ENERGY OPTIMISATION IN RESIDENTIAL APARTMENTS THROUGH THE PASSIVE DESIGN STRATEGIES BY EVALUATING THE LOCAL CONSTRUCTION MATERIALS AND DESIGNS IN SEMI-ARID CLIMATE CONDITION OF TEHRAN

School of the Built Environment

University of Salford

Majid Hashemi Fesharaki

Supervised by:

Dr Yingchun Ji

PhD Thesis 2018

Acknowledgement

I like to express my gratitude to my supervisor Dr. Yingchun Ji without whom this research would not be completed, he always motivated and supported me generously towards completion of this project by his precious guidance and advices. I would also thank Dr. Tara Hughes for her all help for proof reading.

I also would like to extend my appreciation towards my beloved parents who supported me in all aspect of my life especially during my PhD studies, and without them I could achieve the completion of this study.

Last but not least I like to appreciate my friends in heart, Parviz Karimian and Siyavash Amirebrahimi for their valuable supports to encourage me to complete this project.

Abstract

Low energy building design methods, and the corresponding environmental constraints, are widely explored in many developed countries. Tehran characterized by its semi-arid climates and geographical location in a global region is renowned for its high energy consumption and carbon emission rates. This research aims to evaluate the energy performances of low energy housing in multi residential buildings in Tehran and provide design guidance in improving their energy and thermal performances using passive design measures. The research considers the building envelope as the back bone of its energy optimisation. It takes into account the local climatic conditions context and local construction practices as well as the most often used construction materials. In order to fulfil the above stated aim, this research uses annual KWh/m2 as a design selection metric to evaluate various design considerations in Tehran.

A comprehensive, three phase studies have been carried out for the research in order to achieve following objectives: (a) identify building construction factors resulting in high energy consumption in domestic buildings in Tehran; (b) assess the local efficient design and materials contributing to reduction of energy consumption in Tehran (c) evaluate passive domestic design with regards to free running buildings where is applicable (d) propose guidance on better energy performance residential buildings in Tehran through passive design principles.

The finding of this research proves that a systematically selection of various designs and materials within the local practices and market, coupled with considerations of local standard thermal comfort requirements, up to 70% of energy savings can be achieved in Tehran without imposing much change against the cost and design to the existing practices.

Table of Contents

List of Tables

List of Figures

Chapter 1 – Introduction

1. Introduction

Over recent decades the energy performance of buildings has been identified as an important factor in the high levels of global fossil fuel consumption. Buildings have a considerable role in the amount of harmful emissions released into the atmosphere, with responsibility for 70% of sulphur oxides and over 50% of CO_2 (Ghiaus, 2004). In addition, the construction sector is responsible for around 40% of the world’s energy consumption, and significant use of the natural resources of fresh water and forest timbers (16% and 25% respectively) (Ghiaus, 2004). To address these harmful impacts on the environment, human health and most importantly the next generation, there have been attempts to introduce climate responsive designs to developed countries. The purpose of these designs is to create a comfortable indoor temperature while at the same time taking advantage of natural energy sources. This design concept requires an interaction between the building’s specific environment and the effective dynamic factors in the building (Hyde, 2000).

There is considerable evidence that greenhouse gas emissions results in global climate change. Therefore, there is an urgent emphasis on implementing environmental measures in the built environment to avoid dangerous results for following generations (Taleb and Sharples, 2011). Singh et al., (2009) argue that the construction sector can play a significant role to avoid the negative impact of the high levels of fossil fuel use. There are key factors that the construction sector can tackle to successfully achieve a responsive, well-designed building, such as technology, appropriate materials and socio-cultural aspects. Previously, vernacular designs provided comfort to the occupants as much as possible by applying environmentally conscious architectural design strategies (Engin et al., 2007) and these types of designs can inspire new environmental strategies. According to Tzikopoulos et al., (2005) building energy optimisation can potentially decrease CO_2 emissions by 60% worldwide. Consequently, climate responsive buildings are essential for all countries with different climates to save energy and reduce further carbon dioxide emissions (Tzikopoulos et al., 2005). In global context, to reduce the CO2 emissions, the Paris Agreement has been created as an agreement within the United Nations Framework Convention on Climate Change (UNFCCC) dealing with greenhouse gas emissions mitigation, adaptation, and finance starting in the year 2020. The Paris agreement will come into effect in 2020, empowering all countries to act to prevent average global temperatures rising above 2 degrees Celsius and to reap the many opportunities that arise from a necessary global transformation to clean and sustainable development (United nation climate change, 2018). Iran has already signed the agreement and submitted its plan ahead of time.

This chapter presents a general review of significance of strategies to decrease the level of energy consumption in residential buildings, and the methods that developed countries have applied to achieve energy reduction in the future.

Furthermore, this chapter presents the Iranian construction sector and the relevant energy consumption in residential buildings. By assessing the construction sector and energy consumption in Iran, the research question for this study can be formulated along with the aim and objectives. In addition, the outline of the research and challenges encountered, and its contribution to the body of knowledge is briefly presented.

1.1 Global Issues: Residential Buildings Energy Consumption

There are several important factors that influence the energy consumption of the built environment across different regions or countries, such as climate conditions, the energy policies the building is in, and the socio-cultural practices of the people using the building. Applying the energy efficiency methods of one specific region doesn’t guarantee that the same level of energy optimisation can be achieved in another region due to the different culture, climate, type of materials and economic and political conditions. Energy conservation is dealt with in many developed countries in a particular manner for residential buildings, while non-domestic buildings are addressed in general. Based on the climate, building user needs, culture and policies, developed countries have established national codes, strategies or definitions to determine the acceptable level of energy consumption. This amount of energy consumption normally is measured by kWh/m^2a and is classified as low or very low buildings.

Energy efficient buildings are commonly described as ‘eco-houses’ or ‘green buildings’, and the main design intention for low energy building is to reduce the negative impacts of buildings on environment. By reducing the energy consumption of a building, the operating costs are reduced significantly. By 2009 over 20,000 low energy buildings were built in Europe, these low energy buildings are supposed to be better performing than the ordinary buildings (EU, 2009). The prominent characteristics of these types of buildings are high performance insulation, efficient mechanical heating and cooling systems, and appropriate glazing selection. In some cases, these buildings use renewable energy technologies to provide hot water or to meet part of heating requirements (EU, 2009). An EU survey in 2009 showed that around 17 different terms of building energy efficiency had been introduced to address the energy consumption of residential buildings (EU, 2009).

Seven European countries have adopted low energy house building codes. Most of these codes are applicable to new buildings, however they can be applied to existing buildings and are normally expected to reduce energy consumption by 30% - 60%, and this can be assumed to reduce the required energy to between 40 and 60kWh/m^{2}a in Europe (EU, 2009).

It is very difficult to define a unified low energy strategy for all the regions and countries, which is why in Europe every country has its own low energy strategies that have different levels of energy reduction targets (EU, 2009). For instance, in Germany and Austria the target for low energy building is between 40 and 60kWh/m^{2}a annually, this level differs in France as the annual level of energy consumption for low energy building has to be less than 50kWh/m^{2}a. There are also a few countries like Estonia and the UK that have ambitious targets to achieve Zero energy buildings. In fact, every country and region needs to have a carefully considered low energy building strategy that meets the specification of that region (EU, 2009).

1.2 Building energy consumption issues in the context of Iran (Tehran)

Iran has 22,830,003 dwelling units (Iran census, 2016), and consumes 50.9 Mtoe of final energy in the residential sectors during the operational phase (IEA, 2015). This figure accounts for 29% of the total final energy consumption in the country. According to the International Energy Agency (IEA) as of 2015, Iran's residential energy consumption including CO_2 emission, ranks 8th in the world, while Iran's population ranks 17th.

Figure 1.1 shows how final energy consumption in the residential sector is distributed, where natural gas accounts for 78% and electricity and oil products by 13%, respectively (IEA 2015). Iran is the world second largest oil reservoir country and gas as the main source of energy is widely accessible in low prices throughout the country.

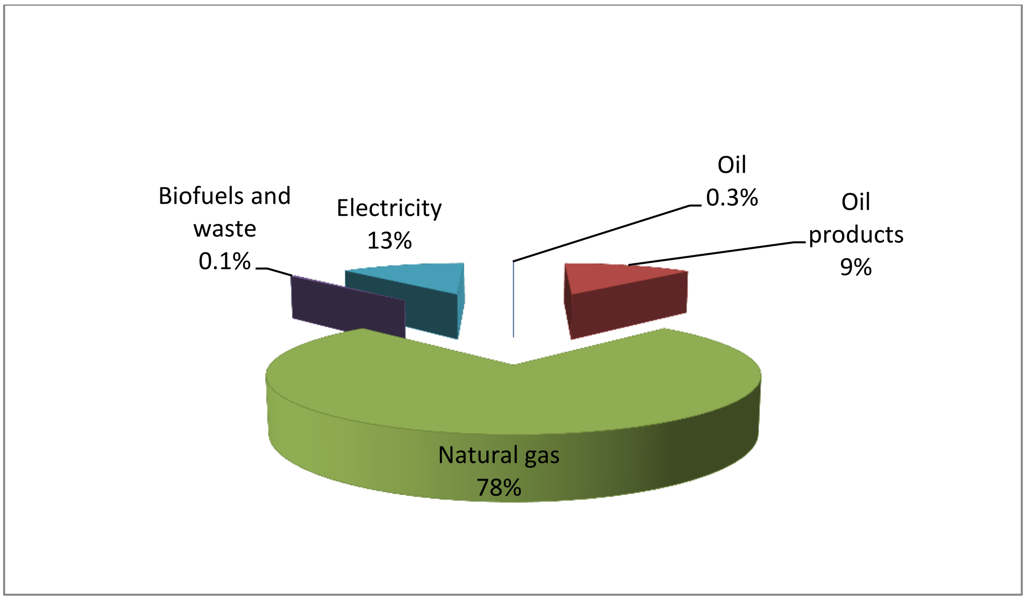


Figure 1.1 -Final Energy Consumption in Residential Sector in Iran, Source: IEA (2015)

According to the Iranian Energy Efficiency Organization (IEEO), a significant amount of the final energy consumed is for heating and cooling in residential buildings, i.e. 76% of total natural gas (for heating) and 30% of electricity (for cooling and heating) (IEEO, 2013).

As a result, many Iranian and international sources raise awareness that energy consumption in Iran are far higher than the world average. 'Trend News' (2014) reported that, according to the IEEO, the energy consumption rate in Iran in all spheres is greater than the global average. The report points out that, Iran's energy consumption per capita for agriculture, housing, industry and transport sectors are 3.3, 1.9, 1.5 and 1.5 times more than global averages, respectively. In Europe, the average energy consumption of the residential sector stands for 200kWh/m^{2}a (Lapillonne, Pollier & Samci 2014)' while the residential sector in Iran consumes, on average 339.2kWh/m^{2}a approximately (Figure 1.2). This figure has been calculated by applying the data of Figure 1.2: Iranian residential sector consumes 50.9Mtoe (million tons of oil equivalent) final energy (IEA, 2015); Tehran province accounts for 39,981,009m^2 residential floor area (Iranian national housing census, 2015).

Annual figures for energy consumption in Iran

Total Residential energy consumption: 50.9 Mtoe = **591,967,000,000 kWh**

Total residential floor area in Iran: 1,745,206,683 m^2 (Iran national census, 2016)

Average final electricity consumption for residential sector in Iran: 35.7kWh/m^{2}a (IEA, 2015). Primary energy: 132.1kWh/m^{2}a

Average final gas consumption for residential sector in Iran: 271.7kWh/m^{2}a (IEA, 2015). Primary energy: 271kWh/m^{2}a

Average oil product consumption: 30.4 kWh/ m^{2}a (IEA, 2015)

Average bio fossil energy consumption: 2.0 kWh/ m^{2}a (IEA, 2015)

Average energy consumption for residential sector in Iran:

576,848,000,000kWh/1,749,393,783m^2 = **339.2 kWh/ m^{2}a or 466.7 kWh/ m^{2}a (primary energy)**

Figure 1.2 – Average Energy Consumption in Residential Buildings in Iran

Iran's general energy consumption pattern has been inefficient for the last few years and contributes towards the excessive consumption of fossil fuels which results in high levels of emissions of pollutants and greenhouse gases (Farahmandpour et al., 2008). The low price of energy and high subsidies represent an effective incentive for the continued energy inefficient consumption pattern and accelerates energy consumption and environmental pollutions (Farahmandpour et al., 2008).

In Iran, as mentioned above, the low price of energy and heavy energy subsidies are the main reasons for high energy consumption in buildings during the operational phase. On the other hand, another parameter includes the development of the building design in the design phase.

It is unknown how energy efficiency is considered in the architectural design process in the country. Although there is a building energy efficiency code 'chapter 19' which addresses a limited number of building envelope elements and their material properties e.g. insulation and U-values, the building codes suffer substantial lack of holistic energy efficiency strategies in terms of passive design for cooling and heating purposes (Further details are given in chapter 5). Specifically, some prominent passive design strategies need to be accounted broader within the codes such as solar gains and control, ventilation, and shadings (Iranian Ministry of Housing & Transport, 2017)

Tehran has a semi-arid climate with hot summers and cold winters, therefore considering passive design methods can potentially contribute to prevent heat loss (thermal loss) by implementing proper insulation, but also reduces the required heat or cold load by providing heating and cooling from the natural environment or other strategies. Various energy statistics around the world verify that energy consumption in Iran is far higher than the world average. It is not known how the construction practices (e.g materials selection and design) and other factors (e.g. economical and socio-cultural), contribute to the high energy consumption in the country.

Therefore, at policy level, there has been lack of guidance for the domestic housing industry to explore passive design. Consequently, passive design of residential buildings in Iran has not been fully explored.

The published books, journals and research on passive house design have been limited to vernacular architecture, translation, emphasizing the importance of energy efficiency and partial passive design analysis. In some cases, to be explained in the following sections, the analyses have been conducted in a way far from the reality of the built or the future construction in Tehran.

Furthermore, an innovative and comprehensive passive design needs to be conducted to address energy reduction in Tehran compatible with the local climate condition, architecture and materials.

1.3 Aims, Objectives and Research Questions

1.3.1 Aims

The aim of this research is to evaluate the energy performances of low energy housing in multi residential buildings in Tehran and provide design guidance in improving their energy and thermal performances using passive design measures.

This aim of this research achieves by assessing building envelope parameters to improve energy efficiency in multi residential buildings in Tehran. This includes; examine how; (a) appropriate selection of local construction fabric and designs, and (b) appropriate selection of human adaptive thermal comfort temperature can potentially achieve a parallel reduction in heating and cooling energy consumption from the current average level of energy consumption towards a greater level. This research looks for “intermediate” or “optimised” solutions, which result in a lower energy demand and adequate comfort throughout the year.

1.3.2 Objectives

1) To determine the average baseline rate of energy consumption of multi residential buildings in Tehran, with reference to the base case and actual utility bills.
2) To identify the influence of the individual local building’s element and designs on the heating and cooling energy performance in residential buildings in Tehran by using a dynamic thermal simulation tool.
3) To evaluate passive domestic design with regards to free running buildings where applicable.
4) To assess the potential optimised cases against the existing low energy building methods in developed countries and the Iranian residential energy label rating.
5) To propose guidance on better energy performance design in residential buildings in Tehran through passive design principles.

1.3.3 Research Questions

1. What is the approximate base line energy consumption for new multi residential buildings in Tehran?
2. How much would the energy efficiency be improved by considering different types of individual local building elements in Tehran?
3. How much energy efficiency will potentially be achieved by implementing the local current practices as a mixed method of ‘passive and active design’ in Tehran?
4. By analysing the local construction practices and available local passive design elements in Tehran, which current practices will improve energy efficiency in Tehran?
5. What level of the Iranian building energy label and other international definition in developed countries can be achieved by the optimised cases in this research?

1.4 Contribution to knowledge

The contribution to the body of knowledge from this research includes; a) to determine the influence of local construction practices (i.e. architectural design and materials) on the amount of energy consumption in typical residential buildings in Tehran, b) proposing energy efficient residential buildings by employing the appropriate combination of local designs and fabric, c) proposing an optimised energy efficient building design in Tehran by considering further energy efficiency solutions (i.e. thermal insulation and solar gain control), and d) assessing the potential level of energy optimisation in comparison with other energy efficiency methods in developed countries.

1.4.1 Identifying the influence of individual local building parameters on energy consumption and thermal comfort performance in typical homes in Tehran

This research will examine the average energy consumption in typical multi residential buildings in Tehran. This value will be considered the baseline energy consumption for Tehran apartment blocks based on the Iranian building code for new built dwellings. As a result, to conduct further analysis and research into improving energy efficiency, this baseline data will be compared with the researcher's findings. In addition, by understanding this benchmark of energy consumption, other researchers will be able to address this benchmark for further studies into energy efficiency in Tehran.

This research will calculate, through simulation tools, the energy consumption in buildings with respect to their construction elements. This calculation will identify the role of each specific building element in regard to its impact on energy consumption. The typical building parameters are classified as the architectural design (form) and construction materials (building envelope). In addition to the role of each parameter to energy performance, the passive performance of these parameters is also considered to determine their overall role in achieving thermal comfort. Therefore, to make a holistic design towards improving the energy efficiency of buildings, this data will help to create an integrated design.

Proposing energy efficient residential building design through an appropriate combination of a) the most energy efficient building parameters and b) passive performance parameters

Following the previous objectives, when the baseline of energy consumption and the impacts on energy from each of the local building elements and passive performance of parameters are identified, then an integrated passive design solution will be proposed. This integrated passive design involves creating a mixed running building from two cases that are created from a) the combination of the best energy efficient building parameters, and b) the combination of the best thermal comfort achieving parameters according to the human adaptive thermal comfort.

The combination of these two cases creates a mixed running building that performs in free running mode (monthly plan) where applicable, and in the other months in conditioning mode. However, it is a challenging process to mix both modes, and there is no guarantee that the mixed building will improve the energy performance in the building. Therefore, the result of this analysis is very important for designers, to identify passive building designs that are appropriately compatible with active designs.

Proposing further optimised energy efficient residential building design through an appropriate combination of the most energy efficient parameters and passive performance by applying thermal insulation and solar gain controls

By applying the local suggested insulation methods, new wall types are created to evaluate the effect of thermal insulation on optimising the previous optimised case in part (C) of contribution to knowledge. In addition, for solar gain purposes different shading types are suggested. The performance of these two strategies (thermal insulation and shadings) is examined in two different contexts; a) energy efficiency, and b) thermal comfort. The best performance parameters of each strategy will create the best active and passive design. Due to the average Tehran temperature records, it is unlikely to achieve a totally free running building throughout the year. A mixed method mode of running buildings will be suggested by examining and comparing the level of energy consumption in each case. The lowest energy consuming case will be selected as the ultimate optimised case for this study.

The result of this analysis will demonstrate a low energy building design that is unable to provide appropriate amounts of thermal comfort without the use of a heating and cooling system throughout the year. However, by carefully analysing the building parameters, it suggests an integrated building design that acts passively when applicable, and contributes to a reduction of unnecessary heating and cooling energy consumption. Achieving this design is crucial while using the best of local material capability, design acceptability and market affordability, it is considered a less ambitious passive design building which still has capabilities to reduce further energy consumption.

Generally, building energy simulation plays a fundamental role in this process since the buildings’ future response to applied passive design strategies is highly sensitive to the local climate factors. However, due to the usually extremely large size of the building design space, it is close to impossible to reach a high level of performance with the trial-and-error approach alone (Stevanović, 2013). Thus, it becomes necessary to use an optimization method coupled with the energy simulations in order to choose the optimal combination of passive solar design strategies for the given location. The efficiency will be determined by calculating the lowest energy consumption base on kWh/m^{2}a. This research will analyse a number of building elements to identify what type of building elements and designs in different typologies could improve energy efficiency. Therefore, in the future, designers can take advantage of this research to enhance the energy performance of buildings by selecting the most appropriate building materials and design.

Assessing the level of achieved optimisation in residential buildings in Tehran against low energy building codes and standards in developed countries, and the Iranian energy rating scheme

After determining the optimised cases, the level of their energy consumption in the context of residential buildings is compared with other low energy building strategies or standards in developed countries. This comparison gives the opportunity to designers, developers and policy makers to measure the level of energy consumption and the consequent harmful effect of greenhouse gas (e.g. CO_2 emissions) in global context.

Domestically the result of optimised cases can be evaluated according to the Iranian energy label that is explained in Chapter Five. The result provides a comprehensive overview of the building energy efficiency position in local context. Therefore, the level of efficiency can be determined from the base case level to optimised case.

1.5 Thesis Layout

Chapter One**:** Introduction

This chapter presents the current issues of the selected subject in the world-wide and regional (Iran) context, and also reviews the background of the subject. In addition, it explains the steps that have been taken by developed countries to address this problem. In the next section of this chapter the main aim, research questions and objectives of this study is presented. The final section of this chapter explains how this chapter would potentially contribute to the body of knowledge, and what the limitations and challenges of this study are.

Chapter Two: Literature Review (1)

This chapter carefully reviews the latest conducted studies and research that contribute to the lowering of energy consumption in buildings. This comprises a range from national and international standards to specific building's elements and designs. Moreover, it is attempted to present the most recent investigations in similar regions as the base-case study to project a better overview towards the purpose of this research.

Chapter Three: Literature Review (2)

This chapter presents a review of the human adaptive standards and conducted investigations around the world to determine the comfort temperature in residential buildings around the world. The next stage of this chapter explains the general principles of building physics, and demonstrates how the material properties play roles in determining the thermal mass and heat transfer in building fabric.

Chapter Four: Research Methodology

This chapter outlines the research design and describes how the research approaches the objectives and the aim step-by-step. There are three different phases of research that is carried out to address the objectives of this research. In addition, sensitivity analysis is applied to identify the most influential building parameter in reducing energy consumption.

Chapter Five: Research Location Profile

This chapter clearly presents the country and specific region of research based on the current construction practices, weather profile, energy regulations and policies and existing building codes. This chapter helps to have a clear view of an appropriate design by considering the required parameters for an energy efficient design. This also helps to determine some appropriate set points of the simulation software tools.

Chapter Six: Research Analysis, Discussions and Results.

This is a very comprehensive chapter, that shows that by employing simulation software all the required parameters of buildings are simulated. The resulting data in the form of graphs and diagrams are presented and discussed and there are several step by step approaches that form an optimised case. The optimised case itself is analysed further to make improvements and each building element and their energy efficiency performance is determined and the potential amount of energy saving is presented.

Chapter Seven: Guideline Design for Energy Efficient Buildings in Tehran

In this chapter, firstly, guidelines for energy saving procedures in Tehran are outlined, and secondly, the achieved results in the previous chapter are compared against the developed countries strategies for low energy buildings. The results indicate the position and reliability of the optimised cases in Tehran in comparison with the developed countries. The research also describes the level of energy efficiency, as a result of the optimised cases, when they are rated by the Iranian energy label requirements.

Chapter Eight: Research Conclusion

This chapter presents how the research questions are approached and answered in this study. This chapter also explains the potential for further research in this area as well as a set of recommendations regarding the energy efficiency implementation in the residential sector in Tehran.

Chapter 2 – Literature Review (1)

2.1 Introduction

According to numerous reports, the building construction and maintenance sectors are responsible for 40% of global energy consumption (Zhou et al., 2014). Furthermore, the building sector is responsible for the consumption of 16% of fresh water and 25% of forest's timbers (Ghiaus, 2004). Buildings are also a great generator of CO_2 emissions in the world by 33% (Beradi et al., 2014). In order to tackle such a huge damage to the environment and the wellbeing of future generations, many sustainable building strategies have been introduced.

Climate responsive design is a widespread attempt to protect the environment by considering enhanced construction methods that consume less energy and consequently emit less CO_2. The main strategies for climate responsive buildings are to utilise the renewable sources of energy in buildings.

Hyde 2013 emphasises that there should be ideal interactions between the dynamic conditions that impact each individual building. Nowadays, in responce to the need of energy efficient buildings, various strategies and methods have been introduced and practiced worldwide (Beradi et al., 2014).

Designing energy efficient buildings is an increasing demand in most of the world. It is important to identify where the knowledge of climate responsive buildings are less well known and the lack of knowledge in crucial aspects of energy efficiency exists.

To achieve this objective, this chapter comprehensively investigates and presents the most recent literature into the tried and tested theories, techniques and strategies relevant to building energy efficiency in general principles, and those more specific to semi-arid climate conditions.

There are two main important area of building energy efficiency to be considered in this chapter. Firstly, architectural design strategies that include building geometry, typology and shading strategies. Secondly, this chapter studies the role of building elements (fabric) in energy optimisation and free running building achievements in semi-arid climate conditions and similar conditions.

By taking into consideration the main aim of this study, this research will present the latest relevant studies that have been carried out to investigate the relevant subjects. The selected studies provide a broad background for energy optimisation. Accordingly, all the background review falls into three categories; a) this part covers sustainable building and low energy buildings, b) the role of architectural design in semi-arid climate and dry conditions, c) the building envelop fabric in semi-arid climate condition.

2.2 Sustainable and Low Design Buildings

Passive design refers to a series of strategies for architectural design, applied by architects when designing buildings, to respond adequately to climate conditions and requirements (Kroner, 1997).

Kroner (1997) argues that passive design is associated with various methods and standards for architectural design, employed with engineers and architects at the design stage, to make the building environmentally sustainable and responsive. The term of building passive design can't be separated from intelligent building design. Intelligent design precedents can be found in well-made passive and low-energy buildings.

"Intelligent buildings" are those that combine both active and passive intelligence, active features and passive design strategies, to provide maximum occupant comfort by using minimum energy (Kroner, 1997). The term "intelligence in buildings" creates excitement among architects and developers as the ultimate design solution, a building that knows how to adapt to every situation, liberating the designer from the duty of finding passive solutions to design problems, and implying that conflict resolution is delegated from the designer to the end product itself. Since an intelligent building uses the least energy possible to survive, prospects for sustainable climatic design in *any* climate seem high (Ochoa and Capeluto 2008). Their research concludes that a building parameter can't individually be selected for the purpose of optimisation, but there should be tool available for designers to evaluate the combination of parameters.

In Europe and many other developed countries, achieving a low energy building is an important governmental aim. In Europe the definition of low energy building has been studied and introduced in four criteria; Building envelope, Energy, Ventilation and follow-up (Britain). However, various researchers have proved that even the term low energy building varies country by country in Europe (Britain, 2011). Furthermore, Britain (2011) concludes that the definition and specifications vary greatly, both between the countries and between different building types within a country. For instance, in many standards the building is exclusively defined by its energy performance. Germany, Austria and Switzerland are those countries with the most definitions considering additional criteria.

2.3 Climate Related Architectural Design

The worldwide energy crisis in the 1970s raised the awareness of the negative impact of high building energy consumption. Consequently, many energy strategies, new energy concepts and energy assessments have been implemented to reduce the energy consumption in buildings and its harmful effects on the environment. (Blaxter et al., 2010).

Energy consumption in the building sector can vary significantly from country to country depending on several indicators ranging from climate, population, income, economic development and household sizes.

According to United Nations Environmental Programme (UNEP) report by Huovila et al., (2007), different methods are available in improving the energy efficiency in buildings; they range from lower to higher technological approaches. Huovila et al., (2007) suggests that the current approaches that can be employed to optimise energy efficiency in buildings, include; low-and zero energy buildings, passive housing design, energy plus buildings, Eco Cities, refurbishment aspects and commissioning processes.

2.3.1 Low-Energy Buildings

Based on a Definition by Huovila et al., (2007) low-energy building can be specified as an approach of reducing energy consumption by 50%. This indicates the amount of energy these buildings use in comparison with the standard building constructed in accordance with the current building regulations. In other words, the 50% concept building consumes only one half of the heating energy of a standard building. The low energy consumption is based on an increased level of thermal insulation (Huovila et al., 2007).

Research conducted by Wojdyga (2009) in Poland shows that the low-energy building, under the specific consideration of low energy building, can be expected to have lower heat demand than the Polish ordinary building. Therefore, this will result in achieving a low-energy building using three times less energy (30.6kWh/m^{2}a) than a building designed in accordance with the Polish standards (95.9 kWh/m^{2}a).

2.3.2 Zero-Energy Buildings

Zero-energy buildings are characterised as the buildings that consume as much energy as they can produce annually. This approach requires state of the art energy systems, such as solar collectors and wind power. In other words, Zero-energy buildings are equipped by on-site renewable energy sources that generate energy equal to the amount of energy consumed in the buildings (Huovila et al., 2007).

However, this method requires a complicated design and professional implementation that results in the most challenging solutions to active sustainable buildings. (Huovila et al., 2007).

2.3.3 Passive House

Passive house buildings are specified as buildings with satisfactory thermal comfort with very low energy consumption. Passive House doesn’t have specific construction methods, instead it recommends a set of performance standards. In addition, designers can select their own architectural design and building materials to meet the specific energy demand targets. The following items are distinctive character of Passive House (Klingenberg, 2013):

1. High levels of insulation
2. Well-insulated window frames and glazing
3. Thermal bridge free design and construction
4. An airtight building envelope
5. Ventilation with highly efficient heat or energy recovery

According to Müller and Berker (2013) A great advantage of The Passive House Standard is its easy compatibility in different regions with different climate conditions as the general approach is the same at all locations. The components of each building construction will differ to another building depending on which climate it is located in. For instance, in warmer regions more concentration should be paid to passive cooling methods, including, shading elements and natural ventilation through the openings. Based on the local conditions, any methods towards Passive House design need to be modified to achieve the required optimisation.

2.3.4 Energy-Plus Buildings and General Passive Design Strategies

Technologies for passive building have been presented and are being commercialised across the world. Furthermore, numerous pilot projects are carried out to apply energy-plus buildings strategies, that means buildings produces more energy than they consume over a year (Huovila et al., 2007).

Among all the strategies proposed to enhance the performance of buildings, the implementation of passive design is proposed as a solution to diminish the need for external sources of energy by designing buildings that are resilient to climate.

Although the common understanding is that passive design does not necessarily have to result in an increase of the construction costs, indeed, one of the key approaches to low energy design is to invest in the building's morphology and selection of the appropriate materials (e.g., windows, walls) so that heating, cooling, and lighting loads are reduced, and in turn, smaller and less costly heating, ventilation, and air conditioning systems are needed (Dwivedi et al., 2012).

Architectural design and material selection play a key role in the energy efficiency of residential units. Bennetts, Radford et al. (2003) concludes that architectural designs applying energy efficiency strategies reduce energy consumption of 40-70%. Architectural designs mainly focus on achieving energy efficiency without the intervention of mechanical equipment (Su, 2008). In effect, the concept of passive design is a relevant methodology to design an environmentally responsive building. Many architectural experts emphasise that the passive design is the best primary approach towards building energy efficiency, Kibert (2012) states that;

> "*Due to the complexity of designing the energy systems for a high-performance green building, the starting point must be full consideration of passive design*".

According to Gong et al. (2012) the passive design strategies are linked to a high amount of energy saving in buildings as well as being cost effective. Gong et al. (2012) has calculated that the average saving of a passive design building is up to 50% of the total primary energy.

However, as the implementation of the passive design is linked to the design phase of the building project, its main strategies, and the impact of those in the building physics and the energy consumption, need to be well known in advance. The general concept of passive design is described as:

> “*an architectural design to provide building’s heating, cooling, lighting, and ventilation systems, relying on sunlight, wind, vegetation, and other naturally occur resources on the building site”* (Thomas, 2003).

In other words, according to Rodriguez-Ubinas et al. (2014) passive design strategies contribute to improve the interior comfort conditions, increasing the energy efficiency in buildings and reducing their energy consumption. Therefore, it is important that the building consumes less energy while maintaining the thermal comfort. The thermal comfort varies from one region to the other depending on specific factors (climate, HVAC systems, time, etc) and active occupant participation (Bessoudo et al., 2010).

Certainly, for the passive design to achieve the energy optimisation goals, the first step towards a sustainable approach counts on adopting the passive strategies by understanding the local climate, local construction practices and operation of building by users (Figure 2.1) (Etzion et al., 1997)

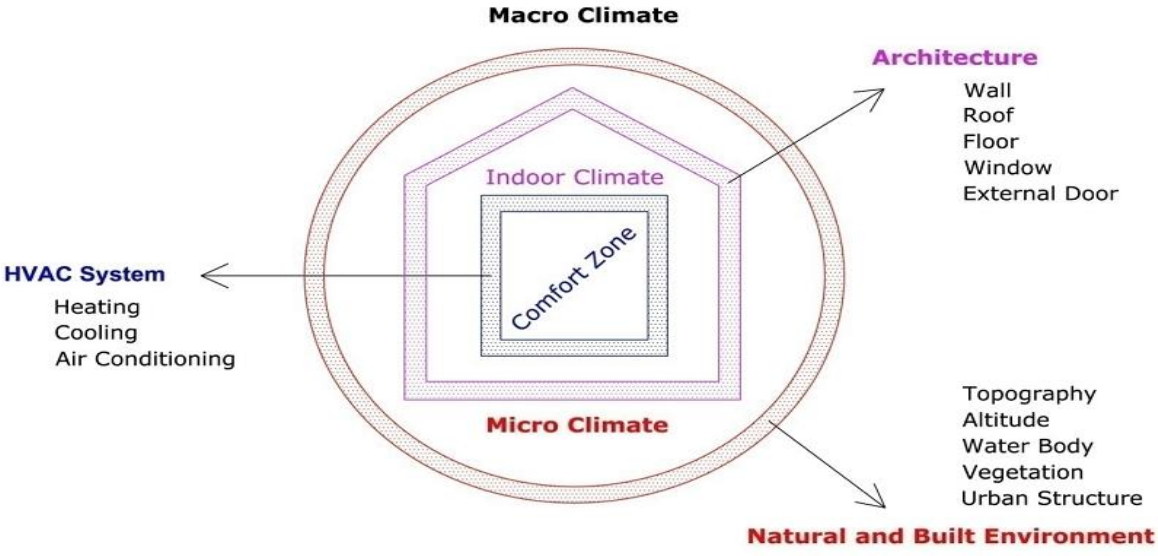


Figure 2.1 – Climate in Relation to Architecture (Nasrolahi, 2009)

Passive design in general is classified as; a) passive heating for a cold climate to minimize heat load in buildings, and b) passive cooling for warm climates to minimise cold load (Bainbridge and Haggard, 2011). For this purpose, according to Chan et al. (2010) building form and fabric need to be designed in a way that in warmer climate or seasons the heating systems provide or collect and store the solar heat, so will be able to maintain the heat inside the building. In comparison, in order to protect the building from solar gains and achieve a cooler space, cooling systems are used. These strategies of utilising the solar behaviour are known as ‘solar passive design’ (Bainbridge and Haggard, 2011). Chan et al. (2010) conducted research in India based on the proper design of orientation, structure, envelope and construction materials of a building, The research concluded that by controlling the thermal loads from the solar heat gain, solar passive designs and double glazing are able to reduce the total heat loss by about 35%.The passive design, including the solar design as discussed by Aldossary (2015), can be classified over the following categories (Figure 2.2):

- Building envelope (construction materials or fabric). This refers to walls, windows, slabs, thermal mass and etc.
- Architectural layout design (form). This refers to such aspects of residential architecture as geometry, typology, proportions and shading techniques in relation to energy performance.

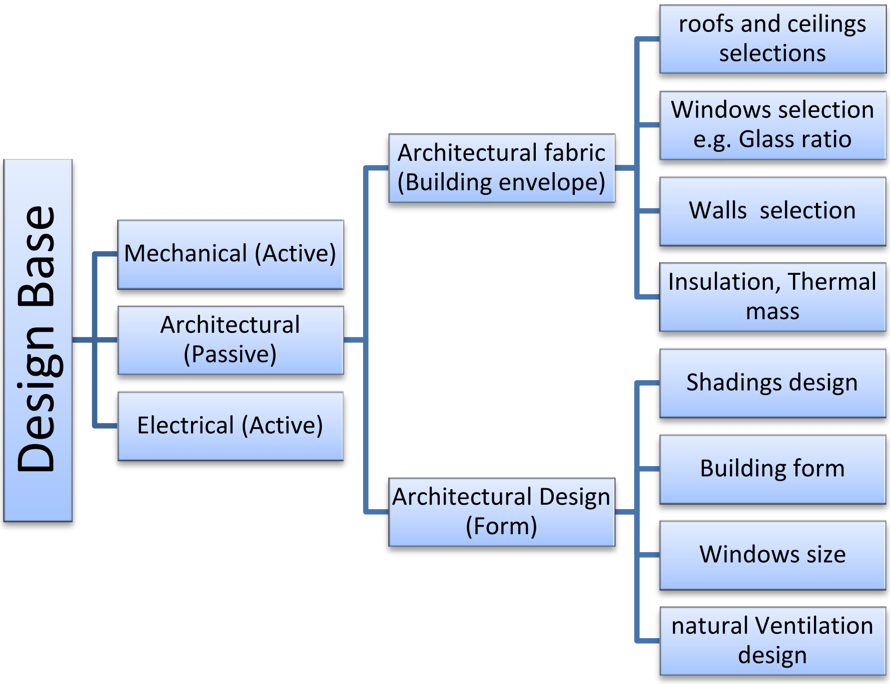


Figure 2.2 – Summary of energy efficiency parameters in the design stage of housing. (Roufechaei, Hassan Abu Bakar et al. 2014) and (Aldossary 2015)

2.4 Sustainable Architectural Design in Hot Semi-Arid Climate Conditions

Reducing energy consumption and CO_2 emissions are crucial roles that need to be carefully examined in this part of literature review. There are different important factors to achieve low energy buildings, for instance, use of renewable natural energies and reducing the energy demand of building. Sensible approaches towards appropriate designs, applying building design and maintaining buildings based on local regulations, construction materials and local traditions result in sustainable architecture (Niroumand et al., 2013). According to Williams et al. (2013) the considerations of sustainable architecture are mostly about the following two main matters; primarily they "*embody the notion that the design of buildings should fundamentally take account of their relationship with and the impact on the natural environment*", and secondly, they are "*concerned with the concept of reducing reliance on fossil fuels to operate a building*". The important parameters for architectural solutions are illustrated in Figure 2.3.

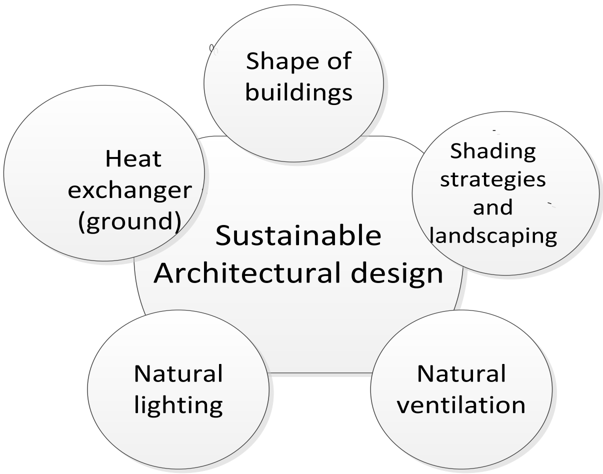


Figure 2.3 – Architectural Design Solutions Structure

2.4.1 Building Shape

Research has established that the building shape is a major contributor that determines energy use (Ourghi et al., 2007). Studies have also shown that the building shape can have a significant impact on the energy costs of heating and cooling (AlAnzi, Seo et al. 2009). Therefore, it is important to consider the optimal building shape at the design stage by considering the local climate conditions. According to Schnieders (2009) another important role of optimal building shape is controlling solar radiation exposure and transmission load. Simply put, the shape of the building impacts on the solar energy it receives directly and affects the energy consumption (Mingfang, 2002). Usually to accomplish an acceptable level of thermal comfort in winter, energy for cooling demand is increased respectively; this can be controlled by decreasing the solar heat (i.e. radiation).

Energy loss as a result of high demand on cooling systems occurs when an exposed surface to the sun results in heat gain. Paceco et al., (2012) stated the total area exposed to the sun in a building can be determined by the shape of the building. Therefore, that impacts on thermal performance of the whole building. It is important to identify design variables, for instance, those that are relevant to heat transfer procedure (Bektas Ekici and Aksoy, 2011). Furthermore, Bektas Ekici and Aksoy (2011) identified both influential parameters of physical environmental and design strategies that impact energy demand. Table 2.1 briefly presents their findings.

Table 2.1 – Building Energy Requirements (Bektas Ekici and Aksoy, 2011)

Physical-environmental parameters	Design parameters
Daily outside temperature (^{o}C) **Solar radiation (W/m^{2})** **Wind direction and speed (m/s)**	Shape factor Transparent surface Orientation Thermal-physical properties of building materials Distance between buildings

The diversity and complication of design variables that affect energy consumption are clearly explained in the above table. Research has also shown that the building shape coefficient, based on energy demand, is related to the level of the heat transfer through the building envelope (AlAnzi et al., 2009).

2.4.2 Shading Devices and External Landscape

This is an effective practice in hot climate countries to cool the surrounding space of a building to minimise the need to of cooling systems. Findings of a study by Simpson and McPherson (1998), from evaluating more than 250 buildings in California, suggest that planting three trees per building have a considerable impact on overall building energy efficiency. The findings showed the applied method resulted in peak cooling energy and correspondingly annual reduction by 7.1% and 2.3% respectively. Higuch and Udagawa (2007) evaluated the effect of different types of trees on cooling energy reduction. Their result showed that some specific types of trees (e.g. deciduous trees) can save up to 20% on annual cooling energy.

Buildings without a shading strategy can have higher energy demand and eventually cause higher energy consumption. Research by Farrar-Nagy et al. (2000) evaluated various options of architectural shadings, windows and site shadings in hot climate conditions to reduce the cooling energy demand. The finding of the research shows that a building without shading system requires 24% more cooling demand. This is dependent on the type of windows, building orientation and any existing overhangs.

One of the commonly used shadings are overhangs that are regarded as shading devices and are available in interior and exterior forms. Different passive solar shading systems studied by Kischkoweit and Lopin (2002) shows that by considering the effect of day-lighting, the sunshades reduce use of internal natural light in the building, however, they contribute to minimising the internal overheating. In another study, Li and Wong (2007) assessed the effect of external obstruction (nearby building) as shading on energy reduction. The study established several numbers of equations that contribute to the assumption of energy reduction through shadings.

A common practice to implement the overhangs is to fix vertical and horizontal shading elements above or on the side of windows to inhibit sun rays from the sky. To identify the specific characteristics of the overhang it is important know the summer and winter sun path, and carefully analyse it. Jorge et al (1993) designed a tool to measure the ideal size of shadings. The tool determined the vertical and horizontal overhangs. A nomogram diagram was invented with researchers for Mediterranean climates to optimise the shading performance through the enhancement of the design. This nomogram was applied to examine the workability of the suggested external overhangs, however the error level measured to be about 10%, which is crucial an important amount of error (Jorge et al., 1993).

External louvres were studied in another research by Panao et al. (2013), he investigated the impact of louvre shadings in a variety of buildings. The findings of the studies show that the use of external shadings will result in a better indoor thermal comfort, and also enhancement of energy conservation.

2.4.3 Natural Ventilation

For centuries humans have taken advantage of natural ventilation as an important strategy to control overheating. Night ventilation is an important strategy to purge and flush out the internal air that has gained heat during the day, and exchange it with cooler outdoor air (Capon and Hacker, 2009). According to sustainability workshop (2017), another advantage of night ventilation is the removal of stored heat within the exposed thermal mass. Windows need to be kept closed during the day, however, by opening the windows at night it removes the warm air from the indoor space and cools down the thermal mass for the next day.

Furthermore, a benefit of night ventilation occurs when the daytime air temperatures are beyond the thermal comfort level and mechanical cooling systems can't be avoided but the night temperature is cool (sustainability work shop, 2017). This strategy can provide passive ventilation in weather that might normally be considered too hot for it. A study conducted by Rachel Capon and Jake Hacker (2009) that focussed on buoyancy-driven ventilation through the building's openings in which three forms were analysed: double glazing windows, single glazing, and double glazing with overhang. The results indicated that double glazing windows that were insulated had a less efficient performance than the other types and retained more heat within the building at night. However, when the natural ventilation was applied to the building, its performance improved a great deal. Much research has been carried out to prove the advantages of natural ventilation. For this purpose, many strategies also have been examined to apply the combination of natural and mechanical ventilation. Although that is the future form of ventilation, there are increased interests in this type of ventilation as a result of its possible advantages (Khanal and Lei, 2011). Solar chimneys are well focused strategies that many researchers have focused on. Lee and Strand (2009) studied the solar chimneys and associated concept of absorptivity, and they reported that by enhancing solar absorber walls from 0.25 to1.0 in solar chimneys, the airflow rate can improve by 57%. Debloise et al (2013) stated that natural ventilation can be promoted in a solar chimney system by designing a gable roof to control solar heat and move the heat into the air through a sloped channel inducing a flow of air. An analytical study conducted by Dai, Sumathy et al. (2003) into improving the effect of natural ventilation in a solar house. In order to conduct this analysis, they applied a solid adsorption cooling cavity as well as solar chimney. The findings of the research showed that a 2.5m^2 solar chimney of a solar house in a regular day, is able to generate 150kg/h airflow (Dai, Sumathy et al. 2003). The research also found that solar adsorption cooling cavity is also able to increase the rate of ventilation at night by up to 20% (Dai, Sumathy et al. 2003).

Following the mentioned studies, natural ventilation can contribute to cooling a house. However, this depends on the climate of the house, and the use of a cooling system that operates by energy is unavoidable in hot summer days. Raman et al. (2001) tested passive solar systems in warmer climate conditions, and the findings showed that temperature variation in the building can be moderated by using a passive system. Raman et al (2001) also established that a designated collector on south walls in combination with a roof duct with an evaporative cooling surface can keep the internal temperature about 30^{o}C while the outdoor temperature reached to 42^{o}C in summer time. Research by Verma et al. (1986) concluded that evaporative strategies for the roof greatly impacted the indoor temperature by achieving a significant reduction in temperature. Mechanical cooling systems are a common method in warmer climates to reduce heat flows. There are different types of cooling systems, they range from simple systems, such as ceiling fans that remove the solar heat from the space, to advanced air conditioning systems (Feist, 2009). Ceiling fans can increase the air velocity surrounding people, but this is not regarded as passive cooling. In addition, thermal discomfort can be reduced by ceiling fans in warm climates. Other common methods in warmer climate condition with minimal humidity levels are evaporative cooler systems that are widely used in semi-arid climate conditions. The most important advantage of evaporative coolers is their low energy consumption as well as simple maintenance and operating procedures. In terms of energy consumption for a typical 2000 square-foot residence, the average energy consumption of evaporative cooler is as low as 250 kWh compared to 850 kWh for conventional air conditioner units, resulting in about 75% energy saving (Bishoyi and Sudhakar, 2017).

According to Feist (2009) another method that is used in ventilation systems is heat recovery and adiabatic cooling. In this method exhaust air is modified and becomes cool, then this passes through the heat exchanger and cools the incoming air supply.

However, the simplest method of natural ventilation is through the windows and openings and has a great share of passive cooling strategies. Night purge ventilation also removes stored heat from any exposed thermal mass (Moosavi, Mahyuddin et al. 2014).

2.4.4 Lighting

An important factor at the design stage of buildings is the natural lighting factor, which due to the health and energy conservation benefits needs to be carefully considered. To reduce the energy consumption in buildings, natural lighting (day-light) becomes more interesting for designers (Li and Lam, 2001). Benefits of natural lighting have been studied by many researchers. The main focus of those researchers has been on promoting householder’s health benefits and their important roles on the physiological rhythms of people (Choi et al., 2012). By using efficient lighting and appliances, heat reducing domestic hot water systems, reductions in internal gains can be achieved. Therefore, according to Feist (2009) this saves energy in both the excess heat production and its removal.

Feist (2009) argues that the sun can act as both of enemy and friend to buildings. Therefore, a careful design needs to consider overheating in warmer seasons due to the poor design.

Nevertheless, the form of buildings and cities is affected by daylight and sunlight access conditions. According to Richardson et al. (2009), the perception of occupants towards the daylight in a building is a main aspect of design when controlling of electric lighting is explained. A study by Mahapatra et al. (2009) on electrical lighting performance shows that proposing solutions to improve the level of daylighting minimises the energy consumption and consequently results in lower energy CO_2 emissions. The study stated that electricity can be replaced by natural energy resources, this is more important for the regions without an electrical grid (Mahapatra et al., 2009).

2.4.5 Ground Heat Exchangers

Earth to Air Heat Exchangers (EAHE) are a practical architectural key solution to improve natural cooling systems. By applying this method, it is assumed that a reasonable contribution can be achieved to moderate the indoor temperatures (Hollmuller and Lachal, 2001). The ground temperature at certain depths remains at a constant level throughout the year, which is due to high thermal inertia exhibited from the ground. This contributes to a heat sink during summer and heat source in winter (Hollmuller and Lachal, 2001). Strategies for EAHE require a comprehensive understanding of mechanical behaviour of heat and humidity from earth to air in an operational air heat exchanger (Kumar et al., 2006). According to Kumar et al (2006) considerable research has been carried out to examine the analytical and numerical models of thermal behaviour, cooling and potential preheating of EAHE.

2.5 Building Envelope Design in Warmer Climate Conditions

In order to achieve energy optimisation for cooling systems, while maintaining a reasonable comfort temperature in hot periods of summer, south European countries have set up many standards and strategies (Rossi and Rocco, 2014). The majority of the researches on climate conditions have greatly focused on the role of building fabric with high thermal inertia, that significantly impact energy saving while maintains the indoor temperature at a satisfactory level (Aste et al., 2010). Disputably, building fabric plays the most crucial role in sustainable buildings. Reduction of energy consumption and maintenance of indoor thermal comfort can be achieved over a long period of time by appropriately designed building fabric. The primary important parts of the building structure include roofs, windows, doors external walls and floors. Furthermore, active energy accounts for the required energy to run conditioning systems, building lighting, ventilation and other internal occupant's activities. Therefore, the bulk use of energy consumption for cooling and heating system operation needed to be considered, as this depends on the building heat gains and loss (Ramesh et al., 2012).

The need for cooling and heating systems can be changed by the level of heat gain or loss, and results in higher energy consumption. Ramesh et al (2012) stated that a low thermal conductivity and appropriate heat capacity design of the building envelope or fabric can potentially reduce the heat gain or loss through the building components and lead to lower energy demand. To reduce solar heat gains in a building, building materials have an important role. The following applicable strategies in building materials achieve solar heat reduction; thermal insulation, radiation barriers, reflective colours and cavities (Feist, 2009).

In order to have a more coherent understanding of the building envelope the following parameters will be discussed separately. With an emphasis on semi-arid climate conditions, four main parameters of building envelope will be discussed; (a) thermal comfort and building envelope insulation, (b) external walls design, (c) roof and floor design, (d) glazing designs (windows).

2.5.1 Building Envelope Insulation and Thermal Comfort

Providing thermal insulation in the building envelope components such as external walls and roof optimise the required energy for cooling and heating systems, and as a result contribute to energy cost saving (Al-Homoud, 2004). Furthermore, in order to maintain the thermal comfort without using a heating or cooling system in a building for a longer period of time, thermal insulation is a great solution, particularly during the changing seasons (Al-Homoud, 2004).

A number of researchers have reported that to reduce the energy consumption, high thermal insulation of the building fabric contributes to a more efficient sustainable building.

Aste et al (2010) states that energy optimisation through the envelope components can be achieved by applying a considerable amount of insulation and thermal mass. Defaux (2007) conducted research to analyse and compare residential buildings, and concluded that a significant amount of about 50% can be saved by applying different insulation thickness and types. Further research by Mitraratane and Vale (2004) suggested that insulation thickness has a crucial energy saving role in timber framed houses in New Zealand. As a result of the research, it is clear that the application of efficient insulation is highly significant for energy optimisation in new buildings (Mithraratne and Vale, 2004).

An efficient method of minimising energy consumption in warmer climates is by selecting building envelope (materials) that contribute to cooling the indoor temperature. Revel et al (2014) assessed the applicability of these kind of systems that effectively reduce the energy consumption in regions with hot summers and milder winters.

To evaluate the thermal performance, they developed an experimental and numerical method that is applicable in different construction materials and building envelopes (Revel et al., 2014b). The following materials were used for the research; ceramic tiles with cool colour, facades with acrylic paints, and bituminous membranes for the envelope system. The research described that cool materials contribute to wall temperature reduction of 4.7 ^{o}C, as a result of heat flux reduction of 50% through the building envelope. Furthermore, according to reports from different locations in Europe, as a result of cool materials a range of 0.6 – 3.5 kWh/m2 energy saving can be achieved. According to the published results, cool façades potentially have a helpful impact on energy saving in annual statistics (Ravel et al., 2014a). Nevertheless, there is a risk of applying this system in colder months in regions with semi-arid climate that has hot summers and cold winters.

In research by Kuzman et al. (2013), comparisons of different construction materials have been conducted. This includes passive house with different construction types, such as wood frame and brick. The research also examined the benefits and drawbacks of the majority of regular construction materials. Kuzman et al., applied an Analytic Hierarchy Process for their research to assess energy optimisation in different building construction types, and it was discovered that wooden buildings could significantly optimise energy conservation in the form of residential buildings (Kuzman et al., 2013).

Considering that people have variable thermal comfort levels in different climate regions, local preferences need to be prioritised at the design stage by architects. In different studies, thermal comfort has been evaluated from different perspectives, but they all have a common objective to find the best way to achieve maximum occupant satisfaction (Zain et al., 2007).

2.5.2 Efficient External Walls

As mentioned above, when designing sustainable buildings, it is important to consider the building envelope materials and strategies. As a result, external walls can be regarded as the most important building fabric of the building envelope. For this purpose, several numbers of techniques and methods have been evaluated and introduced for external walls. A study by Al-Homoud (2004) examined the impact of thermal insulation in a variety of building types in southern Persian Gulf countries. This research shows that a high level of heat gain results in lower energy conservation. However, this can be positively modified in external walls by applying thermal insulation (Al-Homoud, 2004).

To determine the most appropriate thickness of thermal insulation, many studies have been conducted. For instance, according to Zhu, Hurt et al. (2009), heat can be saved during the daytime and discharged later at night by having an optimum level of thermal mass. In warmer climates, with whole day high outdoor temperatures and strong sunshine, the amount of saved heat will be greater than can be released, therefore, there continues to be an energy demand for cooling (Zhu, Hurt et al. 2009).

Further research by Radhi (2009) has considered Bahrain in the Persian Gulf and showed that energy consumption can be reduced by 25% by applying thermal insulation in external walls by considering the dominated skin load of buildings. In addition, a further 5% reduction in energy consumption can be achieved if internal load led building be applied by thermal codes (Radhi, 2009). Radhi (2009) concluded that, in the Middle East, energy consumption can possibly be saved by around 7%, which results in CO_2 emissions potentially dropping by 23.4 million metric tonnes. Double wall technique is another strategy to optimised energy efficiency through the external walls. An assessment by Utama and Gheewala (2009) shows the energy life cycle (kW/m2 year) in multi residential buildings in Indonesian capital city. Clay brick was used a constant parameter within the walls, however the configuration of the external walls was varied, or in other words they used both single and double walls with the same main materials. The findings showed that in terms of energy, performance of double walls is much better than the single wall by approximately 40%. Utama and Gheewala (2009) also examined the impact of concrete and clay in family houses in Jakarta, the results demonstrated that the cement built house has lower energy performance than the clay built house.

Mud also has been examined as a construction material in several studies to measure its energy performance in buildings. For instance, Coffman et al (1980) concluded that the natural cooling effect of mud made external important in buildings. Likewise, in a study by Duffin and Knowles (1981) mud made external walls were identified as important factors to control the indoor thermal conditions. They also emphasised that the number of materials in wall systems could significantly improve energy efficiency as well as comfort level (Coffman et al., 1980). Eventually, Chel et al., (2009) published a report regarding the mud built houses in India. The report concludes that mud houses contribute to further energy efficiency and also in terms of eco-friendly, a home that results in reasonable level of thermal comfort (Chel et al., 2009).

Regarding the wall thickness and configuration of external walls, a considerable amount of research has been conducted. Bolatturk (2006) believes that by applying appropriate thickness of wall insulation, a considerable level of energy saving can be achieved. Bolatturk (2006) added that insulation thickness ranging from 2 cm and 17 cm has the ability to reduce energy consumption by 22% to 79%.

As a result of above research, it can be concluded that the role of thickness of external walls is very important in energy optimisation. Fang and Li (2000) recommended a set of specific thicknesses for external walls such as brick walls: 37 cm, heavy concrete walls: 40 to 45 cm and light concrete walls: 35-40 cm. It is costly to construct thick walls, however, the reduction of energy consumption costs in the long term will compensate the added construction costs and the occupants will eventually benefit economically as well as environmentally (Sisman et al., 2007).

In addition, according to Feist (2009) passive cooling strategies, in particular thermal mass can be supported by the thickness of external walls. This is achievable by storing heat during the daytime and discharging it at night. Adobe walls in Mexico and also in in southern part of US demonstrate the storing of heat during the day and discharging it at night (Feist, 2009).

A very well documented method is having a cavity between external walls as they have a significant impact on heat transmission. Najim (2014) conducted research on external bearing walls and the research confirms that by improving the thermal characteristics of these walls in residential buildings, less operational cooling system is needed, therefore energy consumption reduced considerably. Furthermore, this study emphasises that the integration of air-cavities in external walls, compared with other methods, will have a significant impact on the walls performance (Najim, 2014). The physical characteristics of walls of the building envelope will have great effect on heat transmission. Due to the wall abilities to store heat, they can impact on indoor temperature by contributing in heating and cooling aspects. To achieve such effects, suitable operation is required (Byrne et al., 2013). Cavity wall insulation can also be applied when cooling is required in the building, the cavity insulation stores heat in the outer leaf of the wall and results in releasing the heat to the outdoor space (Byrne et al., 2013). The research demonstrates at which level these methods and strategies are applicable in different climate conditions, in particular in warmer climates, to contribute further to energy optimisation. Other additional methods such as cellulose insulation as well as cavity depth are potentially applicable at the design stage. These methods will contribute to achieve higher levels of energy efficiency through the building envelope. A study by Aviram et al., (2001) concentrated on external walls in terms of cavity depth. They examined how various cavity depths perform by changing the ground surface temperature at the cavity base. Alternatively, Nicoljasen (2005) studied the installation of cellulose installation. They assessed cellulose insulation materials in term of their thermal performance, and they additionally conducted a comparison analysis with stone wools batts. Their findings show that the examined cellulose had less effective thermal mass performance than the stone wool batts (Nicolajsen, 2005).

A study by Wang et al., (2013) examined water thermal storage walls in new buildings as well as retrofitted ones. By applying variance analysis, it was discovered that four important construction factors have a great impact on building energy efficiency; building orientation, southern walls glazing ratio, coefficient of building shape, internal partition (Wang et al., 2013).

2.5.3 Roof Design Considerations

After external walls, the roof as a building envelope element has the most important impact on energy optimisation. The latest studies along with their findings will be discussed here to have a better understanding of the roofs on building envelope energy optimisation. In this section three different types of roofs will be discussed; design for green roofs, design for reflective roofs and white roofs, and insulated roofs.

Green roofs are one of the strategies to achieve energy reduction in buildings. Other terms for green roofs are roof garden or eco-roofs, and that means planting vegetation on the roof of building (Parizotto and Lamberts, 2011). An important method in non-cooled building is designing a roof as an effective solution for the building envelope to contribute to energy conservation and also to improve the internal thermal conditions (Zinzi and Agnoli, 2012). Furthermore, applying cool materials will help lower indoor temperature, this is even applicable during warmer seasons under direct sun rays. The main function of cool materials in roofs are reflecting the solar radiation and during night radiating heat away.

In order to determine the advantages of green roofs, many studies have been conducted to evaluate the green roof energy efficiency abilities in vernacular buildings in southern regions of Australia (Coutts, Daly et al., 2013). Their research shows that by using vegetation a great amount of energy saving can be reached if rooftops be designed accordingly to target specific performance objectives, such as heat mitigation. Therefore, The vegetation on green roofs is a good thermal insulation and they significantly result in energy efficiency (Zinzi and AgnoIi, 2012).

Other advantages of green roofs are providing additional insulation in the roof as a result of soil via evapotranspiration that keeps the roof cool (Zinzi and Agnoli, 2012). According to many studies, green roofs in different concepts have been applied in different countries, and it is evident that buildings can benefit green roofs in regions with variable climates (Williams et al., 2010).

Nevertheless, green roofs are complex to design and when practically applied in buildings, therefore researchers have always been looking for simpler methods. One of the alternative proposed methods is using light colours on roofs, which reflects the sun rays. Light and dark colours have fundamental heat gain differences in roofs (Suehrcke et al., 2008). By designing a highly reflective roof, such as roofs with white coloured surfaces, the building indoor temperature will be cooler and lead to lower energy demand to cool the indoor spaces (Yaghoobian and Srebric 2015).

Suehrcke et al. (2008) performed research in warmer climate regions, and suggested that roof colours can be classified into four categories of dark, medium, light and reflective ones. Their research concluded that by applying reflective and light colours into roofs, downward heat flow will be sharply reduced. The result of this reduction contributes to energy saving (Suehrcke et al., 2008).

For the roof insulation, according to Feist (2009) a building roof with unglazed solar collector can help the cooling process by radiative cooling, or alternatively with movable insulation. Different studies propose to utilise insulation layers, for instance, in three-layer insulation two layers must be located on the roof's inner and outer side, and periodic heat flux can be reduced by placing one layer in the middle (Ozel and Pihtili, 2007). If the position of the insulation is selected appropriately, it can potentially reduce energy consumption, however, the unsuitable position results in no efficiency. Low values of thermal value as well as roof reflection can result in increasing the thermal resistance (R-value) of an insulated roof by 1.5 times (ANSI/ASHRAE, 2004).

Research by Halwatura and Layasinghe (2008) compared insulated roofs with lightweight roofs in hot and arid climates. The results confirmed that insulated roofs have a better performance than lightweight roofs. The details of their study show that thicker insulations i.e. 38mm and 25mm perform more efficiently than the 25mm insulation that shows noteworthy efficiency.

2.5.4 Glazing Design and Windows

The aim of this section is to carefully investigate the state of the art studies in regard to windows and glazing. This section will discuss three important areas; evaluating the role of windows, the role of windows design, and the importance of glazing.

The majority of designers regard windows as one of the most important design elements for sustainable buildings in both warm and cold climates. In modern residential buildings, designing large windows is more common than the smaller ones due to the high rate of heat transfer.

Daylight enters the indoor space through the windows and provides the required lighting during the day (Askar, Probert et al. 2001). An appropriate level of window design that provides sufficient natural lighting can help to improve the quality of the occupant's health as well as impacting on energy efficiency (Askar, Probert et al. 2001). A common glazing design in the Middle East is providing bigger windows in dwellings. Askar, Probert et al. (2001) conducted a study to prove that new buildings in the Middle East are designed with larger glazing area. As a result of such a design more energy is required to cool the indoor temperature (Askar, Probert et al. 2001). Therefore, energy demand can be reduced in different climates by an appropriate design.

Larsson and Moshfegh (2002) conducted a study to explore potential methods to modify the external façade of windows. According to the study, recent attempts to optimise energy efficiency and improve the sustainable building strategies, resulted in fundamental design amendments in windows (Larsson and Moshfegh, 2002). Larsson and Moshfegh (2002) stated that the new window designs impacted on unconventional natural ventilation and heating systems by creating a higher surface temperature on the window inside pane and a lower downdraught. Askar et al. (2001) carried out a study to investigate methods of reducing energy consumption by designing high performance buildings in Middle East buildings. Their study presented that triple glazed windows are able to reduce solar radiation transmission from the outdoor spaces.

Persson et al. (2006), having considered the impact of window size on energy efficiency, confirms that small sized south facing windows in combination with large north facing windows result in high energy demand to maintain the required thermal comfort. The findings of their research indicate that although employing such designs affect the energy efficiency in summer time for cooling purposes, the effect of heating energy is not as significant as cooling energy (Persson et al., 2006). Their research concludes that for improving lighting in internal spaces, increasing the north face windows is beneficial (Persson et al., 2006).

An investigation conducted by Karlsson, J. and Roos (2001) focused on external windows, and demonstrated the value of thermal emittance and its influence on cooling and heating energy demand. They studied different climate conditions and subsequent significance values of low emittance in these regions. They used two different buildings with different construction types. Findings of their research indicate that different values lead to minor changes in the level of energy efficiency (Karlsson and Roos, 2001). In other words, in a south facing residential building, a decrease of 2% of thermal emittance and reaching to 3% will exacerbate the energy performance (Karlsson and Roos, 2001).

Insulated glazing is an approved option to minimise the solar heat effect and decelerate the process of heat transmittance indoors. Of course, there are many techniques around to enhance the performance of external glazing to reduce high energy consumption in buildings. For example, scientists demonstrated energy optimisation by applying different types of multiple panes of window's frame (Manz, 2008).

Today, use of double glazed windows in buildings is a common practice around the world, although these external windows differ based on different insulations. These insulations range from glass type to frame thermal break types (Song et al., 2007). Many experiments and research projects have attempted to enhance double glazed windows' insulation quality to achieve further energy optimisation, for example, applying low-e coating on window glass, gas filling of gaps between glasses, installing polyurethane as a thermal break in windows (Chow and Li, 2013). A number of studies present that insulation materials, such as thermal break elements that are made of aluminium and thick plastic, are able to significantly increase the lowest inner surface temperature and address the acceptable minimum temperature range (Song et al., 2007).

Research carried out by Panao et al., (2013) assessed near Zero-Energy Buildings (nZEB) in terms of the minimum required energy to run these types of buildings in the Mediterranean climate. The findings of their research indicated a direct relationship between the energy efficiency and the level of insulation thickness. In addition, they noted that a suitable thickness ranges between 4mm and 6mm (Panao et al., 2013). Other researchers also identified double glazing as one of the most crucial parameters to address energy efficiency in buildings, and recommended that according to glazing U-values the suitable insulation thicknesses are 6mm and 16mm. Panao et al., (2013) concluded that by considering the required energy in near Zero-Energy Building, demanded energy is significantly dependent on each country's primary energy aspects.

As mentioned in the above sections, a variety of technologies, methods and standards have influenced energy saving in construction. One of the technologies is ‘’Sealdair’’, in which the existing cavity in the window frame seals air, and this results in thermal insulation for external windows (Chow and Li, 2013). Other methods to improve the energy efficiency of windows is by applying low-e coatings to decrease the level of heat exchange between glazing in the external window (Singh, Garg et al. 2008). To reduce internal heat gain in diverse climatic regions, an essential practice is to apply a coating on an appropriate side of the glazing (Chow and Li, 2013). According to Gosselin and Chen (2008), for natural ventilation purposes through the external windows, those double-glazed windows fitted with a semi-open cavity are able to further improve the thermal performance through fluid heat removal.

In order to maintain maximum comfort conditions in indoor spaces of buildings, much research has been conducted to set out and confirm the advantages and benefits of sustainable window design in different climates. In order to explore different aspects of the impact of glazing on the building's energy consumption in Middle East, the economical, technical and local building standards have been explored by many researchers (Bahaj et al., 2008).

2.5.5 Effective Solar Gain Control Strategies

This section reviews the main factors of solar gain control in the context of shading devices, both modern and traditional methods. The main objective to implement any shading devices to control solar gain is to avoid direct solar radiation into the indoor spaces from the opening, although another important consideration is to avoid reflected and diffuse radiation from windows, as shown in Figure 2.4. Furthermore, selection of any shading devices and methods differ depending on the type of building, expected thermal comfort conditions and location of building (Santamouris and Asimakopolous, 1996). Despite the importance of solar gain reduction in buildings, the day lighting requirements need to be met as a priority factor at design stage for shading elements (Santamouris and Asimakopolous, 1996).

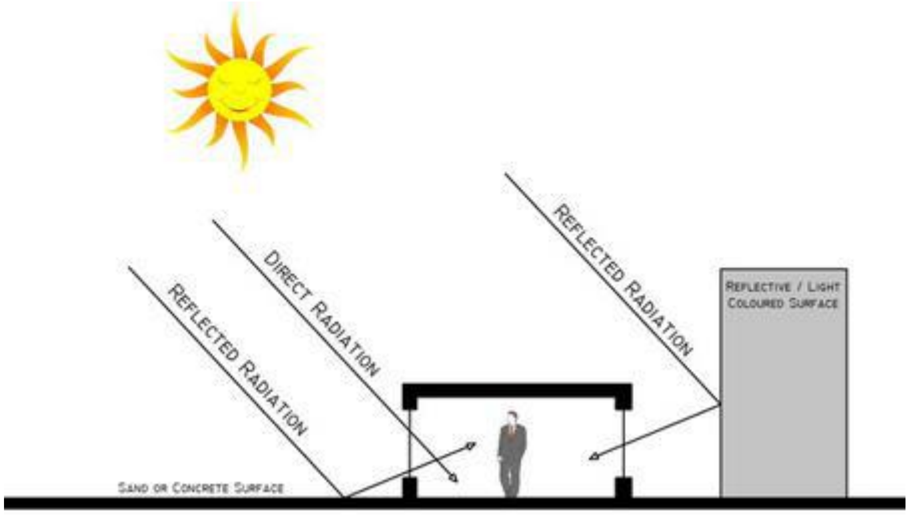


Figure 2.4 – Direct and In-Direct Solar Radiation

Occupant activities, the building's ventilation system and thermal mass have a great role on controlling solar gains through the building envelope. As a result, according to Thomas and Fordham (2001), solar gain control devices should not be regarded as an isolated element, it should be regarded as a system.

A brief definition of solar gain control devices has been given by Stack, Goulding and Lewis (1999), solar gain controls are in order to prevent solar heat from reaching and entering into the internal spaces of building. Therefore, to achieve this objective many shading devices and strategies have been designed.

Depending on solar geometry characteristics, the shading devices have identical performance, although there might be variations in size and shape. As a result, different combinations of shadow e.g. vertical and horizontal follow the same objective, this will help designers to have more options at the design stage (StacK, Goulding, and Lewis, 1999).

Nevertheless, shadings act as important solar gain controls as long as their design doesn't compromise energy consumption and required thermal comfort in other seasons. For instance, according to Asimakopoulos and Santamouris (2013), shading devices must not interfere with the sun path in winter, and shading devices must not obstruct the occupants view through the windows and must comply with natural ventilation regulations to permit the required natural ventilation from the openings.

Designing a shading device is possible only when the sun's location in relation to the building elevation can be determined by incidence angle and shadow angle. Designers will be able distinguish solar altitude and azimuth when they know the sun's path and its association to the earth. This is regularly demonstrated by sun path charts.

2.5.6 External Shading Devices

According to ASHRAE (1993), windows shaded from the outside reduce the solar heat gain by up to 80%. When the glazing allows the passage of infra-red radiation into the indoor space, a large portion of it is captured and later scattered by natural ventilation or mechanical ventilation (McNicholl and Lewis, 1994). Generally, however, shading designs and installation can be costly and technically difficult to be maintained or repaired (O'Cofaigh, Owen, and Fitzgerald, 1999).

Fixed and Adjustable Shadings

These devices are suitable for south facing windows, and are placed above the windows. Overhang location above the window and the width of the projection is important as an appropriate location permits the required rays to pass through the windows when the sun position in the sky is low. The overhang depth needs to consider its distance above the window and the height of opening. In addition, its length is calculated by the width of the window (Lewis, Goulding, and Steemers, 1992).

The performance of the shading devices is designed according to the summer high angle and winter low angle, this means they block the sunlight in the summer and allow it in the winter, they are also effective elements to decrease daylight diffusion (Stack, Goulding and Lewis, 1999). Larger overhangs, achieve more shade than required covering the window surface, this will be a suitable practice in hot climate regions (O'Cofaigh, Owen and Fitzgerald, 1999). Other strategies as stated by Satamouris and Asimakopous (1996) are roof overhangs and long balconies that have positive effect on internal temperatures in hot climate regions, in many buildings this is achieved with tents or pergolas as illustrated in Figure 2.5.

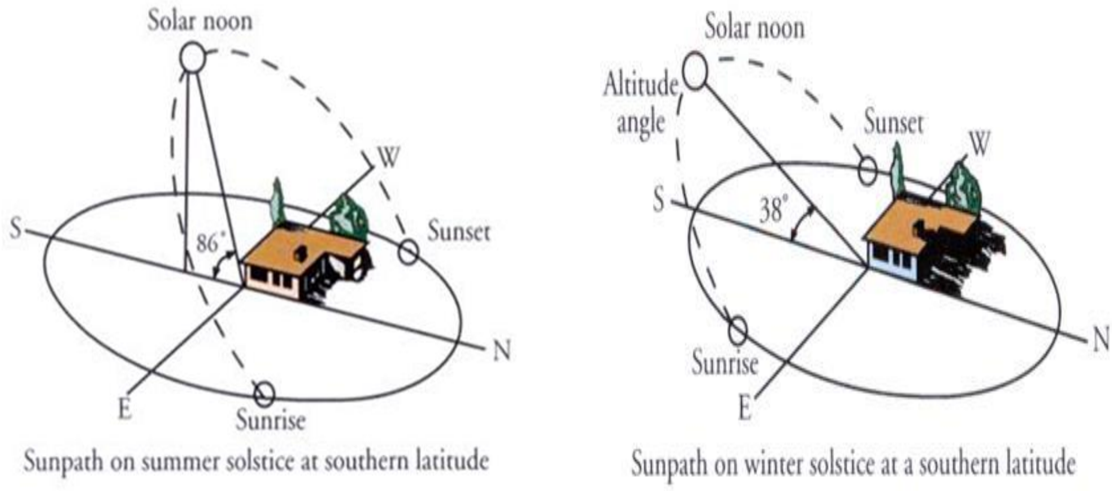


Figure 2.5 – Sun path on summer and winter latitude

There are different types of external shading devices that contribute to control sunlight into the internal spaces, the following devices are the most important external shading devices; light shelves, fixed and movable louvres, shutters, fixed screens, egg-crate and awnings.

Internal Shading Devices

In general practice, to provide occupants privacy, internal shading devices can be adjusted easily at the openings (McNicholl and Lewis, 1994). There are several designs of internal devices, including roller blinds and curtains. However, the internal shading devices are less efficient than external shadings due to lower ability to reduce solar radiation which previously reflected to the surface after transmitting into the internal space from the glazing.A large amount of radiation, in the case of internal shadings, is absorbed and radiated to the room. In addition, another drawback with internal shading is its conflict with natural ventilation and day lighting through the windows (Santamouris and Asimakolous, 1996). Givoni (1994) stated that applying internal shadings for energy reduction in warmer climates are unlikely to be appropriate solutions, in particular for large size openings. However, material properties of internal shading will determine the level of passing radiation into the internal spaces, these material properties are reflection and absorption abilities that need to be considered before installation (Goulding, Owen, Steemers and Directora, 1992). For designing internal shadings, white coloured materials are more suitable due to reflectivity, however, the heat gained in internal shadings are greater than the external shadings (Givoni, 1994).

Fixed Shading Devices

As a common architectural practice, fixed shading devices are widely in use. The window orientation needs to be considered for fixed shading devices at the design stage. The sun path in different seasons is an influential factor to the efficiency of fixed shading devices (Lewis, Goulsing and Steemers, 1992). A common location for overhang shadings is on southern facades and sideways shadings are located in east and west facing facades (Goulding, Owen, Steemers and Directora, 1992). According to Giono (1994), installing vertical fins in northern face facades can protect the building from the low sun in summer morning and late afternoon.

Fixed shadings can be designed as structural elements such as balconies, and non-structural elements as canopies and louvres. Due to the simplicity of these devices for installation and maintenance, building's occupants can easily select to install these devices to cool inside the building (Santamouris and Asimakopolous, 1996).

2.6 Free running buildings

Buildings that don't require heating and cooling are referred to as free running buildings. Free running buildings have a greater range of indoor comfort temperature than conditioned buildings that use heating or cooling systems (Clements-Croome, 2013). Free running buildings benefit from the application of adaptive criteria in which occupants can adapt their dress, behaviour and local environment to maintain thermal comfort (Roaf, Fuentes et al. 2014). Although the term of free running building has been widely used for naturally ventilated buildings in summer time and in warmer climates there have been much research to justify its applicability in both winter and summer (Roaf, Fuentes et al. 2014). It should be noted that free-running can be defined as a mode of operation of a building, rather than a specific building type.

2.6.1Evaluation of Thermal Conditions for Compliance

There are two methods suggested in the new European Standard EN 15251 for evaluating the thermal comfort conditions during an entire season:

1. Percentage outside range - the proportion of the occupied hours during which the temperature lies outside the acceptable zone during the season.

2. Degree hours criterion - The time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by a factor depending on the number of degrees by which the range has been exceeded.

Acceptability of the space on the 'percentage' criterion is on the basis that the temperature in the rooms representing 95% of the occupied space is not more than 3% (or 5% - to be decided on national level) of the occupied hours a day, week, month or year, outside the limits of the specified category (Humphreys, Nicol et al. 2015).

To determine an acceptable threshold temperature beyond the adaptive thermal comfort, as mentioned above most of the standards consider the overheating rather than both overheating and overcooling. Thermal comfort standards measure internal temperatures and thermal resilience to climate change of free-running buildings. McGill et al. studied an eclectic mix of well-insulated dwelling types in a variety of locations. They showed that whereas 58% of monitored living rooms had more than 10% of annual hours over 25°C, fewer than half of these (25%) had more than 1% of assumed occupied hours over 28°C and 33% breached two of the three CIBSE adaptive criteria (Category II based). Conversely, in their study of care settings for the elderly, Gupta et al. found that 30% of flats and communal areas breached two or more of the CIBSE adaptive criteria (Category I based) whilst 70% had more that 1% of occupied hours over 28°C.

2.7 Mixed Mode Buildings

A mixed-mode building is heated in winter, free running in mid-season, and has cooling available in summer as required. A mixed mode of operation, where supplementary air-conditioning is used only when indoor conditions rise outside the acceptable comfort range, can reduce the carbon footprint of the building. It is likely to use less energy than a fully air-conditioned building. Many studies have shown that mixed mode buildings offer energy savings over conventional air-conditioned buildings, for example, in the US (Brager and Baker 2009), the UK (Ezzeldin and Rees 2013) and Australia (Rowe 2003) amongst other countries. Well designed and operated mixed mode buildings have also been documented to show improved comfort, productivity and air quality (Brager 2009 and Rowe 2003) over air-conditioned buildings. Recent European work on mixed mode buildings (Kalz, Pfafferott et al. 2009) using Thermo-Active Building Systems (TABS) show good application in cool, dry climates, but may be less suited to the warmer, often humid climates that characterise many of Australia’s population centres.

A successful mixed mode building needs to maximize occupant comfort and minimise energy use across both its modes of operation. This in turn is affected by inter-related considerations including user expectations for comfort, the manner in which that comfort is provided under each mode, the extent of passive operation achieved, control strategies for change-over and occupant interaction, and the potential of the building fabric and systems to moderate comfort and energy in use.

2.8 State of The Art

The concept of passive design has been hugely expanded, and is well documented in developed countries. The most comprehensive passive design strategies can be seen in German Passivhous as the first standardised passive strategies. According to IPHA (2015) already more than 40,000 passive house units around the world, and 20,000 in Germany alone, have been successfully built and completed. According to Feist (2007), in Central Europe, the passive house means a space heat demand of 15 kWh/(m²a) at the most, this corresponds to a saving of 75% in comparison with the current standard and a saving of at least 90% in relation to existing buildings. In the German Passive House, a requirement for the total primary energy demand including all electrical applications is made. The limit for the Passive House standard is 120 kWh/(m²a) of the total primary energy (Feist, 2007). As a general rule, stated by (Feist, 2005), the following items are highly recommended elements in all climates; a) insulation, b) shading: is absolutely necessary in all climates with high levels of solar radiation, and c) heat recovery (ventilation): is necessary in all cold and hot climates. Research by Schnieders and Hermelink (2006) revealed that by applying Passivhous strategies, the newly constructed buildings, compared to the conventional ones, save 80% of heating space energy in a multi-story building in Germany. The research also concluded that the users are pleased with their homes' thermal comfort.

However, the above strategies are set to design a passive building within a specific organization's framework to achieve the desired value, i,e. 120 kWh/(m²a) .

Consequently, to avoid design complexities with these standardised strategies, several number of researchers have been considering climate conditions and local construction practices. For instance, Qian (2009) from university of Cardiff, in their PhD research investigated energy efficiency in northern China cities, the climatic characteristics of the investigated area described as a region with hot summers and cold winters. The research findings showed that by applying passive design strategies, significant improvements of the energy efficiency of residential buildings in northern China can be achieved and a considerable portion of energy can be saved. Additionally, the research shows that the most effective parameter in heating reduction is to improve thermal insulation, this reduce heating load up to 32.5% on average. The other parameters that reduce cooling demand the most are having a reasonable window area, and night time controlled ventilation—the reduction rate is around 23% and 13% respectively.

Elaiab (2014) conducted PhD research into considering thermal comfort through passive design in Mediterranean climates with reference to Libya. The research findings show that with respect to architectural design, building orientation and solar radiation are the most effective elements of design in this region. The research suggested north facing or east facing buildings, and also compact and narrow buildings are the most effective design. Furthermore, the research emphasises the importance of the role of materials selection, ventilation, roofs and walls selection in achieving thermal comfort. As a result, the research shows using proper insulation in walls and roofs reduce heat loss up to 76%. Also, proper selection of roofs and walls materials reduces heat loss up to 63.1% and 21.4% respectively.

Research conducted by Ahsan (2009) applying passive design in tropical climates shows that wall thickness and material selection can reduce cooling load by 64%, in effect, this will save 26% of total energy in the building.

Aldossary (2015) conducted PhD research with regard to passive design strategies in the hot climate of Saudi Arabia. IES-VE simulation software tools were employed to assess the efficiency of proposed housing prototypes in reference to their architectural design (form) and housing envelope design (fabric). The simulations identified 77kWh/m^{2}a as the lowest energy level that is achievable in Saudi Arabia. The findings suggest that an energy reduction of up to 71.6 % is possible.

Nasrollahi (2009) investigated passive design strategies in cold climate conditions of Iran with reference to Tabriz city. The outcome of the research shows that by applying passive strategies, the potential energy saving of architectural features in Iran's cold climatic region is about 63%. However, by increasing the U-value of the thermal envelope energy saving could increase over 63%. In their research, well-insulated materials identified as the most important effective element to reduce energy, as well-insulated buildings consume only 8.3% of an uninsulated conventional building.

From all the above research on passive energy efficient building, the following specifications are required to be gathered; climatic data for the region, local material details and their properties (U-values & R-values), building details (layout and materials), thermal comfort of the region and relevant passive design strategies to the region.

As the above research suggests, most of the implemented strategies in different regions result in improving the energy efficiency in buildings. However, the rate of performance differs from region to region as a result of the applied methods and the targets of their research.

Therefore, the assumption for this research is to achieve energy efficiency in Tehran's residential buildings by understanding the mentioned specification, and applying the passive design standards.

2.9 Summary

This chapter demonstrated the latest relevant research and studies that were carried out in various regions with different climate conditions, and with a concentration on similar climates to Tehran. First, this chapter focused on the studies concerned with optimal design and strategies that can be implemented in buildings in order to achieve energy optimisation and thermal comfort in buildings. Secondly, this chapter reviewed research conducted regarding the efficient building envelope design in various regions around the world. Although several techniques have been considered, not all strategies are suitable or applicable to Tehran's climate and construction practices.

As a result, the reviewed research and studies of this chapter can potentially contribute to implementing strategies that can be modified to fit to the Tehran's climate and construction practices.

Chapter 3 – Literature Review (2)

3.1 Introduction

Different definitions for thermal comfort in buildings are around, although it is impossible to define an absolute standard for thermal comfort in buildings. Human beings live in almost every corner of the world with different climate conditions, this makes setting a specific thermal comfort that address all climates not possible. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an international standard for defining the thermal comfort and is widely accepted. ASHRAE is defined according the satisfaction of people following the condition of mind with regards to thermal environment (ISO 7330). Thermal comfort as recommended should be considered an environmental property that determines satisfaction of thermal needs psychologically and physiologically. Creating such satisfaction in buildings is a significant process at design stage, particularly if it can be achieved by minimum energy consumption. For this purpose, some passive cooling strategies must be considered in the way that the essential internal air quality for occupant's thermal comfort is met. According to Santamouris, et al, (2001) not necessarily all passive cooling strategies leads to temperature reduction, but contribute to extend the tolerance of indoor temperature by reducing humidity or increasing light.

Thermal comfort also has been defined in other ways, for instance, Huizega et al, (2006) defines thermal comfort as occupants' satisfaction with the building temperature according to its thermal environment. However, Markus and Morris (1980) believe that thermal comfort is a state in which people judge the environment to be neither too cold nor too warm, a kind of neutral point defined by the absence of any feelings of discomfort.

This chapter will review the concept of thermal comfort for humans, and different methods that have been proposed to measure it. Furthermore, this chapter will review the feasibility of building and environmental design that can create appropriate thermal comfort for the occupant and also contribute to reducing energy consumption.

3.2 Thermal Comfort and Occupants

Human temperature system is perceived in the hypothalamus of the brain and monitors the temperature velocity in the blood caused by metabolic changes in the body, these sensations transfer the temperature to the skin and human body and can recognise the level of thermal comfort. The human body has a set point of 37^{o}C, which needs to be maintained. If the temperature of the human body goes lower than this level, a responsive physiological cause raises the metabolic rate resulting in generating more heat, and if the human body temperature increases the body sweats and evaporates moisture from the skin to provide cooling. When the indoor temperature changes quickly or unexpectedly that means the adaptive measures are inefficient, then discomfort feelings occur (Stack, Goulding and Lewis, 1999). Due to the variety of comfort “indices” it is difficult to demonstrate all of them in this study. However, by considering the most important and widely used comfort indices, this study presents the Givoni’s (1998) comprehensive list of comfort indices:

3.2.1 The ASHRAE Temperature and Comfort Zone

Thermal comfort is defined as a ‘condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation’ (ASHRAE, 2013). The main factors of this definition, as shown in Figure 3.1, are relative humidity and temperature (Sensirion, 2014). As demonstrated by Evans (2003), there are five sequential ASHRAE standards that represent different comfort zones. In addition, they present how difficult it is to define a suitable comfort zone to satisfy most of the occupants.

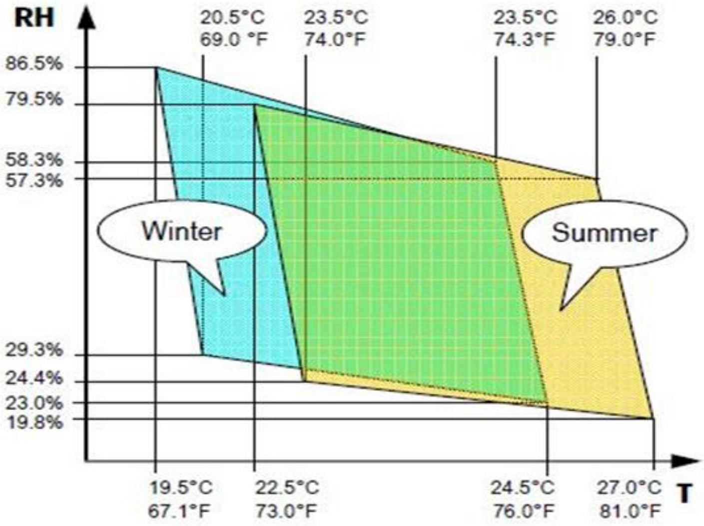


Figure 3.1 – Relative Humidity (RH) / Temperature (T) Diagram Based On Comfort Zone According To ASHRAE 55-1992 Source: Sensirion, 2010

3.2.2 Olgyay Bioclimatic Chart

Olgyay is one of the most widely used bioclimatic charts around the world. Olgyay refers to two climatic factors graphically to present the comfort zone. These two factors are relative humidity and dry bulb temperature, which are plotted in XY axis. Olgyay’s bioclimatic chart was allocated to free running buildings and during natural ventilation only. It was also suggested that the thermal comfort range during summer can be extended for higher temperatures and humidity upon the increase of wind speed (Figure 3.2).

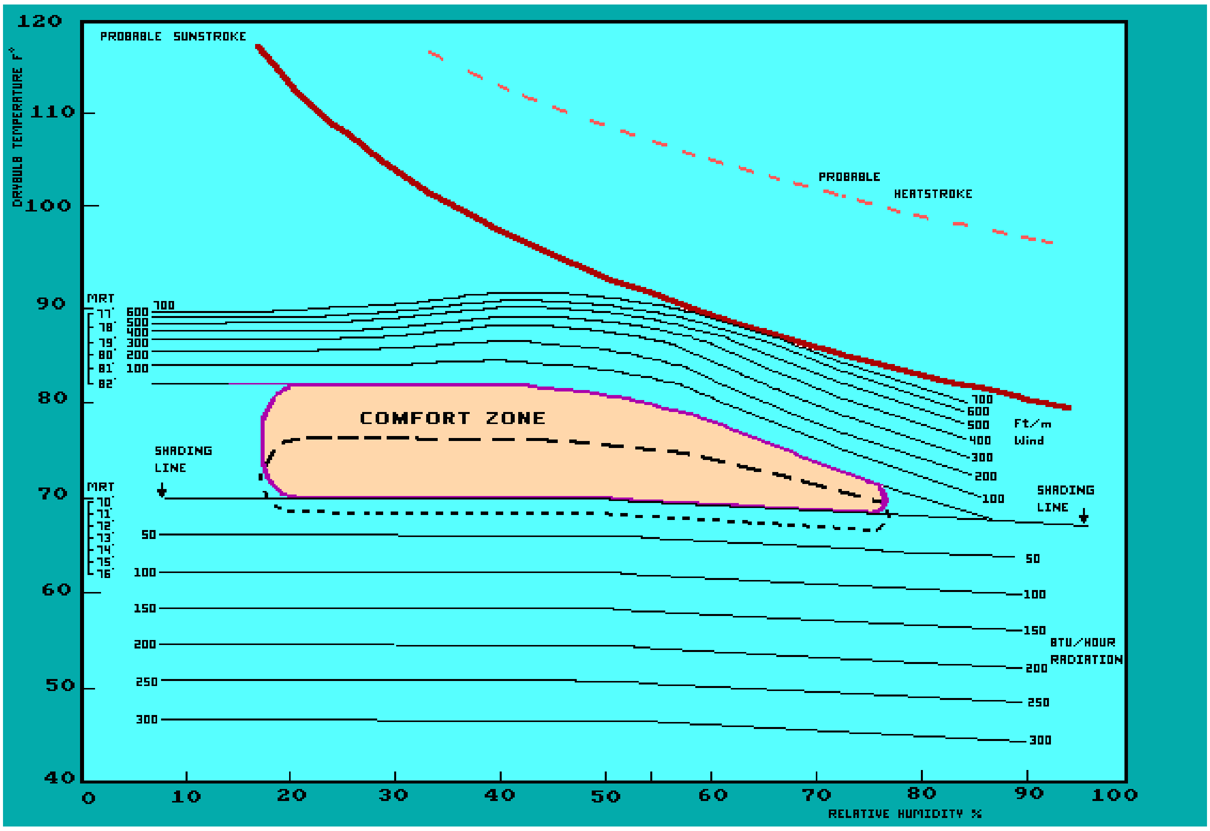


Figure 3.2 – Olgyay's Bio-Climatic Chart

3.2.3 Givoni's Bioclimatic Chart

Givoni created an advanced chart with more advantages than the Olgyay's chart that was applicable when the outdoor and indoor temperatures were close to each other. In addition to using outdoor temperature to make a comfort index, Givoni approximated the internal temperature using other different factors, such as daytime ventilation time, thermal mass and evaporative cooling (Givoni, 1998).

3.2.4 Fanger's Predicted Mean Vote

In order to assess human comfort, Fanger (1970) applied an alternate mathematical model, and assumed that the equation of heat balance can drive a measure of human thermal comfort. The level of comfort can be determined from a subject's vote on a ranking of seven points (Figure 3.3).

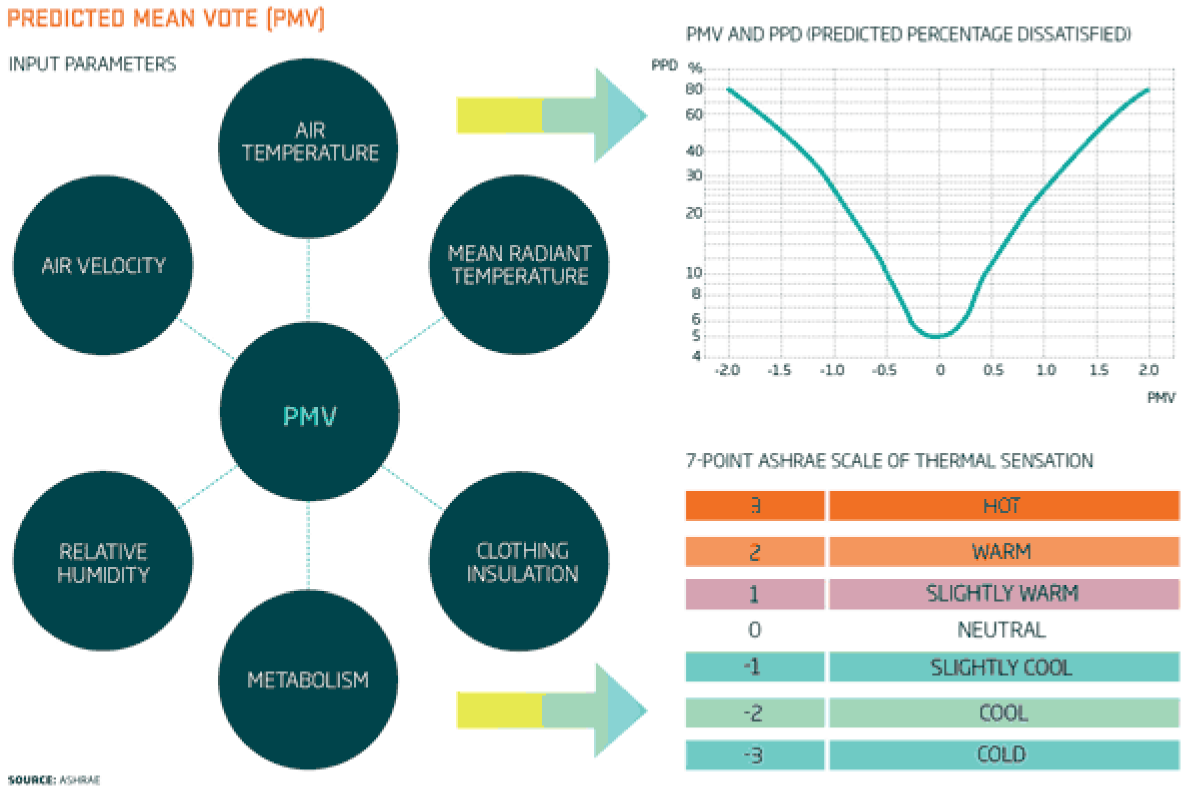


Figure 3.3 – Seven Point Ranking Scale

3.3 Selected Thermal Range Comfort

In the revised Standard of ASHRAE 55, another thermal comfort model was provided, named the ‘Adaptive Comfort Standard’ or ACS, this was adapted to naturally ventilated buildings as well as to HVAC buildings (**Error! Reference source not found.**).

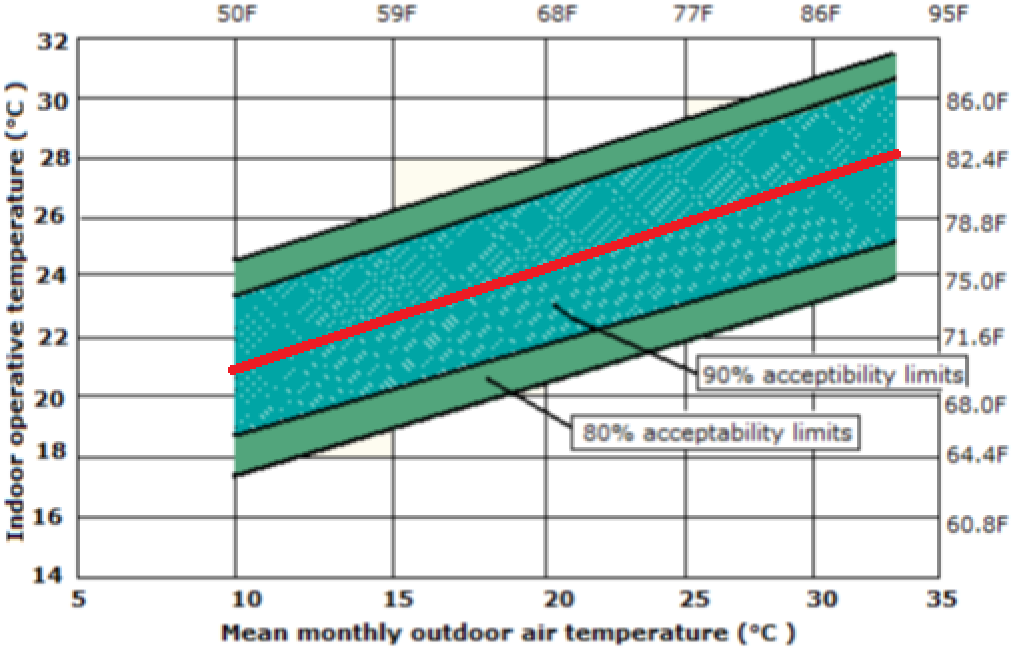


Figure 3.4 – Adaptive Comfort Standard graph (ASHRAE Standard 55, 2004)

The red line in the middle is the neutral operative temperature, or the average comfort range. Other comfort indices previously mentioned include the average indoor air dry-bulb temperature and the mean radiant temperature zones. The 80% acceptable limit line on either side of the red line is the neutral temperature plus or minus 3.5°C. The average comfort range formula presented in the ASHRAE project by de Dear and Brager (2002) is dependent on the outdoor dry bulb temperature. This formula is acceptable when the outdoor temperature is in the range of 10°C to 33°C in warm parts of the world (de Dear and Brager, 2002):

$$T_{comf} = 0.31T_{a,out} + 17.8$$

Where;

- T_{comf} *is the monthly average thermal comfort temperature*
- $T_{a,out}$ *is the average outside monthly temperature*

According to above formula, and as presented in **Error! Reference source not found.**, when the outdoor temperature is 10°C the neutral temperature given by the formula is 20.9 and, according to ASHRAE, ±3.5°C of the maximum and minimum of the neutral temp is also in the comfort range of 80% of occupants. Thus, 20.9 minus 3.5 equal 17.4, which is the minimum comfort temperature. However, when the outdoor temperature is 3°C, the neutral temperature given by the formula is 28.03, which when added to 3.5 is 31.53; this gives the maximum comfort temperature of 80% of the people in the building. So for 80% comfort, the range is almost 17.5°C to 31.5 °C, dependent on the time of year.

3.4 Iran Thermal Comfort Range

The above ASHRAE standard has limitations that might not be suitable to be applied to all regions. Fanger and Toftum (2002) believe that the adaptive comfort standard model has limitations as it is only applicable to mean monthly temperatures from 10°C to 33°C, and for large spaces. It *"does not include [a variety of] human clothing or [a variety of] activity or the four classical thermal parameters that have a well-known impact on the human heat balance [air temperature, radiant temperature, air velocity and humidity] and therefore on the thermal sensation."*

As a result, Heydari (2009) developed the ASHRAE standard in the context of Iran. The country, due to its various climates which ranges from subtropical to sub-polar needs a more comprehensive standard to determine the thermal comfort levels. A high pressure belt hits west and south to the interior of Iran, while low pressure systems develop over the warm waters of the Caspian sea, the Persian Gulf (Heydari, 2009). In addition, due to the position of the mountain ranges and location of seas, various temperatures in different places of country are experienced. Summer temperature ranges from 55^{o}C in the central desert, to as low as 1^{o}C in north-west of the country.

Heydari (2009), in order to propose an acceptable thermal range in the country, conducted field studies and the results showed a good arrangement between comfort temperatures and the mean outdoor temperature. The findings of the study confirmed that people in Iran could achieve comfort in a wider range than the ASHRAE standard or ISO 7730 standard.

Heydari (2009) introduced an equation for comfort temperature calculation in Iran as follows;

$$T_{comf} = 0.30 T_{a,out} + 17.8$$

$$\text{When: } (5°C < Tom < 30°C)$$

According to Heydari (2009), below about 10^{o}C, depending on the building, heating is required, while above 30^{o}C, depending on the extent of shading and magnitude of internal heat gains, cooling is required. The comfort temperature range is ±3.5°C of the maximum and minimum of the neutral temperature that 80% of occupants are comfortable or ±2.5°C that 90% of people feel comfort.

3.5 Concept of Thermal Mass and Heat Transfer

Humans have used the thermal mass in their living places since the ancient times to reach their thermal comfort. Many researchers across different regions describe the initiatives that people applied to their shelters. The vernacular buildings in different regions have been a focus of attention for much research. The natural ventilation and thermal mass insulation of these buildings are the key factors for comfortable temperatures for the occupants.

Cardinale (2013) assessed vernacular dwellings in the warmer climate of south Italy and concluded that high thermal mass of the building fabric can increase the level of constant indoor temperature without the use of air conditioning in midsummer. The thermal storage is also able to guarantee the comfort levels using simple heating systems during the cold seasons. A great number of vernacular building even have a better thermal performance than the new built dwellings. Field research conducted in south of France by Cantin (2010), confirms that the average energy consumption of existing dwellings is higher than the historical buildings, which is as a result of a stronger thermal correlation between outdoor and indoor environment in the historic buildings. Thermal mass is one of the most influential parameters for the vernacular buildings. In this section the thermal impact on building energy efficiency is widely discussed. Many researchers focused on the significance of strategies against high energy consumption in buildings by designing homes with massive thermal mass that can address passive features of a building in order to offset the expected temperature rise. Research by Bill Duster Architects and Arup (2004), confirms that masonry houses that benefit from their high thermal mass can potentially contribute to a significant level of energy optimisation over their lifetime compared to lightweight timber frame buildings.

However, low energy buildings with robust thermal insulation, airtight building shells and often oversized window areas are extremely vulnerable to overheating (Kisilewicz, 2015). The European countries traditionally consider the energy efficiency of buildings based on their cold climate conditions, therefore they are regarded as “heating dominated climates”. As a result of growing thermal insulation use and the use of solar gains in cold climates, overheating phenomena can occur during the warm season. In many regions of Europe the new built energy efficient buildings encounter with overheating issues during summer. European Directive 2010/31/UE, “on the energy performance of buildings” (European

Commission, 2017) emphasise that the building energy efficiency should be met not only in winter, but throughout the year, and not only with regard to facilities, but also to “passive heating and cooling elements, shading, indoor air-quality, adequate natural light and design of the building”. The overheating issue in this region mostly occurs as a result of high airtight buildings and the insulation materials (BRE Guidance Document, 2016). Field research by Simson, Kurnitski, and Maivel (2017) in Estonia confirms that the modern buildings suffer overheating during summer while old buildings are within the comfort regulation range. The study suggested that without adequate passive temperature control the new apartments regularly overheat.

To tackle overheating in dwellings, the primary cause of this phenomenon needs to be considered. In this section, in order to show the concept of energy transfer in the building elements and the influence of the mass, the following concept of heat storage is shown.

Internal temperature can be regulated by the implemented thermal mass in a building’s fabric. This procedure occurs by a steady storing and releasing of heat per unit volume (Dincer, 2009). Generally, any material capable to absorb, store and release heat is characterised with thermal mass. The thermal mass itself can be characterised by its thermal conductivity, specific heat capacity and density (Lienhard, 2013).

As a result of temperature differences, energy moves so this means heat transfers as well. Scientifically, heat transfers by three different modes; conduction, convention and radiation.

There are three important factors on the conduction of heat; density, specific heat, and thermal conductivity. Conductivity determines the ease of heat flows through a building’s envelope. Thermal resistivity is the term describing a material resisting heat condition and is shown in the following equation;

Where;

$$\mathrm{R}=\frac{1}{K}$$

- R= *resistivity (mC/w)*
- K= *conductivity (W/mC)*

From the above equation, it can be seen that a good conductor has poor resistivity and vice versa. For a material with a high heat capacity, moderate conductance and density and a high emissivity and absorptivity, this means an effective thermal mass material. Thickness of materials has a considerable role in heat transfer calculations. In addition, it is important to know the differences between steady- state and dynamic modes of heat transfer in a building element.

3.5.1 Steady state heat transfer

The term of steady state heat conduction refers to heat conduction through the building's envelope in which the temperature of both sides of wall doesn't change for a long period of time. Thickness of walls is an important factor to assume the thermal behaviour of a building. The equation below presents the resistance calculation based on the relation between its resistivity and thickness.

Thermal resistance or R-value $\mathbf{R=r*L}$

Where;

- R= *resistance* (m^2C/W)
- r= *resistivity*
- L=*thickness*

Therefore, a thick layer of material has a higher resistance to heat flow. Resistance is regarded as the R-value of a material, and the U-value of a building envelope is the major factor in the determination of steady-state heat losses and gains. In fact U-value is the inverse of R-value and can be calculated through the following equation:

Thermal conductance, transmittance or U-value $\mathbf{U}=\frac{\boldsymbol{K}}{\boldsymbol{L}}=\frac{\mathbf{1}}{\boldsymbol{R}}$

Where;

- U= conductance (W/m^2C)
- R= resistance (m^2C/W)
- K= *conductivity* (W/m^2C)
- L= *thickness (m)*

To describe a material's thermal behaviour, either resistance or conductance can be used. In steady-state mode, two building elements with the same U-value but different thickness still conduct the same amount of heat, even with different materials.

The steady-state equation is a traditional heat loss assessment for building designers. However, this kind of assessment doesn't consider the dynamic behaviour of the material that in reality, different materials perform in different ways, even with the same U-value (Clarke, 2001).

To consider the thermal mass of materials, there are two important factors to characterise the material's capacity. These two factors are the thermal effectivity and diffusivity. Thermal effectivity, or in other words thermal inertia, measures heat transfer at the surface of a material while thermal diffusivity is the term of heat transfer through the core of a material (Kalogirou, 2002). In addition to thermal effectivity and diffusivity, there are two more factors that need to be considered for an effective thermal mass in a material; decrement factor and time lag of a material.

Time lag means that changes in external temperature and also incident solar radiation do not result in immediate changes at the internal surface. Figure 3.5 shows both sides of a wall in different temperatures (Appleby, 2012). The ability to attenuate the amplitude of the outside temperature to that of the inside is known as the 'decrement factor'.

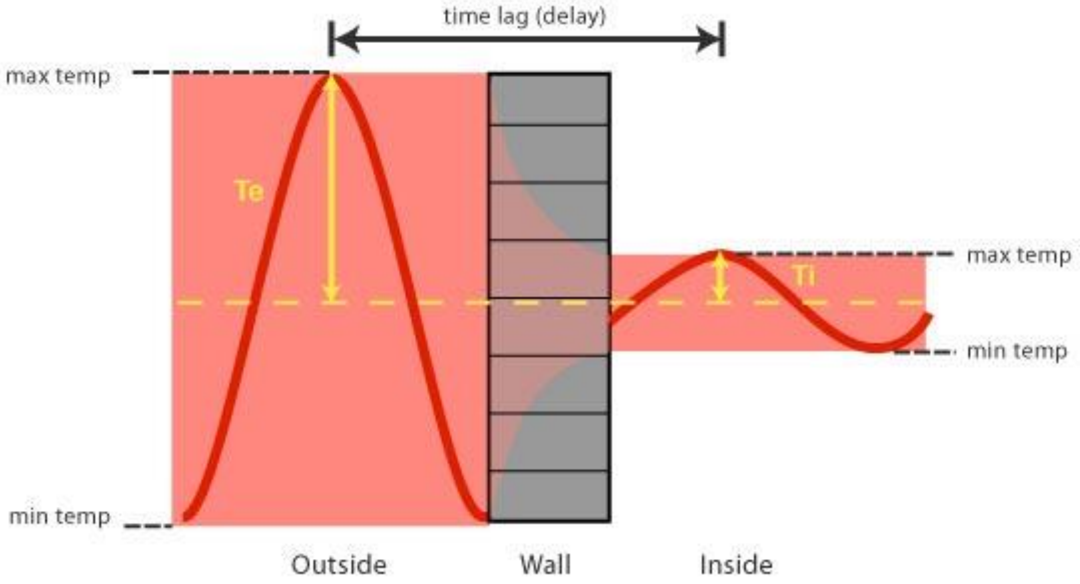


Figure 3.5 – Time Lag Procedure In Both Sides Of An External Wall

In steady state calculations, the R-value is accounted for the main consideration factor, while energy storage capacity or thermal mass has no impact on its calculation. However, it impacts on the time that heat needs to pass through into internal surface.

3.5.2 Dynamic Heat Transfer

Given the above steady state conditions for heat transfer calculations, it can be difficult to understand heat transfer in a building. As a result, dynamic calculation is the only solution to observe and predict the role of thermal mass in the building fabric.

For assessing the dynamic performance of building materials several methods can be used. These methods consider the material's admittance, time lag and decrement factors, to present their dynamic performance.

Therefore, for this research a dynamic evaluation is required. This can be done by applying simulation software, as manual calculation for a whole building seems impossible.

3.6 General Principles for Building Envelope Elements

3.6.1 Windows

Windows are important elements in buildings in different aspects. Windows fulfil many functions in buildings, such as providing visual and auditory contact with outdoors, natural ventilation, and daylighting. Furthermore, windows have important roles in passive solar heating and cooling strategies (Climate Considerations in Building and Urban Design, Givoni, p,52). In some cases, windows are designed to simply capitalize on passive heat gain during the winter, without considering the different needs that accompany each season. Those buildings with massive south glazing often come to regret this approach when the house overheats in the summer and cools down very quickly at night in the winter (More Straw Bale Building: A Complete Guide to Designing and Building with Straw, Magwood and Mack p, 60). Window sizing is a very important consideration. It must be remembered that, even in a house with good solar passive design and the highest quality of glazing, the windows are still net losers of heat in the winter and net gainer in the summer because they are the least insulative element in the building's shell (More Straw Bale Building: A Complete Guide to Designing and Building with Straw, Magwood and Mack, p, 60). Therefore, designing windows in a building depends on variety of factors, and there is no one size fits all strategy for appropriate passive solar design. Much will depend on geographical location, altitude, climate condition, building site, and daylight need inside the building.

Researches have been conducted into optimising the window type, size and location in a specific region. Inanici (2017) conducted research to establish optimum building aspect ratios and south window sizes of residential buildings by considering their thermal performance in six different climatic regions in Turkey, the results indicate that a building that has conventional (25%) south window size is preferable in hot climates due to the need for decreasing heat gain in summer. In cold climates, larger south window sizes up to a certain point are preferred due to the need for increasing heat gains in winter. Lee (2013) studied different aspect of external window's influence on building energy performance to optimize the annual heating, cooling and lighting energy consumption in five typical Asian climates. The results of the research showed that from warmer climates to colder climates, higher solar heat gain coefficient (SHGC), and visible transmittance (Tvis) window properties have advantages for energy optimisation. And also regarding the effect of U-value on heating and cooling energy consumption, from warmer areas to colder areas, triple glazing has a higher level of performance than the other glazing types, this achieved by reducing thermal conductivity. Gasparella (2011) examined the influence of various glazing systems (two double and two triple glazing), window size and orientation of the main windowed façade in the climatic data of four locations in central and southern Europe. The research results showed that the solar transmittance performs significantly better for winter and summer energy needs and for summer peak loads. The windows surface appears to be of minor importance for winter energy needs.

From the above research, it can be seen that three factors of window size, location, and glazing have a great impact on building energy performance. However, these factors have to meet the daylight requirement of building as well as energy performance. Therefore, generally building codes set a minimum window size for buildings based on window wall ratio or window room area ratio. In addition, for a more sophisticated calculation the minimum daylight factor of buildings is considered.

3.6.2 Daylight Factor

The natural light that provides illumination inside a room is usually only a small fraction of the total light available from a complete sky. The amount of daylight inside a room can be measured by comparing it with the total daylight available outside the room. This ratio, or daylight factor, remains constant for a particular situation because the two parts of the ratio vary in the same manner as the sky changes.

The level of daylight in internal spaces can be measured by comparing it with the total available outside the room. Direct sunlight is expected from both values of illuminance, and the daylight factor can be expressed by the following formula:

$$DF = \frac{E_1}{E_0} \times 100$$

Where;

- *DF = daylight factor at a chosen reference point in the room (percent)*

- E_1 = *illuminance at the reference point (lx)*
- E_0 = *Illuminance at that point if the sky was unobstructed (lx)*

For purpose of design, a standard sky is assumed to give a minimum level on the ground, and about 5000 Lux is a commonly used value.

A room in daytime with an average daylight factor of less than 2 percent will seem gloomy and occupants will probably need to use electrical lighting. A room with an average daylighting factor above 5 percent will seem strongly lit up by daylight, and windows producing this effect will be relatively large and therefore liable to give high heat losses or gains. An acceptable range of daylight factor is between 2 percent and 5 percent, with supplementary electric lighting available when needed (Baker, Fanchiotti, and Steemers, 2013).

3.6.3 Average Daylight Calculation

The average daylight factor can be predicted at the design stage using the knowledge of the glazing area, the floor area, the average angle of sky at the window, type of glass and the overall reflection of the surface. The formula below will give the average daylight factor, or it can be transposed to give the area of glazing required to give a certain daylight factor (McMullan, 2012):

$$DF = \frac{A_g \theta T}{A(1-R)}$$

Where;

- *DF = average daylight factor (percent)*
- A_g = *Glazed area of windows (excluding frames or obstructions) in* m^2
- *ϴ= angle of visible sky*
- *T* = transmittance of glazing to diffuse light, including the effect of dirt (Table 3.1)*
- A = *total area of enclosing room surface: ceiling + walls + floor (including windows in* m^2*)*
- R*= *reflectance of surrounding rooms surfaces (Table 3.1)*

Table 3.1 – Transmittance and Reflectance Values

Typical transmittance values	**Approximate reflectance value**
Clear single glazing: $T = 0.8$	Normal office or living room: $R = 0.5$
Clear double glazing: $T = 0.7$	White ceiling and light-coloured walls: $R = 0.5$
Reduce by at least 5% to allow for direct build up	

3.6.4 Thermal Bridging

Heat will choose the easiest path from a heated space to the outdoors, the chosen way is the path with least resistance. This path also doesn't necessarily need to be at right angles to the surface. Sometimes heat will use a "short cut" from a smaller sized material that has a higher level of conductivity than the main material (Passivehaus UK, 2016). This process regarded as thermal bridge.

In other words, thermal bridging occurs where materials with low thermal resistance exist within a whole body of a building element. There are several numbers of factors that determine the heat flow rate of thermal bridging from a building element;

- The level of temperature difference across the thermal bridge,
- The level of thermal conductivity of the materials passing through the insulation layers,
- The cross-sectional area of the thermal bridge.

Thermal bridges are identified in two forms, 2D and 3D. The linear or 2D are located at the junction of two or more building elements and linear thermal transmittance characterise them. The 3D forms are located where a hole has been made into the insulated wall by an element with high thermal conductivity or at the three-dimensional corner. Linear or 2D thermal bridges are the most commonly calculated thermal bridges, while 3D evaluations are carried out rarely.

Measuring thermal bridges in a building can be carried out experimentally by applying standardised test methods on two similar building elements, one by considering thermal bridges and the other one without thermal bridges.

In order to calculate the level of heat transfer through a thermal bridge, numerical calculations need to be done using methods such as finite elements or finite differences methods. To describe the calculation methods for linear thermal bridges the European Standard EN ISO10211-2 has been introduced (ISO, 2017). This calculation can also be carried out by SAP by applying the following formula which means the sum of all linear thermal transmittances (Ψ) x length of detail (L).

$$\mathrm{HTB} = \Sigma\ (\mathrm{L} \times \Psi)$$

Where;

- (Ψ): *the sum of all linear thermal transmittances*
- (L): *length of detail*

The principle for calculating the linear thermal transmittance is depicted in the illustration by Passipedia (2016) as shown in Figure 3.6. The Ψ-value represents the difference between the thermally interrupted component and the uninterrupted component that is assumed for the balance. First the heat flow or the conductance L_{2d} is determined by means of the heat flow simulation. To determine the Ψ-value, L_0 is deducted from the conductance of the uninterrupted building component. It is essential that the linear reference is adhered to throughout. If interior references are used in the context of energy balancing, then Ψ-values based on interior references must also be used. However, exterior dimensions are used more often in practice as these can easily be taken from plans and measurements.

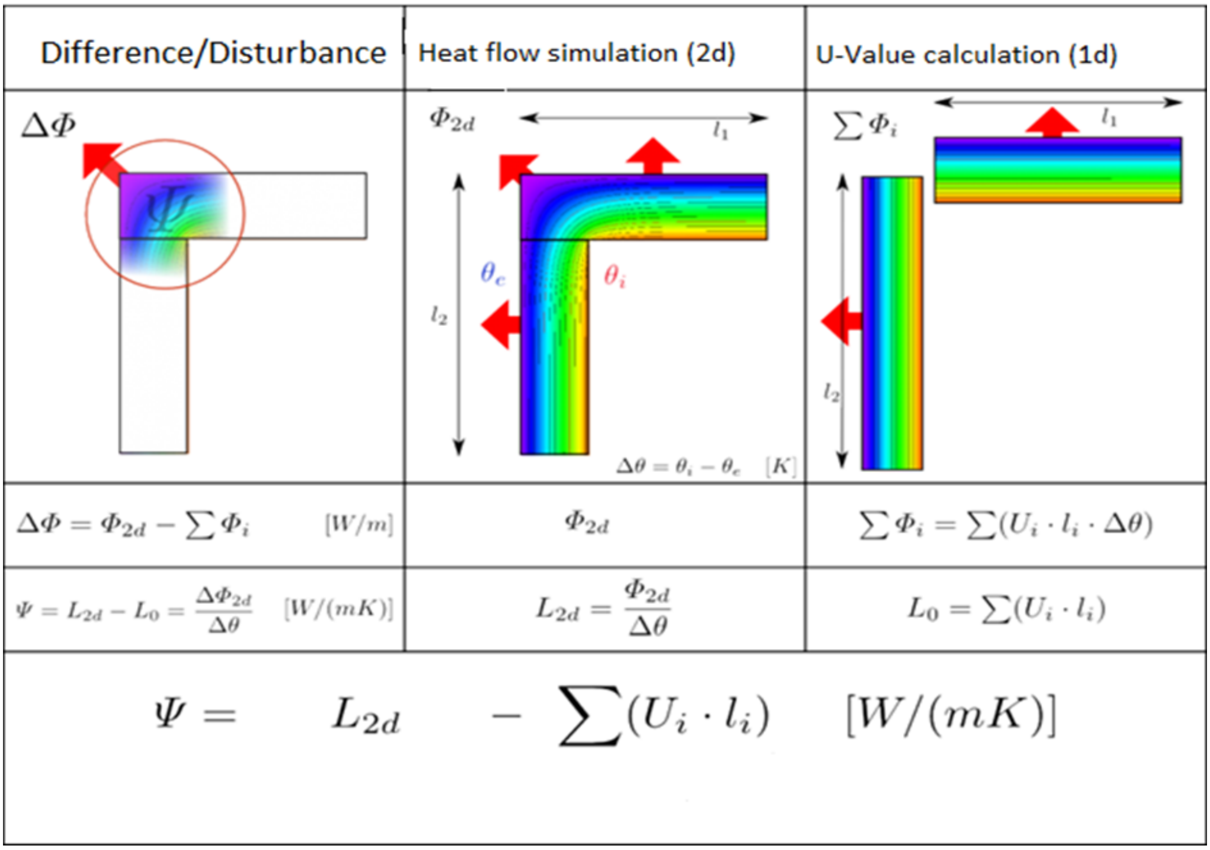


Figure 3.6 – Principles of Linear Thermal Transmittance

3.6.5 Wall to Wall Interface Thermal Bridging

Thermal bridges occur in wall to wall interface when different wall types intersect. In this case, it is necessary to apply adequate lapping of insulation beyond the plane of the wall. The climate of the region and internal condition are influential factors to determine the amount of the insulation that is required to be applied. Evaluation of thermal bridging in wall to wall interface is only possible through 2 and 3-dimentional analysis and field test.

According to the Iranian building code chapter 19 (2011), the Heat transfer coefficients (Ψ) of linear walls connecting the interior and exterior walls with inside insulation are taken from the table 3.2.

Table 3.2 – Heat Transfer Coefficient at External and Internal Walls Intersections (Iranian Building Code Chapter 19, 2012)

E1(cm) **E2(cm)**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**
15-19	0.20	0.24	0.28	o.32	0.36	0.39	0.42
20-25	0.19	0.23	0.27	0.30	0.34	0.37	0.40

External windows can impact the overall conductive heat losses through the building envelope regardless of the level of wall insulation. This is a result of the nature of heat flow to identify the path of least resistance to pass through. Installing windows based on their size impacts significantly the insulation of the building envelope. By replacing 20% of an insulated wall with a window with a U-factor of 0.5 Btu/h, the overall insulating value of the system is reduced by 45%. This high amount of heat transfer means that careful consideration of window design and insulation of the wall to window interface is required. Table 3.3 shows experimental heat flow at the wall to window interface in different cases in accordance with the Iranian building code 19.

Table 3.3 – Heat Transfer at External Walls and External Windows (Iran building code chapter 19, 2012)

Wall Thermal transmittance **E(cm)**	**0.40-0.60**	**0.65-0.85**	**0.90-1.10**	**1.15-1.35**	**1.4-1.6**	**1.65-1.85**	**1.90-2.10**
20-24	0.07	0.08	0.10	0.11	0.12	0.12	0.13
25-29	0.08	0.10	0.12	0.13	0.14	0.15	0.16
30-34	0.09	0.12	0.14	0.16	0.17	0.18	0.19
35-40	0.10	0.14	0.16	0.18	0.19	0.20	0.21

3.6.6 Shadings and Overhangs Design

Windows need shading during the overheating period of the year, which is a function of both climate and building type (Lechner, 2015). Most shading devices consist of either overhangs, vertical fins, or a combination of the two. Considering the ordinary residential building, outside windows are not only the weak part of blocking heat exchange inside and outside, but also are the core component to accept solar radiation incidence heat. It has great significance in the building energy efficiency.

The overhang and many of its variations are the best choice for the south façade. Because they are directionally selective in desirable way, they can block the sun but not the view (Lechner, 2015). Setting up reasonable outside window sunshade systems plays a major role in reducing building energy consumption of air conditioning in summer (Xu).

The first step to design an overhang is to find an overhang length that shades the south windows until the last day of the overheating period. Overheating period means the warmer months when the indoor temperature exceeds the thermal comfort of occupants. Figure 3.7 shows the sun angle at the overheated period. Since the sun is higher in the sky during the rest of overheated period. This full shade line is defined by angle A and is drawn from the windowsill. This angle can be determined by each city's sun path diagram and the angle of sun in a specific time (Lechner, 2015).

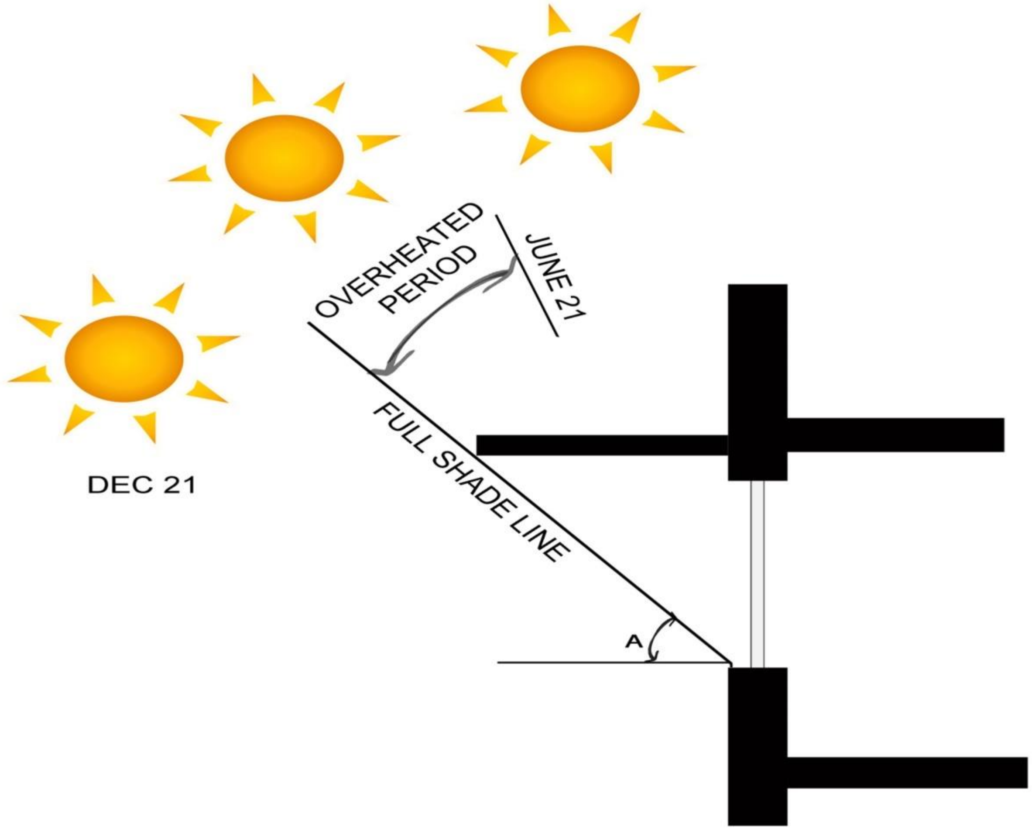


Figure 3.7 – Full Shade Line Designs

If shading is the main objective and passive heating is less required, then a fixed overhang may be used. If both passive heating and shading are desirable then a moveable overhang should be used. Table 3.4 describes design guidelines for both fixed and movable overhangs

Table 3.4 – Design Guide for Fixed and Movable Overhangs (Lechner, 2015)

Designing for fixed south overhang	Designing for movable south overhang
1. Determine the climate region of the building	1. Determine the climate region of the building
2. Determine the angle A from the sun path diagram	2 Determine angle A and B from the sun path diagram
3 On a section of the window, draw the full shade line from the windowsill	3. On a section of the south window, draw the full shade line (angle A) from the windowsill, and draw the full sun line (angle B) from the window head.
4 Any overhang that extends to this line will give a full shade until the last day of the overheated period of the year.	4. A moveable overhang will have to extended to the full shade line during the overheated portion of the year and not extended beyond the full sun line during the under heated period of the year.
5. The high of overhang can be adjusted considering the shading area.	6. The overhang should be extended during the transition period and retracted during the fall transition period.

The appropriate projection size (length of overhang) are calculated by the following Equation based on the illustrated calculation parameters in Figure 3.8.

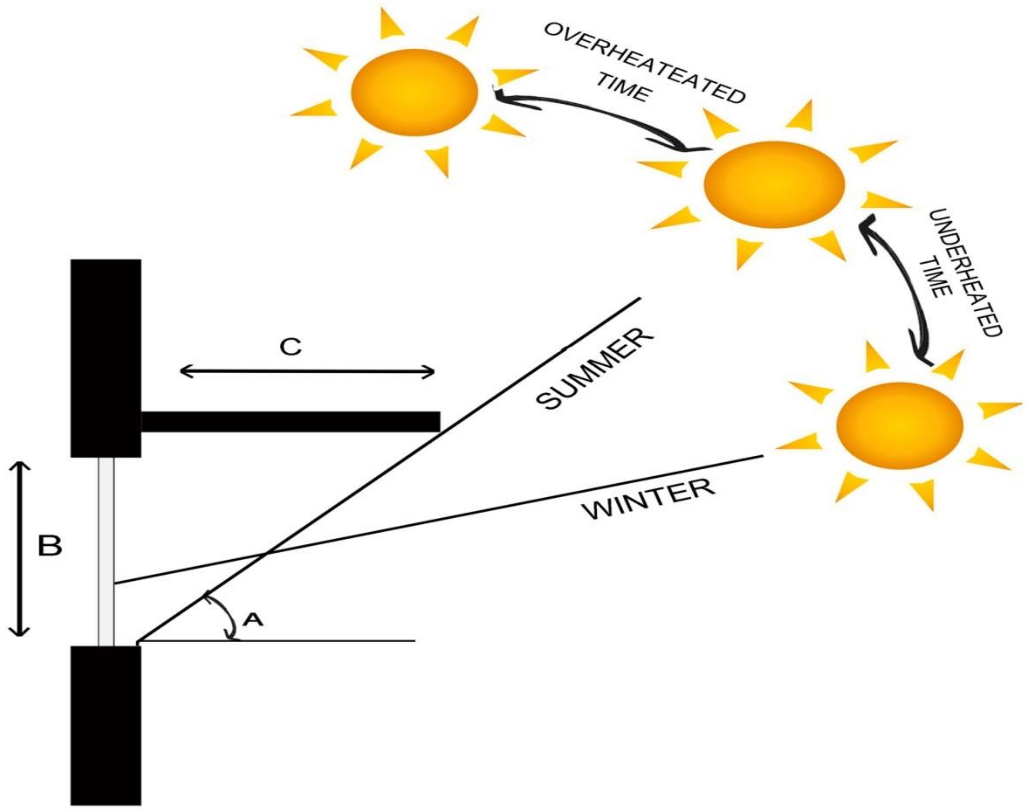


Figure 3.8 – Parameters To Design Overhang Size

Equation:

$$\boldsymbol{tan\ a = \frac{B}{C}}$$

Where;

- ***a =*** *the angle of sun during the warm seasons*
- ***B =*** the height of window
- ***C =*** *projection length*

3.8 Summary

This chapter presented an overview of three important categories of climate responsive building design; (a) strategies to determine the thermal comfort worldwide and in local context, (b) Thermo-physical properties and behaviour of the building materials in context of heat transfer and thermal mass, and (c) general principles for designing the building envelope elements within the required standards or desirable levels. By demonstrating these important factors the current design principles and acceptable ranges are determined. Therefore, an acceptable range of design setting is identified for further evaluation.

Chapter 4 – Research Methodology

4.1 Introduction

By definition research is an original contribution to the existing stock of knowledge making for its advancement. It is the pursuit of truth with the help of study, observation, comparison and systematic method of finding solution to a problem in research. The system approach concerning generalization and the formulation of a theory is also research (Yin, 2009).

According to the book (2011) research is a science, comprehensive, intellectual searching for facts and their significance or inference with reference to the problem under study. Research is considered to be more objective, methodical, well-determined scientific process of investigation and finally at the end it is resulting into a systematic report form. In general, research is always intended to invent or discover new knowledge and answers to the questions and solutions to problems.

This section will demonstrate an in-depth methodology procedure to facilitate a coherent understanding to the applied methods in this research. To plan the methodology of this research, three key terms of research, research approaches, research designs and research methods will be discussed.

4.2 Characteristics and Nature of Research

Kumar (2014), taking to the consideration the research definition, states that research is a process for collecting, analysing and interpreting information to answer questions. But to qualify as research, the process must have certain characteristic: it must, as far as possible be controlled, rigorous, systematic, valid and verifiable, empirical, and critical. Rugg (2006) characterise research based on the nature of finding something new. ‘New’ may simply mean new to everyone (primary research), or it may simply mean to the researcher (secondary) (Rugg, 2006).

Traditionally, scholars have identified three components that form the backbone of all research (a) design, (b) measurement, and (c) analysis (Heppner et al., 2015).

There are a number of attempts to explore and exploit research methodology for scientific disciplines and social sciences. The work of scholars and experts results in producing models which explain research nature, path stage, etc. (Ritchie et al., 2013)

For this research the ‘Research Onion’ (Figure 4.1), which was introduced by Saunders et al. (2009) has been selected. The main advantage of Saunders’ model is its explicit design that strategies and their sequences have been clearly drawn.

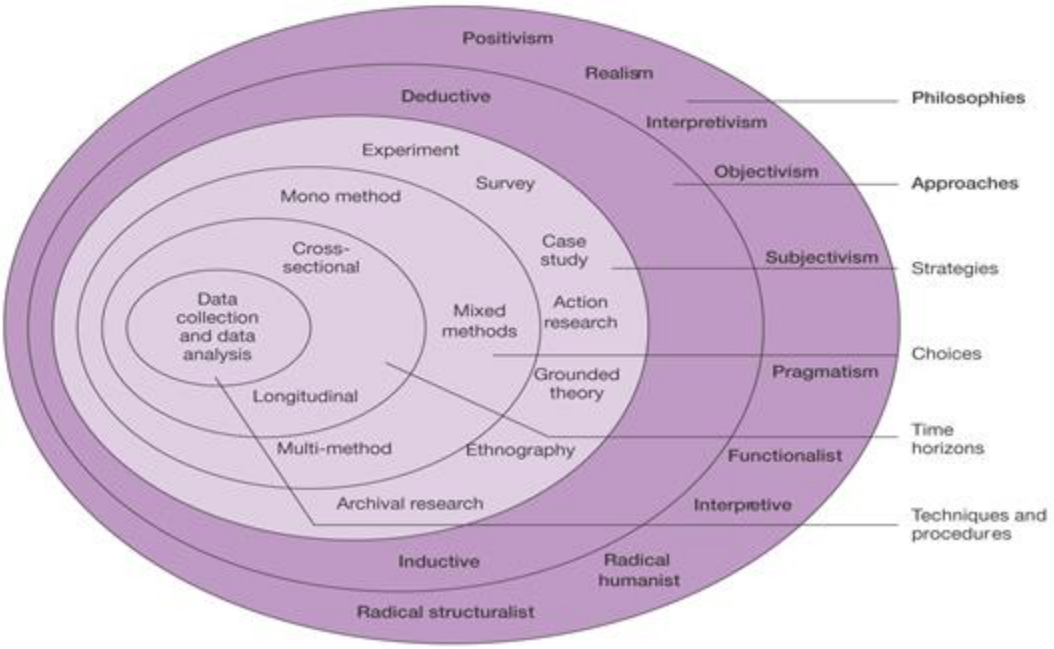


Figure 4.1 – The Research Onion (Saunders et al., 2009)

According to research onion model, the research process should start from outer layer and peels away different layers of onion till it reaches to the centre of onion that identifies the techniques that should be used to collect data in order to answer research questions. The first layer identifies the research philosophy that should be adopted for the research. The second layer considers the research approach that flows from research philosophy. The next three layers: Methodological choice, research strategy or strategies and choosing time horizon for the research, are concentrating on the process of research design. The third layer considers different methodological choices that could be used for the research which is influenced by research philosophy and research approach. The fourth layer considers the most applicable research strategy. The fifth layer concentrates on the time horizon of the research which is dependent on the research questions. The last layer is about different data collection methods that could be used for the research. Choosing the best data collection methods is dependent on previous layers and research questions.

4.3 Type of Research

Two important elements of conduction a research are (a) identifying the research type and (b) research design. Kumar (2014) has classified the research to three perspectives (a) application, (b) objectives and (c) type of information sought. However, Kumar (2014) suggests that these three classifications are not mutually exclusive, that is, a research study can also be classified from the perspective of each above items. According to Kumar (2014) if a research is conducted from the perspective of its objectives, broadly, research endeavour can be classified as: descriptive, explanatory, exploratory and correlational.

Exploratory Research is from the viewpoint of the objectives of a study. This is carried out to investigate the possibilities of undertaking a particular research study. This study is also called a ‘feasibility study’ or a ‘pilot study’. Generally, a research conducted through this method when very little is known about the topic being investigated, or about the context in which the research is to be conducted. Perhaps the topic has never been investigated before, or never in that particular context. The methods used to conduct exploratory research need to be flexible but are not usually as rigorous as those used to pursue other purposes (Blaikie, 2009). This type of research could be conducted through interviewing ‘experts’ in the subject, critical review of literature and conducting focus group interviews. According to Collis and Hussey (2013) the exploratory research is likely adopted for qualitative measures.

According to Kumar (2014) a study classified as *descriptive research* attempts to describe systematically a situation, problem, phenomenon, service or program, or provides information about, say, the living conditions of a community, or describe attitudes towards an issue. According to Andrew et al. (2011); descriptive research focuses on what is happening rather than on why it happens. It typically describes characteristics of a phenomenon through the use of surveys, interviews or observations. Furthermore, statistical or quantitative techniques will be adopted in descriptive research to collect and summarise the data, which means it aims towards an overview of the various characteristics that exists in a phenomenon and not necessarily the reasons why the phenomenon exists (De Vaus and de Vaus, 2001).

Explanatory Research is a research that attempts to clarify why and how there is a relationship between two aspects of a situation or phenomenon (Kumar, 2014). Therefore, the goal of explanatory research is to assess causal relationship between variables, and it can be used to determine the accuracy of a theory (Andrew et al., 2011).

However, it is difficult to differentiate explanatory research with descriptive research as it seeks to answer the ‘why’ questions and any explanation involves description. In order to clarify the difference DeVaus (2001) state that the explanation is used to find why phenomenon exists in order to suggest solutions, whilst the description only gives an overview of a phenomenon. In fact, the explanatory research is used to explain the relationships between variables in a situation or a problem.

The present study concentrates on achieving energy reductions in context of heating and cooling energy in mid-rise residential buildings in Tehran. As the statistics shows, energy demand and consumption in buildings in this region are by far higher than the average figures around the world. The aim of this study is to optimise the heating and cooling loads through the passive design strategies by exploring building envelope elements. It is expected that this selection would contribute to expand the knowledge and understanding of individual designers and organizations about the framework of an efficient design to reduce energy demand in residential sectors. Therefore, this research potentially grouped under both and explanatory and descriptive research.

4.4 Research Philosophy

The term ‘research philosophy’ relates to the development and nature of knowledge Collis and Hussey (2013). The research philosophy is premised by the researcher’s assumptions concerning how the world operates, how acceptable knowledge is defined, and the role values play. These perspectives have the power to direct and to steer the researcher through the research process (Pasian, 2015).

There are three core approaches to reflect on research philosophy: epistemology, ontology and axiology. Each contains important differences, which influence the way a researcher think about the research process (Collis & Hussey, 2013)

4.4.1 Ontology

Ontology refers to the nature of the reality. This raises questions of the assumptions researchers have about the way the world operates and the commitment held to particular view (Saunders et al.). According to Carter and Killam (2013) beliefs about what is real or true determine what can be known about reality. Ontological questions include: what exists? What is true? How can the existing things be sorted? In ontology in order to produce valid knowledge two aspect of ontology are considered; Objectivism and Subjectivism.

Objectivism (Richard F. Fellows, Anita M. M. Liu) considers that reality can be recorded objectively and analysed structurally, whilst subjectivism is subjectively phenomenological and interpretative (usually reliant on experience of the researcher).

For this research, the reality and workability of passive design performance in different region has been proved already through past experiments and implementation. In addition, general strategies of passive design are known, thus these strategies are to be experimented in this research by applying to the semi-arid climate region considering the region construction practices.

The potential amount of energy reduction, by applying passive design strategies in the research, will show how these strategies will contribute towards energy efficiency. These potential reduction amount need to be distinguished by mathematically calculation of statistic and cases data. Therefore, given the above explanations, this research needs to employ an objective method.

4.4.2 Epistemology

Epistemology is the study of the nature of knowledge within a field of study. It is also one of the core areas of philosophy. It is concerned with the nature, methods, validity, scope, source and limits of knowledge. As the study of knowledge, epistemology is concerned with following questions: what are the necessary and sufficient conditions of knowledge? What are its sources? What is the structure? And, what are its limits? (Ahsan, 2009).

In this project, the involvement and role of climate condition and construction practices are important, because their precise details in the region of this research, and also in other regions are their source of knowledge. The focus will be on their mathematically proven data, such as weather data, material mechanical properties and their efficiency selection. In other words, it is about understanding the phenomena via the meaning that, passive strategies, weather data and material characteristics assign to those objective issues. As an objective approach, the researcher is independent from what is being researched (Ahsan, 2009).

This research will emphasise on quantifiable observation that lend themselves to statistical analysis rather than emphasising on interoperating interviews or personal views of participants. Therefore this research approach will be positivism.

4.4.3 Axiology

Axiology is a branch of philosophy that studies judgments about value Saunders et al. (2009). In addition, it concerns what role the researcher’s value play the research process. Values affect the choice within the research process and axiology containing ethics, aesthetics and religion is indeed a fundamental philosophical dimension of a paradigm.

There are two types of values in axiology: *(a) value-laden* statements make reference to something biased on someone's judgment. *Value-free* statements about the world contain no influence by anyone's judgments. As in this research discussions are based on the results from mathematical measurement rather than researcher or other participants' views, therefore the approach will leans towards free value. Figure 4.2 presents the research approach for this research (over the line)

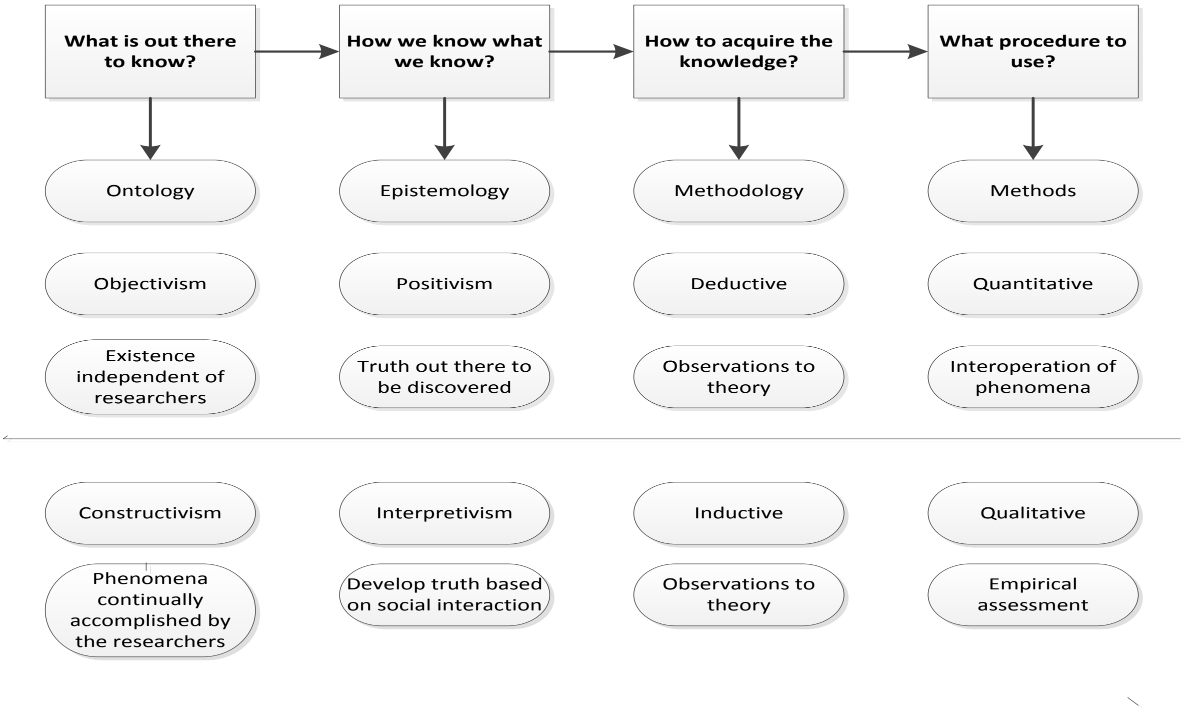


Figure 4.2 – Research Philosophy

4.5 Research Approach

To meet the mentioned objectives in the research the role of research approach is greatly important (Creswell 2003). According to Saunders (2012), there are three main methodological approaches; deductive (testing theory), inductive (building theory) and abductive.

4.5.1 Inductive and Deductive Approach

Inductive is often referred to as bottom-up approach to knowing, in which the researchers use observations to build an abstraction or to describe a picture of the phenomenon that is being studied. In addition to this, inductive reasoning usually leads to inductive methods of data collection that through which the researcher (1) systematically observe the phenomena under investigation, (2) searches for patterns or themes in the observations, and (3) develops a generalization from the analysis of those themes (Lodico et al., 2010). As the mentioned approaches above are out of this research framework, therefore, this approach won’t be applied in this research.

In contrast, deductive reasoning uses a top-down approach to knowing. Researchers use deductive reasoning by first making a general statement of prediction and then asking evidences that would support or disconfirm that statement. There are models of deductive strategies that form a hypothesis that is tested against data, usually obtained from carefully planned experiments. And the aim is not to prove the hypothesis, but rather to attempts to its ‘falsification’ and consider it to be ‘conditionally valid’ until falsified (Bodart and Evrard, 2011). For this research the concept of passive design and building envelope is the main subject of this research. The workability of this concept has been proven through several experiments and research studies in many regions. Although, this is unknown that if this concept will be efficiently applicable in Tehran, this research predict that by applying related strategies this concept will also be effective in Tehran. Therefore, deductive approach is considered as the most appropriate approach for this study.

The abduction approach is the combination of the deductive and inductive approach and is used to explore, examine and explain relationship between variables in a particular situation.

4.6 Methodological Choice

Research methodology is a way to systematically solve the research problems. It may be understood as a science of studying how research is done scientifically (Kumar, 2014).

Research methodology has many dimension and research methods do constitute a part of research methods. Thus when it is talked of research methodology it isn’t only talked of the research method but also, consider the logic behind methods are used in context of research study, and explain why a particular technique or method is used and why the others are not used (Kumar, 2014).

As mentioned in previous section the research approach of this study is a deductive approach, therefore the quantitative research design is adopted to achieve the stated aim and objectives of this research. This means that this research is based on the measurement of quantity or amount. According to Kumar (2012) quantity method is applicable to the phenomena that can be expressed in terms of quantity. According to R. Murray Thomas (2003) quantitative methods are characterised by two sets of writers:

1. Quantitative research uses numbers and statistical methods. It tends to be based on numerical measurement of specific aspects of phenomena; it abstracts from particular instances to seek general description or to test casual hypotheses; it seeks measurement and analyses that are easily replicable by other researchers.
2. Quantitative researchers seek explanations and predictions that will generalize to other persons and places. Careful sampling strategies and experimental designs are aspects of quantitative methods aimed at produce generalizable results. In quantitative research, the researcher's role is to observe and measure, and care is taken to keep the researchers from 'contaminating' the data though personal involvement with the research subjects. Researchers "objectively" are of utmost concern.

4.7 Justification for Selecting Experiment and Case Study

Considering the aim of this research, this is greatly significant to understand the selected research methods. In order to justify the criteria of research method selection, all the methods will be discussed one by one and the reason for selection deselection will be explained.

The case study method strategies have been selected for this research since a crucial part of this research is set to meet the mention objectives. To meet this objectives that part of this research will deal with parametric studies and simulation modelling of buildings by exploring their heating and cooling performance of various building components. In the other word, to test the base case buildings with a combination of selective elements, this research will measure the heating and cooling effect of the buildings. Therefore, based on these data, this research will be able to purpose a guideline for building elements selection within the local construction practices.

As mentioned previously, 8 research strategies were introduced by Saunders *et al.,* (2012). The first research strategy, *Experiment* is suggested for this study, because it requires the full control of researcher over the phenomenon being researched. Furthermore, experimental strategy is suitable primarily for quantitative research design and undertaken in a highly controlled context (Saunders *et al.,* 2012). In fact, as the researcher has full control over the phenomenon of being studied and the research design is quantitative, the experimental research strategy is appropriate for this research. The third research strategy, *Archival research*, makes use of administrative record and documents as the principal source of data (Saunders *et al.,* 2012). Bryman et al. (2002) Discusses that the term 'Archival' has historical connotations and may be misled, but it can refer to recent as well as historical documents. As this research attempts to understand the phenomenon in simulation context, the archival strategy could be partially used in this research for collecting data like case study that makes use of document analysis as one of its data collection techniques. The next research strategy is *Ethnography* which is used to study group and rooted in the inductive research approach (Saunders *et al.,* 2012). In this strategy, the researcher is required to be part of the group which is under his study to observe, talk and understand them in order to be familiar with their behaviours, shared believes, interactions and the events that shaped their lives which will enable the researcher to produce a detailed cultural accounts of the group (Saunders *et al.,*2012). Therefore, the ethnography research strategy requires more time and appropriate for part-time researchers, therefore, it is not suitable for this research. The sixth research strategy is *Action Research*, which is used to promote organisational learning to produce practical outcomes through identifying issues, planning action, taking action and evaluating action (Saunders *et al.,* 2012). According to Coghlan and Brannick (2014), this research strategy is about 'research in action rather than research about action'. Saunders *et al.,* (2012) stated that this type of strategy is best suited for part-time students who have more time and can undertake the research in the organisation that they are working for. In addition, as the nature of action research strategy is longitudinal, it is more appropriate for medium or long-term research projects rather than short-term research projects. In turn, the action research strategy is not appropriate for this research. The *Grounded Theory* research methodology can be used to refer to a methodological approach, a method of inquiry and the result of a research process (Bryant and Charmaz, 2007; Saunders *et al.,* 2012). Grounded theory strategy uses data collection techniques for collecting data and analytic procedures which will lead to develop a theory that explains social interactions and processes in a wide range of contexts (Saunders *et al.,* 2012). As this research is short-term and the aim of this research is not developing theory that is grounded in the data, the grounded theory strategy is not suitable for this particular research. The last research strategy is *Narrative Inquiry*. Saunders *et al.,* (2012) state that narrative inquiry will allow the researcher to analyse the linkages, relationships and socially constructed explanations that occur naturally within narrative accounts in order 'to understand the complex processes which people use in making sense of their organisational realities' (Musson, 2004). This research strategy is more suitable for interpretive and qualitative research; however the nature of this strategy is intensive and time-consuming, therefore these strategies are out of this research framework.

According to the mentioned factors, research aim and objectives, the ‘experiment’ and ‘Case study’ research strategies are more appropriate and suggested for conducting this research. The following sections provide further discussion on case study design and case studies design protocol, and experiments variable.

4.7.1 Case Study Design

There are different ways to approach case study design based on the epistemological standpoint of the researcher (Crowe et al., 2011). In other words, case study can be designed to meet certain requirements of research; therefore, it can be a single case or multiple cases. However, carefully identifying case study research design and details within a particular case will make case studies stronger and provide tools for researchers to study complex phenomena within their context (Baxter and Jack, 2008; Yin, 2009). Yin (2014) discusses four types of case study designs based on the 2x2 matrix that includes single- and multiple-case studies reflecting different design situations and, within these two variants, there can be unitary or multiple units of analysis (Figure 4.3). The four types of case study designs are single-case holistic designs (TYPE 1), single-case embedded designs (TYPE 2), multiple-case holistic designs (TYPE 3) and multiple-case embedded designs (TYPE 4). These classifications enable the researcher to select a case according to the nature of the particular research prior to the research data collection (Zhou et al., 2014).

According to Yin (2014), the first step in case study design is deciding, before collecting any data, on whether the researcher is going to use a single case or multiple cases. Selecting single-case design requires careful and precise investigation of the potential case in order to maximise the access needed for collecting the case study evidence. Therefore, identifying the unit of analysis (the case itself with an operational definition) is the major step in designing and conducting a single case. In the light of this, Yin (2014) states that the single-case study is an appropriate design and greatly justifiable under several circumstances and five conditions – that is having a *critical, unusual, common, revelatory*, or *longitudinal* case. These rationales have been briefly explained.

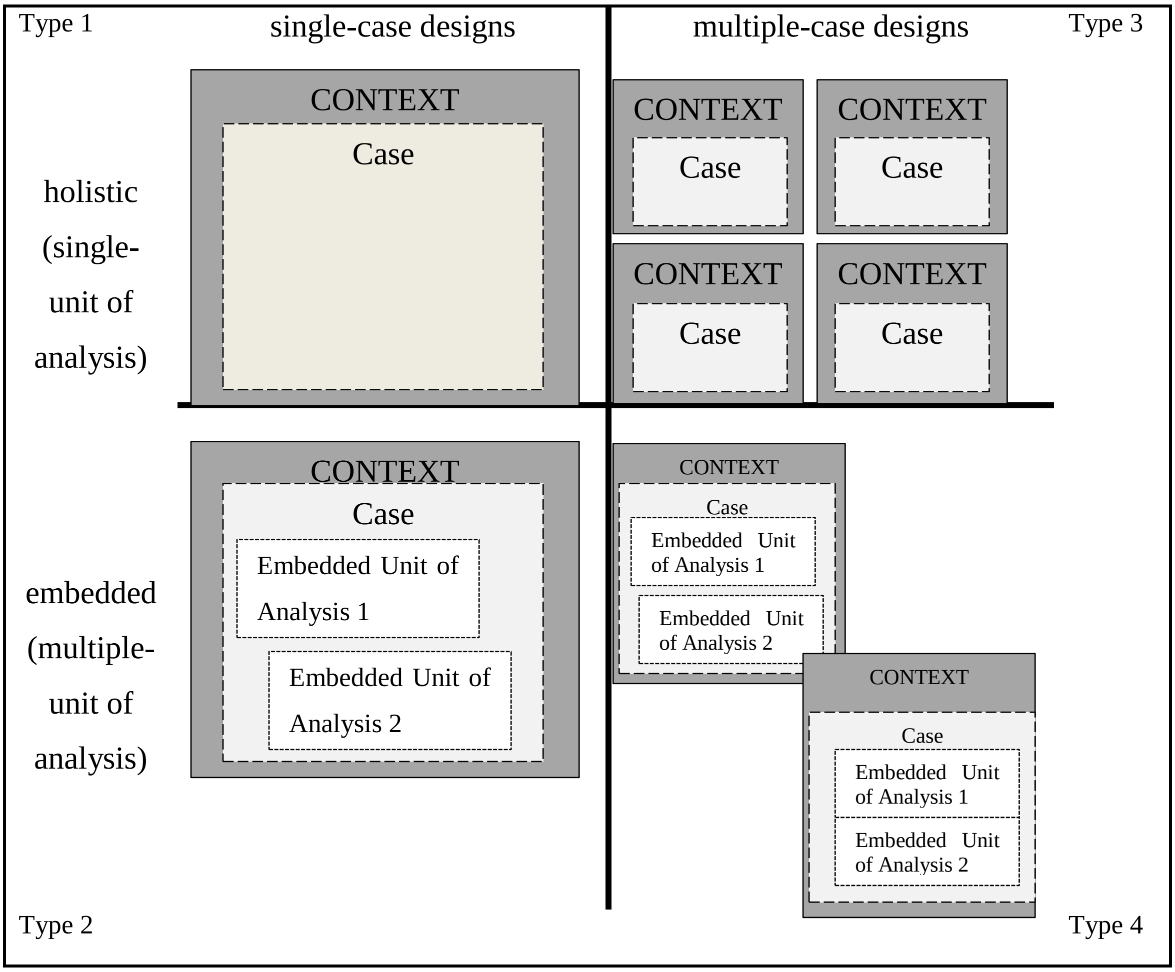


Figure 4.3 – Basic Types of Designs for Case Studies Adapted from Yin (2014)

The first rationale for the single-case study is selecting a *critical* case, where the case represents a critical test of existing and well-formulated theory or theoretical proposition. The second rationale for the single-case study is where the case presents an *unusual* or an *extreme* circumstance, deviating from everyday occurrences. Therefore, single case can be effectively utilised. On the other hand, the third rationale for the single-case study is the *common* case, where the objective of the case is to capture the conditions and circumstances of an everyday situation. The fourth rationale is the *revelatory* case, when the researcher has an opportunity to observe and analyse a phenomenon previously inaccessible to social science inquiry. Finally, a single-case study can be the *longitudinal* case when the same single case is being studied at two or more different points in time.

Despite the mentioned conditions for selecting a single-case design, Yin (2014) states that results of single-case design is quite hard to generalise to the benefit of a larger population, because the study samples in single-case design are often extremely limited. Therefore, multiple-case studies design is suggested, because the evidence and results from multiple cases are often more robust and generalised (Zhou et al., 2014). However, it has its own advantages and disadvantages comparing to single-case designs. The extreme case, the critical case and the revelatory case are associated with single-cases design which cannot usually be satisfied by multiple-cases. However, multiple-case studies considerably reduce the scepticism and criticism that are associated with case studies and provide credibility to research outcomes. Moreover, conducting a multiple-case study design can require more time and resources (Yin, 2009).

According to Yin (2014), conducting multiple-case studies research blunts the scepticism and criticism, and produce stronger effect on the research process and its outcome. Therefore, researchers are advised by Yin (2014) to have at least two cases. The results of multiple-cases are stronger when replicating the pattern matching, and such replications will increase the robustness of the original finding (Amaratunga and Baldry, 2001). In light of this, two or more case-study selection would fall within direct replication logic (Zhou et al., 2014). However, each case in multiple-case studies must be carefully selected, which is either a *literal* replication (predicts similar results) or *theoretical* replication (predicts contrasting results but for anticipatable reasons).

The single-case study design is suitable for the conduct of this research, although the phenomenon being studied does not represent critical, unusual or extreme case situation. However, the phenomenon under study is common and longitudinal case situation. Therefore, the single-case study design is the most suitable approach in the context of this research.

4.7.2 Case Study Selection

The important factor that the researcher should consider during the design phase is selecting the case(s) to study. This is due to the uniqueness of the cases not because they are representative of other cases (Crowe *et al.*, 2011). The first criterion that should be considered by the researcher in selecting a case is to maximise the understanding and perception of the researcher from a case (Stake, 1995). Case studies should be considered rich, as they are choice of many ways of investigating and empirical descriptions of particular instances of a social phenomenon (Yin, 2009). In order to enrich the research process, four residential buildings has been selected to represent the most frequent building components in Tehran. These building have been located in different part of the city with different floor area and minor different designs; however, there are few components with the same characteristics in the buildings. As the cases have similar construction materials and some similar design plans, the average energy consumptions that presents the appropriate case has been selected as the single case for this study.

4.8 Data Collection Methods

They are many ways and wide variety of methods available for designing, carrying out and analysing the result of research. However, as Blaxter et al. (2010)pointed out the choice of the best method is not simply the technical or practical question that might at first appear. Different kinds of research approach produce different kinds of knowledge about the phenomena under study. This research, as an engineering study in built environment field, requires a quantitative research to focus on measurements and amounts of the characteristics of specific cases (Knight and Ruddock, 2009). The quantitative method proposes to measure and analyse causal relationships between variables within a framework of free values. It is based on the positivism that supports empirical research since call phenomena can be reduced to empirical indicators that represent truth. This fact is due to the existence of one truth and is independent of human perception. Therefore, the investigator and the thing investigated are independent entities.

Hence, quantitative research methods work with data in numerical form collected from a representative sample and analysed usually through statistical methods. The ultimate objective is to identify the dependent and independent variables, eliminating inadequate variables, and in this way reduce the complexity of the problem so that the initial hypothesis can be confirmed or discarded (Ritchie et al., 2013)

4.9 Research Systematically Approach

The main aspect of this research methodology concerns the three phases of the project that are required to be conducted in order to answer the research questions and achieve the aims and objectives (Figure 4.4). Each phase of this research is an important requirement before moving on to the next phase of the study.

Creating the base-case concept and calibrating the simulation software is the first phase of this research. The second phase is to propose an optimised case through a parametric analysis of building designs and elements which are conventionally practiced in the country. This includes both the conditioned and unconditioned (free running) modes of buildings. During the third phase the base case is further optimised by applying additional measures. The following sections present each phase in detail.

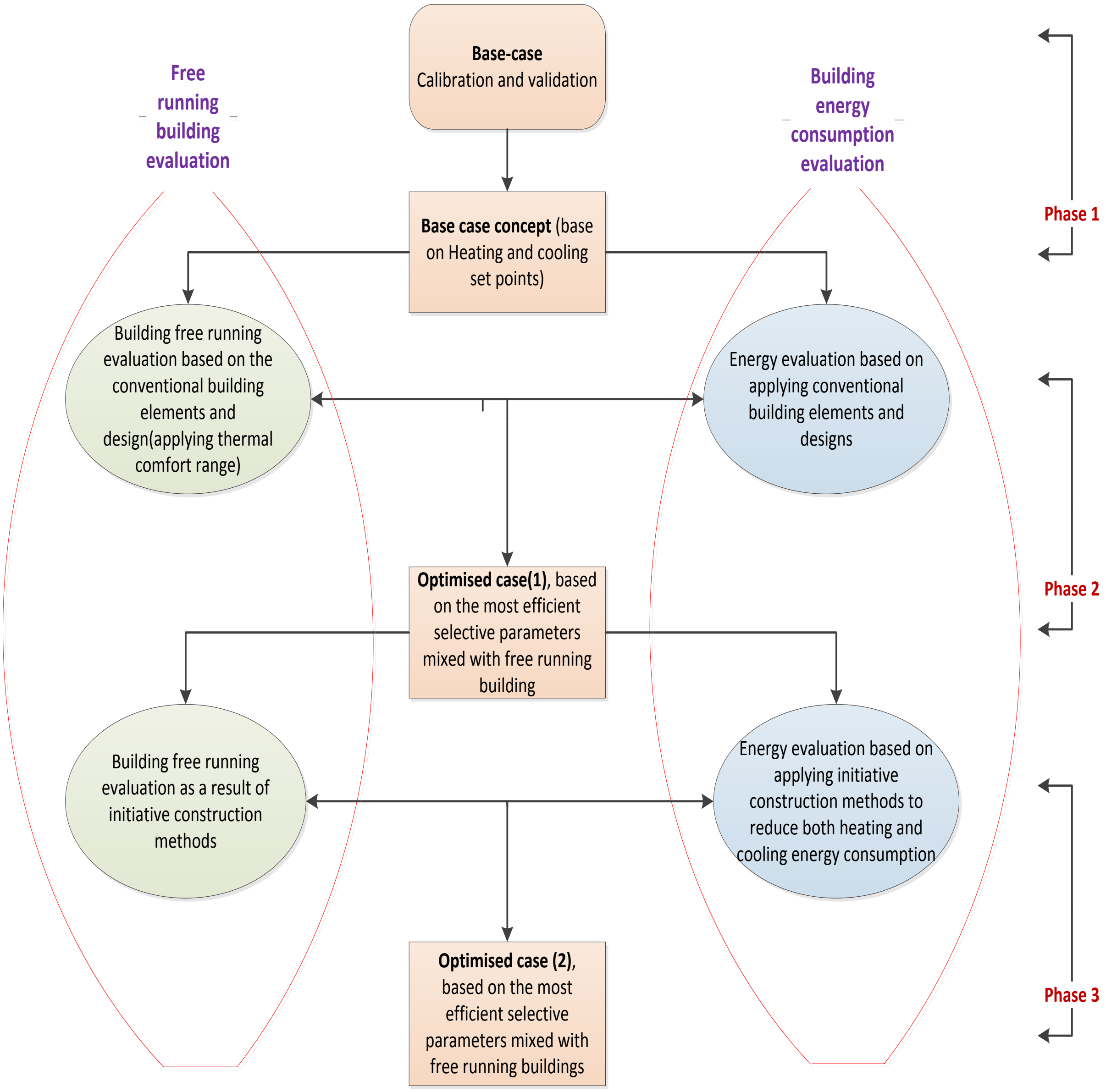


Figure 4.4 – Research Approach Overview

Phase 1

It is important to calibrate and validate the performance of the base case by employing simulation software. For this purpose, the building's drawings and energy bills were provided for simulation and comparison. However, as mentioned previously, the setting points of the occupant activities for controlling the temperature, and occupancy schedules are unknown. To solve this problem, the Iranian housing census presents the average building occupancy and other information and these were applied to the simulation software. The results of the simulation were then compared to the actual building energy bills of the same case, and other similar cases.

Figure 4.5 shows the actual and statistical details of the buildings. It is assumed that the combination of these parameters will reflect the approximate energy performance of the building.

The last step of this phase is to apply the set point temperature that is not applied in the base case, however, the new Iranian building code (chapter 19) requires that new residential buildings have temperature set points and these will be the reference case for the next phase of this research.

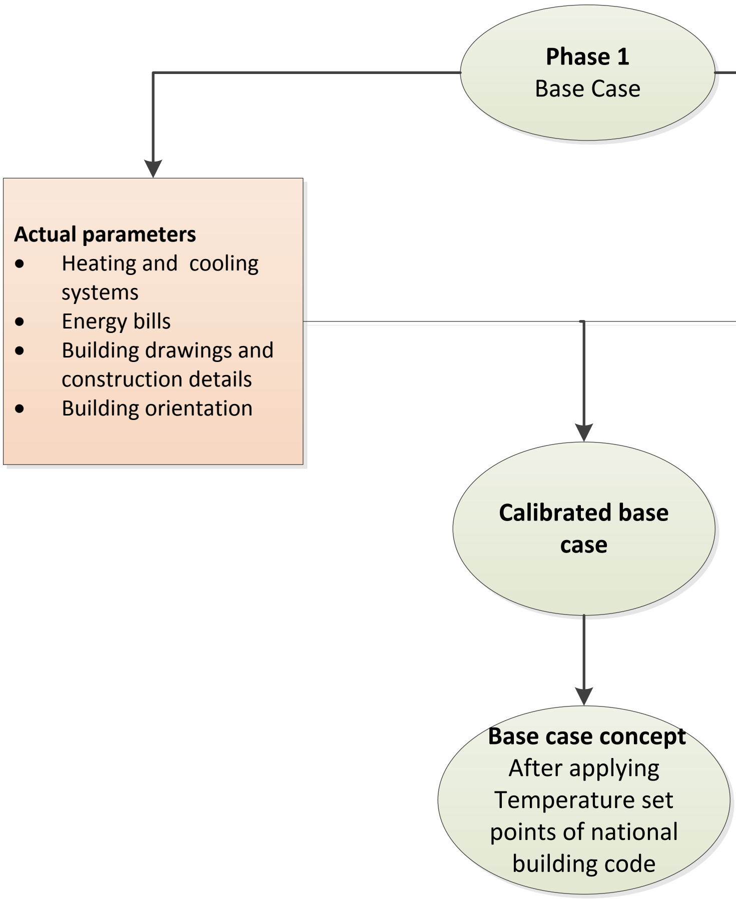


Figure 4.5 – Phase One Flowchart

Phase 2

This section defines how different building fabrics perform, under the same conditions, with respect to thermal comfort and energy consumption performance.

For this section the existing building elements such as wall types, window sizes and types, and different ventilation time plans and controls will be evaluated systematically to a) determine the best element and performance, and b) determine the best case as a result of combination of the evaluated building elements and strategies.

The model and assumptions are kept the same for all the simulations. The only changes are when the building elements and strategies are replaced in turn systematically.
A parallel analysis will be carried out to evaluate the building performance in unconditioned mode, the selected best performance building fabric and designs will then be coupled to the findings of the best energy performance case to create a mixed building design.

Consequently, the base case simulations as a result of each element are then compared to the base case and the best performance is picked to shape the Phase 2 case (Figure 4.6).

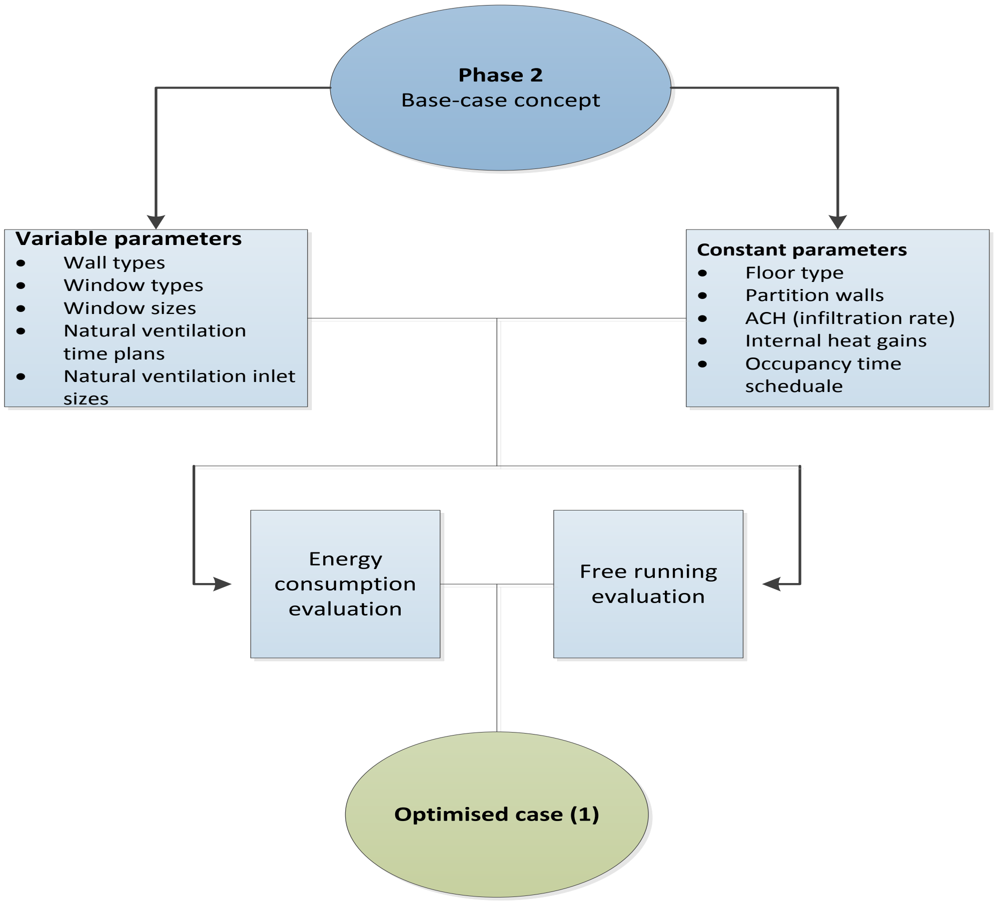


Figure 4.6 – Phase Two Flowcharts

Phase 3

The constant parameters in phase 3 are identical to the previous phase, however, the variable parameters are modified for two main reasons; a) to optimise the heating energy consumption, and b) to optimise the cooling energy consumption. For the first objective, insulation materials with the same details are applied to the wall types. For the second objective, different strategies for solar control through the windows are applied to the building.

The suggested strategies and methods will also be evaluated in unconditioned mode to identify the most efficient building fabric and design for free running buildings.
Eventually, the combination from both evaluations will be examined to suggest the best performance case (Figure 4.7)

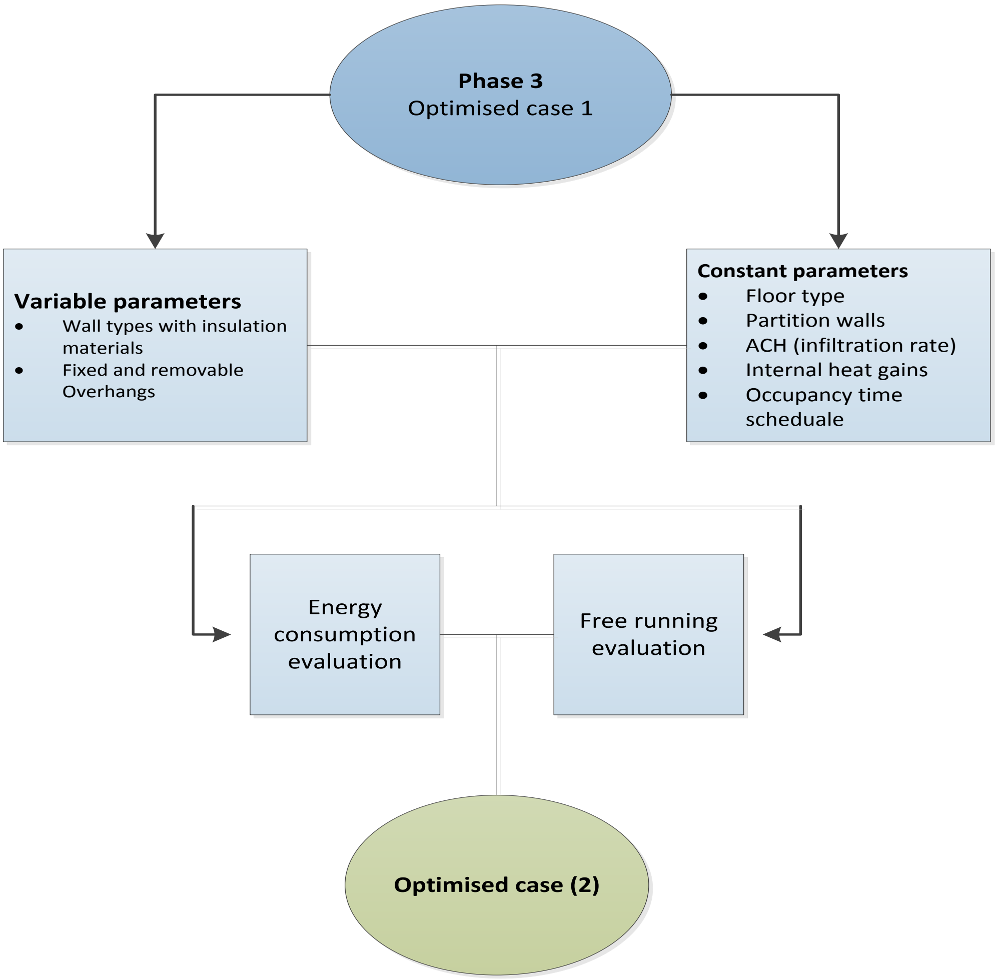


Figure 4.7 – Phase Three Flowcharts

Making multiple design decisions simultaneously is a large challenge for designers when designing for low energy buildings. This is a complicated process to select the best parameters for multiple sub-systems, and predicting this choice will represent the best integrated system. In reality, each parameter integrates with others and impacts on the overall performance. For instance, an efficient glazing system in a passive design needs to be integrated to the other strategies to be optimized. This includes the amount of thermal mass and insulation, solar gain control and space heating controls.

Therefore, in this study, depending on the parameters frequency, parametric or sensitivity analyses are considered.

The limitations of these methods have been identified and have been addressed during the analysis. For example, during a parametric analysis an analysis might be performed on a parameter, during which the other parameters are set to values that do not allow it to be properly characterized. A compelling example is the level of thermal insulation of walls, while the material with higher thermal mass performs better than the others, once they are integrated with natural ventilation during summer time, the performance changed conversely.

Chapter 5 – Development of Base Case and Scenarios

5.1 Tehran’s Climate Condition

Tehran is the capital of Iran. It is located at longitude 35.41°East, latitude 51.19°North with an elevation of 1190 m (Delfani et al., 2010). Tehran features a semi-arid climate according to the Köppen climate classification (Figure 5.1).

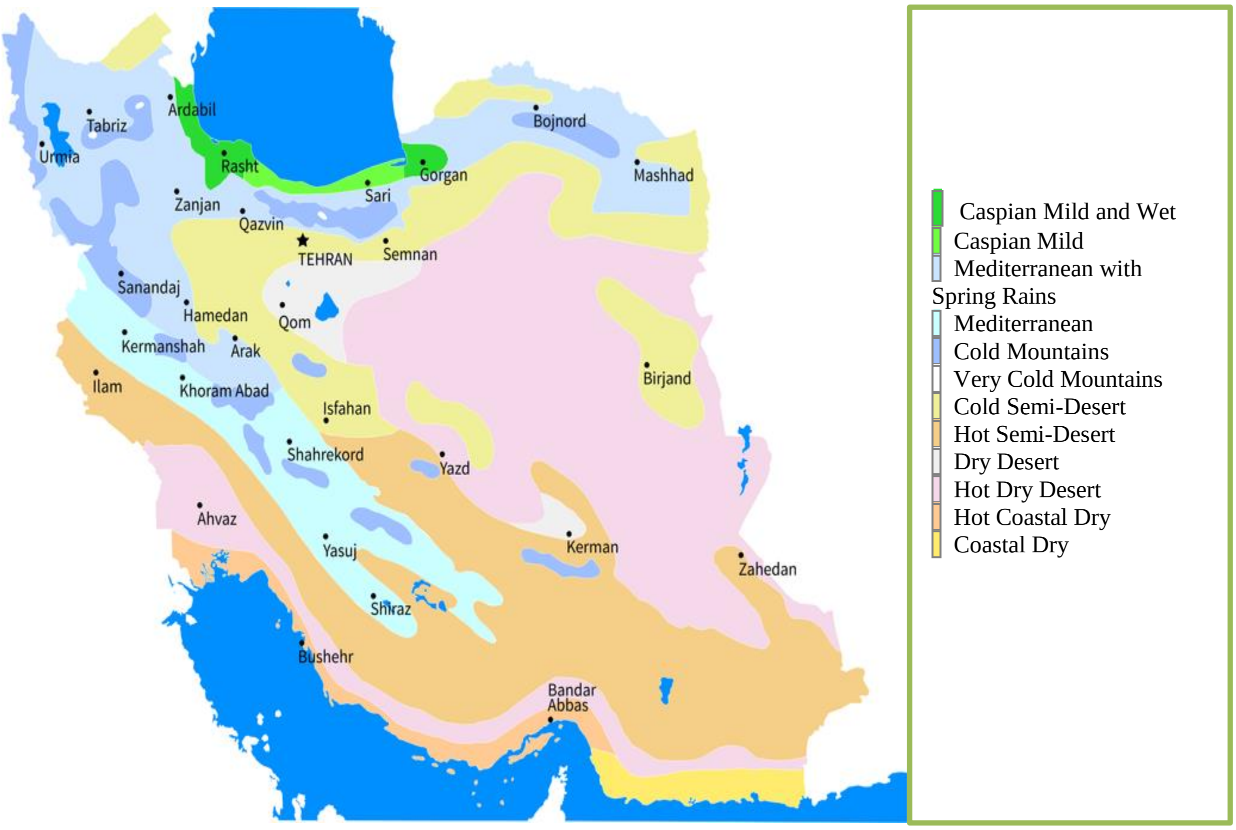
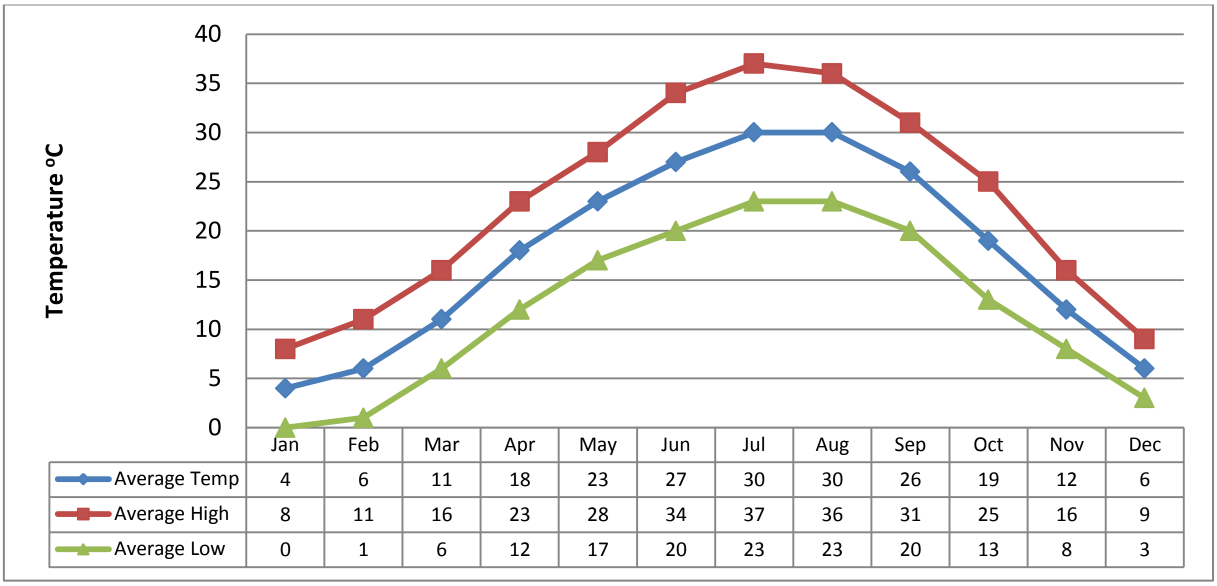


Figure 5.1 – Iran's Climate Classification, Source Iran Hydrology (2009)

Tehran’s geographical location is responsible for its unique climate classification as a semi-arid climate. This is due to its surrounding conditions with the towering Alborz Mountains to its north, and the central desert to the south. It can be generally described as mild in the spring and autumn, hot and dry in the summer, and cold in the winter (Lázaro and Marcos, 2006). In Tehran, the average temperature is 30°C from June to August. The winter average temperature is 6°C from December to February. Figure 5.2 shows the average monthly temperature and average high and low temperature (Iran meteorological organization, 2015).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temp	4	6	11	18	23	27	30	30	26	19	12	6
Average High	8	11	16	23	28	34	37	36	31	25	16	9
Average Low	0	1	6	12	17	20	23	23	20	13	8	3

Figure 5.2 – Average, High, and Low Monthly Temperatures in Tehran

During the summer, Tehran has the longest sunshine period with more than 10 hours a day. However, even during winter time, Tehran maintains an average of more than 5 hours sunshine a day. The monthly sun hours is shown in Figure 5.3 (Allmetsat, 2015).

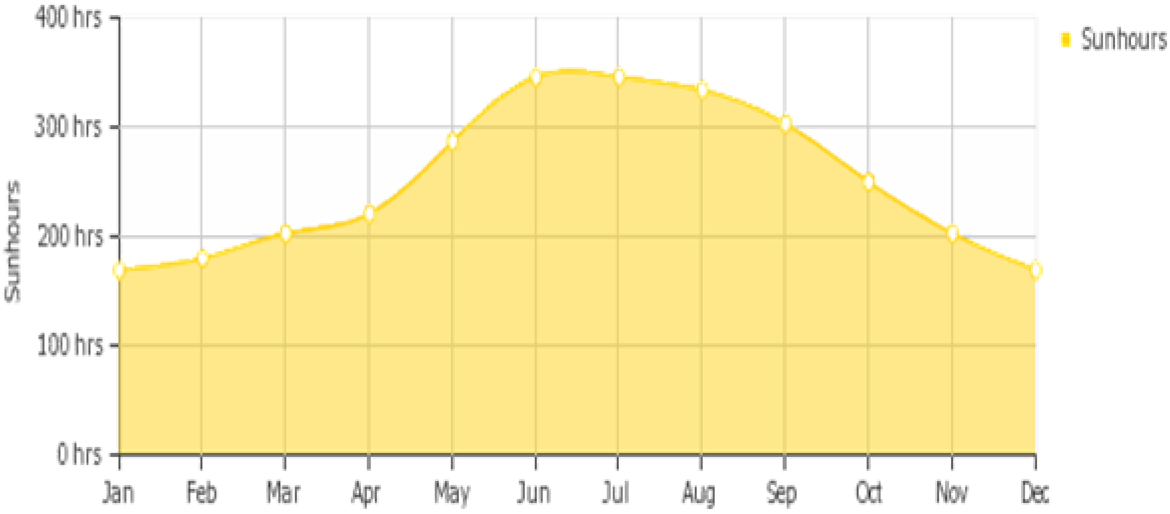


Figure 5.3 – Average Monthly Sun Hours in Tehran (Wethrt-And-Climate.Com, 2017)

As presented in Figure 5.4, over the course of the year the typical wind speeds vary from 0 m/s to 8 m/s (calm to fresh breeze), and rarely exceeds 14 m/s (strong breeze). The *highest* average wind speed of 4 m/s (gentle breeze) occurs around May 11, at which time the average daily maximum wind speed is 8 m/s (fresh breeze). The *lowest* average wind speed of 2 m/s (light breeze) occurs around December 9, at which time the average daily maximum wind speed is 4 m/s (gentle breeze).

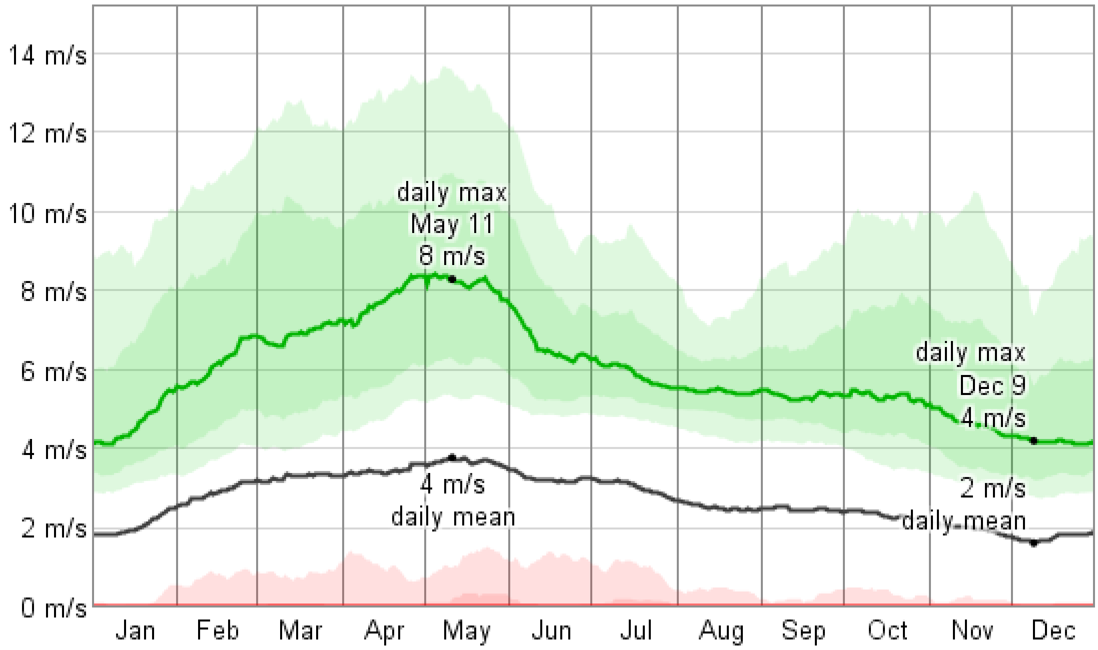


Figure 5.4 – The Average Daily Minimum (Sperling Et Al.), Maximum (Green and Thorogood), and Average (Black) Wind Speed Source: Weatherspark (2015)

5.2 Tehran's Housing Practice

The building pattern of house types is shifting in Iran. Historically, one-storey masonry courtyard houses have been widespread across the country. In Tehran specifically, this pattern has been rapidly changing in favour of multi-storey steel or concrete structures. Over recent years, the demolition of single or multi-family terraced houses and the redevelopment of terraced apartments has been expedited in Tehran.

DWnews (2013), reported that according to Nikzad, former Minister of Housing, from 2006 to 2013, more than 5.8 million household units had been built in Iran. On the basis of the licenses issued by the Municipal Building in Tehran in 2011, from the total residential units about 0.2% are single-story buildings, 0.3% are two-story buildings, 1.1% are threestory buildings, 4.3% are four-story buildings, and 94% are five-story buildings (Khabar online 2012). Annually, more than 179,000 residential units are built in Tehran, which is higher than other cities in the country. Annually, around 19,000 residential complexes are built in Tehran. Consequently, nine dwelling units are built in a residential complex on average (Khabar online, 2012). Consbank (2013) reported that according to Khadem, head of Planning and Budget Commission of the City Council, Tehran will need 3.4 millions of dwelling units until 2025.

The statistics above shows that of housing construction in Tehran, mid to high-rise buildings and residential complexes are growing sharply. Considering the future needs, it is expected that the construction rate will grow sharply.

5.3 Energy Consumption in Iran

Iran is one of the richest fossil fuel reservoir countries in the world and ranks fourth for oil reservoirs and second for natural gas. The Iranian economy is hugely dependent on fossil fuel exports. Iran is a country that is regarded as a high consumer of energy and emitter of CO_2. Iran's CO_2 emissions, as shown in Figure 5.5, ranks 7th in the world (Global Energy Statistical Yearbook 2017). Iran's final energy consumption is around 175.7 Mtoe, of which the residential sector is responsible for approximately 30% (IEA, 2015).

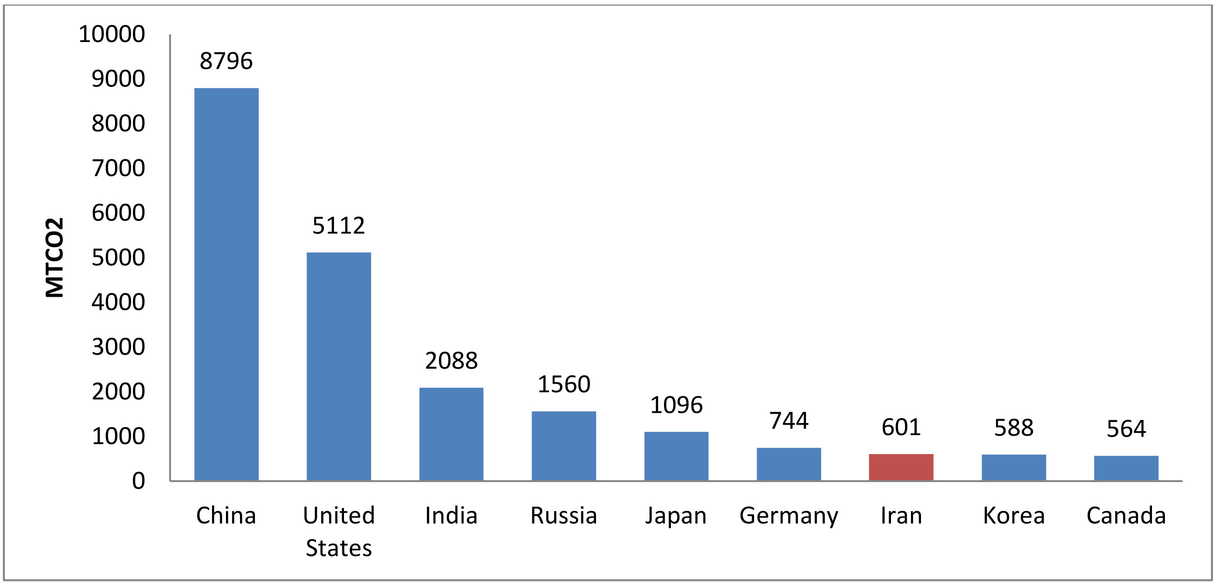


Figure 5.5 – World CO2 Emissions Ranking (Global Energy Statistical Yearbook 2017)

Figure 5.6 shows the final energy break down in Iran and it can be seen that residential buildings have the highest energy consumption in the country, this is higher than the industrial and transport sectors.

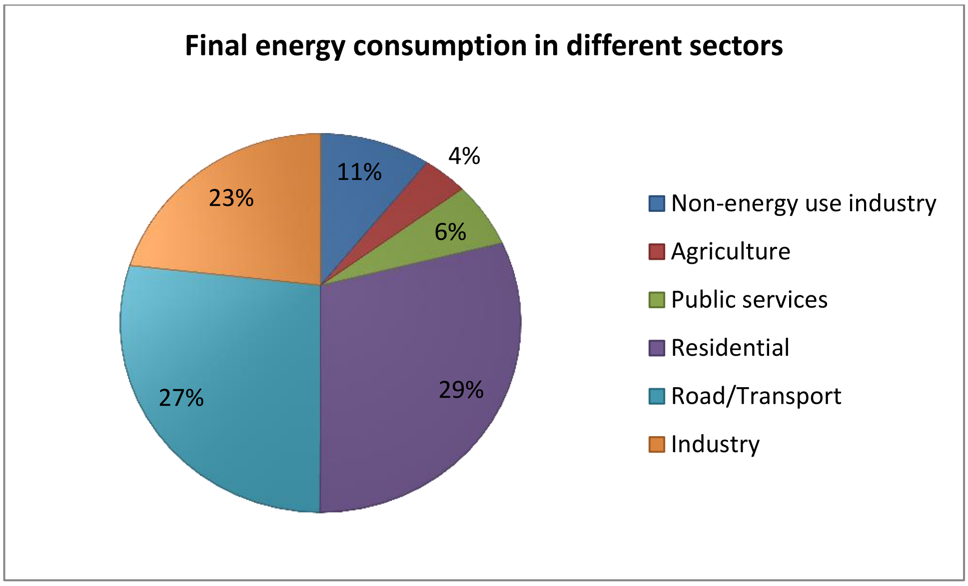


Figure 5.6 – Final Energy Consumption Breakdown by Sector

Energy consumption in Iranian domestic buildings is among the highest top ten countries and according to IEA (2015) it ranks 8th in the world. However, Iran is the lowest consumer of renewable energy among the top countries as only 0.3% of its energy for residential buildings are provided by renewable and biomass energy. As shown in Figure 5.7, by considering the fossil fuel energy consumption in domestic buildings, Iran ranking shifts from the 8th position to 5th after India with a minor difference in fossil fuel consumption.

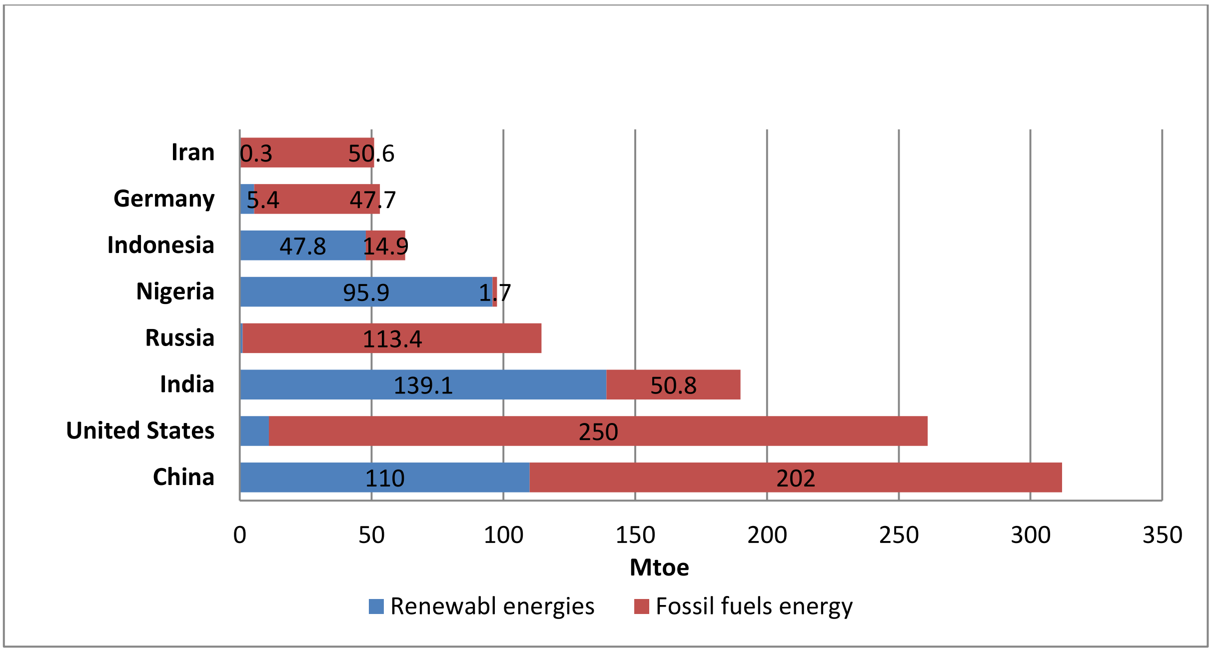
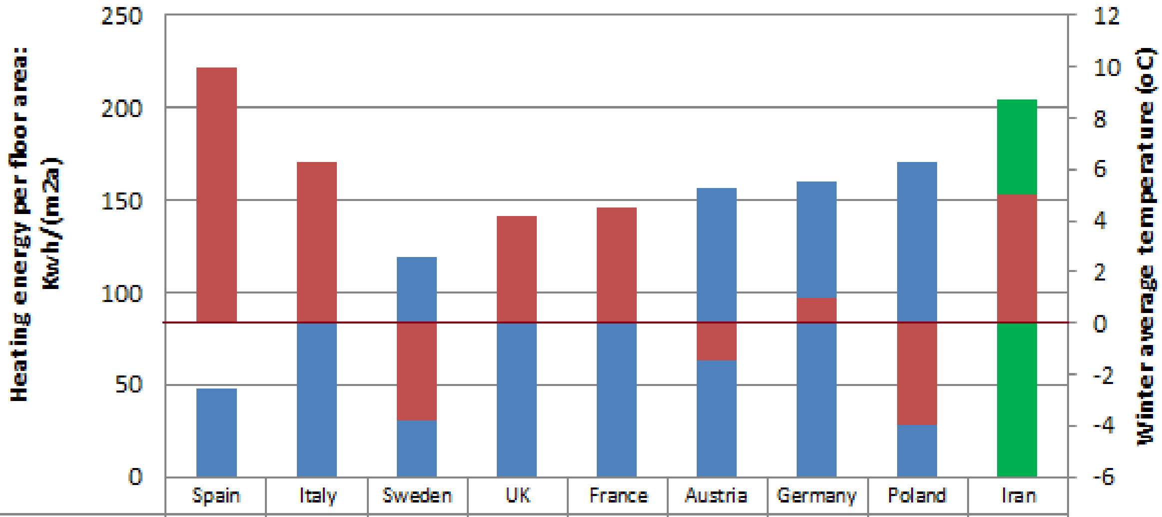


Figure 5.7 – Total Domestic Energy Consumption (Fossil Fuels and Renewables) In Eight Highest Domestic Energy Consuming Countries

In order to demonstrate the high energy consumption in Iran, the required energy for heating spaces are compared with some major European countries. This comparison has considered the total heating energy by presenting the monthly average temperatures in winter months of December, January and February. As shown in Figure 5.8 Iran has a relatively warmer winter than most of the listed countries, although the heating energy consumption by considering the countries winter temperature is by far higher than European countries. For instance, the average temperature of the selected months in France has almost similar temperatures to Iran by being 10% colder, while, conversely, the amount of heating energy is around 35% less than Iran.



	Spain	Italy	Sweden	UK	France	Austria	Germany	Poland	Iran
■ Heating energy	48	102	119	133	134	157	160	170	204
■ Average winter temp	10	6.3	-3.8	4.2	4.5	-1.5	1	-4	5

Figure 5.8 – Average Annual Space Heating In Selected European Countries and Iran Along With the Average Winter Temperature in February, January and December (EU, 2016)

The Iranian government is allocating huge subsidies to energy. This figure is estimated to be 82 billion US dollars annually, of which gas and electricity accounts for 36% and 21% respectively (*Hamshahri Online*, 2012). Although for the last few years government has decided to lift these subsidies, the complete lift of subsidies leads to an increase of household expenditures of 34% in urban and 27% in rural areas (Karbassi et al., 2007). In effect, the government decided to partially remove the subsidies, in turn, allocating a monthly cash benefit (cash handouts) to all Iranians. According to the Iran Daily (2010), until recently a four-member Iranian household received an annual average of $400 subsidies for oil and natural gas.

5.4 Households in Iran

According to the Iranian national census as of 2016, 24.2 million families in Iran live in 22.8 million dwellings. Of those, around 60% live in single family houses, and the other 40% in apartment blocks. About 75% of families live in urban areas and 25% in rural areas. Apartment blocks account of over 77% of dwelling types in Tehran. The total floor area of constructed dwelling in Iran is 1.7 billion (m^2). Apartment blocks account for 35.9% of total floor area, and single family houses 64%.

The Iranian residential sector, as table 5.1 shows, have access to over 93% of natural gas as the main source for heating demand, and 100% of electricity as the main source for cooling demand (Iranian National census, 2011).

Table 5.1 – Energy Access in Iran & Tehran

Access to utilities	Iran	Tehran
Natural gas	93.7%	100.0%
Electricity	100.0%	100.0%
Drinking water	99.3%	98.5%

In urban dwellings 77.1% of floor areas are heated during cold months, while 67.7% of floor areas are cooled during warm months. However in Tehran, these figures increase to 91.7% for heating and 90.4% for cooling.

In Iran over 80% of apartment blocks use natural gas for heating systems (e.g., gas fire heater, gas fire place and radiator central heating) to provide heating demand, and around 71% use electrical evaporating cooling system for space cooling.

The average heating system is in operation for 17 hours during the day in cold months, and cooling system for 12 hours in warm months.

In Iran over 98% of dwellings use heating systems, natural gas is the main source of energy for heating in apartment blocks by over 94%. Table 5.2 shows the most frequent heating systems in the different type of dwellings in Iran. This differs in Tehran as the majority of apartments, according to the Iranian census organization (2011), use radiator central heating for space heating.

Table 5.2 – Heating System Type in Iran In Iran

type of heating system	Apartments %	Single family houses %	Type of energy
Fire gas	3.3	86.7	Gas
Radiator central heating	90.2	12.1	Gas (99.6%)
Package	6.2	0.5	Gas (99.4%)
Fire place	0.3	0.69	Gas

In Iran electricity is the main source of cooling systems for the dwellings, and the evaporative cooler system is the dominant cooling system for both apartments and single houses as approximately 70% of apartments are equipped with this cooling system (Table 5.3).

Table 5.3 – Cooling System Type in Iran

Type of heating system	Apartments %	Single family houses %	Type of energy
Evaporative cooler	69.7	48.3	Electricity
Fan	4	12.7	Electricity
Air conditioner	7.4	9.8	Electricity
Evaporative cooler & fan	11.1	13.9	Electricity
Air conditioner & Fan	4.8	12.8	Electricity

In Iran, in winter the heating systems are almost operative non-stop in the months of December, January and February. Radiator heating systems are the most common systems by over 90% (Table 5.4). In summer time, the operative time for cooling systems is more moderate between consumers. According Table 5.5 the majority of people (63.6%) use their cooling systems for less than 1000 hours.

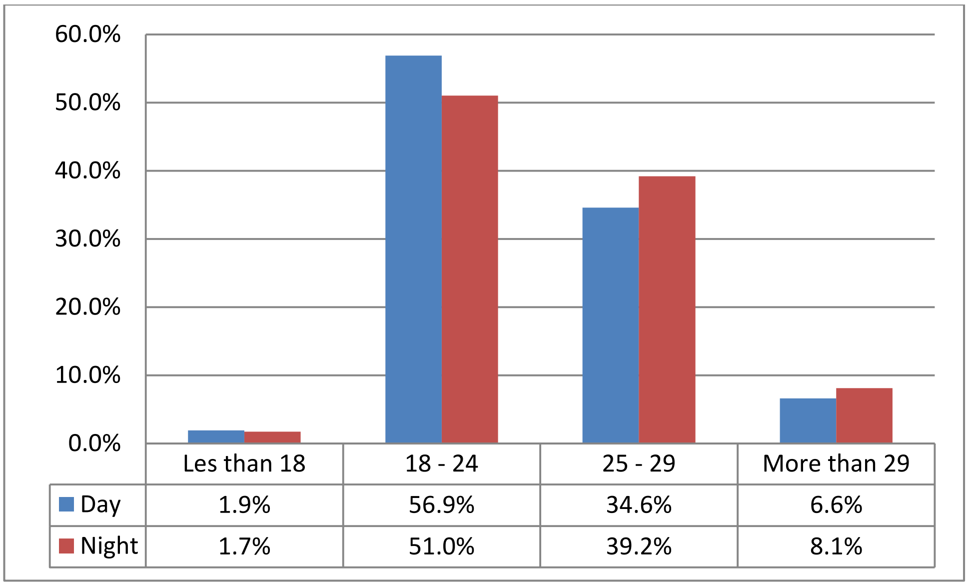
Table 5.4 – Cooling Systems Operation Time By System Type

Type of heating system	**500 hrs and less %**	**501 - b1000 hrs %**	**1001 – 1501 hrs %**	**1501 – 2160 hrs %**
Fire gas	4.7	11	16.7	67.9
Radiator central heating	0.1	3.2	6.5	90.3
Package	3.7	7.9	13.6	73.4

Table 5.5 – Cooling System Operation Time By System Type

Type of cooling system	**500 hrs and less %**	**501 - 1000 hrs %**	**1001 – 1501 hrs %**	**1501 – 2160 hrs %**
Evaporative cooler	34.5	29.1	20.4	16
Package	45.3	17.6	3.4	33.7
Air conditioner	34	23.6	13.5	29

According to the Iranian national census, over 91% of residents are unaware of their indoor temperature during the day and night. However, according to the respondents over 90% feel comfort in 18-29 centigrade indoor temperature. This temperature range accounts for both summer and wintertime (Figure 5.9).



	Les than 18	18 - 24	25 - 29	More than 29
🟦 Day	1.9%	56.9%	34.6%	6.6%
🟥 Night	1.7%	51.0%	39.2%	8.1%

Figure 5.9 – Indoor Operative Temperatures during Day and Night in All Seasons

Although, In Iran, installing double glazing windows for new buildings is compulsory by the Iranian building code, only 8.3% of dwellings are equipped with double glazed windows. Furthermore, only 6.3% of walls have been insulated and less than 5% are protected against air leakage by air tightening materials.

5.5 Iranian Energy Efficiency Regulatory or Standard Methods

In the early 1990s, the Iranian government, having come to the realisation of the burden of high energy subsidies, residential sector high energy consumption and also its extreme contribution to CO_2 emissions respectively, decided to set building energy efficiency codes and regulations (IFCO, 2015). As a result, the country today has an energy efficiency code that is called Chapter 19. The main focus of this chapter is on the reduction of energy consumption by optimizing mechanical and electrical equipment, as well as a number of architectural insulation methods. In this code, buildings are divided into four groups which are ordered in terms of their energy conservation requirements (Fayaz and kari, 2009). The building code has classified the country into three general climatic zones. The group affiliation of each building is specified by the type of the climatic zone where the city is located, building’s usage, its heated floor area and the building’s location (small or large city). In addition, there are recommendations for the mechanical and lighting equipment (Fayaz and Kari, 2009). However, within this code, it is the building envelope insulation methods to avoid heat loss which are mostly under consideration.

Along with the energy efficiency code, energy efficiency organizations have been established to improve energy consumption, such as;

- Iranian Energy Efficiency Organisation (IEEO-SABA): The aim of this organization is to improve energy efficiency through optimisation of mechanical equipment in industry (SABA, 2015).
- Iranian Fuel Conservation Company (IFCO): a subsidiary of National Iranian Oil Company (NIOC), established in 2000 with the mission to regiment the fuel consumption in different sectors through review and survey of the current trend of consumption and executing conservation measures nationwide (IFCO, 2015).

However, the energy efficiency code (chapter 19) and the related organizations (IFCO & IEEO) have had a lower than expected contribution to energy savings in buildings through the architecture design as a result of the following;

- Chapter 19: Focus on building envelope strategies, yet poor insulation and large thermal bridges (Global Environmental Facilities, 2009). Also lack of an experimental or prototype model according to the Chapter 19 in order to evaluate the amount of energy efficiency in buildings.
- IEEO: An organization run by Iranian ministry of energy, mainly focuses on energy efficiency in mechanical equipment in buildings and industry. Therefore, the organization does not offer any architectural sustainability.

- IFCO: This organization has published many books, journals and raised awareness through adverts. However books are mostly translated from the western sources, some related to energy audit and guide of materials to enhance the public awareness over energy consumption.

- Iranian residential building energy label

  The Iranian building energy label has been designed as the national standard (IS14254) to indicate the building energy performance to the occupant and for future energy efficiency regulations. This label has a rating system to classify the building energy performance based on the building's total primary energy consumption. One of the most important methods for energy rating for this label is by employing simulation software tools such as IES-VE, Energy Plus and Design Builder.

  There are different parameters to determine the building energy efficiency rate. These parameters are the building's primary energy consumption, climate of the region, building type and floor area.

5.6 Base Case and Selection of Simulation Parameters

The base case building is a three-bedroom unit of a five storey conventional multi residential building in Tehran (Figure 5.10). The selected unit is an intermediate floor which represents the majority of the new built apartment units in Tehran in terms of building envelope and floor layout. Therefore the case study is a prototype building which is constructed of a similar building (Figure 5.11).

The geographical location of the base case model is based on a building in real life; Latitude: 35° 44' 54.514" North and longitude: 51° 27' 7.200" East at an altitude of 1342.5m above sea level (Figure 5.12).

Figure 5.10 – Image of the Actual Building

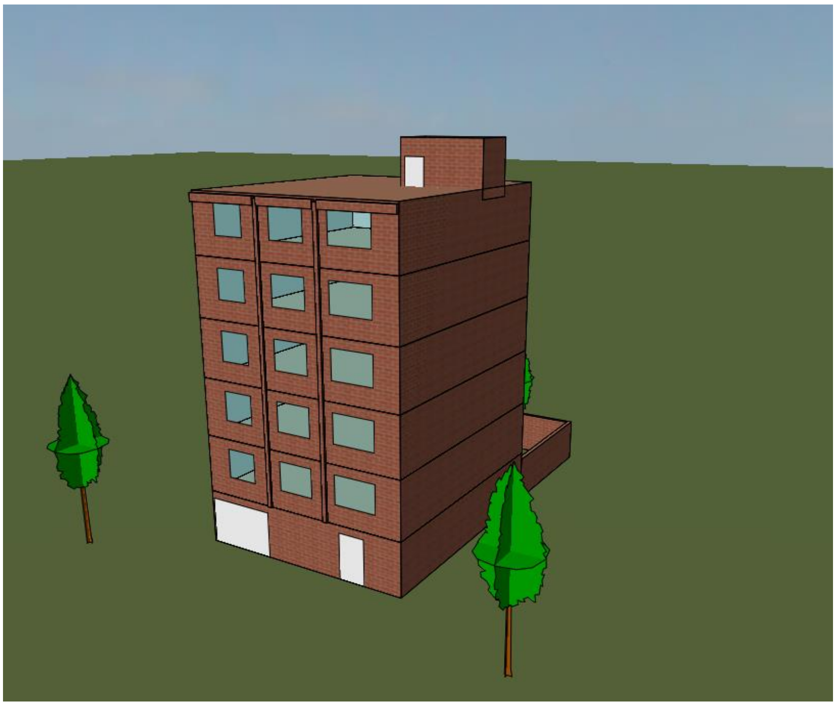


Figure 5.11 – Building Prototype Model

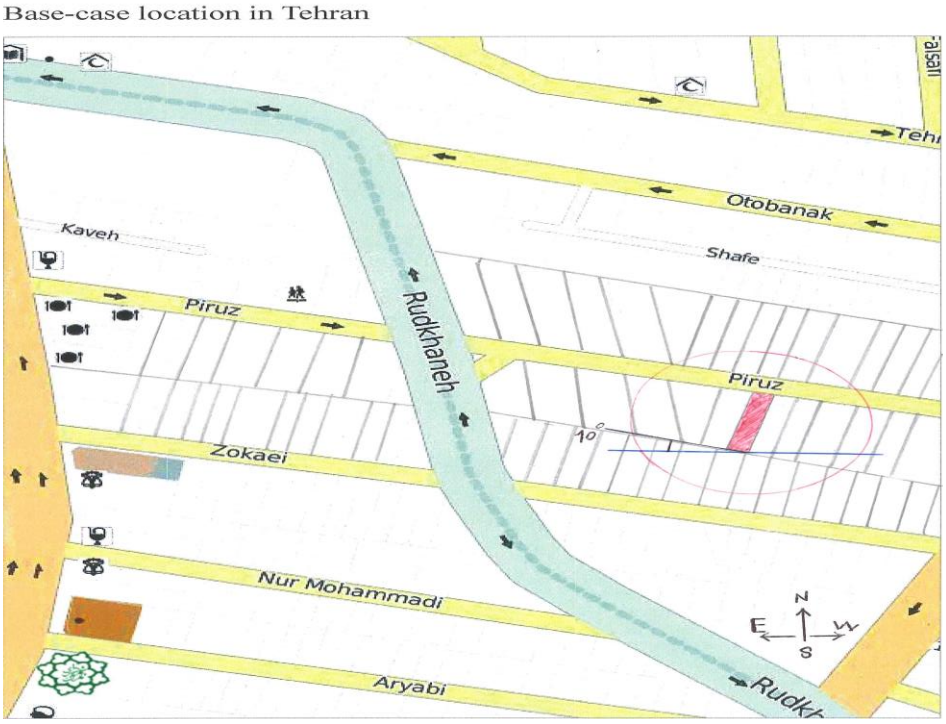


Figure 5.12 – Geographical Location of the Building (Marked In Red)

The total floor area of the building is 128.3m^2, of which 113.5m^2 is conditioned space. The whole conditioned space is heated, while 105.5m^2 is cooled. The unit contains a living room, open space kitchen, three bedrooms and WC and bath room.

In addition, the building materials assigned according to the available materials in the IES-VE simulation software's materials library. The material property adjusted to the model based on the specified values of Iranian standard organization.

5.6.1 Walls

The construction of the base-case is a conventional structure in Tehran that is widely used by designers. Both the external and internal wall types of this building consist of the hollow clay block (Figure 5.13) that has been widely in use for the last 20 years in the country.

The external wall thickness is 28cm with total U-value of 1.34 W/m^{2}K. Table 5.6 demonstrates the material properties of the different layers of the wall.

Dimensions	mm
Length (A)	250
Height(C)	200
Width (B)	100

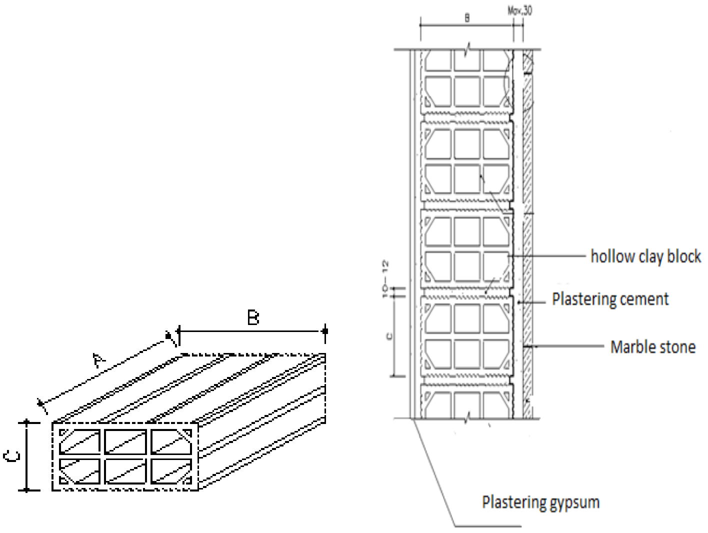


Figure 5.13 – Structure of the Base Case Wall and Layers Details

Table 5.6 – Clay Wall (Base Case) Material Properties

Material (outside to inside)	**Thickness mm**	**Conductivity W/(m.K)**	**Density kg/m^3**	**Specific heat capacity J/(kg.K)**	R-Value: 0.55 m^{2}K/w U-Value: 1.34 W/m^{2}K Thermal mass: 107.9 KJ/(m^2.K)
Marble stone	30	2.77	2600	802	
Plastering (cement)	20	0.1	1100	1000	
Hollow clay block (HCLB)	200	0.5	1300	800	
Plastering (Gypsum)	30	1.0	1400	837	

5.6.2 Floor and Roof

The floor consists of light polystyrene with hollow clay blocks and a top layer of concrete. The roof also consists of the same materials of floors in addition to waterproof layers. The floor and roof details are shown in Figure 5.14, the U-value of roof is 0.79 W/m^{2}K and floor is 0.56 W/m^{2}K.

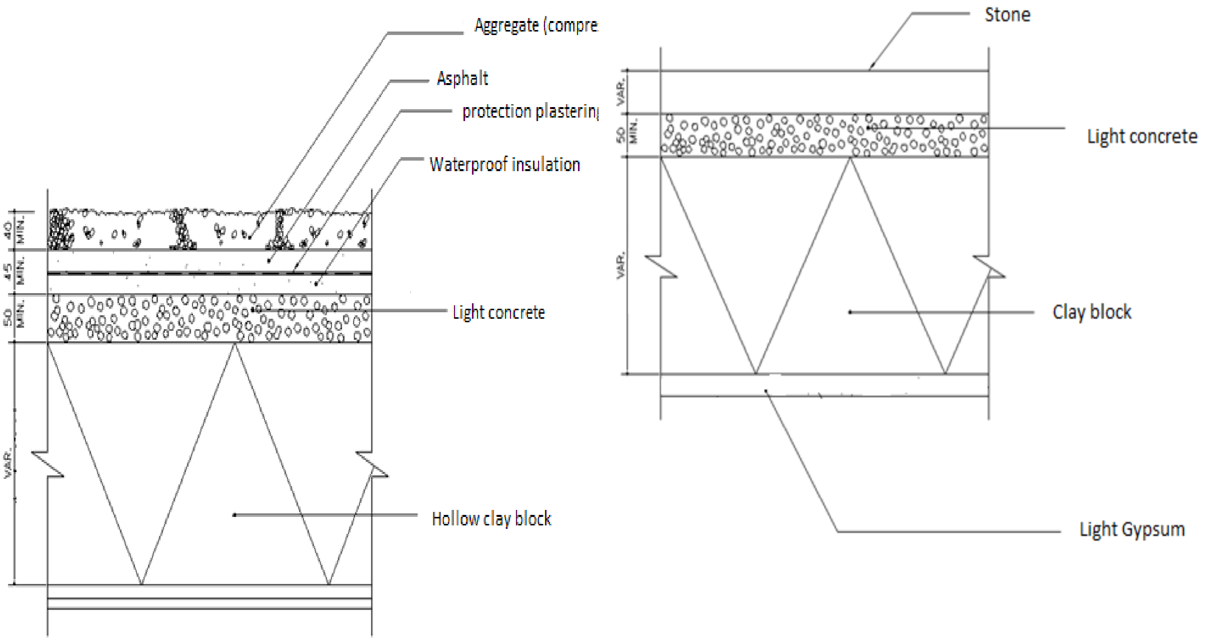


Figure 5.14 – Base Case Roof Details (Left) and Floor Details (Right)

5.6.3 Windows

The windows in the base case apartment are double glazing metal frame with clear glass. From the window to floor ratio it is clear that a daylight factor of 2 has been assigned for this building. The openable window sizes are 25% of total area of the windows. The height of all the windows are consistently 1.5 m. The total area of windows is 27% of the room floor area. Table 5.7 shows other details of window as mentioned by the manufacturer.

Table 5.7 – Base Case Window Details

Windows details	Value	Unit
U-value	3.18	W/(m2 ·K)
g-value	0.73	%
A_{frame}	27.3	%
Co-value	0.85	%
Glass thickness	4-6	mm
Gas filling	Air	-
Gap width	12	mm
Frame material	Metal	-

5.6.4 Shading System or Devices

There is not any specific external shading for the base case, this is conventional practice in Tehran to design buildings without external shading devices. However, for internal shadings, curtains or blinds are commonly in use for two main reasons; a) as a Muslim country privacy of people, in particular women, inside the home is highly important, b) Iranians consider the curtains a significant aspect of interior design, therefore the aesthetics purpose of curtains means that majority of the residential buildings have curtains installed.

5.6.5 Heating System

Most of the Iranian individual residential buildings use a heating stove for heating purposes. Natural gas or Kerosene is the main source of fuel for these stoves. However, in new buildings, especially in multi residential buildings a central heating system with air handling units, radiators or fan coils are used. The central heating systems in Iran usually consume natural gas, although in some cases they run on oil and gas.

The main heating system of the base-case is a central heating radiator system that is widely in use in Tehran apartment buildings. According to the Iranian national housing census (2011), over 85% of apartments in Tehran are operated by central heating systems.

The boiler is the main component of a central heating system. They come in many sizes, delivering various amounts of heat energy, run on different fuel types and have various energy ratings. According to general boiler sizing procedures in Tehran, for per square meter of floor area, approximately 128Kcal energy is required to be delivered. Therefore, the boiler type is selected based on total floor area multiplied by 128 plus 20%. This calculation specifies the boiler capacity. Based on manufacturers' details, the heat delivery time is worked out by dividing the total demand by delivery capacity per square meter (Iran boiler Co, 2017).

$$Hours = \frac{required\ loads\ (kW)}{delivery\ loads\ (kWh)}$$

To calculate the amount of energy, the fuel consumption per hours is calculated by applying the following formula:

$$W = \frac{(Qb)}{10500\ (C) * (E)}$$

Where

Qb = Boiler heating power (Kcal/hr)

W = Fuel weight (m^3/hr)

E = Boiler efficiency (50%)

C = Fuel value for gas (Kcal/kg)

Therefore, the energy consumption for the heating system is:

$$\text{Heating energy} = W * H$$

5.6.6 Cooling Systems

Evaporative coolers are the common cooling system in the cities of Iran with low air humidity. The simple installation and lower operating cost than refrigerative air conditioning are the advantages of this equipment. This cooling system operates on electricity. This system is reasonably useful for climates where the air temperature is high and the humidity is low. The base-case building is cooled by evaporative coolers.

In addition, according to Iranian national housing census (2010) over 70% of apartments in Tehran are equipped with evaporative coolers.

According to a research by Bhatia (2012), most of the Iranian manufacturers produce evaporative cooling systems that consume 750 Watt/hr. The efficiency rate of these cooling systems has been evaluated to be 80%. According to manufacturers, a 4500 CFM evaporative cooling system is able to create 19000 BTU/hr cooling loads. Therefore, one can apply the following formula to calculate the electricity consumption for the whole cooling period (Bhatia, 2012).

$$CFM = \frac{V}{0.1 * \ (EDBT - EWBT)}$$

Where

CFM = Air Volume in Cubic Feet per Minute

V = Volume of conditioning spaces (ft^3)

EDBT = Entering ambient dry bulb temperature in °F (100 for Tehran)

EWBT = Entering ambient wet bulb temperature in °F (76 for Tehran)

Then

$$Hours = \frac{Total\ required\ cooling\ load\ (BTU)}{0.8 * Qs}$$

Where

Qs = Cooling capacity (BTU/hr)

Then

Hours * 0.75Kw = Total electricity

5.6.7 Internal Gains

In this research heat gains are control variables. They remain stable throughout the simulations and analysis. As a result they won't affect the dependent variables. In this research building design and fabric are independent factors, and energy consumption is a dependent variable.

Household appliances

Operational electrical equipment and household appliances generate heat to the space. The amount of heat depends on the equipment power and operational time. "*All of the electric energy that goes into equipment, such as electric motors and computers, ends up as waste heat in the space*" (Brown and Dekay 2001, p.44).

5.7 Development of the Base-Case, Selection of Parameters and Rules of Calculation

The following rules are set by ASHRAE to calculate the cooling load for each component of lights, people and applications. However, to adopt the ASHRAE calculations, Iranian regular practice for these calculations have also been applied (FINE HVAC 14).

1. Calculate 24 h profile of component heat gains for design day (for conduction, first account for conduction time delay by applying conduction time series).
2. Split heat gains into radiant and convective parts using radiant and convective parts.
3. Apply appropriate radiant time series to radiant part of heat gains to account for time delay in conversion to cooling load.
4. Sum convective part of heat gain and delayed radiant part of heat gain to determine cooling load for each hour for each cooling load component.

5.7.1 Lighting

Occupied spaces are affected by heat gains from electric lighting. The amount of heat is directly dependent on illumination level and the efficiency of the light source (Brown and Dekay 2001, p.42). The radiation energy emitted from a lamp will result in a heat gain to the space only after it has been absorbed by the room surfaces. According to the Iranian national housing census (2010) the average use of fluorescent lightings are 6.1 hours a day for each household.

$$Q\text{-}l \quad = (W * 3.412) * Fu * Fs * CLF\text{-}h \text{ (sensible heat gain)}$$

Where;

Q-l = Sensible Heat Gain (SHG) from lights
*W = Lighting power output in Watts (Btu/hr = W * 3.412)*
FU = Usage factor or percentage of maximum design for each hour of the day
Fs = Service Allowance Factor or Multiplier
CLF-h = Cooling Load Factor (CLF) for given hour. This depends on zone type, total hours that lights are on, and number of hours after lights are turned on.

However, when the lighting specifications are not known the following equation is applied:

$$W = K \times A$$

Where;

A *=Area*
K *=Lighting density =3 W/ft^2 (for residential buildings)*

As a result, the assigned lighting gains for the base-case is assumed to be 32.3 W/m^2

5.7.2 Occupants

One of the important factors in heat load calculation is the “people” load. As a rule of thumb, one can use 400Btuh/person for internal heat gains. However Iranian sources (Davoodi, 2012) recommended the following heat gain to be applied (Table 5.8).

Table 5.8 – People Internal Gain

	Heat generated by people		
Application	Sensible	Latent	Total(Btuh)
Home and theatre	200	250	450

Iranian sources suggested the following equation to calculate the heat gains from people;

$$Q_{total} = Q_p * Coefficient$$

Where;

Qp = heat gains from people = 450Btuh (including sensible and latent heat gains)

Coefficient = 0.5

450 * 0.5 = 225Btuh = 65W

5.7.3 Household and Appliances

Iranian national housing census statistics shows that on average most of the household equipment is used for less than 10 hours a month. The following Table (5.9) shows the most effective equipment that runs for more than 10 hours a month in Iranian dwellings.

Table 5.9 – Heat Gains by Appliances

	Heat generated by equipment	
	Total(Btuh)	Operation time (daily)
Cooking oven	3500	2.2h
TV (32”)	340	3.8h

5.7.4 Occupancy Set Points

According to municipality statistics (2008), only 21% of women are employed, while over 82% of men are employed. As a result the majority of residential buildings in Tehran are occupied all day round. This occupancy means that the cooling and heating systems are required to be operative all the time as long as the thermal comfort temperature is met. However, this type of occupancy affects the heat gains from people as during the weekdays and school time, it is assumed that one person is at home.

5.7.5 Heating and Cooling Set Points

Although Iranian building codes recommended a setting point of 20^{o}C in the winter and 28^{o}C in the summer, it is required that buildings are equipped with a thermostat to control the internal temperature. Likewise, the base case, is not equipped with thermostats, therefore, the temperature set points in simulation was worked out according to the average set point temperature Tehran according to the national housing census (2010). The census states that while the majority of residents are not aware of the internal temperature, the internal temperature in winter is on average 23^{o}C and in the summer 26^{o}C.

5.7.6 Natural Ventilation Settings

The main natural ventilation inlet in residential buildings in Tehran is through the windows. It is almost impossible to assume the exact window opening time and the degree of the openings. However, for this study, it was assumed that according to Iranian building code recommendations, windows would be open when the external temperatures are between 20^{o}C and 25^{o}C. The degree of opening for the base case was assigned as 50% as the window type is centre-hung. The opening time was also assigned all day round when the mentioned external temperature is met.

5.7.7 Infiltration Rate (ACH)

Infiltration rate is one of the most important factors to predict the energy performance of buildings. One of the main reasons for this importance is the heat loss and gains through the infiltrations are comparable with heat transfer through a well or poor insulated envelope (O’Brien, 2010). This means that the estimation of model infiltrations is of great significance. However, this can only be identified accurately by applying a blower door test (ASHRAE, 2005). This can be applied after the construction has been completed.

For this study, the infiltration rate was assigned as a fixed rate based on the average Iranian new built building infiltration rates are around 0.70 ach (Zomorodian, 2015). However this rate for old buildings increases up to three times (Zomorodian, 2015).

5.7.8 Orientation

Building regulations in Iran state that only 60% of the site can be built on and the remaining area (40%) must be used as courtyard. Courtyards must be located on the southern side of south-north orientated sites and on the eastern side of sites orientated east-west. These rules intend to maximize the solar energy through the wide windows that are open to through the wide windows that are open to the courtyard. Therefore, some houses are east-facing but the majority face south (Nasrolahi, 2009). For this reason, only south-north typology has been selected for evaluation in this research.

5.7.9 Floor selection

Household location of the simulation was set at the middle floor, as opposed to the top- or bottommost floors. In addition, majority of units are located in the middle floors (floors between top and bottom floor) therefore this study focuses on the majority floors that are expressed middle floor or intermediate floors. Households other than the target were blocked in general under the same set temperature to create conditions similar to the actual conditions for the target household in relation to the outer environment.

5.8 Selection of Variable Scenarios

5.8.1 Wall Types

Iranian building codes clearly illustrate wall types with their construction details. However, there are few of those that are commonly used in residential buildings. Shaghayegh (2013) identified the most frequently used wall types in residential buildings in Tehran. This study applied these walls in Phase1, and the suggested insulated walls in Phase 2. Table 5.10 shows wall types in Phase1 and Table 5.11 shows insulated walls in Phase 2.

Table 5.10 – Conventional Local Wall Types

WT1 (Base-case)					
Material (outside to inside)	**Thickness mm**	**Conductivity W/(m.K)**	**Density kg/m^3**	**Specific heat capacity J/(kg.K)**	R-Value: 0.55 m^{2}K/W
Marble stone	30	2.77	2600	802	U-Value: 1.34 W/m^{2}K

Plastering (cement)	20	0.1	1100	1000	Thermal mass: 107.9 kJ/(m^2.K)
Hollow clay block (HCLB)	200	0.5	1300	800	
Plastering (Gypsum)	30	1.0	1400	837	

WT2

Material (outside to inside)	**Thickness mm**	**Conductivity W/(m.K)**	**Density kg/m^3**	**Specific heat capacity J/(kg.K)**	
Marble stone	30	2.77	2600	802	R-Value: 1.09 m^2K/W U-Value: 0.77 W/m^2K Thermal mass: 83.0 kJ/(m^2.K)
Plastering (cement)	20	0.1	1100	1000	
Hollow LECA block (LECA)	200	0.23	900	1000	
Plastering (Gypsum)	30	1.0	1400	837	

WT3

Material (outside to inside)	**Thickness mm**	**Conductivity W/(m.K)**	**Density kg/m^3**	**Specific heat capacity J/(kg.K)**	
Marble stone	30	2.77	2600	802	R-Value: 1.4 m^2K/W U-Value: 0.62W/m^2K Thermal mass: 69.0 kJ/(m^2.K)
Plastering (cement)	20	0.1	1100	1000	
Concrete (AAC)clay block (HCLB)	200	0.17	700	1000	
Plastering (Gypsum)	30	1.0	1400	837	

Table 5.11 – Suggested Insulated Wall Types

WT4

Materials	Thickness mm	Conductivity W/(m.K)	Density kg/m^3	Specific heat capacity J/(kg.K)	
Marble stone	30	2.77	2600	802	R-Value: 1.80 m^{2}K/W U-Value: 0.50W/m^{2}K Thermal mass: 84.1 kJ/(m^2.K)
Plastering (cement)	20	0.1	1100	1000	
Hollow clay block	100	0.5	1300	800	
EPS	50	0.04	15	1340	
Hollow clay block	100	0.5	1300	800	
Plastering (Gypsum)	30	1.0	1400	837	

WT5

Materials	Thickness mm	Conductivity W/(m.K)	Density kg/m^3	Specific heat capacity J/(kg.K)	
Marble stone	30	2.77	2600	802	R-Value: 2.27 m^{2}K/W U-Value: 0.40 W/m^{2}K Thermal mass: 98.1 kJ/(m^2.K)
Plastering (cement)	20	0.1	1100	1000	
Hollow LECA block (HCLBI)	200	0.23	900	1000	
EPS	50	0.04	15	1340	
Hollow LECA block	200	0.23	900	1000	

(HCLBI)					
Plastering (Gypsum)	30	1.0	1400	837	

WT6					
Materials	**Thickness mm**	**Conductivity W/(m.K)**	**Density kg/m^3**	**Specific heat capacity J/(kg.K)**	
Marble stone	30	2.77	2600	802	R-Value: 2.58 m^{2}K/W U-Value: 0.36 W/m^{2}K Thermal mass: 84.1 kJ/(m^2.K)
Plastering (cement)	20	0.1	1100	1000	
Concrete (AAC) block	200	0.17	700	1000	
EPS	50	0.04	15	1340	
Concrete (AAC) block	200	0.17	700	1000	
Plastering (Gypsum)	30	1.0	1400	837	

5.8.2 Window Types

This research analysed various local existing glazing types with 2 and 3 panes, total glazing U-values between 2.4-4.1 W/(m^2 ·K) and glazing (glass) U-value between 2-3 W/(m^2 ·K). The description of all glazing types studied is shown in Table 5.12. Variant names are made up so that the first number stands for the number of panes, Arg for argon, Air for air, Met for metal frame and Pvc for PVC frame. The double, triple and glazing properties were calculated using local window manufacturers' and Iranian building code chapter 19 (Azingroup, 2017). The IES-VE simulation software calculates the detailed window model parameters at standard conditions of ISO 15099. Generally simple glass without any coated materials was used in all gaps between panes. (Azingroup, 2017)

Table 5.12 – Local Window Types

	Glass thickness (mm)	**Gas filling**	**Gap width (mm)**	**U-value (glass), W/(m^2 ·K)**	**Total U-value(Metal frame by U-factor: 5 W/(m^2.K)**	**Total U-value(PVC frame by U-factor: 2.5 W/(m^2.K)**
Double glazing	4 - 6	Air	12	2.7	3.18 WiT1(Base-case)	3.1 WiT2
Double glazing	4 - 6	Argon	12	2.56	3.0 WiT3	2.55 WiT4
Triple glazing	4 - 6 - 4	Air	9.9	1.86	2.46 WiT5	1.97 WiT6
Triple glazing	4 - 6 - 4	Argon	9.9	1.69	2.35 WiT7	1.85 WiT8

According to the Iranian building code ‘chapter four’, the minimum size of an external window should not be less than 1/8 of the floor area of the room. Consequently, Iranian building code applies a window- to-floor ratio (WFR) factor for designing window size. By considering the daylight factor calculation method, it can be confirmed that the Iranian building code has worked out this figure by considering a general suggested minimum daylight factor that is 2% in this case. The criterion of 2% average daylight factor in the daylight zone (up to 4m from the external wall) has been used to calculate minimum window size for this research as well. The applied ratio suggests approximately a minimum size of 13% WFR which is equivalent to 16.6% of window-to- wall ratios (WWR). As mentioned before, the favourable daylight factor is between 2% and 5%. Therefore, in this research a range of 2% to 5% by 1unit interval has been applied for the further evaluation (Table 5.13). To identify the best performance window size all the selected window sizes based on WWR will be analysed.

Table 5.13 – Window to Wall Ratios Based On Daylight Factor

Daylight Factor %	**Window to Floor Ratio**	**Window to Wall Ratio (WWR)%**	**Windows name**

	(WFR)%		
2	13	16.6	WiS4
3	19.5	24.9	WiS3
4	26	32.2	WiS2
5	32.5	41.5	WiS1

5.8.3 Shading Design

By using simulation software analysis, this research quantitatively analyses different types of horizontal overhang sizes in southern external windows in base-case buildings. However, it is important to systematically assign the relevant size of overhangs. The selection criteria are mainly based on the solar altitude, azimuth and orientation of the building. The angle of sun was determined in both hot and cold months of year. The selected overhang sizes are based on the sun angle during the hot summer months, this means that they block the sun path towards the windows, therefore the window glazed areas at these angles and above are minimized. Therefore, the objective is to maximize shading during the peak cooling season while allowing direct sunlight and heat gain during the heating season, for this purpose all the selected overhang sizes need to be analysed and measure the sunshade’s effect on reducing solar radiation heat. The overhang positon for all cases remain constantly at 520mm above the windows, this position is according to recommendation of Sustainable Design (2016) for Tehran coordinates (Figure 5.13) and (Table 5.14).

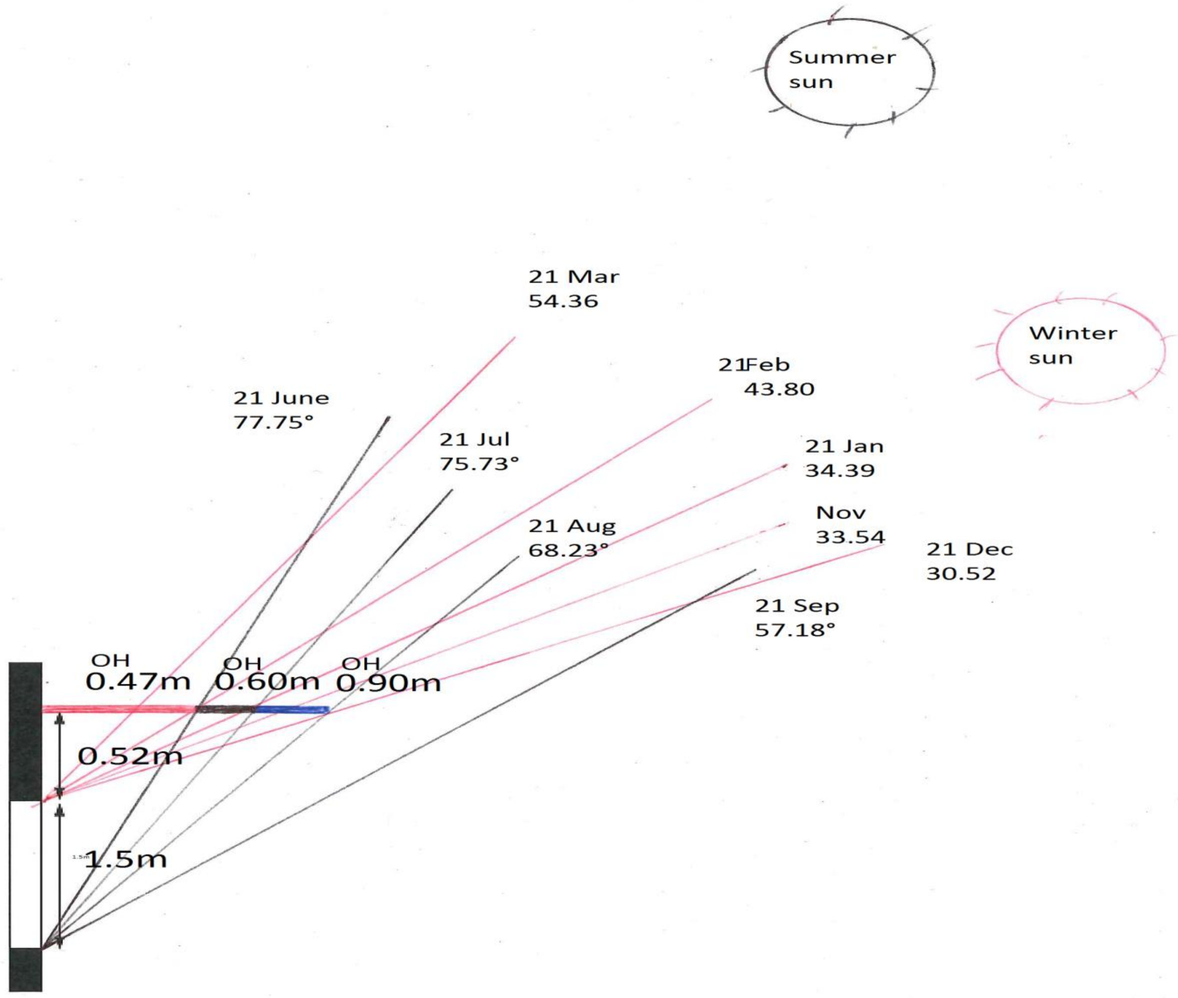


Figure 5.15 – Sun Angle and Overhang Sizes in Different Months

Table 5.14 – Proposed Overhang Depth Based on the Sun Angle in Summer Time

Month	Sun angle	Proposed overhang depth (mm)	Blocked solar in Winter months
Jun	77.75°	470	Mar
Jul	75.73°	600	Mar, Feb
Aug	68.23°	900	Mar, Feb, Nov, Jan
Sep	57.18°	Over size object	N/A

In addition, removable shadings and external blind or shutters were assigned for further optimization analysis.

5.8.4 Ventilation time profile

The selected ventilation profile for the actual base case is the ‘all day ventilation’ where the windows are open where the outdoor temperature is between 20 and 25 as suggested by the Iranian building code chapter 19. However, this practice will be evaluated against other suggested ventilation time profiles to apply the most efficient one.

5.9 Summary

This chapter had two main sections; the first section presented an overview of the profile of the country including climate condition, energy balance and household statistics. This chapter highlights the high energy consumption in the country, more specifically in the residential sector in Iran. The energy statistics were compared with developed countries to present a better image of the country’s energy consumption. The household statistics present the general occupants behaviour profile along with common conditioning systems. The second part of this chapter explained the construction characteristics of the selected base-case, and determined the selection factor and logic for building parameters including windows size, shadings, natural ventilation and internal gains.

Chapter 6 – Data Analysis, Simulations and Discussion (1)

6.1 Introduction

The building designs and fabric data presented in this chapter was carefully taken from the building drawings and local building codes and standards. This data was then imported into the simulation software (IES-VE).

The simulation results are illustrated in graphs for further discussion. In this chapter all the outlined phases of the methodology were carried out by using the IES-VE. The first phase of this research required that the simulation software be validated through a comparison analysis between the amount of energy consumed in the base-case according to the energy bills and the base case prototype. The calculated level of energy consumption of the base case potentially presents the base-line energy consumption in Tehran in different contexts. For instance, it seems a straight forward procedure to calculate the baseline energy from the multiple energy bills in Tehran. However, this chapter looks at the Iranian standards for required internal temperature set points for new buildings in which their baseline energy consumption is unknown and needs to be analysed by simulation software tools.

The second phase is the analysis in two parallel but separate parts, one as a free running building and the other as a conditioned building according to the actual building operation profile. During these analyses the energy and passive performance of each parameter of the building envelope are discussed. In effect, the combination of the best parameter performance of each building element and design form the best case in each part. Finally, a mixed case of free running building and conditioned mode of building, shape the optimized case of this research.

The third phase of this research follows similar methods as the second phase, the difference is where the new variable parameters including walls, as thermal insulation and shading devices, as solar protection solutions are added to the optimized case. Likewise, in this phase, the optimized case is a combination of free running and conditioned building.

6.2 Active Building

6.2.1 Validation and Calibration

The base case apartment block is occupied; however, no experimental data has been recorded. The building materials and details are according to the building drawings.

In order to simulate the occupant behaviour profile, the Iranian national census statistics are applied to the building. This includes the average number of people per square metre, people and household heat gains, occupied hours, operational heating and cooling systems hours. Furthermore, to validate and calibrate the building performance, utilities bills of the same buildings and other building in the same region were collected and analysed.

As mentioned previously the base cases in this research are not equipped with controlled temperature set points in reality. To define an approximate internal temperature, national census and statistical data are used to assume the most appropriate set points.

To select a base case to present the Tehran's most conventional apartments in terms of design and materials, four apartment units in different blocks were selected with the same construction materials and similar design. The annual energy utilities of these units were collected and are presented in the Table 6.1 along with the general description of apartments.

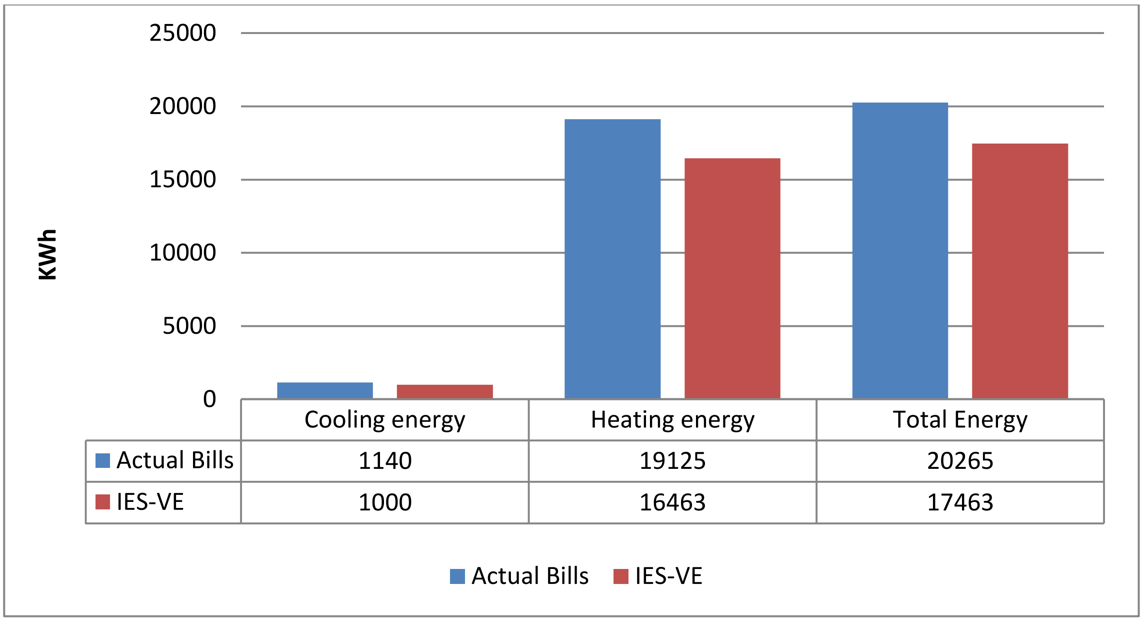
Table 6.1 – Details of Selected Apartment Units in Tehran Along With Their Heating and Cooling Energy Consumption

	Total conditioned area (m^2)	**Total Energy kWh/m^2a**	**Electricity for cooling. kWh/m^2a**	**Gas for heating kWh/m^2a**	**Total cooling and heating energy kWh/m^2a**
Apartment A	98	275.2	11.9	182.1	194.2
Apartment B	112	207.7	7.3	142.8	150.1
Apartment C	128	256.6	10.2	170.8	181.0
Apartment D	144	289.6	11.5	194.8	206.3

The average heating and cooling energy consumption in the four apartments is 182.5kWh/m^2a which is very close to the figure in Apartment C. As a result, Apartment C is considered for the base case model to evaluate and examine further potential energy optimization.

The utility energy bills indicate that the total heating and cooling energy consumption in Apartment C is 20,260kWh/m^{2}a. Heating energy is considered to be 75% of the total gas bill as mentioned by National Iranian Gas Company (2012), and cooling energy is accounting for 30% of total electricity according Tehran Electricity Distribution Company (2014).

Having simulated Apartment C using IES software, the energy consumption in Apartment C is different than the actual utility bills. As shown in Figure 6.1 heating energy consumption in simulation software indicates 14.0% less than the actual bills, and cooling energy also indicate 12.3% less that the actual utility bills. The total actual cooling and heating energy consumption is higher than the simulated case by 13.8%.



	Cooling energy	Heating energy	Total Energy
🟦 Actual Bills	1140	19125	20265
🟥 IES-VE	1000	16463	17463

Figure 6.1 – Annual energy consumptions for the Base-case (actual bills and IES-VE simulation)

The difference between the actual building energy consumption and the IES-VE models looks reasonable as some input parameters may not exactly represent the actual building parameters due to unknown quality of construction work and occupant behaviour.

6.2.2 Walls Analysis

In this section the base case wall and other two conventional walls in Tehran residential buildings were analysed, the wall details are described in the chapter five and are named as WT1, WT2 and WT3. During the walls analysis, to evaluate their energy performance, all parameters are kept constant and the same as the base case and only the walls are replaced.

The annual sensible heating load (Figure 6.2) shows that January is the coldest month with the highest level of heating load demand. In all cases heating is required from April until October. WT3 demands the lowest energy in all heating months. While WT1 has the highest demand loads in all heating months.

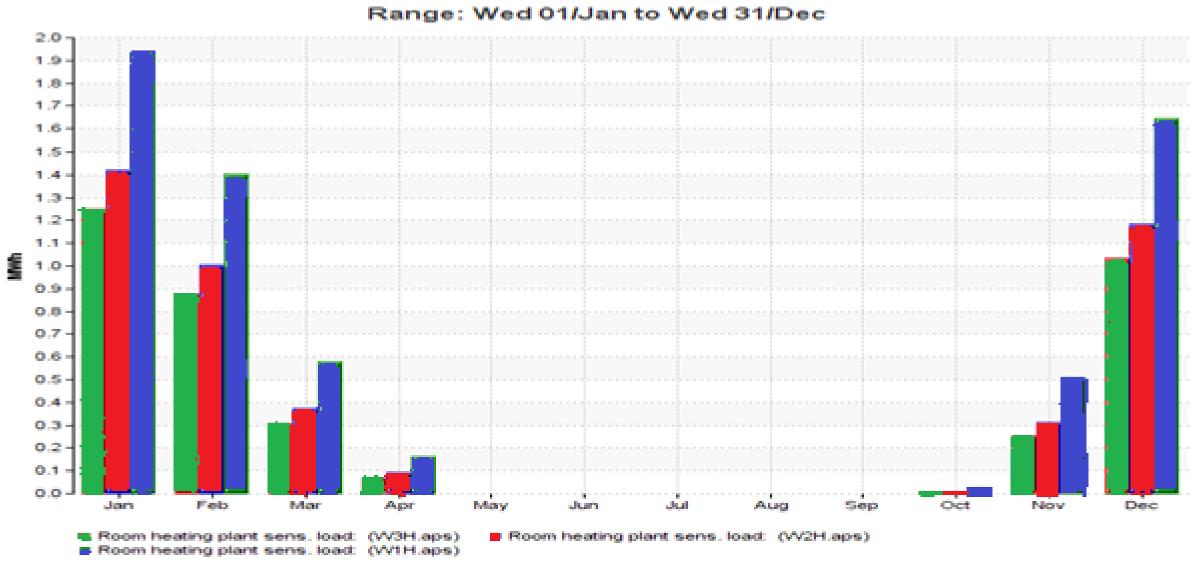


Figure 6.2 – Monthly Sensible Heating Loads as a Result of Different Walls. W1H, W2H and W3H Represent WT1, WT2 and WT3 Respectively

The cooling sensible loads data (Figure 6.3) shows that cooling is required from April to October. The highest demand month is August and the lowest is April. The WT1 has the highest demand in all months except October and April, in which it demands slightly less than other wall types. On the other hand, WT3 has the lowest demand in all months except October and April. Therefore, in April and October that are, in order, the beginning and the end points of cooling months, the wall type impacts differently on building cooling loads. This is a result of the low temperatures at night and closing windows.

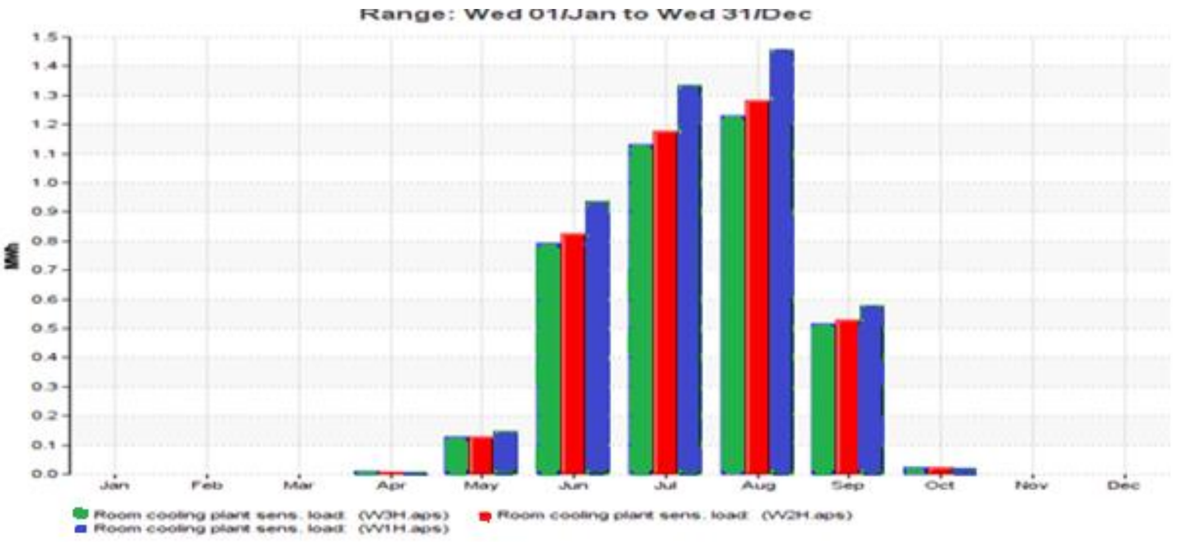


Figure 6.3 – Monthly Sensible Cooling Loads as a Result of Different Walls. W1H, W2H and W3H Represent WT1, WT2 and WT3 Respectively

As the cooling and heating months were identified, the total sensible loads of all months throughout the year show (Figure 6.4) that January has the highest demand loads by over 1.90mWh, and October has the least demand by less than 0.05mWh. In all months WT3 has the lowest demand, and WT1 has the highest demand.

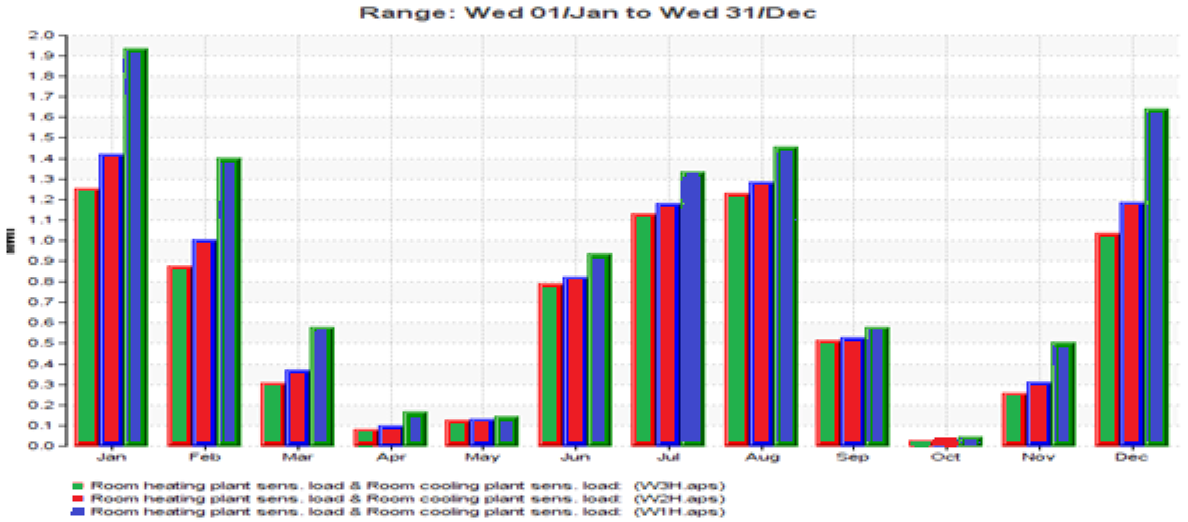


Figure 6.4 – Monthly Sensible Loads as a Result of Different Walls. W1H, W2H and W3H Represent WT1, WT2 and WT3 Respectively

As a result of the demand loads data, it can be assumed that cooling and heating energy will change in the line with the changes in sensible loads. As shown in Figure 6.5, the highest energy consumption in the summer is in August when the cooling system of the base case model consumes 0.231mWh energy. However, the amount of energy in WT2 and WT3 are relatively lower than the base case, but are still the highest in summer time.

The result shows that cooling energy in different wall types differs sharply in June, July and August, but the differences in May and September are insignificant. Furthermore, in October and April as was identified for sensible loads, WT1 has the best performance.

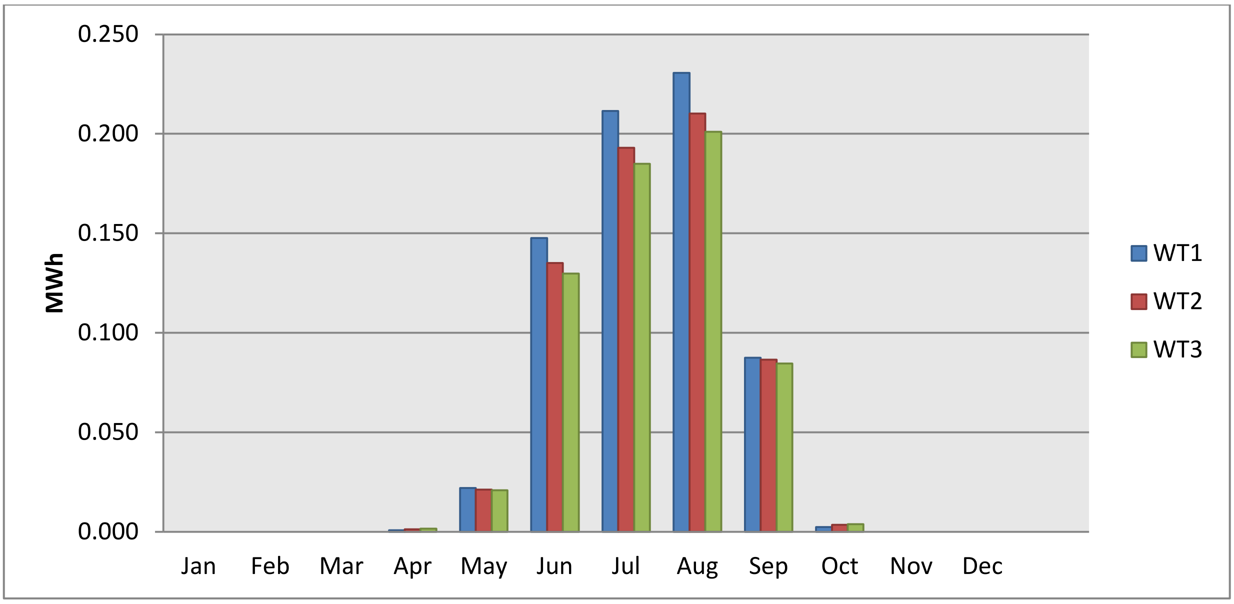


Figure 6.5 – Monthly Cooling Energy Consumptions as a Result of Different Walls

During the winter time, the highest energy consumption is in January when all the wall types consume higher energy than the other months in winter. Figure 6.6 shows that WT3 consumes the lowest energy in January, 35% lower than the WT1. In addition, it can be seen that the performance of WT3 is significantly better than other wall types over all the summer months.

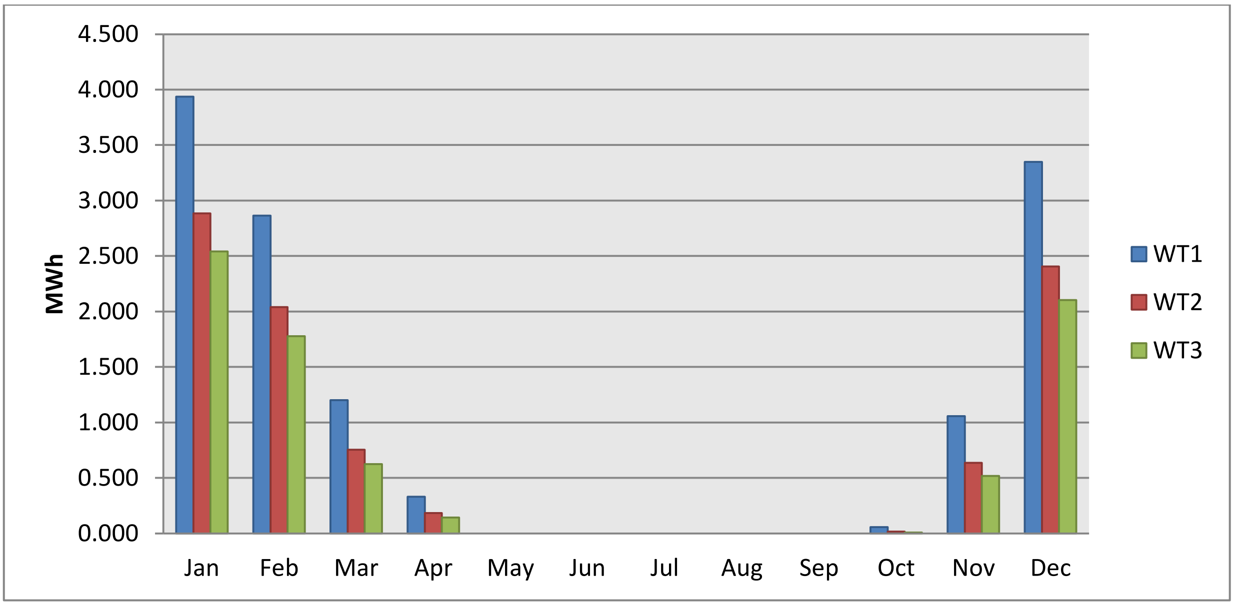


Figure 6.6 – Monthly Heating Energy Consumptions as a Result of Different Walls

Considering the total energy consumption in each individual month, Figure 6.7 shows that January is the highest energy consuming month and May is the lowest month.

Nevertheless, WT3 has a considerably better performance overall in all months, although the cooling energy consumption for case WT3 is not the best performance.

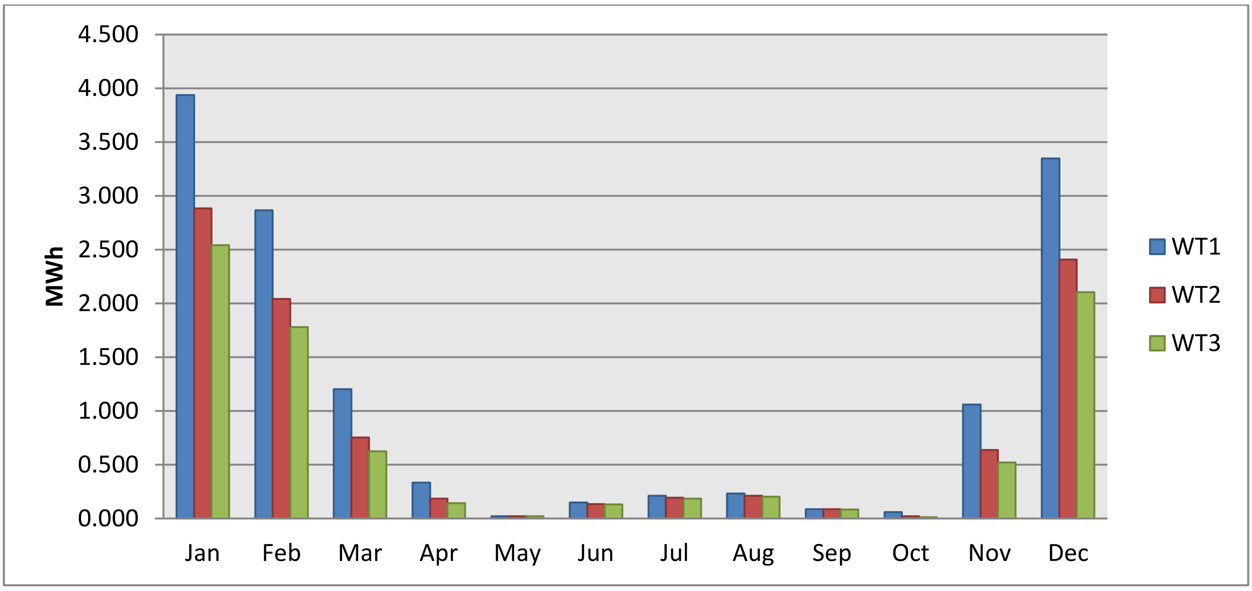
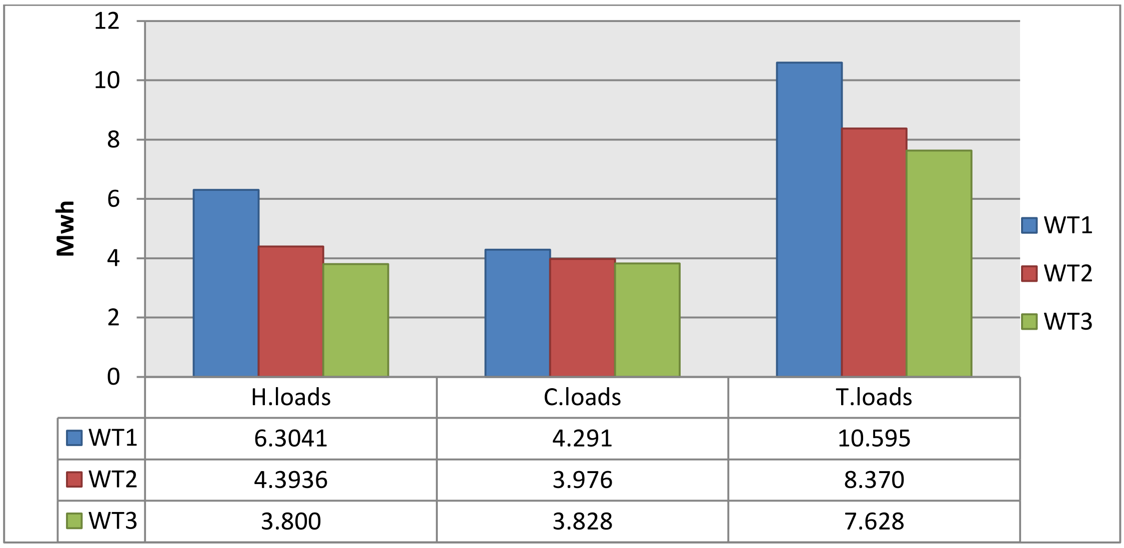


Figure 6.7 – Monthly Total Energy Consumptions as a Result of Different Walls

After simulating the wall types the results show (Figure 6.8) that the base case model requires the highest sensible loads for heating, cooling and consequently total energy. By replacing the WT2, the heating demand loads decrease by 30%, cooling loads by 7.5% and total energy by 21%. A further load reduction is achieved by replacing WT3 heating loads reduce 13.5% compared to WT2 and cooling loads and total loads decrease by 3.6% and 21% respectively.

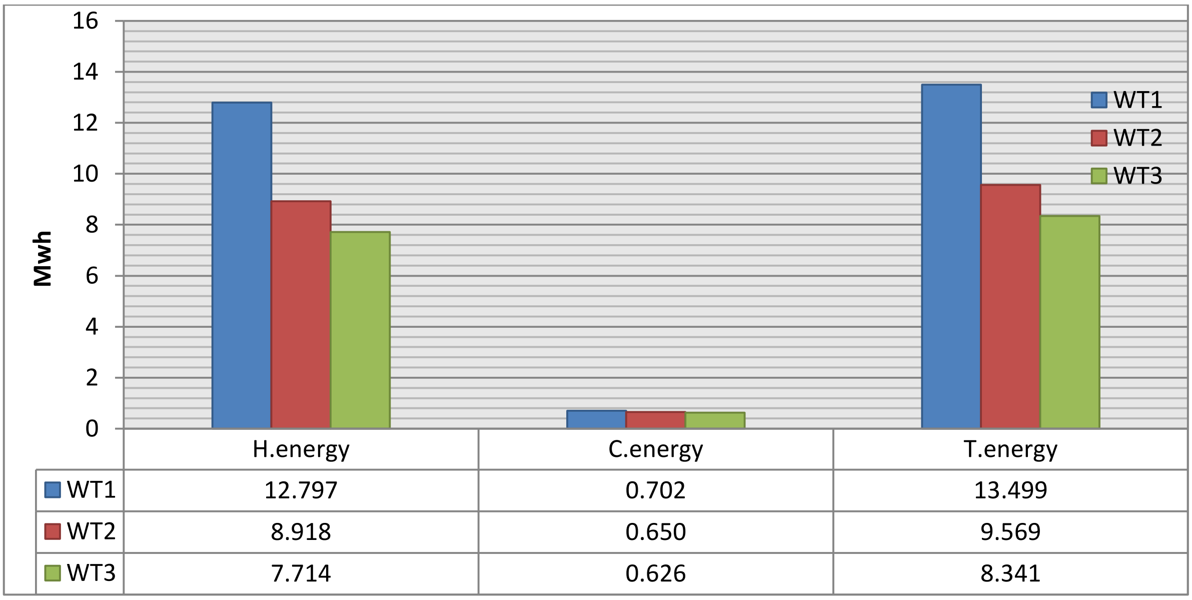
Consequently, WT3 potentially reduces the heating, cooling and total loads by 40%, 11% and 28% respectively.



	H.loads	C.loads	T.loads
WT1	6.3041	4.291	10.595
WT2	4.3936	3.976	8.370
WT3	3.800	3.828	7.628

Figure 6.8 – Total Annual Sensible Heating and Cooling Loads by Applying Different Walls. H.Load: Heating Load, C.Load: Cooling Load, T.Load: Total Load

Considering the sensible loads of the building, Figure 6.9 shows that WT1 (Hollow clay block) as the base case wall consumes a total energy of 13.499MWh, and the heating and cooling consumption are 12.797MWh and 0.702MWh respectively. However, by replacing WT2 (LECA block) the total energy decreases by 29%. Although WT3 (AAC blocks) has the best performance in both heating and cooling energy consumption, the greatest improvement is achieved as a result of heating energy reduction by 40% against 11% reduction of cooling energy.

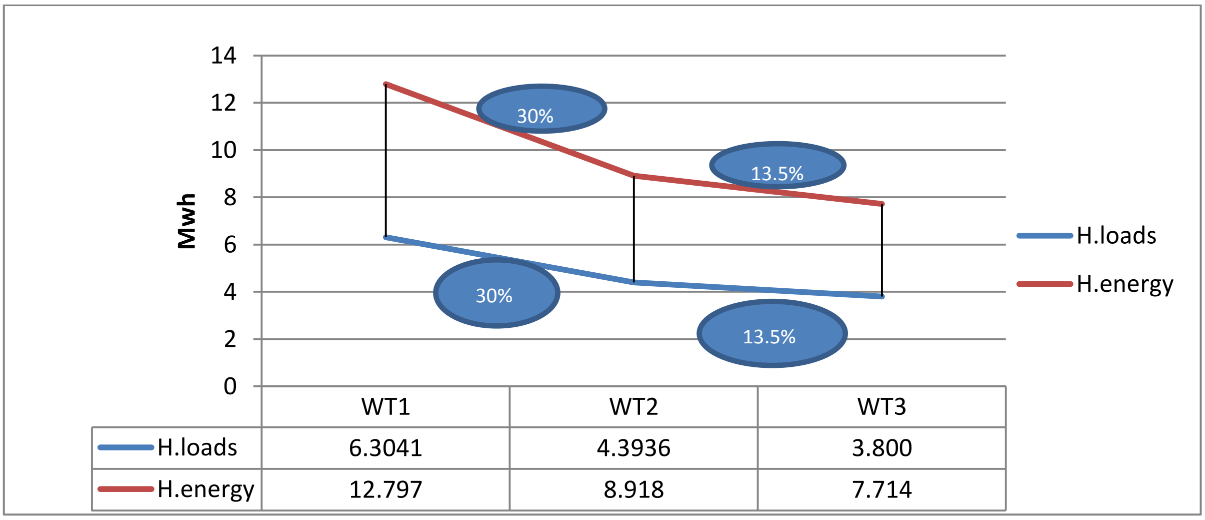


	H.energy	C.energy	T.energy
🟦 WT1	12.797	0.702	13.499
🟥 WT2	8.918	0.650	9.569
🟩 WT3	7.714	0.626	8.341

Figure 6.9 – Annual Total Heating And Cooling Energy Consumption By Applying Different Walls. H.Energy: Heating Energy, C.Energy: Cooling Energy, T.Energy: Total Energy

Obviously, the proportion of changes in heating and cooling energy consumption is exactly the same as in the sensible loads (Figure 6.10). Therefore, the percentages of changes are the same as sensible loads too. However, the total energy consumption doesn't follow this rule, as the amount of delivered energy for heating and cooling are calculated through a different procedure.

Consequently, as Figure 6.11 shows, although the total sensible loads in WT3 decreases by 28% compared to the base case, total energy decreases by a greater percentage of up to 40%.



	WT1	WT2	WT3
H.loads	6.3041	4.3936	3.800
H.energy	12.797	8.918	7.714

Figure 6.10 – Relation of Sensible Loads and Delivered Energy as a Result of Different Walls

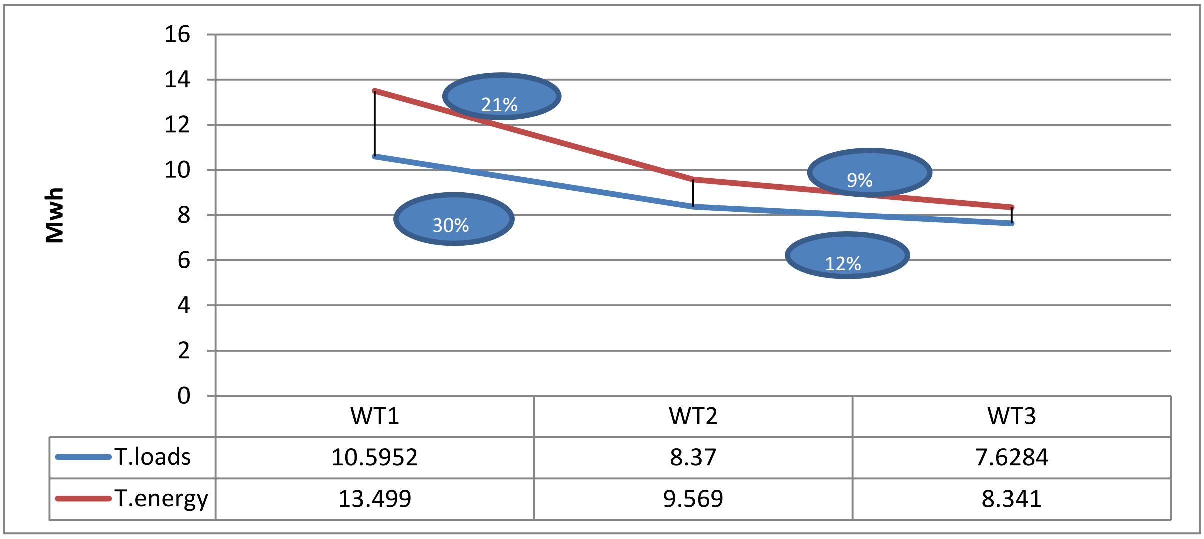
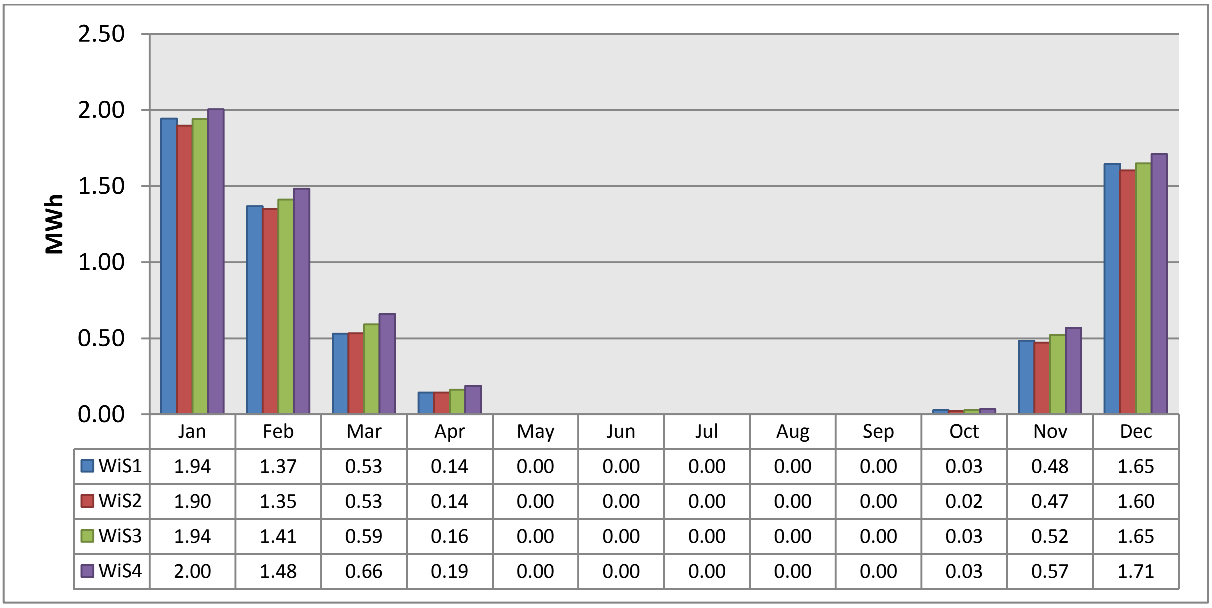


Figure 6.11 – Relation of Total Sensible Loads and Total Energy Consumption in Different Wall Types

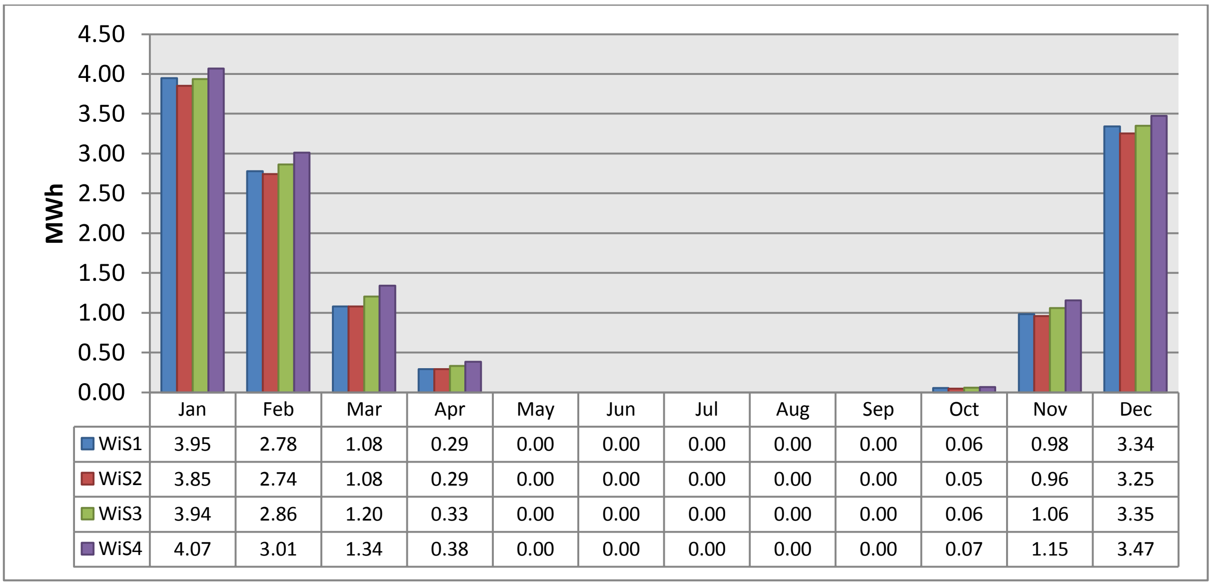
6.2.3 Window Size Analysis

The window's annual sensible heating load shows that January is the coldest month with the highest level of heating load demand (Figure 6.12). In all cases heating is required from October until April. The lowest demand window belongs to type WiS2 (WWR: 32.2%) which has the lowest demand in all heating months, contrary to this, WiS4 (WWR: 16.6%) has the highest demand loads in all the heating months. However, the difference between cooling loads in WiS2 and WiS4 barely reaches 5% and in some months, reaches zero. Following the sensible loads, it can be assumed that window type WiS2 consumes the lowest heating energy (Figure 6.13). The range of energy consumption is as low as 20kWh in October (WiS2) to the highest consumption rate of 2MWh (WiS4) in January. Accordingly, WiS4 has the worst performance months of 30kWh in October and 2MWh in January.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	1.94	1.37	0.53	0.14	0.00	0.00	0.00	0.00	0.00	0.03	0.48	1.65
🟥 WiS2	1.90	1.35	0.53	0.14	0.00	0.00	0.00	0.00	0.00	0.02	0.47	1.60
🟩 WiS3	1.94	1.41	0.59	0.16	0.00	0.00	0.00	0.00	0.00	0.03	0.52	1.65
🟪 WiS4	2.00	1.48	0.66	0.19	0.00	0.00	0.00	0.00	0.00	0.03	0.57	1.71

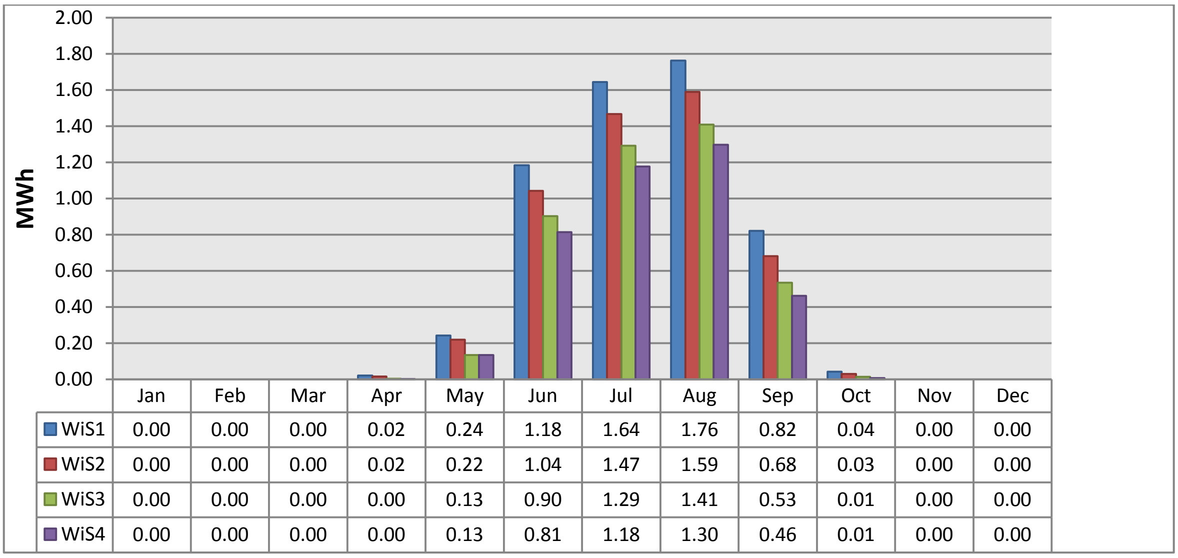
Figure 6.12 – Monthly Heating Sensible Loads in Different Window Sizes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	3.95	2.78	1.08	0.29	0.00	0.00	0.00	0.00	0.00	0.06	0.98	3.34
🟥 WiS2	3.85	2.74	1.08	0.29	0.00	0.00	0.00	0.00	0.00	0.05	0.96	3.25
🟩 WiS3	3.94	2.86	1.20	0.33	0.00	0.00	0.00	0.00	0.00	0.06	1.06	3.35
🟪 WiS4	4.07	3.01	1.34	0.38	0.00	0.00	0.00	0.00	0.00	0.07	1.15	3.47

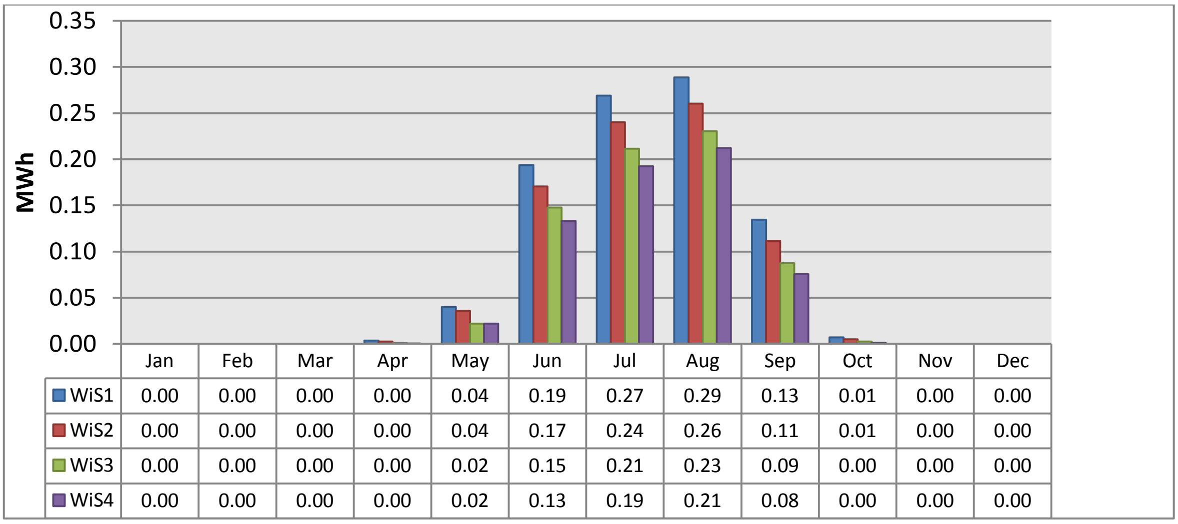
Figure 6.13 – Monthly Heating Energy Consumptions in Different Window Sizes

The cooling sensible loads data as shown in Figure 6.14 illustrate that cooling is required from April to October in all cases. The highest demand month is in August and the lowest is in April. The WiS1 as the largest window size has the highest demand in all months. The required loads are considerably high for all the window sizes. In addition, WiS4 and WiS3 reduce the required sensible loads to the minimum amount that can be considerably important for free ruining building design in April and October. Likewise, cooling energy consumption reduces in all months by applying WiS4 (Figure 6.15).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	0.00	0.00	0.00	0.02	0.24	1.18	1.64	1.76	0.82	0.04	0.00	0.00
🟥 WiS2	0.00	0.00	0.00	0.02	0.22	1.04	1.47	1.59	0.68	0.03	0.00	0.00
🟩 WiS3	0.00	0.00	0.00	0.00	0.13	0.90	1.29	1.41	0.53	0.01	0.00	0.00
🟪 WiS4	0.00	0.00	0.00	0.00	0.13	0.81	1.18	1.30	0.46	0.01	0.00	0.00

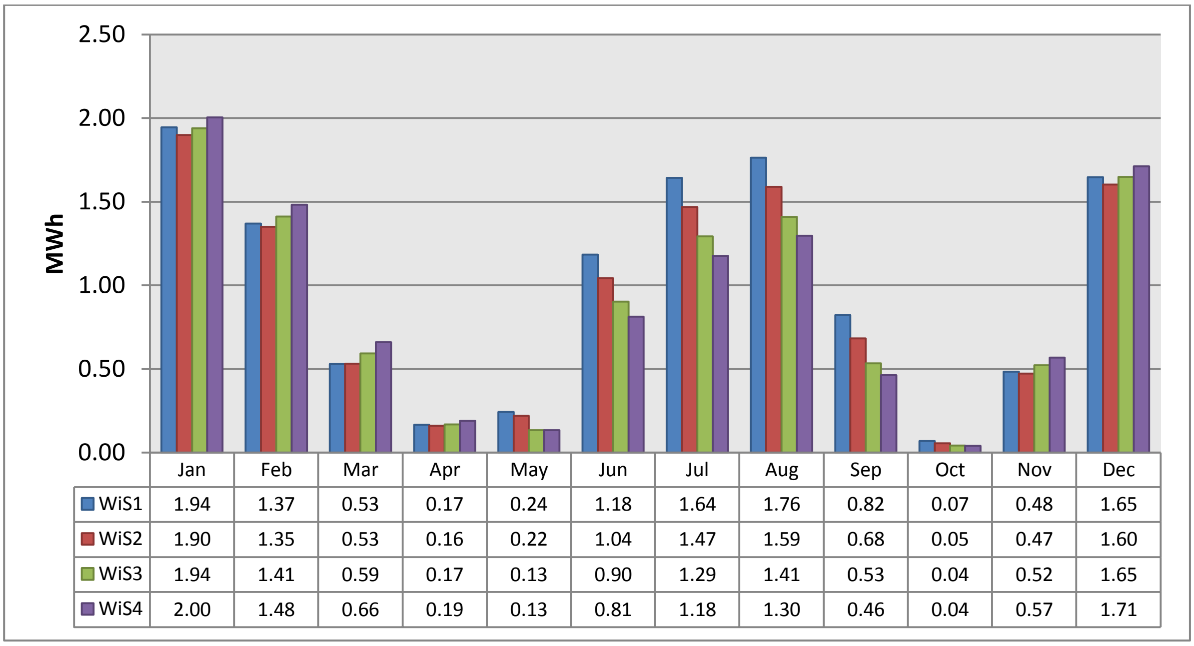
Figure 6.14 – Monthly Cooling Sensible Loads With Different Window Size



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	0.00	0.00	0.00	0.00	0.04	0.19	0.27	0.29	0.13	0.01	0.00	0.00
🟥 WiS2	0.00	0.00	0.00	0.00	0.04	0.17	0.24	0.26	0.11	0.01	0.00	0.00
🟩 WiS3	0.00	0.00	0.00	0.00	0.02	0.15	0.21	0.23	0.09	0.00	0.00	0.00
🟪 WiS4	0.00	0.00	0.00	0.00	0.02	0.13	0.19	0.21	0.08	0.00	0.00	0.00

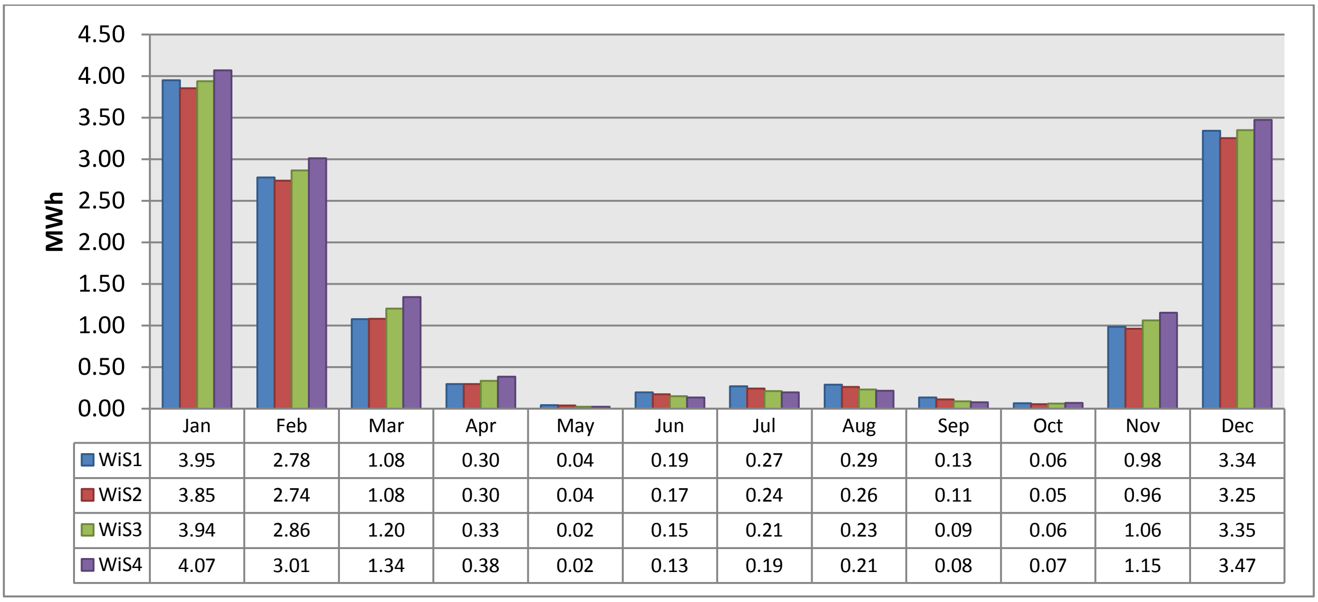
Figure 6.15 – Monthly Heating Sensible Loads with Different Window Sizes

The sensible load in each case shows that each window size performs differently in various seasons based on the cooling and heating demands and energy consumption. As discussed earlier, WiS2 and WiS4 have the lowest demand in winter and summer respectively. Therefore, to finalize the best case, the total sensible loads for the all cases need to be identified. Figure 6.16 shows that the sensible loads and energy consumption (Figure 6.17) are very different in the cooling and heating seasons. These differences are a result of using energy sources for the space heating and cooling. Clearly, the higher the amount of heating needed, the more the heating sensible loads in need dealing with in winter than the cooling energy in summer to deal with the cooling loads. In addition, for window sizes, the performances vary in different months. Consequently, no single window size can suit all the seasons. In this case, the accumulative best performance will be considered.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	1.94	1.37	0.53	0.17	0.24	1.18	1.64	1.76	0.82	0.07	0.48	1.65
🟥 WiS2	1.90	1.35	0.53	0.16	0.22	1.04	1.47	1.59	0.68	0.05	0.47	1.60
🟩 WiS3	1.94	1.41	0.59	0.17	0.13	0.90	1.29	1.41	0.53	0.04	0.52	1.65
🟪 WiS4	2.00	1.48	0.66	0.19	0.13	0.81	1.18	1.30	0.46	0.04	0.57	1.71

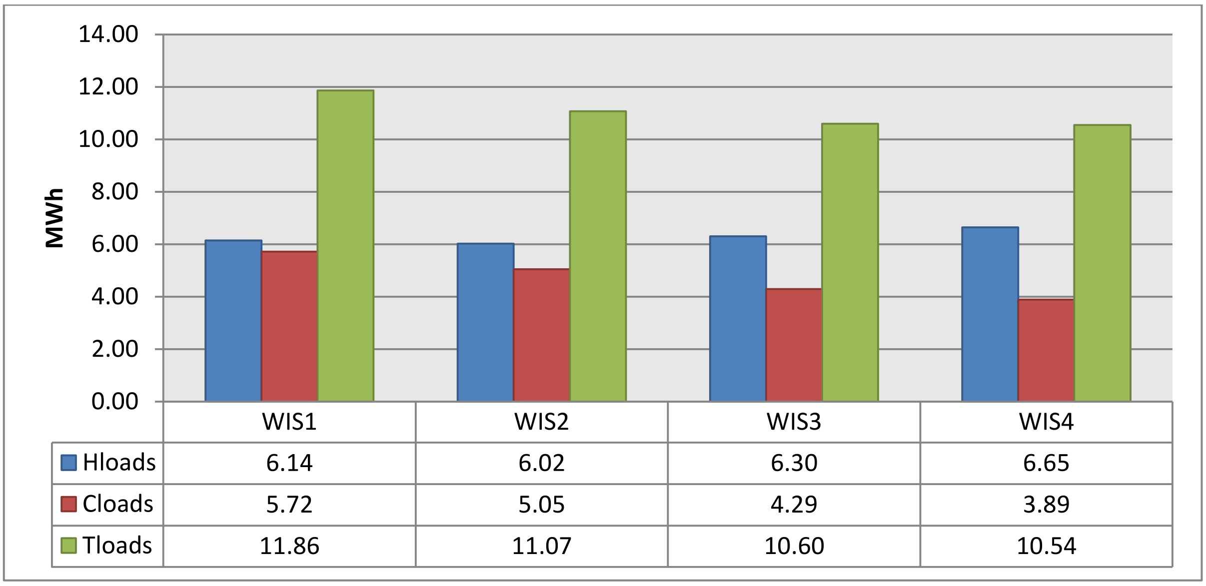
Figure 6.16 – Total Monthly Sensible Loads with Different Window Sizes



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS1	3.95	2.78	1.08	0.30	0.04	0.19	0.27	0.29	0.13	0.06	0.98	3.34
🟥 WiS2	3.85	2.74	1.08	0.30	0.04	0.17	0.24	0.26	0.11	0.05	0.96	3.25
🟩 WiS3	3.94	2.86	1.20	0.33	0.02	0.15	0.21	0.23	0.09	0.06	1.06	3.35
🟪 WiS4	4.07	3.01	1.34	0.38	0.02	0.13	0.19	0.21	0.08	0.07	1.15	3.47

Figure 6.17 – Total Monthly Energy Consumptions with Different Window Sizes

The total sensible load of WiS4, which is the smallest window, indicates the best total load than the other cases (Figure 6.18). However, as Figure 6.19 shows WiS2 has the lowest total energy consumption compared to the other window sizes. Although, WiS2 demands the lowest heating load, the cooling load is higher than the WiS3 and WiS4. Consequently, the total energy consumption will determine the best case for further analysis.



	WIS1	WIS2	WIS3	WIS4
🟦 Hloads	6.14	6.02	6.30	6.65
🟥 Cloads	5.72	5.05	4.29	3.89
🟩 Tloads	11.86	11.07	10.60	10.54

Figure 6.18 – Annual Sensible Loads in Different Window Sizes

	WIS1	WIS2	WIS3	WIS4
🟦 Henergy	12.47	12.227	12.797	13.493
🟥 Cenergy	0.935	0.825	0.702	0.636
🟩 Tenergy	13.406	13.053	13.499	14.13

Figure 6.19 – Annual Energy Consumptions in Different Window Sizes

Figure 6.20 shows how the sensible loads in different cases changes when using different window sizes. It clearly shows that by replacing WiS2 the demand load decreases by 6.6% following 2.6% in total energy reduction. However, although by replacing WiS3 sensible loads decrease by 4.4%, the total energy consumption increases by 3.2%. By replacing WiS4, the total sensible loads improve by 0.6%, but the total energy increases by another 4.7%. Consequently, the WiS2 has the best energy performance among the other cases regardless of the sensible loads.

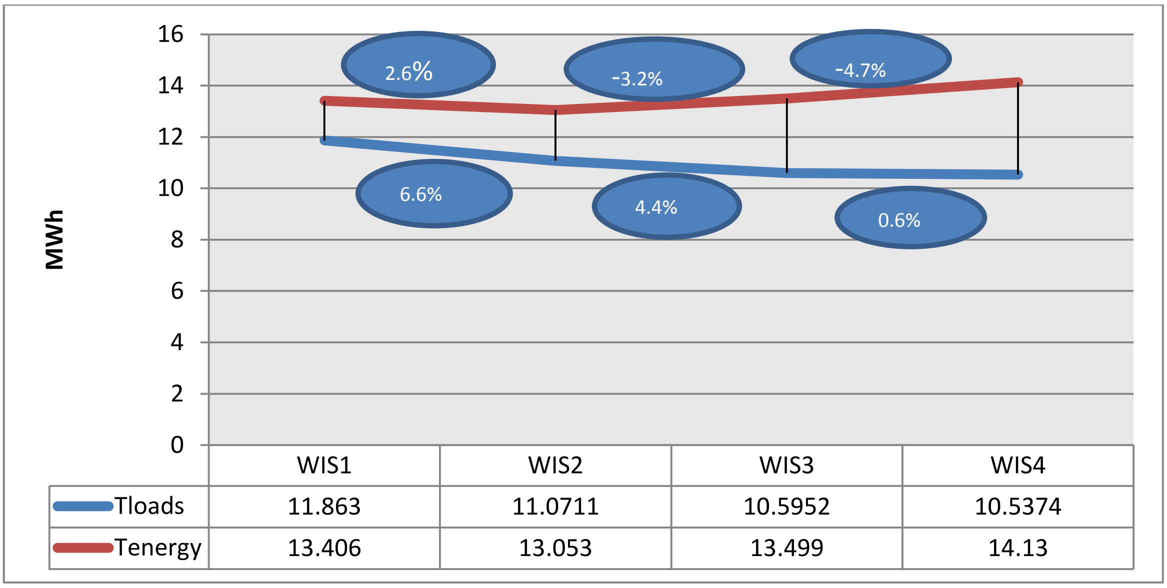
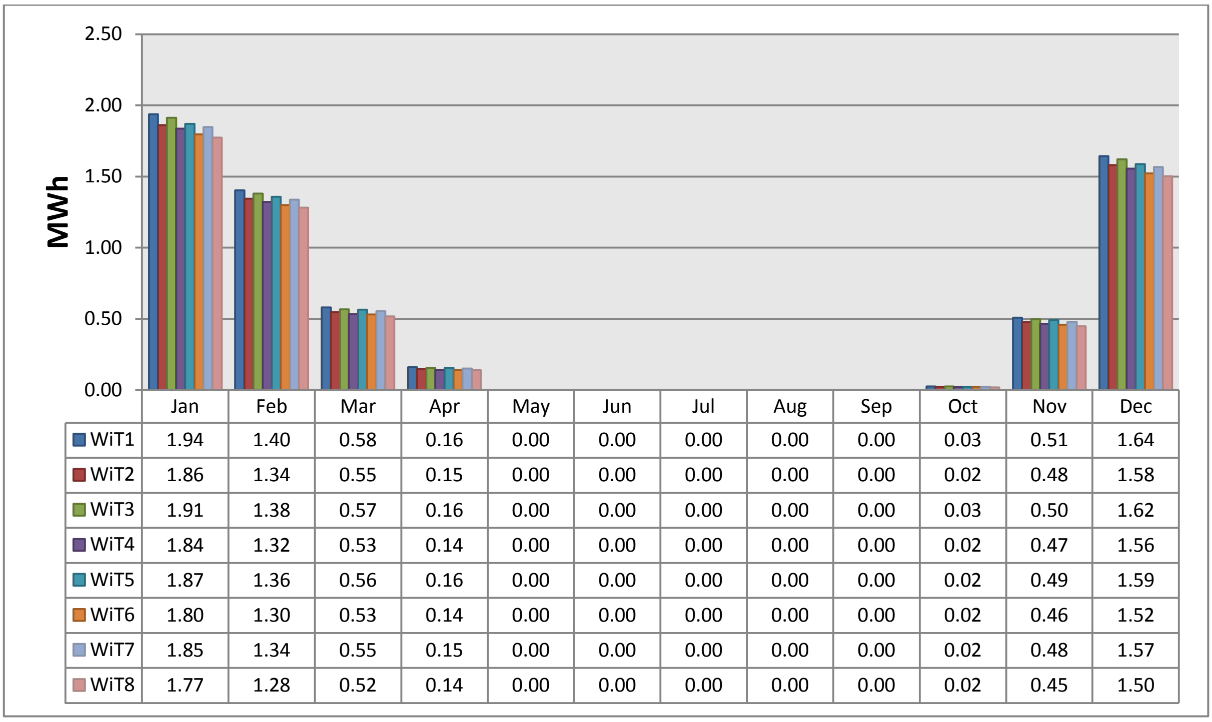


Figure 6.20 – Relations of Changes In Sensible Loads And Energy Consumptions In Different Window Sizes

6.2.4 Window Types

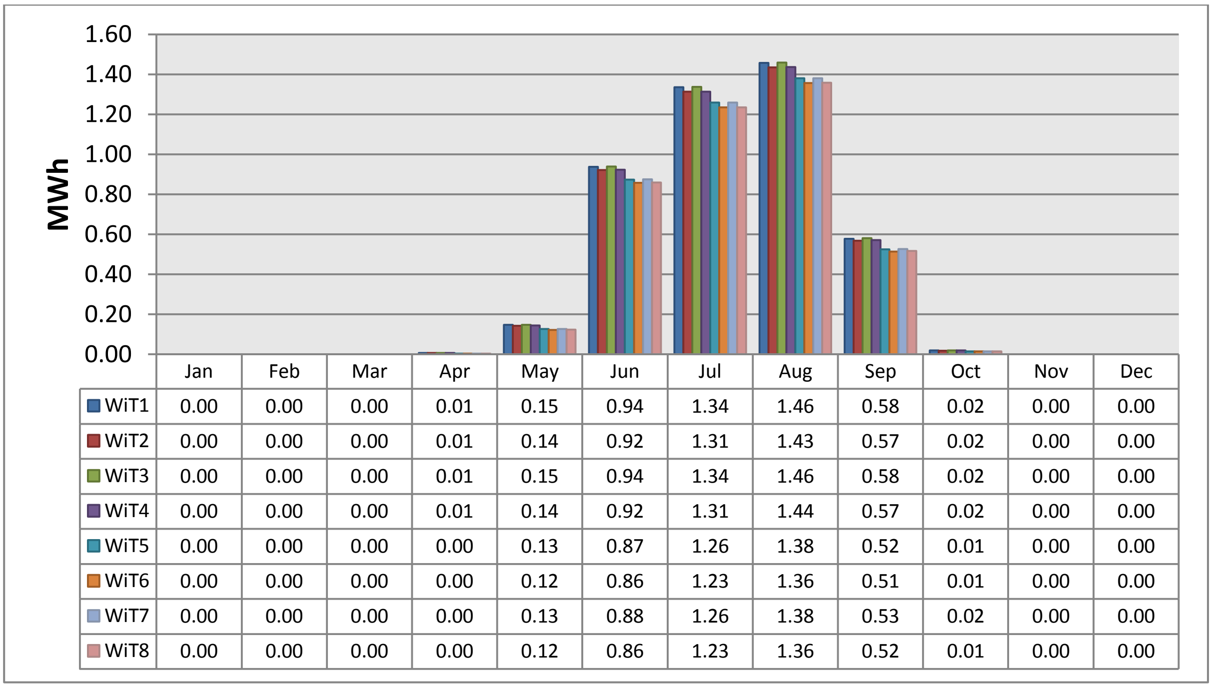
The base case window requires the highest demand load in all months, however, this demand in October and April is very similar to WiT3. Type WiT8 in the coldest months has a better performance than the other windows, this performance accounts for an 8.5% improvement to the base case. In October and April, all the windows have a similar performance with minor differences. The total optimized heating loads from the best case to worst case in all heating months are approximately 580kWha (Figure 6.21).

For the cooling season, WiT8 has generally a better performance than other cases too. However, as Figure 6.22 shows WiT6 also has a very similar performance to WiT8. July and August are the highest cooling demand months and both WiT8 and WiT6 perform the same. The average performance between the low- and high-performance window types are on average 8.5%, which accounts for approximately 410 kWh cooling loads reduction in summer season.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WiT1	1.94	1.40	0.58	0.16	0.00	0.00	0.00	0.00	0.00	0.03	0.51	1.64
WiT2	1.86	1.34	0.55	0.15	0.00	0.00	0.00	0.00	0.00	0.02	0.48	1.58
WiT3	1.91	1.38	0.57	0.16	0.00	0.00	0.00	0.00	0.00	0.03	0.50	1.62
WiT4	1.84	1.32	0.53	0.14	0.00	0.00	0.00	0.00	0.00	0.02	0.47	1.56
WiT5	1.87	1.36	0.56	0.16	0.00	0.00	0.00	0.00	0.00	0.02	0.49	1.59
WiT6	1.80	1.30	0.53	0.14	0.00	0.00	0.00	0.00	0.00	0.02	0.46	1.52
WiT7	1.85	1.34	0.55	0.15	0.00	0.00	0.00	0.00	0.00	0.02	0.48	1.57
WiT8	1.77	1.28	0.52	0.14	0.00	0.00	0.00	0.00	0.00	0.02	0.45	1.50

Figure 6.21 – Monthly Heating Sensible Loads With Different Window Types

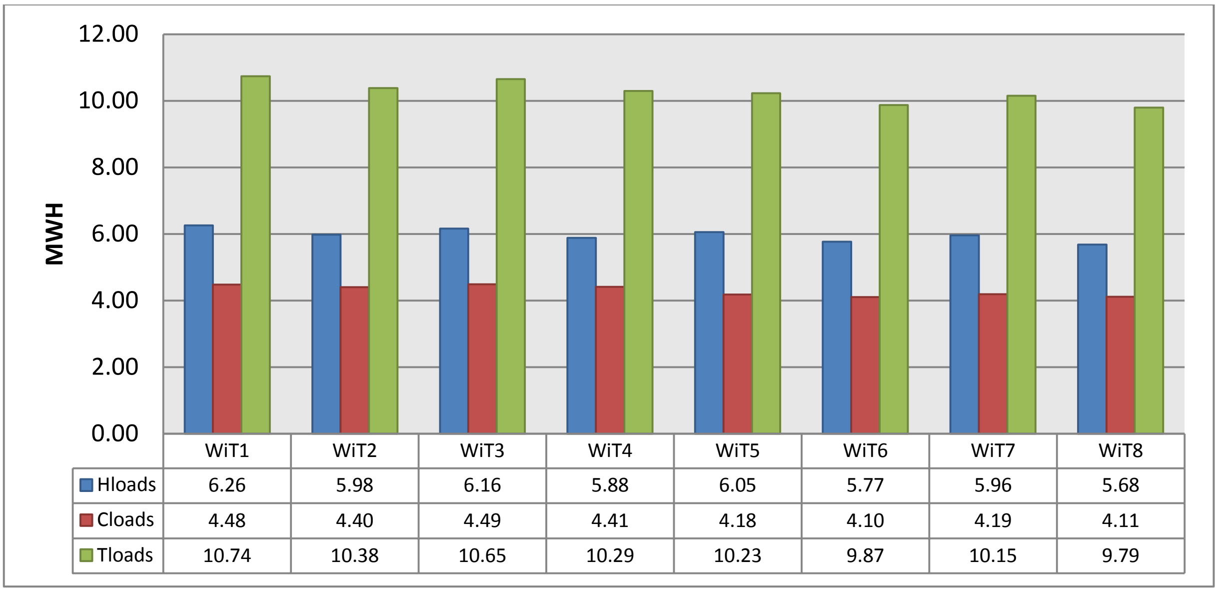


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WiT1	0.00	0.00	0.00	0.01	0.15	0.94	1.34	1.46	0.58	0.02	0.00	0.00
WiT2	0.00	0.00	0.00	0.01	0.14	0.92	1.31	1.43	0.57	0.02	0.00	0.00
WiT3	0.00	0.00	0.00	0.01	0.15	0.94	1.34	1.46	0.58	0.02	0.00	0.00
WiT4	0.00	0.00	0.00	0.01	0.14	0.92	1.31	1.44	0.57	0.02	0.00	0.00
WiT5	0.00	0.00	0.00	0.00	0.13	0.87	1.26	1.38	0.52	0.01	0.00	0.00
WiT6	0.00	0.00	0.00	0.00	0.12	0.86	1.23	1.36	0.51	0.01	0.00	0.00
WiT7	0.00	0.00	0.00	0.00	0.13	0.88	1.26	1.38	0.53	0.02	0.00	0.00
WiT8	0.00	0.00	0.00	0.00	0.12	0.86	1.23	1.36	0.52	0.01	0.00	0.00

Figure 6.22 – Monthly Cooling Sensible Loads with Different Window Sizes

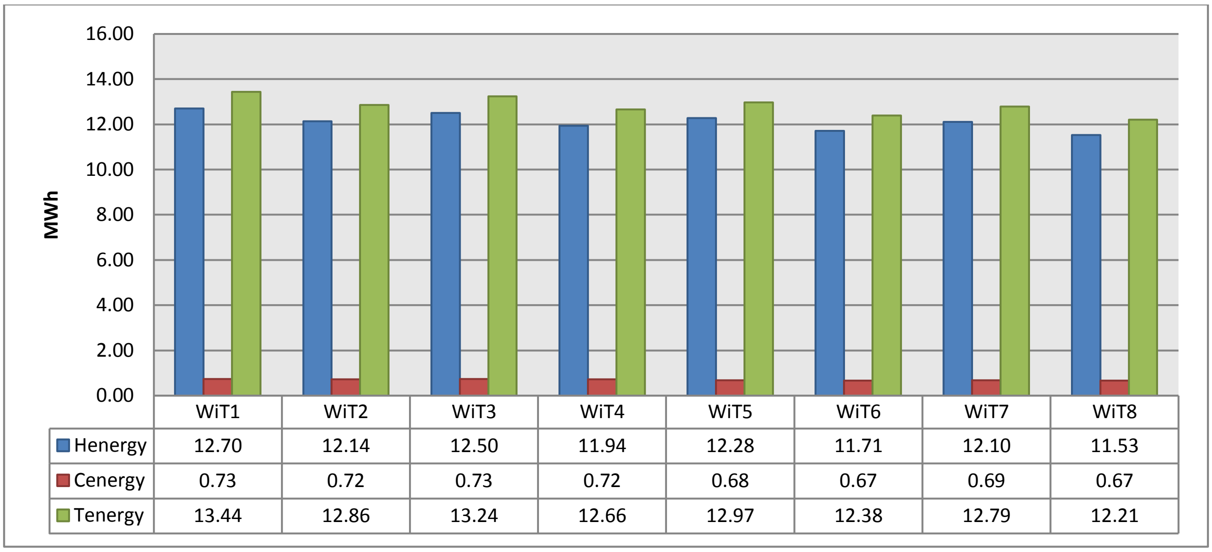
As Figure 6.23 shows, the total heating loads in the base case has the largest demand of 6.26MWh compared to WiT8 of 5.68MWh. Although the total cooling loads follow this trend, WiT6 has a slightly better performance than the other cases. As a result, the total sensible load with WiT8 has the best performance by 9.79MWh, which means a total of 9% optimization.

Regarding the energy consumption, as expected, by applying WiT8 reduces energy consumption in all the months for both cooling and heating energy (Figure 6.24). In addition, over 95% of energy consumption in the building is for heating purposes. As a result, a 9.2% reduction in heating loads means only a 60kWh energy reduction, while 8.2% reduction in cooling loads means an energy reduction of 1221kWh.



	WiT1	WiT2	WiT3	WiT4	WiT5	WiT6	WiT7	WiT8
🟦 Hloads	6.26	5.98	6.16	5.88	6.05	5.77	5.96	5.68
🟥 Cloads	4.48	4.40	4.49	4.41	4.18	4.10	4.19	4.11
🟩 Tloads	10.74	10.38	10.65	10.29	10.23	9.87	10.15	9.79

Figure 6.23 – Annual Heating and Cooling Sensible Loads with Different Window Types



	WiT1	WiT2	WiT3	WiT4	WiT5	WiT6	WiT7	WiT8
🟦 Henergy	12.70	12.14	12.50	11.94	12.28	11.71	12.10	11.53
🟥 Cenergy	0.73	0.72	0.73	0.72	0.68	0.67	0.69	0.67
🟩 Tenergy	13.44	12.86	13.24	12.66	12.97	12.38	12.79	12.21

Figure 6.24 – Annual Heating and Cooling Energy Demand with Different Window Types

The performances of window types show that the changes in the required load and energy consumption won't suggest further efficiency of the cases. For instance, by replacing WiT4 with WiT5, the demand load decreases slightly, however, the total energy consumption increases by 2.5%. As a result, while the total demand load decreases by 9% from the base case to WiT8, the energy consumption decreases by 4.9% only.

6.2.5 Natural ventilation

In the hot summer days of Tehran, ventilation is not an option. This will be discussed later in the free running building section of this chapter. Consequently, this study considers the use of night ventilation as a common solution for semi-arid climate conditions with hot summer days and cooler nights.

For this purpose, three-night ventilation plans have been selected for further analysis (Table 6.2).

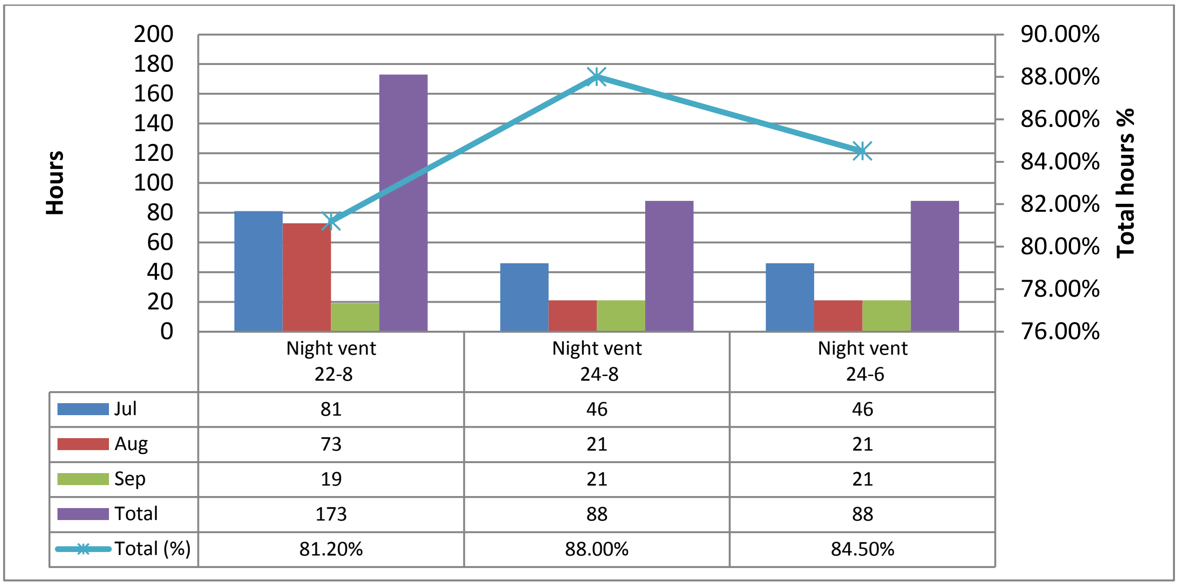
Table 6.2 – Natural Ventilation Time Plan

Ventilation type	**Time**
Night vent 22-8	22:00 – 08:00
Night vent 24-8	24:00 – 08:00
Night vent 24-6	24:00 – 06:00

Figure 6.25 shows that night ventilation 24-8 has the highest thermal comfort in the summer months with approximately 88% thermal comfort at all time. Although the night ventilation 24-6, which is within the night ventilation 24-8 hours range, has the same thermal comfort hours, the percentage of thermal comfort is less than the Night vent 24-8. This is due to the longer time plan range of Night vent 24-8.

The best performance months are in August and September in which only 21 hours of the planned time is beyond the thermal comfort which is less than 10% of the total planned time. On the other hand, in July, despite a high achievement of thermal comfort by reducing the non-comfort hours from 81 hours in the base case to 41 hours, this month has the highest number of non-comfort hours.

The higher the percentage of thermal comfort means that the less the mechanical system is required to heat or cool the internal spaces. Therefore, priority for selecting the best case is for higher percentages when the numbers of total hours are the same. However, the higher percentage should not compromise the thermal comfort hours.



	Night vent 22-8	Night vent 24-8	Night vent 24-6
🟦 Jul	81	46	46
🟥 Aug	73	21	21
🟩 Sep	19	21	21
🟪 Total	173	88	88
Total (%)	81.20%	88.00%	84.50%

Figure 6.25 – Impacts of nigh ventilation plans on thermal comfort, hours indicate the reaching uncomfortable hours in each month and the total amount shows the percentage of thermal comfort duration in each month

The above analysis proves that the time plan of Night vent 24-8 has the best performance among all the cases. Therefore, in this section this time plan is examined with coupling the window openable sizes to find the most optimized ventilation form. The selected openable sizes are 50%, 75% and 100%.

Figure 6.26 shows that as expected, the openable 100% size achieves the highest thermal comfort hours with 92%. The increase of thermal comfort percentage from the base case to the larger openable sizes has a steady growth. The openable 100% has the best performance in August and September as the uncomfortable temperature decreases by 50% compared to the base case. This optimisation becomes slightly slower in July where thermal comfort temperatures increase by 20%. The slower optimisation in July is obviously a result of the high temperatures during this month.

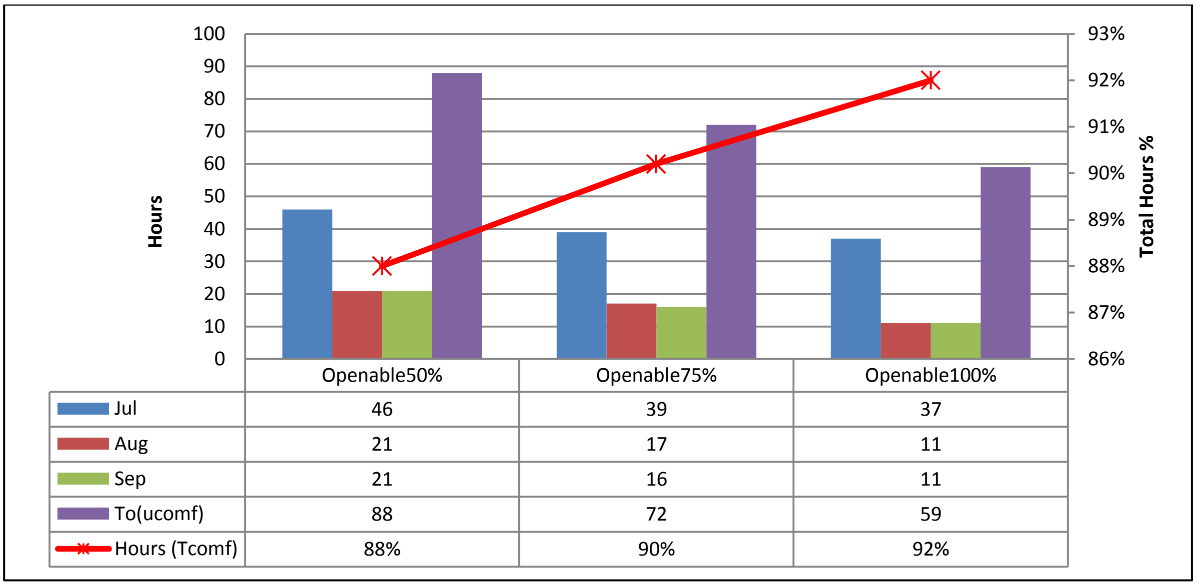


Figure 6.26 – Impacts Of Openable Sizes On Thermal Comfort

In this section, the cooling loads and subsequent energy performance of the building as a result of night ventilation is explored. According to Figure 6.27 the lowest cooling sensible load is 3.72MWh for the 100% openable case. The night ventilation by applying 100% openable windows resulted in a 13.3% cooling load reduction compared to the base case.

In addition, the total sensible load decreases from 10.60MWh to 9.94MWh, this means a total reduction of 6.2%.

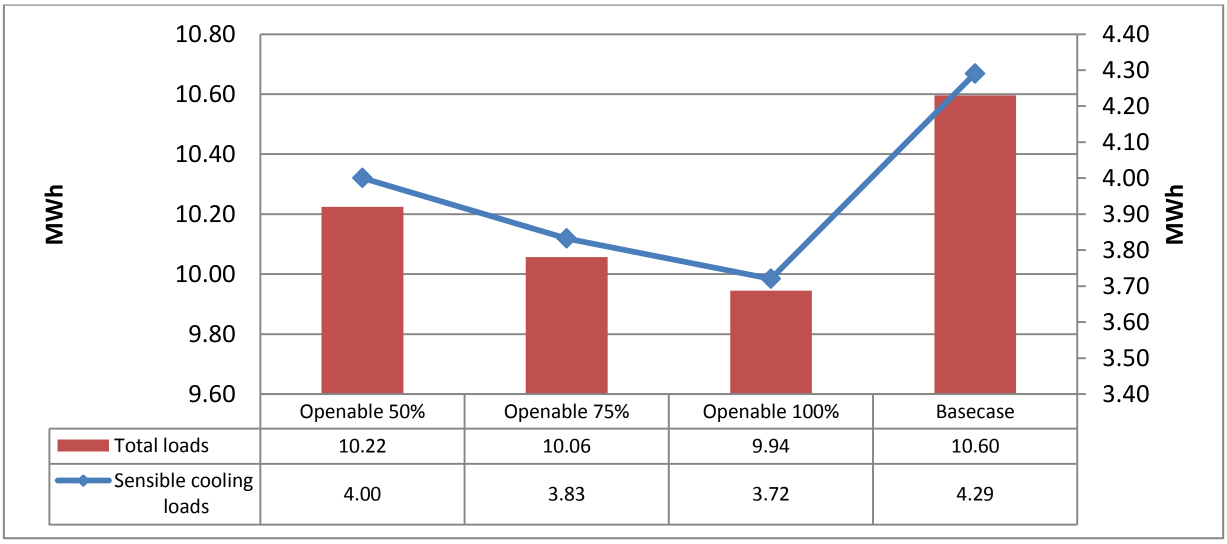


Figure 6.27 – Cooling and Total Sensible Loads as a Result of Night Ventilation Inlet Size

Figure 6.28 shows that the cooling energy (electricity) decreases from 700kWh (Base-case) to 610kWh in Openable 100% mode. This means that night ventilation will contribute not only to the energy reduction but it will economically have a big benefit to house holders.

The total load is impacted less as the amount of cooling energy is in general far less than the heating energy.

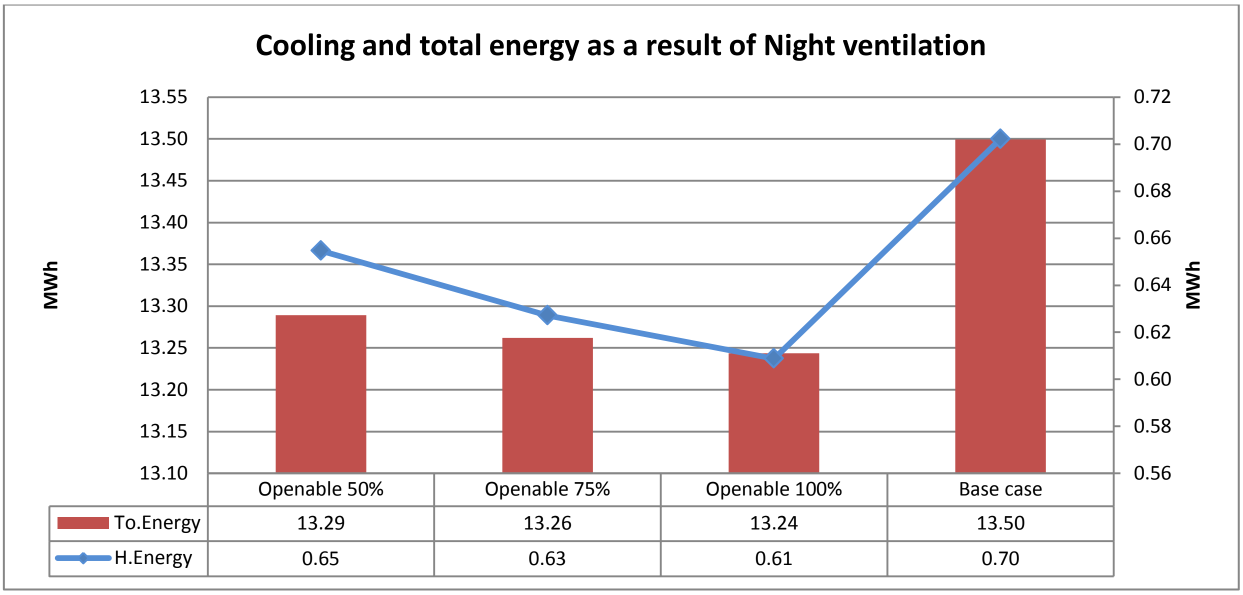


Figure 6.28 – Total and Cooling Energy Consumptions as a Result of Natural Ventilation Inlet Size

6.2.6 Walls Thermal Performance Evaluation

The first approach is to make a clear evaluation of the performance of the building’s fabric thermal system when exposed to dynamic weather conditions. For this purpose, the internal temperature of the hottest and coldest days over a year is identified to examine the internal temperature changes in the building.

In winter the coldest internal temperature (day 17) does not coincide with the coldest external temperature (day 16). Figure 6.29 shows that despite the external temperature of about -5^{o}C, all the different fabrics are able to keep the internal temperatures above 5.5^{o}C due to the low U-Value of the building’s envelope. This shows that, with tighter building regulations regarding the fabric, the role of good passive design becomes even more significant.

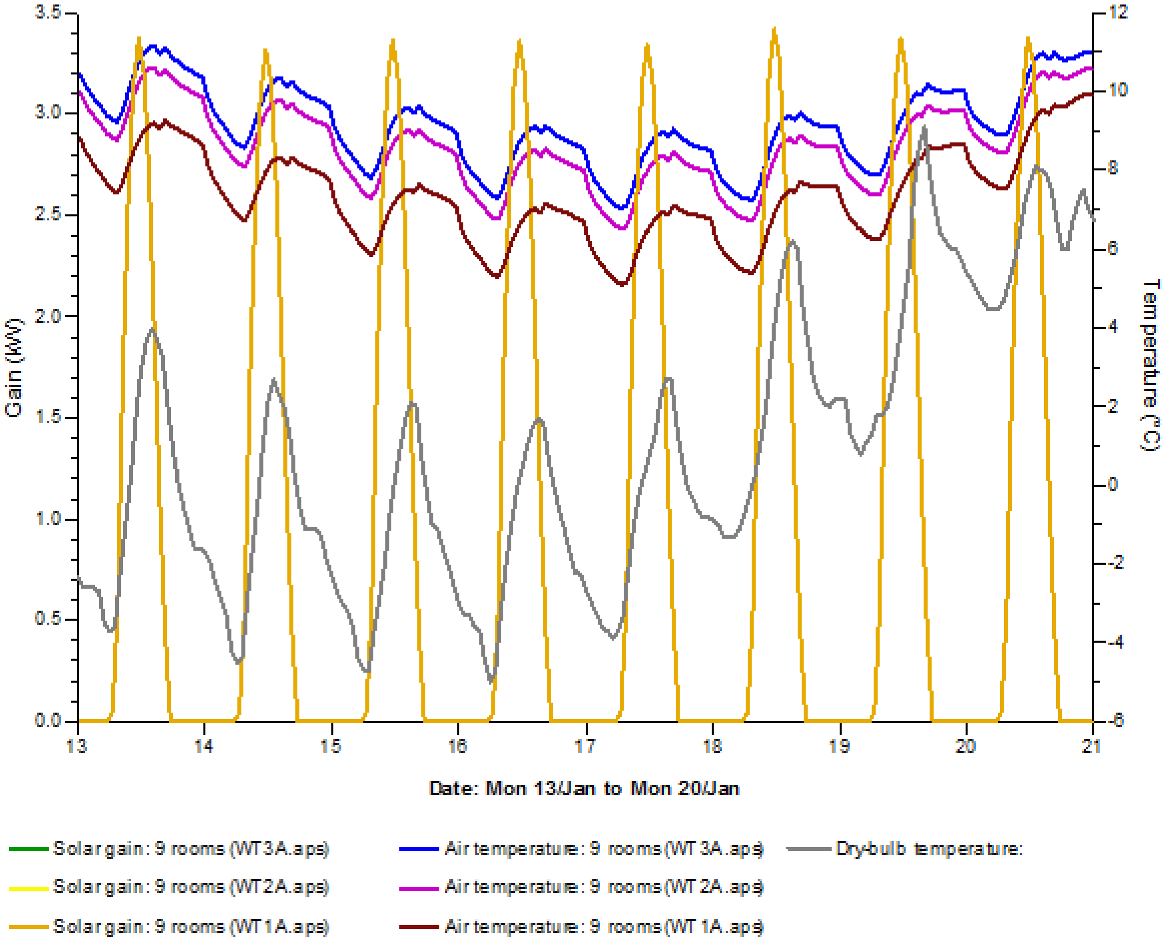


Figure 6.29 – Walls Thermal Behaviour in the Coldest Week

The day with the coldest external temperature (Figure 6.30) shows the thermal mass of the WT1 is contributing to a ‘flatter’ pattern of temperature change with a slower response to gains and so a smaller minimum and maximum peak temperature (5.31 and 7.12°C respectively). In this time of the year, WT3 seems to have a faster response to solar gains and warms up to a higher temperature (9.10°C) also keeping the internal space warmer for a longer time.

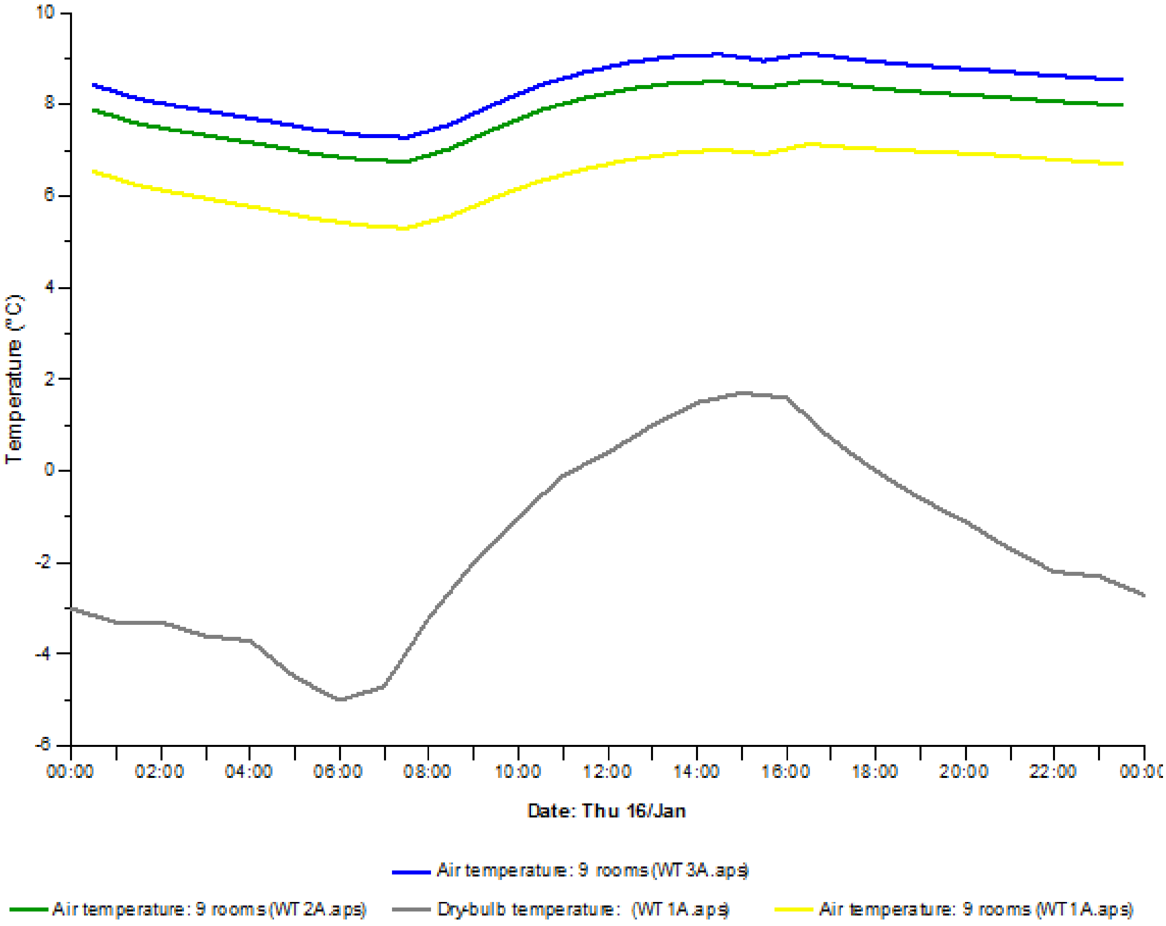


Figure 6.30 – Walls Thermal Behaviour in the Coldest Day

Figure 6.31 shows the warmest week when peak temperatures can be found. All the different fabrics were able to maintain fairly stable internal temperature (within 5°C on a daily basis) despite the external temperature swings and the different availability of solar radiation.

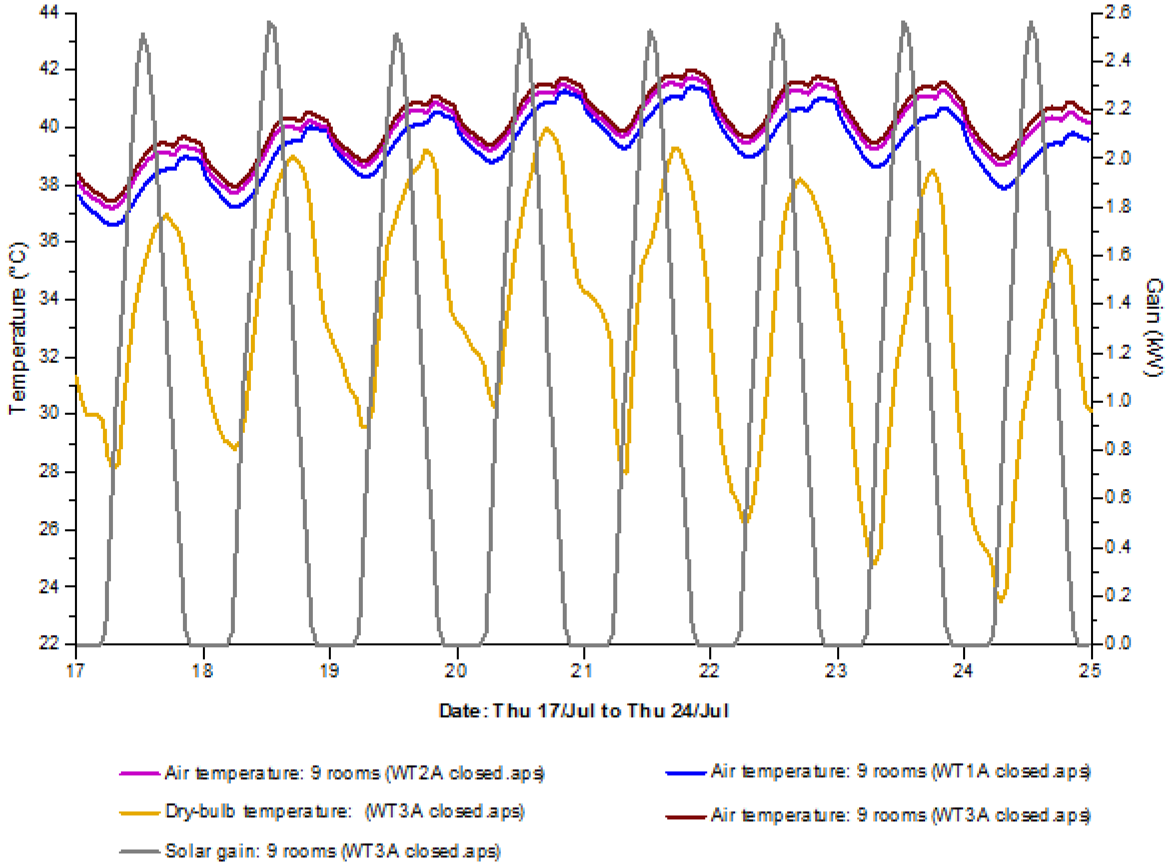


Figure 6.31 – Walls Thermal Behaviour in the Warmest Week

A closer look at the day with the peak temperature (Figure 6.32) reveals that the worst performers (WT3) has a close behavioural pattern to the other wall types reaching 42°C, which is about 1°C higher than the best performer (WT1). Interestingly, at night when the outside temperatures drop, all parameters perform at a similar pace and the internal space seems to be affected greatly from the stored heat in the walls during the day. In fact, the internal temperature decreases slightly at night, this temperature drop is considerably little compared to the external temperature drop. This means that the external solar heat is consistently absorbed by the walls and avoids significant increases in the internal temperature during the day. Conversely, when the outdoor temperature begins to drop in the evening, the internal temperature experiences small drops due to heat discharged into the internal spaces. Although, different wall types react almost similarly with little differences only, in the long term more energy will be consumed if a mechanical device is used for space conditioning.

As this analysis is carried out in an adiabatic situation, the natural ventilating effect is not considered, therefore, in the following sections (Section for Natural ventilation effect) the effect of natural ventilation and wall performances during the warmest day will be discussed comprehensively.

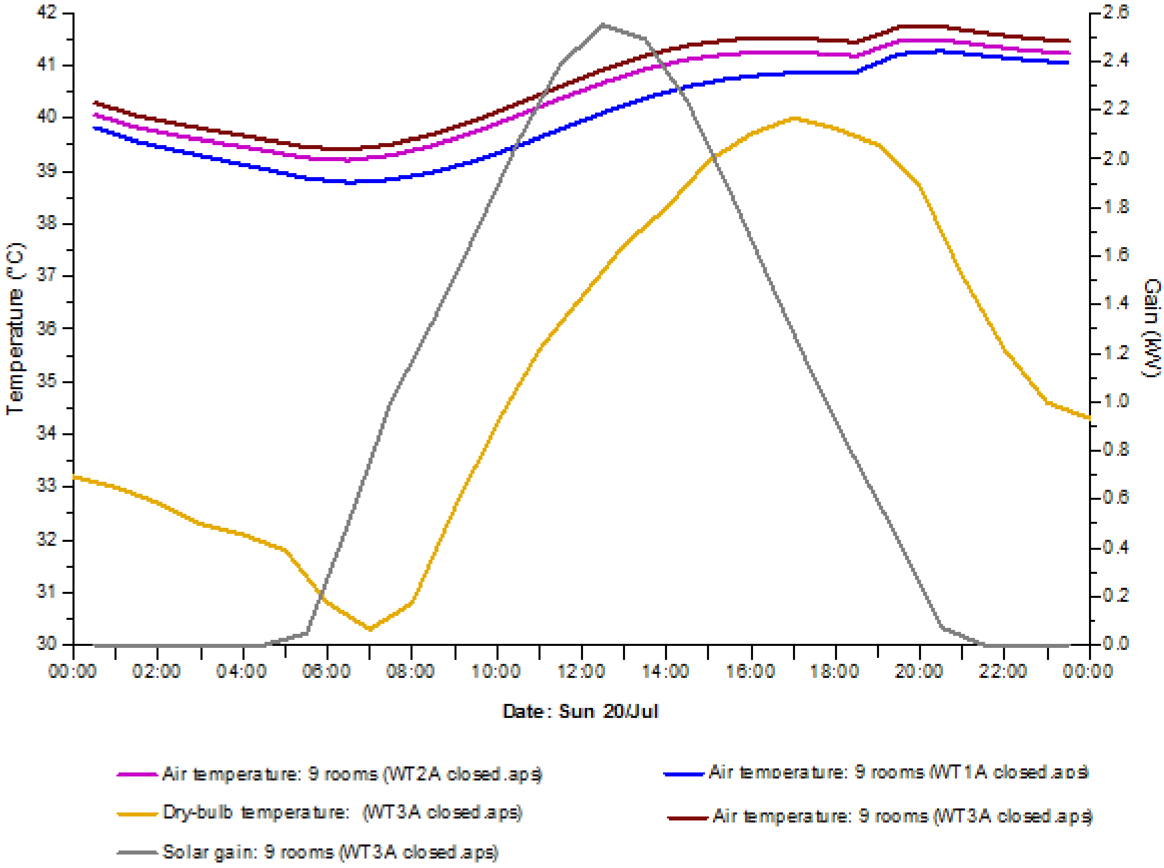


Figure 6.32 – Walls Thermal Behaviour in The Coldest Day

6.2.7 Window Thermal Behaviour

Window types based on their specifications play an important role on building energy efficiency. Window's U-value, Solar Heat Gain Coefficient (SHGC) or Shading Coefficient (SC) is the most influential factors to determine their energy efficiency performance. In order to evaluate existing windows systems, the warmest day of year has been selected to examine the temperature fluctuations based on different window types.

Figure 6.33 shows that all the eight window types have a relatively similar performance with minor differences. The largest temperature gap between the best and the worst performance on the high peak time is less than 0.5°C. WiT4 has the best performance, while WiT1 (Base case) has the worst performance.

Surprisingly, WiT4 has a middle range U-value among the other cases. The U-value for WiT4 is 2.46 W/m²K while the WiT8 has a u-value of 1.85 W/m²K as the lowest and WiT1 has the highest of 3.18 W/m²K.

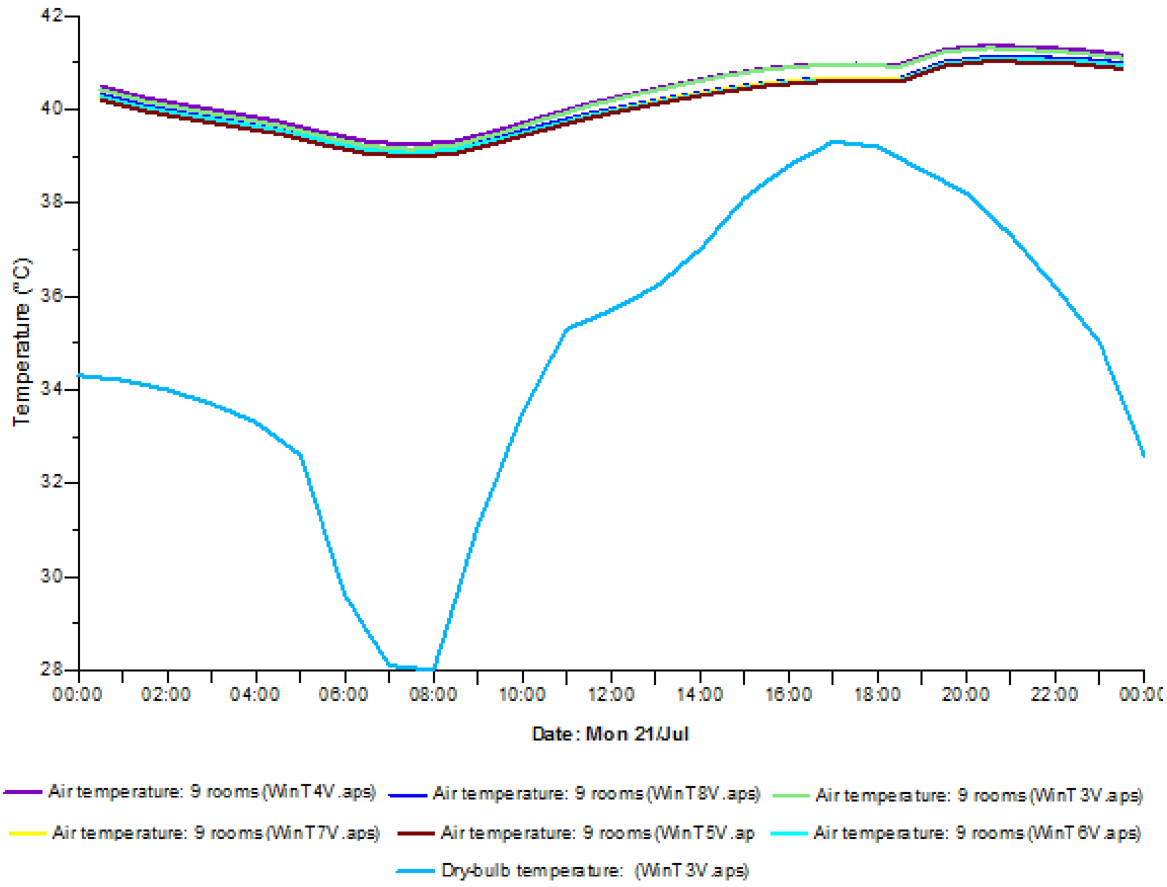


Figure 6.33 – Window Types Thermal Behaviour on the Warmest Day

Likewise, on the coldest day of winter the temperature differences between the windows types are considerably small. Figure 6.34 shows that WiT5 has the best performance during most of the day. However, even these little different temperature ranges between the parameters can significantly impact on the building's heating energy consumption. These little temperature differences during the winter are due to the higher u-values that transfer the heat faster to the outside than the windows with lower U-values. The U-value of windows are almost higher than the walls, therefore by considering the walls and windows u-values and the area proportion, it is not logically possible to expect a better performance for window types towards the total thermal and energy efficiency of the building at this stage.

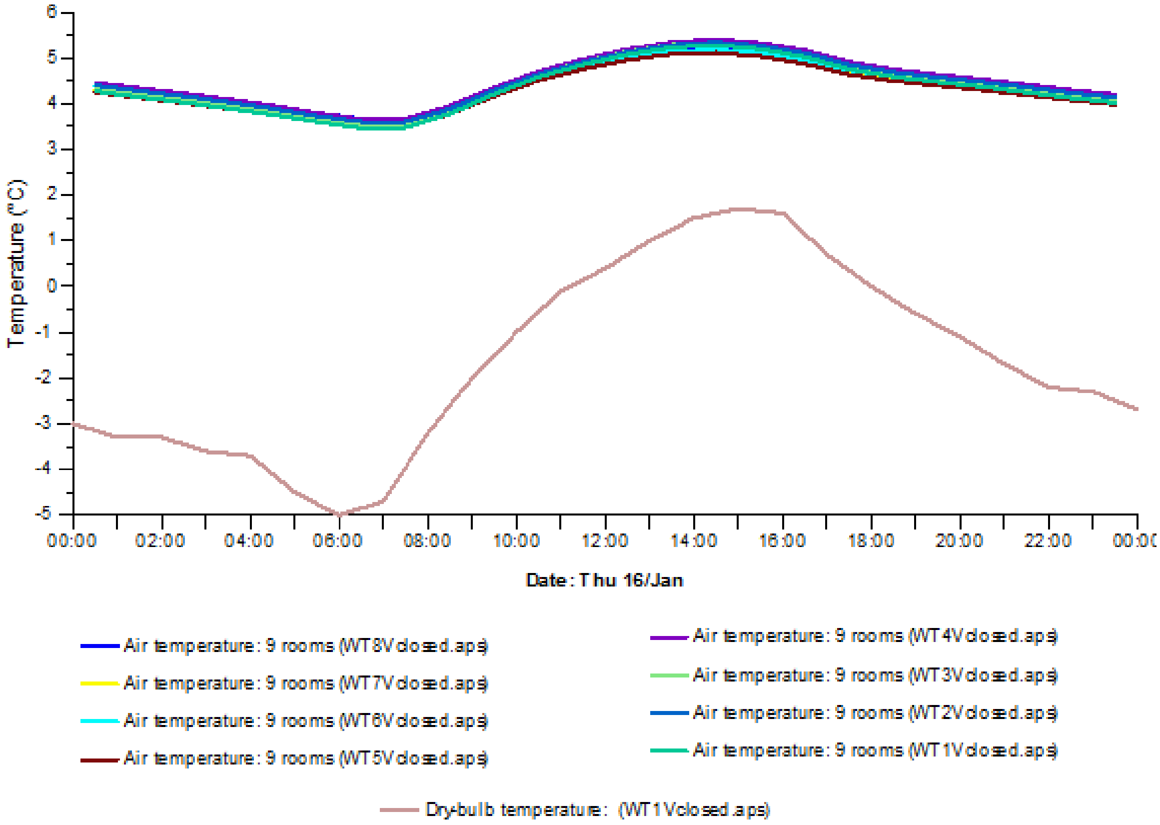


Figure 6.34 – Window Types Thermal Behaviour on the Coldest Day

6.2.8 Best active case selection

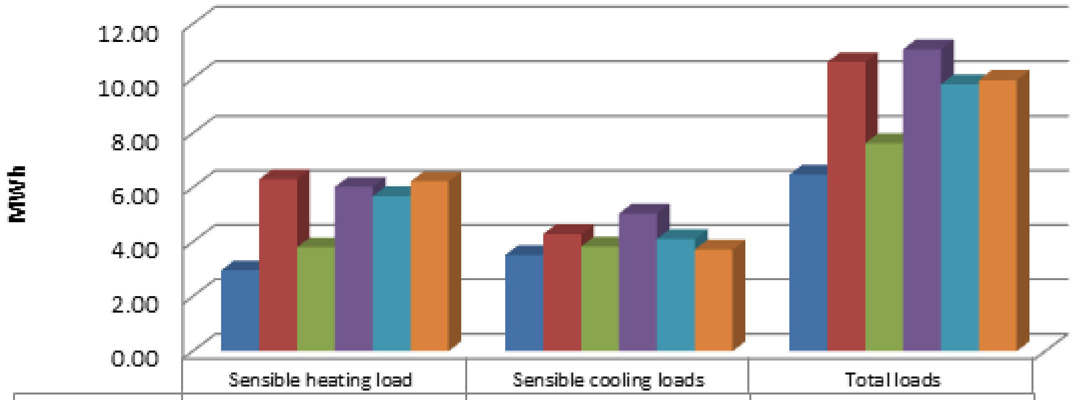
In order to identify the best energy optimised building, the best performance parameters from the above findings are selected (Table 6.3). The selected parameters have the best energy performance; however, this condition is applicable as long as their total primary energy is the lowest among other parameters.

Table 6.3 – Best Energy Performance Parameters

Parameters	***Type***	***Descriptions***
Wall	WT3	Wall with AAC block
Window size	WiS2	Window with WWR 32.2%
Window type	WiT8	
Ventilation	Openable 100%	Triple glazing window with argon filling

The active optimized case was formed by combining the best performing parameters in the above analysis. The active optimised case as shown in Figure 6.35 achieves a lower total sensible load than the base case by 39%. The heating sensible loads drop sharply by 54% while the cooling loads decreases by 18%.

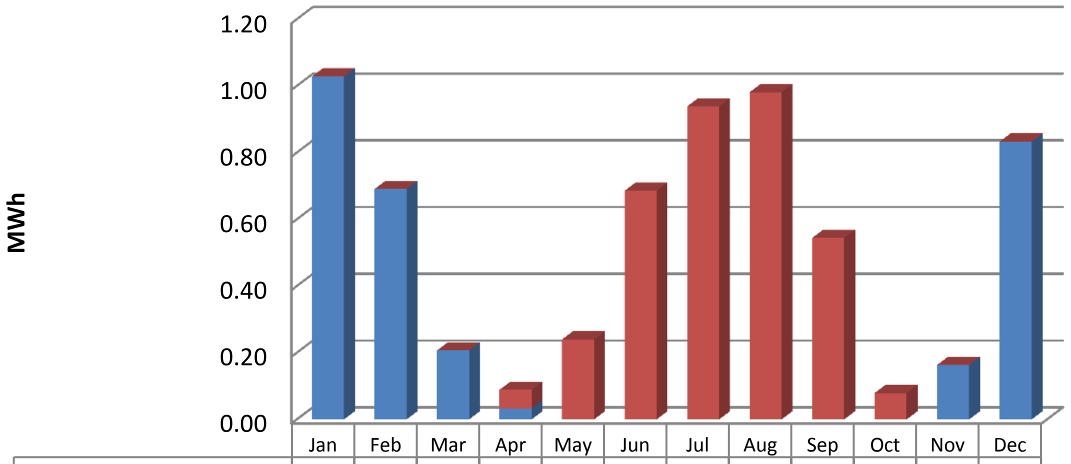
There is no surprise that WT3 as a single parameter has the biggest share in reducing the sensible loads among the active optimized case. According to the analysis, the share of WT3 in reducing the sensible loads from the base case to the active optimized case is 25% out of the total 39%, while the other cases have less than 15% shared accumulatively.



	Sensible heating load	Sensible cooling loads	Total loads
🟦 Total Opt case	2.96	3.52	6.48
🟥 Total Bcase	6.30	4.29	10.60
🟩 WT3	3.80	3.83	7.63
🟪 WiS2	6.02	5.05	11.07
🟦 WiT8	5.68	4.11	9.79
🟧 Night vent100%	6.22	3.72	9.94

Figure 6.35 – Total Sensible Loads in Parameters Singly and Active Optimised Case

For the active optimized case, in the monthly context (Figure 6.36), January has the highest required sensible loads as well as the highest heating loads. In the summer months, August and July have the highest sensible load requirements. April is the only month that both cooling and heating loads are required. Both the cooling and the heating loads are the lowest requirement in April in comparison to the other months.

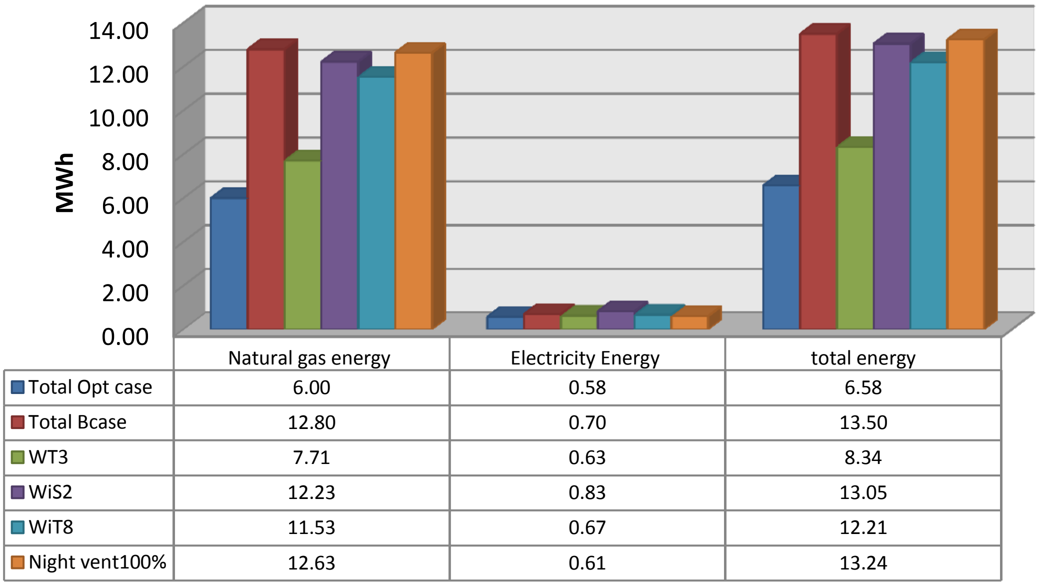


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 Sensible cooling loads	0.00	0.00	0.00	0.06	0.24	0.69	0.94	0.98	0.54	0.08	0.00	0.00
🟦 Sensible heating load (Mwh)	1.03	0.69	0.21	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.83

Figure 6.36 – Monthly Sensible Loads in Active Optimises Case

For energy consideration, as shown in Figure 6.37, the active optimised case reaches a lower total energy consumption by over 51% than the base case. As discussed earlier, the largest share of the total energy consumption is as a result of the heating energy that decreases from an annual 12.80MWh to 6MWh. Electricity consumption also decreases from an annual 0.7MWh to 0.58MWh respectively.

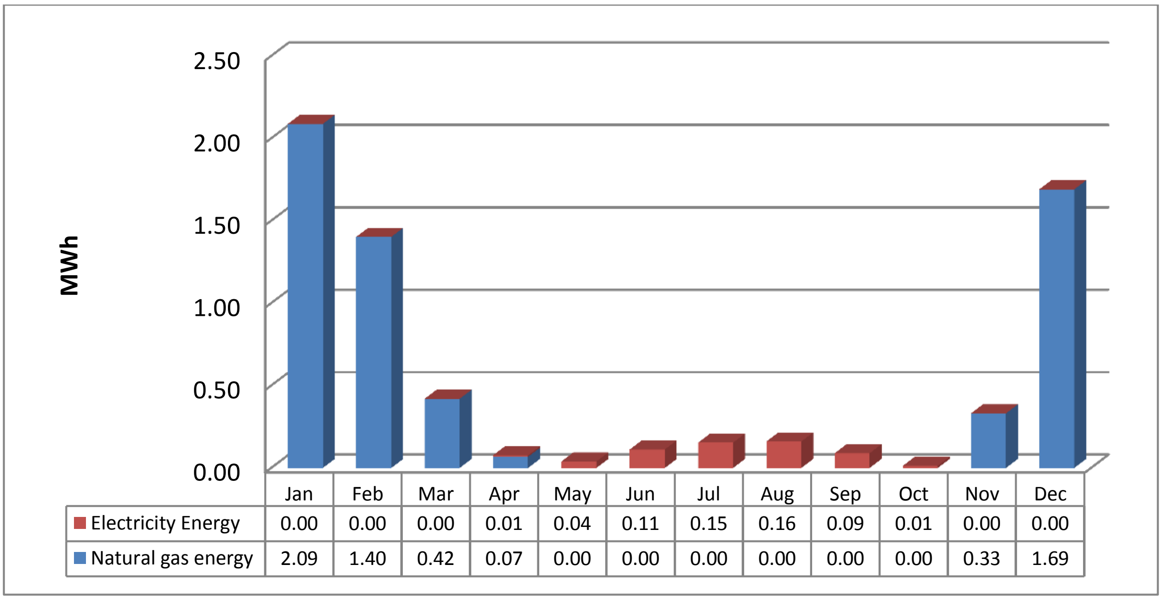
For energy, WT3 has the most significant role by accounting for 30% out of the 51% reduction, while the other parameters impact on energy reduction by 21%. The lowest impact rate related to Night vent 100%, which decreases the heating energy by 1.3%. However, night ventilation is not assumed to impact on heating energy as it is active during summers only, so the total energy consumption is not affected considerably. On the other hand, Night vent 100% has the best cooling reduction performance among the other parameters by 13% out of the total 17% of cooling optimization.



	Natural gas energy	Electricity Energy	total energy
🟦 Total Opt case	6.00	0.58	6.58
🟥 Total Bcase	12.80	0.70	13.50
🟩 WT3	7.71	0.63	8.34
🟪 WiS2	12.23	0.83	13.05
🟦 WiT8	11.53	0.67	12.21
🟧 Night vent100%	12.63	0.61	13.24

Figure 6.37 – Total Heating And Cooling Energy Consumption In Parameters (Singly) And Active Optimised Case

The optimized case has the lowest energy consumption in October and May with 0.01MWh and 0.04MWh respectively. The highest energy consumption months are January and February with 2.09MWh and 1.69MWh respectively (Figure 6.38).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 Electricity Energy	0.00	0.00	0.00	0.01	0.04	0.11	0.15	0.16	0.09	0.01	0.00	0.00
🟦 Natural gas energy	2.09	1.40	0.42	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.33	1.69

Figure 6.38 – Monthly Energy Consumption, Heating: Natural Gas And Cooling: Electricity

6.3 Passive Building (Free Running Building)

In this section the effect of the building fabric and designs on achieving thermal comfort in the unconditioned mode is evaluated. This evaluation examines the effects of each of the single elements and designs in achieving thermal comfort, and eventually a combination of the best parameters to shape the best passive base case. The thermal comfort range, as explained in previous chapters is applied based on the Heydari method which is an amended version of ASHRAE standard 55, provides minimum requirements for acceptable thermal indoor environments. Some parameters are evaluated based on both 80% and 90% acceptability temperature by occupants, however, the rest of the parameters are evaluated on 80% acceptability only.

6.3.1 Walls Analysis

If the role of natural ventilation is used to predict how the building fabric would impact on the thermal comfort, the results reveal that in the warmest days of year, opposite to the earlier findings in the previous section, WT3 has a better performance than the other walls. WT1 has the worst performance in the case of natural ventilation due to the amount of heat absorbance and discharge. As Figure 6.39 shows, outdoor temperatures from 11:00 AM to 8:00 PM is higher than the indoor temperature; in this situation WT1 absorbs solar heat, then in the evening at 8:00 PM when the indoor temperature starts to decrease below the outdoor temperature WT1 starts to discharge to the cooler indoor space until 11 AM. This process creates a higher indoor temperature than the other wall types.

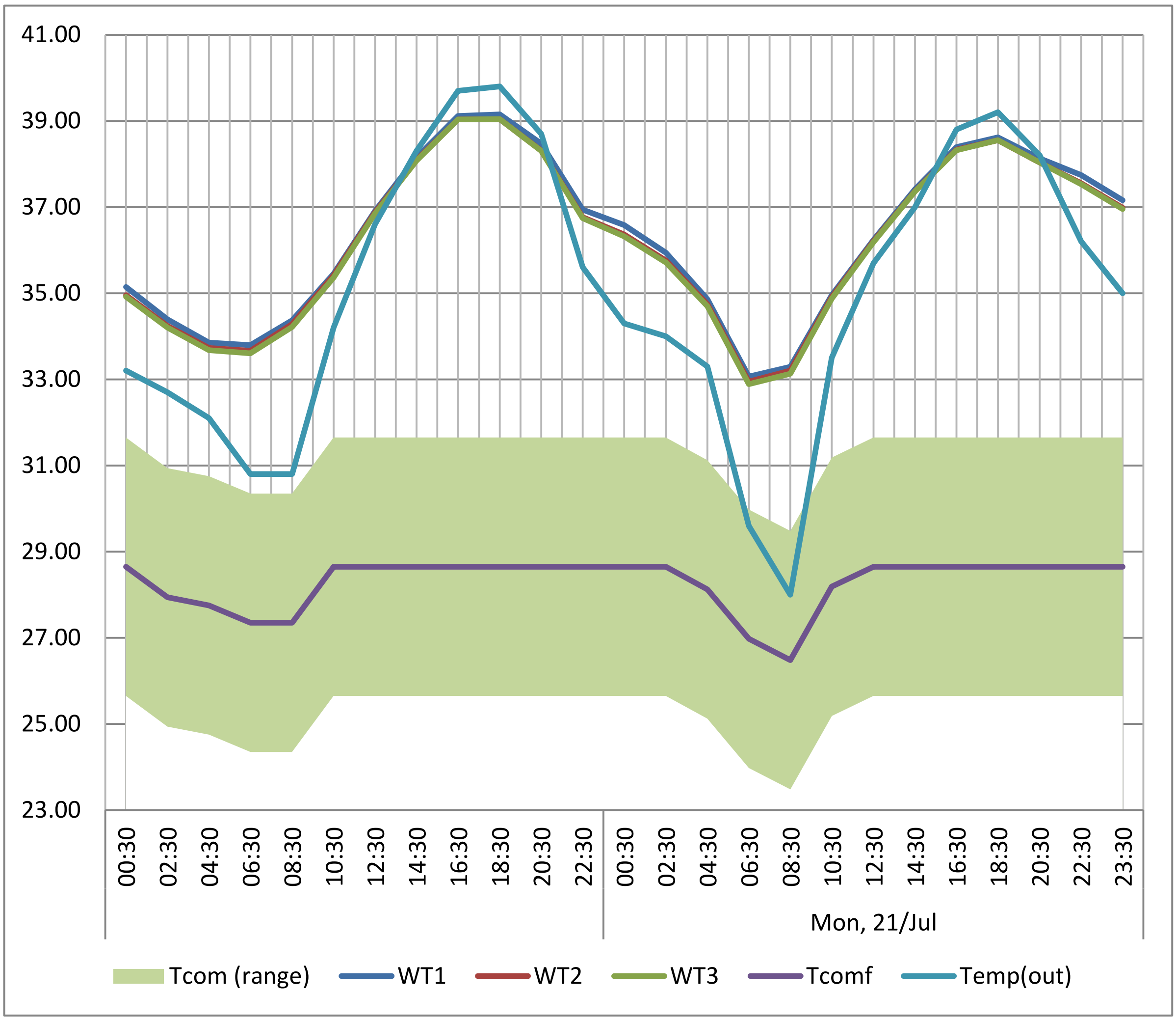


Figure 6.39 – Impact of Ventilation on Internal Temperature in Different Walls in Warmest Days

In winter, WT3 as mentioned previously, also has a better performance than the other walls; this is due to the lower U-values. As Figure 6.40 shows, WT3 performs the best in comparison to the other walls in November and March, this is a result of the internal temperature that is close to the thermal comfort range. Furthermore, WT1 is unable to maintain a significant amount of the time within the thermal comfort, unlike the WT3. In addition, the thermal comfort performances indicate that WT3 in April and November has the best performance within the range of 80% acceptability. The performance of WT3 suggests a free running building in these months is achievable, as over 95% of the indoor temperature falls within thermal comfort whereas WT1 is as low as 65% in November and 85% in April.

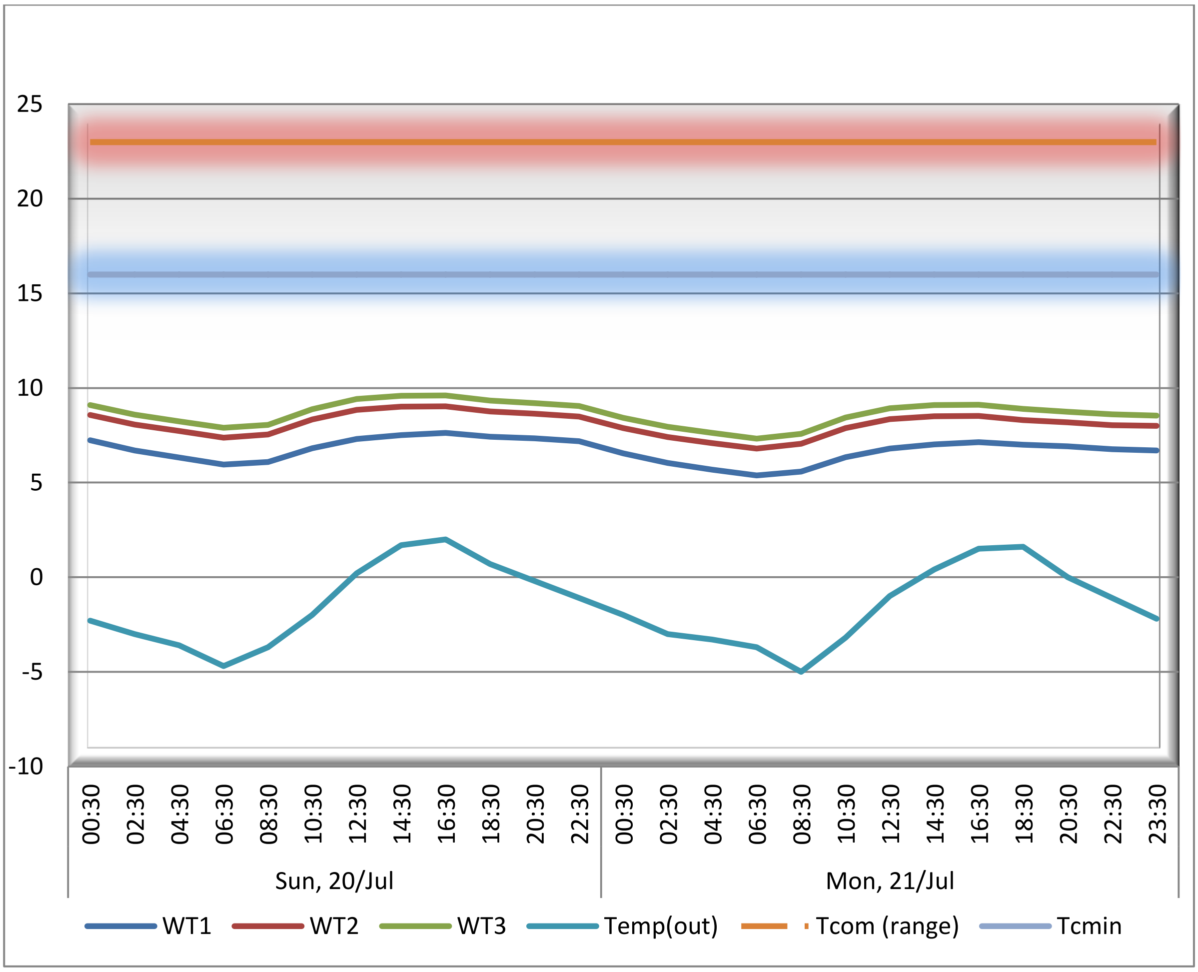


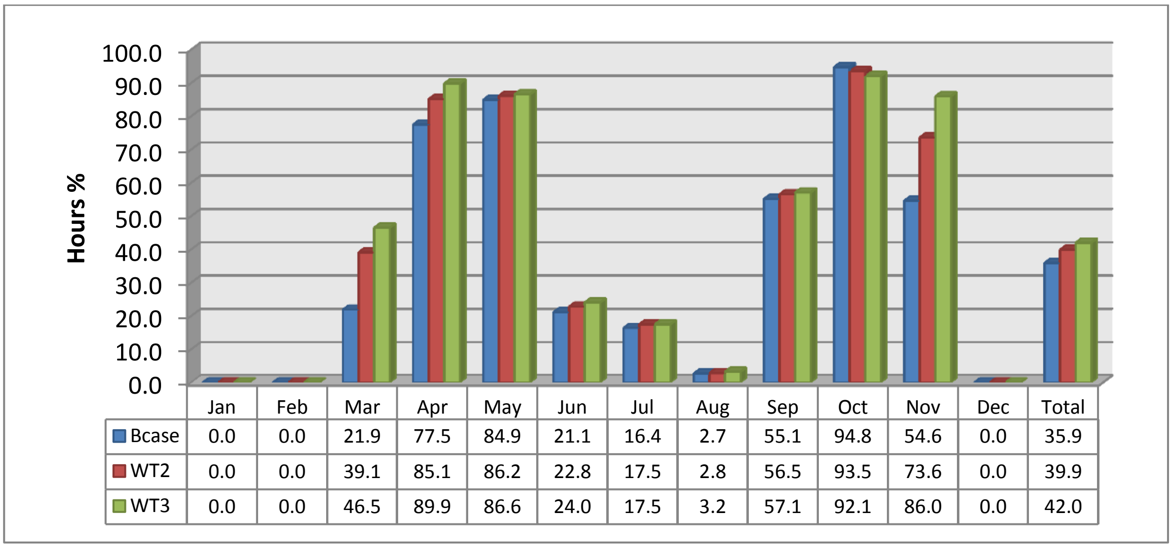
Figure 6.40 – Impact of Ventilation on Internal Temperature in Different Walls in Coldest Days

The total performance of walls shows that thermal comfort range improves in all wall types by approximately 6% from WT1 (base-case) to WT3. The most significant difference takes place during the autumn and spring seasons.

The results reveal that if the 90% thermal comfort acceptability is used, none of the wall types can achieve free running months (Figure 6.41), while by considering the 80% acceptability both the WT1 and WT2 achieve two free running months in May and October, and WT3 achieves four free running months in April, May, October and November (Figure 6.42).

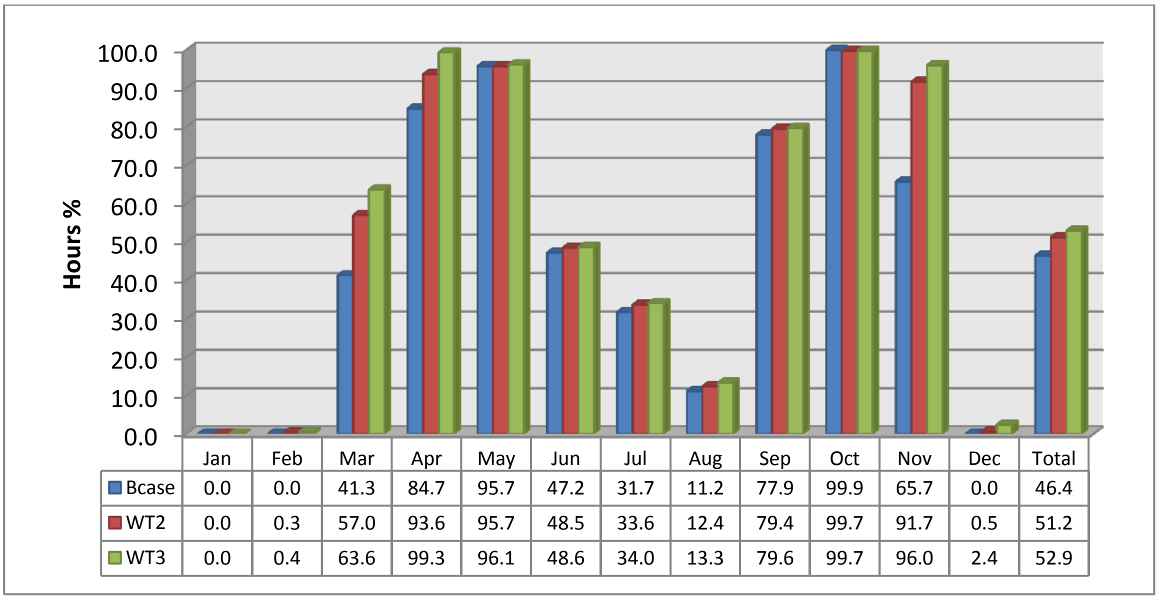
Accordingly, the most important finding of this section is that WT3 is the best performer during the warm seasons when the natural ventilation is active. Although, in summer time as a result of WT3 during short periods of time and even in September about 80% of time falls within the thermal comfort range, they are not enough of a comfortable range for free running purposes. As a result, a combination of measuring energy consumption and free running building will be the most important factor to select the building fabric and designs that are considered later in this chapter.

As demonstrated in Figures 6.41& 6.42, the total thermal comfort duration with different wall types are varied and WT3 has the best overall thermal temperature by being within the thermal comfort range more than 52% of the time. Although the duration of thermal comfort in some months do not meet the free running requirement; it could possibly lead to lower energy consumption.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
🟦 Bcase	0.0	0.0	21.9	77.5	84.9	21.1	16.4	2.7	55.1	94.8	54.6	0.0	35.9
🟥 WT2	0.0	0.0	39.1	85.1	86.2	22.8	17.5	2.8	56.5	93.5	73.6	0.0	39.9
🟩 WT3	0.0	0.0	46.5	89.9	86.6	24.0	17.5	3.2	57.1	92.1	86.0	0.0	42.0

Figure 6.41 – Monthly Thermal Comforts Duration as a Result of Different Wall Types With 90% Acceptability



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
🟦 Bcase	0.0	0.0	41.3	84.7	95.7	47.2	31.7	11.2	77.9	99.9	65.7	0.0	46.4
🟥 WT2	0.0	0.3	57.0	93.6	95.7	48.5	33.6	12.4	79.4	99.7	91.7	0.5	51.2
🟩 WT3	0.0	0.4	63.6	99.3	96.1	48.6	34.0	13.3	79.6	99.7	96.0	2.4	52.9

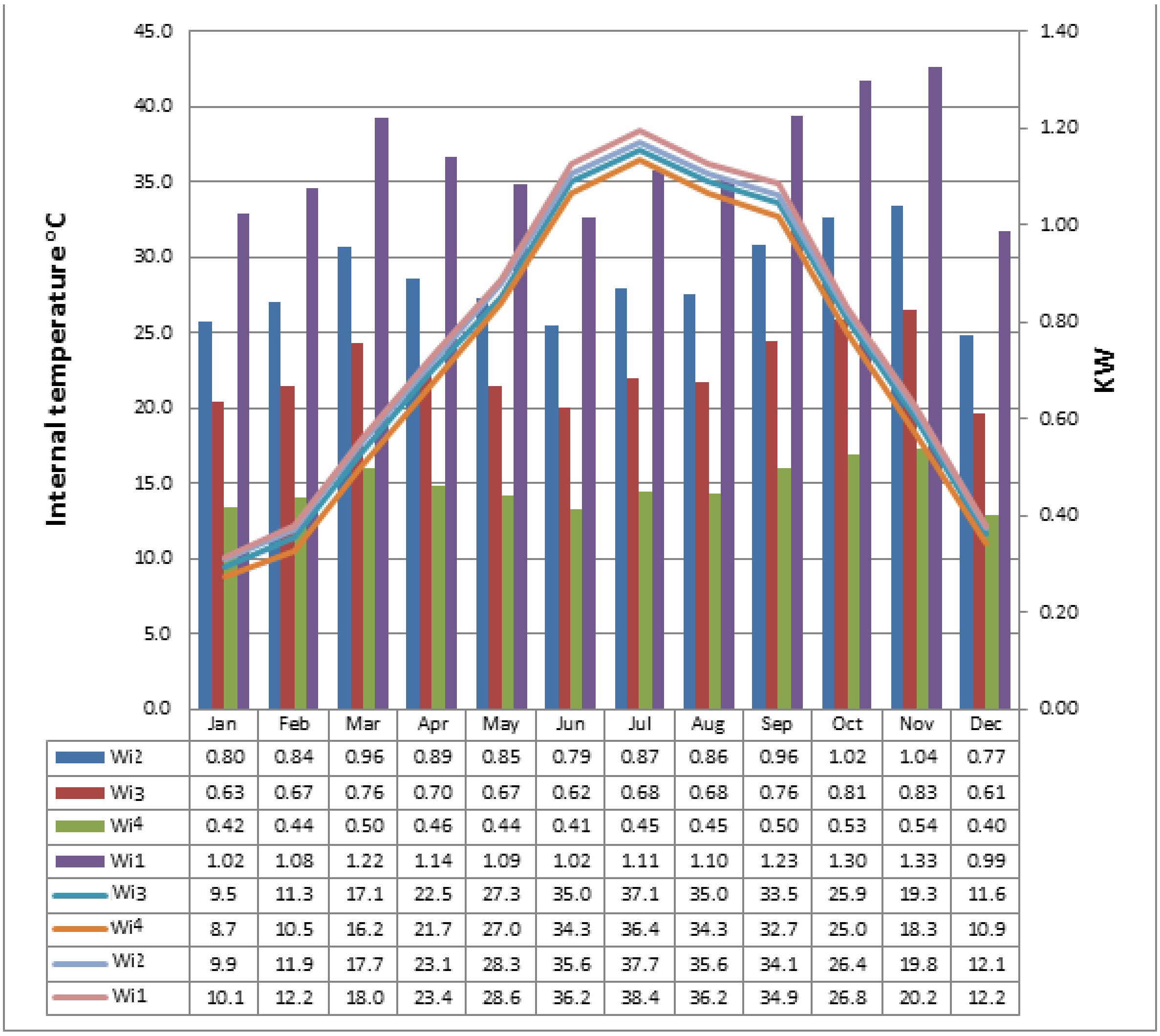
Figure 6.42 – Monthly Thermal Comforts Duration as a Result of Different Wall Types With 80% Acceptability

6.3.2 Window Sizes Analysis

Replacing windows with ones of other sizes has a great effect on the summer and winter internal temperatures. As Figure 6.43 shows WiS1, as the largest window size, has the highest internal temperature of 38.4^{o}C in the warmest month of the year. These high temperatures are big challenges for thermal comfort purposes. However, as expected the smaller windows result in lower internal temperatures in summer. WiS4 is the smallest sized window and has the lowest internal temperature of 36.4^{o}C, which is 2^{o}C less than the WiS1. In addition, as it is assumed that during the winter months the larger window benefit higher internal temperatures than the smaller windows. Therefore, WiS1 temperature reaches 10.1^{o}C on the coldest day of year, while WiS4 temperature reaches 8.7^{o}C.

The role of ventilation has not been examined yet, therefore the most important parameter to impact the internal temperature at this stage is the amount of solar gain through the windows. After simulating the building’s solar gain for the entire year and comparing this with the values of other windows sizes, Figure 6.43 shows that the building solar gain by applying WiS4 is higher than other window sizes over all months. The total WiS1 solar gain over a year reaches over 13.4MWh. The lowest solar gain reached 5.6MWh by applying WiS4 which is due to the smaller size of glazing.

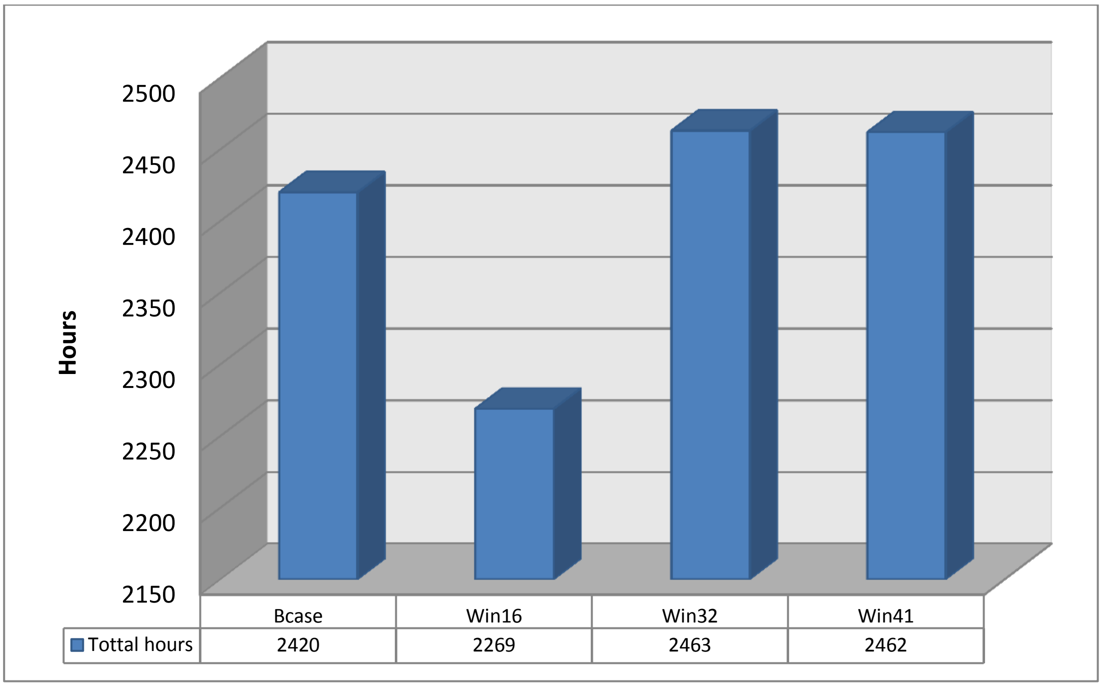
As mentioned, larger windows have more favourable temperature levels than smaller ones in summer time and vice versa in wintertime. Thus, the total performance over the entire year will determine the best window size.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wi2	0.80	0.84	0.96	0.89	0.85	0.79	0.87	0.86	0.96	1.02	1.04	0.77
Wi3	0.63	0.67	0.76	0.70	0.67	0.62	0.68	0.68	0.76	0.81	0.83	0.61
Wi4	0.42	0.44	0.50	0.46	0.44	0.41	0.45	0.45	0.50	0.53	0.54	0.40
Wi1	1.02	1.08	1.22	1.14	1.09	1.02	1.11	1.10	1.23	1.30	1.33	0.99
Wi3	9.5	11.3	17.1	22.5	27.3	35.0	37.1	35.0	33.5	25.9	19.3	11.6
Wi4	8.7	10.5	16.2	21.7	27.0	34.3	36.4	34.3	32.7	25.0	18.3	10.9
Wi2	9.9	11.9	17.7	23.1	28.3	35.6	37.7	35.6	34.1	26.4	19.8	12.1
Wi1	10.1	12.2	18.0	23.4	28.6	36.2	38.4	36.2	34.9	26.8	20.2	12.2

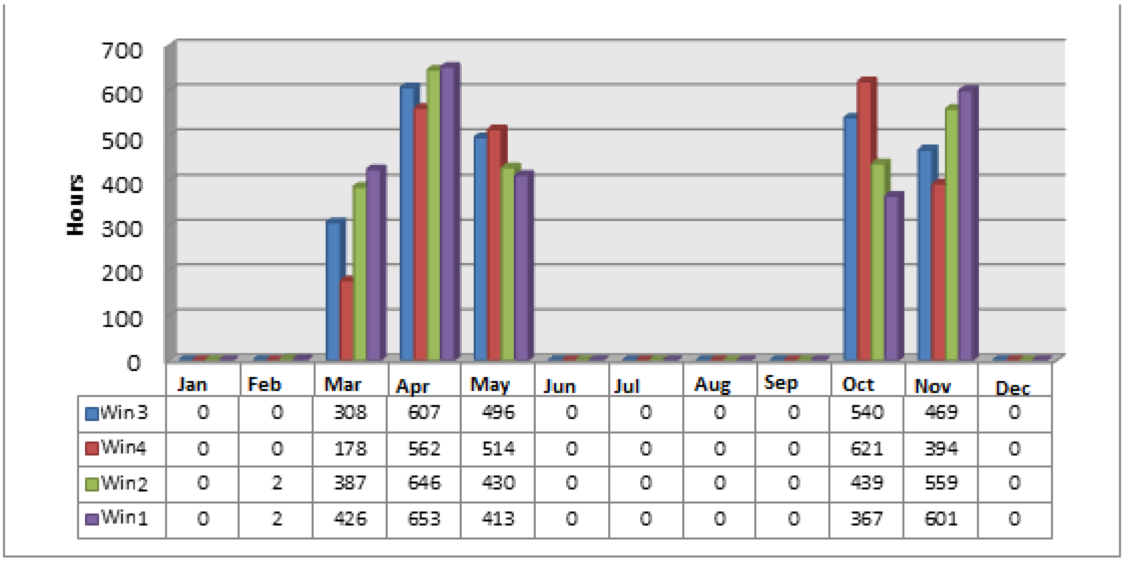
Figure 6.43 – Effect Of Different Window Sizes on Internal Temperature and Solar Gain. Wi41: Wis1, Wis16: Wis4, Wibcase: Wis3, Wis32: Wis2

By calculating the total hours of thermal comfort temperature in each case, as illustrated in Figure 6.44, it can be seen that the total hours in all cases are very similar. However, the thermal comfort duration in summer months and winter months are almost zero. Yet, there are temperature differences in the milder months of year. These differences are inevitable as the larger window sizes have a better performance in colder months compared to the smaller windows which have a better performance in warmer months. Figure 6.45 shows the fluctuation of thermal comfort in different months. For instance, In March WiS1 has the worst performance with 178 hours of thermal comfort, while WiS1 has over 426 hours of thermal comfort. In October, WiS4 has the best performance by 621 hours against WiS1 with approximately half of this amount.



	Bcase	Win16	Win32	Win41
■ Tottal hours	2420	2269	2463	2462

Figure 6.44 – Annual Total Hours of Thermal Comfort in Different Window Sizes (Without Natural Ventilation)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Win3	0	0	308	607	496	0	0	0	0	540	469	0
■ Win4	0	0	178	562	514	0	0	0	0	621	394	0
■ Win2	0	2	387	646	430	0	0	0	0	439	559	0
■ Win1	0	2	426	653	413	0	0	0	0	367	601	0

Figure 6.45 – Monthly Hours of Thermal Comfort in Different Window Sizes (Without Natural Ventilation)

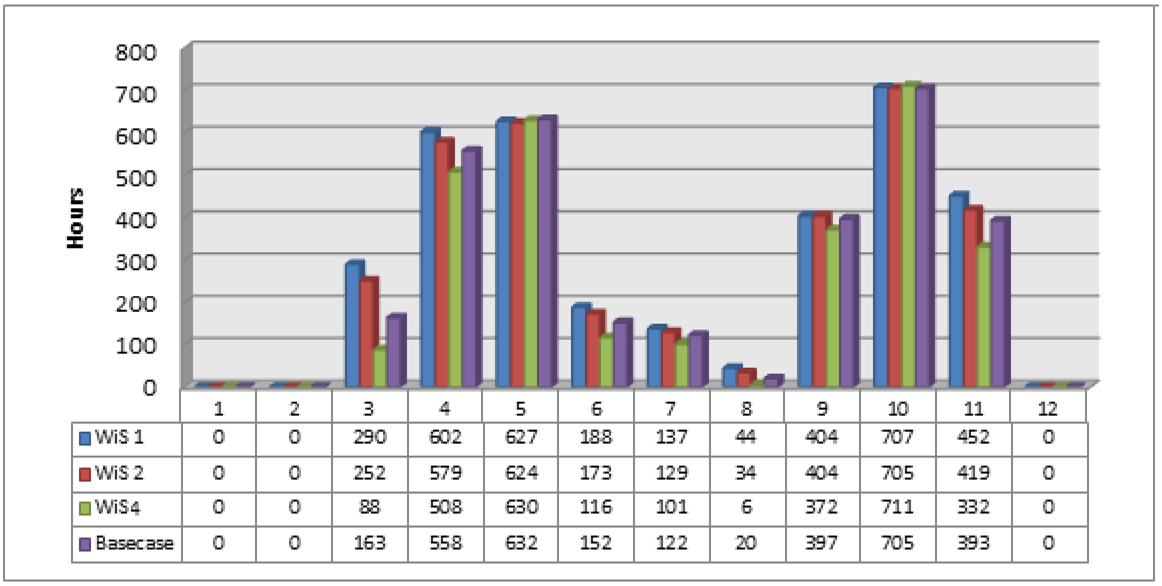
The above findings are limited to windows size performance without considering natural ventilation. As a result of the effect of windows size on thermal comfort temperatures, it can be understood that it is not credible to judge window performance by size alone. For instance, Figure 6.46 shows that window size without natural ventilation does not provide any thermal comfort in summer months from June until September.

To consider natural ventilation for the window sizes in this study, there are limitations at this stage. For instance, for the wall types discussed earlier, the role of natural ventilation was considered at the same level for all wall types. However, by changing the window sizes, the ventilation inlet size also changes, therefore, window sizes can’t be compared by their size only. Due to the existence of more than one variable, in fact, natural ventilation inlet sizes are sub-dependent of windows size.

Consequently, in this study the performance of window size depends on the size of natural ventilation inlet. Thus, the expectation is that the larger window sizes provide larger ventilation inlets. For this purpose, at this stage the size of openable windows are fixed to 25% of window size. Later in ventilation analysis, different openable sizes will be examined.

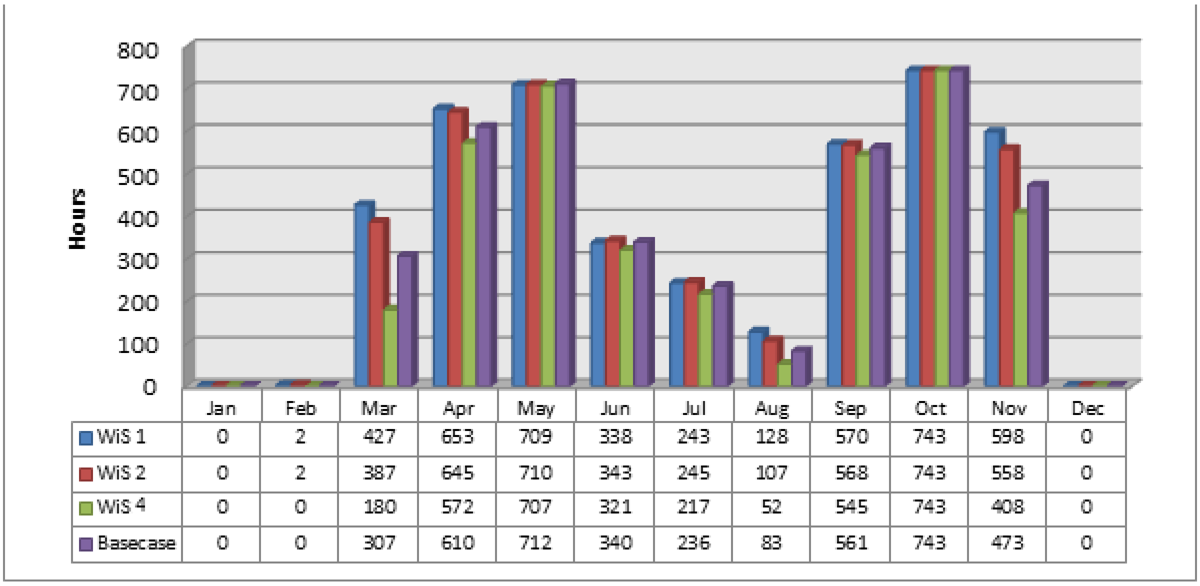
Applying natural ventilation to the building by different window sizes, contributes to more thermal comfort hours in warmer months. Natural ventilation in hot summer months has a reasonable impact on thermal comfort. As shown in Figure 6.47, May and October have a great number of thermal hours in all window sizes, these are advantageous for free running buildings within the range of 80% satisfactory of thermal comfort.

Window size and openable size disadvantage each other in summer. For instance, WiS1 is the largest window and should have the worst performance in the summer, however, owing to its openable size, it compensates the disadvantage factor of high solar gains through the windows. Therefore, as Figure 6.48 shows there is almost a balance of thermal comfort hours between different window sizes and openable sizes. While these differences in all cases are not tangible, WiS1 has a better overall performance than the other cases.



	1	2	3	4	5	6	7	8	9	10	11	12
🟦 WiS 1	0	0	290	602	627	188	137	44	404	707	452	0
🟥 WiS 2	0	0	252	579	624	173	129	34	404	705	419	0
🟩 WiS4	0	0	88	508	630	116	101	6	372	711	332	0
🟪 Basecase	0	0	163	558	632	152	122	20	397	705	393	0

Figure 6.46 – Monthly Hours of Thermal Comfort in Different Window Sizes (Without Natural Ventilation)

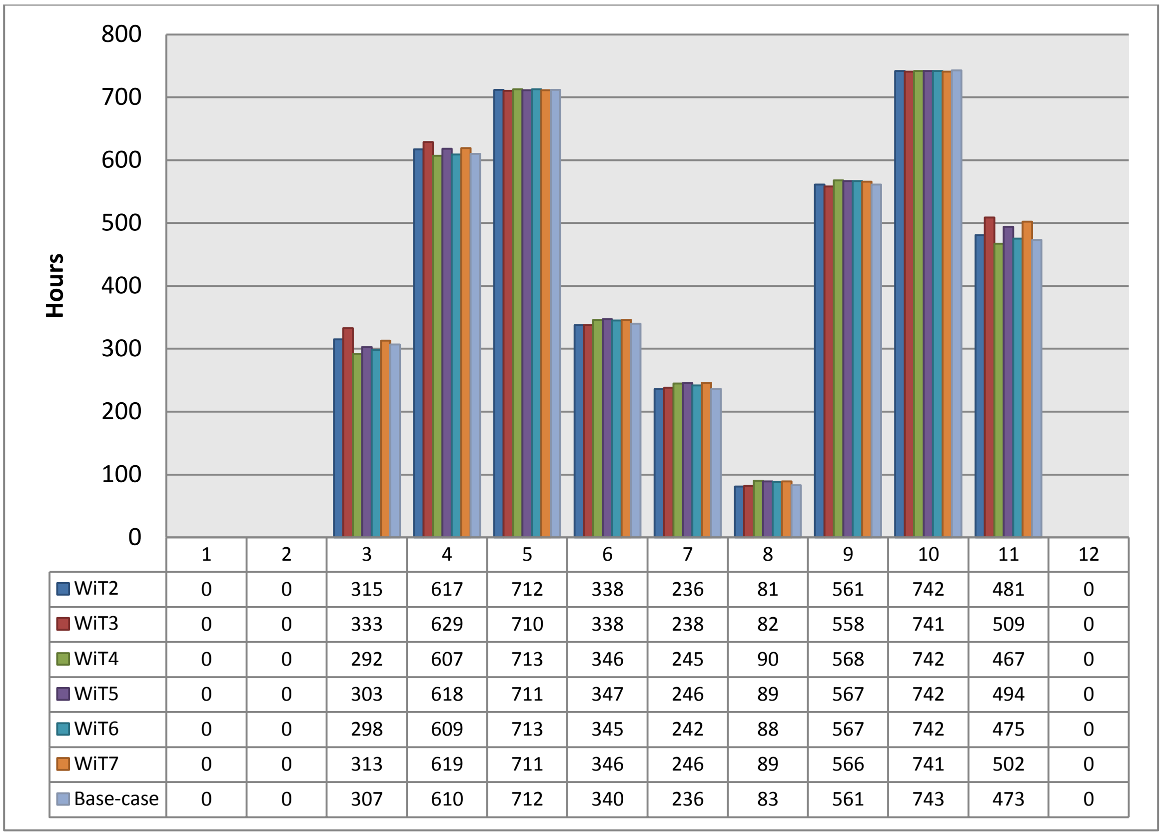


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 WiS 1	0	2	427	653	709	338	243	128	570	743	598	0
🟥 WiS 2	0	2	387	645	710	343	245	107	568	743	558	0
🟩 WiS 4	0	0	180	572	707	321	217	52	545	743	408	0
🟪 Basecase	0	0	307	610	712	340	236	83	561	743	473	0

Figure 6.47 – Monthly Hours of Thermal Comfort in Different Window Sizes (With Natural Ventilation 80% Satisfactory)

6.3.3 Window Type Analysis

Natural ventilation and its influence on window types are evaluted in this section. Figure 6.48 shows that all window types perfom in a very similar way as WiT4, with just a very minor difference has the best performance. This little variation in temperatures is assumed to be a result of high U-value and shading coefficient of all the window types. The U-value of windows are almost higher than the walls, therefore by considering the wall and windows U-value, this is not logically possible a better performance for window types at this stage.



	1	2	3	4	5	6	7	8	9	10	11	12
WiT2	0	0	315	617	712	338	236	81	561	742	481	0
WiT3	0	0	333	629	710	338	238	82	558	741	509	0
WiT4	0	0	292	607	713	346	245	90	568	742	467	0
WiT5	0	0	303	618	711	347	246	89	567	742	494	0
WiT6	0	0	298	609	713	345	242	88	567	742	475	0
WiT7	0	0	313	619	711	346	246	89	566	741	502	0
Base-case	0	0	307	610	712	340	236	83	561	743	473	0

Figure 6.48 – Monthly Thermal Comfort Hours in Different Window Types

6.3.4 Ventilation Time Plan

There are three ventilation time plans that are defined as; a) Full day ventilation, b) night 10:00 PM – 6:00 AM ventilation and c) day ventilation 6:00 AM – 10 PM.

Figure 6.49 presents the warmest days of year from early morning of 20th of July to late in the evening of 21st of July. It can be seen that most of the time, despite the operational natural ventilation, the indoor temperature is higher than the external temperature. However, this situation has an exception when the outdoor temperature reaches the peak at about 40°C, at this point, the indoor temperature in all the ventilation time plans falls below the external temperature. This situation is far more highlighted in night ventilation mode when at around the peak outdoor temperature, the night ventilation method shows a more stable temperature and lower internal temperature than the other methods due to the advantage of thermal mass. At the peak point, when the natural ventilation is operative during the day time, the indoor temperature becomes mixed with the extremely hot outdoor temperature, as a result the indoor temperature increases to 39.5°C. This is above the internal temperature when the windows are closed during the night ventilation mode. This process obviously represents benefits of night cooling thermal mass.

The above process shows that high temperatures in summer when keeping the windows closed during the day avoid purging the maintained lower air temperature to the ambient, and as a result avoids replacing it with the external hot air. Therefore, by opening the windows during the night, and closing them during the day, the thermal mass activities are controlled and help to avoid overheating.

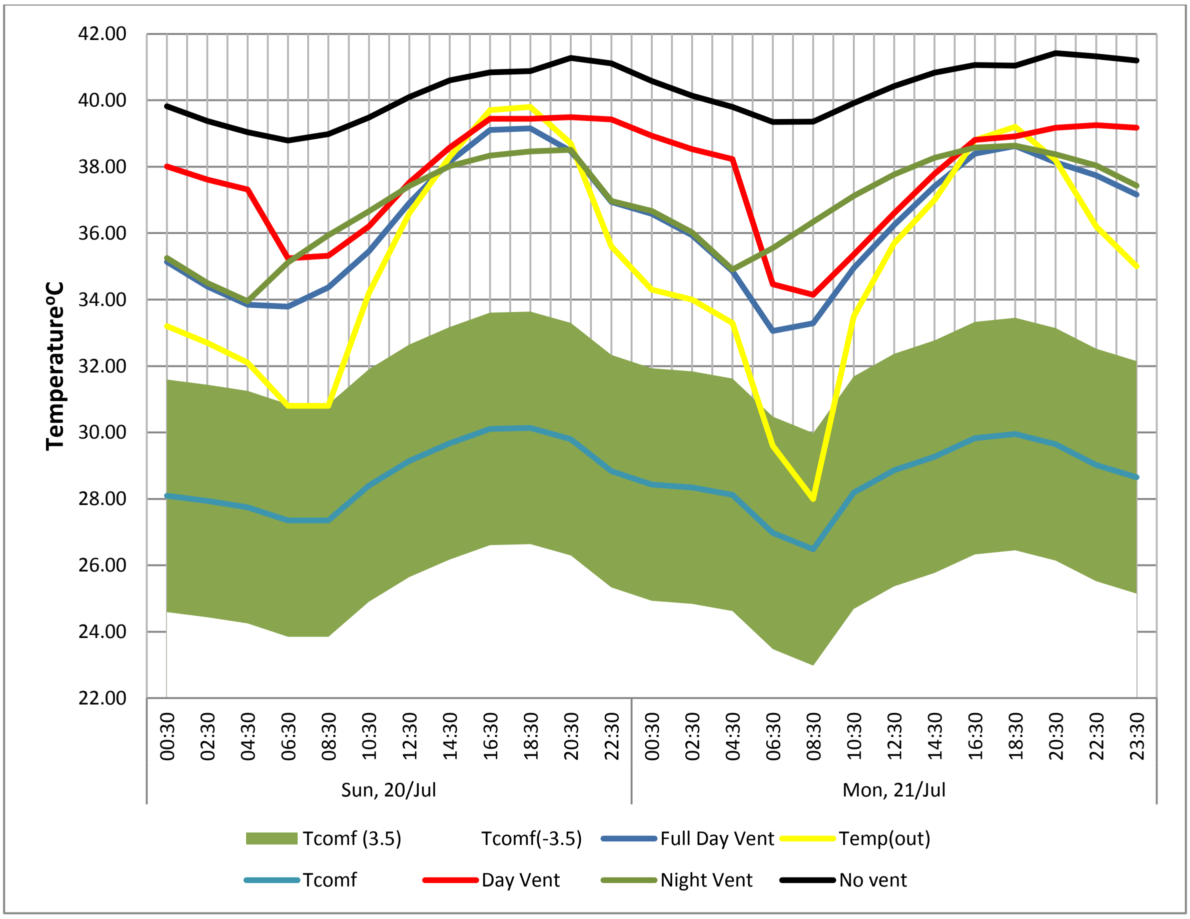
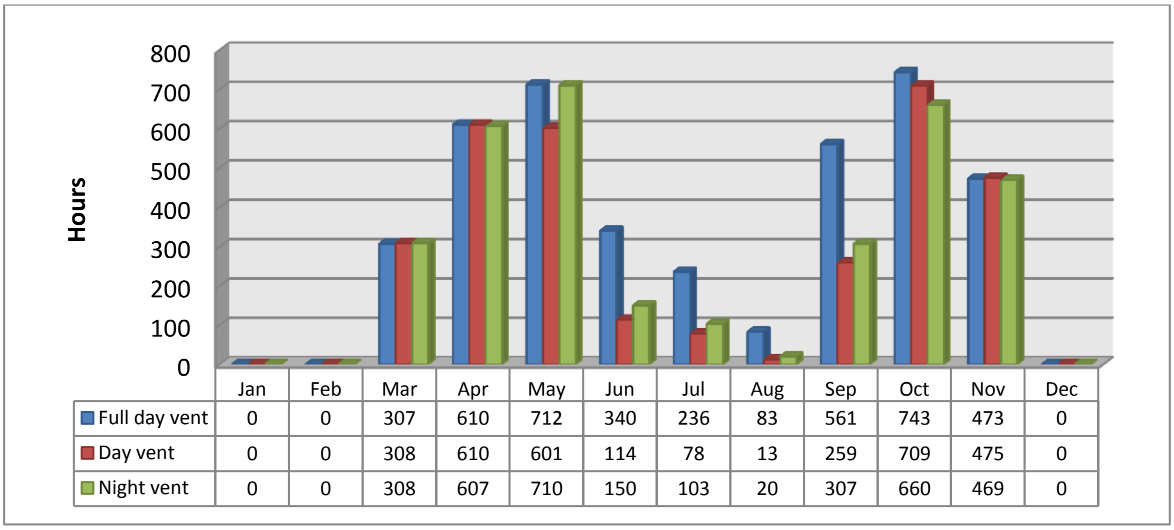


Figure 6.49 – Performance of Different Ventilation Plans In the Warmest Day

The above process happens at the peak point temperatures only, and doesn't represent the whole of the summer days.

As long as the windows are closed in the morning, the internal temperature increases sharply which is due to the differences between the internal and external temperatures. In fact, as the internal temperature fluctuations are minimized in line with external temperature, the thermal mass starts to discharge heat. As a result, a sharp increase in temperature happens, however, this sharp increase becomes slower and steadier when the outdoor temperature increases. At this time, the building fabric starts to absorb heat through their thermal mass capacity, and contrary to the day or full day ventilation methods won’t fluctuate with the external temperature.

In order to determine the best method it is necessary to examine the total performance of each ventilation mode over the entire year. Figure 4.50 shows that even at the peak point of the days, the full day natural ventilation method has a better performance than other methods to maintain a cooler indoor temperature. Consequently, the total hourly performance of each method over a year are evaluated and presented. Overally, full day ventilation has the best performance among the other methods by achieving over 4065 hours of thermal comfort. The best performance months are from June to September with a significant difference from the other methods. Although the numer of comfort hours vary in different cases, none of the methods are capable of creating a suitable thermal comfort that allows buildings to run free of mechanical heating and cooling systems. Moreover, selecting the most aproprate method would possibly decrease energy consumption in the building during warmer months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 Full day vent	0	0	307	610	712	340	236	83	561	743	473	0
🟥 Day vent	0	0	308	610	601	114	78	13	259	709	475	0
🟩 Night vent	0	0	308	607	710	150	103	20	307	660	469	0

Figure 6.50 – Monthly Thermal Comforts as Result of Different Natural Ventilation Modes

6.3.5 Evaluation of Window Openable Size Ratio

This section evaluates the importance of the window’s openable size. For this purpose, a variety of openable ratios have been selected. The ratios are 50%, 75% and 100%, the ratio of the base case is 25% and compares with other cases.

Figure 6.51 shows the warmest day of year and the performances of all the openable sizes. The diurnal maximum and minimum temperatures are fairly high, 40^{o}C at peak point and 30.5^{o}C at the lowest point. Window openable sizes perform differently during the night and part of day time. The outdoor temperature is lower than the indoor temperature from 8:00 PM to 10:30 AM. During this time larger openable sizes create a cooler indoor temperature than the smaller sizes. It can be noticed that there is a temperature gap of 2^{o}C between 25% and 50% openable sizes. This temperature gap implies that higher volumes of natural ventilation contribute to purge the higher amount of discharged heat during the night and early morning. On the other hand, as the outdoor temperature begins to increase, the indoor temperature also starts to increase, however, the indoor temperature increases at a slower speed as a result of thermal mass and the heat sink phenomena. Moreover, at this high temperature, it seems that the openable window sizes have an opposite performance. Smaller openable windows mean lower indoor temperatures achieved during the afternoon. This is a result of high outdoor temperatures and a fluctuating indoor and outdoor temperature.

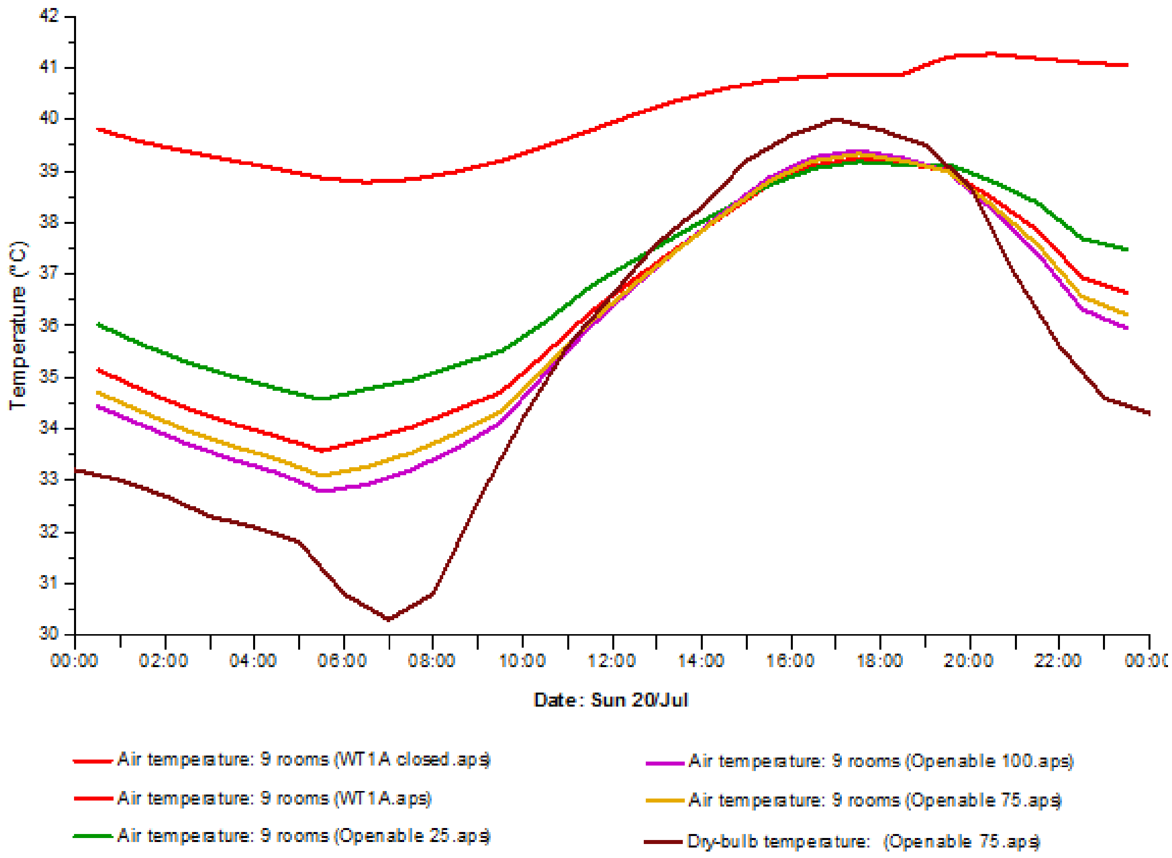


Figure 6.51 – Natural Ventilation Impacts on Internal Temperature Based on Openable Sizes on Warmest Day (On 22/Jul)

Consequently, the best solution for such a high temperature is to apply night ventilation and have larger window openable sizes. However, it is not a reasonable assumption that all summer days have a temperature as high as the above figures. For instance, in another day during the same month (July), the outdoor temperature is a little lower than the earlier selected day. Figure 5.52 shows that the peak point temperature is at 33^{o}C and lowest at 25^{o}C. The result shows despite the high temperature, openable sizes can maintain an indoor temperature within the thermal comfort from 12:00 AM to 12:00 PM. Larger windows maintain more time within the thermal comfort range. On the other hand, during the afternoon, contrary to the above figure, the ‘Openable100%’ maintains its trend to bring the indoor temperature lower than other cases. This is due to the lower outside temperature that has a lower impact on the indoor temperature. Therefore selecting an option for windows openable sizes is more effective in night-time in all summer time, and during day time it depends on the level of the outdoor temperature where the thermal mass may play a role in moderating the indoor temperature swings by coupling to external air.

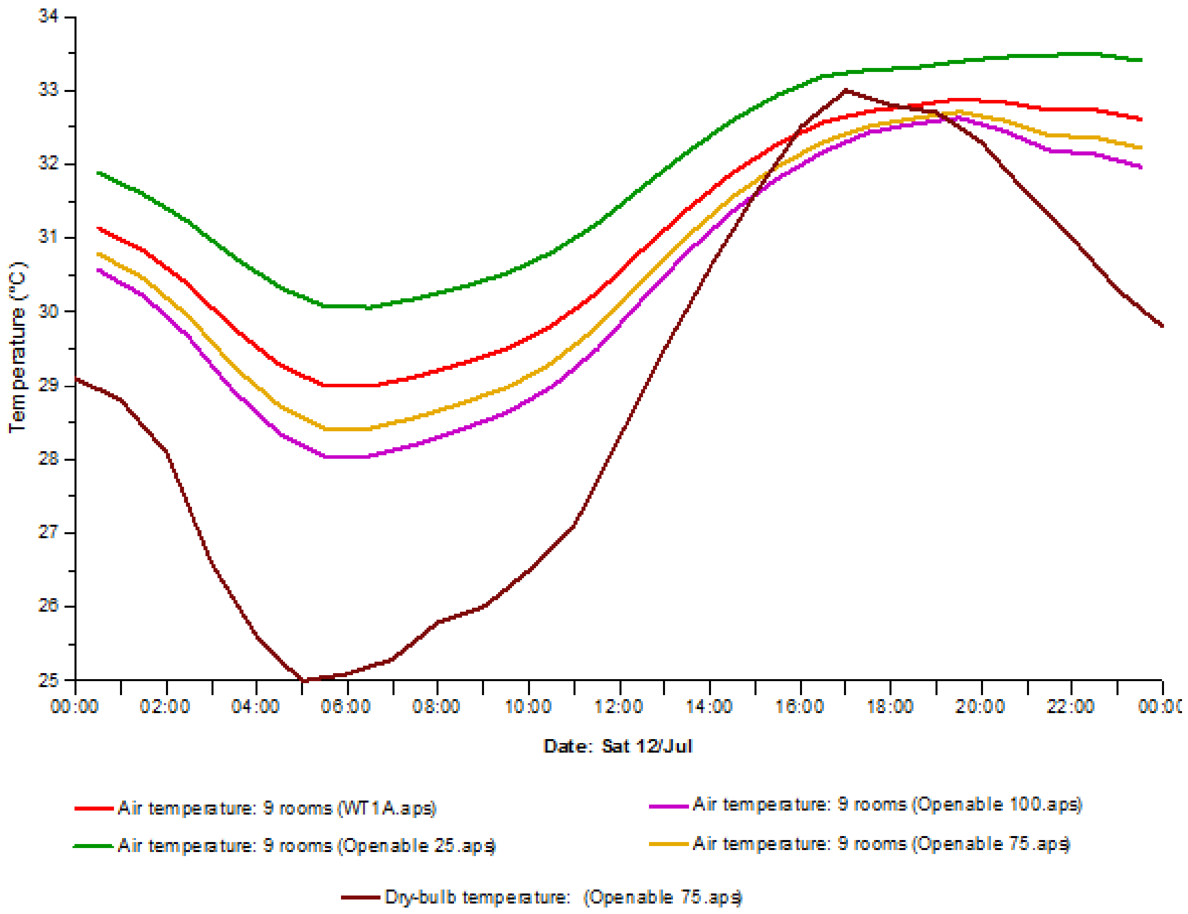


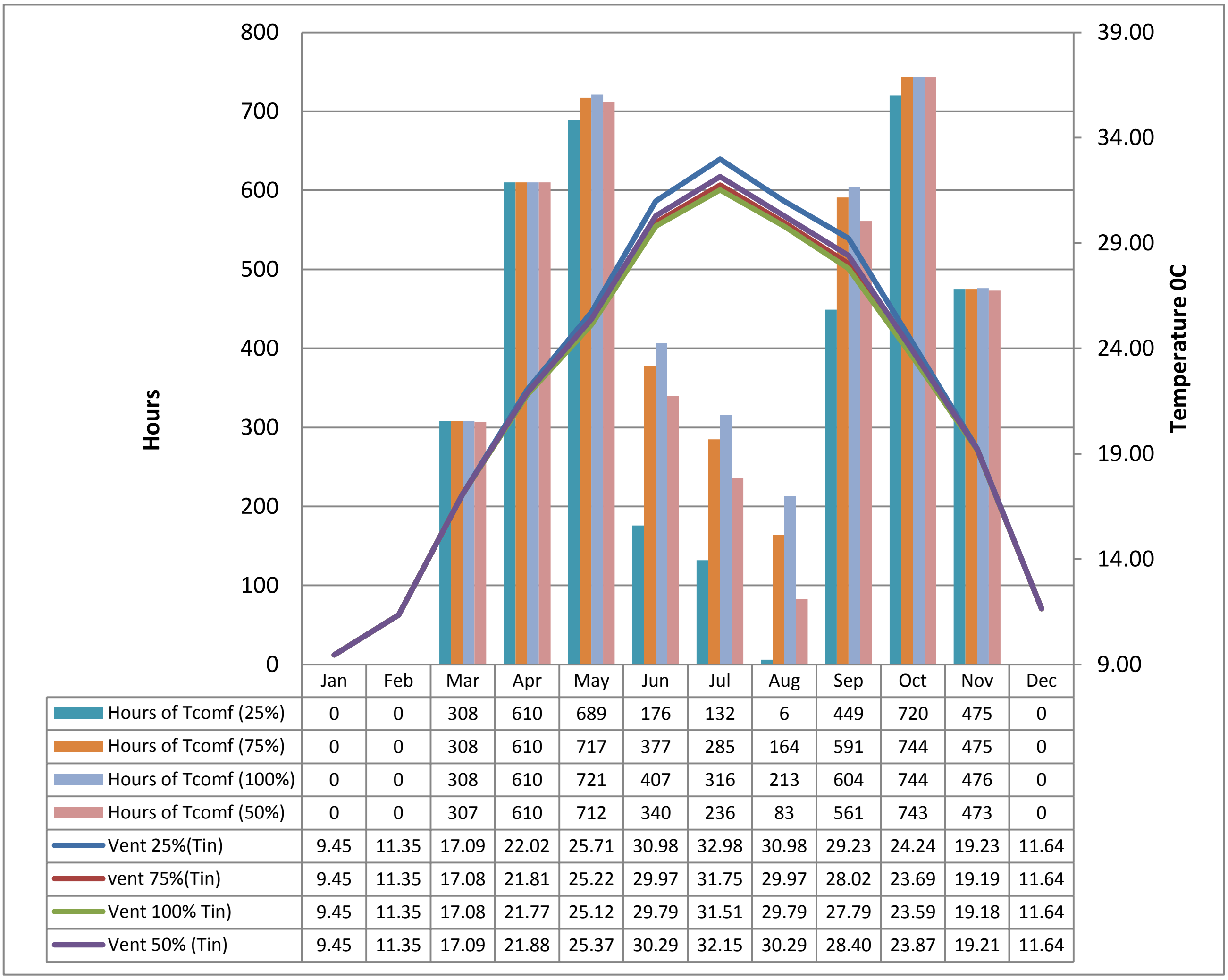
Figure 6.52 – Natural Ventilation Impacts on Internal Temperature Based on Openable Sizes (On 12/Jul)

Consequently, window openable sizes may have different characteristics, as the larger ones are more suitable for night time, while this depends on the outdoor temperature. Therefore, to find the best overall performance the overall hourly temperature of summer time and the thermal comfort range needs to be assessed.

In terms of internal temperature, applying the 100% openable window results in achieving the lowest summer internal temperature (Figure 6.53). On the other hand, openable 25% has the highest internal temperature among the other cases. These temperature differences between the 50%, 75% and 100% openable sizes have a steady different pace from June to September. The 75% and 100% openable sizes are fairly similar with minor differences. Openable 25% has the highest temperature difference from the other cases. For instance, the indoor temperature for the 100% case is 31.51^{o}C in July; this increases to 31.75^{o}C in the case of 75% and 32.15^{o}C in the case of 50%. However, a sharper decrease happens in the case of 25% to 32.98^{o}C. These results show that the larger window openable sizes have an overall better performance than other sizes in all summer months. This includes both during the day and night time, although at some certain outdoor temperatures, the larger size of openable windows causes internal overheating.

Taking into consideration the thermal comfort hours, there are significant differences between the different openable sizes. Prominent differences are noticed from June to August. June is the most distinctive month, as 25% openable window size provides 176 hours of thermal comfort while the 100% openable provides 407 hours. This figure shows that in June with a general lower outdoor temperature, the size of openable windows has a great impact on the internal temperature. Another important variation can be seen in August, during this month the 25% openable size provides 6 hours of thermal comfort only, while this amount increases to 213 hours. This difference shows that during the day time none of the openable sizes are able to provide thermal comfort. However, during the night time openable 100%, owing to its larger ventilation inlet, flushes warm air out of the building, the warm air discharges heat as a result of thermal mass, therefore large openable window size lowers the indoor temperature within the thermal comfort range.

The above results show that the ventilation sizes are useful for cooling down the warm indoor temperatures during the summer. However, the results are far from considering a free running building in the warmest months, although there are still useful improvements to decreasing the use of mechanical cooling systems.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours of Tcomf (25%)	0	0	308	610	689	176	132	6	449	720	475	0
Hours of Tcomf (75%)	0	0	308	610	717	377	285	164	591	744	475	0
Hours of Tcomf (100%)	0	0	308	610	721	407	316	213	604	744	476	0
Hours of Tcomf (50%)	0	0	307	610	712	340	236	83	561	743	473	0
Vent 25%(Tin)	9.45	11.35	17.09	22.02	25.71	30.98	32.98	30.98	29.23	24.24	19.23	11.64
vent 75%(Tin)	9.45	11.35	17.08	21.81	25.22	29.97	31.75	29.97	28.02	23.69	19.19	11.64
Vent 100% Tin)	9.45	11.35	17.08	21.77	25.12	29.79	31.51	29.79	27.79	23.59	19.18	11.64
Vent 50% (Tin)	9.45	11.35	17.09	21.88	25.37	30.29	32.15	30.29	28.40	23.87	19.21	11.64

Figure 6.53 – Monthly Thermal Comforts and Average Monthly Internal Temperatures as Result of Openable Sizes. (Tin: Internal Temperature)

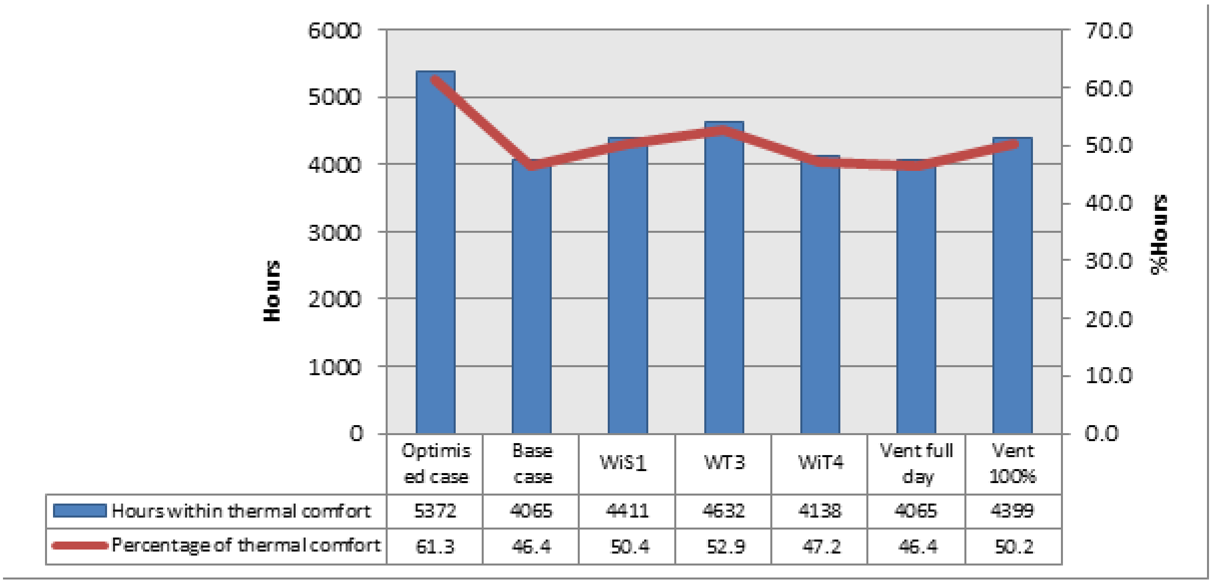
6.3.6 Best Combination Parameters for Optimized Free Running Building Base-Case

To explore the most potentially energy efficient thermal comfort case in apartment blocks in Tehran, the best performance of each of the individual parameters in the previous sections are put together to evaluate the performance for this new case. Consequently, the new case has the following description (Table 6.4).

Table 6.4 – Combined Parameters for the New Case

Parameter	**Type of parameter**
Wall	WT3
Window size	WiS1
Window type	WiT4
Ventilation time plan	Full day
Ventilation openable size	100%

Figure 6.54 presents the changes of thermal comfort performance by applying the most efficient parameters as a new case (passive optimized case). The optimized case provides 5372 hours of thermal comfort which is 32% higher than the base case. The data in Figure 6.54 also shows that the strongest impact on thermal comfort is a result of the wall types. In this case, by replacing WT3, the performance of the base case increases by 14% and that has the highest percentage among the other parameters. The full day ventilation that was already in place for the base case has not had any important impact. This is because the full day ventilation is the best time plan ventilation among the other plans. Therefore, by changing a single parameter of the base case, a maximum of 14% of efficiency can be achieved. This implies that for achieving a high performance thermal comfort building or achieving a more free running building, all the building parameters need to be considered and the best performance of each case should be applied to the building model.

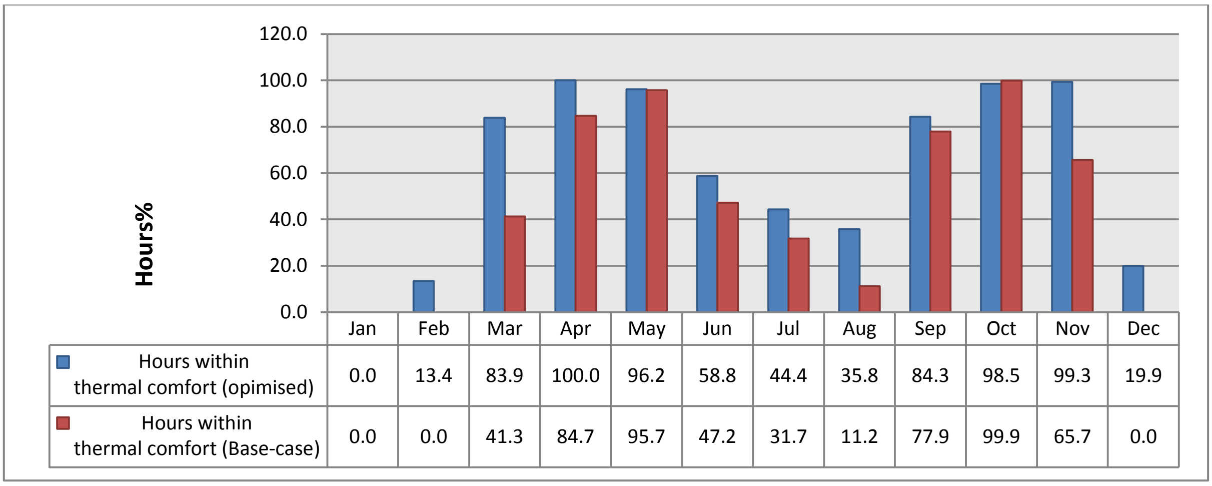


	Optimised case	Base case	WiS1	WT3	WiT4	Vent full day	Vent 100%
Hours within thermal comfort	5372	4065	4411	4632	4138	4065	4399
Percentage of thermal comfort	61.3	46.4	50.4	52.9	47.2	46.4	50.2

Figure 6.54 – Annual Thermal Comforts in Different Parameters, Base Case and Optimised Case

As shown in Figures 6.55 and 6.56, for free running purposes in the base case, October and May can be considered as free running building months, as over 95% of the internal temperatures fall within the thermal comfort. However, the optimized case has the ability to achieve more free running months, in addition to the mentioned months April and November are placed among the free running months by achieving approximately 100% thermal comfort. Furthermore, the overall thermal comfort of all months except October has improved which will be very important when considering the energy consumption in the building. The most significant improvement happens in March with thermal comfort temperatures increased from 41.3% to 83.9%. This increase can be assumed to be a result of the larger window size in the optimized case in March, in which the internal temperature is slightly lower than thermal comfort temperature. However, with replacing a larger window, more solar radiation enters the internal space. Thus, the internal temperature is increased to the thermal comfort level. On the other hand, as the larger windows are assumed to have larger openable size, therefore, in the summer the ventilation flushes out that extra solar heat.

In the winter, the indoor thermal comfort improves reasonably; in December and February the indoor temperature increases and 19.9% and 13.4% thermal comfort is achieved accordingly. Although this amount of thermal comfort is inadequate for free running building during winter, it will be capable of reducing the heating load and energy consumption.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 Hours within thermal comfort (opimised)	0.0	13.4	83.9	100.0	96.2	58.8	44.4	35.8	84.3	98.5	99.3	19.9
🟥 Hours within thermal comfort (Base-case)	0.0	0.0	41.3	84.7	95.7	47.2	31.7	11.2	77.9	99.9	65.7	0.0

Figure 6.55 – Monthly Thermal Comfort Comparisons between The Base-Case And The Optimised Case

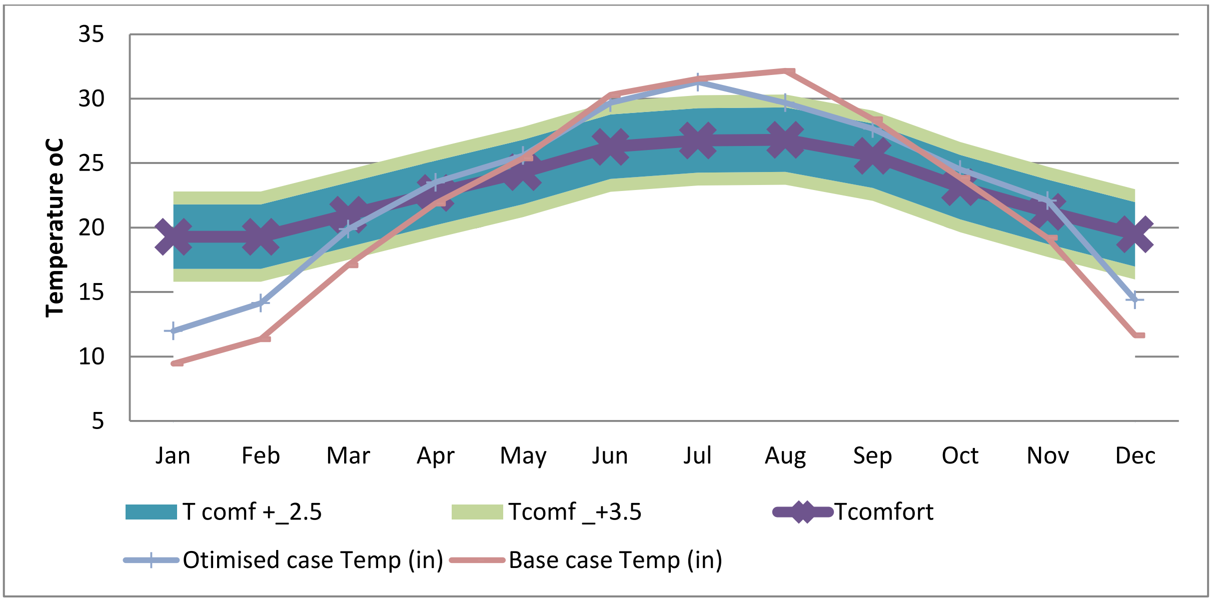


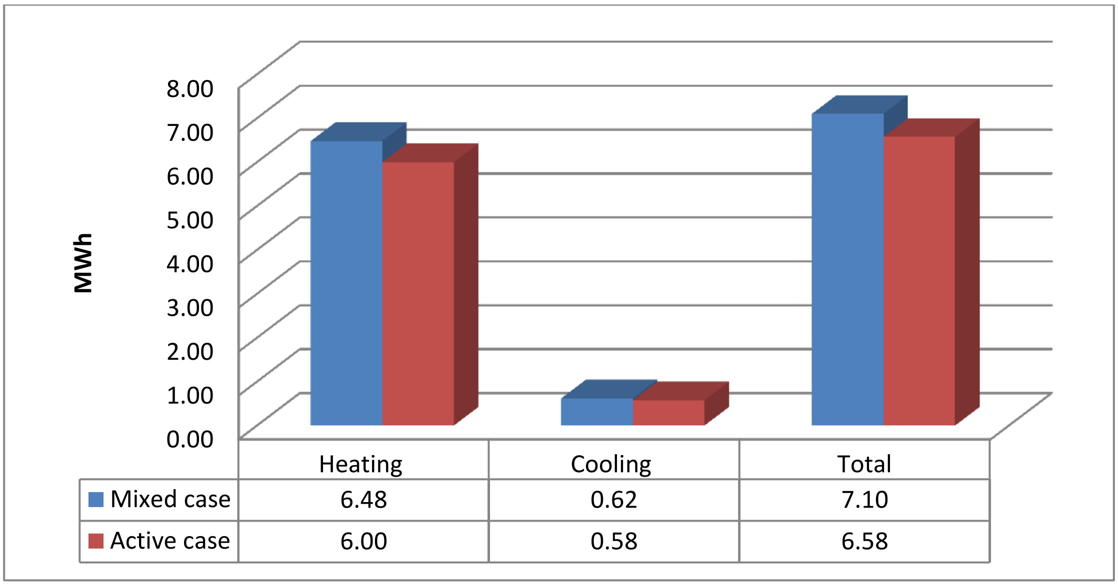
Figure 6.56 – Annual Thermal Comfort Situation in Base-Case and Optimised Case

6.4 Mixed Building Design

To evaluate a mixed building of free running and active building, the best free running case that was identified in earlier sections is examined in a mixed form. For this purpose, all the regular settings that have been applied in the energy analysis are applied to the best free running building case. However, cooling and heating systems remain de-active during the free running months i.e. April, May, October and November. After this process, both cases are compared in terms of the energy consumption to finalize whether or not the free running building (now mixed with active building) can achieve further energy efficiency performance.

The only differences between the free running building and best active building are on window type and window size, and the rest of parameters remain the same.

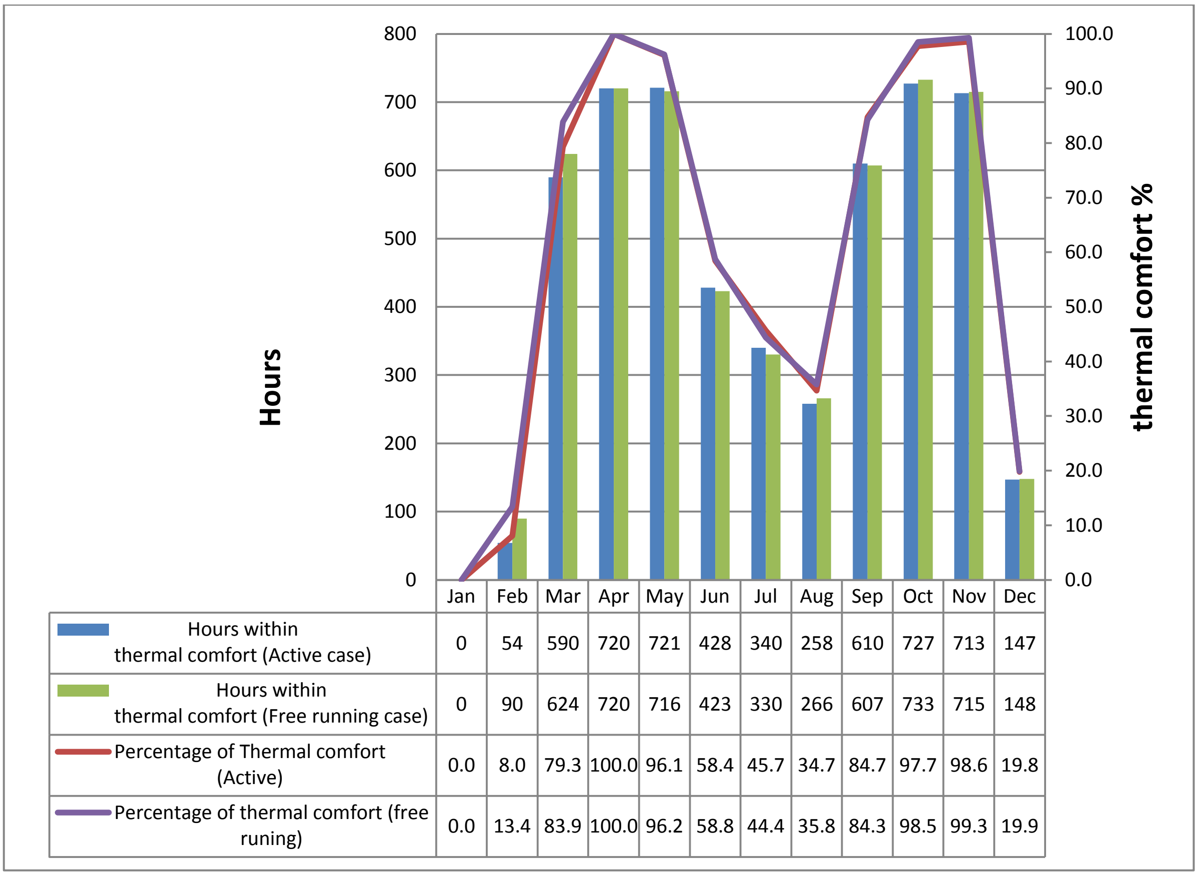
Figure 6.57 shows that the mixed case, despite the de-active heating and cooling systems in four months, consumes higher energy by 7.9%. The energy consumption increases in both the cooling and heating by 7.0 % and 8.0 % respectively. As a result, it can be concluded that the best free running building parameters are not the best for energy efficiency of a mixed building. Therefore, the optimized case, without considering the free running months, still performs more efficiently.



	Heating	Cooling	Total
🟦 Mixed case	6.48	0.62	7.10
🟥 Active case	6.00	0.58	6.58

Figure 6.57 – Total Heating and Cooling Energy Consumption in Mixed and Active Cases

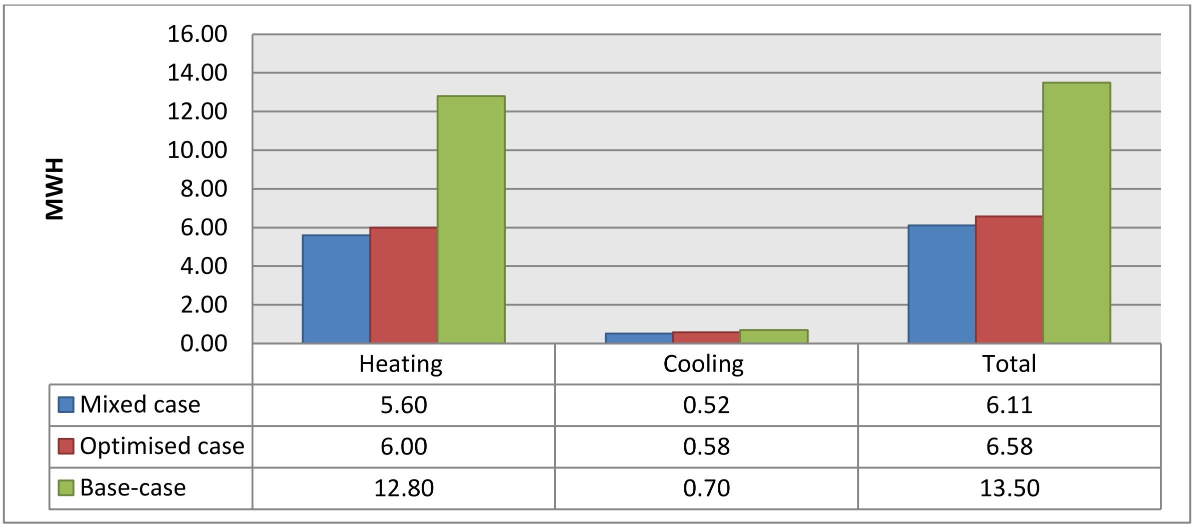
Nevertheless, to take advantage of the free running building mode, the optimized case (active case) is considered and measured as a free running building. The results show that the parameters in this case perform slightly less efficiently than the previous free running case to provide thermal comfort. As shown in Figure 6.58, differences in both cases are negligible. Figure 6.58 demonstrates the monthly thermal comfort in each case to understand the performance gap between the cases. As the window size and type are different parameters in these two cases, the thermal performances in all months change very slightly.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 Hours within thermal comfort (Active case)	0	54	590	720	721	428	340	258	610	727	713	147
🟩 Hours within thermal comfort (Free running case)	0	90	624	720	716	423	330	266	607	733	715	148
Percentage of Thermal comfort (Active)	0.0	8.0	79.3	100.0	96.1	58.4	45.7	34.7	84.7	97.7	98.6	19.8
Percentage of thermal comfort (free runing)	0.0	13.4	83.9	100.0	96.2	58.8	44.4	35.8	84.3	98.5	99.3	19.9

Figure 6.58 – Monthly Thermal Performances in Free Running Building Case an Active Case (For This Analysis the Conditioning System Are In Active)

Consequently, the optimized case is evaluated by de-activating the cooling and heating system in April, May, October and November. The result shows that the new mixed case consumes the lowest energy by 6.11MWh and is 7.14% lower than the optimized active case and approximately 55% better than the base-case. The heating energy also decreases by 6.6% and 56% respectively. The cooling energy has the lowest trend line as it decreases by 10.3% from the optimized active case to the mixed case and over 25% to the base-case (Figure 6.59).



	Heating	Cooling	Total
🟦 Mixed case	5.60	0.52	6.11
🟥 Optimised case	6.00	0.58	6.58
🟩 Base-case	12.80	0.70	13.50

Figure 6.59 – Total Heating and Cooling Energy Consumption from the Base Case to Final Optimised Base Case (Mixed Case)

The above figures show that the lowest energy optimization achieved for cooling energy is 10.3% from the mixed case compared to the base-case, while corresponding energy optimization for the heating energy is 56%. This emphasizes the fact that the conventional building parameters and strategies have a greater impact on avoiding heat losses, and less on solar heat gain control.

The small amount of cooling energy consumption might imply a misleading concept on the importance of cooling energy. However, as mentioned in previous sections, electricity as the main source of cooling energy is expensive and less abundant. The price of 1kW of electricity is approximately equivalent to 10kW of natural gas energy (Iranian power supplier organization, 2017). In addition, as stated by the Iranian Power supplier organization (2017) 1kW of electricity is equivalent to 3.7kW of primary energy.

Although the economic analysis is beyond the objectives of this study, in order to justify the importance of the reduction of the cooling energy a brief economic analysis is given in this section.

For this purpose, the Table 6.5 shows the value of natural gas energy and electricity. The cost of 1kW electricity is selected as 10 units of value and for 1kW of natural gas as 1unit of value. The table shows that the total cost of electricity for the base-case accounts for 35% of total energy cost while the amount of energy consumption (base on kWh) is less than 5% of total energy.

However, for the optimized case, natural gas consumption and subsequently the cost significantly decreases sharply from 12800 to 5600 units, while the electricity cost drops slightly from 5600 units to 5200 units only. In this case, the natural gas cost is higher than electricity by 7.15% only, while the consumption is still considerably higher by 90%.

Subsequently, the above analysis suggests that further robust designs and strategies are required to reduce the cooling energy further. In addition, although the above strategies significantly contributed to energy reduction in total, the most emphases are still on reducing the heating energy rather than cooling energy.

Table 6.5 – Energy Cost Evaluation as a Result of the Base Case And Optimised Case

	Electricity kWh	**Natural gas kWh**	**Electricity Cost (unit)**	**Natural gas cost (unit)**	**Total cost (unit)**
Base-case	700	12800	7000	12800	19800
Optimized case (mixed)	520	5600	5200	5600	10800

Phase Three

In the previous chapter it was shown that the walls have the most significant impact on energy reduction, and it emphasized the need for more concentration on strategies to reduce the cooling energy consumption. At this stage of the research, shadings as important strategies to reduce overheating in buildings will be examined in different forms. Following this, the performance of insulation in different wall types will be evaluated.

At this stage shadings are assumed to be an essential part of the design, so the optimized case (mixed case) from the previous section is considered as the base case. Therefore, this is a building with the same design as the optimized case in addition to different shading types which are assumed to block solar radiation in summer and allow it in winter.

6.5 Overhangs evaluation

This section presents the results of three different shading types in overhang form (sizes), each shading size is designed according to the strategies mentioned in chapter Five. The overhang sizes are 47cm, 60cm and 90cm.

The warmest day of the year shows how the internal temperature fluctuated in different cases. As shown in Figure 6.60 the shading90 results in the lowest internal temperature during whole day. Although the differences between the internal temperatures in each case are small, it is assumed that the impacts on energy are considerable.

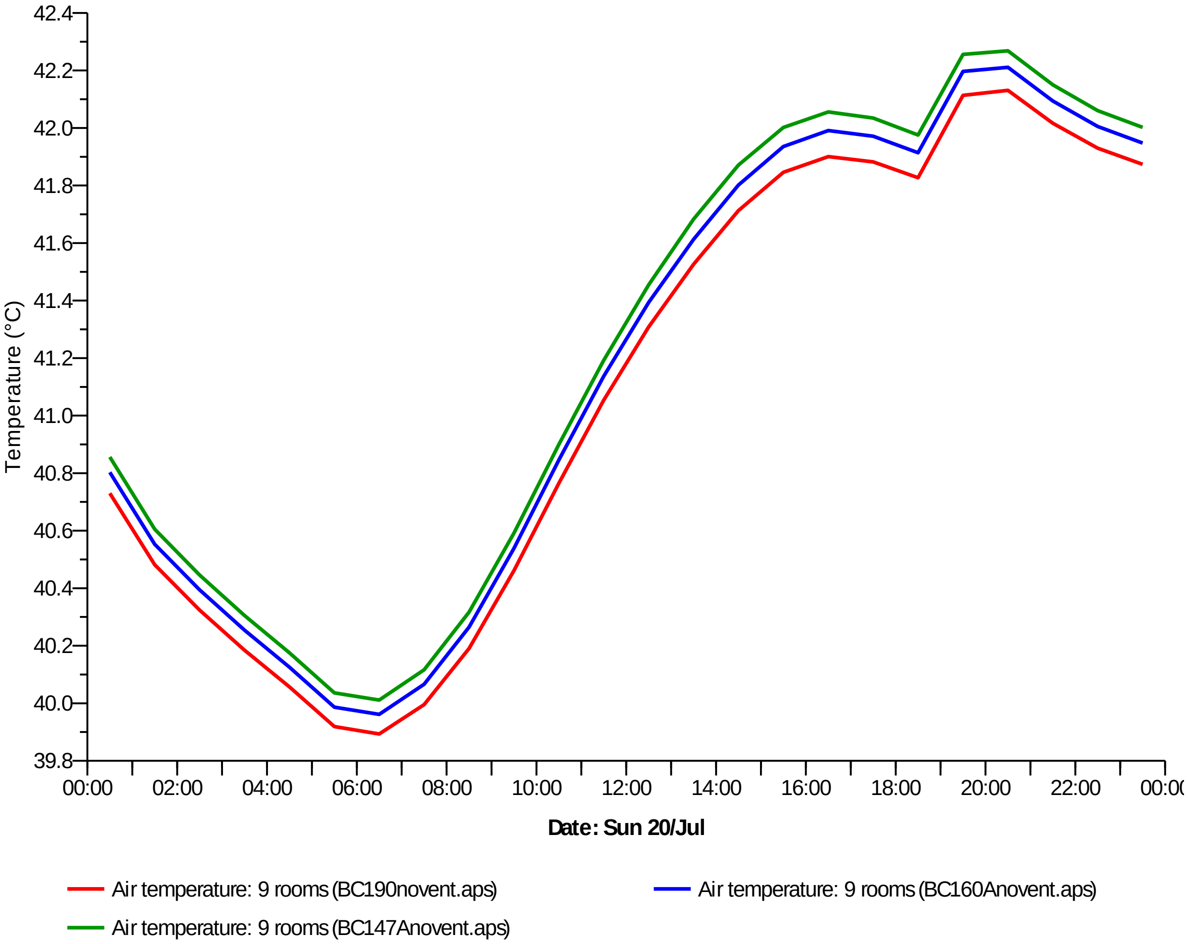


Figure 6.60 – Internal Temperatures in Warmest Day as a Result of Different Overhangs

On the other hand, Figure 6.61 shows temperature differences on the coldest day of the year. Contrary to the summer, case shading47 as the smallest overhang width, has the highest internal temperature. Therefore, as expected the overhang sizes have opposite advantages in different seasons. Therefore, the total amount of energy consumption, and free running months, have a significant impact on choosing an overhang size.

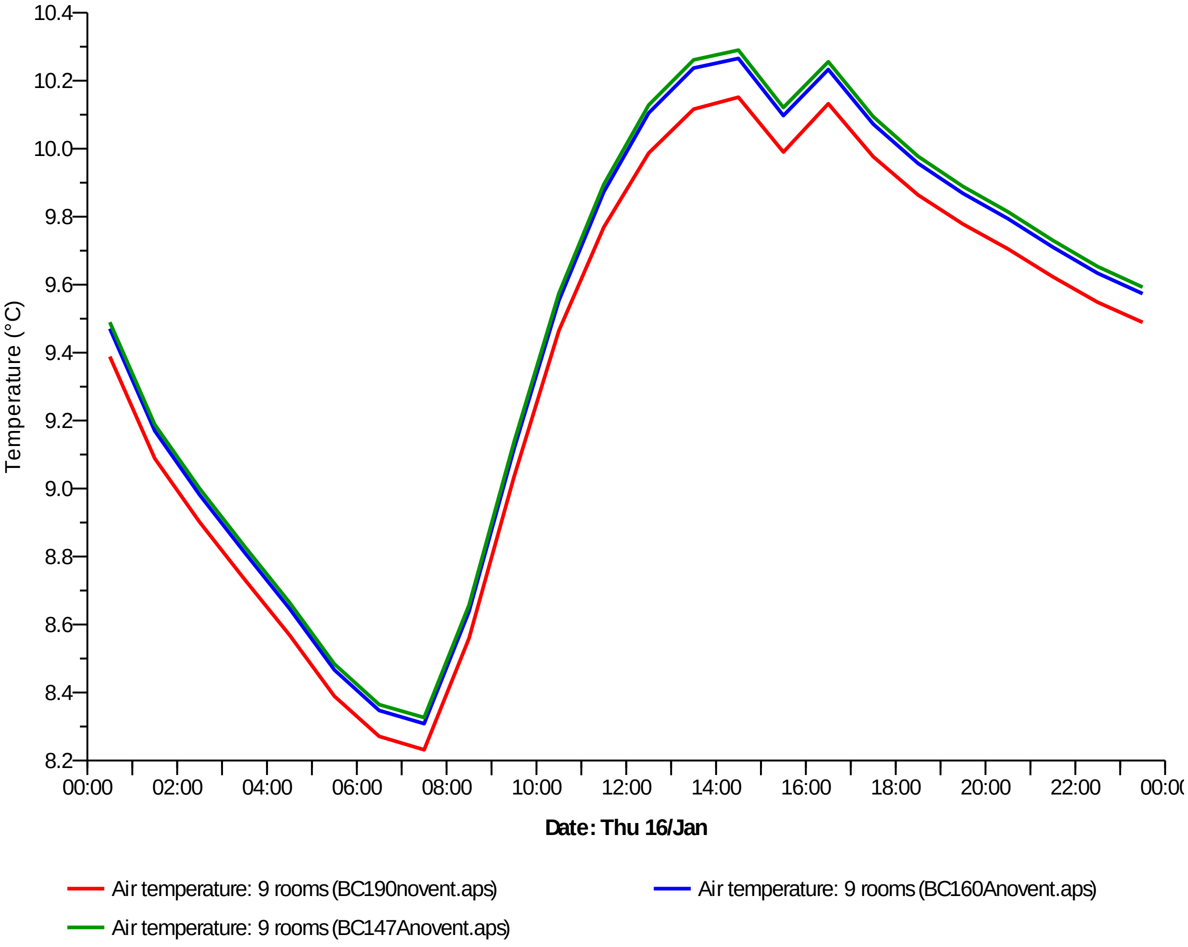


Figure 6.61 – Internal Temperatures in Warmest Day As A Result Of Different Overhangs

Windows have a great role to play on the amount of heat gains in building. The ability of higher solar gain in the winter means higher indoor temperatures and consequently lower energy consumption. On the other hand, lower solar gains in the summer means lower indoor temperature. Table 6.6 shows that the accumulated solar gains due to OH90, during the cold months of winter (January, February, March and December), are the lowest among the other cases by 396kWh/m^2. The highest solar gains are achieved by OH47 during winter by 437kWh/m2. During the summer the highest solar gains are by OH47 by 76kWh/m^2, while the lowest is achieved by OH90 by 46kWh/m2.

Table 6.6 – Monthly Solar Gains As Result Of Different Overhang Sizes (Kwh/M2)

	OH90	OH60	OH47	Base-case
Jan	120	120	120	120
Feb	94	110	110	110
Mar	62	78	87	91
Apr	10	23	31	46
May	3	1	1	19
Jun	1	0	0	9
Jul	2	1	1	13
Aug	6	3	16	33
Sep	37	50	59	69
Oct	87	100	110	110
Nov	110	120	120	120
Dec	120	120	120	120

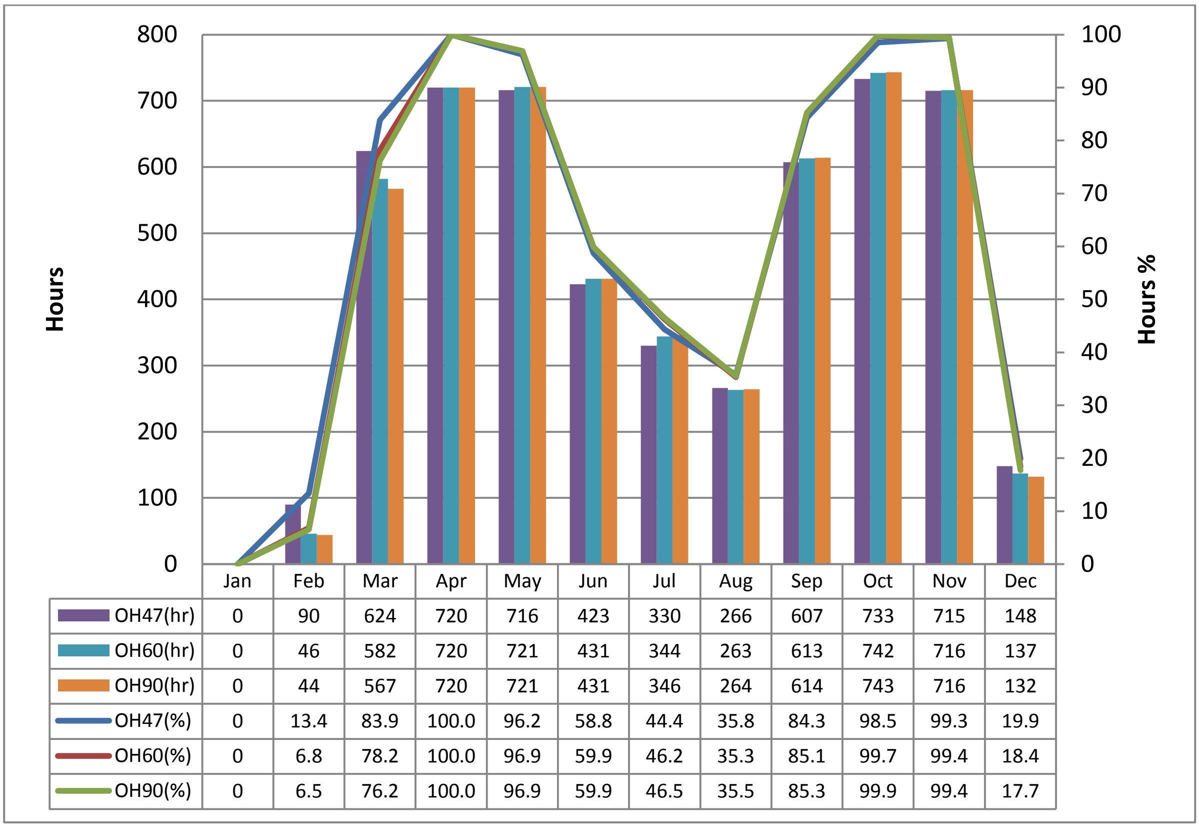
In order to evaluate the impact of shading in comparison with the base-case, Table 6.7 shows that all cases provide the same shading in June and July by 91%. Nevertheless, in August and September OH47 provides the lowest shading by 60% and 16% respectively. In winter, all the overhangs were fairly able to allow the maximum of heat gains. The best performances during cold months are achieved by OH90 that in all cold months except March avoided the shading by 100%. Only during March the OH47 resulted in 3% shading.

Table 6.7 – Monthly Shading Percentage over the Windows as a Result of Different Overhang Sizes

	OH47	OH60	OH90
Jan	0%	0%	1%
Feb	0%	0%	9%
Mar	3%	12%	32%
Apr	41%	52%	77%
May	87%	87%	87%
Jun	91%	91%	91%
Jul	91%	91%	91%
Aug	60%	86%	86%
Sep	16%	27%	52%
Oct	0%	3%	16%
Nov	0%	0%	3%
Dec	0%	0%	0%

6.5.1 Overhangs Thermal Comfort Evaluation

For free running purposes, the impact of natural ventilation is considered, and as shown in Figure 6.62, April is the highest performance month as 100% of time it is within the thermal comfort. October, May and November also have a high performance thermal comfort temperature as in all cases more than 95% of times are within the thermal comfort. Therefore, it can be concluded that all shading cases achieve the free running requirement in the mentioned above months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OH47(hr)	0	90	624	720	716	423	330	266	607	733	715	148
OH60(hr)	0	46	582	720	721	431	344	263	613	742	716	137
OH90(hr)	0	44	567	720	721	431	346	264	614	743	716	132
OH47(%)	0	13.4	83.9	100.0	96.2	58.8	44.4	35.8	84.3	98.5	99.3	19.9
OH60(%)	0	6.8	78.2	100.0	96.9	59.9	46.2	35.3	85.1	99.7	99.4	18.4
OH90(%)	0	6.5	76.2	100.0	96.9	59.9	46.5	35.5	85.3	99.9	99.4	17.7

Figure 6.62 – Monthly Thermal Comforts as a Result of Different Overhang Sizes

Annual thermal comfort analysis shows (Figure 6.63) that OH47 has the best thermal comfort hours among the other cases by achieving 60.67% hours of annual thermal comfort, while the worst case is OH90 with 59.33% thermal comfort hours.

Surprisingly, the base-case without any overhangs still has a better performance than all overhang sizes with 61.20% thermal comfort hours.

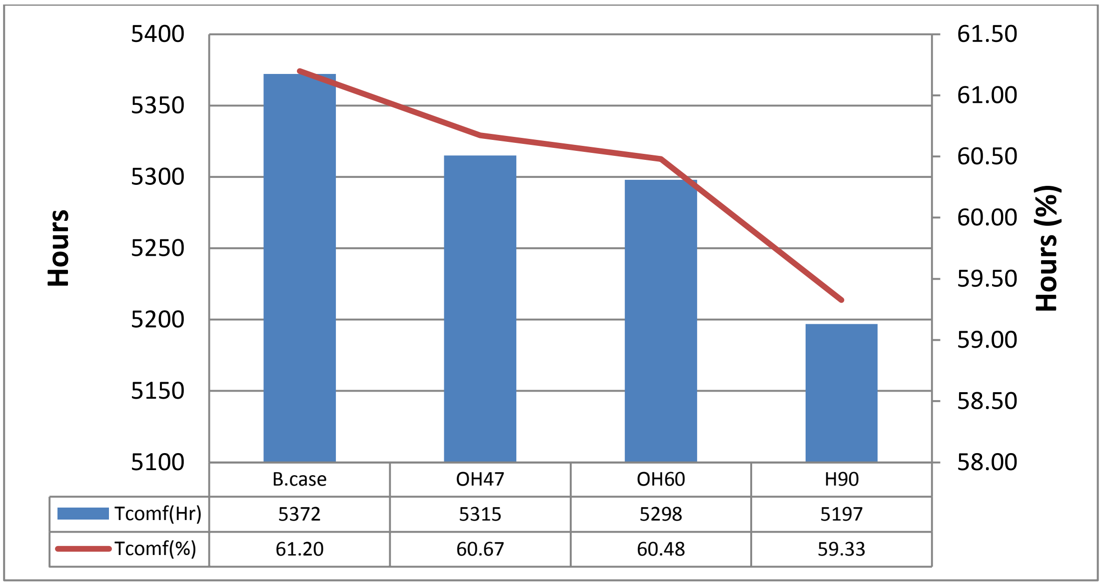


Figure 6.63 – Annual Thermal Comforts As A Result Of Different Overhang Sizes

6.5.2 Overhangs Energy Impact

Shadings impact the sensible loads in winter and summer, this results in controlling the amount of solar gains through the windows on warmer days and eventually providing a less conditioned space. As Figure 6.64 shows, case OH47 requires the highest annual total sensible loads by 5.63MWh. The lowest total sensible load is achieved by OH90 with 5.56MWh. OH90 also requires the lowest cooling loads with 2.50MWh. These amounts of low sensible loads were expected due the larger size of the overhang and its contribution to lower heat gains through the windows. On the other hand, OH90 requires the highest heating load as the large overhang size casts more shade on the windows during winter, although the height of the overhangs are designed to be at their most effective place above the windows. Furthermore, all cases show a better performance than the base case in total. This improvement is a result of the reduction in cooling sensible loads.

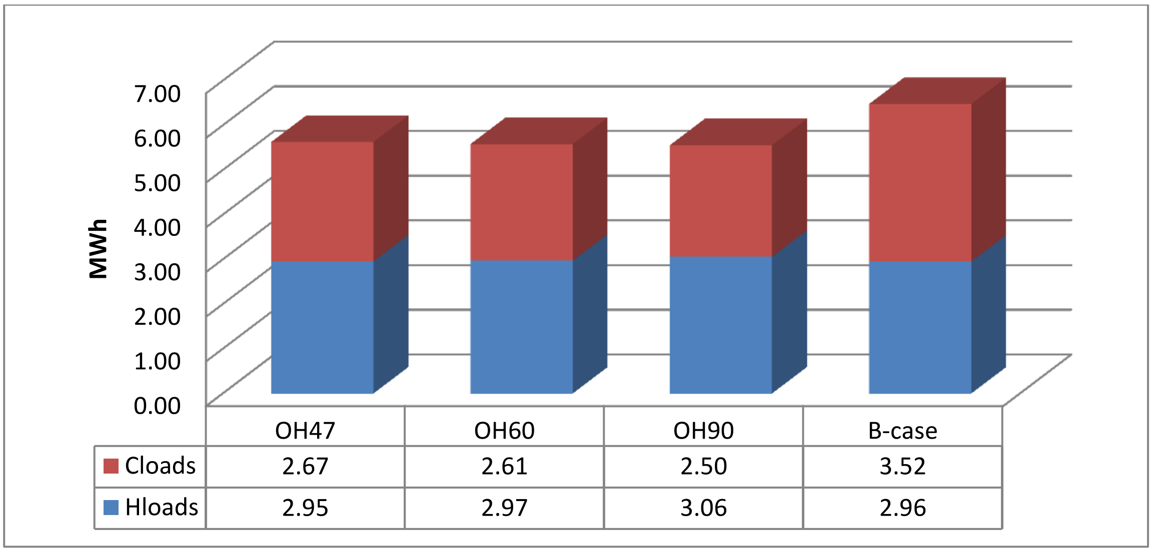


Figure 6.64 – Annual Heating and Cooling Sensible Loads In Different Overhang Sizes

Although fluctuation in the amount of heating and cooling sensible loads reflect the same fluctuation rate in the amount of heating and cooling energy consumption, the total energy consumption rate does not follow this pattern. Therefore, it is expected that the order of the amount of total energy consumption in each case differ from the result of the total sensible loads. In effect, Figure 6.65 shows that the lowest energy consumption is achieved by applying OH47 with 6.09MWh energy consumption. This amount of energy is less than the base case by 0.35%.

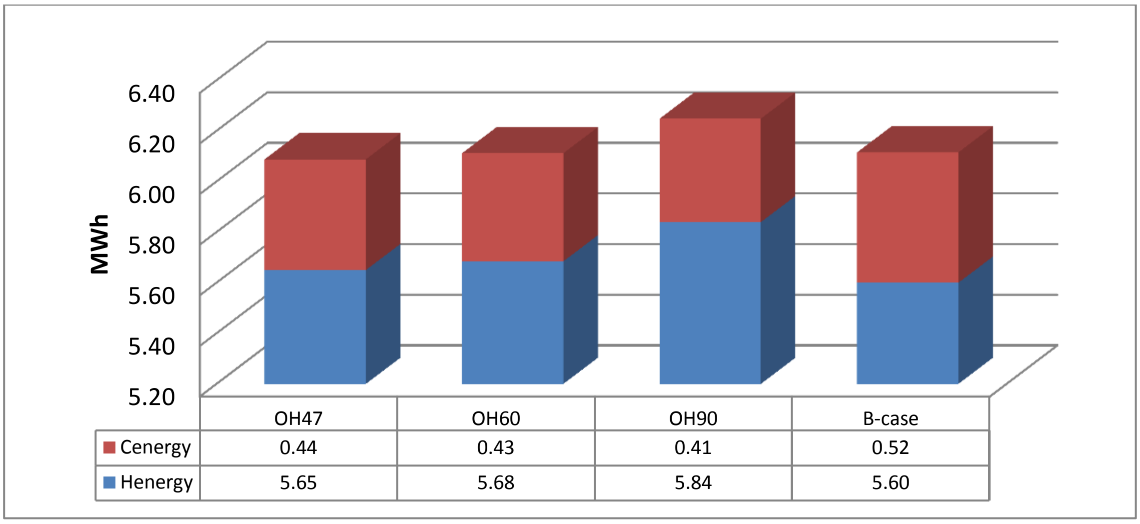
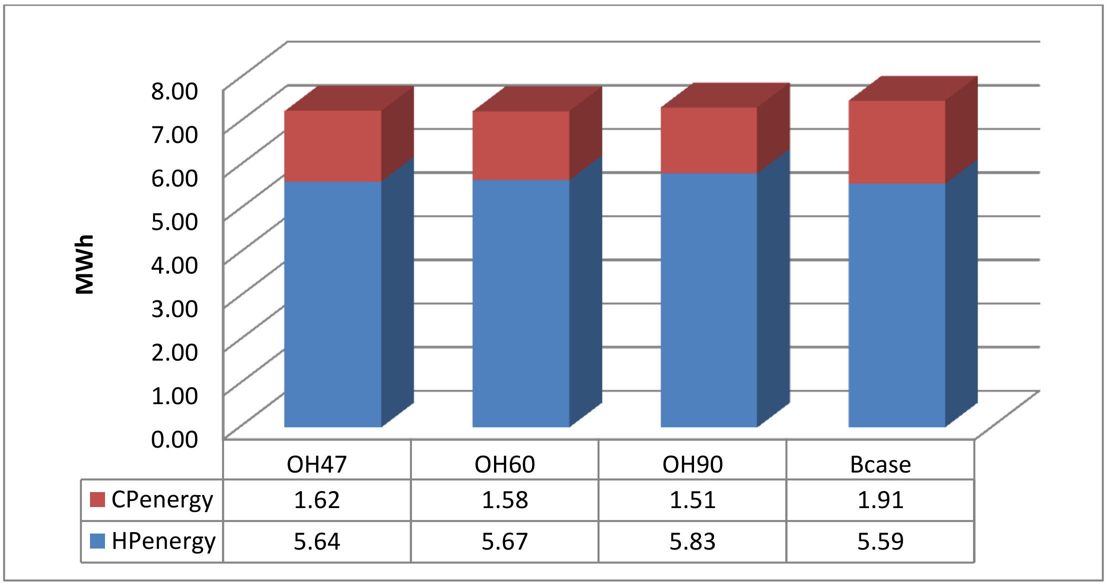


Figure 6.65 – Annual Heating and Energy with Different Overhang Sizes

As mentioned previously, before deciding to select the most efficient element, the primary energy consumption must be considered. The lowest total primary energy consumption among the overhang cases is OH60 with 7.25 MWh that is more efficient than the base case model by 3.2% (Figure 6.66).

In conclusion, it seems that overhangs have a minor impact on the total energy consumption, which in some aspect is negligible, however, the significant reduction of the cooling energy would be an important achievement for economic and technical purposes.



	OH47	OH60	OH90	Bcase
🟥 CPenergy	1.62	1.58	1.51	1.91
🟦 HPenergy	5.64	5.67	5.83	5.59

Figure 6.66 – Total Primary Energy Consumptions In Different Overhang Sizes

6.5.3 Movable Overhangs

Fore movable overhangs, the best cooling performance is selected as the building shading device, therefore will not affect the building energy and thermal comfort performance in colder months. For this purpose, OH90 has the best performance among the other cases in terms of efficient heating energy performance. The active months for removable shading have been selected as June, July, September and August.

The result in Table 6.7 shows that the movable overhangs provide more shading in all summer months than the fixed overhangs. The average shading in summer (June-September) increases from 80% to 90% by using OH90 as a movable overhang. The main reason for this is the decreasing height of the overhang above the windows from the 52cm to 0. Furthermore, as the movable overhang is de-active in winter, therefore the building has the opportunity for full solar heat gain. In contrary, in the summer months (from June to September), the total heat gains dropped significantly from 46kWh/m^2 to 11kWh/m^{2}a.

Table 6.8 – Monthly Heat Gains and Shading Amount by Applying Fixed and Movable Overhangs

Heat gains (kWh/M^2)			***Shading (%)***	
	Movable	**OH90 (fixed)**	**Movable**	**OH90 (fixed)**
Jan	86	120	0%	1%
Feb	110	94	0%	9%
Mar	91	62	0%	32%
Apr	46	10	0%	77%
May	19	3	0%	87%
Jun	0	1	95%	91%
Jul	0	2	95%	91%
Aug	2	6	91%	86%
Sep	9	37	80%	52%
Oct	110	87	0%	16%
Nov	120	110	0%	3%
Dec	120	120	0%	0%

The sensible loads analysis shows that the cooling loads decrease by 33% compared to the base-case and the heating load remains the same as the base-case. Consequently, the total loads decrease by 18.8% (Figure 6.67).

The total energy consumption also decreases by 4.5%. Although the total energy reduction is not of significance, the total electricity reduction is reasonably reduced from 520kWh to 380kWh (Figure 6.68).

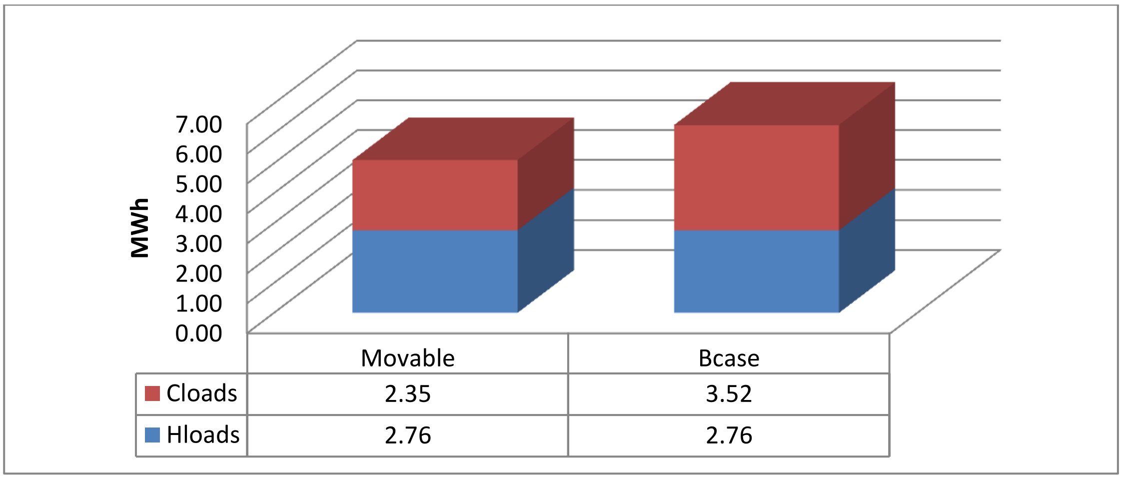


Figure 6.67 – Total Heating and Cooling Sensible Loads in Base-Case and Movable Cases

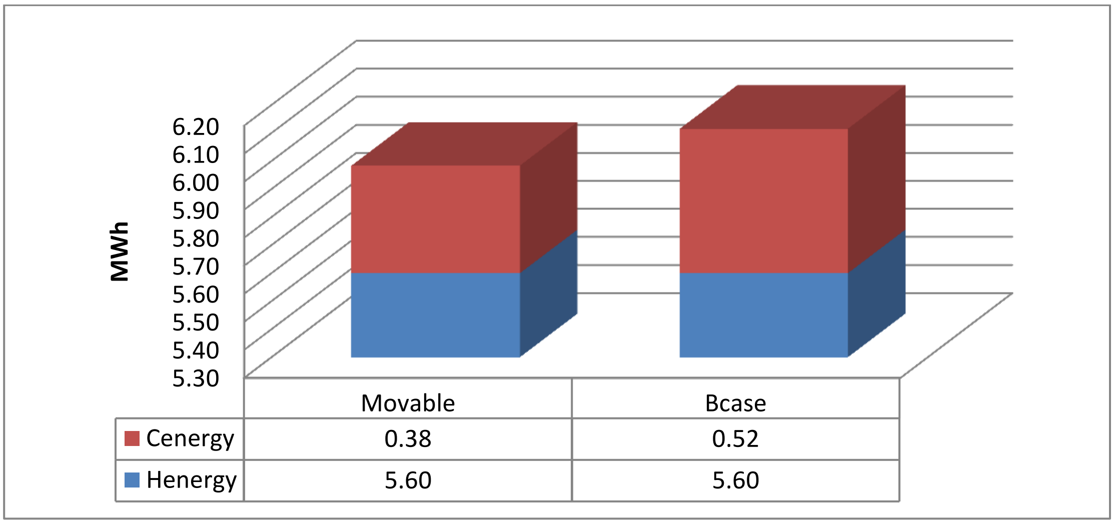
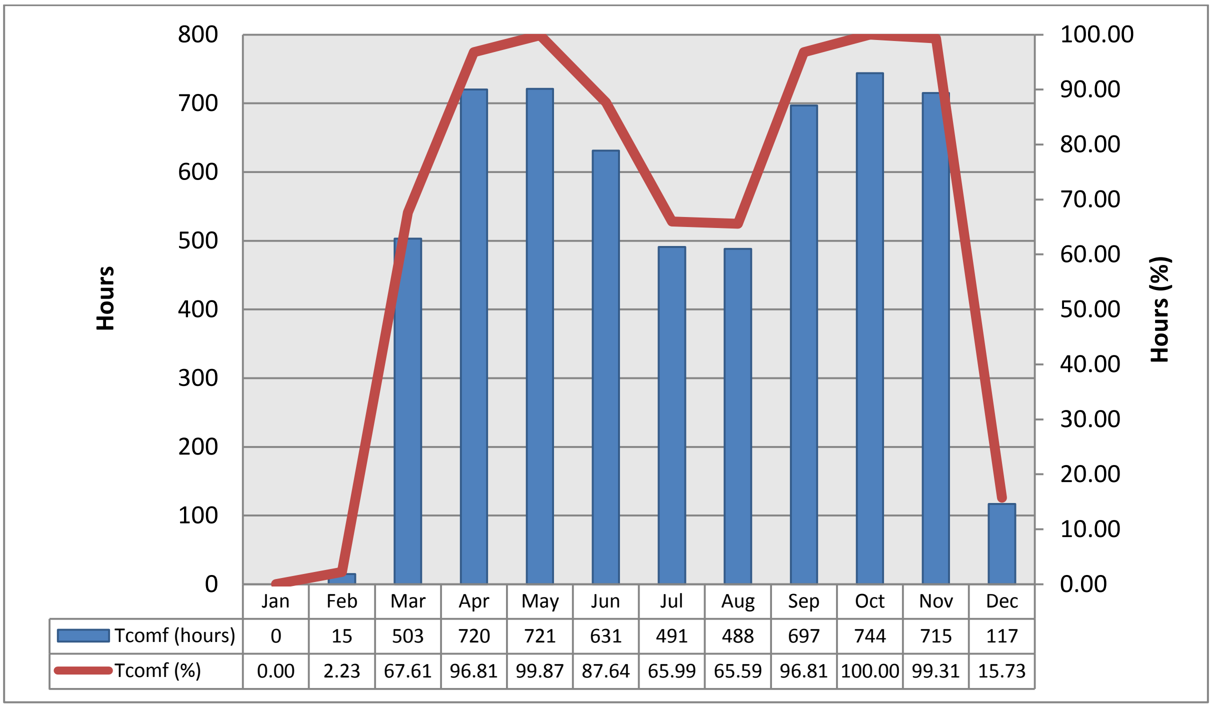


Figure 6.68 – Total Energy Consumption in Base-Case and Movable Cases

6.5.4 Internal Curtains

In order to improve the solar gain control in summer months, the internal shading in form of a light coloured curtain is coupled with the removable overhangs. The indoor light colour has an ability to absorb less heat and reflect more. The curtain is set to operate once the windows are closed to avoid blocking the natural ventilation flow.

The thermal comfort analysis shows (Figure 6.69) that removable overhangs are capable of creating free running building in September, where the thermal comfort temperature is provided for more than 96% of hours throughout the month, and only 23 hours in whole month are over the thermal comfort range.



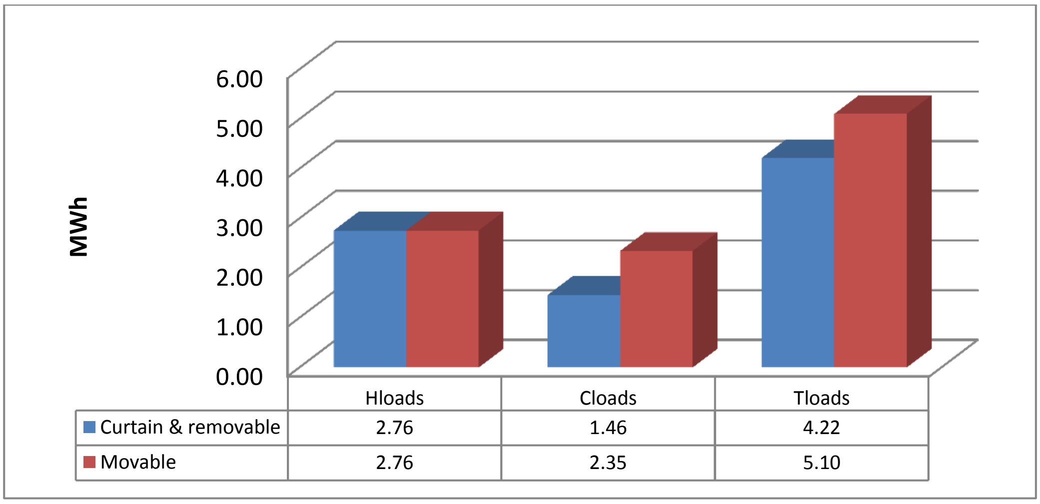
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tcomf (hours)	0	15	503	720	721	631	491	488	697	744	715	117
Tcomf (%)	0.00	2.23	67.61	96.81	99.87	87.64	65.99	65.59	96.81	100.00	99.31	15.73

Figure 6.69 – Monthly Thermal Comforts In Case Of Internal Curtain

The result in figure 6.70 shows that in the case of internal shading, the cooling sensible loads significantly drops by 37% and results in a 17.2% reduction of total sensible loads.

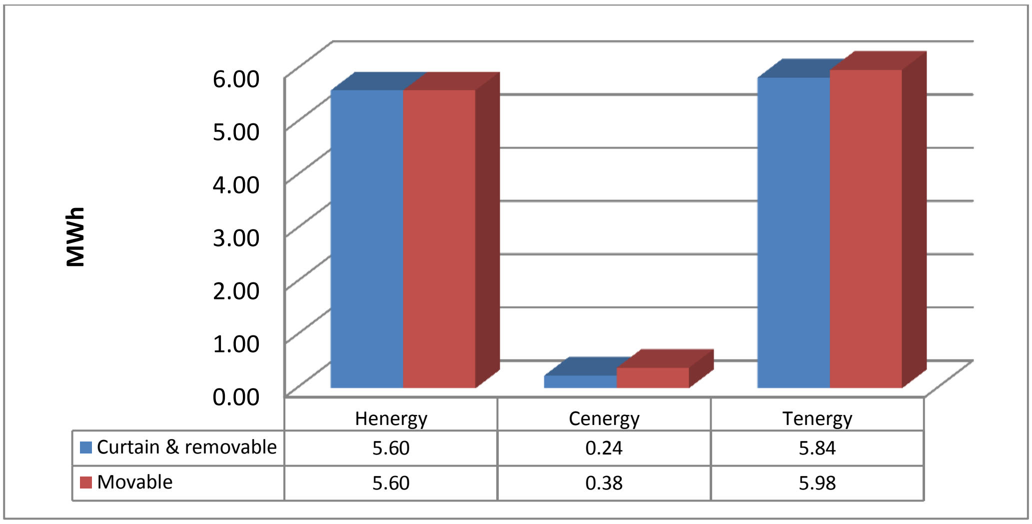
The electricity consumption also significantly decreases from 380kWh to 240kWh. The total energy decreases by 2.3% respectively (Figure 6.71).

The results show that internal shading has a great effect on energy efficiency strategies, and appropriate control of internal shadings is an important factor to reduce energy consumption in both summer and winter.



	Hloads	Cloads	Tloads
🟦 Curtain & removable	2.76	1.46	4.22
🟥 Movable	2.76	2.35	5.10

Figure 6.70 – Total Sensible Loads As A Result Of Curtain In Comparison With The Movable Overhangs



	Henergy	Cenergy	Tenergy
🟦 Curtain & removable	5.60	0.24	5.84
🟥 Movable	5.60	0.38	5.98

Figure 6.71 – Total Sensible Loads As A Result Of Curtain In Comparison With The Movable Overhangs

6.5.5 Shutters

Internal thermal blinds or curtains can help a lot in preventing heat loss through windows in winter, but to tackle unwanted radiant heat gain in the hotter months, it’s far more efficient to stop the sun hitting the glass in the first place with appropriate external shading.

By considering external blind or shutters, as Figure 6.72 shows that the thermal comfort improves considerably, however this improvement doesn’t achieve any further free running months than the other cases. The most considerable improvement is achieved in June when the thermal comfort time exceeds 92% and very close to the free running building requirements.

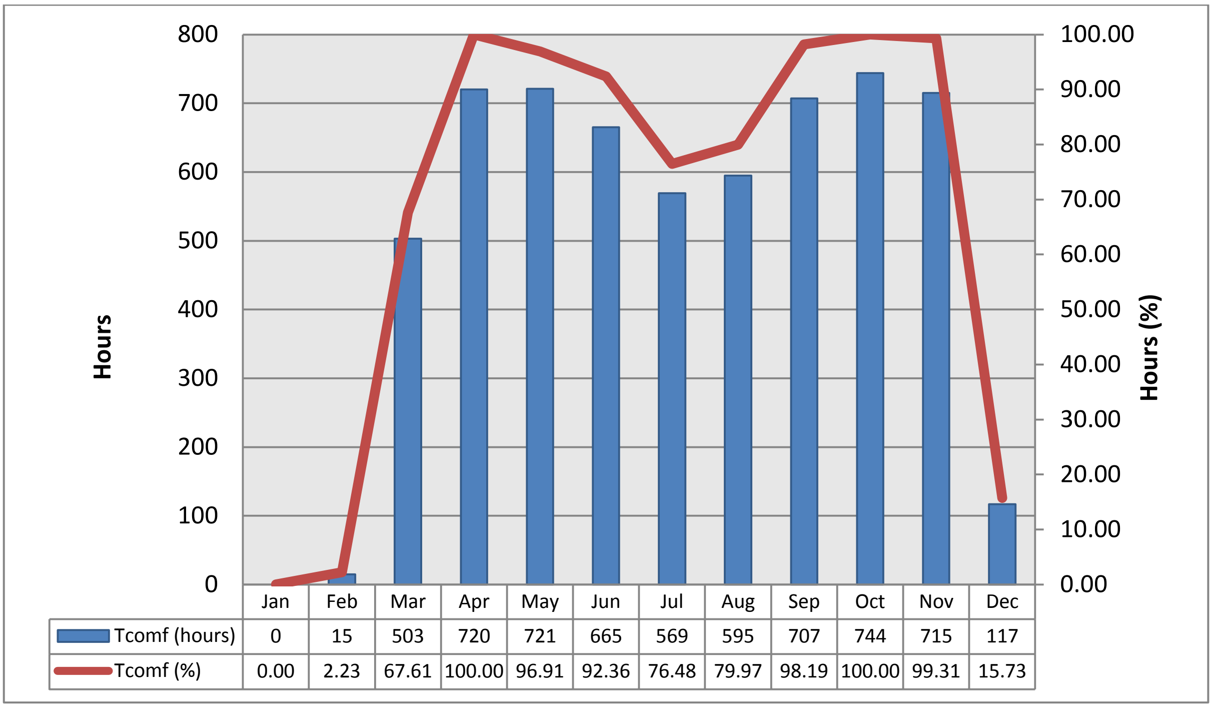


Figure 6.72 – Monthly Thermal Performances As A Result Of Applying Shutters

The energy analysis shows (Figure 6.73) that by applying external shading or blinds, the cooling and total sensible loads considerably decrease to at the lowest point 1.11MWh and 3.87MWh respectively. Electricity consumption decreases significantly from 240kWh in internal shading case to 170kWh in shutter case.

The deflecting of the sun rays before reaching the windows and absorbing the heat has the most impact on cooling energy reduction among the other shading strategies. However as mentioned before, this strategy could adversely increase the lighting demand as the daylight factor decreases as result of external shading devices.

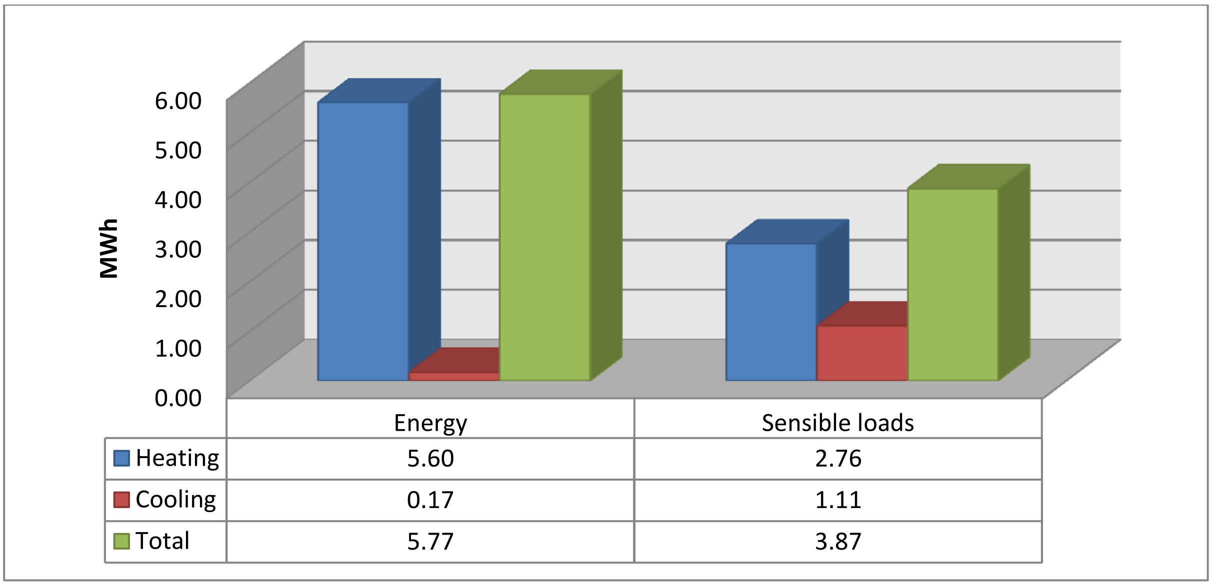


Figure 6.73 – Total Heating and Cooling Sensible Loads and Energy Consumption As A Result Of Shutter

6.6 Use of Insulation Material in Walls

In terms of thermal insulation, among the insulation materials in the country Polystyrene is an easily accessible and cheap material. In addition, Polystyrene has an R-value of approximately 1.59m^2K/W. This R-value is significantly high and is adequate for residential, commercial, and industrial buildings. The suggested polystyrene thickness is 50mm in all cases, this is intended to be within the effective R-value rate and to avoid the unnecessary wall thickness.

In order to investigate the impact of thermal transmittance (U-value) of the external walls on indoor temperatures, polystyrene is added to the existing wall types. The new wall types are simulated under the best case in previous section (Phase 2) to measure the changes in indoor thermal comfort as well as energy consumptions.

As the purpose of this section is to optimize the effect of the building fabric on energy efficiency, the combination of thermal mass and insulation is highly important. The initial design was to place the polystyrene right in the middle of building walls and then consider the thermal and energy performance of the walls.

At this stage the combination of thermal mass and insulation of wall materials are examined to identify the impact of insulated walls on thermal comfort and energy efficiency. The effect of mass and insulation location is related to mass layer and affects the time lag of the heat flux through a wall and the ability of reducing interior temperature fluctuation (Byrne and Ritschard, 1985).

Figure 6.74 shows that the effect of thermal mass on indoor temperatures by adding insulation to different wall types. The internal temperatures in all cases are maintained by steady fluctuation of 2^{o}C, while outdoor temperatures fluctuated from 28^{o}C to 39^{o}C within a day. WT4 has the lowest internal temperature, while WT6 has the highest temperature. Furthermore, all the wall cases have less efficient performance than the base case. This is obviously due to the insulation characteristics to avoid the heat transfer during night when the outdoor temperature drops by far lower than the indoor temperature. As a result, thermal insulation in summer is not as beneficial as wall types without insulation materials.

On summer nights when the outdoor temperature falls below the indoor temperature, the insulation layer inside walls resists the outward heat flow and causes a delay in the discharging of thermal mass heat, and consequently results in higher indoor temperatures.

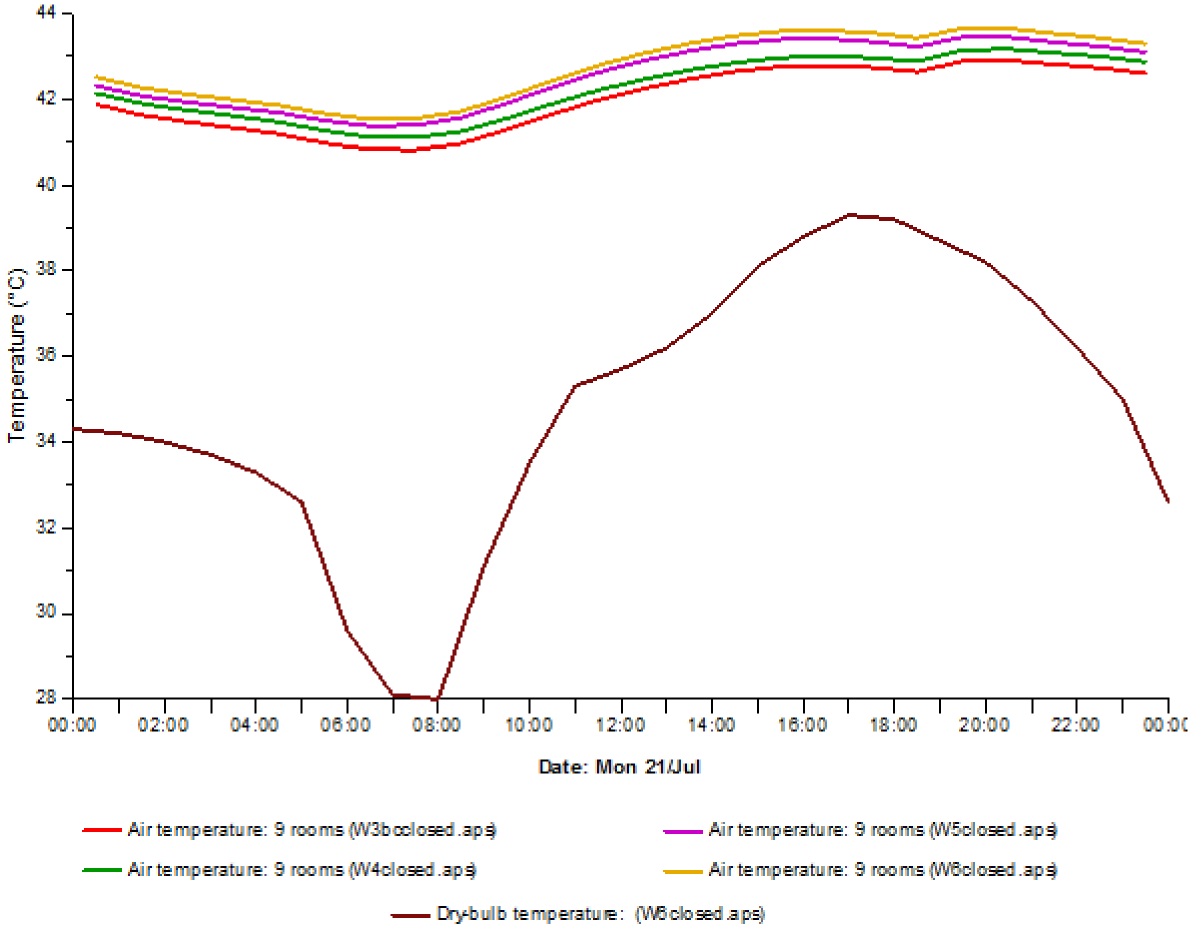


Figure 6.74 – Internal Temperatures in Different Insulated Wall Types in Warmest Day

Despite the above findings, Figure 6.75 shows that natural ventilation in both full day and night ventilation compensate the disadvantages of using insulation. In this case, natural ventilation significantly purges the indoor heat and creates a lower indoor temperature at a similar level of uninsulated walls. During the night, the outdoor temperature drops below the indoor temperature, but the indoor temperature is still within the thermal comfort. During the day, the indoor temperature falls below the hot outdoor temperature. Although the indoor day temperature is out of the thermal comfort range, it will be potentially advantageous for reducing cooling energy consumption. As Figure 6.75 illustrates, the insulated walls coupled with the natural ventilation even performs better than the uninsulated wall during the day. This is a result of insulation ability to avoid heat absorbance, therefore less heat discharges to the indoor space, and the natural ventilation has less heat to be purged.

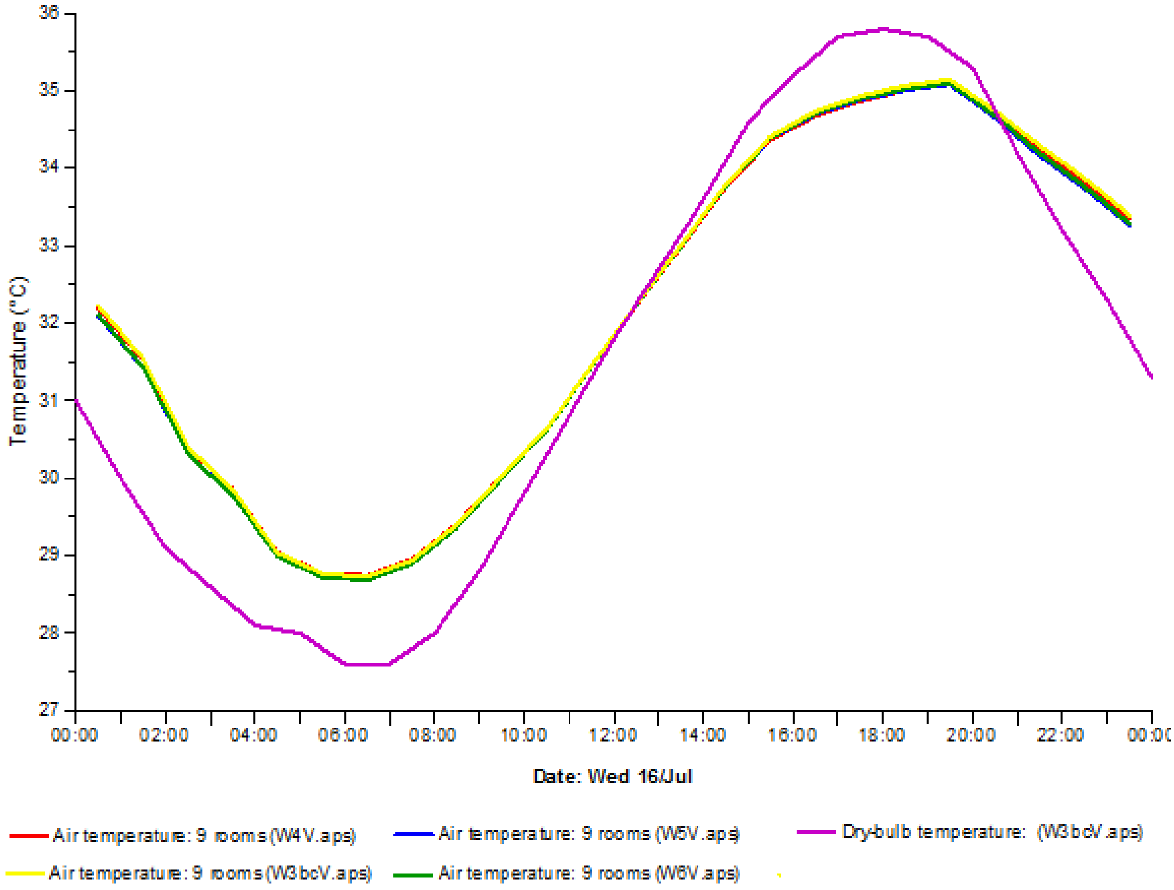


Figure 6.75 – The Effect of Natural Ventilation on Internal Temperature in Warmest Day

The great advantage of insulated walls can be observed in winter time as illustrated by Figure 6.76. For instance, on the coldest day of year, while the outdoor temperature fluctuated from -5^{o}C at 6:00 AM to 2^{o}C at 03:00 PM, the indoor temperature in WT6 fluctuated from 10.5^{o}C at 7:00 AM to 12^{o}C at 2:00 PM. Therefore, the outdoor temperature fluctuation is about 7^{o}C, while the indoor temperature maintains about 1.5^{o}C variation. Therefore, the insulation perfectly keeps the indoor temperature higher than outdoor temperature in winter, and in summer by applying the natural ventilation, the indoor temperature significantly drops to a reasonable level.

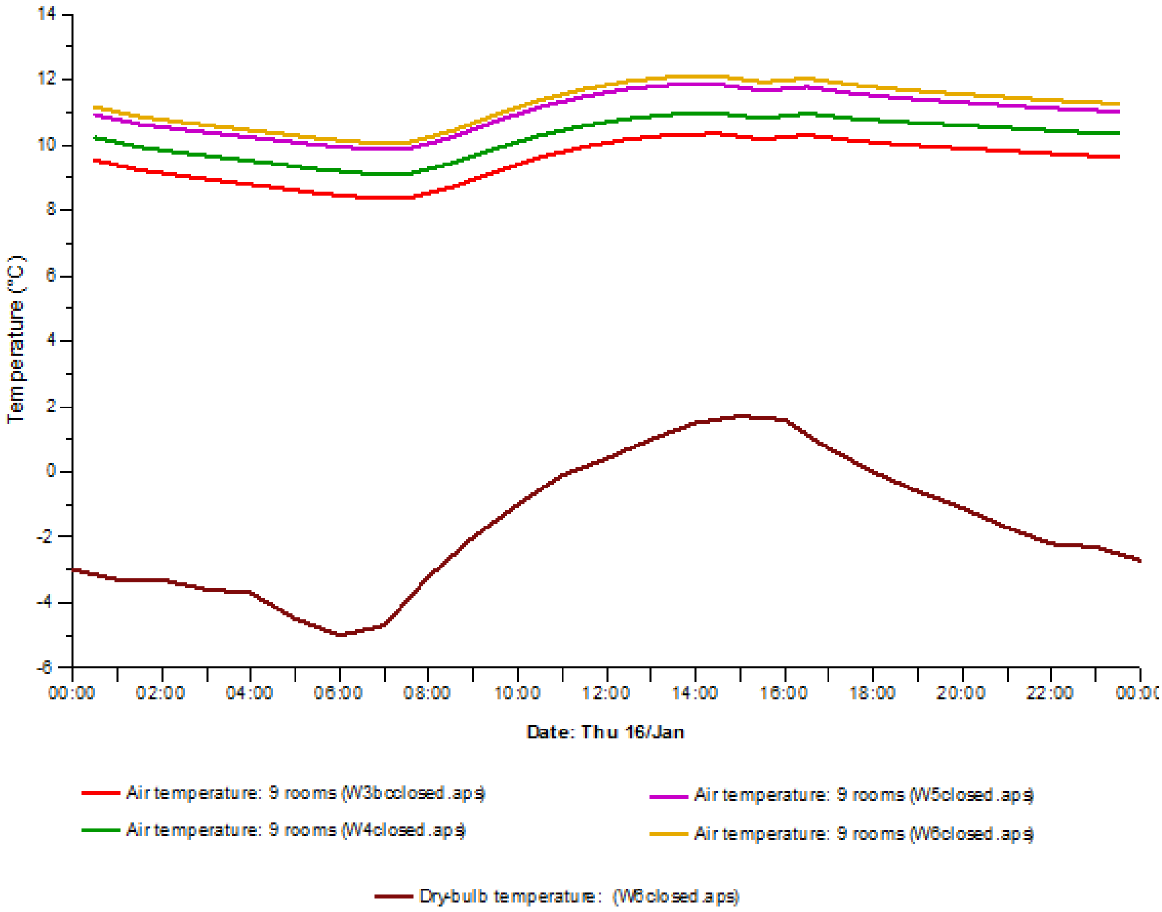
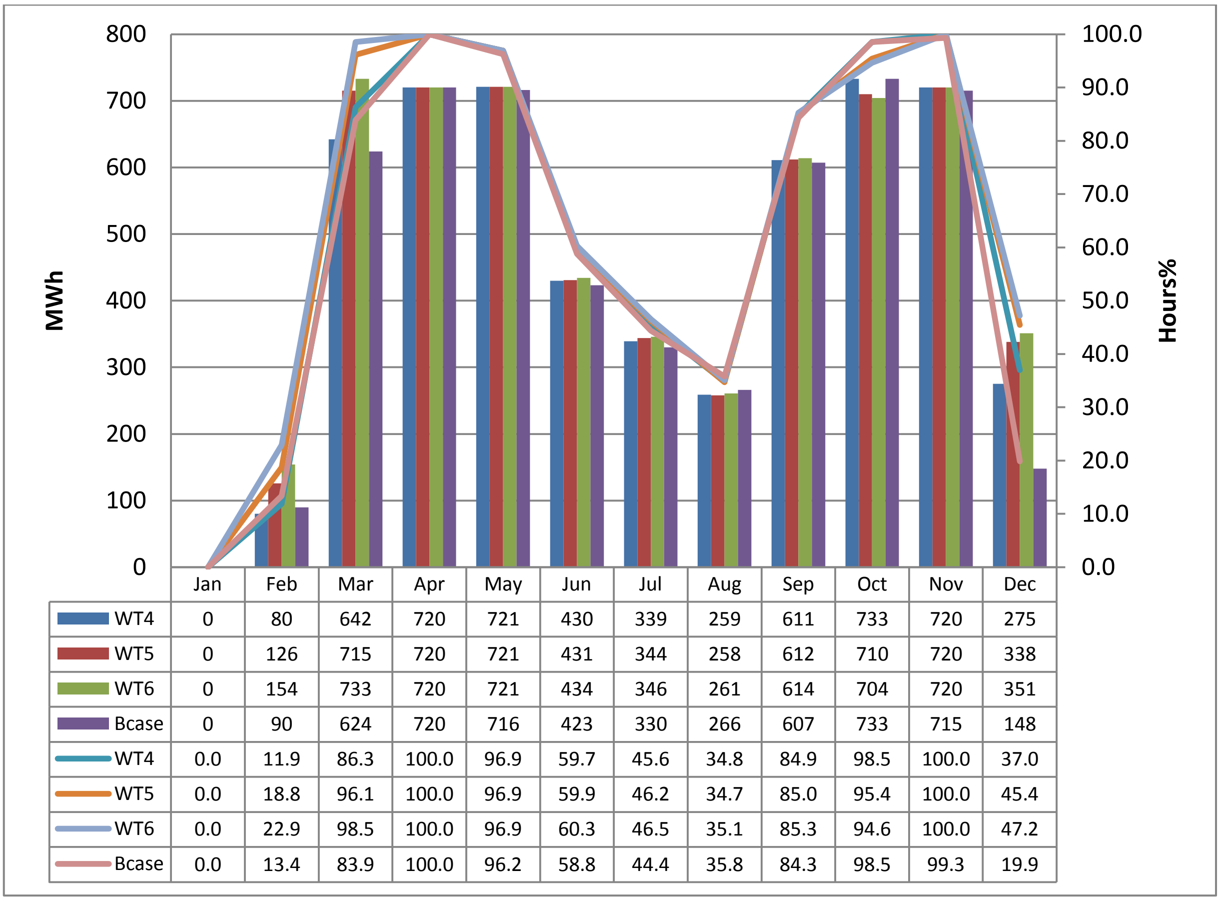


Figure 6.76 – Internal Temperature As A Result Of Different Insulated Wall Types In Coldest Day

6.6.1 Thermal Comfort Performance

For thermal comfort purposes, the conditioning system is assumed to be de-active all year round. According to Figure 6.77, all insulated wall types have a better performance than the base-case in all months, except October. Achieving better operational temperatures was expected as a result of insulation materials characteristics in cold weather, however, during the summer, as discussed earlier, the natural ventilation significantly contributes to a more efficient performance than the base-case model. In the base-case, a free running building within thermal comfort range was achieved over four months. Figure 6.77 clearly shows that WT5 and WT6 are capable of achieving one further free running month in March where the internal temperature is within the thermal comfort with 96.1% and 98.5% respectively. Although WT4 performs better than the base-case in March, the thermal comfort does not reach the desirable free running month. The most impressive improvement happens in December, when the thermal comfort duration is optimized by 57% with 148 hours in the base-case to 351 hours in WT6.



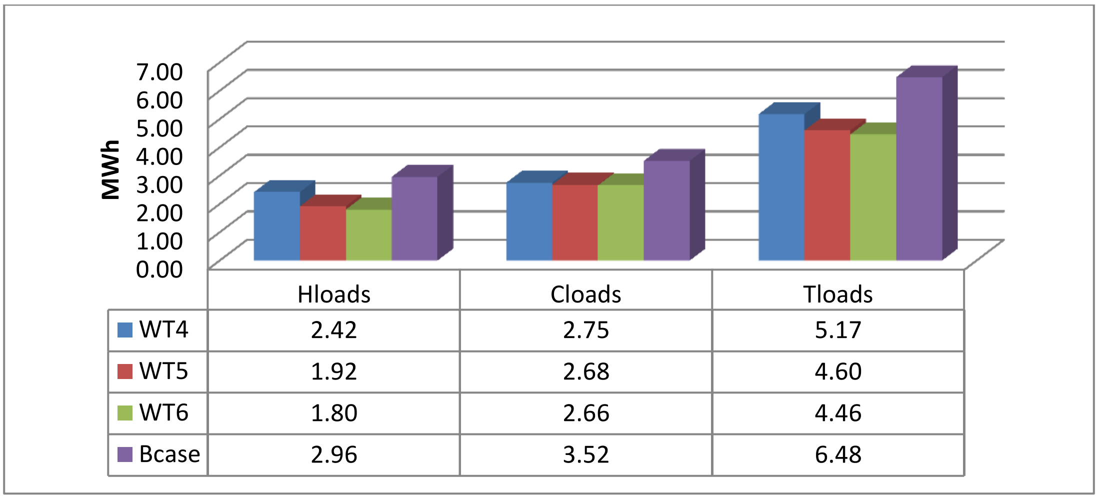
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▬ WT4	0	80	642	720	721	430	339	259	611	733	720	275
▬ WT5	0	126	715	720	721	431	344	258	612	710	720	338
▬ WT6	0	154	733	720	721	434	346	261	614	704	720	351
▬ Bcase	0	90	624	720	716	423	330	266	607	733	715	148
— WT4	0.0	11.9	86.3	100.0	96.9	59.7	45.6	34.8	84.9	98.5	100.0	37.0
— WT5	0.0	18.8	96.1	100.0	96.9	59.9	46.2	34.7	85.0	95.4	100.0	45.4
— WT6	0.0	22.9	98.5	100.0	96.9	60.3	46.5	35.1	85.3	94.6	100.0	47.2
— Bcase	0.0	13.4	83.9	100.0	96.2	58.8	44.4	35.8	84.3	98.5	99.3	19.9

Figure 6.77 – Monthly Thermal Performances As A Result Of Different Insulated Wall Types

6.6.2 Energy Analysis

As discussed above, the WT4 performs without mechanical heating and cooling systems in May, April, October and November. Likewise, WT5 and WT6 perform free running in these months plus March, for which the energy analysis has been applied.

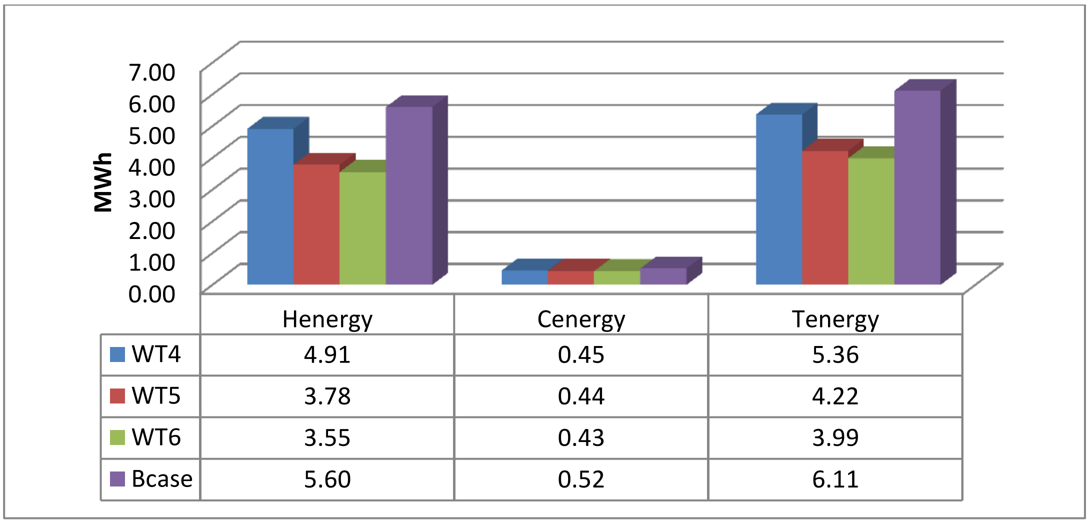
The sensible loads analysis shows (Figure 6.78) that WT6 performs more efficiently than the other cases in both heating and cooling sensible loads. Cooling loads in WT6 decreases by 39% from the base-case, while the heating loads decrease by 24.5%. The total load also decreases by 31%. Accordingly, both the cooling and heating loads have significant optimization in comparison with the base-case. Among the wall types considerable differences occur for heating loads, as WT4 requires an extra 620kWh heating load than WT6. On the other hand, the cooling loads are very close to each other.



	Hloads	Cloads	Tloads
🟦 WT4	2.42	2.75	5.17
🟥 WT5	1.92	2.68	4.60
🟩 WT6	1.80	2.66	4.46
🟪 Bcase	2.96	3.52	6.48

Figure 6.78 – Annual Total Heating and Cooling Sensible Loads As A Result Of Different Insulated Walls

Following the sensible loads, as Figure 6.79 shows, the heating energy consumption decreases from 5.6MWh in the base-case to 3.55MWh with WT6. Heating energy also decreases from 520kWh in the base-case to 355kWh with WT6. The most important change is in total energy consumption where WT4 has the highest energy consumption among the other cases by 5.36 MWh. On the other hand, WT6 has the lowest total energy consumption by 3.99 MWh that is approximately 35% less than the reference case.



	Henergy	Cenergy	Tenergy
🟦 WT4	4.91	0.45	5.36
🟥 WT5	3.78	0.44	4.22
🟩 WT6	3.55	0.43	3.99
🟪 Bcase	5.60	0.52	6.11

Figure 6.79 – Total Heating and Cooling Energy Consumption As A Result Of Different Insulated Wall Types

The overall result shows that insulated walls are considerably effective in winter months compared to the summer months. Furthermore, these types of walls without applying natural ventilation would perform inefficiently and cause overheating. Applying the natural ventilation could control the overheating, however, insulation in these wall types wouldn’t contribute to achieving a significant cooling energy reduction. Therefore, it is important to consider in the next section the shading effect in summer time, while insulated walls are in place.

6.7 Two Dimensional Analysis Shadings for Shading and Thermal Insulation

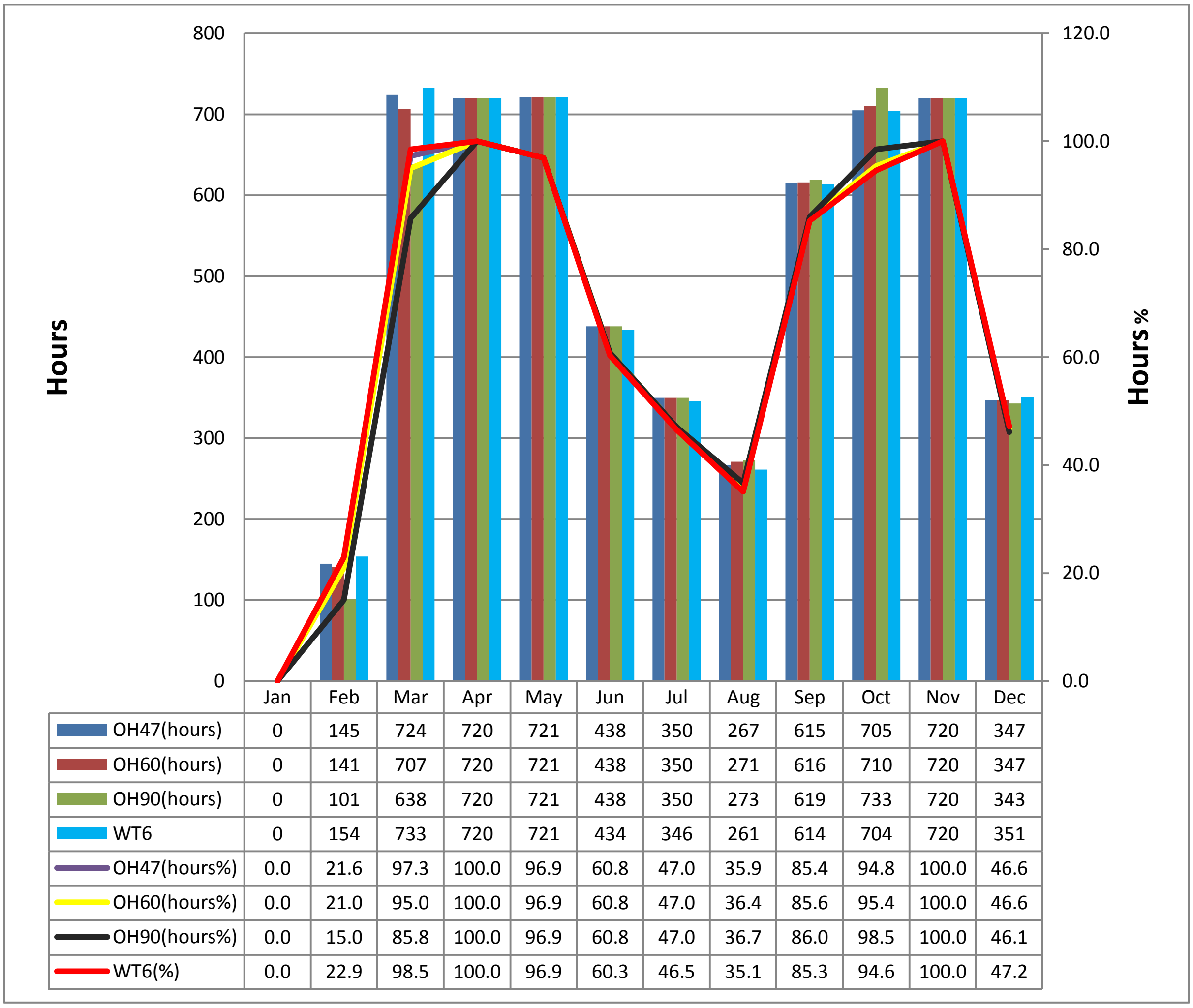
The solar gain control through the windows’ overhangs and shadings were discussed in the previous section. Findings of the previous section project the same strategies with the same descriptions for this section. At this stage the impact of the combination of shadings and insulated walls on thermal comfort and energy consumption is evaluated.

6.7.1 Thermal Comfort Analysis

For thermal comfort purposes as Figure 6.80 shows, OH47 and OH60 provide thermal comfort for more than 95% of the time in March, April, May, October and November, therefore the building could be regarded as a free running building during these months. However, OH90 due to the size of overhang and providing undesirable shading in March fails to achieve free running requirements.

Overhang OH47 achieves the best thermal comfort duration by over 66% annual thermal comfort among the other overhang cases. OH47 summer performance is the worst among the other cases, in particular in August and September; however, the size of the overhang results in lowering the undesirable shading in winter time.

However, neither of the overhang sizes are capable of improving the occupant thermal comfort. Therefore, it can be concluded that fixed overhangs are not suitable strategies to provide further thermal comfort once they are coupled with insulated walls. Nevertheless, energy analysis needs to be conducted to find out if the overhangs could play efficient roles in energy reduction in buildings.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OH47(hours)	0	145	724	720	721	438	350	267	615	705	720	347
OH60(hours)	0	141	707	720	721	438	350	271	616	710	720	347
OH90(hours)	0	101	638	720	721	438	350	273	619	733	720	343
WT6	0	154	733	720	721	434	346	261	614	704	720	351
OH47(hours%)	0.0	21.6	97.3	100.0	96.9	60.8	47.0	35.9	85.4	94.8	100.0	46.6
OH60(hours%)	0.0	21.0	95.0	100.0	96.9	60.8	47.0	36.4	85.6	95.4	100.0	46.6
OH90(hours%)	0.0	15.0	85.8	100.0	96.9	60.8	47.0	36.7	86.0	98.5	100.0	46.1
WT6(%)	0.0	22.9	98.5	100.0	96.9	60.3	46.5	35.1	85.3	94.6	100.0	47.2

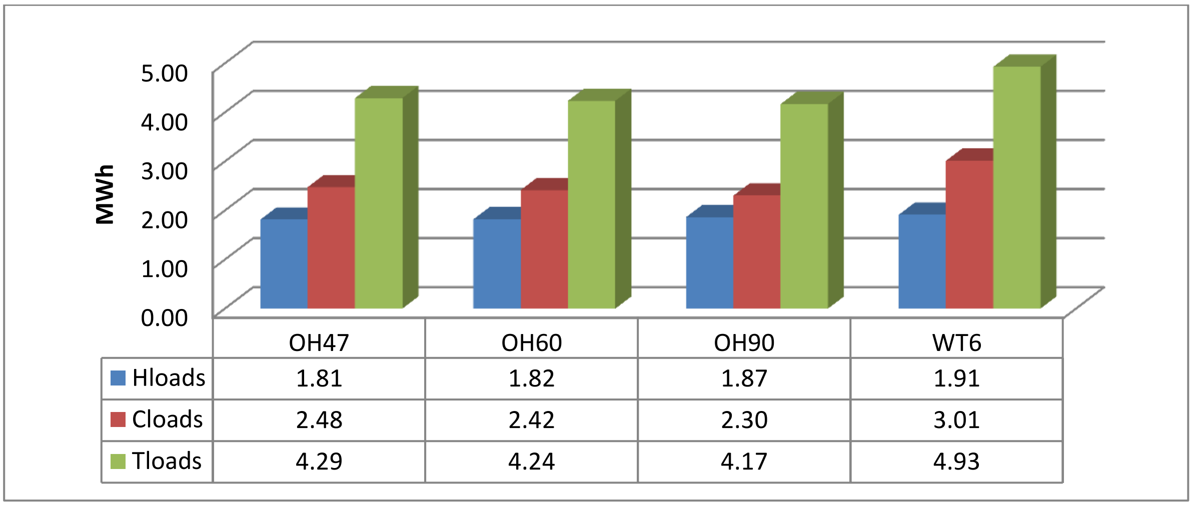
Figure 6.80 – Monthly Thermal Comforts As A Result Of Different Overhang Sizes

6.7.2 Energy Analysis

The results of the sensible loads show (Figure 6.81) that the lowest sensible loads are achieved by OH90 by a total 4.17MWh. This amount has been optimized 15.5% from the base-case. The best cooling loads as expected were achieved by OH90 by 2.30MWh which is an improvement of 23.5%. The best heating was achieved by OH47 with 1.81MWh and is lower than the base-case by 5.2%.

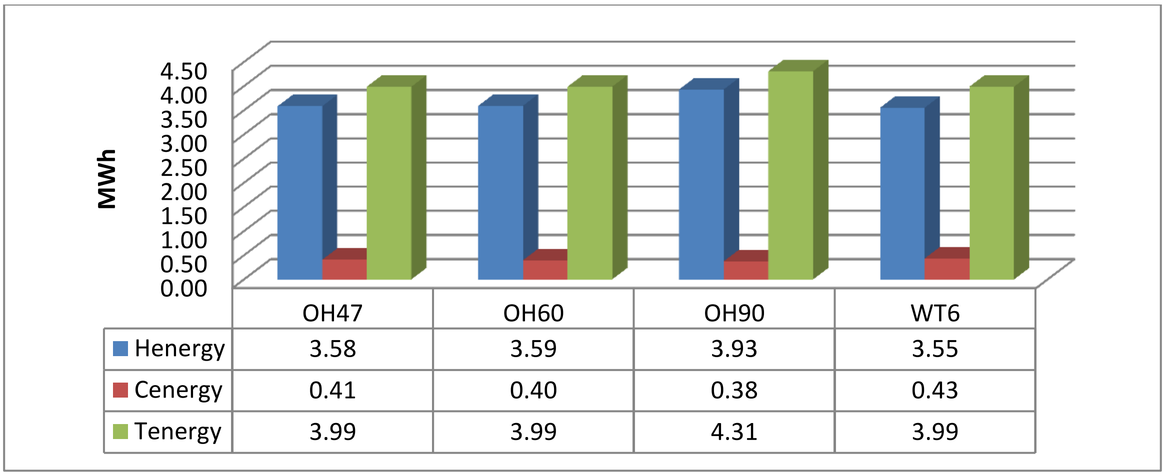
Nevertheless, the next step is to analyse the energy consumption as a result of each case. Surprisingly, the energy analyses show (Figures 6.81 and 6.82) that OH47 and OH60 consume the same total energy of 3.99MWh which is the same as the base-case. OH90 is the only case with different total energy consumption, and consumes the highest energy with 4.31MWh. Although the total energy consumption is the same, the cooling and heating are different as was expected from the sensible loads results.

Consequently, to identify the best case, the primary energy consumption must to be measured.



	OH47	OH60	OH90	WT6
🟦 Hloads	1.81	1.82	1.87	1.91
🟥 Cloads	2.48	2.42	2.30	3.01
🟩 Tloads	4.29	4.24	4.17	4.93

Figure 6.81 – Total Heating and Cooling Sensible Loads As A Result Of Different Overhang Sizes

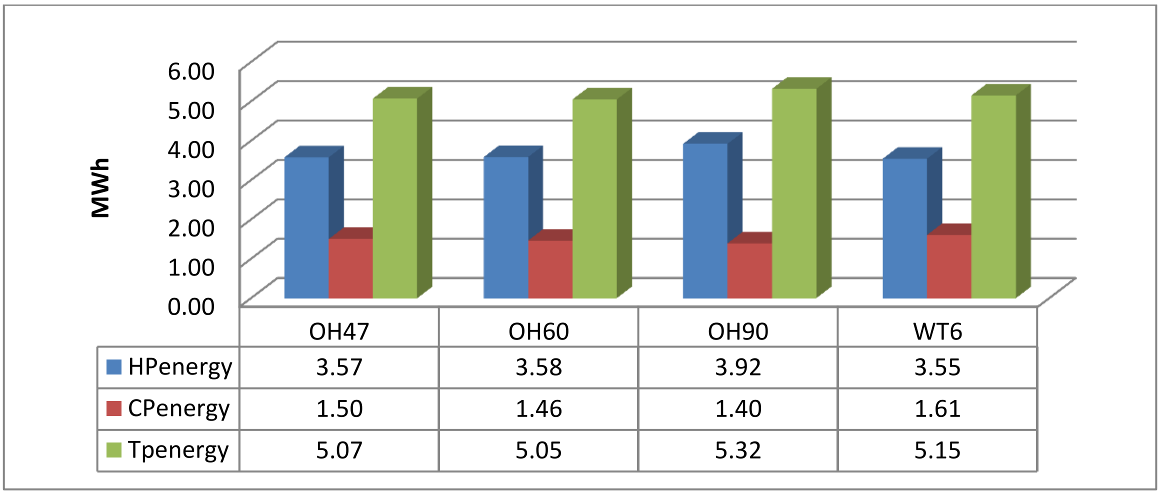


	OH47	OH60	OH90	WT6
🟦 Henergy	3.58	3.59	3.93	3.55
🟥 Cenergy	0.41	0.40	0.38	0.43
🟩 Tenergy	3.99	3.99	4.31	3.99

Figure 6.82 – Total Heating And Cooling Energy Consumption As A Result Of Different Overhang Sizes

The primary energy analysis shows (Figure 6.83) that OH60 achieves the lowest primary energy consumption with 5.05MWh while the highest consumption achieves by OH90 with 5.32MWh. OH60 has the lowest primary energy consumption while neither the cooling nor heating energy are the lowest among the other cases.

Therefore, from the primary energy consumption it can be determined that the best overhang selection to optimize the energy efficiency, with the given details, is OH60. Consequently, the best overhang selection has to be able to block the sun rays of 21st of July. In general theory, the best overhang selection must be designed to block sun rays between 21st of Jun and 21st of August at the highest sun angle.



	OH47	OH60	OH90	WT6
🟦 HPenergy	3.57	3.58	3.92	3.55
🟥 CPenergy	1.50	1.46	1.40	1.61
🟩 Tpenergy	5.07	5.05	5.32	5.15

Figure 6.83 – Total Heating and Cooling Primary Energy Consumption As A Result Of Overhang Sizes

6.8 Other Shading Methods

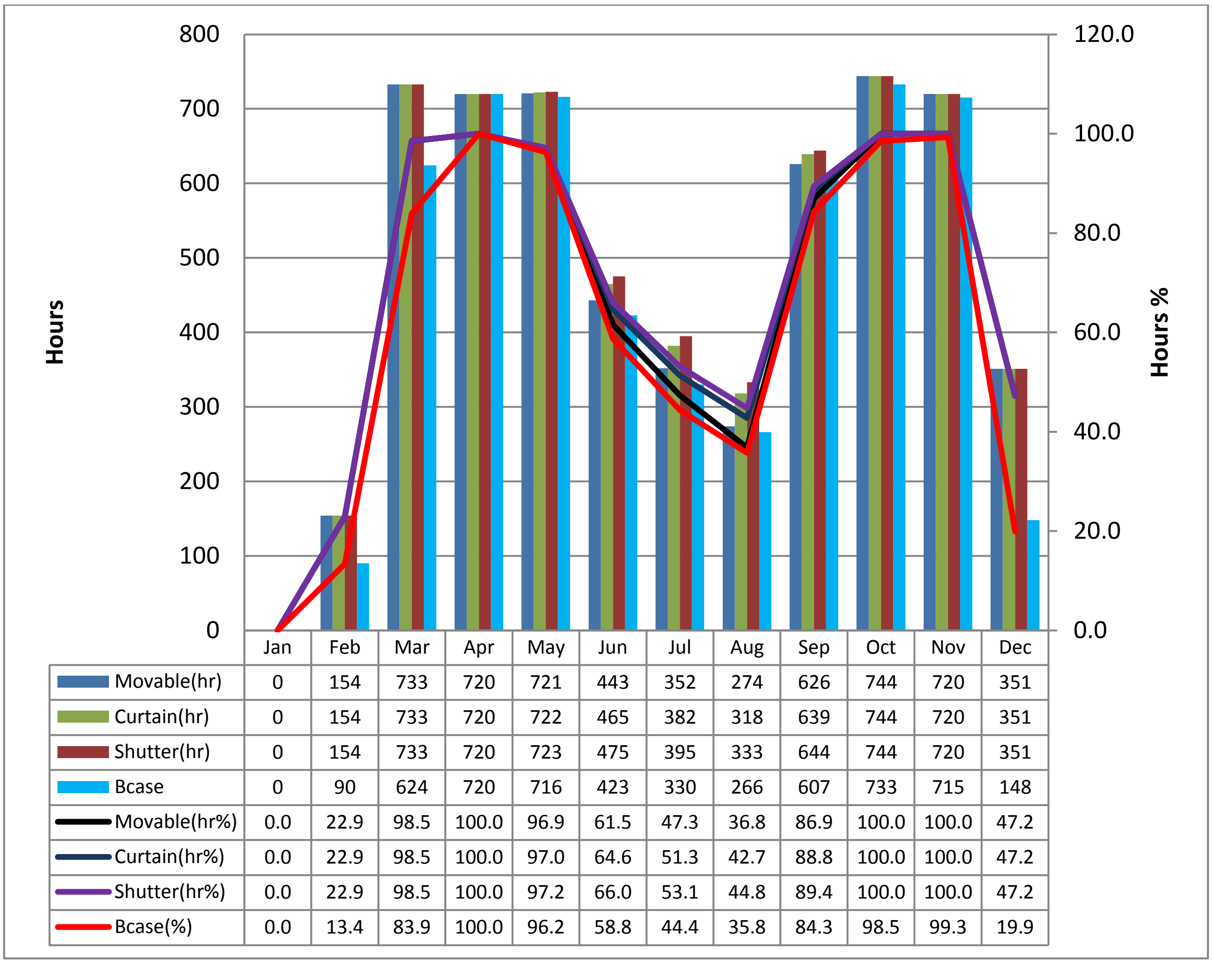
In order to evaluate other shading methods to achieve both total and cooling energy reduction, other methods including movable, internal and external blinds are applied to the existing model. The achieved thermal comforts as a result of these shading solutions are also compared to the base model to evaluate the potential optimizations.

The Figure 6.84 shows that all the shading strategies have a considerable impact on thermal comfort optimization. Due to the character of these strategies, the advantageous winter solar gains are not affected and remains at the same amount of the base-case. Movable shading (OH90) improves the thermal comfort in the summer by achieving 67% thermal comfort over a year.

By applying an internal blind with controllable time that avoids the window opening schedule, a considerable amount of thermal comfort is achieved. The thermal comfort time increases by 110 hours from the movable case and reaches 68% of total thermal comfort.

By applying external blinds, further thermal comfort is achieved. Thermal comfort is improved by further 45 hours and reaches 68.5% thermal comfort duration.

Although the improvement of thermal comfort hours does not result in achieving more free running months, it is expected that they would greatly impact on reducing the cooling energy consumption.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Movable(hr)	0	154	733	720	721	443	352	274	626	744	720	351
Curtain(hr)	0	154	733	720	722	465	382	318	639	744	720	351
Shutter(hr)	0	154	733	720	723	475	395	333	644	744	720	351
Bcase	0	90	624	720	716	423	330	266	607	733	715	148
Movable(hr%)	0.0	22.9	98.5	100.0	96.9	61.5	47.3	36.8	86.9	100.0	100.0	47.2
Curtain(hr%)	0.0	22.9	98.5	100.0	97.0	64.6	51.3	42.7	88.8	100.0	100.0	47.2
Shutter(hr%)	0.0	22.9	98.5	100.0	97.2	66.0	53.1	44.8	89.4	100.0	100.0	47.2
Bcase(%)	0.0	13.4	83.9	100.0	96.2	58.8	44.4	35.8	84.3	98.5	99.3	19.9

Figure 6.84 – Monthly Thermal Comforts As A Result Of Different Shading Methods

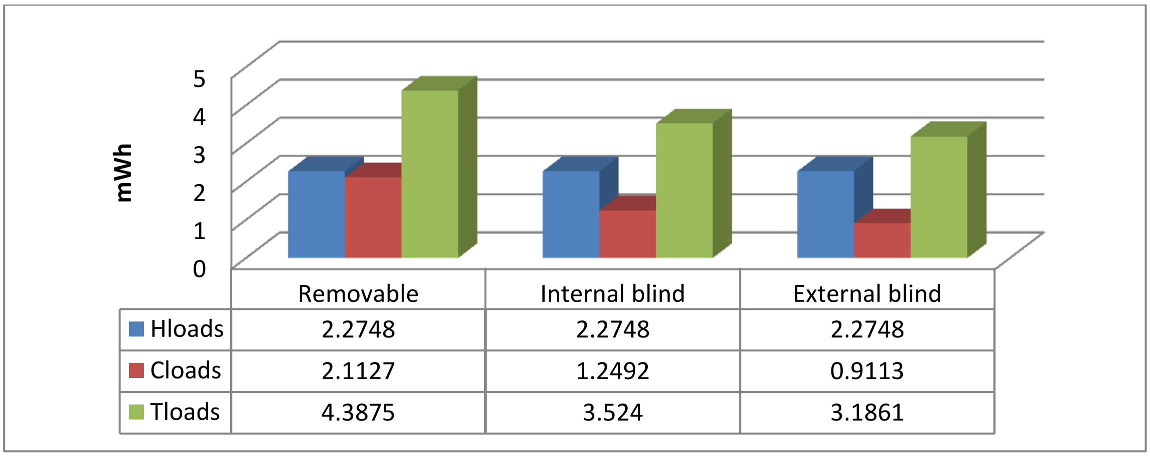
For sensible loads analysis, as shown in Figure 6.85, by applying external blinds the cooling loads decrease from 2.11MWh in the movable case to 911 kWh with external blinds. The total loads as a result of cooling loads decrease by 27% and reaches to the lowest amount of 3.16 MWh.

Having applied the removable overhangs, as shown in Figure 6.86, the total energy consumption decreases further from the fixed overhang types. This can be improved by applying internal blinds and a simple scheduled control. Internal blinds can achieve further

150kWh cooling energy reductions, and is capable of decreasing energy consumption by approximately 3.5% in comparison with the removable overhangs.

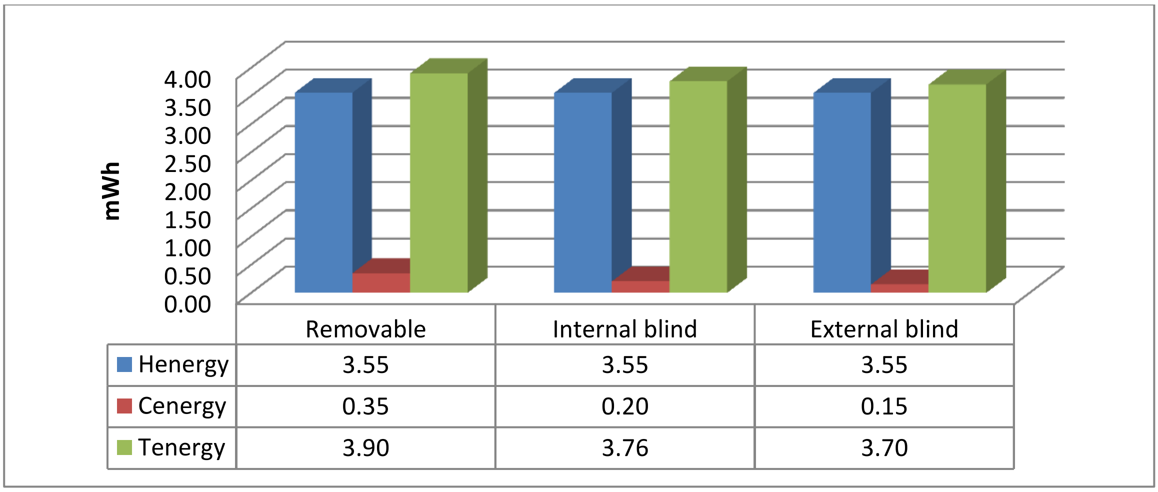
The ultimate energy reduction is achieved when the external blind replaces the internal one, with the specific scheduled control method. In this case, the overall energy consumption decreases by another approximately 2% and reaches 3.7MWh.

Although, the total energy consumption, as a result of different shading methods, improves slightly, the cooling energy consumption is optimized significantly and results in great energy costs reduction and less pressure on power distribution in the country.



	Removable	Internal blind	External blind
🟦 Hloads	2.2748	2.2748	2.2748
🟥 Cloads	2.1127	1.2492	0.9113
🟩 Tloads	4.3875	3.524	3.1861

Figure 6.85 – Total Heating and Cooling Sensible Load in Different Shading Devices



	Removable	Internal blind	External blind
🟦 Henergy	3.55	3.55	3.55
🟥 Cenergy	0.35	0.20	0.15
🟩 Tenergy	3.90	3.76	3.70

Figure 6.86 – Total Heating and Cooling Energy Consumption in Different Shading Device

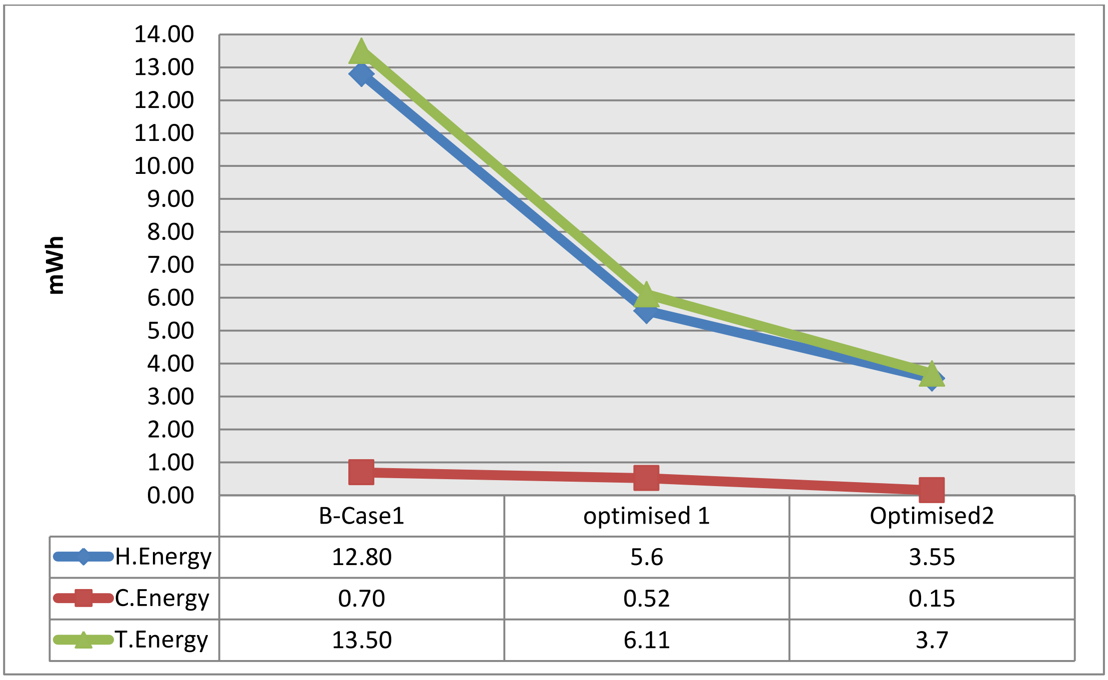
6.9 Summary

As shown below (Figure 6.87), the energy performance during different phases of this research, in the first phase the base-case consumes the highest energy in all types. The Optimized case1, which represents the second phase, has been significantly optimized by 54% in overall energy consumption. The amount of heating energy in this phase reduces in a greater proportion as the applied strategies had a concentration on thermal mass insulation rather than solar control. Therefore, heating energy consumption decreased by 56%, while cooling energy decreased by 25%.

In the third phase (Optimised2), insulation materials added to the wall types improved their heating performance. On the other hand, to improve the cooling performance, solar gain controls were applied to the building openings by different methods.

The results show that by applying both methods the building reacts profoundly to improve the energy efficiency. Therefore, in comparison to the base-case, cooling energy is reduced by 78.5%, and heating energy reduced by 72.3%. This proves that both applied heating and cooling strategies had performed equally to optimize the total energy consumption.

Finally, the base-case total energy consumption reduced from 13.5MWh to 3.7MWh in Optimized case 2. This means a very significant total energy reduction of 72.6%



	B-Case1	optimised 1	Optimised2
H.Energy	12.80	5.6	3.55
C.Energy	0.70	0.52	0.15
T.Energy	13.50	6.11	3.7

Figure 6.87 – Achieved Energy Optimisation from the Base-Case Concept to the Optimised Case in Phase3

Chapter 7 – Discussion (2) and Proposed Guidelines

7.1 Introduction

During the 1970's, new multi residential buildings gradually started to appear in the housing market in Tehran by copying western countries' architecture and engineering. At this time residential constructions were dominated by multi residential building types in Tehran. These buildings usually followed a similar design and elevation of their early generations, although few internal and external design methods have been changed for the last few years. However, these changes barely considered the environmental impact of the building, and energy efficiency is not a considered option.

The energy consumption of these homes is relatively high, mainly due to the abundant sources of fossil fuels, low cost of energy and lack of a comprehensive energy regulatory framework. Although it is not the aim of this research to establish a regulatory framework, it is beneficial to improve the building codes by understanding the impact of the current local building designs and materials on energy consumption. Therefore, according to the findings of the previous chapter, a brief guideline for further energy optimisation through the building envelope in Tehran is presented. For this purpose, in addition to the building fabric and design considerations, the possibility of using the human adoptive temperature for free running building purposes is carefully assessed. Furthermore, the findings of Chapter 6 are used to scale the achieved level of energy efficiency in Tehran against the international and internal (energy label rating) levels.

7.2 Summary of Guidelines for Building Passive Design Elements in Tehran

Energy efficiency in buildings is not a well-documented approach in Iran yet, although patchy research has been done in several studies. The worldwide awareness of the need to address the high level of energy consumption draws attention to the need for sustainable building designs. As mentioned, the only Iranian building codes for building environmental design indicates the climate classification of the country and the required energy saving based on the building type. The building code specifies the material properties for designers to manually calculate heat loss. Building codes are required to clearly address the conventional building elements, and specify the minimum standards. This can potentially be linked with the Iranian building energy label to easily help engineers design low energy buildings. Iran is a country with large climatic differences, and its building code includes values that are adjusted to the local conditions. However, for better regional regulations in Tehran, establishing regional energy efficiency requirements is necessary. In this case, a model building is developed for which values are set for each of the building parameters.

In Chapter 6, following the aim of this study, it was indicated that potentially a large amount of energy can be saved by an appropriate combination of local materials and designs, and by applying the required thermal comfort range for exercising free running building mixed with building active mode when is required, and by applying strategies for heat gain control and thermal insulation. Most of the recommended strategies in this research have minimal cost implication at both design and operation stage and are conventional local materials.

Walls

The simulation results show that wall selection has the most thermal performance effect on buildings among the other building elements. Wall types with lower U-values or higher R-values effectively have better energy performance. The gap between the U-values in conventional walls is considerably high, while by selecting an appropriate wall system a considerable amount of energy saving can be achieved. Although, the low U-value wall system (WT3) with considerable energy efficiency is implemented in Tehran, the wider use of the high U-value wall system (WT1) implies a lack of knowledge or ignorance of designers and engineers in selecting an appropriate wall system.

Shadings

Solar gain control in summer, through an appropriate shading design, can significantly influence the energy saving. However, the design of overhangs is the most challenging part of this research due to their sensitive operation and impact on internal temperatures during summer and winter. Shadings strategies are complicated, as there are requirements to design with respect to the movement of the sun in the sky and it requires three dimensional simulations. As a result of this research, the fixed overhangs in most cases are less energy efficient than the building without overhangs or provide a minor advantage. Conversely, movable overhangs demonstrate high energy efficiency.

Natural Ventilation

It is important to mention that natural ventilation plays a very important role in reducing energy, providing thermal comfort and achieving free running buildings in Tehran. During the hot summer months of Tehran, natural ventilation can perfectly provide the internal thermal comfort, this improves if the evaluated time plan is applied to the building. Shading strategies are complicated, as there must be consideration of the movement of the sun in the sky and this requires three dimensional simulations. The proposed shading types in this research need to be controlled by the occupant directly. For this purpose, the occupants need to be educated and informed how to do this. Thermal comfort, according to the required range, creates free running buildings depending on the building envelope design. Free running building can be achieved up to five months of year (March, April, May, October and November) in optimised cases, while the base case model operates actively over all the months.

Thermal Insulation

The role of insulation materials in walls on energy performance was examined, and despite the low performance of insulated walls in adiabatic conditions in summer, by integration with the use of natural ventilation, its performance considerably increases further. Therefore, insulated walls are required to be designed along with an adequate size of natural ventilation inlet. The disadvantage with the selected insulation is its thickness, which is recommended to be replaced with thinner insulation materials with similar material properties such as ‘vacuum insulation’. In general, thermal insulation in walls significantly avoids heat loss in wintertime through the walls and also contributes to maintain the room cooler for longer durations when the cooling system is operational.

Windows Size and Type

Windows need special attention, beyond the role of insulation they provide daylight and also heat from sunlight. The optimum size of windows in winter and summer are hugely different in Tehran when considering their energy performance. Smaller windows in summer helps reduce solar heat into the building and consequently less cooling is required. However, in winter larger windows contribute to solar heat gain and as result less heating is required. In light of the mentioned situation, it is noted that the lowest total energy consuming window needs to be selected in which the window sizes are designed for higher daylight factors have an overall better performance than the other window sizes. It worth mentioning that if the energy cost reduction is the purpose of the design, then with respect to the electricity and gas prices, the size of windows can be changed. Both the double and triple glazing windows with argon gas filling significantly contribute to energy efficiency, although the Iranian manufactured windows have high U-values compared to the available windows in developed countries.

Use of Simulation Software

Energy simulation tools can help the building designers to design a more energy efficient building that is very close to the building energy performance in reality. The simulation models give more flexibility and freedom than the prospective models to designers.

7.3 Summary of Potential Energy Achievement in Tehran

Figure 7.1 shows the total annual heating and cooling energy consumption for the actual and its simulated model, and the new base-case (after temperature set point change) and the achieved optimised cases. As mentioned earlier, the actual energy bills are selected for validation purposes, however, as Iranian building codes require temperature set points of 20^{o}C in winter and 28^{o}C in summer, for the new base-case this temperature set point is used to re-simulate the actual bills model. The optimised cases need to be compared with this new base-case rather than the case with actual energy bills.

Consequently, the optimised case 1, the integrated model of the best building fabric and appropriate free buildings months, approximately reduces the total energy by 52.6%, heating energy by 56% and cooling energy by 25.8%. This reduction improves further by considering the optimised case 2 which is based on a combination of optimised case 1 and suggested solutions for solar heat gain controls, e.g. shading devices, and thermal insulation. In this case, the total annual energy reduces by 73%, heating energy by 72% and cooling by 78.5% respectively.

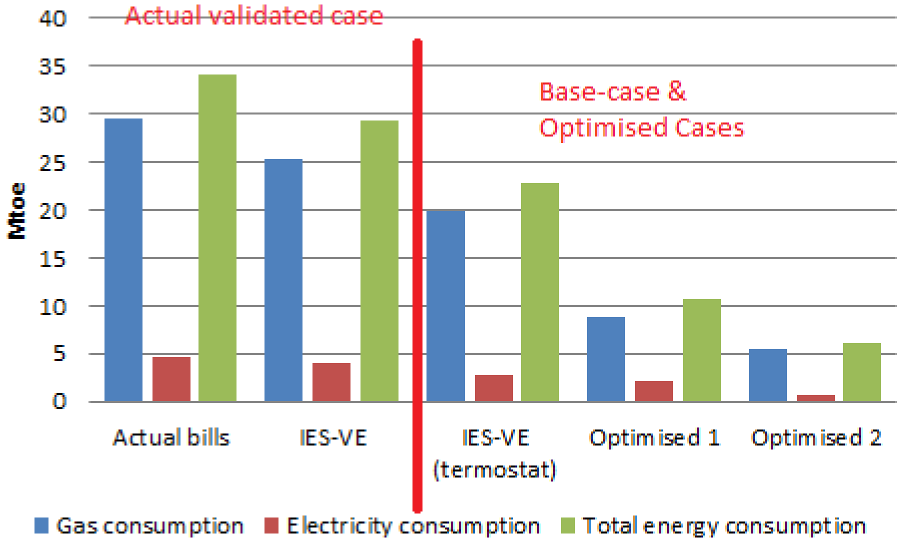


Figure 7.1 – Annual Total Heating and Cooling Energy Consumption in Different Cases

7.4 International Low Energy Houses in Comparison With the Achieved Optimized Cases in Tehran

In this section, the scale of energy consumption based on kWh/m^{2}a for the base-case, optimized case 1 and optimized case 2 is presented and is compared with some European standards. As there are not any standards or definitions to specify a certain level of energy consumption in the region (in the Middle East), the nominated European countries were selected for comparison. Therefore Figure 7.3 presents a comparison between the levels of energy consumption for the different cases in this study with the European standard.

As shown in Figure 7.3, the base-case building in Tehran indicates a high level of energy consumption in comparison with the mentioned European standards. However, the other optimized cases show very low energy consumption within the European standards. The case optimised1 achieves lower energy consumption than The German Passivhaus and the Czech low energy home. Additionally, the case optimised2 can achieve lower energy consumption than all the standards except the very low energy house in the Czech Republic. Although, in comparison with the European standards the findings of this research demonstrate significant energy efficiency achievements, the mentioned standards in Europe are basic requirements, and further advanced standards aim at achieving near zero or zero energy consumption, of which some are already in place and some are to be compulsory in near future.

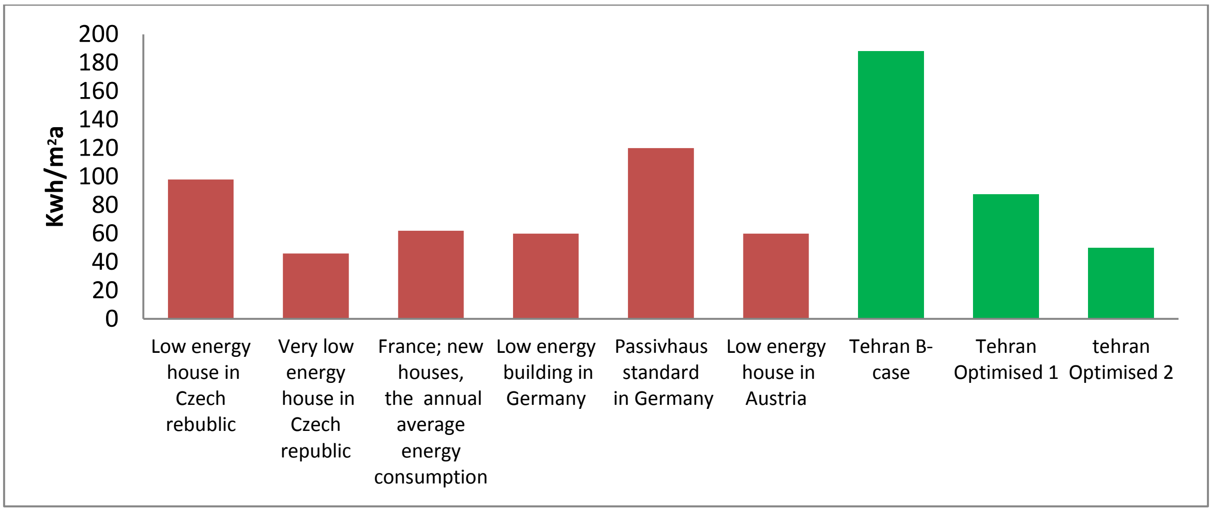


Figure 7.2 – Total Annual Energy Consumptions in Tehran in Different Cases In Comparison With European Standards

7.5 Thermal Comfort Consideration

In order to achieve thermal comfort in Tehran, with hot summers and cold winters, heating and cooling systems are required. In Iran, on average 75% of total gas energy is consumed for heating and 30% of electricity for cooling the internal spaces. All the energy efficiency strategies aim to reduce the energy consumption while providing the required satisfactory indoor temperature for the occupants. In order to reduce the cooling and heating system operation time and provide thermal comfort, several strategies including passive design have been introduced.

For the selected base-case in this research, cooling and heating systems are unavoidable solutions to provide the required thermal comfort. As a part of this research, it is desirable to minimize energy consumption while also providing a reasonable level of thermal comfort. The results of this research, based on the simulations, indicate that this aim has been achieved.

The appropriate selection of building materials and design reduces the need of mechanical heating cooling in five months of year in Tehran. Although these months are not the months with the most severe temperatures, the energy reduction as a result of free running building in the context of each calendar month is reduced by approximately 10%. Surprisingly, adding any types of shading will not contribute to further free running building achievement in optimized case 2. This is due to the summer high temperature and winter low temperature in which shading strategies can achieve significant energy reduction but fail to achieve a whole month free running building. Likewise, in winter, thermal insulation reduces the required heating energy but fails to achieve further free running building requirements.

In summary, based on the human adaptive temperature recommended for Tehran, the human body can tolerate a wider temperature range than the mechanical heating and cooling set points. The acceptable temperatures are calculated by the following equation: ($T_{comf} = 17.8 + 0.31 * T_{out}$) provided that $5 < T_{out} < 30$ and within an acceptable range of -+3.5oC or -+2.5oC. Therefore, although the conditioning temperature set point is between 20°C and 28°C, in many months in both summer and winter the internal temperatures are out of the conditioning temperature range but within the human adaptive temperature range. If the internal temperature remains within the adaptive temperature for more than 95% of the whole month then the free running month concept has been met.

7.6 Iranian Energy Label

The Iranian Energy Conservation Organization introduced the building energy label in 2012 (Ministry of Housing and Transport, 2012). This label is not compulsory for buildings and is regarded as a guideline to audit the required energy in a building. The energy label calculation is based on the regional climate, occupancy type and size category. In order to calculate the building required energy, the primary energy needs to be considered by applying the following equation:

$$Eactual = \frac{\sum i(QFi \times (HVi \times 0.278) + QE \times FC}{AF}$$

Where;

- E*actual: Is the annual building energy consumption over the building floor area (Kwh/m^2.year)*
- QFi: *Total natural gas consumption*
- HVi: *Coefficient used for Primary energy (Nm^3): natural gas: 37.68*
- QE: *Total electricity consumption*
- FC: *Coefficient used for primary energy; Electricity: 3.7*
- AF: *Total floor area (m^2)*

Buildings based on their energy consumption are classified and rated according to Table 7.1.

Table 7.1 – Iranian Residential Energy Rate Calculation Guide (Ministry Of Housing And Transport, 2012)

Energy rate	**Residential < 1000m^2**
A	$R < 1$
B	$1.0 \leq R < 1.9$
C	$1.9 \leq R < 2.7$
D	$2.7 \leq R < 3.4$
E	$3.4 \leq R < 4.0$
F	$4.0 \leq R < 4.5$
G	$4.5 \leq R < 5.0$
Not qualified for a label	$5.0 \leq R$

To identify the building energy rate (R) the actual energy consumption based on its primary energy is derived on the ideal energy consumption as shown in the below equation:

$$R = \frac{E_{act}}{E_{ideal}}$$

Where;

- E*act: Primary energy consumption*
- E*ideal: Ideal energy consumption based on the climate classification, For Tehran: 83*

After the simulation analysis, the base-case and optimized cases are evaluated to identify their energy label rating according to the suggested Iranian rating procedure. For this purpose, the estimated total energy consumption in each case has been determined, and in order to be as close as the actual energy consumption, the differences between the actual energy consumption and the IES-VE simulation are applied to the final calculations. These differences were determined earlier during the simulation tool validation.

As shown in Table 7.2, the base-case in reality has a very low energy rate (F), however by considering the conditioning set points of 20^{o}C to 28^{o}C by using thermostats, the energy rating improves to a more reasonable rate (D). The optimized1 case indicates a great energy efficiency level at a rate (B) which is considered a green building by the Iranian code. The optimized2 case demonstrates the best energy efficiency rate (A), confirming that the highest required energy efficiency in the country can be reached by applying the methods proposed in this research.

Table 7.2 – The Achieved Energy Rate in Different Cases

Building Case	Annual total final Energy consumption (Kwh)	Classification rate (R)	Label rate
Actual energy bills	39369	4.2	**F**
Base-case (IES-VE)	29400	3.2	**D**
Optimised1	15870	1.7	**B**
Optimised2	7518	0.8	**A**

According to the results of this research, both the cooling and heating energy efficiency is significantly improved in both optimized cases. All the building envelope parameters can reach the required minimum U-values in developing countries, and this is expected with the roof U-value that as in the base case study, is an intermediate apartment unit, therefore the U-value of the roof is kept at constant level. Table 7.3 compares building envelope parameters and the related U-values. It can be noted that there is a big gap between the levels of U-values in the base-case and the developed countries, however, the U-value for the optimized cases reach close to the developed countries.

Table 7.3 –Comparison of U-Value Requirements In Developed Countries With The Research Cases

	External walls W/m^2K	Window W/m^2K	Roof W/m^2K
Base-case	1.34	3.18	0.79
Optimised1	0.62	1.85	0.79
Optimised2	0.36	1.85	0.79
UK (part L)	0.3-0.35	1.8-2.2	0.16-0.25
Germany (EnEV)	<0.35	<1.7	<0.25
Canada (MNEBC)	<0.37	1.4-2.7	0.14-0.29

7.7 Use of Simulation Software at the Design Stage

To successfully predict and manage energy consumption and conservation, it is necessary to take advantage of simulation tools. Simulation software is able to predict and analyses the level of energy consumption and also the efficiency of the desirable design and present a comprehensive report of the energy performance of the building. Currently, several simulation tools are available to designers for modelling and analysis, for example, IES-VE, Energy Plus, Design builder and others. Designers can receive a great deal of support through these tools at the design stage to predict the building energy demand and energy consumption. Furthermore, designers can have the flexibility to change and modify their design based on their energy consumption target, client's requirements and the availability of materials. The simulation tools can also be employed by governmental organizations to approve building licenses based on the predicted energy consumption as reported by simulation tools.

7.8 Summary

This chapter presented a guideline for low energy buildings in Tehran and assessed the optimized cases in Tehran against the country's recommended energy label for residential buildings, and international standards in developed countries. The optimized cases are perfectly placed within the developed countries energy efficiency requirements. The optimised1 case performs better than the well-known German Passivhaus, and the optimised2 case has a better performance than most of the given strategies. With regards to the Iranian residential energy label, while the base-case rated at a very low level (D), the optimized1 case achieved level (B) and optimized2 case reached the best performance rate (A).

Chapter 8 – Conclusion and Recommendations

8.1 Introduction

The main aim of this research was to evaluate the energy performance of low energy housing in multi residential buildings in Tehran that meet the existing current construction codes and available building designs and fabric. Five research questions were presented in Chapter 1, each question was designed to help the researcher address the research objectives.

This chapter presents the findings of this study and sets out the answers to the research questions. In addition, this chapter presents the conclusions achieved during this study, and demonstrates the outcome and contribution to the body of knowledge. A summary of limitations that the researcher faced during the research process is also presented and a list of guidelines and recommendations for the building designers and developers are also offered for further energy efficiency consideration in Tehran.

8.2 Research Conclusions

It is very important to state that this research successfully accomplished the proposed aims for this research. As mentioned, this research mainly aimed at evaluating the energy performance of low energy housing in multi residential buildings in Tehran, taking into consideration the local climate, local construction practices, and occupants' behaviour profile. Chapter Five demonstrated the above parameters by considering different sources to reach the most reliable data in Tehran and the wider country context. In Chapter Six the role of individual materials and design in energy efficiency, and achieving thermal comfort in Tehran residential buildings were determined. The optimised case was established as a result of the selection of the most efficient materials. Furthermore, for further energy efficiency and thermal comfort, methods for controlling solar gains and the effects of thermal insulation were examined. In Chapter Seven, a comparison between the achieved optimised cases and available low energy definitions in developed countries was made in order to evaluate the position of low energy buildings in Tehran against International codes. This research determined the level of energy rating according to the Iranian building energy label, by using various building parameters at the domestic scale.

8.3 Answers to Research Questions

Research Question 1

1. What is the approximate baseline energy consumption for new multi residential buildings in Tehran?

In Chapter 6 the heating and cooling baseline energy for the selected base cases (4 cases) were calculated, based on actual energy bills. The actual energy bills showed that the average total energy consumption in these cases is 256.5kWh/m^{2}a. This level of energy was used to determine the approximate heating and cooling energy consumption when considering the national statistic for the proportion of heating and cooling energy to the total energy consumption. It was assumed that the baseline cooling and heating energy in multi residential buildings in Tehran is approximately 182.5kWh/m^{2}a, which compares to favourably to 188kWh/m^{2}a in the selected base case (reference case). However, as mentioned in the research question, the baseline energy consumption for a new building needed to be identified, therefore the IES-VE simulation tool was employed to calculate this approximate baseline energy consumption. Following this, the heating and cooling consumption was converted to total annual energy consumption (kwh/m^{2}a) in Chapter 7 in order to present the baseline of total energy consumption in the base case for new buildings. As a result, the base-case total energy consumption for new buildings was estimated to be approximately 188kwh/m^{2}a.

Research Question 2

2. How much would the energy efficiency be improved by considering different types of individual building elements from the individual selection of building elements in Tehran?

In Chapter 5, the relevant available and applicable building elements in the local context were presented. The influence of each parameter on thermal comfort and energy efficiency were analysed and compared with the base case. This analysis identified the level of efficiency achieved by each parameter. As identified in the second phase, wall types were the most effective parameters in terms of both the thermal comfort and energy efficiency. However, it was noticed that the use of natural ventilation not only optimises the thermal comfort performance, it improved the energy efficiency level of the walls in the warmer months when high thermal mass walls were replaced to a lower thermal mass walls with lower U-values. In other words, efficiency levels of the wall types are dependent on the natural ventilation, therefore, WT3 had the best cooling performance when the natural ventilation is in operation. On the other hand, WT1 has a better cooling performance without operational natural ventilation. However, the amount of annual total energy consumption determined the best performance case, which is WT3 in this case.

In terms of window size performance, it was noticed that while larger windows contributed to better thermal comfort performance in both winter and summer, the total energy consumption was not in line with this process. This means that middle size windows based on middle rate of daily factor are most suitable for use in Tehran. Therefore, for the mixed building design or active design, use of middle rate daily factors is recommended. For window types, all the existing window types had relatively high thermal U-values, and all had a small effect for both energy efficiency and thermal comfort. Although the double glazed windows with Argon filling had better performance during the free running evaluation, triple glazed windows were more effective when the conditioning system is active. This means that in order to avoid overheating, it was best practice to use middle U-value window types.

Natural ventilation was the back bone of achieving thermal comfort in the warmer months in Tehran and avoided the unnecessary use of the heating system in both free running building mode and night ventilation plan from 24:00 AM – 8:00 AM.

Research Question 3

3. How much energy efficiency will potentially be achieved by implementing the local current practices as a mixed method of ‘passive and active design’ in Tehran?

In Chapter 6 it was proved that by considering the climate conditions of Tehran and the local construction and design availabilities, a less ambitious passive design in Tehran could be expected. However, by considering both the potential active and passive design, a mixed method to optimise the level of energy consumption in the base-case was evaluated. In order to evaluate a mixed building that was combined with free running building and active building modes, the best free running case that had been identified in the earlier sections was examined in a mixed form. For this purpose, all the regular settings that had been applied in energy analysis were applied to the best free running building case. It was noticed that that mixed case, despite the de-active heating and cooling systems over four months, consumed higher energy by 7.9%. In addition, the energy consumption increased in both the cooling and heating by 7.0 % and 8.0 % respectively. As a result, it was concluded that the best free running building parameters were not the best energy efficient solution for a mixed building. Therefore, the optimized case, without considering the free running months, still performed more efficiently. Nevertheless, to take advantage of the free running building mode, the optimized case (active case) was considered and measured as a free running building. The results showed that the parameters in this case performed just slightly less efficiently than the previous free running case to provide thermal comfort due to negligible differences in both cases. Consequently, the optimized case was evaluated by de-activating the cooling and heating system in April, May, October and November. The result showed that the new mixed case consumed the lowest energy by 6.11MWh and 7.14% lower than the optimized active case and approximately 55% less than the base-case. The heating energy also decreased by 6.6% and 56% respectively. The cooling energy had the lowest trend line as it decreased by 10.3% from the optimized active case to the mixed case and over 25% from the base-case. The above results showed that the lowest energy optimization achieved 10.3% for cooling energy from the mixed case to the base-case, while corresponding energy optimization for heating energy is 56%. This emphasizes that the conventional building parameters and strategies have a greater impact on avoiding heat losses, and less on solar heat gain control.

Research Question 4

4. By analysing the local construction practices and available local passive design elements in Tehran, which current practices will improve energy efficiency in Tehran?

This questioned was answered in Chapter 6 Phase 3. The selected elements to optimise energy consumption and achieve further free running building were; a) Polystyrenes as thermal insulation in the walls, and b) Shading devices to control solar heat gains in summer. These parameters were added to the building in the IES-VE simulation tool. The base case for this analysis was the previous optimised case. The most challenging part of this section was the selection of shading devices as fixed overhangs affected the building energy consumption oppositely in summer and winter. It was noticed that using fixed overhangs in Tehran wasn't an appropriate method to be practiced. Therefore, the concept of movable overhangs was examined along with other internal and external shading methods. All these methods showed a positive effect on energy optimisation and thermal comfort. The analysis showed that by applying both methods, the building reacted profoundly to improving energy efficiency. Therefore, in comparison to the base-case, cooling energy reduced by 78.5%, and heating energy reduced by 72.3%. This proved that both applied heating and cooling strategies had performed in an equal level to optimize the total energy consumption. Finally, the base-case total energy consumption reduced from 13.5MWh to 3.7MWh in Optimized case 2. This results in a very significant total energy reduction of 72.6% from the concept base case in phase 1 to the optimised case 2.

Research Question 5

5. What level of the Iranian building energy label and other international definition in developed countries can be achieved by the optimised cases in this research?

This was addressed in Chapter 7. To scale the level of energy consumption in residential buildings in Tehran against the international low energy buildings standards, the amount of energy consumption in the optimised cases were calibrated to the total energy consumption. It was assumed that multi residential buildings in Tehran, based on the concept base case, consumed 188kWh/m^{2}a which is far higher than the all the selected European standards. The most prominent voluntary standards in Germany required 36% less energy than the base case of this study. However, the optimized cases demonstrated very promising results, with the optimised case1 below the German Passivhaus and Czech low energy building standards with an approximate total energy consumption of 87.5kWh/m^{2}a. The optimised2 case achieved an even lower energy consumption than most of the low energy standards, except the 'Very low energy building standard of Czech' by 10% difference with approximately 50kWh/m^{2}a. This result indicated that Tehran multi residential buildings were capable of achieving global low energy building rates by optimising the current local building elements.

In the domestic context, as addressed in Chapter 7, the current Tehran residential buildings, based on the actual energy bill, rated F in the Iranian residential energy label. However, this rate in base-case concept was D, and when considering the optimised1 case this reached a rate B. Furthermore, the optimised2 case could achieve the most desirable rate of an A label. Consequently, it was possible to achieve the best required energy consumption rate in the residential buildings in the country by applying this research method.

8.4 Research Limitations

A summary of limitations that the author faced during this research are described here.

Limitation One

The primary difficulty was selecting building cases that the author could have access to the both construction details (drawings) and the building energy performance (energy bills). The researcher had reasonable access to multi residential buildings and their construction details as they were available from different sources, however, it was very difficult to have access to their energy bills as the residential buildings were already sold. Conversely, the author had an abundant access to the energy bills for different cases but without access to their construction details. As a result, there were only a few cases available to author to meet the requirement for this research.

Limitation Two

As the occupant’s behaviour profile was unknown, it was a great challenge for the researcher to select accurate data that reflected the required settings for the simulation tool. For this purpose, the researcher studied the national census and statistics from which to draw approximate and average occupant behaviour. Among the behaviour profile parameters some were not possible to be understood from the mentioned source, therefore by assuming their influence on building energy, the relevant experience of the researcher was applied to the settings.

Limitation Three

The accurate infiltration rate of the building is a very important technical aspect of energy modelling in buildings. Due to technical limitations, there was no information on the building infiltration rate, and it was impossible to find an analytical solution to determine the infiltration rate of the building. Therefore, the author applied the average infiltration rate that was examined in other studies and kept it as a constant rate throughout the research. The other technical problem was with the variation of manufacturers' data sheet for the material properties for the same building materials. Therefore, as it was unknown which manufacturers supplied the building materials for the selected building cases, to solve this problem the Iranian standard organisation data for these materials were used in this study. Furthermore, it was unknown to the author if all the construction details in the drawings were met during construction phase as it is sometimes common that developers replace other building elements to those specified in the drawings.

8.5 Research Recommendations

This research proposes a set of guidelines for selecting the most appropriate building design and fabric to achieve a passive design that contributes to higher energy efficiency in multi residential buildings in semi-arid climates of Tehran. In general, it is worth expressing a set of recommendations for achieving low energy buildings in the high energy consuming context of Tehran. However, to achieve the above goal, a variety of professional groups in the construction sector, including researchers, engineers, policy makers, developers, end users and all stakeholders need to be aware of the importance of energy saving, and of course be informed of the most appropriate methods and strategies that have been already evaluated or examined. The following technical recommendations are applicable if building passive designs are considered to achieve free running building mode and night ventilation.

8.5.1 Technical Recommendations for Engineers and Designers

- It is important that building designers consider energy efficiency in their design concept. By considering sustainable design methods at the design stage a great level of energy saving can be achieved during the operation stage.
- Learning and using building environmental simulation tools during the design stage can help the designers have a general overview of the level of the energy efficiency in their design.
- Use of high thermal insulation materials with high R-values (high resistance) to avoid external heat into the buildings through walls and roofs in summer, while avoiding heat escape from the internal space in winter.
- Design medium and large size windows by considering the daylight factors, the larger windows are more efficient when they are incorporated with larger openable size in summer, and larger windows in winter accept more solar heat that contributes to space heating.

- Use of double and triple glazing windows with overall low U-value as an appropriate method to avoid heat escaping to the outdoor during winter and avoiding direct solar gain into internal space.
- Avoid the use of fixed overhangs, as the overall energy efficiency is either negligible or in some cases inefficient. Movable overhangs greatly contribute to energy saving with larger depth size.
- Use of internal and external blinds is helpful, although the daylighting might be compromised in this case.
- To avoid unwanted insulated walls, other insulation materials with similar efficiency specification but less thickness can be used.
- Use of more efficient central heating systems contribute to lower heating energy consumption as the average efficiency for current systems in Iran are currently about 50%.
- Use of thermostats or any other temperature controlling methods to set the temperature at the desired level and increase energy savings.

8.5.2 Recommendations for Public Awareness and End Users

- Considering the advantage of 'full day natural ventilation' during the end of spring and the beginning of autumn, and night ventilation in summer from the late in the evening until the morning.
- Use of warmer clothes during the night and sleeping time.
- Use of temperature set points at all conditioning times, applying the setting temperatures of 20°C during winter time and 28°C in summer time.
- Avoid keeping the conditioning system active in unoccupied spaces during the day or night.
- Appropriate control of shadings when required, avoid blocking solar heat gains by inappropriate use of shading during day and natural ventilation in warmer days.
- Understanding the significant financial benefits of the energy efficiency methods and the reducing the costs of energy bills.

8.5.3 Recommendations for Policy Makers and Relevant Regulatory Bodies

- The Iranian building code chapter 19 needs to be modified and the importance of passive design, natural ventilation and mixed running buildings should be considered in the building code.
- The current building design approval system doesn’t include the energy efficiency requirements for buildings, this need to be revised.
- There are financial incentives in the context of low interest loans for building renovations, incentives as such can also be allocated for retrofitting as well.
- Standards for building main elements e.g. blocks, windows need to be established (i.e. specific range of material properties).
- The Iranian energy label needs to become compulsory for new buildings in the near future, and the implementation of the requirement needs to be controlled in different phases.

8.6 Further Studies

From this research, the offered guidelines and recommendations are concentrated on existing local building elements and their influence on energy efficiency in Tehran. For this purpose, the selected parameters are limited to the conventional elements, as a result the following studies can take place in future for further energy efficiency achievement through passive design strategies.

- Considering the passive design in other regions with similar climate conditions and examining the workability and performance within the Iranian climate and building regulations. Further, for further efficiency achievement the current building codes and regulations can be studied for further amendments. It was proved that the current building elements and the viable design changes can achieve about 10% energy reduction by performing as a free running building. Therefore, there is potentially still more room for improvement with regard to achieving passive design.
- Due to the limitations in changing the shape and orientation of buildings, these two important factors of passive design were not considered in this research. However, for future studies for new urban design, these factors can and should be considered along with the other passive design parameters.

- It was noted that due to the special climate of Tehran, with hot summers and cold winters and pleasant weather during spring and autumn, while a building element may perform efficiently in one season, its performance adversely impacts efficiency in other seasons. Therefore, in this case, the designer must always consider and balance the energy performance of the building. In light of the mentioned situation, it is beneficial to consider examining building elements that are able to perform efficiently in different conditions i.e. phase change materials, walls and low e windows (glass).
- In many developed countries it is common practice to use renewable energies and onsite energy generation in residential buildings. However, this is not common practice in Iran due to economic and technical reasons, therefore further studies need to be conducted to evaluate the role of renewables along with other passive design strategies in saving energy and providing further thermal comfort in buildings in Tehran.

References

AHSAN, T. (2009). Passive design features for energy-efficient residential buildings in tropical climates: the context of Dhaka, Bangladesh.
AKBARI, H., BERHE, A. A., et al. (2005). Aging and weathering of cool roofing membranes. *Lawrence Berkeley National Laboratory*.
ALANZI, A., et al. (2009). "Impact of building shape on thermal performance of office buildings in Kuwait." Energy Conversion and Management 50(3): 822-828.
ALDOSSARY, N (2015). Domestic sustainable and low energy design in hot climatic regions. (PhD thesis), University of Cardiff, Cardiff, Retrieved from http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.637158
AL-HOMOUD, M. S. (2004). The effectiveness of thermal insulation in different types of buildings in hot climates. *Journal of Thermal Envelope and Building Science,* 27**,** 235-247.
ANDREW, D. P. S., PEDERSEN, P. M., et al. (2011). *Research Methods and Design in Sport Management*, Human Kinetics.
ARUP/BILL DUNSTER ARCHITECTS (2011), UK Housing and Climate Change Heavyweight versus Lightweight Construction, Arup Research + Development, Bill Dunster Architects, UK, 2004.
ASHRAE. (1993). American Society of Heating, Refrigerating and Air Conditioning Engineers Handbook of fundamentals, Residential Cooling and Heating Calculations (SI Edition ed.).
ASKAR, H., PROBERT, S., et al. 2001. Windows for buildings in hot arid countries. *Applied Energy,* 70**,** 77-101.
ASIMAKOPOULOS, D. AND M. SANTAMOURIS (2013). Passive Cooling of Buildings, Taylor & Francis.
ASTE, N., ADHIKARI, R., et al. 2010. Beyond the EPBD: the low energy residential settlement Borgo Solare. *Applied Energy,* 87**,** 629-642.
ASTE, N., ANGELOTTI, A., et al. (2009). The influence of the external walls thermal inertia on the energy performance of well insulated buildings. *Energy and Buildings,* 41**,** 1181-1187.
AZO. (2010). Determining Thermal Comfort Using a Humidity and Temperature Sensor, Retrieved 05 May, (2015) from https://www.azosensors.com/article.aspx?ArticleID=487
BAHAJ, A. S., JAMES, P. A., et al. (2008). Potential of emerging glazing technologies for highly glazed buildings in hot arid climates. *Energy and Buildings,* 40**,** 720-731.
BAINBRIDGE, D. & HAGGARD, K.(2011). *Passive Solar Architecture: Heating, Cooling, Ventilation, Daylighting and More Using Natural Flows*, Chelsea Green Publishing.
BAKER, N. V., et al. (2015). Daylighting in Architecture: A European Reference Book, Taylor & Francis.
BEKTAS EKICI, B. AND U. T. AKSOY (2011). "Prediction of building energy needs in early stage of design by using ANFIS." Expert Systems with Applications 38(5): 5352-5358.
BATES, A. J., SADLER, J. P., et al. (2013). Vegetation development over four years on two green roofs in the UK. *Urban forestry & urban greening,* 12**,** 98-108.
BAKER, N. V., et al. (2015). Daylighting in Architecture: A European Reference Book, Taylor & Francis.
BENNETTS, H., et al. (2003). Understanding Sustainable Architecture, Taylor & Francis.
BERARDI, U., GHAFFARIANHOSEINI, A., et al. (2014). State-of-the-art analysis of the environmental benefits of green roofs. *Applied Energy,* 115**,** 411-428.
BESSOUDO, M., TZEMPELIKOS, A., et al. (2010). Indoor thermal environmental conditions near glazed facades with shading devices – Part I: Experiments and building thermal model. *Building and Environment*, 45**,** 2506-2516
BISHOYI, D. AND K. SUDHAKAR (2017). "Experimental performance of a direct evaporative cooler in composite climate of India." Energy and Buildings 153(Supplement C): 190-200..
BLAIKIE, N. 2009. *Designing Social Research*, Wiley.

BLAXTER, L., HUGHES, C., et al. 2010. *How To Research*, McGraw-Hill Education.

BODART, M. & EVRARD, A. 2011. *Architecture & Sustainable Development (vol.1): 27th International Conference on Passive and Low Energy Architecture*, Presses universitaires de Louvain.

BOJIC, M., YIK, F., et al. 2002. Thermal insulation of cooled spaces in high rise residential buildings in Hong Kong. *Energy conversion and management,* 43**,** 165-183.

BOLATTÜRK, A. 2006. Determination of optimum insulation thickness for building walls with respect to various fuels and climate zones in Turkey. *Applied thermal engineering,* 26**,** 1301-1309.

BRAGER, G. AND L. BAKER (2009). "Occupant satisfaction in mixed-mode buildings." Building Research & Information 37(4): 369-380.

BRITAIN, G. "Low-energy buildings in Europe."

BRE GUIDANCE DOCUMENTS. (2016). Overheating in dwelling guidance document, Retrieved 10 February, 2017 from https://www.bre.co.uk/filelibrary/Briefing%20papers/116885-Overheating-Guidance-v3.pdf

BRYMAN, A., BRYMAN, P. O. S. R. A., et al. 2002. *Quantitative Data Analysis with SPSS Release 8 for Windows: A Guide for Social Scientists*, Taylor & Francis.

BYRNE, A., BYRNE, G., et al. 2013. Transient and quasi-steady thermal behaviour of a building envelope due to retrofitted cavity wall and ceiling insulation. *Energy and Buildings,* 61**,** 356-365.

CANTIN, R., et al. (2010). "Field assessment of thermal behaviour of historical dwellings in France." Building and Environment 45(2): 473-484.

CAPON, R. and J. HACKER (2009). Modelling climate change adaptation measures to reduce overheating risk in existing dwellings. Eleventh International IBPSA Conference.

CARDINALE, T., et al. (2013). "Evaluation of the efficacy of traditional recovery interventions in historical buildings. A new selection methodology." Energy Procedia 40: 515-524.

CARTER, L. & KILLAM, L. 2013. *Research terminology simplified: Paradigms, axiology, ontology, epistemology and methodology*, Laura Killam.

CASTILLO-CAGIGAL, M., GUTIÉRREZ, A., et al. 2011. A semi-distributed electric demand-side management system with PV generation for self-consumption enhancement. *Energy Conversion and Management,* 52**,** 2659-2666.

CHOI, J.-H., BELTRAN, L. O., et al. 2012. Impacts of indoor daylight environments on patient average length of stay (ALOS) in a healthcare facility. *Building and environment,* 50**,** 65-75.

CHOW, T.-T. & LI, C. 2013. Liquid-filled solar glazing design for buoyant water-flow. *Building and Environment,* 60**,** 45-55.

CITHERLET, S. & DEFAUX, T. 2007. Energy and environmental comparison of three variants of a family house during its whole life span. *Building and Environment,* 42**,** 591-598.

CLEMENTS-CROOME, D. (2013). Intelligent buildings: an introduction, Routledge.

COFFMAN, C., DUFFIN, R., et al. 1980. Are adobe walls optimal phase-shift filters? *Advances in Applied Mathematics,* 1**,** 50-66.

COGHLAN, D. & BRANNICK, T. 2014. *Doing Action Research in Your Own Organization*, SAGE Publications.

COLLIS, J. & HUSSEY, R. (2013). *Business Research: A Practical Guide for Undergraduate and Postgraduate Students*, Palgrave Macmillan.

CONSBANK (2009), مسکن (Dwelling demand in Iran), Reterived 23 June, 2015 from http://consbank.com

COUTTS, A. M., et al. (2013). "Assessing practical measures to reduce urban heat: Green and cool roofs." Building and Environment 70: 266-276.

CROWE, S., CRESSWELL, K., et al. (2011). The case study approach. *BMC Medical Research Methodology,* 11**,** 1-9.
DAI, Y. J., et al. (2003). "Enhancement of natural ventilation in a solar house with a solar chimney and a solid adsorption cooling cavity." Solar Energy 74(1): 65-75.
DE VAUS, D. A. & DE VAUS, P. D.(2001). *Research Design in Social Research,* Sage Publications (CA).
DE DEAR, R. J. and G. S. Brager (2002). "Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55." Energy and Buildings 34(6): 549-561.
DELFANI, S., KARAMI, M., et al. (2010). The effects of climate change on energy consumption of cooling systems in Tehran. *Energy and Buildings,* 42**,** 1952-1957.
DENZIN, N. K. & LINCOLN, Y. S. (2005). *The SAGE Handbook of Qualitative Research,* Sage Publications.
DUFFIN, R. & KNOWLES, G. (1981). Temperature control of buildings by adobe wall design. *Solar Energy,* 27**,** 241-249.
DWIVEDI, A., SAHAGAL, P. P., et al. (2012). How To Make Energy Efficient Building. *i-Manager's Journal on Future Engineering and Technology,* 8**,** 1.
EASTERBY-SMITH, M., THORPE, R., et al. (2008). *Management Research*, SAGE.
EISENHARDT, K.N. AND GRAEBNER, M.E. (2007), *Theory building from cases: Opportunities and challenges*, Academy of Management Journal, **50**(1), 25- 32.
EKICI, B. B. & AKSOY, U. T. (2011). Prediction of building energy needs in early stage of design by using ANFIS. *Expert Systems with Applications,* 38**,** 5352-5358.
ELAIAB, F (2014). Thermal comfort investigation of multi-storey residential buildings in Mediterranean climate with reference to Darnah, Libya. (PhD Thesis), University of Nottingham, Nottingham, retrieved from http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.625521
ETZION, Y., PEARLMUTTER, D., et al. (1997). Adaptive architecture: integrating low-energy technologies for climate control in the desert. *Automation in Construction,* 6**,** 417-425.
EU (2009). LOW ENERGY BUILDINGS IN EUROPE: CURRENT STATE OF PLAY, DEFINITIONS AND BEST PRACTICE The proposal for a recast of the Directive on the energy performance of buildings (EPBD)
EUROPEAN COMMISSION. (2017). Energy Performance of Buildings Directive (2010/31/EU), Retrieved 11 Dec, 2017 from https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings
EUROPEIA, C. (2009). Low energy buildings in Europe: current state of play, definitions and best practice. Luxemburgo: Serviço das publicações da União Europeia.
EZZELDIN, S. AND S. J. REES (2013). "The potential for office buildings with mixed-mode ventilation and low energy cooling systems in arid climates." Energy and Buildings 65: 368-381.

FANG, X. & LI, Y. (2000). Numerical simulation and sensitivity analysis of lattice passive solar heating walls. *Solar energy,* 69**,** 55-66.
FANGER, P. O. AND J. TOFTUM (2002). "Extension of the PMV model to non-air-conditioned buildings in warm climates." Energy and Buildings 34(6): 533-536.
FANGER, P. O. (1970). Thermal Comfort - analysis and Applications in Environmental Engineering. Copenhagen: Danish Technical Press.
FARAHMANDPOUR, B., NASSERI, I., et al (2008). Analysis of ultimate energy consumption by sector in Islamic Republic of Iran. Proceedings of the 3rd IASME/WSEAS international conference on Energy & environment, 2008. World Scientific and Engineering Academy and Society (WSEAS), 151-157.

FARRAR-NAGY, S., REEVES, P., et al. Impacts of shading and glazing combinations on residential energy use in a hot dry climate. Proceedings of the 2000 ACEEE Summer Study of Energy Efficiency in Buildings, 2000. 1.63-1.76.

FAYAZ, R. & KARI, B. M. (2009). Comparison of energy conservation building codes of Iran, Turkey, Germany, China, ISO 9164 and EN 832. *Applied Energy,* 86, 1949-1955.

FEIST, W. (2005). First Steps: What can be a Passive House in your region with your climate. *Passive House Institute (www. passiv. de), Darmstadt*.

FEIST, W. (2007). What is a passive house. *Passive House Institute*.

FORUZANMEHR, A. AND M. VELLINGA (2011). "Vernacular architecture: questions of comfort and practicability." Building Research & Information 39(3): 274-285.

GASPARELLA, A., et al. (2011). "Analysis and modelling of window and glazing systems energy performance for a well insulated residential building." Energy and Buildings 43(4): 1030-1037.

GIVONI, B. (1994). Passive Low Energy Cooling of Buildings. Canada: Wiley John & Sons inc.

GIVONI, B. (1998). Climate Considerations in Building and Urban Design. Toronto: John Wiley & sons inc.

GONG, X., AKASHI, Y., et al. (2012). Optimization of passive design measures for residential buildings in different Chinese areas. *Building and Environment,* 58, 46-57.

GOULDING, J. R., OWEN, L. J., STEEMERS, T. C., & DIRECTORA, C. O. (1992). Energy In Architecture, The European Passive Solar Handbook. London: London : B.T. Batsford for the Commission of the European Communities, Directorate General XII for Science, Research and Development.

GREEN, J. & THOROGOOD, N. (2009). *Qualitative methods for health research,* Los Angeles, Sage.

HALWATURA, R. & JAYASINGHE, M. (2008). Thermal performance of insulated roof slabs in tropical climates. *Energy and Buildings,* 40, 1153-1160.

HALWATURA, D., et al. (2015). "Drought severity–duration–frequency curves: a foundation for risk assessment and planning tool for ecosystem establishment in post-mining landscapes." Hydrology and Earth System Sciences 19(2): 1069-1091.

HEPPNER, P. P., WAMPOLD, B. E., et al. (2015). *Research Design in Counseling*, Cengage Learning.

HEYDARI, S. (2009). "Comfort Temperature of Iranian People in City of Tehran."

HOLLMULLER, P. & LACHAL, B. (2001). Cooling and preheating with buried pipe systems: monitoring, simulation and economic aspects. *Energy and Buildings,* 33, 509-518.

HUIZENGA, C., et al. (2006). "Air quality and thermal comfort in office buildings: results of a large indoor environmental quality survey."

HUMPHREYS, M., et al. (2015). Adaptive thermal comfort: Foundations and analysis, Routledge.

HYDE, R. (2013). *Climate responsive design: A study of buildings in moderate and hot humid climates*, Taylor & Francis.

IEA. (2015). Energy balance statistic, Retrieved 11 July, 2017, from https://www.iea.org/Sankey/#?c=Islamic Republic of Iran&s=Final consumption

IEEO (2013). سازمان بهره‌وری انرژی سابا [Iranian Energy Efficiency Organization], Retrieved 12 February, 2016, from http://www.saba.org.ir/fa/masrafeenergy/sakhteman

INTERNATIONAL PASSIVE HOUSE ASSOCIATION. (2015). The Passive House – sustainable, affordable, comfortable, versatile, Retrieved 04 Jul 2016 from https://passivehouse-international.org/index.php?page_id=79

IRANIAN BUILDING CODE. (2011). مبحث نوزدهم مقررات ملي ساختمان ايران [Iranian Building Code Chapter 19], Retrieved 12 April, 2015 from https://profs.basu.ac.ir/araghchian/upload_file/567.1688.file_ref.2388.2851.pdf

IRAN BOILER CO (2016). بویلر انتخاب و محاسبه [Boiler selection and calculations], Reterieved 12 June, 2016 from http://iranboiler.com/%

IRAN MANAGEMENT AND PLANING ORGANISATION. (2007). طراحی معیارهای و مقررات ساختمانی تیپ جزئیات .اجرایی و [Design and implementation rules and standards. Building Brief Details], Retrieved 23 March, 2015 from http://www.dres.ir/fanni/memari/DocLib14/%

IRAN METEOROLOGICAL ORGANIZATION (2015). پورتال سازمان هواشناسی کشورمحصولات و خدمات] Retrieved from http://www.irimo.ir/far/wd/720-%

IRAN MINISTRY OF HOUSING AND TRANSPORT (2017). [مباحث مقررات ملی ساختمان/مبحث نوزدهم Retrieved From http://www.nbri.ir.

IRANIAN NATIONAL HOUSING CENSUS (2016), Population and Housing Censuses, Retrieved from https://www.amar.org.ir/english/Population-and-Housing-Censuses/Census-2016-General-Results.

ISO .(2017). Thermal bridges in building construction, Retrieved 01 September, 2017 from https://www.iso.org/standard/65710.html

JORGE, J., PUIGDOMENECH, J., et al. (1993). A practical tool for sizing optimal shading devices. *Building and Environment,* 28**,** 69-72.

KALOGIROU, S. A., et al. (2002). "Energy analysis of buildings employing thermal mass in Cyprus." Renewable Energy 27(3): 353-368.

KALZ, D., et al. (2009). "Building signatures correlating thermal comfort and low-energy cooling: in-use performance." Building Research & Information 37(4): 413-432.

KISILEWICZ, T. AND A. DUDZIŃSKA (2015). "Summer overheating of a passive sports hall building." Archives of Civil and Mechanical Engineering 15(4): 1193-1201.

KARBASSI, A. R., ABDULI, M. A., et al. (2007). Sustainability of energy production and use in Iran. *Energy Policy,* 35**,** 5171-5180.

KARLSSON, J. & ROOS, A.(2001). Annual energy window performance vs. glazing thermal emittance—the relevance of very low emittance values. *Thin Solid Films,* 392**,** 345-348.

KHANAL, R. & LEI, C. (2011). Solar chimney—A passive strategy for natural ventilation. *Energy and Buildings,* 43**,** 1811-1819.

KIBERT, C. J. (2012). *Sustainable Construction: Green Building Design and Delivery,* Wiley.

KISCHKOWEIT-LOPIN, M. (2002). An overview of daylighting systems. *Solar Energy,* 73**,** 77-82.

KNIGHT, A. & RUDDOCK, L. (2009). *Advanced Research Methods in the Built Environment,* Wiley.

KRONER, W. M. (1997). An intelligent and responsive architecture. *Automation in Construction,* 6**,** 381-393.

KUMAR, R. (2014). *Research Methodology: A Step-by-Step Guide for Beginners,* SAGE Publications.

KUMAR, R., KAUSHIK, S., et al. (2006). Heating and cooling potential of an earth-to-air heat exchanger using artificial neural network. *Renewable Energy,* 31**,** 1139-1155.

KUZMAN, M. K., GROŠELJ, P., et al.(2013). Comparison of passive house construction types using analytic hierarchy process. *Energy and Buildings,* 64**,** 258-263.

LARSSON, U. & MOSHFEGH, B. (2002). Experimental investigation of downdraught from well-insulated windows. *Building and Environment,* 37**,** 1073-1082.

LÁZARO, M. & MARCOS, E. An Approach to the Integration of Qualitative and Quantitative Research Methods in Software Engineering Research. PhiSE, 2006.

LEE, J., et al. (2013). "Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements." Renewable Energy 50: 522-531.

LEE, J., et al. (2013). "Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements." Renewable Energy 50: 522-531.

LEWIS, O. J., GOULDING, J. R., & STEEMERS, T. C. (1992). Energy Conscious Design - A Primer for Architects. London: B.T Balsford Ltd.

LIENHARD, J. H. (2013). A heat transfer textbook, Courier Corporation.

LI, D. H. & LAM, J. C. (2001). Evaluation of lighting performance in office buildings with daylighting controls. *Energy and Buildings,* 33**,** 793-803.

LI, D. H. & WONG, S. L. (2007). Daylighting and energy implications due to shading effects from nearby buildings. *Applied Energy,* 84**,** 1199-1209.

LODICO, M. G., SPAULDING, D. T., et al. (2010). *Methods in Educational Research: From Theory to Practice,* Wiley.

MAGWOOD, C. AND P. MACK (2005). More straw bale building: a complete guide to designing and building with straw, New Society Publishers.

MAHAPATRA, S., CHANAKYA, H., et al. (2009). Evaluation of various energy devices for domestic lighting in India: technology, economics and CO 2 emissions. *Energy for Sustainable Development,* 13**,** 271-279.

MCNICHOLL, A., & LEWIS, J. O. (Eds.). (1994). Daylighting in Buildings. Energy Research Group University College of Dublin for the European Commission.

McMULLAN, R. (2012). Environmental Science in Building, Palgrave Macmillan.

MARKUS, T. A. AND E. N. MORRIS (1980). Buildings, Climate, and Energy, Pitman Pub.

MINGFANG, T. (2002). "Solar control for buildings." Building and Environment 37(7): 659-664.

MOHAMMAD, S. AND A. SHEA (2013). "Performance evaluation of modern building thermal envelope designs in the semi-arid continental climate of Tehran." Buildings 3(4): 674-688.

MOOSAVI, L., ET AL. (2014). "THERMAL PERFORMANCE OF ATRIA: AN OVERVIEW OF NATURAL VENTILATION EFFECTIVE DESIgns." Renewable and Sustainable Energy Reviews 34(Supplement C): 654-670.

NAJAFI, G., GHOBADIAN, B., et al. (2015). Solar energy in Iran: Current state and outlook. *Renewable and Sustainable Energy Reviews,* 49**,** 931-942.

NAJIM, K. B. (2014). External load-bearing walls configuration of residential buildings in Iraq and their thermal performance and dynamic thermal behaviour. *Energy and Buildings,* 84**,** 169-181.

NASROLLAHI, F. 2009. *Climate and Energy Responsive Housing in Continental Climates: The Suitability of Passive Houses for Iran's Dry and Cold Climate,* D 83.

NICOL, F., et al. (2012). Adaptive Thermal Comfort: Principles and Practice, Taylor & Francis.

NICOLAJSEN, A. (2005). Thermal transmittance of a cellulose loose-fill insulation material. *Building and Environment,* 40**,** 907-914.

NIROUMAND, H., ZAIN, M. F. M., et al. (2013). A guideline for assessing of critical parameters on Earth architecture and Earth buildings as a sustainable architecture in various countries. *Renewable and Sustainable Energy Reviews,* 28**,** 130-165.

O'Brien, W. and H. B. Gunay (2014). "The contextual factors contributing to occupants' adaptive comfort behaviors in offices–A review and proposed modeling framework." Building and Environment 77: 77-87.

OCHOA, C. E. AND I. G. CAPELUTO (2008). "Strategic decision-making for intelligent buildings: Comparative impact of passive design strategies and active features in a hot climate." Building and Environment 43(11): 1829-1839.

O'COFAIGH, E., OWEN, L. J., & FITZGERALD, E. (1999). A GREEN VITRUVIUS: principles and practice of sustainable architectural design. London: James & James.

ORAL, G. K. & YILMAZ, Z. (2003). Building form for cold climatic zones related to building envelope from heating energy conservation point of view. *Energy and Buildings,* 35**,** 383-388.
OURGHI, R., AL-ANZI, A., et al. (2007). A simplified analysis method to predict the impact of shape on annual energy use for office buildings. *Energy Conversion and Management,* 48**,** 300-305.
PALMERO-MARRERO, A. I. & OLIVEIRA, A. C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy,* 87**,** 2040-2049.
PANÃO, M. J. O., REBELO, M. P., et al. (2013). How low should be the energy required by a nearly Zero-Energy Building? The load/generation energy balance of Mediterranean housing. *Energy and Buildings,* 61**,** 161-171.
PARIZOTTO, S. & LAMBERTS, R. (2011). Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. *Energy and Buildings,* 43**,** 1712-1722.
PASIAN, B. 2015. *Designs, Methods and Practices for Research of Project Management*, Ashgate Publishing Company.
PASSIPEDIA. (2016). What defines thermal bridge free design?, Reterieved 09 September, 2016 from https://passipedia.org/basics/building_physics_-_basics/what_defines_thermal_bridge_free_design
PASSIVHAUS UK. (2016). Passivhaus primer, designer guide, Retrieved 21 April, 2017 from http://www.passivhaus.org.uk/filelibrary/Primers/KN4430_Passivhaus_Designers_Guide_WEB.pdf
PASSIVE HOUSE INSTITUTE. (2012). Passive house requirement, Retrieved 19 March, 2015 from http://www.passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm
PERSSON, M.-L., ROOS, A., et al. (2006). Influence of window size on the energy balance of low energy houses. *Energy and Buildings,* 38**,** 181-188.
RADHI, H. (2009). Can envelope codes reduce electricity and CO2 emissions in different types of buildings in the hot climate of Bahrain? *Energy,* 34**,** 205-215.
RAKOTO-JOSEPH, O., GARDE, F., et al. (2009). Development of climatic zones and passive solar design in Madagascar. *Energy Conversion and Management,* 50**,** 1004-1010.
RAMAN, P., MANDE, S., et al. (2001). A passive solar system for thermal comfort conditioning of buildings in composite climates. *Solar Energy,* 70**,** 319-329.
RAMESH, T., PRAKASH, R., et al. (2012). Life cycle energy analysis of a residential building with different envelopes and climates in Indian context. *Applied Energy,* 89**,** 193-202.
RITCHIE, J., et al. (2013). Qualitative Research Practice: A Guide for Social Science Students and Researchers, SAGE Publications.
ROAF, S., et al. (2014). Ecohouse, Taylor & Francis.
ROBSON, C. (1994). *Experiment, Design and Statistics in Psychology,* Penguin Books, Limited.
RODRIGUEZ-UBINAS, E., MONTERO, C., et al. (2014). Passive design strategies and performance of Net Energy Plus Houses. *Energy and Buildings,* 83**,** 10-22.
RUGG, G. (2006). A Gentle Guide to Research Methods, McGraw-Hill Education.
ROSSI, M. & ROCCO, V. M. (2014). External walls design: The role of periodic thermal transmittance and internal areal heat capacity. *Energy and Buildings,* 68**,** 732-740.
ROUFECHAEI, K. M., HASSAN ABU BAKAR, A., et al. (2014). Energy-efficient design for sustainable housing development. *Journal of Cleaner Production,* 65**,** 380-388.
ROWE, D. (2003). "A study of a mixed mode environment in 25 cellular offices at the University of Sydney." International Journal of Ventilation 1(4): 53-64.

SANTAMOURIS, M., & ASIMAKOPOLOUS, D. (1996). Passive Cooling of Building. London: James & James (Science Publishers) Ltd.
SANTAMOURIS, M., ASIMAKOPOULOS, D. N., ASSIMAKOPOULOS, V. D., CHRISOMALLIDOU, N., KLITSIKAS, N., MANGOLD, D., et al. (2001). Energy and Climate in The Urban Built Environment (second ed.). (M. Santamouris, Ed.) London: James & James.
QIAN, L (2009). Energy efficiency design of residential buildings in North China cities. (PhD Thesis), University odf Cardiff, Cardiff, reterieved from http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.584530
SABA (2012) آبی کولرهای در برق مصرف سازی بهینه [Evaporative cooler optimisation in Electricity consumption], Reterived 09 Jun, 2016 from http://www.saba.org.ir/fa/lab1/savingenergy/koolerabi
SALVADOR, M. & GRIEU, S. (2012). Methodology for the design of energy production and storage systems in buildings: Minimization of the energy impact on the electricity grid. *Energy and Buildings,* 47**,** 659-673.
SAUNDERS, M., LEWIS, P., et al. (2009). *Research Methods for Business Students*, Financial Times Prentice Hall.
SCHNIEDERS, J. (2009). *Passive Houses in South West Europe*, Passivhaus Institut.
SCHNIEDERS, J. & HERMELINK, A. (2006). CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. *Energy Policy,* 34**,** 151-171.
SHARMA, Y. AND B. SINGH (2009). "Development of biodiesel: current scenario." Renewable and Sustainable Energy Reviews 13(6-7): 1646-1651.
SIMPSON, J. R. & MCPHERSON, E. G. (1998). Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento. *Atmospheric Environment,* 32**,** 69-74.
SINGH, M., et al. (2008). "Different glazing systems and their impact on human thermal comfort—Indian scenario." Building and Environment 43(10): 1596-1602.
SISMAN, N., KAHYA, E., et al. (2007). Determination of optimum insulation thicknesses of the external walls and roof (ceiling) for Turkey's different degree-day regions. *Energy Policy,* 35**,** 5151-5155.
SONG, S.-Y., JO, J.-H., et al. (2007). Evaluation of inside surface condensation in double glazing window system with insulation spacer: A case study of residential complex. *Building and environment,* 42**,** 940-950.
SPERLING, K., et al. (2010). "Evaluation of wind power planning in Denmark–towards an integrated perspective." Energy 35(12): 5443-5454.
STAKE, R. E. (1995). *The art of case study research,* London, Sage Publications Ltd.
STACK, A., GOULDING, J. R., & LEWIS, O. J. (1999). Shading systems: solar shading for the European climates. University College Dublin, Energy Research Group. Dublin: European Commission Directorates - General for Research and Energy & Transport.
STEVANOVIĆ, S. (2013). "Optimization of passive solar design strategies: A review." Renewable and Sustainable Energy Reviews 25(0): 177-196.
SU, B. (2008). Building Passive Design and Housing Energy Efficiency. *Architectural Science Review,* 51**,** 277-286.
SUEHRCKE, H., PETERSON, E. L., et al. (2008). Effect of roof solar reflectance on the building heat gain in a hot climate. *Energy and Buildings,* 40**,** 2224-2235.
SUSTAINABLE BY DESIGN (2017), Overhang Recommendations, Reterieved 15 January, 2017 from http://www.susdesign.com/overhang_recs/index.php
SUSTAINABILITY WORKSHOPS. (2017). Building envelop, Retrieved 18 January, 2017, Retrieved from https://sustainabilityworkshop.autodesk.com/building-design.

TALEB, H. M. AND S. SHARPLES (2011). "Developing sustainable residential buildings in Saudi Arabia: A case study." Applied Energy 88(1): 383-391.
THOMAS, R. M. (2003). *Blending Qualitative and Quantitative Research Methods in Theses and Dissertations,* SAGE Publications.
THOMSEN, K. E. & WITTCHEN, K. B. (2008). *European national strategies to move towards very low energy buildings*, Danish Building Research Institute.
TSOUTSOS, T., ANAGNOSTOU, J., et al. (2003). Solar cooling technologies in Greece. An economic viability analysis. *Applied Thermal Engineering,* 23**,** 1427-1439.
TZIKOPOULOS, A., et al. (2005). "Modeling energy efficiency of bioclimatic buildings." Energy and Buildings 37(5): 529-544.
UTAMA, A. & GHEEWALA, S. H. (2009). Indonesian residential high rise buildings: A life cycle energy assessment. *Energy and Buildings,* 41**,** 1263-1268.
VERMA, R., BANSAL, N., et al. (198)6. The comparative performance of different approaches to passive cooling. *Building and Environment,* 21**,** 65-69.
WANG, W., TIAN, Z., et al. (2013). Investigation on the influencing factors of energy consumption and thermal comfort for a passive solar house with water thermal storage wall. *Energy and Buildings,* 64**,** 218-223.
WILLIAMS, N. S., RAYNER, J. P., et al. (2010). Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia. *Urban Forestry & Urban Greening,* 9**,** 245-251.
WILLIAMSON, T. J., RADFORD, A., et al. 2003. *Understanding sustainable architecture,* Taylor & Francis.
WILSON, J. (2010). *Essentials of Business Research: A Guide to Doing Your Research Project*, SAGE Publications.
YAGHOOBIAN, N. AND J. SREBRIC (2015). "Influence of plant coverage on the total green roof energy balance and building energy consumption." Energy and Buildings 103: 1-13.
YAZDANPANAH, M., KOMENDANTOVA, N., et al. (2015). Governance of energy transition in Iran: Investigating public acceptance and willingness to use renewable energy sources through socio-psychological model. *Renewable and Sustainable Energy Reviews,* 45**,** 565-573.
YIN, R. K. (2009). *Case Study Research: Design and Methods*, SAGE Publications.
ZHOU, Y., CLARKE, L., et al. 2014. Modeling the effect of climate change on US state-level buildings energy demands in an integrated assessment framework. *Applied Energy,* 113**,** 1077-1088.
ZINZI, M. & AGNOLI, S. (2012). Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region. *Energy and Buildings,* 55**,** 66-76.

ZHU, L., et al. (2009). "Detailed energy saving performance analyses on thermal mass walls demonstrated in a zero energy house." Energy and Buildings 41(3): 303-310.

Appendix

۹

نوع مصرف : خانگي
شماره اشتراك : ۳۰۷۳۰۵۴۸۵۸ - ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰

كد حوزه : ۰۰۶
سريال كنتور : ۷۰۵۵۵۳۶
شماره پرونده : ۹۱۹۱۵۰

گروه : B
ظرفيت : ۴۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۵ / ۰۶ / ۱۵	۹۵ / ۰۸ / ۰۳	۴۴۵,۹۹۰	۴۴۶,۹۷۲	۹۸۲	۹۸۲
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۱,۳۴۳,۷۳۸	۲۵۳,۴۳۶	۱۴۴,۳۹۷	۷,۲۴۹	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۵۵	۹۱۸	۱۱۲	۱۳۴,۳۷۴

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۱,۸۸۴,۰۰۰	۹۵ / ۰۹ / ۳۰	۰۰۰۰۱۸۸۴۱۵۵۰۵	۷۳۰۵۴۸۰۶۲۳۷

نام مشترك : اقاي عزت اله ساري نوايي　　شهر : تهران　　تعداد واحد : ۹
نوع مصرف : خانگي　　كد حوزه : ۰۰۶　　گروه : B
شماره اشتراك : ۳۰۷۳۰۵۴۸۵۸ - ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷　　سريال كنتور : ۶۸۰۱۸۰۵　　ظرفيت : ۴۰
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰　　شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۵ / ۰۵ / ۰۵	۹۵ / ۰۶ / ۱۵	۴۴۵,۲۵۸	۴۴۵,۹۹۰	۷۳۲	۷۳۲
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۸۳۶,۴۴۲	۲۱۲,۰۵۸	۹۴,۹۰۹	۶,۰۶۶	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۵۴	۷۹۹	۹۱۸	۸۳,۶۴۴

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۱,۲۳۳,۰۰۰	۹۵ / ۰۸ / ۱۵	۰۰۰۰۱۲۳۳۱۵۴۱۴	۷۳۰۵۴۸۰۶۲۳۷

نام مشترك : اقاي عزت اله ساري نوايي　　شهر : تهران　　تعداد واحد : ۹
نوع مصرف : خانگي　　كد حوزه : ۰۰۶　　گروه : B
شماره اشتراك : ۳۰۷۳۰۵۴۸۵۸ - ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷　　سريال كنتور : ۶۸۰۱۸۰۵　　ظرفيت : ۴۰
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰　　شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۵ / ۰۳ / ۱۹	۹۵ / ۰۵ / ۰۵	۴۴۴,۳۳۳	۴۴۵,۲۵۸	۹۲۵	۹۲۵
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۱,۰۶۸,۴۳۸	۲۴۸,۲۶۴	۱۱۹,۱۴۲	۷,۱۰۱	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۵۳	۱۰	۷۹۹	۱۰۶,۸۴۴

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۱,۵۴۹,۰۰۰	۹۵ / ۰۶ / ۳۱	۰۰۰۰۱۵۴۹۱۵۳۱۲	۷۳۰۵۴۸۰۶۲۳۷

نام مشترك : اقاي عزت اله ساري نوايي
شهر : تهران
تعداد واحد : ۹

نوع مصرف : خانگي
كد حوزه : ۰۰۶
گروه : B

شماره اشتراك : ۳۰۷۳۰۵۴۸۵۸ - ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷
سريال كنتور : ۶۸۰۱۸۰۵
ظرفيت : ۴۰

كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰
شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۵ / ۰۲ / ۰۸	۹۵ / ۰۳ / ۱۹	۴۴۳,۴۱۹	۴۴۴,۳۳۳	۹۱۴	۹۱۴
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۱,۰۷۲,۰۴۲	۲۱۷,۲۳۱	۱۱۶,۵۹۳	۶,۲۱۴	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۵۲	۷۲۶	۱۰	۱۰۷,۲۰۴

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۱,۵۲۰,۰۰۰	۹۵ / ۰۵ / ۱۶	۰۰۰۰۱۵۲۰۱۵۲۵۰	۷۳۰۵۴۸۰۶۲۳۷

نام مشترك : له ساري نوايي اقاي عزت ا
شهر : تهران
تعداد واحد : ۹

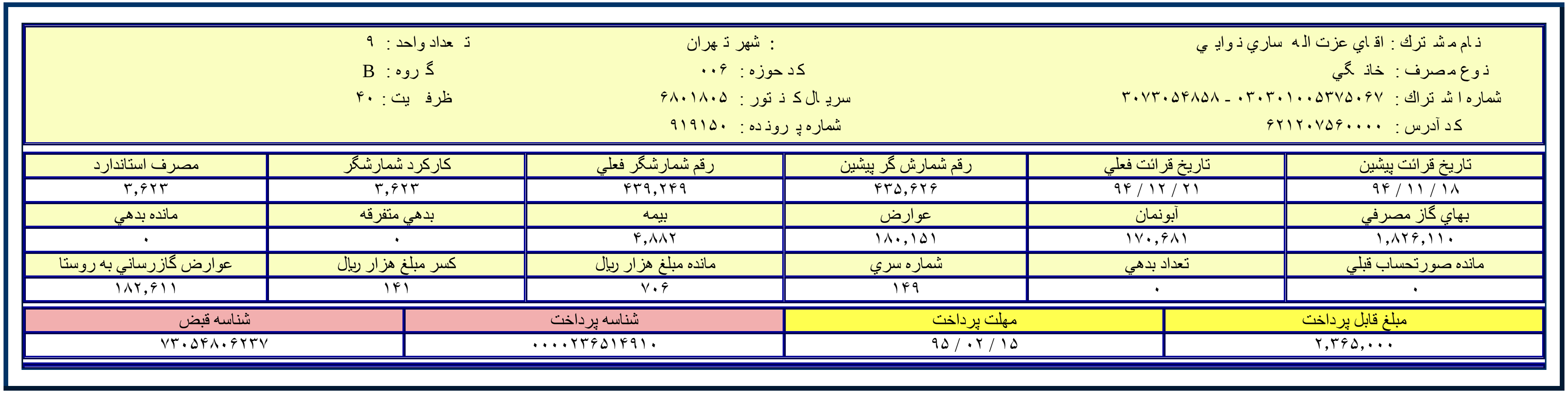
نوع مصرف : خانگي
كد حوزه : ۰۰۶
گروه : B

شماره اشتراك : ۳۰۷۳۰۵۴۸۵۸ - ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷
سريال كنتور : ۶۸۰۱۸۰۵
ظرفيت : ۴۰

كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰
شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۱۲ / ۲۱	۹۵ / ۰۲ / ۰۸	۴۳۹,۲۴۹	۴۴۳,۴۱۹	۴,۱۷۰	۴,۱۷۰
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۴,۰۳۷,۰۰۶	۲۴۳,۰۹۱	۳۸۵,۸۳۳	۶,۹۵۴	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۵۰	۱۴۱	۷۲۵	۴۰۳,۷۰۰

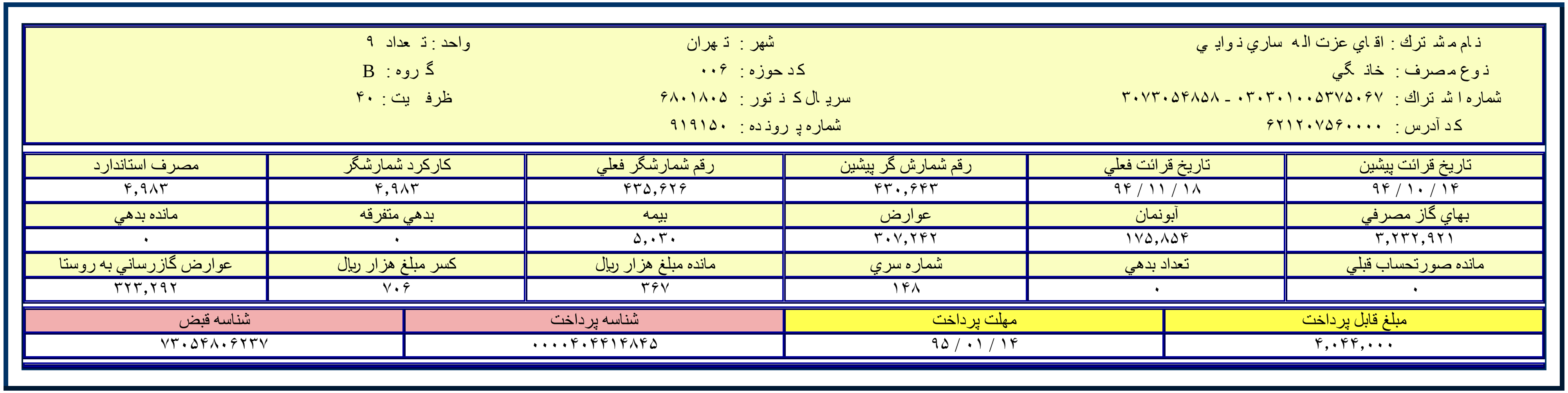
مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۵,۰۷۶,۰۰۰	۹۵ / ۰۳ / ۳۰	۰۰۰۰۵۰۷۶۱۵۰۹۱	۷۳۰۵۴۸۰۶۲۳۷



نام مشترك : اقاي عزت اله ساري نوايي شهر تهران : تعداد واحد : ۹
نوع مصرف : خانگي كد حوزه : ۰۰۶ گروه : B
شماره اشتراك : ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷ - ۳۰۷۳۰۵۴۸۵۸ سريال كنتور : ۶۸۰۱۸۰۵ ظرفيت : ۴۰
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰ شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارشگر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۱۱ / ۱۸	۹۴ / ۱۲ / ۲۱	۴۳۵,۶۲۶	۴۳۹,۲۴۹	۳,۶۲۳	۳,۶۲۳
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۱,۸۲۶,۱۱۰	۱۷۰,۶۸۱	۱۸۰,۱۵۱	۴,۸۸۲	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۴۹	۷۰۶	۱۴۱	۱۸۲,۶۱۱

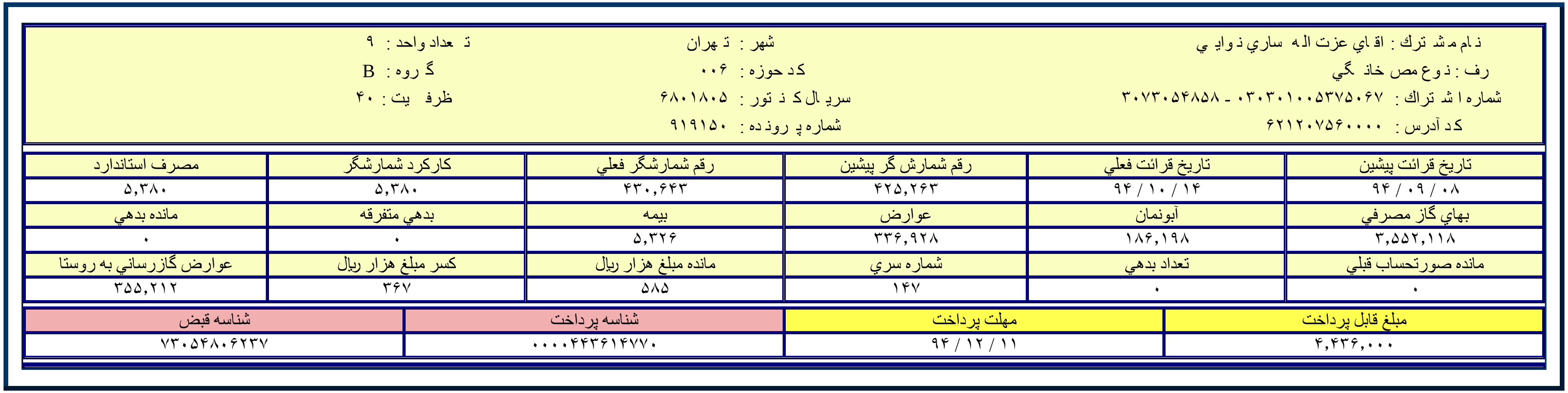
مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۲,۳۶۵,۰۰۰	۹۵ / ۰۲ / ۱۵	۰۰۰۰۲۳۶۵۱۴۹۱۰	۷۳۰۵۴۸۰۶۲۳۷



نام مشترك : اقاي عزت اله ساري نوايي شهر : تهران واحد : تعداد ۹
نوع مصرف : خانگي كد حوزه : ۰۰۶ گروه : B
شماره اشتراك : ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷ - ۳۰۷۳۰۵۴۸۵۸ سريال كنتور : ۶۸۰۱۸۰۵ ظرفيت : ۴۰
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰ شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارشگر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۱۰ / ۱۴	۹۴ / ۱۱ / ۱۸	۴۳۰,۶۴۳	۴۳۵,۶۲۶	۴,۹۸۳	۴,۹۸۳
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۳,۲۳۲,۹۲۱	۱۷۵,۸۵۴	۳۰۷,۲۴۲	۵,۰۳۰	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۴۸	۳۶۷	۷۰۶	۳۲۳,۲۹۲

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۴,۰۴۴,۰۰۰	۹۵ / ۰۱ / ۱۴	۰۰۰۰۴۰۴۴۱۴۸۴۵	۷۳۰۵۴۸۰۶۲۳۷



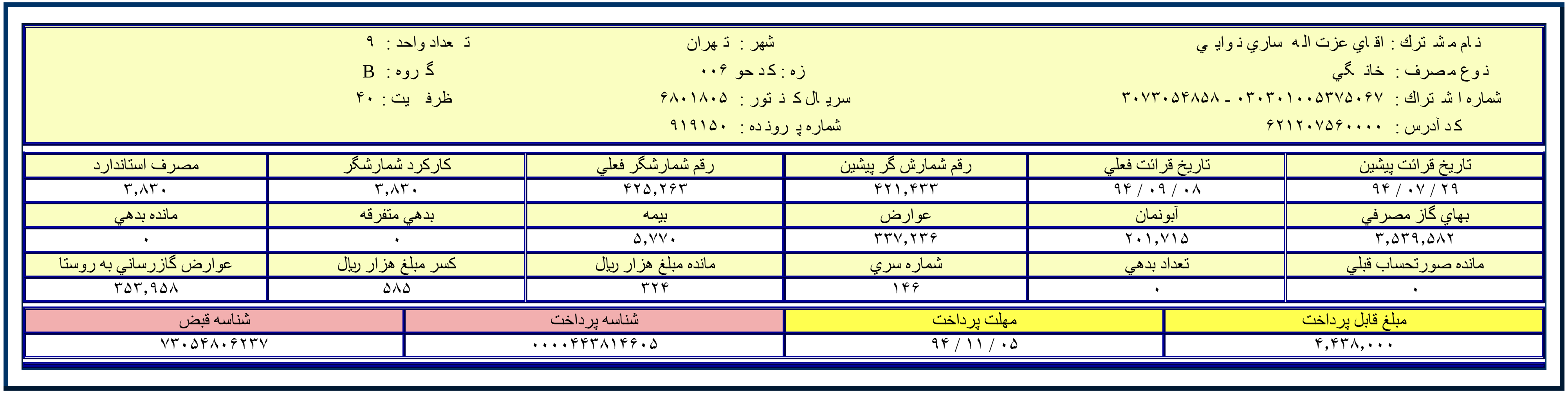
نام مشترك : اقاي عزت اله ساري نوايي
رف : نوع مص خانگي
شماره اشتراك : ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷ - ۳۰۷۳۰۵۴۸۵۸
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰

شهر : تهران
كد حوزه : ۰۰۶
سريال كنتور : ۶۸۰۱۸۰۵
شماره پرونده : ۹۱۹۱۵۰

تعداد واحد : ۹
گروه : B
ظرفيت : ۴۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارشگر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۰۹ / ۰۸	۹۴ / ۱۰ / ۱۴	۴۲۵,۲۶۳	۴۳۰,۶۴۳	۵,۳۸۰	۵,۳۸۰
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۳,۵۵۲,۱۱۸	۱۸۶,۱۹۸	۳۳۶,۹۲۸	۵,۳۲۶	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۴۷	۵۸۵	۳۶۷	۳۵۵,۲۱۲

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۴,۴۳۶,۰۰۰	۹۴ / ۱۲ / ۱۱	۰۰۰۰۴۴۳۶۱۴۷۷۰	۷۳۰۵۴۸۰۶۲۳۷



نام مشترك : اقاي عزت اله ساري نوايي
نوع مصرف : خانگي
شماره اشتراك : ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷ - ۳۰۷۳۰۵۴۸۵۸
كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰

شهر : تهران
زه : كد حو ۰۰۶
سريال كنتور : ۶۸۰۱۸۰۵
شماره پرونده : ۹۱۹۱۵۰

تعداد واحد : ۹
گروه : B
ظرفيت : ۴۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارشگر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۰۷ / ۲۹	۹۴ / ۰۹ / ۰۸	۴۲۱,۴۳۳	۴۲۵,۲۶۳	۳,۸۳۰	۳,۸۳۰
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۳,۵۳۹,۵۸۲	۲۰۱,۷۱۵	۳۳۷,۲۳۶	۵,۷۷۰	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۴۶	۳۲۴	۵۸۵	۳۵۳,۹۵۸

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۴,۴۳۸,۰۰۰	۹۴ / ۱۱ / ۰۵	۰۰۰۰۴۴۳۸۱۴۶۰۵	۷۳۰۵۴۸۰۶۲۳۷

نام مشترك : اقاي عزت اله ساري نوايي
شهر : تهران
تعداد واحد : ۹

نوع مصرف : خانگي
كد حوزه : ۰۰۶
گروه : B

شماره اشتراك : ۰۳۰۳۰۱۰۰۵۳۷۵۰۶۷ - ۳۰۷۳۰۵۴۸۵۸
سريال كنتور : ۶۸۰۱۸۰۵
ظرفيت : ۴۰

كد آدرس : ۶۲۱۲۰۷۵۶۰۰۰۰
شماره پرونده : ۹۱۹۱۵۰

تاريخ قرائت پيشين	تاريخ قرائت فعلي	رقم شمارش گر پيشين	رقم شمارشگر فعلي	كاركرد شمارشگر	مصرف استاندارد
۹۴ / ۰۶ / ۳۰	۹۴ / ۰۷ / ۲۹	۴۲۰,۸۴۰	۴۲۱,۴۳۳	۵۹۳	۵۹۳
بهاي گاز مصرفي	آبونمان	عوارض	بيمه	بدهي متفرقه	مانده بدهي
۶۸۴,۴۶۵	۱۵۵,۱۶۵	۷۵,۹۶۵	۴,۴۳۸	۰	۰
مانده صورتحساب قبلي	تعداد بدهي	شماره سري	مانده مبلغ هزار ريال	كسر مبلغ هزار ريال	عوارض گازرساني به روستا
۰	۰	۱۴۵	۸۴۵	۳۲۴	۶۸,۴۴۶

مبلغ قابل پرداخت	مهلت پرداخت	شناسه پرداخت	شناسه قبض
۹۸۹,۰۰۰	۹۴ / ۰۹ / ۲۹	۰۰۰۰۰۹۸۹۱۴۵۵۶	۷۳۰۵۴۸۰۶۲۳۷

Actual Base	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	2.31	0.00	2.31	4697.8	0.0	4697.8	4686.7	0.0	4686.7
Feb	5.0	10.2	19.3	672	0.0	0.0	1.73	0.00	1.73	3518.4	0.0	3518.4	3510.0	0.0	3510.0
Mar	10.7	16.0	21.0	533	0.0	211.0	0.88	0.00	0.88	1782.3	0.0	1782.3	1778.1	0.0	1778.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.29	0.05	0.35	594.4	8.6	603.0	593.0	31.8	624.8
May	21.7	26.1	24.3	24	245.0	475.0	0.01	0.31	0.31	14.8	50.0	64.9	14.8	185.1	199.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	1.29	1.29	0.0	211.4	211.4	0.0	782.2	782.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.70	1.70	0.0	278.3	278.3	0.0	1029.8	1029.8
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.82	1.82	0.0	297.1	297.1	0.0	1099.4	1099.4
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.90	0.90	0.0	146.9	146.9	0.0	543.5	543.5
Oct	17.8	25.1	23.1	46	183.0	515.0	0.10	0.05	0.15	209.3	7.6	216.9	208.8	28.2	237.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.77	0.00	0.77	1554.2	0.0	1554.2	1550.5	0.0	1550.5
Dec	5.6	10.6	19.5	744	0.0	0.0	2.02	0.00	2.02	4091.9	0.0	4091.9	4082.1	0.0	4082.1
				3355	3236.0	2169.0	8.11	6.11	14.22	16463.1	1000.0	17463.1	16424.0	3700.1	20124.1

WAT1	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.94	0.00	1.94	3937.2	0.0	3937.2	3927.8	0.0	3927.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.41	0.00	1.41	2864.7	0.0	2864.7	2857.9	0.0	2857.9
Mar	10.7	16.0	21.1	533	0.0	211.0	0.59	0.00	0.59	1201.8	0.0	1201.8	1198.9	0.0	1198.9
Apr	16.3	21.1	22.9	225	158.0	337.0	0.16	0.00	0.17	331.5	0.8	332.3	330.7	2.8	333.5
May	21.7	26.1	24.5	24	245.0	475.0	0.00	0.13	0.13	0.0	22.0	22.0	0.0	81.3	81.3
Jun	28.3	33.6	26.6	0	645.0	75.0	0.00	0.90	0.90	0.0	147.6	147.6	0.0	546.3	546.3
Jul	29.9	35.4	27.1	0	671.0	73.0	0.00	1.29	1.29	0.0	211.5	211.5	0.0	782.4	782.4
Aug	30.1	36.0	27.1	0	727.0	17.0	0.00	1.41	1.41	0.0	230.5	230.5	0.0	853.0	853.0
Sep	25.9	32.9	25.8	0	524.0	196.0	0.00	0.53	0.53	0.0	87.4	87.4	0.0	323.3	323.3
Oct	17.8	25.1	23.3	46	183.0	515.0	0.03	0.01	0.04	56.8	2.4	59.2	56.7	8.8	65.5
Nov	11.4	18.7	21.3	367	83.0	270.0	0.52	0.00	0.52	1057.8	0.0	1057.8	1055.3	0.0	1055.3
Dec	5.6	10.6	19.5	744	0.0	0.0	1.65	0.00	1.65	3347.5	0.0	3347.5	3339.5	0.0	3339.5
	17.2	**22.8**	23.0	**3561**	**3580.0**	**1619.0**	**6.30**	**4.29**	**10.60**	**12797.3**	**702.2**	**13499.5**	**12766.9**	**2598.0**	**15364.9**

WAT2	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.42	0.00	1.42	2883.8	0.0	2883.8	2877.0	0.0	2877.0
Feb	5.0	10.2	19.3	672	0.0	0.0	1.01	0.00	1.01	2040.2	0.0	2040.2	2035.3	0.0	2035.3
Mar	10.7	16.0	21.0	533	0.0	211.0	0.37	0.00	0.37	753.5	0.0	753.5	751.7	0.0	751.7
Apr	16.3	21.1	22.7	225	158.0	337.0	0.09	0.01	0.10	183.5	1.3	184.8	183.1	4.7	187.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	21.3	21.3	0.0	78.6	78.6
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.83	0.83	0.0	135.1	135.1	0.0	499.8	499.8
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.18	1.18	0.0	192.9	192.9	0.0	713.8	713.8
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.28	1.28	0.0	210.1	210.1	0.0	777.5	777.5
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.53	0.53	0.0	86.5	86.5	0.0	319.9	319.9
Oct	17.8	25.1	23.1	46	183.0	515.0	0.01	0.02	0.03	16.2	3.5	19.8	16.2	13.1	29.3
Nov	11.4	18.7	21.2	367	83.0	270.0	0.31	0.00	0.31	635.2	0.0	635.2	633.7	0.0	633.7
Dec	5.6	10.6	19.5	744	0.0	0.0	1.19	0.00	1.19	2406.4	0.0	2406.4	2400.6	0.0	2400.6
	17.2		23.0	**3378**	**3650.0**	**1732.0**	**4.39**	**3.98**	**8.37**	**8918.8**	**650.7**	**9569.5**	**8897.6**	**2407.5**	**11305.1**

WAT3	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.25	0.00	1.25	2540.5	0.0	2540.5	2534.5	0.0	2534.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.88	0.00	0.88	1778.3	0.0	1778.3	1774.1	0.0	1774.1
Mar	10.7	16.0	21.0	533	0.0	211.0	0.31	0.00	0.31	624.4	0.0	624.4	622.9	0.0	622.9
Apr	16.3	21.1	22.7	225	158.0	337.0	0.07	0.01	0.08	142.5	1.5	144.0	142.2	5.6	147.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	20.9	20.9	0.0	77.3	77.3
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.79	0.79	0.0	129.7	129.7	0.0	480.0	480.0
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.13	1.13	0.0	184.9	184.9	0.0	684.2	684.2
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.23	1.23	0.0	201.1	201.1	0.0	744.0	744.0
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.52	0.52	0.0	84.5	84.5	0.0	312.8	312.8
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.02	0.03	7.3	3.8	11.1	7.3	14.0	21.3
Nov	11.4	18.7	21.2	367	83.0	270.0	0.26	0.00	0.26	519.3	0.0	519.3	518.0	0.0	518.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.04	0.00	1.04	2102.3	0.0	2102.3	2097.3	0.0	2097.3
				3318	**3702.0**	**1740.0**	**3.80**	**3.83**	**7.63**	**7714.6**	**626.4**	**8341.1**	**7696.3**	**2317.9**	**10014.1**

WAT4	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	0.99	0.00	0.99	2003.6	0.0	2003.6	1998.8	0.0	1998.8
Feb	5.0	10.2	19.3	672	0.0	0.0	0.68	0.00	0.68	1370.5	0.0	1370.5	1367.2	0.0	1367.2
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	429.3	0.0	429.3	428.3	0.0	428.3
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.01	0.05	80.2	1.8	82.0	80.0	6.8	86.8
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.12	0.12	0.0	19.9	19.9	0.0	73.7	73.7
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.74	0.74	0.0	120.9	120.9	0.0	447.4	447.4
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.05	1.05	0.0	172.0	172.0	0.0	636.5	636.5
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.14	1.14	0.0	186.9	186.9	0.0	691.4	691.4
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.49	0.49	0.0	80.9	80.9	0.0	299.5	299.5
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.02	0.02	0.0	4.0	4.0	0.0	15.0	15.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.17	0.00	0.17	340.0	0.0	340.0	339.2	0.0	339.2
Dec	5.6	10.6	19.5	744	0.0	0.0	0.80	0.00	0.80	1624.0	0.0	1624.0	1620.1	0.0	1620.1
				3140	**3867.0**	**1753.0**	**2.88**	**3.58**	**6.47**	**5847.6**	**586.6**	**6434.2**	**5833.7**	**2170.3**	**8004.0**

WAT5	Day Tem	Mean I Tem	Tcomfort	hours lessTcomf -2	Hours above Tcomf +2	Hours withinTcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	0.98	0.00	0.98	1983.7	0.0	1983.7	1979.0	0.0	1979.0
Feb	5.0	10.2	19.3	672	0.0	0.0	0.67	0.00	0.67	1353.6	0.0	1353.6	1350.4	0.0	1350.4
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	421.2	0.0	421.2	420.2	0.0	420.2
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.01	0.05	73.7	1.7	75.4	73.5	6.2	79.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.12	0.12	0.0	19.3	19.3	0.0	71.4	71.4
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.73	0.73	0.0	119.4	119.4	0.0	441.9	441.9
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.04	1.04	0.0	170.2	170.2	0.0	629.9	629.9
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.13	1.13	0.0	185.1	185.1	0.0	684.9	684.9
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.49	0.49	0.0	80.0	80.0	0.0	295.9	295.9
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.02	0.02	0.0	4.0	4.0	0.0	14.9	14.9
Nov	11.4	18.7	21.2	367	83.0	270.0	0.16	0.00	0.16	326.8	0.0	326.8	326.1	0.0	326.1
Dec	5.6	10.6	19.5	744	0.0	0.0	0.79	0.00	0.79	1603.7	0.0	1603.7	1599.9	0.0	1599.9
				3145	**3873.0**	**1742.0**	**2.84**	**3.54**	**6.38**	**5762.8**	**579.7**	**6342.5**	**5749.1**	**2145.0**	**7894.1**

WAT6	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	12.0	19.0	744	0.0	0.0	0.93	0.00	0.93	1890.5	0.0	1890.5	1886.0	0.0	1886.0
Feb	5.0	13.8	19.3	619	0.0	53.0	0.63	0.00	0.63	1284.2	0.0	1284.2	1281.1	0.0	1281.1
Mar	10.7	19.3	21.0	189	0.0	555.0	0.19	0.00	0.19	390.6	0.0	390.6	389.6	0.0	389.6
Apr	16.3	23.5	22.7	0	158.0	562.0	0.03	0.01	0.04	65.8	1.9	67.6	65.6	6.9	72.5
May	21.7	25.8	24.3	0	245.0	499.0	0.00	0.12	0.12	0.0	19.5	19.5	0.0	72.1	72.1
Jun	28.3	32.0	26.3	0	645.0	75.0	0.00	0.72	0.72	0.0	118.2	118.2	0.0	437.3	437.3
Jul	29.9	34.6	26.8	0	671.0	73.0	0.00	1.03	1.03	0.0	168.2	168.2	0.0	622.5	622.5
Aug	30.1	35.5	26.8	0	727.0	17.0	0.00	1.12	1.12	0.0	182.7	182.7	0.0	675.9	675.9
Sep	25.9	30.0	25.6	0	524.0	196.0	0.00	0.49	0.49	0.0	79.8	79.8	0.0	295.2	295.2
Oct	17.8	25.0	23.1	0	183.0	561.0	0.00	0.03	0.03	0.0	4.2	4.2	0.0	15.4	15.4
Nov	11.4	22.0	21.2	21	83.0	616.0	0.15	0.00	0.15	300.2	0.0	300.2	299.5	0.0	299.5
Dec	5.6	14.7	19.5	562	0.0	182.0	0.75	0.00	0.75	1522.3	0.0	1522.3	1518.7	0.0	1518.7
		24.0	23.0	**3088**	**3916.0**	**1756.0**	**2.69**	**3.51**	**6.20**	**5453.6**	**574.4**	**6028.0**	**5440.6**	**2125.2**	**7565.8**

Orientation 15	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf - 2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.99	0.00	1.99	4032.4	0.0	4032.4	4022.8	0.0	4022.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.46	0.00	1.46	2972.7	0.0	2972.7	2965.7	0.0	2965.7
Mar	10.7	16.0	21.0	533	0.0	211.0	0.61	0.00	0.61	1246.0	0.0	1246.0	1243.1	0.0	1243.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.01	0.17	322.8	1.4	324.2	322.0	5.3	327.3
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.17	0.17	0.0	27.7	27.7	0.0	102.5	102.5
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	1.00	1.00	0.0	163.9	163.9	0.0	606.3	606.3
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.38	1.38	0.0	226.4	226.4	0.0	837.8	837.8
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.50	1.50	0.0	245.9	245.9	0.0	909.9	909.9
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.56	0.56	0.0	91.9	91.9	0.0	340.0	340.0
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.02	0.05	61.1	2.6	63.7	61.0	9.7	70.7
Nov	11.4	18.7	21.2	367	83.0	270.0	0.56	0.00	0.56	1134.6	0.0	1134.6	1131.9	0.0	1131.9

Dec	5.6	10.6	19.5	744	0.0	0.0	1.69	0.00	1.69	3438.8	0.0	3438.8	3430.6	0.0	3430.6
	17.2	**22.8**	23.0	**3561**	**3580.0**	**1619.0**	**6.51**	**4.64**	**11.15**	**13208.4**	**759.9**	**13968.3**	**13177.0**	**2811.6**	**15988.6**
30	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf - 2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.95	0.00	1.95	3962.2	0.0	3962.2	3952.7	0.0	3952.7
Feb	5.0	10.2	19.3	672	0.0	0.0	1.43	0.00	1.43	2910.4	0.0	2910.4	2903.5	0.0	2903.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.60	0.00	0.60	1226.9	0.0	1226.9	1224.0	0.0	1224.0
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.01	0.17	331.7	1.0	332.7	330.9	3.7	334.6
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.14	0.14	0.0	23.5	23.5	0.0	86.9	86.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.93	0.93	0.0	151.4	151.4	0.0	560.2	560.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.32	1.32	0.0	215.6	215.6	0.0	797.7	797.7
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.43	1.43	0.0	234.8	234.8	0.0	868.7	868.7
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.54	0.54	0.0	88.8	88.8	0.0	328.7	328.7
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.02	0.04	56.8	2.6	59.5	56.7	9.7	66.4
Nov	11.4	18.7	21.2	367	83.0	270.0	0.53	0.00	0.53	1080.0	0.0	1080.0	1077.4	0.0	1077.4
Dec	5.6	10.6	19.5	744	0.0	0.0	1.66	0.00	1.66	3370.8	0.0	3370.8	3362.8	0.0	3362.8
	17.2		23.0	**3378**	**3650.0**	**1732.0**	**6.37**	**4.39**	**10.76**	**12938.8**	**717.8**	**13656.6**	**12908.1**	**2655.7**	**15563.8**
-15	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf - 2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.95	0.00	1.95	3961.5	0.0	3961.5	3952.1	0.0	3952.1
Feb	5.0	10.2	19.3	672	0.0	0.0	1.41	0.00	1.41	2868.4	0.0	2868.4	2861.6	0.0	2861.6
Mar	10.7	16.0	21.0	533	0.0	211.0	0.59	0.00	0.59	1191.6	0.0	1191.6	1188.8	0.0	1188.8
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.01	0.16	324.4	0.8	325.2	323.6	3.0	326.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.15	0.15	0.0	24.1	24.1	0.0	89.1	89.1
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.94	0.94	0.0	153.6	153.6	0.0	568.3	568.3
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.33	1.33	0.0	217.8	217.8	0.0	805.9	805.9

Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.45	1.45	0.0	237.1	237.1	0.0	877.2	877.2
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.54	0.54	0.0	87.8	87.8	0.0	324.9	324.9
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	59.1	1.9	61.0	58.9	7.1	66.1
Nov	11.4	18.7	21.2	367	83.0	270.0	0.53	0.00	0.53	1071.8	0.0	1071.8	1069.3	0.0	1069.3
Dec	5.6	10.6	19.5	744	0.0	0.0	1.66	0.00	1.66	3367.6	0.0	3367.6	3359.6	0.0	3359.6
				3318	**3702.0**	**1740.0**	**6.33**	**4.42**	**10.75**	**12844.4**	**723.1**	**13567.6**	**12813.9**	**2675.6**	**15489.5**

-30	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf - 2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.97	0.00	1.97	4008.0	0.0	4008.0	3998.5	0.0	3998.5
Feb	5.0	10.2	19.3	672	0.0	0.0	1.43	0.00	1.43	2899.7	0.0	2899.7	2892.8	0.0	2892.8
Mar	10.7	16.0	21.0	533	0.0	211.0	0.59	0.00	0.59	1192.8	0.0	1192.8	1190.0	0.0	1190.0
Apr	16.3	21.1	22.7	225	158.0	337.0	0.15	0.01	0.16	314.0	1.1	315.1	313.3	3.9	317.2
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.17	0.17	0.0	28.3	28.3	0.0	104.6	104.6
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	1.03	1.03	0.0	167.8	167.8	0.0	620.8	620.8
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.41	1.41	0.0	230.1	230.1	0.0	851.4	851.4
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.53	1.53	0.0	249.6	249.6	0.0	923.6	923.6
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.55	0.55	0.0	90.5	90.5	0.0	334.9	334.9
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	60.3	1.5	61.8	60.1	5.6	65.7
Nov	11.4	18.7	21.2	367	83.0	270.0	0.55	0.00	0.55	1117.7	0.0	1117.7	1115.1	0.0	1115.1
Dec	5.6	10.6	19.5	744	0.0	0.0	1.69	0.00	1.69	3429.1	0.0	3429.1	3420.9	0.0	3420.9
				3140	**3867.0**	**1753.0**	**6.41**	**4.70**	**11.11**	**13021.6**	**768.9**	**13790.5**	**12990.7**	**2844.8**	**15835.5**

WIS1	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.94	0.00	1.94	3946.3	0.0	3946.3	3936.9	0.0	3936.9
Feb	5.0	10.2	19.3	672	0.0	0.0	1.37	0.00	1.37	2778.1	0.0	2778.1	2771.5	0.0	2771.5
Mar	10.7	16.0	21.1	533	0.0	211.0	0.53	0.00	0.53	1076.9	0.0	1076.9	1074.4	0.0	1074.4
Apr	16.3	21.1	22.9	225	158.0	337.0	0.14	0.02	0.17	291.5	3.6	295.1	290.8	13.4	304.3
May	21.7	26.1	24.5	24	245.0	475.0	0.00	0.24	0.24	0.0	39.8	39.8	0.0	147.4	147.4
Jun	28.3	33.6	26.6	0	645.0	75.0	0.00	1.18	1.18	0.0	193.8	193.8	0.0	717.0	717.0
Jul	29.9	35.4	27.1	0	671.0	73.0	0.00	1.64	1.64	0.0	268.9	268.9	0.0	995.0	995.0
Aug	30.1	36.0	27.1	0	727.0	17.0	0.00	1.76	1.76	0.0	288.5	288.5	0.0	1067.5	1067.5
Sep	25.9	32.9	25.8	0	524.0	196.0	0.00	0.82	0.82	0.0	134.4	134.4	0.0	497.3	497.3
Oct	17.8	25.1	23.3	46	183.0	515.0	0.03	0.04	0.07	55.8	6.9	62.7	55.7	25.5	81.2
Nov	11.4	18.7	21.3	367	83.0	270.0	0.48	0.00	0.48	981.3	0.0	981.3	979.0	0.0	979.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.65	0.00	1.65	3340.8	0.0	3340.8	3332.8	0.0	3332.8
	17.2	**22.8**	23.0	**3420**	**3712.0**	**1628.0**	**6.14**	**5.72**	**11.86**	**12470.7**	**936.0**	**13406.7**	**12441.1**	**3463.1**	**15904.2**

2	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.90	0.00	1.90	3852.7	0.0	3852.7	3843.6	0.0	3843.6
Feb	5.0	10.2	19.3	672	0.0	0.0	1.35	0.00	1.35	2741.7	0.0	2741.7	2735.2	0.0	2735.2
Mar	10.7	16.0	21.0	533	0.0	211.0	0.53	0.00	0.53	1079.6	0.0	1079.6	1077.0	0.0	1077.0
Apr	16.3	21.1	22.7	225	158.0	337.0	0.14	0.02	0.16	293.3	2.6	295.9	292.6	9.6	302.3
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.22	0.22	0.0	35.9	35.9	0.0	132.8	132.8
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	1.04	1.04	0.0	170.6	170.6	0.0	631.1	631.1
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.47	1.47	0.0	240.2	240.2	0.0	888.6	888.6
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.59	1.59	0.0	260.1	260.1	0.0	962.3	962.3

Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.68	0.68	0.0	111.6	111.6	0.0	412.8	412.8
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.03	0.05	47.9	5.1	53.0	47.8	18.9	66.7
Nov	11.4	18.7	21.2	367	83.0	270.0	0.47	0.00	0.47	958.8	0.0	958.8	956.5	0.0	956.5
Dec	5.6	10.6	19.5	744	0.0	0.0	1.60	0.00	1.60	3253.3	0.0	3253.3	3245.5	0.0	3245.5
	17.2		23.0	**3456**	**3663.0**	**1641.0**	**6.02**	**5.05**	**11.07**	**12227.3**	**826.0**	**13053.3**	**12198.2**	**3056.2**	**15254.4**
3	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.94	0.00	1.94	3937.2	0.0	3937.2	3927.8	0.0	3927.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.41	0.00	1.41	2864.7	0.0	2864.7	2857.9	0.0	2857.9
Mar	10.7	16.0	21.0	533	0.0	211.0	0.59	0.00	0.59	1201.8	0.0	1201.8	1198.9	0.0	1198.9
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.00	0.17	331.5	0.8	332.3	330.7	2.8	333.5
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	22.0	22.0	0.0	81.3	81.3
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.90	0.90	0.0	147.6	147.6	0.0	546.3	546.3
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.29	1.29	0.0	211.5	211.5	0.0	782.4	782.4
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.41	1.41	0.0	230.5	230.5	0.0	853.0	853.0
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.53	0.53	0.0	87.4	87.4	0.0	323.3	323.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	56.8	2.4	59.2	56.7	8.8	65.5
Nov	11.4	18.7	21.2	367	83.0	270.0	0.52	0.00	0.52	1057.8	0.0	1057.8	1055.3	0.0	1055.3
Dec	5.6	10.6	19.5	744	0.0	0.0	1.65	0.00	1.65	3347.5	0.0	3347.5	3339.5	0.0	3339.5
	17.2	**22.8**	23.0	**3561**	**3580.0**	**1619.0**	**6.30**	**4.29**	**10.60**	**12797.3**	**702.2**	**13499.5**	**12766.9**	**2598.0**	**15364.9**
4	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	2.00	0.00	2.00	4068.7	0.0	4068.7	4059.1	0.0	4059.1
Feb	5.0	10.2	19.3	672	0.0	0.0	1.48	0.00	1.48	3010.1	0.0	3010.1	3002.9	0.0	3002.9
Mar	10.7	16.0	21.0	533	0.0	211.0	0.66	0.00	0.66	1339.0	0.0	1339.0	1335.8	0.0	1335.8

Apr	16.3	21.1	22.7	225	158.0	337.0	0.19	0.00	0.19	382.0	0.1	382.2	381.1	0.5	381.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	21.9	21.9	0.0	81.1	81.1
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.81	0.81	0.0	133.1	133.1	0.0	492.4	492.4
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.18	1.18	0.0	192.5	192.5	0.0	712.1	712.1
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.30	1.30	0.0	212.2	212.2	0.0	785.0	785.0
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.46	0.46	0.0	75.6	75.6	0.0	279.7	279.7
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	68.0	1.2	69.2	67.8	4.6	72.4
Nov	11.4	18.7	21.2	367	83.0	270.0	0.57	0.00	0.57	1153.2	0.0	1153.2	1150.5	0.0	1150.5
Dec	5.6	10.6	19.5	744	0.0	0.0	1.71	0.00	1.71	3472.5	0.0	3472.5	3464.3	0.0	3464.3
	17.2		23.0	**3456**	**3715.0**	**1589.0**	**6.65**	**3.89**	**10.54**	**13493.6**	**636.6**	**14130.2**	**13461.5**	**2355.4**	**15816.9**

WinT1	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.94	0.00	1.94	3932.3	0.0	3932.3	3923.0	0.0	3923.0
Feb	5.0	10.2	19.3	672	0.0	0.0	1.40	0.00	1.40	2845.7	0.0	2845.7	2838.9	0.0	2838.9
Mar	10.7	16.0	21.0	533	0.0	211.0	0.58	0.00	0.58	1178.0	0.0	1178.0	1175.2	0.0	1175.2
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.01	0.17	325.4	1.1	326.5	324.6	4.1	328.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.15	0.15	0.0	24.0	24.0	0.0	88.9	88.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.94	0.94	0.0	153.3	153.3	0.0	567.3	567.3
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.34	1.34	0.0	218.6	218.6	0.0	808.9	808.9
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.46	1.46	0.0	238.5	238.5	0.0	882.5	882.5
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.58	0.58	0.0	94.5	94.5	0.0	349.6	349.6
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.02	0.05	53.8	3.1	56.9	53.7	11.6	65.2
Nov	11.4	18.7	21.2	367	83.0	270.0	0.51	0.00	0.51	1031.4	0.0	1031.4	1029.0	0.0	1029.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.64	0.00	1.64	3337.3	0.0	3337.3	3329.4	0.0	3329.4
	17.2	**22.8**	23.0	**3561**	**3580.0**	**1619.0**	**6.26**	**4.48**	**10.74**	**12703.9**	**733.2**	**13437.1**	**12673.7**	**2712.8**	**15386.5**

WinT2	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.86	0.00	1.86	3780.5	0.0	3780.5	3771.5	0.0	3771.5
Feb	5.0	10.2	19.3	672	0.0	0.0	1.34	0.00	1.34	2727.3	0.0	2727.3	2720.8	0.0	2720.8

Mar	10.7	16.0	21.0	533	0.0	211.0	0.55	0.00	0.55	1108.8	0.0	1108.8	1106.2	0.0	1106.2
Apr	16.3	21.1	22.7	225	158.0	337.0	0.15	0.01	0.15	300.0	1.1	301.1	299.3	4.0	303.3
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.14	0.14	0.0	23.4	23.4	0.0	86.5	86.5
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.92	0.92	0.0	150.7	150.7	0.0	557.6	557.6
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.31	1.31	0.0	214.9	214.9	0.0	795.0	795.0
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.43	1.43	0.0	234.8	234.8	0.0	868.7	868.7
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.57	0.57	0.0	92.9	92.9	0.0	343.7	343.7
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.02	0.04	45.9	3.0	48.9	45.8	11.2	57.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.48	0.00	0.48	968.3	0.0	968.3	966.0	0.0	966.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.58	0.00	1.58	3206.0	0.0	3206.0	3198.4	0.0	3198.4
	17.2		23.0	**3534**	**3591.0**	**1635.0**	**5.98**	**4.40**	**10.38**	**12136.8**	**720.7**	**12857.5**	**12107.9**	**2666.7**	**14774.6**
WinT3	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.91	0.00	1.91	3881.0	0.0	3881.0	3871.7	0.0	3871.7
Feb	5.0	10.2	19.3	672	0.0	0.0	1.38	0.00	1.38	2803.0	0.0	2803.0	2796.4	0.0	2796.4
Mar	10.7	16.0	21.0	533	0.0	211.0	0.57	0.00	0.57	1151.2	0.0	1151.2	1148.5	0.0	1148.5
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.01	0.16	316.1	1.1	317.2	315.3	4.2	319.6
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.15	0.15	0.0	24.2	24.2	0.0	89.5	89.5
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.94	0.94	0.0	153.6	153.6	0.0	568.2	568.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.34	1.34	0.0	218.7	218.7	0.0	809.2	809.2
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.46	1.46	0.0	238.7	238.7	0.0	883.2	883.2
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.58	0.58	0.0	95.0	95.0	0.0	351.3	351.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.02	0.04	51.0	3.2	54.1	50.8	11.8	62.6
Nov	11.4	18.7	21.2	367	83.0	270.0	0.50	0.00	0.50	1008.1	0.0	1008.1	1005.7	0.0	1005.7
Dec	5.6	10.6	19.5	744	0.0	0.0	1.62	0.00	1.62	3291.4	0.0	3291.4	3283.6	0.0	3283.6
	17.2	**22.8**	23.0	**3546**	**3591.0**	**1623.0**	**6.16**	**4.49**	**10.65**	**12501.8**	**734.4**	**13236.2**	**12472.0**	**2717.5**	**15189.5**
WinT4	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.84	0.00	1.84	3728.9	0.0	3728.9	3720.0	0.0	3720.0
Feb	5.0	10.2	19.3	672	0.0	0.0	1.32	0.00	1.32	2684.7	0.0	2684.7	2678.3	0.0	2678.3
Mar	10.7	16.0	21.0	533	0.0	211.0	0.53	0.00	0.53	1082.2	0.0	1082.2	1079.6	0.0	1079.6
Apr	16.3	21.1	22.7	225	158.0	337.0	0.14	0.01	0.15	290.9	1.1	292.0	290.2	4.2	294.4
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.14	0.14	0.0	23.5	23.5	0.0	87.1	87.1

Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.92	0.92	0.0	151.0	151.0	0.0	558.5	558.5
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.31	1.31	0.0	214.9	214.9	0.0	795.3	795.3
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.44	1.44	0.0	235.0	235.0	0.0	869.4	869.4
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.57	0.57	0.0	93.4	93.4	0.0	345.5	345.5
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.02	0.04	43.2	3.1	46.3	43.1	11.4	54.6
Nov	11.4	18.7	21.2	367	83.0	270.0	0.47	0.00	0.47	945.2	0.0	945.2	942.9	0.0	942.9
Dec	5.6	10.6	19.5	744	0.0	0.0	1.56	0.00	1.56	3160.1	0.0	3160.1	3152.6	0.0	3152.6
	17.2		23.0	**3515**	**3602.0**	**1643.0**	**5.88**	**4.41**	**10.29**	**11935.2**	**722.0**	**12657.2**	**11906.8**	**2671.4**	**14578.2**

WinT5	Day Tem	Mean I Tem	Tcomfort	hours lessTcomf -2	Hours above Tcomf +2	Hours withinTcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.87	0.00	1.87	3797.7	0.0	3797.7	3788.7	0.0	3788.7
Feb	5.0	10.2	19.3	672	0.0	0.0	1.36	0.00	1.36	2755.7	0.0	2755.7	2749.2	0.0	2749.2
Mar	10.7	16.0	21.0	533	0.0	211.0	0.56	0.00	0.56	1145.9	0.0	1145.9	1143.2	0.0	1143.2
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.00	0.16	316.1	0.6	316.7	315.3	2.3	317.6
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	20.7	20.7	0.0	76.4	76.4
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.87	0.87	0.0	143.0	143.0	0.0	529.2	529.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.26	1.26	0.0	205.9	205.9	0.0	761.7	761.7
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.38	1.38	0.0	225.8	225.8	0.0	835.3	835.3
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.52	0.52	0.0	85.8	85.8	0.0	317.6	317.6
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.01	0.04	49.3	2.4	51.7	49.2	8.9	58.1
Nov	11.4	18.7	21.2	367	83.0	270.0	0.49	0.00	0.49	994.5	0.0	994.5	992.1	0.0	992.1
Dec	5.6	10.6	19.5	744	0.0	0.0	1.59	0.00	1.59	3222.0	0.0	3222.0	3214.4	0.0	3214.4
	17.2	**22.8**	23.0	**3572**	**3554.0**	**1634.0**	**6.05**	**4.18**	**10.23**	**12281.3**	**684.1**	**12965.4**	**12252.1**	**2531.3**	**14783.4**

WinT6	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.80	0.00	1.80	3645.5	0.0	3645.5	3636.8	0.0	3636.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.30	0.00	1.30	2637.2	0.0	2637.2	2630.9	0.0	2630.9
Mar	10.7	16.0	21.0	533	0.0	211.0	0.53	0.00	0.53	1076.5	0.0	1076.5	1073.9	0.0	1073.9
Apr	16.3	21.1	22.7	225	158.0	337.0	0.14	0.00	0.15	290.7	0.6	291.3	290.0	2.2	292.2
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.12	0.12	0.0	20.0	20.0	0.0	73.9	73.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.86	0.86	0.0	140.3	140.3	0.0	519.2	519.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.23	1.23	0.0	202.0	202.0	0.0	747.3	747.3
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.36	1.36	0.0	221.9	221.9	0.0	821.1	821.1
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.51	0.51	0.0	84.2	84.2	0.0	311.4	311.4
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.01	0.03	41.6	2.3	43.9	41.5	8.5	50.1

Nov	11.4	18.7	21.2	367	83.0	270.0	0.46	0.00	0.46	931.6	0.0	931.6	929.4	0.0	929.4
Dec	5.6	10.6	19.5	744	0.0	0.0	1.52	0.00	1.52	3090.7	0.0	3090.7	3083.3	0.0	3083.3
	17.2		23.0	**3544**	**3571.0**	**1645.0**	**5.77**	**4.10**	**9.87**	**11713.7**	**671.3**	**12385.0**	**11685.9**	**2483.7**	**14169.6**

WinT7	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.85	0.00	1.85	3751.8	0.0	3751.8	3742.9	0.0	3742.9
Feb	5.0	10.2	19.3	672	0.0	0.0	1.34	0.00	1.34	2717.8	0.0	2717.8	2711.3	0.0	2711.3
Mar	10.7	16.0	21.0	533	0.0	211.0	0.55	0.00	0.55	1122.0	0.0	1122.0	1119.3	0.0	1119.3
Apr	16.3	21.1	22.7	225	158.0	337.0	0.15	0.00	0.16	308.0	0.7	308.6	307.2	2.4	309.6
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	20.8	20.8	0.0	76.9	76.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.88	0.88	0.0	143.2	143.2	0.0	530.0	530.0
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.26	1.26	0.0	205.9	205.9	0.0	762.0	762.0
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.38	1.38	0.0	225.9	225.9	0.0	836.0	836.0
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.53	0.53	0.0	86.3	86.3	0.0	319.1	319.1
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.02	0.04	46.9	2.5	49.3	46.8	9.1	55.9
Nov	11.4	18.7	21.2	367	83.0	270.0	0.48	0.00	0.48	973.6	0.0	973.6	971.3	0.0	971.3
Dec	5.6	10.6	19.5	744	0.0	0.0	1.57	0.00	1.57	3180.8	0.0	3180.8	3173.2	0.0	3173.2
	17.2	**22.8**	23.0	**3559**	**3561.0**	**1640.0**	**5.96**	**4.19**	**10.15**	**12100.8**	**685.3**	**12786.1**	**12072.1**	**2535.5**	**14607.5**

WinT8	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.77	0.00	1.77	3599.4	0.0	3599.4	3590.8	0.0	3590.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.28	0.00	1.28	2599.2	0.0	2599.2	2593.0	0.0	2593.0
Mar	10.7	16.0	21.0	533	0.0	211.0	0.52	0.00	0.52	1053.0	0.0	1053.0	1050.5	0.0	1050.5
Apr	16.3	21.1	22.7	225	158.0	337.0	0.14	0.00	0.14	282.6	0.6	283.2	281.9	2.4	284.3
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.12	0.12	0.0	20.1	20.1	0.0	74.3	74.3
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.86	0.86	0.0	140.6	140.6	0.0	520.1	520.1
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.23	1.23	0.0	202.1	202.1	0.0	747.6	747.6
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.36	1.36	0.0	222.1	222.1	0.0	821.7	821.7
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.52	0.52	0.0	84.6	84.6	0.0	313.0	313.0
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.01	0.03	39.4	2.4	41.8	39.3	8.8	48.1
Nov	11.4	18.7	21.2	367	83.0	270.0	0.45	0.00	0.45	910.9	0.0	910.9	908.7	0.0	908.7
Dec	5.6	10.6	19.5	744	0.0	0.0	1.50	0.00	1.50	3049.3	0.0	3049.3	3042.0	0.0	3042.0
	17.2		23.0	**3527**	**3579.0**	**1654.0**	**5.68**	**4.11**	**9.79**	**11533.6**	**672.4**	**12206.0**	**11506.2**	**2487.9**	**13994.1**

Overh 47	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.95	0.00	1.95	3948.6	0.0	3948.6	3939.2	0.0	3939.2
Feb	5.0	10.2	19.3	672	0.0	0.0	1.41	0.00	1.41	2865.5	0.0	2865.5	2858.7	0.0	2858.7
Mar	10.7	16.0	21.0	533	0.0	211.0	0.60	0.00	0.60	1220.6	0.0	1220.6	1217.7	0.0	1217.7
Apr	16.3	21.1	22.7	225	158.0	337.0	0.17	0.00	0.17	347.5	0.6	348.1	346.7	2.2	349.0
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	21.5	21.5	0.0	79.7	79.7
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.90	0.90	0.0	146.7	146.7	0.0	542.7	542.7
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.29	1.29	0.0	210.9	210.9	0.0	780.4	780.4
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.38	1.38	0.0	226.3	226.3	0.0	837.3	837.3
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.53	0.53	0.0	86.3	86.3	0.0	319.3	319.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.02	0.04	55.6	2.8	58.4	55.5	10.2	65.7
Nov	11.4	18.7	21.2	367	83.0	270.0	0.51	0.00	0.51	1040.2	0.0	1040.2	1037.7	0.0	1037.7
Dec	5.6	10.6	19.5	744	0.0	0.0	1.65	0.00	1.65	3351.9	0.0	3351.9	3344.0	0.0	3344.0
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**6.32**	**4.25**	**10.57**	**12830.0**	**695.1**	**13525.1**	**12799.5**	**2572.0**	**15371.5**

60	Day Tem	Mean I Tem	Tcomfort	hours less Tcomf -2	Hours above Tcomf +2	Hours within Tcomf	Sensible heating load (Mwh)	Sensible cooling loads	Total loads	Natural gas energy (Kwh)	Electricity Energy (Kwh)	total energy	Primary Energy Natural gas	Primary Energy Electricity	Total primary Energy
Jan	3.9	8.5	19.0	744	0.0	0.0	1.95	0.00	1.95	3954.2	0.0	3954.2	3944.8	0.0	3944.8
Feb	5.0	10.2	19.3	672	0.0	0.0	1.43	0.00	1.43	2894.4	0.0	2894.4	2887.5	0.0	2887.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.62	0.00	0.62	1249.5	0.0	1249.5	1246.5	0.0	1246.5
Apr	16.3	21.1	22.7	225	158.0	337.0	0.18	0.00	0.18	357.7	0.4	358.1	356.8	1.6	358.5
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	21.0	21.0	0.0	77.6	77.6
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.89	0.89	0.0	146.1	146.1	0.0	540.7	540.7
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.28	1.28	0.0	210.1	210.1	0.0	777.3	777.3
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.36	1.36	0.0	222.5	222.5	0.0	823.3	823.3
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.50	0.50	0.0	82.2	82.2	0.0	304.1	304.1

Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	58.1	2.4	60.4	57.9	8.8	66.8
Nov	11.4	18.7	21.2	367	83.0	270.0	0.52	0.00	0.52	1045.9	0.0	1045.9	1043.4	0.0	1043.4
Dec	5.6	10.6	19.5	744	0.0	0.0	1.65	0.00	1.65	3357.0	0.0	3357.0	3349.0	0.0	3349.0
	17.2		23.0	**3626**	**3537.0**	**1597.0**	**6.36**	**4.18**	**10.55**	**12916.7**	**684.7**	**13601.4**	**12886.0**	**2533.4**	**15419.4**

90	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.97	0.00	1.97	4004.6	0.0	4004.6	3995.1	0.0	3995.1
Feb	5.0	10.2	19.3	672	0.0	0.0	1.46	0.00	1.46	2967.0	0.0	2967.0	2960.0	0.0	2960.0
Mar	10.7	16.0	21.0	533	0.0	211.0	0.65	0.00	0.65	1313.4	0.0	1313.4	1310.3	0.0	1310.3
Apr	16.3	21.1	22.7	225	158.0	337.0	0.19	0.00	0.19	379.0	0.2	379.2	378.1	0.8	378.9
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.13	0.13	0.0	20.5	20.5	0.0	75.9	75.9
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.89	0.89	0.0	145.4	145.4	0.0	538.1	538.1
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.28	1.28	0.0	208.8	208.8	0.0	772.5	772.5
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.33	1.33	0.0	217.8	217.8	0.0	806.0	806.0
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.45	0.45	0.0	73.8	73.8	0.0	272.9	272.9
Oct	17.8	25.1	23.1	46	183.0	515.0	0.03	0.01	0.04	64.1	1.6	65.8	64.0	6.1	70.1
Nov	11.4	18.7	21.2	367	83.0	270.0	0.54	0.00	0.54	1088.7	0.0	1088.7	1086.1	0.0	1086.1
Dec	5.6	10.6	19.5	744	0.0	0.0	1.67	0.00	1.67	3396.6	0.0	3396.6	3388.5	0.0	3388.5
	17.2	**22.8**	23.0	**3682**	**3494.0**	**1584.0**	**6.51**	**4.08**	**10.59**	**13213.5**	**668.2**	**13881.7**	**13182.1**	**2472.3**	**15654.4**

OH47- free run	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.03	0.00	1.03	2099.4	0.0	2099.4	2094.4	0.0	2094.4
Feb	5.0	10.2	19.3	672	0.0	0.0	0.70	0.00	0.70	1415.1	0.0	1415.1	1411.7	0.0	1411.7
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	433.8	0.0	433.8	432.8	0.0	432.8

Apr	16.3	21.1	22.7	225	158.0	337.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.57	0.57	0.0	92.7	92.7	0.0	343.2	343.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.84	0.84	0.0	137.6	137.6	0.0	509.2	509.2
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.89	0.89	0.0	144.9	144.9	0.0	536.3	536.3
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.38	0.38	0.0	62.4	62.4	0.0	230.8	230.8
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Dec	5.6	10.6	19.5	744	0.0	0.0	0.84	0.00	0.84	1701.5	0.0	1701.5	1697.5	0.0	1697.5
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**2.95**	**2.67**	**5.63**	**5649.9**	**437.7**	**6087.6**	**5636.5**	**1619.4**	**7255.9**

OH60- free run	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.04	0.00	1.04	2104.5	0.0	2104.5	2099.5	0.0	2099.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.70	0.00	0.70	1420.4	0.0	1420.4	1417.0	0.0	1417.0
Mar	10.7	16.0	21.0	533	0.0	211.0	0.22	0.00	0.22	453.5	0.0	453.5	452.4	0.0	452.4
Apr	16.3	21.1	22.7	225	158.0	337.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.56	0.56	0.0	92.2	92.2	0.0	341.2	341.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.83	0.83	0.0	136.6	136.6	0.0	505.5	505.5
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.86	0.86	0.0	140.7	140.7	0.0	520.8	520.8
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.35	0.35	0.0	57.6	57.6	0.0	213.1	213.1
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Dec	5.6	10.6	19.5	744	0.0	0.0	0.84	0.00	0.84	1706.0	0.0	1706.0	1702.0	0.0	1702.0
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**2.97**	**2.61**	**5.58**	**5684.4**	**427.2**	**6111.6**	**5670.9**	**1580.5**	**7251.4**

OH90- free run	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.05	0.00	1.05	2125.8	0.0	2125.8	2120.8	0.0	2120.8
Feb	5.0	10.2	19.3	672	0.0	0.0	0.73	0.00	0.73	1486.0	0.0	1486.0	1482.4	0.0	1482.4
Mar	10.7	16.0	21.0	533	0.0	211.0	0.25	0.00	0.25	507.1	0.0	507.1	505.9	0.0	505.9
Apr	16.3	21.1	22.7	225	158.0	337.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.56	0.56	0.0	91.2	91.2	0.0	337.6	337.6
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.83	0.83	0.0	135.2	135.2	0.0	500.3	500.3
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.83	0.83	0.0	135.0	135.0	0.0	499.6	499.6
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.29	0.29	0.0	47.4	47.4	0.0	175.3	175.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Nov	11.4	18.7	21.2	367	83.0	270.0	0.00	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Dec	5.6	10.6	19.5	744	0.0	0.0	0.85	0.00	0.85	1720.4	0.0	1720.4	1716.3	0.0	1716.3
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**3.06**	**2.50**	**5.56**	**5839.3**	**408.9**	**6248.2**	**5825.4**	**1512.9**	**7338.3**

Vent 24-8 50%	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.93	0.00	1.93	3918.5	0.0	3918.5	3909.2	0.0	3909.2
Feb	5.0	10.2	19.3	672	0.0	0.0	1.40	0.00	1.40	2834.3	0.0	2834.3	2827.5	0.0	2827.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.58	0.00	0.58	1172.9	0.0	1172.9	1170.1	0.0	1170.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.02	0.18	322.8	3.9	326.6	322.0	14.3	336.4
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.18	0.18	0.0	29.8	29.8	0.0	110.4	110.4

Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.83	0.83	0.0	135.7	135.7	0.0	502.0	502.0
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.12	1.12	0.0	183.2	183.2	0.0	677.9	677.9
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.20	1.20	0.0	195.8	195.8	0.0	724.6	724.6
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.60	0.60	0.0	98.2	98.2	0.0	363.4	363.4
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.05	0.07	44.1	8.0	52.1	43.9	29.7	73.6
Nov	11.4	18.7	21.2	367	83.0	270.0	0.50	0.00	0.50	1018.5	0.0	1018.5	1016.0	0.0	1016.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.64	0.00	1.64	3323.7	0.0	3323.7	3315.8	0.0	3315.8
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**6.22**	**4.00**	**10.22**	**12634.7**	**654.7**	**13289.4**	**12604.7**	**2422.3**	**15027.0**
Vent 24-8 75%	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.93	0.00	1.93	3918.5	0.0	3918.5	3909.2	0.0	3909.2
Feb	5.0	10.2	19.3	672	0.0	0.0	1.40	0.00	1.40	2834.3	0.0	2834.3	2827.5	0.0	2827.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.58	0.00	0.58	1172.9	0.0	1172.9	1170.1	0.0	1170.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.02	0.18	322.8	3.6	326.4	322.0	13.4	335.4
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.17	0.17	0.0	27.8	27.8	0.0	102.8	102.8
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.79	0.79	0.0	129.4	129.4	0.0	478.7	478.7
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.08	1.08	0.0	176.9	176.9	0.0	654.6	654.6
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.16	1.16	0.0	189.1	189.1	0.0	699.7	699.7
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.57	0.57	0.0	92.5	92.5	0.0	342.2	342.2
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.05	0.07	44.1	7.9	51.9	43.9	29.1	73.1
Nov	11.4	18.7	21.2	367	83.0	270.0	0.50	0.00	0.50	1018.5	0.0	1018.5	1016.0	0.0	1016.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.64	0.00	1.64	3323.7	0.0	3323.7	3315.8	0.0	3315.8
	17.2		23.0	**3626**	**3537.0**	**1597.0**	**6.22**	**3.83**	**10.06**	**12634.7**	**627.2**	**13261.9**	**12604.7**	**2320.5**	**14925.2**
100vent 24-624/06/2017	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours lessTcomf -2**	**Hours above Tcomf +2**	**Hours withinTcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**

Jan	3.9	8.5	19.0	744	0.0	0.0	1.93	0.00	1.93	3918.5	0.0	3918.5	3909.2	0.0	3909.2
Feb	5.0	10.2	19.3	672	0.0	0.0	1.40	0.00	1.40	2834.3	0.0	2834.3	2827.5	0.0	2827.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.58	0.00	0.58	1172.9	0.0	1172.9	1170.1	0.0	1170.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.02	0.18	322.8	3.4	326.2	322.0	12.7	334.7
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.16	0.16	0.0	26.4	26.4	0.0	97.8	97.8
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.77	0.77	0.0	125.2	125.2	0.0	463.2	463.2
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.06	1.06	0.0	172.8	172.8	0.0	639.2	639.2
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.13	1.13	0.0	184.5	184.5	0.0	682.5	682.5
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.54	0.54	0.0	88.7	88.7	0.0	328.3	328.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.05	0.07	44.1	7.8	51.8	43.9	28.7	72.6
Nov	11.4	18.7	21.2	367	83.0	270.0	0.50	0.00	0.50	1018.5	0.0	1018.5	1016.0	0.0	1016.0
Dec	5.6	10.6	19.5	744	0.0	0.0	1.64	0.00	1.64	3323.7	0.0	3323.7	3315.8	0.0	3315.8
	17.2	**22.8**	23.0	**3682**	**3494.0**	**1584.0**	**6.22**	**3.72**	**9.94**	**12634.7**	**608.8**	**13243.5**	**12604.7**	**2252.5**	**14857.2**

WAT4	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.93	0.00	1.93	3918.5	0.0	3918.5	3909.2	0.0	3909.2
Feb	5.0	10.2	19.3	672	0.0	0.0	1.40	0.00	1.40	2834.3	0.0	2834.3	2827.5	0.0	2827.5
Mar	10.7	16.0	21.0	533	0.0	211.0	0.58	0.00	0.58	1172.9	0.0	1172.9	1170.1	0.0	1170.1
Apr	16.3	21.1	22.7	225	158.0	337.0	0.16	0.02	0.18	322.8	4.0	326.8	322.0	14.8	336.8
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.18	0.18	0.0	28.8	28.8	0.0	106.7	106.7
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.89	0.89	0.0	145.4	145.4	0.0	537.8	537.8
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.23	1.23	0.0	201.0	201.0	0.0	743.6	743.6
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.32	1.32	0.0	215.5	215.5	0.0	797.4	797.4
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.65	0.65	0.0	105.6	105.6	0.0	390.6	390.6
Oct	17.8	25.1	23.1	46	183.0	515.0	0.02	0.14	0.16	47.3	23.0	70.3	47.2	85.1	132.3
Nov	11.4	18.7	21.2	367	83.0	270.0	0.51	0.02	0.53	1025.2	4.0	1029.2	1022.7	14.8	1037.5
Dec	5.6	10.6	19.5	744	0.0	0.0	1.64	0.00	1.64	3323.7	0.0	3323.7	3315.8	0.0	3315.8

	17.2		23.0	**3578**	**3424.0**	**1758.0**	**6.23**	**4.44**	**10.67**	**12644.7**	**727.2**	**13371.9**	**12614.6**	**2690.8**	**15305.4**

Curtain	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.03	0.00	1.03	2087.4	0.0	2087.4	2082.5	0.0	2082.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.69	0.00	0.69	1401.9	0.0	1401.9	1398.6	0.0	1398.6
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	419.8	0.0	419.8	418.8	0.0	418.8
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.00	0.04	71.7	0.1	71.8	71.5	0.4	71.9
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.11	0.11	0.0	17.9	17.9	0.0	66.2	66.2
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.65	0.65	0.0	106.2	106.2	0.0	393.0	393.0
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.94	0.94	0.0	153.7	153.7	0.0	568.6	568.6
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.99	0.99	0.0	162.1	162.1	0.0	599.7	599.7
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.30	0.30	0.0	49.3	49.3	0.0	182.4	182.4
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.01	0.01	0.0	1.6	1.6	0.0	5.8	5.8
Nov	11.4	18.7	21.2	367	83.0	270.0	0.17	0.00	0.17	340.2	0.0	340.2	339.4	0.0	339.4
Dec	5.6	10.6	19.5	744	0.0	0.0	0.83	0.00	0.83	1690.6	0.0	1690.6	1686.6	0.0	1686.6
	17.2		23.0	**3649**	**3517.0**	**1594.0**	**2.96**	**3.00**	**5.96**	**6011.6**	**490.8**	**6502.4**	**5997.4**	**1815.9**	**7813.3**

Shutter	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.03	0.00	1.03	2087.4	0.0	2087.4	2082.5	0.0	2082.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.69	0.00	0.69	1401.9	0.0	1401.9	1398.6	0.0	1398.6
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	419.8	0.0	419.8	418.8	0.0	418.8
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.00	0.04	71.7	0.0	71.7	71.5	0.1	71.6
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.09	0.09	0.0	14.2	14.2	0.0	52.4	52.4
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.58	0.58	0.0	94.5	94.5	0.0	349.7	349.7

Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.85	0.85	0.0	139.0	139.0	0.0	514.4	514.4
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.87	0.87	0.0	141.7	141.7	0.0	524.1	524.1
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.20	0.20	0.0	33.0	33.0	0.0	122.1	122.1
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.00	0.00	0.0	0.1	0.1	0.0	0.5	0.5
Nov	11.4	18.7	21.2	367	83.0	270.0	0.17	0.00	0.17	340.2	0.0	340.2	339.4	0.0	339.4
Dec	5.6	10.6	19.5	744	0.0	0.0	0.83	0.00	0.83	1690.6	0.0	1690.6	1686.6	0.0	1686.6
	17.2		23.0	**3626**	**3537.0**	**1597.0**	**2.96**	**2.58**	**5.54**	**6011.6**	**422.5**	**6434.2**	**5997.4**	**1563.3**	**7560.6**

Removable	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.03	0.00	1.03	2087.4	0.0	2087.4	2082.5	0.0	2082.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.69	0.00	0.69	1401.9	0.0	1401.9	1398.6	0.0	1398.6
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	419.8	0.0	419.8	418.8	0.0	418.8
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.00	0.04	71.7	0.3	71.9	71.5	1.0	72.5
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.14	0.14	0.0	22.3	22.3	0.0	82.3	82.3
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.74	0.74	0.0	120.4	120.4	0.0	445.6	445.6
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	1.05	1.05	0.0	172.1	172.1	0.0	636.8	636.8
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	1.07	1.07	0.0	175.3	175.3	0.0	648.6	648.6
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.34	0.34	0.0	56.3	56.3	0.0	208.3	208.3
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.01	0.01	0.0	1.5	1.5	0.0	5.6	5.6
Nov	11.4	18.7	21.2	367	83.0	270.0	0.17	0.00	0.17	340.2	0.0	340.2	339.4	0.0	339.4
Dec	5.6	10.6	19.5	744	0.0	0.0	0.83	0.00	0.83	1690.6	0.0	1690.6	1686.6	0.0	1686.6
	17.2	**22.8**	23.0	**3682**	**3494.0**	**1584.0**	**2.96**	**3.35**	**6.31**	**6011.6**	**548.2**	**6559.8**	**5997.4**	**2028.2**	**8025.6**

Removable & Curtain	**Day Tem**	**Mean I Tem**	**Tcomfort**	**hours less Tcomf -2**	**Hours above Tcomf +2**	**Hours within Tcomf**	**Sensible heating load (Mwh)**	**Sensible cooling loads**	**Total loads**	**Natural gas energy (Kwh)**	**Electricity Energy (Kwh)**	**total energy**	**Primary Energy Natural gas**	**Primary Energy Electricity**	**Total primary Energy**
Jan	3.9	8.5	19.0	744	0.0	0.0	1.03	0.00	1.03	2087.4	0.0	2087.4	2082.5	0.0	2082.5
Feb	5.0	10.2	19.3	672	0.0	0.0	0.69	0.00	0.69	1401.9	0.0	1401.9	1398.6	0.0	1398.6
Mar	10.7	16.0	21.0	533	0.0	211.0	0.21	0.00	0.21	419.8	0.0	419.8	418.8	0.0	418.8
Apr	16.3	21.1	22.7	225	158.0	337.0	0.04	0.00	0.04	71.7	0.0	71.7	71.5	0.0	71.5
May	21.7	26.1	24.3	24	245.0	475.0	0.00	0.10	0.10	0.0	15.8	15.8	0.0	58.5	58.5
Jun	28.3	33.6	26.3	0	645.0	75.0	0.00	0.62	0.62	0.0	101.7	101.7	0.0	376.1	376.1
Jul	29.9	35.4	26.8	0	671.0	73.0	0.00	0.91	0.91	0.0	148.5	148.5	0.0	549.4	549.4
Aug	30.1	36.0	26.8	0	727.0	17.0	0.00	0.93	0.93	0.0	152.1	152.1	0.0	562.9	562.9
Sep	25.9	32.9	25.6	0	524.0	196.0	0.00	0.23	0.23	0.0	37.6	37.6	0.0	139.1	139.1
Oct	17.8	25.1	23.1	46	183.0	515.0	0.00	0.00	0.00	0.0	0.1	0.1	0.0	0.4	0.4
Nov	11.4	18.7	21.2	367	83.0	270.0	0.17	0.00	0.17	340.2	0.0	340.2	339.4	0.0	339.4
Dec	5.6	10.6	19.5	744	0.0	0.0	0.83	0.00	0.83	1690.6	0.0	1690.6	1686.6	0.0	1686.6
	17.2	**22.8**	23.0	**3682**	**3494.0**	**1584.0**	**2.96**	**2.79**	**5.75**	**6011.6**	**455.8**	**6467.4**	**5997.4**	**1686.4**	**7683.8**

مهلت پرداخت مشمول بدهی قبلی نمی باشد

کد اقتصادی : ۴۱۱۱-۵۶۴۵-۴۳۵۱

مشترک محترم: سیدمجتبی خضرایی ۱۰۱۱
نشانی: شریعتی مقابل پارک شریعتی کوچه پیروز
کدپستی: ۱۶۶۱۷۳۹۷۷۶ پلاک: ۳۷ تعدادخانوار: ۱
پرونده: ۷۱۱۸۶۱/۹ شناسایی: ۲/۰۶/۲۱۳۱۳/۱۰/۲۴۶۵۰
رمزرایانه: ۰۳۰۶۱۹۱/۴ بدنه کنتور: ۱۰۶۱۹۱۶۶
تعرفه : خانگی(۱-۱) (۱۰۱۰) نوع فعالیت: ۱۰۰۱
تاریخ نصب اولیه: ۵۴/۰۲/۱۷ فاز/آمپر: ۱۵/۱
تاریخ آخرین تعویض: ارقام/ضریب ۱/۵
تاریخ انقضای پروانه: نحوه قرائت مامور ۰۰

مصرف ۶۰ روز	۱	۲	۳	۴	۵	۶
سال گذشته				۴۴۹	۳۷۱	۳۳۴
سال جاری	۳۹۴	۳۷۷	۵۷۸	۴۶۰	۴۴۸	

تاریخ صدور: ۹۴/۰۹/۰۹ مراجعه بعدی: ۹۴/۱۰/۲۳

منطقه برق پاسداران

شرح	تاریخ	میان بار	اوج بار	کم بار	دوره
قرائت کنونی:	۹۴/۰۹/۰۱	۱۳۰۱۲	۰	۰	۹۴ ۵
قرائت پیشین:	۹۴/۰۷/۰۵	۱۲۵۹۳	۰	۰	
مصرف(kwh)		۴۱۹	۰	۰	

مصرف کل دوره: ۴۱۹ متوسط مصرف ۳۰ روزه: ۲۲۴/۴۶ تعداد روز دوره ۵۶

پله های مصرف ۳۰ روزه	نرخ (ریال)	مصرف ۳۰ روزه	مبلغ ۳۰ روزه	فرمول محاسبه و مبلغ
مصرف ۰ تا ۱۰۰	۴۰۹	۱۰۰	۴۰۹۰۰	تعداد روز * (۳۰ / مبالغ ماهانه) ۵۶ (۳۰ / ۱۱۳۶۲۷) مبلغ مصرف(ریال) ۲۱۲۱۰۳
مازاد بر ۱۰۰ تا ۲۰۰	۴۷۷	۱۰۰	۴۷۷۰۰	
مازاد بر ۲۰۰ تا ۳۰۰	۱۰۲۳	۲۴/۴۶	۲۵۰۲۷	
مازاد بر ۳۰۰ تا ۴۰۰	۱۸۴۱	۰	۰	
مازاد بر ۴۰۰ تا ۵۰۰	۲۱۱۴	۰	۰	
مازاد بر ۵۰۰ تا ۶۰۰	۲۶۶۰	۰	۰	
مازاد بر ۶۰۰	۲۹۳۳	۰	۰	

شرح مصرف	نرخ(ریال)	مصرف	شرح مبلغ	مبلغ
میزان مصرف در اوج بار	۴۰۹		هزینه مصرف اوج بار	
میزان مصرف در کم باری	۲۰۵		تخفیف مصرف کم باری	

۲۲۲۸۲۳۸۲ پاسخگویی صورتحساب: ۲۲۲۸۸۱۹۹

عنوان	مبلغ(ریال)
مبلغ مصرف	۲۱۲۱۰۳
آبونمان	۱۸۶۶۶
بهای برق دوره	۲۳۰۷۶۹
مالیات بر ارزش افزوده	۲۰۷۶۹
مبلغ بیمه	۴۶۶
عوارض برق	۱۲۵۷۰
بدهکاری	۹۹۵
کسر هزار ریال	۵۶۹

مبلغ قابل پرداخت: ۲۶۵۰۰۰

مهلت پرداخت: ۹۴/۰۹/۲۴

شرکت توزیع نیروی برق تهران بزرگ * با تشکر از پرداخت غیر حضوری - الکترونیکی صورتحساب دوره پیشین خود.

مهلت پرداخت مشمول بدهی قبلی نمی باشد

کد اقتصادی : ۴۱۱۱-۵۶۴۵-۴۳۵۱

مشترک محترم: سیدمجتبی خضرایی ۲۹۹۷
نشانی: شریعتی مقابل پارک شریعتی کوچه پیروز
کدپستی: ۱۶۶۱۷۳۹۷۷۶ پلاک: ۳۷ تعدادخانوار: ۱
پرونده: ۷۱۱۸۶۱/۹ شناسایی: ۲/۰۶/۲۱۳۱۳/۱۰/۲۴۶۵۰
رمزرایانه: ۰۳۰۶۱۹۱/۴ بدنه کنتور: ۱۰۶۱۹۱۶۶
تعرفه : خانگی(۱-۱) (۱۰۱۰) نوع فعالیت: ۱۰۰۱
تاریخ نصب اولیه: ۵۴/۰۲/۱۷ فاز/آمپر: ۱۵/۱
تاریخ آخرین تعویض: ارقام/ضریب ۱/۵
تاریخ انقضای پروانه: نحوه قرائت مامور ۰۰

مصرف ۶۰ روز	۱	۲	۳	۴	۵	۶
سال گذشته			۵۰۹	۴۴۹	۳۷۱	۳۳۴
سال جاری	۳۹۴	۳۷۷	۵۷۸	۴۶۰		

تاریخ صدور: ۹۴/۰۷/۱۲ مراجعه بعدی: ۹۴/۰۹/۰۲

منطقه برق پاسداران

آدرس: چهارراه فرمانیه-خ موحد دانش-سه راه نسترن

شرح	تاریخ	میان بار	اوج بار	کم بار	دوره
قرائت کنونی:	۹۴/۰۷/۰۵	۱۲۵۹۳	۰	۰	۹۴-۴
قرائت پیشین:	۹۴/۰۵/۱۰	۱۲۱۵۶	۰	۰	
مصرف(kwh)		۴۳۷	۰	۰	

مصرف کل دوره: ۴۳۷ متوسط مصرف ۳۰ روزه: ۲۳۰ تعداد روز دوره ۵۷

پله های مصرف ۳۰ روزه	نرخ (ریال)	مصرف ۳۰ روزه	مبلغ ۳۰ روزه	فرمول محاسبه و مبلغ
مصرف ۰ تا ۱۰۰	۴۰۹	۱۰۰	۴۰۹۰۰	تعداد روز * (۳۰ / مبالغ ماهانه) ۵۷ (۳۰ / ۱۱۹۲۹۰) مبلغ مصرف(ریال) ۲۲۶۶۵۱
مازاد بر ۱۰۰ تا ۲۰۰	۴۷۷	۱۰۰	۴۷۷۰۰	
مازاد بر ۲۰۰ تا ۳۰۰	۱۰۲۳	۳۰	۳۰۶۹۰	
مازاد بر ۳۰۰ تا ۴۰۰	۱۸۴۱	۰	۰	
مازاد بر ۴۰۰ تا ۵۰۰	۲۱۱۴	۰	۰	
مازاد بر ۵۰۰ تا ۶۰۰	۲۶۶۰	۰	۰	
مازاد بر ۶۰۰	۲۹۳۳	۰	۰	

شرح مصرف	نرخ(ریال)	مصرف	شرح مبلغ	مبلغ
میزان مصرف در اوج بار	۴۰۹		هزینه مصرف اوج بار	
میزان مصرف در کم باری	۲۰۵		تخفیف مصرف کم باری	

واحد حوادث: ۱۲۱ یا ۲۲۵۴۳۷۰۱ پاسخگویی صورتحساب: ۲۲۲۸۸۱۹۹

عنوان	مبلغ(ریال)
مبلغ مصرف	۲۲۶۶۵۱
آبونمان	۱۸۹۹۹
بهای برق دوره	۲۴۵۶۴۹
مالیات بر ارزش افزوده	۲۲۱۰۸
مبلغ بیمه	۴۷۴
عوارض برق	۱۳۱۱۰
بدهکاری	۶۵۴
کسر هزار ریال	۹۹۵

مبلغ قابل پرداخت: ۲۸۱۰۰۰

مهلت پرداخت: ۹۴/۰۷/۲۷