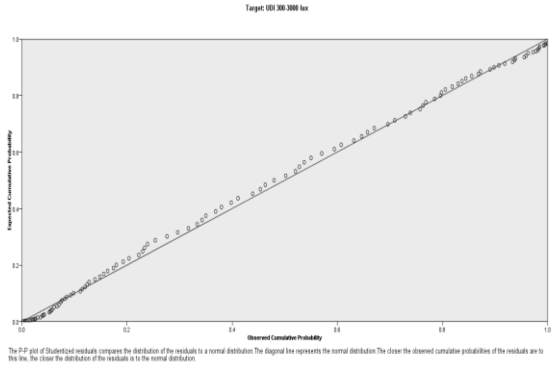
The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.



The P-P plot of Studentized residuals compares the distribution of the residuals to a normal distribution.The diagonal line represents the normal distribution.The closer the observed cumulative probabilities of the residuals are to this line, the closer the distribution of the residuals is to the normal distribution.

Appendix 11: Decisional synopses of combinations at south-east and south-west orientations

Orientation=south-east, WWR=100%, depth=400mm

South-East orientation, 400mm — WWR 100% — Solar gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	80	34	44	65	5	16
		30°	79	32	41	62	4	14
		40°	78	28	38	58	3	12
		50°	77	27	37	57	2	11
		60°	76	26	36	56	1	10
	d/l=1.5	20°	85	45	54	70	13	25
		30°	84	43	49	69	9	24
		40°	83	42	48	68	8	23
		50°	82	40	47	67	7	21
		60°	81	39	46	66	6	20
	d/l=2	20°	90	55	64	75	22	35
		30°	89	53	63	74	19	33
		40°	87	51	60	72	18	31
		50°	86	50	59	71	15	29
		60°	88	52	61	73	17	30

South-East orientation, 400mm — WWR 100% — Net Electricity

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	63	20	69	16	1	40
		30°	67	28	79	22	5	47
		40°	87	38	84	27	7	49
		50°	89	48	86	41	13	56
		60°	90	57	88	50	15	59
	d/l=1.5	20°	61	21	65	18	2	42
		30°	62	24	68	17	3	44
		40°	64	25	71	19	4	45
		50°	66	30	80	23	6	51
		60°	73	37	83	26	10	54
	d/l=2	20°	75	36	74	35	11	55
		30°	72	33	77	31	9	53
		40°	70	32	78	29	8	52
		50°	76	39	81	34	12	58
		60°	82	46	85	43	14	60

South-East orientation, 400mm — WWR 100% — Lighting gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	14	36	70	27	43	82
		30°	32	46	80	41	52	85
		40°	53	56	83	49	61	87
		50°	58	66	86	59	74	89
		60°	63	76	88	68	79	90
	d/l=1.5	20°	4	18	55	11	31	72
		30°	7	30	60	17	38	77
		40°	12	35	64	22	40	78
		50°	21	42	73	34	45	81
		60°	29	44	75	39	48	84
	d/l=2	20°	1	15	47	8	23	62
		30°	2	20	51	10	25	67
		40°	3	19	50	9	26	65
		50°	5	24	54	13	33	69
		60°	6	28	57	16	37	71

South-East orientation, 400mm — WWR 100% — Saving

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	31	11	39	8	3	18
		30°	28	9	32	6	1	15
		40°	36	10	30	7	2	13
		50°	41	14	37	12	4	16
		60°	45	19	44	17	5	20
	d/l=1.5	20°	61	49	63	48	26	50
		30°	54	38	57	33	23	47
		40°	51	29	53	25	21	42
		50°	52	34	55	27	22	43
		60°	56	40	58	35	24	46
	d/l=2	20°	90	79	89	78	66	80
		30°	85	71	86	70	62	76
		40°	81	67	82	65	59	72
		50°	83	69	84	68	60	73
		60°	87	75	88	74	64	77

South-East orientation, 400mm — WWR 100% — Cooling plant sensible load (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	78	26	47	58	1	20
		30°	77	28	46	56	2	17
		40°	79	30	45	57	3	16
		50°	76	33	48	60	5	18
		60°	80	36	49	63	8	19
	d/l=1.5	20°	85	40	55	70	10	25
		30°	84	38	54	69	6	24
		40°	82	34	51	67	4	21
		50°	81	37	52	66	7	22
		60°	83	39	53	68	9	23
	d/l=2	20°	90	50	65	75	15	35
		30°	89	43	62	74	13	31
		40°	87	41	59	72	11	27
		50°	86	42	61	71	12	29
		60°	88	44	64	73	14	32

South-East orientation, 400mm — WWR 100% — ADI

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	24	38	70	32	48	83
		30°	33	50	78	41	57	88
		40°	39	54	79	47	58	87
		50°	42	55	82	51	62	89
		60°	46	59	84	53	65	90
	d/l=1.5	20°	7	19	63	14	30	75
		30°	11	35	67	21	40	80
		40°	15	37	69	27	44	81
		50°	20	43	72	34	49	85
		60°	25	45	74	36	52	86
	d/l=2	20°	1	10	56	4	17	68
		30°	2	16	60	8	26	73
		40°	3	18	61	9	28	71
		50°	5	22	64	12	29	76
		60°	6	23	66	13	31	77

South-East orientation, 400mm — WWR 100% — PV +

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	5	5	5	5	5	5
		30°	3	3	3	3	3	3
		40°	1	1	1	1	1	1
		50°	2	2	2	2	2	2
		60°	4	4	4	4	4	4
	d/l=1.5	20°	10	10	10	10	10	10
		30°	9	9	9	9	9	9
		40°	7	7	7	7	7	7
		50°	6	6	6	6	6	6
		60°	8	8	8	8	8	8
	d/l=2	20°	15	15	15	15	15	15
		30°	13	13	13	13	13	13
		40°	11	11	11	11	11	11
		50°	12	12	12	12	12	12
		60°	14	14	14	14	14	14

South-East orientation, 400mm — WWR 100% — LESS THAN 300LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	13	29	70	25	45	86
		30°	24	49	78	36	56	87
		40°	33	51	79	39	57	88
		50°	42	54	82	49	60	89
		60°	43	58	84	53	62	90
	d/l=1.5	20°	7	18	64	12	34	77
		30°	8	35	68	20	44	80
		40°	11	38	67	26	46	81
		50°	17	47	71	32	52	83
		60°	21	48	73	37	55	85
	d/l=2	20°	1	16	59	4	23	69
		30°	2	19	63	9	30	74
		40°	3	21	61	10	31	72
		50°	4	27	65	15	40	76
		60°	6	28	65	13	41	75

South-East orientation, 400mm — WWR 100% — Electricity: Meter-(MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	77	38	82	32	9	50
		30°	83	47	84	41	12	54
		40°	87	52	85	48	13	57
		50°	89	55	86	53	22	59
		60°	90	58	88	56	28	60
	d/l=1.5	20°	63	21	71	14	4	40
		30°	67	29	75	19	6	45
		40°	72	33	78	25	8	46
		50°	76	39	80	31	10	49
		60°	79	44	81	35	11	51
	d/l=2	20°	62	16	61	15	1	34
		30°	64	20	66	17	2	36
		40°	65	23	69	18	3	37
		50°	68	27	73	24	5	42
		60°	70	30	74	26	7	43

South-East orientation, 400mm — WWR 100% — 300-3000 LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 100%	d/l=1	20°	13	29	70	25	45	86
		30°	24	49	78	36	56	87
		40°	33	51	79	39	57	88
		50°	41	54	82	49	60	89
		60°	43	58	84	53	62	90
	d/l=1.5	20°	7	18	64	12	34	77
		30°	8	35	68	20	44	80
		40°	11	38	67	26	46	81
		50°	17	47	71	32	52	83
		60°	21	48	73	37	55	85
	d/l=2	20°	1	16	59	4	23	69
		30°	1	19	63	9	30	74
		40°	3	21	61	10	31	72
		50°	4	27	65	15	40	76
		60°	6	28	65	13	42	75

Orientation=south-east, WWR=100%, depth=600mm

South-East orientation — 600mm — WWR 100% — Solar gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	80	34	43	64	5	16
	30°	79	32	41	62	4	14
	40°	78	28	38	58	3	12
	50°	77	27	37	57	2	11
	60°	76	26	35	56	1	10
d/l=1.5	20°	85	45	54	70	13	25
	30°	84	44	50	69	9	24
	40°	83	42	48	68	8	23
	50°	82	40	47	67	7	21
	60°	81	39	46	66	6	20
d/l=2	20°	90	55	65	75	22	36
	30°	89	53	63	74	19	33
	40°	87	52	61	73	18	31
	50°	86	49	59	71	15	29
	60°	88	51	60	72	17	30

South-East orientation — 600mm — WWR 100% — Net Electricity

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	61	21	70	16	1	38
	30°	65	25	78	19	4	43
	40°	81	39	84	28	10	51
	50°	88	50	87	41	13	55
	60°	90	58	89	49	15	59
d/l=1.5	20°	63	23	66	18	3	45
	30°	62	22	69	17	2	44
	40°	64	26	75	20	5	47
	50°	68	36	80	24	7	53
	60°	76	42	85	30	12	57
d/l=2	20°	73	34	74	33	8	52
	30°	67	31	72	27	6	48
	40°	71	35	77	29	9	54
	50°	82	37	79	32	11	56
	60°	86	46	83	40	14	60

South-East orientation — 600mm — WWR 100% — Lighting gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	12	39	70	27	43	82
	30°	32	47	78	40	52	85
	40°	44	59	84	51	63	88
	50°	53	66	86	60	76	89
	60°	73	77	87	68	79	90
d/l=1.5	20°	4	19	55	8	30	72
	30°	5	26	58	11	35	74
	40°	10	37	64	24	42	80
	50°	17	41	71	33	46	81
	60°	28	45	75	38	48	83
d/l=2	20°	1	15	49	7	23	61
	30°	2	14	50	6	22	62
	40°	3	20	54	9	31	65
	50°	18	25	56	13	34	67
	60°	21	29	57	16	36	69

South-East orientation — 600mm — WWR 100% — Saving

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	26	11	33	7	3	17
	30°	25	9	27	6	1	13
	40°	28	10	30	8	2	14
	50°	37	15	34	12	4	16
	60°	45	19	41	18	5	20
d/l=1.5	20°	66	49	71	47	29	50
	30°	56	39	60	35	23	46
	40°	54	36	57	31	21	43
	50°	55	38	58	32	22	44
	60°	59	42	63	40	24	48
d/l=2	20°	88	78	89	77	62	80
	30°	83	70	85	68	53	74
	40°	81	65	82	64	51	72
	50°	86	69	84	67	52	73
	60°	90	76	87	75	61	79

South-East orientation — 600mm — WWR 100% — Cooling plant sensible load (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	78	27	47	58	1	20
	30°	76	26	45	56	2	16
	40°	77	31	46	57	3	17
	50°	79	33	48	59	4	18
	60°	80	35	49	63	8	19
d/l=1.5	20°	85	40	55	70	10	25
	30°	84	38	53	69	6	23
	40°	82	36	52	67	5	22
	50°	81	37	51	66	7	21
	60°	83	39	54	68	9	24
d/l=2	20°	90	50	65	75	15	34
	30°	88	43	62	74	13	30
	40°	86	41	60	72	11	29
	50°	87	42	61	71	12	28
	60°	89	44	64	73	14	32

South-East orientation — 600mm — WWR 100% — ADI

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	25	43	73	36	51	85
	30°	31	49	75	40	54	87
	40°	38	55	80	47	60	88
	50°	42	57	81	52	62	89
	60°	46	59	83	53	65	90
d/l=1.5	20°	5	26	66	14	34	78
	30°	10	32	67	19	39	79
	40°	16	37	70	27	45	82
	50°	20	41	71	33	48	84
	60°	24	44	72	35	50	86
d/l=2	20°	1	11	56	4	17	68
	30°	2	15	58	6	23	69
	40°	3	18	61	9	28	74
	50°	8	21	63	12	29	76
	60°	7	22	64	13	30	77

South-East orientation — 600mm — WWR 100% — PV +

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	5	5	5	5	5	5
	30°	2	2	2	2	2	2
	40°	1	1	1	1	1	1
	50°	3	3	3	3	3	3
	60°	4	4	4	4	4	4
d/l=1.5	20°	10	10	10	10	10	10
	30°	9	9	9	9	9	9
	40°	7	7	7	7	7	7
	50°	6	6	6	6	6	6
	60°	8	8	8	8	8	8
d/l=2	20°	15	15	15	15	15	15
	30°	13	13	13	13	13	13
	40°	11	11	11	11	11	11
	50°	12	12	12	12	12	12
	60°	14	14	14	14	14	14

South-East orientation — 600mm — WWR 100% — LESS THAN 300LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	12	42	76	26	50	86
	30°	20	44	77	33	52	87
	40°	31	54	80	43	57	88
	50°	37	56	82	49	59	89
	60°	46	58	85	53	62	90
d/l=1.5	20°	5	23	66	9	35	78
	30°	6	29	67	16	38	79
	40°	11	39	68	24	48	81
	50°	14	45	71	32	51	83
	60°	18	47	72	34	55	84
d/l=2	20°	1	15	61	4	25	69
	30°	2	17	60	7	28	70
	40°	3	22	63	8	36	73
	50°	19	26	65	10	40	75
	60°	21	30	64	12	41	74

South-East orientation — 600mm — WWR 100% — Electricity: Meter-(MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	77	39	82	31	9	51
	30°	83	46	84	41	12	54
	40°	85	53	86	48	13	57
	50°	88	56	87	52	21	59
	60°	90	58	89	55	28	60
d/l=1.5	20°	64	23	69	14	3	40
	30°	67	29	74	18	6	45
	40°	71	34	79	25	8	47
	50°	76	37	80	32	10	49
	60°	78	44	81	36	11	50
d/l=2	20°	61	17	62	16	1	33
	30°	63	19	65	15	2	35
	40°	66	24	68	20	4	38
	50°	72	27	70	22	5	42
	60°	75	30	73	26	7	43

South-East orientation — 600mm — WWR 100% — 300-3000 LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	12	42	76	26	50	86
	30°	20	44	77	33	52	87
	40°	31	54	80	43	57	88
	50°	37	56	82	49	59	89
	60°	46	58	85	53	62	90
d/l=1.5	20°	5	23	66	9	35	78
	30°	6	29	67	16	38	79
	40°	11	39	68	24	48	81
	50°	14	45	71	32	51	83
	60°	18	47	72	34	55	84
d/l=2	20°	1	15	61	4	25	69
	30°	2	17	60	7	28	70
	40°	3	22	63	8	36	73
	50°	19	26	65	10	40	75
	60°	21	30	64	12	41	74

Orientation=south-east, WWR=80%, depth=400mm

South-East orientation, 400mm — WWR 80% — Solar gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	80	35	44	65	5	17	
30°	79	33	41	63	4	14	
40°	78	29	38	61	3	13	d/l=1
50°	77	27	37	59	2	12	
60°	76	26	36	57	1	10	
20°	85	45	54	70	11	25	
30°	84	43	49	69	9	24	
40°	83	42	48	68	8	23	d/l=1.5
50°	82	40	47	67	7	22	
60°	81	39	46	66	6	21	
20°	90	55	64	75	20	34	
30°	89	53	62	74	19	32	
40°	87	51	58	72	16	30	d/l=2
50°	86	50	56	71	15	28	
60°	88	52	60	73	18	31	

South-East orientation, 400mm — WWR 80% — Net Electricity

	SC	SL	SR	DC	DL	DR	
20°	63	22	70	16	1	42	
30°	69	30	76	20	5	45	
40°	82	37	83	28	7	48	d/l=1
50°	89	50	87	41	13	52	
60°	90	53	88	49	15	55	
20°	61	21	67	17	2	44	
30°	62	23	72	18	3	46	
40°	64	25	74	19	4	47	d/l=1.5
50°	65	33	81	24	6	51	
60°	75	40	85	29	11	54	
20°	71	36	77	31	10	58	
30°	68	35	79	27	9	57	
40°	66	34	78	26	8	56	d/l=2
50°	73	39	84	32	12	59	
60°	80	43	86	38	14	60	

South-East orientation, 400mm — WWR 80% — Lighting gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	17	39	73	31	44	83	
30°	36	49	80	42	54	86	
40°	45	58	82	52	62	88	d/l=1
50°	57	69	85	61	75	89	
60°	64	76	87	70	79	90	
20°	4	21	56	11	30	71	
30°	8	28	59	19	37	77	
40°	12	35	63	24	40	78	d/l=1.5
50°	22	41	72	34	46	81	
60°	29	43	74	38	48	84	
20°	1	14	47	6	20	60	
30°	2	16	51	9	25	66	
40°	3	18	50	10	26	65	d/l=2
50°	5	23	53	13	32	67	
60°	7	27	55	15	33	68	

South-East orientation, 400mm — WWR 80% — Saving

	SC	SL	SR	DC	DL	DR	
20°	30	12	39	8	3	18	
30°	25	9	31	6	1	14	
40°	27	10	28	7	2	13	d/l=1
50°	38	15	35	11	4	16	
60°	45	19	41	17	5	20	
20°	60	49	62	47	32	50	
30°	53	40	58	34	23	48	
40°	51	33	54	26	21	43	d/l=1.5
50°	52	36	55	29	22	44	
60°	56	42	57	37	24	46	
20°	89	78	90	77	68	80	
30°	85	71	86	70	63	76	
40°	81	67	83	65	59	72	d/l=2
50°	82	69	84	66	61	74	
60°	87	75	88	73	64	79	

South-East orientation, 400mm — WWR 80% — Cooling plant sensible load (MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	28	48	57	1	20	
30°	76	30	47	56	2	17	
40°	78	32	46	58	3	16	d/l=1
50°	79	35	49	62	7	18	
60°	80	38	50	65	10	19	
20°	85	40	55	70	8	25	
30°	84	36	53	68	5	24	
40°	81	34	51	66	4	21	d/l=1.5
50°	82	37	52	67	6	22	
60°	83	39	54	69	9	23	
20°	90	45	64	75	14	33	
30°	88	43	61	73	12	29	
40°	86	41	59	71	11	26	d/l=2
50°	87	42	60	72	13	27	
60°	89	44	63	74	15	31	

South-East orientation, 400mm — WWR 80% — ADI

	SC	SL	SR	DC	DL	DR	
20°	19	42	70	32	48	84	
30°	29	51	78	40	55	88	
40°	36	54	79	45	58	87	d/l=1
50°	39	56	82	49	60	89	
60°	43	59	83	52	63	90	
20°	7	25	64	14	34	75	
30°	13	35	67	21	41	81	
40°	15	38	68	27	46	80	d/l=1.5
50°	20	44	71	33	50	85	
60°	24	47	74	37	53	86	
20°	1	10	57	4	18	69	
30°	2	16	62	8	26	73	
40°	3	17	61	9	28	72	d/l=2
50°	6	23	66	12	30	76	
60°	5	22	65	11	31	77	

South-East orientation, 400mm — WWR 80% — PV +

	SC	SL	SR	DC	DL	DR	
20°	5	5	5	5	5	5	
30°	3	3	3	3	3	3	
40°	1	1	1	1	1	1	d/l=1
50°	2	2	2	2	2	2	
60°	4	4	4	4	4	4	
20°	10	10	10	10	10	10	
30°	9	9	9	9	9	9	
40°	7	7	7	7	7	7	d/l=1.5
50°	6	6	6	6	6	6	
60°	8	8	8	8	8	8	
20°	15	15	15	15	15	15	
30°	13	13	13	13	13	13	
40°	11	11	11	11	11	11	d/l=2
50°	12	12	12	12	12	12	
60°	14	14	14	14	14	14	

South-East orientation, 400mm — WWR 80% — LESS THAN 300LUX

	SC	SL	SR	DC	DL	DR	
20°	13	39	70	26	47	86	
30°	25	50	77	35	55	87	
40°	27	51	79	40	56	88	d/l=1
50°	38	57	82	49	60	89	
60°	43	58	83	52	61	90	
20°	4	23	64	12	33	78	
30°	9	34	67	19	44	80	
40°	11	36	68	23	45	81	d/l=1.5
50°	17	46	71	32	53	84	
60°	18	48	72	37	54	85	
20°	1	13	59	5	22	69	
30°	2	21	63	8	31	74	
40°	3	20	62	9	30	73	d/l=2
50°	5	28	66	15	41	76	
60°	7	29	65	15	42	75	

South-East orientation, 400mm — WWR 80% — Electricity: Meter-(MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	39	82	31	10	51	
30°	83	47	84	43	12	54	
40°	85	52	86	48	18	56	d/l=1
50°	89	57	87	53	25	58	
60°	90	59	88	55	29	60	
20°	64	24	73	15	4	41	
30°	68	30	76	21	7	45	
40°	72	33	78	27	8	46	d/l=1.5
50°	75	38	80	32	9	49	
60°	79	44	81	35	11	50	
20°	61	17	65	13	1	34	
30°	62	20	69	14	2	36	
40°	63	22	70	16	3	37	d/l=2
50°	66	26	71	19	5	40	
60°	67	28	74	23	6	42	

South-East orientation, 400mm — WWR 80% — 300-3000 LUX

	SC	SL	SR	DC	DL	DR	
20°	13	39	70	26	47	86	
30°	25	50	77	35	55	87	
40°	27	51	79	40	56	88	d/l=1
50°	38	57	82	49	60	89	
60°	43	58	83	52	61	90	
20°	4	23	64	12	33	78	
30°	9	34	67	19	44	80	
40°	11	36	68	23	45	81	d/l=1.5
50°	17	46	71	32	53	84	
60°	18	48	72	37	54	85	
20°	1	13	59	5	22	69	
30°	2	21	63	8	31	74	
40°	3	20	62	9	30	73	d/l=2
50°	5	28	66	15	41	76	
60°	7	29	65	15	42	75	

Orientation=south-east, WWR=80%, depth=600mm

South-East orientation, 600mm — Solar gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	80	35	44	65	5	18
		30°	79	33	41	63	4	14
		40°	78	30	38	61	3	13
		50°	77	27	37	60	2	11
		60°	76	26	36	58	1	10
	d/l=1.5	20°	85	45	54	70	12	25
		30°	84	43	50	69	9	24
		40°	83	42	48	68	8	23
		50°	82	40	47	67	7	22
		60°	81	39	46	66	6	21
	d/l=2	20°	90	55	64	75	20	34
		30°	89	53	62	74	19	32
		40°	87	51	57	72	16	29
		50°	86	49	56	71	15	28
		60°	88	52	59	73	17	31

South-East orientation, 600mm — Net Electricity

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	61	21	69	16	1	40
		30°	66	27	75	19	4	42
		40°	81	39	84	30	8	49
		50°	88	48	87	41	13	52
		60°	90	55	89	47	15	57
	d/l=1.5	20°	62	22	71	18	2	46
		30°	63	23	72	17	3	45
		40°	64	29	78	20	5	50
		50°	70	36	83	24	10	53
		60°	77	43	86	33	12	58
	d/l=2	20°	68	34	76	28	7	54
		30°	65	31	74	25	6	51
		40°	67	35	79	26	9	56
		50°	73	38	82	32	11	59
		60°	80	44	85	37	14	60

South-East orientation, 600mm — Lighting gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	18	39	73	31	43	82
		30°	33	47	78	40	51	85
		40°	46	59	84	52	64	88
		50°	57	69	86	62	76	89
		60°	63	77	87	71	79	90
	d/l=1.5	20°	3	20	56	10	30	70
		30°	6	27	58	16	36	74
		40°	13	37	65	25	42	80
		50°	23	41	72	35	45	81
		60°	28	44	75	38	50	83
	d/l=2	20°	2	14	48	7	21	60
		30°	1	15	49	8	22	61
		40°	4	19	53	11	29	66
		50°	5	24	54	12	32	67
		60°	9	26	55	17	34	68

South-East orientation, 600mm — Saving

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	26	11	30	7	3	18
		30°	24	9	27	6	1	13
		40°	28	10	29	8	2	14
		50°	34	15	32	12	4	16
		60°	42	19	38	17	5	20
	d/l=1.5	20°	65	49	71	46	33	50
		30°	56	40	60	36	23	47
		40°	52	37	57	31	21	44
		50°	55	39	58	35	22	45
		60°	59	43	61	41	25	48
	d/l=2	20°	88	78	90	77	64	80
		30°	84	70	86	68	54	74
		40°	81	66	83	63	51	72
		50°	82	69	85	67	53	73
		60°	87	76	89	75	62	79

South-East orientation, 600mm — Cooling plant sensible load (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	77	29	47	57	1	20
		30°	76	30	46	56	2	16
		40°	78	32	48	58	3	17
		50°	79	34	49	62	7	18
		60°	80	38	50	64	10	19
	d/l=1.5	20°	85	40	55	70	8	25
		30°	84	36	53	68	4	23
		40°	82	35	52	67	5	22
		50°	81	37	51	66	6	21
		60°	83	39	54	69	9	24
	d/l=2	20°	90	45	65	75	15	33
		30°	88	43	61	73	12	28
		40°	87	41	59	71	11	26
		50°	86	42	60	72	13	27
		60°	89	44	63	74	14	31

South-East orientation, 600mm — ADI

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	24	45	73	35	52	86
		30°	28	48	74	40	54	87
		40°	37	55	80	47	59	88
		50°	41	56	81	50	61	89
		60°	43	57	82	53	62	90
	d/l=1.5	20°	7	26	66	14	36	78
		30°	9	30	67	17	39	79
		40°	16	38	68	27	46	83
		50°	18	42	71	33	49	84
		60°	21	44	72	34	51	85
	d/l=2	20°	1	13	58	6	19	69
		30°	2	15	60	8	25	70
		40°	3	20	63	10	29	75
		50°	5	23	65	12	32	77
		60°	4	22	64	11	31	76

South-East orientation, 600mm — PV +

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	5	5	5	5	5	5
		30°	2	2	2	2	2	2
		40°	1	1	1	1	1	1
		50°	3	3	3	3	3	3
		60°	4	4	4	4	4	4
	d/l=1.5	20°	10	10	10	10	10	10
		30°	9	9	9	9	9	9
		40°	7	7	7	7	7	7
		50°	6	6	6	6	6	6
		60°	8	8	8	8	8	8
	d/l=2	20°	15	15	15	15	15	15
		30°	13	13	13	13	13	13
		40°	11	11	11	11	11	11
		50°	12	12	12	12	12	12
		60°	14	14	14	14	14	14

South-East orientation, 600mm — LESS THAN 300LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	15	42	73	27	50	86
		30°	21	45	77	33	51	87
		40°	30	54	80	44	58	88
		50°	36	56	81	48	59	89
		60°	43	57	83	52	62	90
	d/l=1.5	20°	4	24	66	12	37	78
		30°	8	29	67	19	39	79
		40°	11	41	68	23	49	82
		50°	16	46	71	32	53	84
		60°	20	47	72	34	55	85
	d/l=2	20°	1	16	61	7	26	69
		30°	2	18	60	9	25	70
		40°	3	22	64	10	35	75
		50°	5	28	65	13	38	76
		60°	5	31	63	14	40	74

South-East orientation, 600mm — Electricity: Meter-(MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	77	38	82	31	9	51
		30°	83	46	84	40	12	54
		40°	85	53	86	48	18	57
		50°	89	56	87	52	25	58
		60°	90	59	88	55	30	60
	d/l=1.5	20°	63	22	72	15	3	41
		30°	67	28	75	20	6	45
		40°	71	33	79	27	8	47
		50°	76	37	80	32	10	49
		60°	78	44	81	35	11	50
	d/l=2	20°	61	16	65	13	1	34
		30°	62	19	68	14	2	36
		40°	64	24	70	17	4	39
		50°	66	26	73	21	5	42
		60°	69	29	74	23	7	43

South-East orientation, 600mm — 300-3000 LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	15	42	73	27	50	86
		30°	21	45	77	33	51	87
		40°	30	54	80	44	58	88
		50°	36	56	81	48	59	89
		60°	43	57	83	52	62	90
	d/l=1.5	20°	4	24	66	12	37	78
		30°	8	29	67	19	39	79
		40°	11	41	68	23	49	82
		50°	16	46	71	32	53	84
		60°	20	47	72	34	55	85
	d/l=2	20°	1	16	61	7	26	69
		30°	2	18	60	9	25	70
		40°	3	22	64	10	35	75
		50°	5	28	65	13	38	76
		60°	5	31	63	14	40	74

Orientation=south-east, WWR=60%, depth=400mm

South-East orientation — 400mm — Solar gain (MWh)

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	80	35	44	65	5	19	d/l=1
	30°	79	34	42	64	4	17	
	40°	78	32	40	63	3	13	
	50°	77	31	37	61	2	12	
	60°	76	30	36	60	1	11	
	20°	84	45	54	70	10	25	d/l=1.5
	30°	85	43	52	69	9	24	
	40°	83	41	48	68	8	23	
	50°	82	39	47	67	7	22	
	60°	81	38	46	66	6	21	
	20°	90	55	62	75	20	33	d/l=2
	30°	89	53	59	74	18	29	
	40°	87	50	57	72	16	28	
	50°	86	49	56	71	14	26	
	60°	88	51	58	73	15	27	

South-East orientation — 400mm — Net Electricity

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	62	21	66	16	1	39	d/l=1
	30°	65	27	73	20	3	42	
	40°	78	34	77	25	6	43	
	50°	88	46	81	35	11	50	
	60°	90	52	86	45	14	53	
	20°	61	22	71	17	2	48	d/l=1.5
	30°	64	24	72	18	4	49	
	40°	63	26	74	19	5	47	
	50°	67	32	79	23	7	54	
	60°	75	40	85	30	8	55	
	20°	69	37	82	31	12	58	d/l=2
	30°	68	36	84	28	9	57	
	40°	70	38	83	29	10	56	
	50°	76	44	87	33	13	59	
	60°	80	51	89	41	15	60	

South-East orientation — 400mm — Lighting gain (MWh)

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	20	40	73	33	44	83	d/l=1
	30°	36	51	80	42	55	87	
	40°	45	58	81	52	63	88	
	50°	57	68	85	62	74	90	
	60°	61	75	86	67	77	89	
	20°	4	21	56	11	28	71	d/l=1.5
	30°	7	31	60	19	37	78	
	40°	15	35	65	27	39	79	
	50°	26	41	72	34	46	82	
	60°	29	43	76	38	48	84	
	20°	1	12	47	5	18	59	d/l=2
	30°	2	16	50	9	23	66	
	40°	3	17	49	10	25	64	
	50°	6	22	53	13	30	69	
	60°	8	24	54	14	32	70	

South-East orientation — 400mm — Saving

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	29	13	34	10	4	20	d/l=1
	30°	25	8	28	6	2	14	
	40°	27	9	26	7	1	12	
	50°	33	15	30	11	3	16	
	60°	41	18	35	17	5	19	
	20°	59	49	61	47	36	50	d/l=1.5
	30°	56	42	58	39	24	48	
	40°	51	37	53	31	21	44	
	50°	52	38	54	32	22	45	
	60°	55	43	57	40	23	46	
	20°	89	78	90	77	69	81	d/l=2
	30°	84	71	86	70	63	76	
	40°	80	67	83	65	60	72	
	50°	82	68	85	66	62	74	
	60°	87	75	88	73	64	79	

South-East orientation — 400mm — Cooling plant sensible load (MWh)

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	76	30	48	56	1	20	d/l=1
	30°	77	32	47	58	2	19	
	40°	78	33	46	60	3	16	
	50°	79	36	49	63	8	18	
	60°	80	39	50	65	10	17	
	20°	84	38	55	70	6	25	d/l=1.5
	30°	85	35	53	68	5	24	
	40°	81	34	51	66	4	21	
	50°	82	37	52	67	7	22	
	60°	83	40	54	69	9	23	
	20°	90	45	64	75	14	31	d/l=2
	30°	88	43	61	73	12	28	
	40°	86	41	57	71	11	26	
	50°	87	42	59	72	13	27	
	60°	89	44	62	74	15	29	

South-East orientation — 400mm — ADI

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	16	42	70	30	49	84	d/l=1
	30°	27	51	77	41	56	88	
	40°	31	53	75	43	57	87	
	50°	38	55	80	48	60	89	
	60°	40	58	82	50	61	90	
	20°	7	24	64	14	34	76	d/l=1.5
	30°	10	37	67	22	45	83	
	40°	15	39	68	26	47	81	
	50°	18	44	71	32	52	85	
	60°	21	46	72	33	54	86	
	20°	1	11	59	4	20	69	d/l=2
	30°	2	17	63	8	28	74	
	40°	3	19	62	9	29	73	
	50°	6	23	65	13	36	78	
	60°	5	25	66	12	35	79	

South-East orientation — 400mm — PV +

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	5	5	5	5	5	5	d/l=1
	30°	3	3	3	3	3	3	
	40°	1	1	1	1	1	1	
	50°	2	2	2	2	2	2	
	60°	4	4	4	4	4	4	
	20°	10	10	10	10	10	10	d/l=1.5
	30°	9	9	9	9	9	9	
	40°	7	7	7	7	7	7	
	50°	6	6	6	6	6	6	
	60°	8	8	8	8	8	8	
	20°	15	15	15	15	15	15	d/l=2
	30°	13	13	13	13	13	13	
	40°	11	11	11	11	11	11	
	50°	12	12	12	12	12	12	
	60°	14	14	14	14	14	14	

South-East orientation — 400mm — LESS THAN 300LUX

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	12	40	70	24	48	86	d/l=1
	30°	21	51	75	36	55	87	
	40°	26	50	78	38	56	88	
	50°	32	56	81	46	59	89	
	60°	41	58	82	52	61	90	
	20°	4	26	66	13	34	79	d/l=1.5
	30°	8	39	68	19	47	80	
	40°	11	37	67	22	45	83	
	50°	17	44	71	30	53	85	
	60°	18	49	72	35	54	84	
	20°	1	14	60	6	25	69	d/l=2
	30°	2	23	63	10	33	74	
	40°	3	20	62	9	31	73	
	50°	5	28	65	15	42	76	
	60°	6	29	64	16	43	77	

South-East orientation — 400mm — Electricity: Meter-(MWh)

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	77	39	82	31	9	50	d/l=1
	30°	83	48	84	40	13	54	
	40°	86	52	85	47	18	56	
	50°	89	57	87	53	24	58	
	60°	90	59	88	55	27	60	
	20°	63	25	72	15	4	41	d/l=1.5
	30°	70	30	75	21	7	45	
	40°	71	33	78	28	8	46	
	50°	76	38	80	32	10	49	
	60°	79	43	81	35	11	51	
	20°	61	17	66	12	1	34	d/l=2
	30°	62	20	68	14	2	36	
	40°	64	23	69	16	3	37	
	50°	65	26	73	19	5	42	
	60°	67	29	74	22	6	44	

South-East orientation — 400mm — 300-3000 LUX

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l
WWR 60%	20°	12	40	70	24	48	86	d/l=1
	30°	21	51	75	36	55	87	
	40°	26	50	78	38	56	88	
	50°	32	56	81	46	59	89	
	60°	41	58	82	52	61	90	
	20°	4	26	66	13	34	79	d/l=1.5
	30°	8	39	68	19	47	80	
	40°	11	37	67	22	45	83	
	50°	17	44	71	30	53	85	
	60°	18	49	72	35	54	84	
	20°	1	14	60	6	25	69	d/l=2
	30°	2	23	63	10	33	74	
	40°	3	20	62	9	31	73	
	50°	5	28	65	15	42	76	
	60°	6	29	64	16	43	77	

Orientation=south-east, WWR=60%, depth=600mm

South-East orientation

600mm

WWR 60% — Solar gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	80	35	44	65	5	19	d/l=1
30°	79	34	42	64	4	16	
40°	78	32	40	63	3	13	
50°	77	31	37	62	2	12	
60°	76	30	36	60	1	11	
20°	85	45	55	70	10	25	d/l=1.5
30°	84	43	52	69	9	24	
40°	83	41	48	68	8	23	
50°	81	38	46	66	6	21	
60°	82	39	47	67	7	22	
20°	90	54	61	75	20	33	d/l=2
30°	89	53	59	74	18	29	
40°	87	50	57	72	15	27	
50°	86	49	56	71	14	26	
60°	88	51	58	73	17	28	

South-East orientation

600mm

WWR 60% — Net Electricity

	SC	SL	SR	DC	DL	DR	
20°	61	20	69	16	1	40	d/l=1
30°	66	25	70	19	2	42	
40°	79	36	77	29	6	47	
50°	88	45	84	37	11	49	
60°	90	51	86	44	14	52	
20°	62	24	74	17	3	50	d/l=1.5
30°	63	22	73	18	4	48	
40°	65	31	80	21	5	53	
50°	72	39	83	26	9	54	
60°	78	43	87	33	13	56	
20°	67	34	81	28	8	58	d/l=2
30°	64	32	75	23	7	55	
40°	68	35	82	27	10	57	
50°	71	41	85	30	12	59	
60°	76	46	89	38	15	60	

South-East orientation

600mm

WWR 60% — Lighting gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	21	39	73	33	44	82	d/l=1
30°	36	49	79	42	52	85	
40°	46	59	84	53	64	88	
50°	57	68	86	61	74	90	
60°	62	76	87	67	78	89	
20°	4	22	56	11	31	71	d/l=1.5
30°	9	24	58	17	35	75	
40°	16	37	65	28	41	80	
50°	26	40	72	34	45	81	
60°	29	43	77	38	50	83	
20°	1	12	47	6	18	60	d/l=2
30°	2	14	48	7	20	63	
40°	3	19	51	10	27	66	
50°	5	23	54	13	30	69	
60°	8	25	55	15	32	70	

South-East orientation

600mm

WWR 60% — Saving

	SC	SL	SR	DC	DL	DR	
20°	28	12	31	9	3	18	d/l=1
30°	23	8	24	6	1	13	
40°	27	10	26	7	2	14	
50°	32	15	30	11	4	16	
60°	36	19	33	17	5	20	
20°	62	49	69	46	37	50	d/l=1.5
30°	54	41	60	38	25	47	
40°	51	39	56	34	21	44	
50°	52	40	57	35	22	45	
60°	59	43	61	42	29	48	
20°	88	78	90	76	65	80	d/l=2
30°	83	71	86	68	58	75	
40°	81	67	84	63	53	72	
50°	82	70	85	66	55	74	
60°	87	77	89	73	64	79	

South-East orientation

600mm

WWR 60% — Cooling plant sensible load (MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	30	47	57	1	20	d/l=1
30°	76	32	46	56	2	16	
40°	78	33	48	61	4	19	
50°	79	36	49	64	8	18	
60°	80	38	50	65	10	17	
20°	85	39	55	70	6	25	d/l=1.5
30°	83	34	51	68	3	22	
40°	81	35	52	66	5	23	
50°	82	37	53	67	7	21	
60°	84	40	54	69	9	24	
20°	90	45	63	75	14	31	d/l=2
30°	88	42	59	73	11	28	
40°	86	41	58	71	12	26	
50°	87	43	60	72	13	27	
60°	89	44	62	74	15	29	

South-East orientation

600mm

WWR 60% — ADI

	SC	SL	SR	DC	DL	DR	
20°	20	45	72	35	53	87	d/l=1
30°	25	49	73	39	55	85	
40°	36	54	80	46	58	88	
50°	37	56	81	47	59	89	
60°	40	57	82	50	60	90	
20°	7	29	66	15	38	79	d/l=1.5
30°	9	27	67	19	42	78	
40°	14	41	68	28	48	83	
50°	17	43	69	30	51	84	
60°	18	44	70	32	52	86	
20°	1	13	61	6	24	71	d/l=2
30°	2	16	62	8	26	74	
40°	3	21	63	10	31	75	
50°	5	23	65	12	34	77	
60°	4	22	64	11	33	76	

South-East orientation

600mm

WWR 60% — PV +

	SC	SL	SR	DC	DL	DR	
20°	5	5	5	5	5	5	d/l=1
30°	2	2	2	2	2	2	
40°	1	1	1	1	1	1	
50°	3	3	3	3	3	3	
60°	4	4	4	4	4	4	
20°	10	10	10	10	10	10	d/l=1.5
30°	9	9	9	9	9	9	
40°	7	7	7	7	7	7	
50°	6	6	6	6	6	6	
60°	8	8	8	8	8	8	
20°	15	15	15	15	15	15	d/l=2
30°	13	13	13	13	13	13	
40°	11	11	11	11	11	11	
50°	12	12	12	12	12	12	
60°	14	14	14	14	14	14	

South-East orientation

600mm

WWR 60% — LESS THAN 300LUX

	SC	SL	SR	DC	DL	DR	
20°	12	44	72	29	51	86	d/l=1
30°	16	45	74	32	53	87	
40°	26	54	80	43	58	88	
50°	34	56	81	47	59	89	
60°	37	57	82	49	60	90	
20°	6	28	66	15	39	78	d/l=1.5
30°	8	22	67	18	41	79	
40°	10	42	68	24	50	83	
50°	17	46	69	33	52	84	
60°	20	48	70	35	55	85	
20°	1	21	62	7	31	71	d/l=2
30°	1	19	61	9	25	73	
40°	3	23	63	10	36	75	
50°	4	27	65	12	38	77	
60°	4	30	64	14	40	76	

South-East orientation

600mm

WWR 60% — Electricity: Meter-(MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	38	82	32	10	51	d/l=1
30°	83	46	84	39	13	54	
40°	86	53	85	47	20	57	
50°	89	56	87	52	24	59	
60°	90	58	88	55	27	60	
20°	63	25	74	15	4	42	d/l=1.5
30°	68	29	75	21	7	45	
40°	72	34	79	30	8	48	
50°	76	37	80	31	9	49	
60°	78	43	81	33	11	50	
20°	61	17	66	12	1	35	d/l=2
30°	62	19	69	14	2	36	
40°	64	23	70	16	3	40	
50°	65	26	71	18	5	41	
60°	67	28	73	22	6	44	

South-East orientation

600mm

WWR 60% — 300-3000 LUX

	SC	SL	SR	DC	DL	DR	
20°	12	44	72	29	51	86	d/l=1
30°	16	45	74	32	53	87	
40°	26	54	80	43	58	88	
50°	34	56	81	47	59	89	
60°	37	57	82	49	60	90	
20°	6	28	66	15	39	78	d/l=1.5
30°	8	22	67	18	41	79	
40°	10	42	68	24	50	83	
50°	17	46	69	33	52	84	
60°	20	48	70	35	55	85	
20°	1	21	62	7	31	71	d/l=2
30°	1	19	61	9	25	73	
40°	3	23	63	10	36	75	
50°	4	27	65	12	38	77	
60°	4	30	64	14	40	76	

Orientation=south-west, WWR=100%, depth=400mm

South-West orientation, 400mm — WWR 100% — Solar gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	80	34	44	65	5	18
	30°	79	32	41	63	4	14
	40°	78	29	38	61	3	13
	50°	77	27	37	57	2	11
	60°	76	26	36	56	1	10
d/l=1.5	20°	85	45	54	70	12	25
	30°	84	43	49	69	9	24
	40°	83	42	48	68	8	23
	50°	82	40	47	67	7	21
	60°	81	39	46	66	6	20
d/l=2	20°	90	55	64	75	22	35
	30°	89	53	62	74	19	33
	40°	88	52	60	73	17	31
	50°	86	50	58	71	15	28
	60°	87	51	59	72	16	30

South-West orientation, 400mm — WWR 100% — Net Electricity

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	62	19	66	16	1	34
	30°	68	27	75	21	4	45
	40°	85	38	83	28	7	50
	50°	89	46	87	40	13	54
	60°	90	56	88	49	15	58
d/l=1.5	20°	61	22	65	17	2	41
	30°	63	24	69	18	3	44
	40°	64	25	71	20	5	48
	50°	67	29	79	23	6	51
	60°	70	36	81	26	8	53
d/l=2	20°	77	39	72	33	10	52
	30°	74	35	76	31	9	55
	40°	73	37	80	30	11	57
	50°	78	43	82	32	12	59
	60°	84	47	86	42	14	60

South-West orientation, 400mm — WWR 100% — Lighting gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	15	33	67	23	42	81
	30°	32	47	79	40	51	85
	40°	52	57	84	49	63	88
	50°	60	64	86	59	74	89
	60°	62	76	87	70	78	90
d/l=1.5	20°	3	16	53	9	27	68
	30°	8	30	61	18	38	77
	40°	11	37	66	25	43	80
	50°	21	41	73	35	45	82
	60°	29	44	75	39	48	83
d/l=2	20°	1	13	46	5	20	58
	30°	4	19	50	10	26	65
	40°	2	22	54	12	31	69
	50°	6	24	55	14	34	71
	60°	7	28	56	17	36	72

South-West orientation, 400mm — WWR 100% — Saving

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	32	11	38	8	3	18
	30°	28	9	29	6	1	14
	40°	35	10	30	7	2	15
	50°	41	13	37	12	4	16
	60°	45	19	44	17	5	20
d/l=1.5	20°	61	49	63	47	25	50
	30°	55	39	58	34	23	48
	40°	51	31	53	26	21	43
	50°	52	33	54	27	22	42
	60°	56	40	57	36	24	46
d/l=2	20°	90	79	89	78	65	80
	30°	85	71	86	70	62	76
	40°	81	68	82	66	59	72
	50°	83	69	84	67	60	73
	60°	87	75	88	74	64	77

South-West orientation, 400mm — WWR 100% — Cooling plant sensible load (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	78	29	46	60	1	16
	30°	77	32	47	58	2	17
	40°	79	33	48	62	3	18
	50°	76	34	49	64	7	19
	60°	80	38	50	65	10	20
d/l=1.5	20°	85	40	55	70	8	25
	30°	84	37	53	69	5	24
	40°	82	35	51	67	4	22
	50°	81	36	52	66	6	21
	60°	83	39	54	68	9	23
d/l=2	20°	90	45	63	75	15	31
	30°	89	43	59	74	13	28
	40°	87	41	56	72	11	26
	50°	86	42	57	71	12	27
	60°	88	44	61	73	14	30

South-West orientation, 400mm — WWR 100% — ADI

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	22	39	72	35	50	85
	30°	31	51	78	42	56	87
	40°	37	54	79	47	59	88
	50°	41	55	81	49	61	89
	60°	44	58	83	53	63	90
d/l=1.5	20°	7	19	66	14	34	77
	30°	11	33	67	21	40	80
	40°	16	38	69	27	46	82
	50°	20	43	70	32	48	84
	60°	25	45	73	36	52	86
d/l=2	20°	1	10	57	4	17	68
	30°	2	15	60	8	26	71
	40°	3	18	62	9	28	74
	50°	5	23	64	12	29	75
	60°	6	24	65	13	30	76

South-West orientation, 400mm — WWR 100% — PV +

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	5	5	5	5	5	5
	30°	3	3	3	3	3	3
	40°	1	1	1	1	1	1
	50°	2	2	2	2	2	2
	60°	4	4	4	4	4	4
d/l=1.5	20°	10	10	10	10	10	10
	30°	9	9	9	9	9	9
	40°	7	7	7	7	7	7
	50°	6	6	6	6	6	6
	60°	8	8	8	8	8	8
d/l=2	20°	15	15	15	15	15	15
	30°	13	13	13	13	13	13
	40°	11	11	11	11	11	11
	50°	12	12	12	12	12	12
	60°	14	14	14	14	14	14

South-West orientation, 400mm — WWR 100% — LESS THAN 300LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	12	34	73	25	50	86
	30°	22	44	77	35	54	87
	40°	38	53	79	41	57	88
	50°	47	55	81	48	59	89
	60°	45	58	83	51	61	90
d/l=1.5	20°	4	19	66	10	36	78
	30°	9	31	67	18	42	80
	40°	14	39	68	24	49	82
	50°	17	43	70	29	52	84
	60°	20	46	72	33	56	85
d/l=2	20°	1	15	60	7	26	69
	30°	2	21	62	8	30	71
	40°	3	23	63	10	32	74
	50°	5	26	65	12	37	76
	60°	6	28	64	16	39	75

South-West orientation, 400mm — WWR 100% — Electricity: Meter-(MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	77	36	81	31	9	50
	30°	83	46	84	41	12	54
	40°	86	52	85	47	13	57
	50°	89	55	87	53	17	59
	60°	90	58	88	56	24	60
d/l=1.5	20°	63	21	70	14	3	38
	30°	68	29	75	20	7	45
	40°	74	34	79	27	8	48
	50°	76	39	80	32	10	49
	60°	78	44	82	35	11	51
d/l=2	20°	62	18	61	15	1	33
	30°	64	23	65	16	2	37
	40°	66	26	69	19	4	40
	50°	67	28	72	22	5	42
	60°	71	30	73	25	6	43

South-West orientation, 400mm — WWR 100% — 300-3000 LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	12	34	73	25	50	86
	30°	22	44	77	35	54	87
	40°	38	53	79	41	57	88
	50°	47	55	81	48	59	89
	60°	45	58	83	51	61	90
d/l=1.5	20°	4	19	66	10	36	78
	30°	9	31	67	18	42	80
	40°	14	39	68	24	49	82
	50°	17	43	70	29	52	84
	60°	20	46	72	33	56	85
d/l=2	20°	1	15	60	7	26	69
	30°	2	21	62	8	30	71
	40°	3	23	63	10	32	74
	50°	5	26	65	12	37	76
	60°	6	28	64	16	39	75

Orientation=south-west, WWR=100%, depth=600mm

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Solar gain (MWh)
WWR 100%	20°	80	34	43	65	5	17		
	30°	79	32	41	62	4	14		
	40°	78	28	38	59	3	12	d/l=1	
	50°	77	27	37	57	2	11		
	60°	76	26	36	56	1	10		
	20°	85	45	54	70	13	25		
	30°	84	44	50	69	9	24		
	40°	83	42	48	68	8	23	d/l=1.5	
	50°	82	40	47	67	7	21		
	60°	81	39	46	66	6	20		
	20°	90	55	64	75	22	35		
	30°	89	53	63	74	19	33		
	40°	88	52	61	73	18	31	d/l=2	
	50°	86	49	58	71	15	29		
	60°	87	51	60	72	16	30		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Net Electricty
WWR 100%	20°	61	21	66	16	1	40		
	30°	65	25	75	19	4	45		
	40°	79	37	82	26	8	50	d/l=1	
	50°	88	47	86	41	13	55		
	60°	90	56	89	48	15	59		
	20°	62	23	67	18	2	43		
	30°	63	24	69	17	3	46		
	40°	64	27	76	20	5	49	d/l=1.5	
	50°	68	34	81	22	6	53		
	60°	77	42	85	30	12	58		
	20°	74	36	72	32	10	52		
	30°	70	33	73	29	7	51		
	40°	71	35	78	28	9	54	d/l=2	
	50°	83	39	80	31	11	57		
	60°	87	44	84	38	14	60		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Lighting gain (MWh)
WWR 100%	20°	12	39	70	26	43	82		
	30°	29	47	79	41	52	85		
	40°	45	58	84	50	62	88	d/l=1	
	50°	54	65	86	60	73	89		
	60°	75	76	87	67	78	90		
	20°	3	19	55	9	31	72		
	30°	5	30	59	15	37	77		
	40°	10	36	64	23	42	80	d/l=1.5	
	50°	17	40	71	33	46	81		
	60°	27	44	74	38	48	83		
	20°	2	13	49	6	22	61		
	30°	1	16	51	7	25	63		
	40°	4	20	53	8	32	66	d/l=2	
	50°	18	24	56	11	34	68		
	60°	21	28	57	14	35	69		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Saving
WWR 100%	20°	26	11	33	7	3	17		
	30°	25	9	27	6	1	13		
	40°	28	10	30	8	2	14	d/l=1	
	50°	35	15	34	12	4	16		
	60°	45	19	40	18	5	20		
	20°	67	49	71	46	29	50		
	30°	57	41	61	37	23	47		
	40°	54	36	56	31	21	43	d/l=1.5	
	50°	55	38	58	32	22	44		
	60°	60	42	63	39	24	48		
	20°	90	78	89	77	62	80		
	30°	84	70	85	68	53	74		
	40°	81	65	82	64	51	72	d/l=2	
	50°	86	69	83	66	52	73		
	60°	88	76	87	75	59	79		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Cooling plant sensible load (MWh)
WWR 100%	20°	78	30	47	60	1	18		
	30°	76	31	46	58	2	16		
	40°	77	33	48	61	3	17	d/l=1	
	50°	79	34	49	64	7	19		
	60°	80	37	50	65	10	20		
	20°	85	40	55	70	9	25		
	30°	84	38	53	69	5	24		
	40°	82	35	51	67	4	22	d/l=1.5	
	50°	81	36	52	66	6	21		
	60°	83	39	54	68	8	23		
	20°	90	45	63	75	15	32		
	30°	88	43	59	74	13	28		
	40°	86	41	56	72	11	27	d/l=2	
	50°	87	42	57	71	12	26		
	60°	89	44	62	73	14	29		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	ADI
WWR 100%	20°	24	44	72	36	49	85		
	30°	32	52	78	42	55	87		
	40°	37	54	80	47	59	88	d/l=1	
	50°	40	57	81	51	61	89		
	60°	45	58	83	53	65	90		
	20°	7	26	66	14	34	77		
	30°	13	33	67	20	39	79		
	40°	16	38	69	27	45	82	d/l=1.5	
	50°	19	41	70	31	48	84		
	60°	23	43	73	35	50	86		
	20°	1	10	56	4	17	68		
	30°	2	15	60	8	25	71		
	40°	3	18	62	9	28	74	d/l=2	
	50°	6	21	63	11	29	75		
	60°	5	22	64	12	30	76		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	PV +
WWR 100%	20°	5	5	5	5	5	5		
	30°	2	2	2	2	2	2		
	40°	1	1	1	1	1	1	d/l=1	
	50°	3	3	3	3	3	3		
	60°	4	4	4	4	4	4		
	20°	10	10	10	10	10	10		
	30°	9	9	9	9	9	9		
	40°	7	7	7	7	7	7	d/l=1.5	
	50°	6	6	6	6	6	6		
	60°	8	8	8	8	8	8		
	20°	15	15	15	15	15	15		
	30°	13	13	13	13	13	13		
	40°	11	11	11	11	11	11	d/l=2	
	50°	12	12	12	12	12	12		
	60°	14	14	14	14	14	14		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	LESS THAN 300LUX
WWR 100%	20°	12	41	73	26	50	86		
	30°	22	46	77	36	55	87		
	40°	29	53	79	44	57	88	d/l=1	
	50°	37	56	81	49	59	89		
	60°	48	58	83	52	61	90		
	20°	3	23	66	9	34	78		
	30°	7	32	67	18	42	80		
	40°	10	39	68	24	47	82	d/l=1.5	
	50°	15	43	70	30	51	84		
	60°	16	45	71	33	54	85		
	20°	1	12	60	5	24	69		
	30°	2	17	62	6	31	72		
	40°	3	21	63	8	34	74	d/l=2	
	50°	19	27	65	11	38	76		
	60°	20	28	64	14	40	75		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	Electricity: Meter-(MWh)
WWR 100%	20°	77	38	82	31	9	51		
	30°	83	46	84	40	12	54		
	40°	85	52	86	47	13	57	d/l=1	
	50°	88	56	87	53	17	59		
	60°	90	58	89	55	24	60		
	20°	64	23	69	14	3	41		
	30°	67	29	75	20	7	45		
	40°	72	34	79	27	8	48	d/l=1.5	
	50°	76	37	80	32	10	49		
	60°	78	44	81	35	11	50		
	20°	62	19	61	15	1	33		
	30°	63	22	66	16	2	36		
	40°	65	26	68	18	4	39	d/l=2	
	50°	73	28	70	21	5	42		
	60°	74	30	71	25	6	43		

South-West orientation

600mm

WWR	Angle	SC	SL	SR	DC	DL	DR	d/l	300-3000 LUX
WWR 100%	20°	12	41	73	26	50	86		
	30°	22	46	77	36	55	87		
	40°	29	53	79	44	57	88	d/l=1	
	50°	37	56	81	49	59	89		
	60°	48	58	83	52	61	90		
	20°	3	23	66	9	34	78		
	30°	7	32	67	18	42	80		
	40°	10	39	68	24	47	82	d/l=1.5	
	50°	15	43	70	30	51	84		
	60°	16	45	71	33	54	85		
	20°	1	12	60	5	24	69		
	30°	1	17	62	6	31	72		
	40°	3	21	63	8	34	74	d/l=2	
	50°	19	27	65	11	38	76		
	60°	20	28	64	14	40	75		

Orientation=south-west, WWR=80%, depth=400mm

South-West orientation, 400mm — WWR 80% — Solar gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	80	35	44	65	5	18	d/l=1
30°	79	33	41	63	4	14	
40°	78	31	38	62	3	13	
50°	77	28	37	60	2	12	
60°	76	27	36	58	1	11	
20°	85	45	54	70	10	25	d/l=1.5
30°	84	43	49	69	9	24	
40°	83	42	48	68	8	23	
50°	82	40	47	67	7	22	
60°	81	39	46	66	6	21	
20°	90	55	64	75	20	34	d/l=2
30°	89	53	61	74	19	32	
40°	87	51	57	72	16	29	
50°	86	50	56	71	15	26	
60°	88	52	59	73	17	30	

South-West orientation, 400mm — WWR 80% — Net Electricity

	SC	SL	SR	DC	DL	DR	
20°	62	21	66	16	1	38	d/l=1
30°	68	29	76	20	4	44	
40°	81	39	83	30	7	50	
50°	89	47	86	41	13	52	
60°	90	53	88	48	15	54	
20°	61	22	65	17	2	43	d/l=1.5
30°	63	24	71	18	3	46	
40°	64	25	75	19	5	49	
50°	67	33	78	23	6	51	
60°	74	40	85	26	11	55	
20°	72	35	77	31	8	56	d/l=2
30°	69	34	79	27	9	57	
40°	70	36	82	28	10	58	
50°	73	42	84	32	12	59	
60°	80	45	87	37	14	60	

South-West orientation, 400mm — WWR 80% — Lighting gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	15	38	68	28	43	81	d/l=1
30°	35	49	79	42	55	86	
40°	47	59	84	51	64	88	
50°	57	70	85	61	74	89	
60°	62	76	87	72	78	90	
20°	3	20	53	10	27	67	d/l=1.5
30°	8	30	60	19	36	77	
40°	14	37	65	26	41	80	
50°	22	40	73	34	46	82	
60°	31	44	75	39	48	83	
20°	1	12	45	5	18	58	d/l=2
30°	2	17	50	9	24	63	
40°	4	21	52	11	29	66	
50°	6	23	54	13	32	69	
60°	7	25	56	16	33	71	

South-West orientation, 400mm — WWR 80% — Saving

	SC	SL	SR	DC	DL	DR	
20°	32	12	37	8	3	18	d/l=1
30°	25	9	29	6	1	14	
40°	30	10	31	7	2	13	
50°	38	15	33	11	4	16	
60°	45	19	40	17	5	20	
20°	60	49	62	47	27	50	d/l=1.5
30°	55	41	58	35	23	48	
40°	51	34	54	26	21	44	
50°	52	36	53	28	22	43	
60°	56	42	57	39	24	46	
20°	89	79	90	77	67	80	d/l=2
30°	85	71	86	70	63	76	
40°	81	68	83	65	59	72	
50°	82	69	84	66	61	74	
60°	87	75	88	73	64	78	

South-West orientation, 400mm — WWR 80% — Cooling plant sensible load (MWh)

	SC	SL	SR	DC	DL	DR	
20°	76	31	46	59	1	16	d/l=1
30°	77	32	47	60	2	17	
40°	78	33	48	63	6	18	
50°	79	36	49	64	8	19	
60°	80	40	50	65	10	20	
20°	85	38	55	70	5	25	d/l=1.5
30°	84	35	53	68	3	23	
40°	81	34	51	66	4	21	
50°	82	37	52	67	7	22	
60°	83	39	54	69	9	24	
20°	90	44	61	75	14	29	d/l=2
30°	88	43	58	73	12	28	
40°	86	41	56	71	11	26	
50°	87	42	57	72	13	27	
60°	89	45	62	74	15	30	

South-West orientation, 400mm — WWR 80% — ADI

	SC	SL	SR	DC	DL	DR	
20°	24	45	71	35	53	86	d/l=1
30°	29	50	77	40	55	87	
40°	37	54	79	46	59	88	
50°	39	56	81	48	60	89	
60°	41	57	82	51	62	90	
20°	7	26	66	14	36	78	d/l=1.5
30°	12	33	67	22	42	80	
40°	15	38	68	27	47	83	
50°	17	43	70	32	49	84	
60°	23	44	72	34	52	85	
20°	1	13	58	6	19	69	d/l=2
30°	2	16	61	8	25	73	
40°	3	18	63	9	28	74	
50°	5	20	64	10	30	75	
60°	4	21	65	11	31	76	

South-West orientation, 400mm — WWR 80% — PV +

	SC	SL	SR	DC	DL	DR	
20°	5	5	5	5	5	5	d/l=1
30°	3	3	3	3	3	3	
40°	1	1	1	1	1	1	
50°	2	2	2	2	2	2	
60°	4	4	4	4	4	4	
20°	10	10	10	10	10	10	d/l=1.5
30°	9	9	9	9	9	9	
40°	7	7	7	7	7	7	
50°	6	6	6	6	6	6	
60°	8	8	8	8	8	8	
20°	15	15	15	15	15	15	d/l=2
30°	13	13	13	13	13	13	
40°	11	11	11	11	11	11	
50°	12	12	12	12	12	12	
60°	14	14	14	14	14	14	

South-West orientation, 400mm — WWR 80% — LESS THAN 300LUX

	SC	SL	SR	DC	DL	DR	
20°	15	41	73	27	50	86	d/l=1
30°	21	46	77	36	55	87	
40°	29	53	79	43	57	88	
50°	35	56	81	48	59	89	
60°	42	58	82	51	60	90	
20°	4	25	66	13	37	78	d/l=1.5
30°	8	32	67	19	44	80	
40°	11	40	68	23	49	83	
50°	17	45	70	30	52	84	
60°	18	47	71	33	54	85	
20°	1	16	61	6	26	69	d/l=2
30°	2	20	62	8	31	72	
40°	3	22	63	10	34	74	
50°	4	24	65	12	38	76	
60°	6	28	64	14	39	74	

South-West orientation, 400mm — WWR 80% — Electricity: Meter-(MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	37	81	31	9	50	d/l=1
30°	83	46	84	42	12	54	
40°	85	52	86	48	16	57	
50°	89	56	87	53	23	58	
60°	90	59	88	55	27	60	
20°	63	24	71	14	3	40	d/l=1.5
30°	69	30	75	20	7	45	
40°	74	34	79	28	8	47	
50°	76	39	80	32	10	49	
60°	78	44	82	35	11	51	
20°	61	18	64	13	1	33	d/l=2
30°	62	21	68	15	2	36	
40°	65	25	70	17	4	38	
50°	66	26	72	19	5	41	
60°	67	29	73	22	6	43	

South-West orientation, 400mm — WWR 80% — 300-3000 LUX

	SC	SL	SR	DC	DL	DR	
20°	15	41	73	27	50	86	d/l=1
30°	21	46	77	36	55	87	
40°	29	53	79	43	57	88	
50°	35	56	81	48	59	89	
60°	42	58	82	51	60	90	
20°	4	25	66	13	37	78	d/l=1.5
30°	8	32	67	19	44	80	
40°	11	40	68	23	49	83	
50°	17	45	70	30	52	84	
60°	18	47	71	33	54	85	
20°	1	16	61	6	26	69	d/l=2
30°	2	20	62	8	31	72	
40°	3	22	63	10	34	74	
50°	4	24	65	12	38	76	
60°	6	28	64	14	39	74	

Orientation=south-west, WWR=80%, depth=600mm

South-West orientation, 600mm — WWR 80% — Solar gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	80	35	44	65	5	18
		30°	79	33	41	63	4	14
		40°	78	31	38	62	3	13
		50°	77	30	37	60	2	12
		60°	76	27	36	59	1	11
	d/l=1.5	20°	85	45	54	70	10	25
		30°	84	43	51	69	9	24
		40°	83	42	48	68	8	23
		50°	82	40	47	67	7	22
		60°	81	39	46	66	6	21
	d/l=2	20°	90	55	64	75	20	34
		30°	89	53	61	74	19	32
		40°	87	50	57	72	16	28
		50°	86	49	56	71	15	26
		60°	88	52	58	73	17	29

South-West orientation, 600mm — WWR 80% — Net Electricity

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	61	21	66	16	1	41
		30°	65	27	74	19	3	43
		40°	81	38	82	28	7	49
		50°	89	46	87	40	13	51
		60°	90	53	88	47	15	56
	d/l=1.5	20°	62	22	69	17	2	45
		30°	63	24	73	18	4	48
		40°	64	30	77	20	5	50
		50°	70	36	83	23	10	52
		60°	78	42	85	32	12	58
	d/l=2	20°	71	34	75	29	8	55
		30°	67	33	76	25	6	54
		40°	68	35	79	26	9	57
		50°	72	39	84	31	11	59
		60°	80	44	86	37	14	60

South-West orientation, 600mm — WWR 80% — Lighting gain (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	16	39	73	31	43	82
		30°	35	49	79	42	53	86
		40°	46	58	84	51	63	88
		50°	57	68	85	61	75	89
		60°	62	76	87	70	78	90
	d/l=1.5	20°	3	20	56	10	30	71
		30°	8	29	59	18	36	77
		40°	14	37	65	25	41	80
		50°	22	40	72	34	45	81
		60°	28	44	74	38	48	83
	d/l=2	20°	1	13	47	6	21	60
		30°	2	17	50	9	24	64
		40°	4	19	52	11	27	66
		50°	5	23	54	12	32	67
		60°	7	26	55	15	33	69

South-West orientation, 600mm — WWR 80% — Saving

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	26	11	30	7	3	17
		30°	25	9	27	6	1	13
		40°	28	10	29	8	2	14
		50°	34	15	31	12	4	16
		60°	41	19	38	18	5	20
	d/l=1.5	20°	65	49	70	46	32	50
		30°	56	42	60	37	23	47
		40°	53	36	57	33	21	44
		50°	55	39	58	35	22	45
		60°	59	43	62	40	24	48
	d/l=2	20°	89	78	90	76	63	80
		30°	84	71	86	68	54	75
		40°	81	66	83	64	51	72
		50°	82	69	85	67	52	73
		60°	87	77	88	74	61	79

South-West orientation, 600mm — WWR 80% — Cooling plant sensible load (MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	77	31	46	59	1	18
		30°	76	32	47	60	2	16
		40°	78	33	48	63	5	17
		50°	79	36	49	64	8	19
		60°	80	38	50	65	10	20
	d/l=1.5	20°	85	40	55	70	6	25
		30°	84	35	53	68	3	23
		40°	81	34	51	66	4	21
		50°	82	37	52	67	7	22
		60°	83	39	54	69	9	24
	d/l=2	20°	90	45	62	75	15	30
		30°	88	43	58	73	13	28
		40°	87	41	56	71	11	26
		50°	86	42	57	72	12	27
		60°	89	44	61	74	14	29

South-West orientation, 600mm — WWR 80% — ADI

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	24	45	72	35	52	86
		30°	29	51	77	41	55	87
		40°	37	54	79	46	59	88
		50°	39	56	81	49	60	89
		60°	43	57	82	53	62	90
	d/l=1.5	20°	7	25	66	14	36	78
		30°	10	33	67	21	40	80
		40°	15	38	68	27	47	83
		50°	17	42	70	30	48	84
		60°	20	44	71	34	50	85
	d/l=2	20°	1	13	58	6	18	69
		30°	2	16	61	8	26	73
		40°	3	19	63	9	28	74
		50°	5	23	65	12	32	75
		60°	4	22	64	11	31	76

South-West orientation, 600mm — WWR 80% — PV +

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	5	5	5	5	5	5
		30°	2	2	2	2	2	2
		40°	1	1	1	1	1	1
		50°	3	3	3	3	3	3
		60°	4	4	4	4	4	4
	d/l=1.5	20°	10	10	10	10	10	10
		30°	9	9	9	9	9	9
		40°	7	7	7	7	7	7
		50°	6	6	6	6	6	6
		60°	8	8	8	8	8	8
	d/l=2	20°	15	15	15	15	15	15
		30°	13	13	13	13	13	13
		40°	11	11	11	11	11	11
		50°	12	12	12	12	12	12
		60°	14	14	14	14	14	14

South-West orientation, 600mm — WWR 80% — LESS THAN 300LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	15	41	72	27	50	86
		30°	21	48	77	35	55	87
		40°	30	53	79	43	58	88
		50°	36	56	81	47	59	89
		60°	42	57	83	51	60	89
	d/l=1.5	20°	4	23	66	11	37	78
		30°	8	32	67	18	44	80
		40°	11	40	68	24	49	82
		50°	17	45	70	29	52	84
		60°	19	46	71	33	54	85
	d/l=2	20°	1	15	61	7	25	69
		30°	2	20	62	9	31	73
		40°	3	22	63	10	34	74
		50°	6	26	65	13	38	76
		60°	5	28	64	14	39	75

South-West orientation, 600mm — WWR 80% — Electricity: Meter-(MWh)

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	77	37	82	31	9	51
		30°	83	46	84	40	12	54
		40°	85	52	86	47	16	57
		50°	89	56	87	53	22	58
		60°	90	59	88	55	28	60
	d/l=1.5	20°	63	24	72	15	3	41
		30°	67	30	75	20	7	45
		40°	73	33	79	26	8	48
		50°	76	38	80	32	10	49
		60°	78	44	81	34	11	50
	d/l=2	20°	61	18	65	13	1	35
		30°	62	21	68	14	2	36
		40°	64	25	70	17	4	39
		50°	66	27	71	19	5	42
		60°	69	29	74	23	6	43

South-West orientation, 600mm — WWR 80% — 300-3000 LUX

WWR	d/l	Angle	SC	SL	SR	DC	DL	DR
WWR 80%	d/l=1	20°	15	41	72	27	50	86
		30°	21	48	77	35	55	87
		40°	30	53	79	43	58	88
		50°	36	56	81	47	59	89
		60°	42	57	83	51	60	89
	d/l=1.5	20°	4	23	66	11	37	78
		30°	8	32	67	18	44	80
		40°	11	40	68	24	49	82
		50°	17	45	70	29	52	84
		60°	19	46	71	33	54	85
	d/l=2	20°	1	15	61	7	25	69
		30°	2	20	62	9	31	73
		40°	3	22	63	10	34	74
		50°	6	26	65	13	38	76
		60°	5	28	64	14	39	75

Orientation=south-west, WWR=60%, depth=400mm

South-West orientation — 400mm — WWR 60% — Solar gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	81	36	45	66	6	20	
30°	80	35	43	65	5	18	
40°	79	33	41	64	4	15	d/l=1
50°	78	32	40	62	3	13	
60°	77	31	39	61	1	12	
20°	86	46	55	71	11	26	
30°	85	44	53	70	10	25	
40°	84	42	49	69	9	24	d/l=1.5
50°	83	38	48	68	8	23	
60°	82	37	47	67	7	22	
20°	91	56	63	76	21	34	
30°	90	54	60	75	19	30	
40°	89	52	59	74	17	29	d/l=2
50°	87	50	57	72	14	27	
60°	88	51	58	73	16	28	

South-West orientation — 400mm — WWR 60% — Net Electricity

	SC	SL	SR	DC	DL	DR	
20°	63	22	66	17	1	38	
30°	67	26	72	20	4	43	
40°	79	35	78	27	7	48	d/l=1
50°	89	46	81	36	12	49	
60°	91	54	86	45	15	52	
20°	62	23	68	18	3	47	
30°	64	25	73	19	5	50	
40°	65	30	75	21	6	53	d/l=1.5
50°	69	34	80	24	8	55	
60°	76	40	84	31	10	56	
20°	70	37	82	28	9	57	
30°	71	39	85	29	11	58	
40°	74	41	87	32	13	59	d/l=2
50°	77	44	88	33	14	60	
60°	83	51	90	42	16	61	

South-West orientation — 400mm — WWR 60% — Lighting gain (MWh)

	SC	SL	SR	DC	DL	DR	
20°	19	40	71	30	44	82	
30°	36	51	80	43	57	88	
40°	48	60	84	54	65	89	d/l=1
50°	58	70	86	63	75	91	
60°	62	76	87	68	78	90	
20°	4	20	53	11	27	69	
30°	10	33	61	21	37	79	
40°	18	38	66	29	42	81	d/l=1.5
50°	26	41	74	35	47	83	
60°	31	45	77	39	49	85	
20°	1	12	46	5	17	59	
30°	3	16	50	9	24	64	
40°	6	22	52	13	28	67	d/l=2
50°	7	23	55	14	32	72	
60°	8	25	56	15	34	73	

South-West orientation — 400mm — WWR 60% — Saving

	SC	SL	SR	DC	DL	DR	
20°	30	13	35	10	4	21	
30°	26	9	28	7	1	15	
40°	29	11	27	8	3	14	d/l=1
50°	34	16	31	12	5	17	
60°	42	20	37	18	6	19	
20°	60	50	62	48	36	51	
30°	56	43	59	40	25	49	
40°	52	38	55	32	22	46	d/l=1.5
50°	53	39	54	33	23	45	
60°	57	44	58	41	24	47	
20°	90	79	91	78	69	81	
30°	85	72	87	71	64	77	
40°	82	68	84	66	61	74	d/l=2
50°	83	70	86	67	63	75	
60°	88	76	89	73	65	80	

South-West orientation — 400mm — WWR 60% — Cooling plant sensible load (MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	32	47	60	1	17	
30°	78	33	48	63	3	18	
40°	79	34	49	64	7	21	d/l=1
50°	80	39	50	65	10	20	
60°	81	41	51	67	11	19	
20°	86	37	55	71	4	26	
30°	84	35	54	69	5	24	
40°	82	36	52	66	6	22	d/l=1.5
50°	83	38	53	68	8	23	
60°	85	40	56	70	9	25	
20°	91	45	62	76	15	31	
30°	89	44	59	74	13	29	
40°	87	42	57	72	12	27	d/l=2
50°	88	43	58	73	14	28	
60°	90	46	61	75	16	30	

South-West orientation — 400mm — WWR 60% — ADI

	SC	SL	SR	DC	DL	DR	
20°	19	46	72	33	53	86	
30°	27	50	74	41	56	87	
40°	31	54	78	44	58	88	d/l=1
50°	37	55	80	47	59	89	
60°	39	57	81	49	60	90	
20°	7	26	66	14	38	79	
30°	9	36	67	20	43	82	
40°	15	40	68	25	48	83	d/l=1.5
50°	17	42	69	29	51	84	
60°	18	45	71	32	52	85	
20°	1	13	61	6	22	70	
30°	2	16	62	8	28	73	
40°	3	21	63	10	30	75	d/l=2
50°	4	23	64	11	34	76	
60°	5	24	65	12	35	77	

South-West orientation — 400mm — WWR 60% — PV +

	SC	SL	SR	DC	DL	DR	
20°	5	5	5	5	5	5	
30°	3	3	3	3	3	3	
40°	1	1	1	1	1	1	d/l=1
50°	2	2	2	2	2	2	
60°	4	4	4	4	4	4	
20°	10	10	10	10	10	10	
30°	9	9	9	9	9	9	
40°	7	7	7	7	7	7	d/l=1.5
50°	6	6	6	6	6	6	
60°	8	8	8	8	8	8	
20°	15	15	15	15	15	15	
30°	13	13	13	13	13	13	
40°	11	11	11	11	11	11	d/l=2
50°	12	12	12	12	12	12	
60°	14	14	14	14	14	14	

South-West orientation — 400mm — WWR 60% — LESS THAN 300LUX

	SC	SL	SR	DC	DL	DR	
20°	12	42	72	24	51	86	
30°	19	48	77	34	55	87	
40°	25	53	79	43	58	88	d/l=1
50°	31	56	80	46	59	90	
60°	36	57	81	49	60	89	
20°	4	26	66	13	38	78	
30°	7	35	67	20	45	82	
40°	11	41	68	23	50	83	d/l=1.5
50°	16	44	69	30	52	84	
60°	18	47	71	33	54	85	
20°	1	17	61	8	28	70	
30°	2	21	62	9	32	73	
40°	3	22	63	10	37	74	d/l=2
50°	5	27	65	14	39	76	
60°	6	29	64	15	40	75	

South-West orientation — 400mm — WWR 60% — Electricity: Meter-(MWh)

	SC	SL	SR	DC	DL	DR	
20°	77	38	82	32	10	50	
30°	84	47	85	42	14	55	
40°	87	54	86	48	19	58	d/l=1
50°	90	57	88	53	24	59	
60°	91	61	89	56	27	60	
20°	64	25	72	16	4	41	
30°	69	31	76	22	8	46	
40°	75	36	80	29	9	49	d/l=1.5
50°	78	39	81	33	11	51	
60°	79	44	83	35	12	52	
20°	62	17	66	13	1	34	
30°	63	21	70	15	3	37	
40°	65	26	71	18	5	40	d/l=2
50°	67	28	73	20	6	43	
60°	68	30	74	23	7	45	

South-West orientation — 400mm — WWR 60% — 300-3000 LUX

	SC	SL	SR	DC	DL	DR	
20°	12	42	72	24	51	86	
30°	19	48	77	34	55	87	
40°	25	53	79	43	58	88	d/l=1
50°	31	56	80	46	59	90	
60°	36	57	81	49	60	89	
20°	4	26	66	13	38	78	
30°	7	35	67	20	45	82	
40°	11	41	68	23	50	83	d/l=1.5
50°	16	44	69	30	52	84	
60°	18	47	71	33	54	85	
20°	1	17	61	8	28	70	
30°	2	21	62	9	32	73	
40°	3	22	63	10	37	74	d/l=2
50°	5	27	65	14	39	76	
60°	6	29	64	15	40	75	

Orientation=south-west, WWR=60%, depth=600mm

South-West orientation — 600mm — WWR 60% — Solar gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	80	35	44	65	5	19
	30°	79	34	42	64	4	17
	40°	78	33	40	63	3	13
	50°	77	31	39	62	2	12
	60°	76	30	36	61	1	11
d/l=1.5	20°	85	45	55	70	10	25
	30°	84	43	52	69	9	24
	40°	83	41	48	68	8	23
	50°	81	37	46	66	7	22
	60°	82	38	47	67	6	21
d/l=2	20°	90	54	60	75	20	32
	30°	89	53	59	74	18	29
	40°	87	50	57	72	15	27
	50°	86	49	56	71	14	26
	60°	88	51	58	73	16	28

South-West orientation — 600mm — WWR 60% — Net Electricity

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	61	20	66	16	1	40
	30°	65	28	70	19	2	42
	40°	76	35	75	29	6	47
	50°	88	44	83	38	11	48
	60°	90	50	85	45	15	51
d/l=1.5	20°	62	23	73	17	3	49
	30°	63	22	74	18	4	52
	40°	64	31	77	21	5	53
	50°	71	39	84	26	9	54
	60°	79	43	87	32	13	56
d/l=2	20°	68	34	81	27	8	58
	30°	67	33	80	24	7	55
	40°	69	36	82	25	10	57
	50°	72	41	86	30	12	59
	60°	78	46	89	37	14	60

South-West orientation — 600mm — WWR 60% — Lighting gain (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	20	39	73	33	44	82
	30°	35	49	79	42	56	87
	40°	46	58	83	52	63	88
	50°	55	68	85	60	74	89
	60°	62	75	86	67	77	90
d/l=1.5	20°	4	21	57	11	30	72
	30°	9	26	59	17	37	78
	40°	16	36	65	28	41	80
	50°	25	40	71	34	45	81
	60°	29	43	76	38	48	84
d/l=2	20°	1	12	47	5	18	61
	30°	2	15	50	8	24	64
	40°	3	19	51	10	27	66
	50°	6	22	53	13	31	69
	60°	7	23	54	14	32	70

South-West orientation — 600mm — WWR 60% — Saving

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	28	12	31	8	3	18
	30°	23	9	24	6	1	14
	40°	26	10	25	7	2	13
	50°	32	15	30	11	4	16
	60°	37	19	33	17	5	20
d/l=1.5	20°	64	49	69	46	36	50
	30°	55	42	60	39	27	48
	40°	51	38	56	34	21	44
	50°	53	40	57	35	22	45
	60°	59	43	61	41	29	47
d/l=2	20°	88	78	90	75	65	80
	30°	84	71	86	68	58	76
	40°	81	67	83	63	52	72
	50°	82	70	85	66	54	74
	60°	87	77	89	73	62	79

South-West orientation — 600mm — WWR 60% — Cooling plant sensible load (MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	76	31	47	59	1	20
	30°	77	32	46	62	2	16
	40°	78	34	48	63	6	18
	50°	79	37	49	64	9	19
	60°	80	40	50	66	10	17
d/l=1.5	20°	85	38	55	70	5	25
	30°	83	33	53	68	3	23
	40°	81	35	51	65	4	21
	50°	82	36	52	67	7	22
	60°	84	39	54	69	8	24
d/l=2	20°	90	44	61	75	14	30
	30°	88	42	58	73	12	28
	40°	86	41	56	71	11	26
	50°	87	43	57	72	13	27
	60°	89	45	60	74	15	29

South-West orientation — 600mm — WWR 60% — ADI

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	19	45	71	35	53	86
	30°	27	51	74	41	56	87
	40°	34	54	78	46	58	88
	50°	37	55	80	47	59	89
	60°	39	57	81	49	60	90
d/l=1.5	20°	7	26	66	14	38	79
	30°	10	29	67	21	43	82
	40°	15	40	68	25	48	83
	50°	16	42	69	30	50	84
	60°	18	44	70	31	52	85
d/l=2	20°	1	13	61	6	24	72
	30°	2	17	62	8	28	73
	40°	3	20	63	9	32	75
	50°	5	23	65	12	36	77
	60°	4	22	64	11	33	76

South-West orientation — 600mm — WWR 60% — PV +

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	5	5	5	5	5	5
	30°	2	2	2	2	2	2
	40°	1	1	1	1	1	1
	50°	3	3	3	3	3	3
	60°	4	4	4	4	4	4
d/l=1.5	20°	10	10	10	10	10	10
	30°	9	9	9	9	9	9
	40°	7	7	7	7	7	7
	50°	6	6	6	6	6	6
	60°	8	8	8	8	8	8
d/l=2	20°	15	15	15	15	15	15
	30°	13	13	13	13	13	13
	40°	11	11	11	11	11	11
	50°	12	12	12	12	12	12
	60°	14	14	14	14	14	14

South-West orientation — 600mm — WWR 60% — LESS THAN 300LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	14	42	72	27	51	86
	30°	21	48	77	35	56	87
	40°	24	53	79	43	58	88
	50°	33	55	81	47	59	90
	60°	37	57	82	49	60	89
d/l=1.5	20°	5	26	66	12	40	78
	30°	8	29	67	19	45	80
	40°	11	41	68	23	50	83
	50°	16	44	69	31	52	85
	60°	18	46	70	32	54	84
d/l=2	20°	1	17	61	7	30	71
	30°	2	20	62	9	34	73
	40°	3	22	64	10	36	74
	50°	4	25	65	13	39	76
	60°	5	28	63	15	38	75

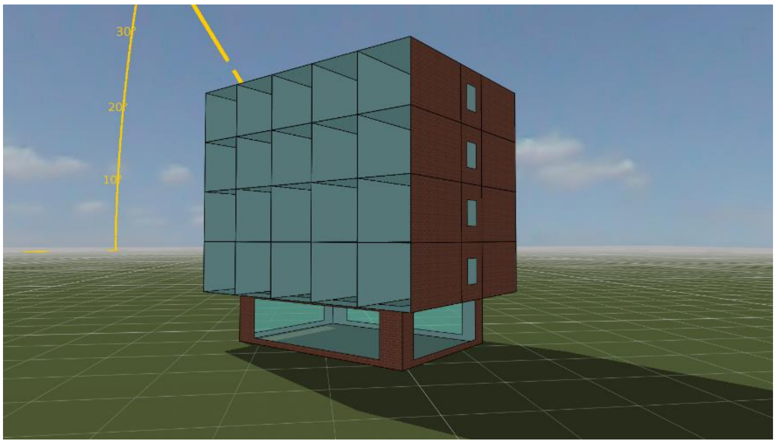
South-West orientation — 600mm — WWR 60% — Electricity: Meter-(MWh)

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	77	38	82	31	10	51
	30°	83	46	84	40	13	55
	40°	86	53	85	47	18	57
	50°	89	56	87	52	23	59
	60°	90	58	88	54	26	60
d/l=1.5	20°	63	25	73	15	4	44
	30°	68	30	75	22	7	45
	40°	74	34	79	29	8	48
	50°	76	37	80	32	9	49
	60°	78	42	81	33	11	50
d/l=2	20°	61	17	66	12	1	35
	30°	62	21	69	14	2	36
	40°	64	24	70	16	3	39
	50°	65	27	71	19	5	41
	60°	67	28	72	20	6	43

South-West orientation — 600mm — WWR 60% — 300-3000 LUX

d/l	Angle	SC	SL	SR	DC	DL	DR
d/l=1	20°	14	42	72	27	51	86
	30°	21	48	77	35	56	87
	40°	24	53	79	43	58	88
	50°	33	55	81	47	59	90
	60°	37	57	82	49	60	89
d/l=1.5	20°	5	26	66	12	40	78
	30°	8	29	67	19	45	80
	40°	11	41	68	23	50	83
	50°	16	44	69	31	52	85
	60°	18	46	70	32	54	84
d/l=2	20°	1	17	61	7	30	71
	30°	2	20	62	9	34	73
	40°	3	22	64	10	36	74
	50°	4	25	65	13	39	76
	60°	5	28	63	15	38	75

Appendix 12: Base-case scenario results for all orientations



BASE CASE RESULTS-ENERGY ASSESSEMENT INDICATORS												
No.	Orientation	WWR	Depth	d/l	Angle	Glazing	Glass	Solar gain (MWh)	Lighting gain (MWh)	Cooling plant sensible load (MWh)	PV-meter-(MWh)	Electricity: Meter-(MWh)
1	180	100-	N/A	N/A	N/A	S-	C	285.3984	27.0627	204.3789	N/A	195.6702
2	135	100-	N/A	N/A	N/A	S-	C	291.5512	26.3074	213.0406	N/A	201.0475
3	225	100-	N/A	N/A	N/A	S-	C	290.7478	26.2738	206.8546	N/A	199.9967

BASE CASE RESULTS-DAYLIGHTING ASSESSEMENT INDICATORS											
No.	Orientation	WWR	Depth	d/l	Angle	Glazing	Glass	ADI (Klix)	UDI less than 300 lux	UDI 300-3000 lux	UDI more than 3000 lux
1	180	100-	N/A	N/A	N/A	S-	C	4013.847	0.79%	98.08%	1.13%
2	135	100-	N/A	N/A	N/A	S-	C	3921.114	0.92%	95.96%	3.12%
3	225	100-	N/A	N/A	N/A	S-	C	3907.052	0.72%	95.31%	3.97%

Appendix 13: Sensitivity analysis results of 'Predictor Importance' of all input/output variables

This tool facilitates visualising all the input variables and their percentages of influence on each of the output variable for cross comparison purposes.