SCHOOL OF ENGINEERING AND INFORMATION TECHNOLOGY

MURDOCH UNIVERSITY SCIENCE AND COMPUTING BUILDING ENERGY SIMULATION & MECHANICAL ENGINEERING GREEN BUILDING DESIGN

ENG470 ENGINEERING HONOURSTHESIS FINAL REPORT

YI XIN YAW

BACHELOR OF ENVIRONMENTAL ENGINEERING

UNIT COORDINATOR: PROFESSOR PARISA ARABZADEH BAHRI

SUPERVISOR: DR MARTIN ANDA,

ACADEMIC CHAIR OF ENVIRONMENTAL ENGINEERING

EXECUTIVE SUMMARY

Anchored in teaching, research and community engagement approaches, Murdoch University is setting up the development of a symbolic new mixed use campus precinct expansion which is listed as one of Murdoch University's strategic plan. As stated above, a part of the strategic plan includes the development of a new Mechanical Engineering Building (MEB) in order to engage future Mechanical Engineering students. This newly proposed MEB would be designed and constructed as an extension building from the existing Science and Computing Building that is located at the Murdoch South Street campus. Hence, the major focus of this research study investigate the new Murdoch University Mechanical Engineering green building structure and design by analysing the energy consumption of the existing Science and Computing building.

The annual energy consumption of the existing building is obtained through the identification of construction materials, building design and building operational activities. All this information is then simulated using Virtual Environment by Integrated Environmental Solutions (IES-VE). The outline of this IES-VE modelling tool and implementation procedures is illustrated in Chapter 3 (Methodology) and the simulation results used to identify the major sources of the energy use are included in Chapter 4 (Results). The results showed the massive energy consumption that being used in the current Science and Computing building and the annual energy consumption is broken down into different components that makes up the total energy use.Moreover, the possibilities for building energy consumption reduction are discussed and this is based on the low embodied energy building materials and low existing building operational energy reduction strategies.

For the sake of achieving green star building standard, NABERS self rating tools are introduced by determining the building operational routines and its design structure. The existing building's NABERS score will be recognised as a useful measure for the new MEB design ideas and the selection of appliances used in order to achieve the low energy building objectives.

Furthermore, the structure and design of the new MEB are drafted based on the essential requirements using SketchUp drawing tool. The dimensions and working purpose of each individual floor are illustrated and reviewed. On the other hand, basic specifications of the MEB such as experimentation and research laboratory requirements, computer appliances and HVAC demands are determined in order to diagnose the NABERS rating and thus establish a new target for green building achievement. The estimated new building energy consumption is generated and possible strategies which include energy efficiency design, energy efficient technologies and renewable technologies are discussed in Chapter 5.

Generally, a green building is achieved through an integration of energy efficient programs and environmentally friendly construction projects. Thus, an introduction of potential sustainable strategies is illustrated in Chapter 6 in order to develop Murdoch University into a carbon-neutral community. The potential sustainable strategies that are discussed in this thesis project included rainwater harvesting technology, wastewater treatment plants, timber prefabricated construction and green roof garden implementation. Lastly, project summary is included in Chapter 6 (Conclusion) and several recommendations are discussed that would be important to be evaluated and discussed for further improvement.

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GLOSSARY

Building monitoring systems or Building Management System (BMS): includes strategies and policies for analysis and improvement. The building monitoring system is an automated system that checks on the engineering duties, security and other building systems for the purpose of documentation, reporting and operational organisation of systems to maximise protection, security, operational work as well as total cost minimisation and efficiency (Property Council of Australia, Sustainable Development Guide 2001).

Embodied energy: The non-renewable energy consumed through the acquisition of raw materials, their assembly processes, manufacturing, transportation to site and construction processes. (Corus Construction Centre Glossary 2015).

Emissions: The release of greenhouse gases into the atmosphere.

Energy efficiency (general): The quantity and quality of valuable work that can be carried out by an energy using structure per unit of energy consumption. It is usually described as a ratio of useful energy output to energy input. A piece of device or system is interpreted as more energy efficient to the level that it performs more functional effort for the same energy consumption, or else achieve the same quantity of useful work for less energy consumption.

Energy performance: Quantifiable results relating to energy use and consumption. The phrase includes energy effectiveness, energy intensity, energy management, fuel option and greenhouse gas emissions resulting directly and indirectly from energy use.

Green Building: The structural and operational processes which are environmentally acceptable and resource-efficient throughout the whole building's life-cycle which includes construction, operation, maintenance, renovation and demolition.

Greenhouse gases: The atmospheric gases that contributes to climate change and global warming. The major greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_20), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Groundwater: The body of water in the soil and this includes all pores of which are saturated with water. If the body of water is present at all times it represents permanent or true groundwater according to AS/NZS 1547:2000 *On-site domestic wastewater management.*

Irrigation: The distribution of effluent into the topsoil by a shallow subsurface or covered surface drip irrigation system, a shallow subsurface LPED irrigation system or an above ground spray irrigation system.

Photovoltaic: Generating electricity from the sunlight using photocells. (Property Council of Australia, Sustainable Development Guide 2001).

Recycled material: Disposed materials that are diverted or separated from the waste stream. They are re-established as material feedstock and processed into marketed end products. (Property Council of Australia, Sustainable Development Guide 2001).

LIST OF NOMENCLATURE AND ABBREVIATIONS

NABERS: National Australian Built Environment Rating Systems

GBCA: Green Building Council of Australia

HVAC: Heating, Ventilation, and Air Conditioning

KWh: Kilowatt hour

MWh: Megawatt hour

MJ: Megajoule

WA: Western Australia

CLT: Cross Laminated Timber

BMS: Building Management System

Table of Contents

EXECUTIVE SUMMARY **2**

ACKNOWLEDGEMENT **4**

GLOSSARY **5**

LIST OF NOMENCLATURE AND ABBREVIATIONS **11**

TABLE OF CONTENTS **11**

CHAPTER 1: INTRODUCTION **13**

1.1 PROJECT AIM 13

1.2 BACKGROUND 13

1.3 PROJECT SCOPE 18

1.4 OBJECTIVES 21

1.5 STRUCTURE OF PROJECT 23

CHAPTER 2: LITERATURE REVIEW **25**

CHAPTER 3: METHODOLOGY **30**

3.1 ENERGY SIMULATION USING IES-VE MODELLING TOOL 31

3.1.1 INTRODUCTION TO THE IES-VE MODELLING TOOL 32

3.1.2 VIRTUAL ENVIRONMENT MODULES AND COMPONENTS 33

3.1.3 IES-VE MODELLING TOOL IMPLEMENTATION PROCEDURES 34

3.1.4 INPUT INFORMATION FOR THE EXISTING BUILDING ENERGY SIMULATION 40

3.1.5 EXISTING BUILDING IN 3D VIEW FROM IES-VEMODELLING TOOL 40

3.2 INTRODUCTION TO NABERS RATINGTOOL 41

3.2.1 NABERS ASSESSMENT DESCRIPTION 43

3.2.2 THE SCIENCE AND COMPUTING BUILDING INPUT DATA FOR NABERS RATING 43

3.2.3 THE NEW BUILDING DESIGN INPUT DATA FOR NABERS RATING 45

3.3 INTRODUCTION TO SKETCHUP PROGRAMME 46

3.3.1 SKETCHUP MODELLING TOOL DRAWING PROCESS 47

CHAPTER 4: RESULTS **49**

4.1 RESULTS OF THE EXISTING BUILDING ENERGY SIMULATION BY USING IES-VE 49

4.1.1 RESULTS OF THE TOTAL NATURAL GAS CONSUMPTION IN THE SCIENCE AND COMPUTING BUILDING 50

4.1.2 RESULTS OF THE TOTAL ELECTRICITY CONSUMPTION IN THE EXISTING BUILDING 51

4.1.3 RESULTS OF THE TOTAL ENERGY CONSUMPTION IN THE EXISTING BUILDING 52

4.1.4 ANNUAL HVAC CONSUMPTION 53

4.2 NABERS RATING CALCULATORRESULTS 58
4.2.1 THE SCIENCE AND COMPUTING BUILDING NABERS RATING SCORE 59
4.2.2 THE ESTIMATED ENERGY CONSUMPTION FOR THE NEW BUILDING WITH SAME DESIGN AND ENERGY PERFORMANCE AS THE EXISTING BUILDING........ 61
4.2.3 THE ESTIMATED ENERGY CONSUMPTION FOR THE NEW BUILDING WITH NABERS RATINGS 4, 5 AND 6........ 62
4.3 FINAL RESULTS OF MECHANICAL ENGINEERING BUILDING 3D 63
DRAWINGS 63

CHAPTER 5: DISCUSSION 64

5.1 DISCUSSION OF THE BUILDING ENERGY SIMULATION USING IES-VE MODELING TOOL 64
5.1.1 LOW EXISTING BUILDING EMBODIED ENERGY BUILDING MATERIALS INVESTIGATION........ 67
5.1.2 SCIENCE AND COMPUTING BUILDING OPERATIONAL ENERGY REDUCTION STRATEGIES........ 73
5.2 DISCUSSION ON THE NABERS RATING TOOLS - LOW ENERGY BUILDING PROPOSED STRATEGIES 79
5.2.1 ENERGY EFFICIENCY DESIGN........ 79
5.2.2 ENERGY EFFICIENT TECHNOLOGIES 81
5.2.3 RENEWABLE ENERGIES 82
5.3 DISCUSSION ON THE MECHANICAL ENGINEERING BUILDING STRUCTURE DESIGN AND MEASUREMENTS 85
5.3.1 GROUND FLOOR OF THE BUILDING 87
5.3.1 1ST FLOOR OF THE BUILDING 92
5.3.2 2ND Floor of the Building 92
5.3.3 3RD Floor of the Building........ 92

CHAPTER 6: NEW BUILDING INTEGRATION STRATEGIES REVIEW........ 93

6.1 RAINWATER HARVESTING FOR LABORATORY PURPOSE 95
6.2 WASTEWATER TREATMENT PLANT 96
6.3 TIMBER PREFABRICATED CONSTRUCTION 97
6.4 GREEN ROOF GARDEN........ 100

CHAPTER 7: CONCLUSION........ 102

CHAPTER 8: RECOMMENDATION AND FUTURE WORK 104

REFERENCES 105

APPENDICES 116

CASE STUDIES 125

PROJECT OVERVIEW FOR GREENSKILLS BUILDING 125

Table 1: The virtual environment modules and components. 33
Table 2: Input information for the Science and Computing building energy simulation. 40
Table 3: Important information and description based on different categories in the existing building 41
Table 4: Description of NABERS assessment (adapted from NABERS 2014). 43
Table 5: Other important information from the Science and Computing building for 44
Table 6: The energy data input from the Science and Computing building. 44
Table 7: Input information of the new MEB that is used in NABERS rating. 45
Table 8: Results of the total natural gas consumption in the Science and Computing Building which simulated through IES-VE program. 50
Table 9: Results of the total electricity consumption which excluded the lighting consumption in the Science and Computing Building and simulated through IES-VE modeling system 51
Table 10: The results of the total energy consumption in the existing building which simulated through IES-VE program. 52
Table 11: The results of the annual boiler load in the Science and Computing building which simulated through IES-VE modeling system. 54
Table 12: The result of the annual chiller load in the Science and Computing building which simulated through IES-VE modeling tool. 56
Table 13: The estimated energy consumption for new building based on the same design and energy performance as the existing building. 61
Table 14: The estimated energy consumption for the new Mechanical Engineering building in order to achieve NABERS Ratings 4, 5 and 6. 62
Table 15: The building material types and their associated U-value. 66
Table 16: The existing building materials and recommended low energy building materials 67
Table 17: Australian Average Energy Intensity Trends by Building types, 1999-2020 (Department of Climate Change and Energy Efficiency 2015). 73
Table 18: Measurement of the new Mechanical Engineering Building. 86
Table 19: Top 10 world-wide Mechanical Engineering programs 88
Table 20: Comparison of CLT panels and conventional concrete construction. 99

Figure 1 The Earth view aerial map showing the location of Murdoch University South Street campus (adapted from Google Earth 2015). 14
Figure 2 The Satellite view aerial map location of Murdoch University South Street campus (adapted from Google Maps 2015) 14
Figure 3: The exact location (shaded blue) of the newly proposed Mechanical Engineering Building at Murdoch University South Street campus. 15
Figure 4: The location of the existing Science and Computing Building at Murdoch University (adapted from Google Earth 2015). 15
Figure 5: Benefits of green building design. 17
Figure 6: The IEC Virtual Environment start-up page 34
Figure 7: The application section in the IES-VE 35
Figure 8: Floor plans in DXF form which are imported into the IES software. 36
Figure 9: The differentiation and description of each component used in the design of the new MEB (A and M 2015). 37
Figure 10: The differentiation and description of each component (A and M 2015). 38
Figure 11: The final outcome after all the data is inserted into the Virtual Environment software. 39
Figure 12: The existing building output in a 3D view. 40
Figure 13: 3D view of the Science and Computing Building using ModelViewer. 40
Figure 14: Demonstration of the base structure development. 47
Figure 15: Demonstration of the pulling up the sculpt function. 48
Figure 16: Demonstration of the ground floor structure. 48
Figure 17: Total annual energy consumption in pie chart form. 53
Figure 18: Peak day load of boiler in the Science and Computing building on 2 of July 2015 that simulated through IES-VE modeling system 55
Figure 19: Peak day load of the chiller system at the Science and Computing building on 18 of April 2015 which simulated through IES-VE modeling system 57
Figure 20: Science and Computing building's NABERS rating score. 59
Figure 21: Final 3D drawing of the new Mechanical Engineering Building. 63
Figure 22: Image of lightweight aggregates from masonry rubble. 69
Figure 23: (a) Single glazing properties and (b) Double glazing properties (Australian Double Glazing 2015). 70
Figure 24: Example of prompts (Bin 2012). 76

Figure 25: Schematic detailing of the solar energy storage system at Josh's House (Solar Balance 2015). 84
Figure 26: Mechanics of Solid Laboratory in Curtin University........ 90
Figure 27: The 3D drawing of the new building with integrated sustainable strategies........ 94
Figure 28: The CLT lifecycle form (Lehmann et al. 2012). 97
Figure 29: Science and Computing Building level 1 floor plan 116
Figure 30: Science and Computing Building level 2 floor plan 117
Figure 31: Science and Computing Building Level 3 floor plan. 118
Figure 32: Existing Building material information for IES-VE simulation. 118
Figure 33: Input information (LOCATION) for the existing building. 119
Figure 34: Input information (WEATHER) for the existing building.. 120
Figure 35: Existing building Sun Path diagram. 121
Figure 36: Existing Building Weather Data. 120
Figure 37: Existing Building systems energy report. 121
Figure 38: Engagement Methods for workplace environmental sustainability programs 121
Figure 39: NABERS reverse calculator result for 4 star ratings. 122
Figure 40: NABERS reverse calculator result for 5 star ratings. 123
Figure 41: NABERS reverse calculator result for 6 star ratings. 124

CHAPTER 1: INTRODUCTION

1.1 PROJECT AIM

To develop a green building concept for the newly proposed School Of Engineering and Information Technology Mechanical Engineering building.

1.2 BACKGROUND

Murdoch University is a public university based in Perth, Western Australia which is recognised as one of Australia's leading research institutions, as more industries around the world place their belief and resources into projects carried out at Murdoch University. This connection favours Murdoch's research candidates and scientists with the opportunity to make amazing discoveries (Murdoch.edu.au 2015). Murdoch University has three Australian campuses: South Street campus, Rockingham campus and Peel campus. The main focus of our green building project will be based on the South Street campus, which is located 15 km south of the Perth CBD and 8 km east of Fremantle. South Street campus consists of different facilities, research rooms and buildings. An Earth view (Figure 1) and Satellite view (Figure 2) aerial map showing the location of Murdoch South Street campus are provided (Whereis 2011).

Figure 1 The Earth view aerial map showing the location of Murdoch University South Street campus (adapted from Google Earth 2015).

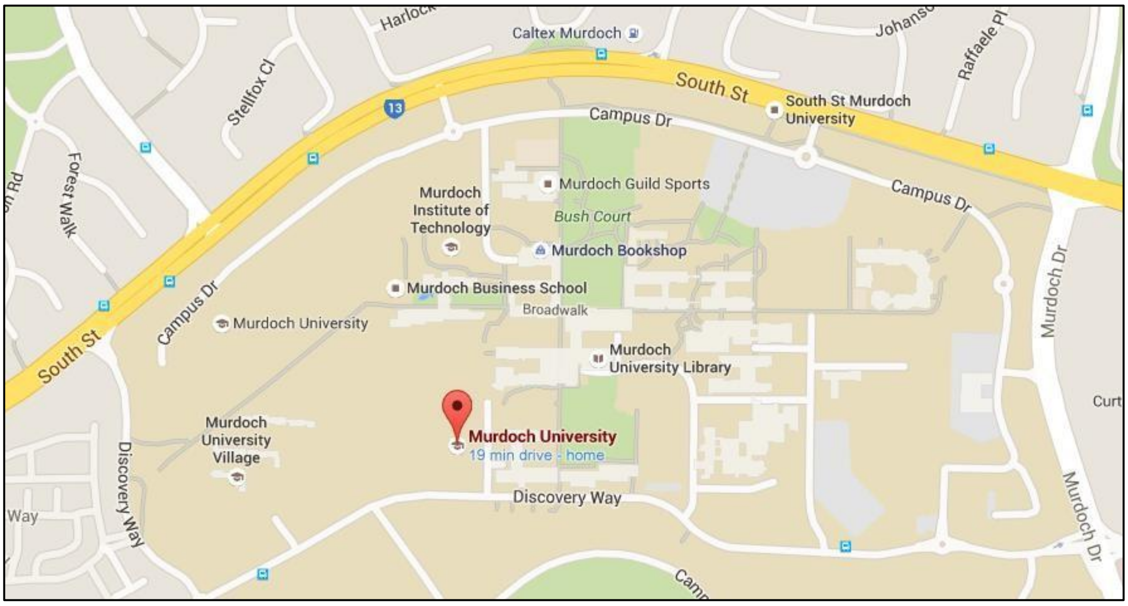


Figure 2 The Satellite view aerial map location of Murdoch University South Street campus (adapted from Google Maps 2015)

Murdoch University is considering the development of a new Mechanical Engineering building at the South Street campus which as an extension of the Science and Computing Building (existing building), which in another words, annual energy consumption of the Science and Computing building will be identified to used as a benchmark to develop an energy reduction plans for the future Mechanical Engineering Building. Therefore, the annual energy consumption of the Science and Computing Building is identified by using energy simulation modeling tools and thus design a low energy and green MEB based on those results.

Figure 4: The location of the existing Science and Computing Building at Murdoch University (adapted from Google Earth 2015).

Figure 3: The exact location (shaded blue) of the newly proposed Mechanical Engineering Building at Murdoch University South Street campus.

A green building, which is also known as green construction or sustainable building indicates the structure of the building and the building operating process are environmentally friendly and resource-efficient throughout a building's life-cycle. Australia is at the leading edge of sustainable building operation by developing green design, renewable and energy efficient building material implementation and also low energy practices (Austrade.gov.au 2015). By designing a new Mechanical Engineering Green building, we can promote the staff and students health as well as improve the productivity standards and also indirectly lowering GHG emission. This low environmental impact outcome can be achieved by minimising the use of fossil fuels which would in turn reduce waste output, mitigates pollution and environmental degradation (Austrade.gov.au 2015). The benefits of green building are summarised below (Figure 5).

Moreover, it is a known that green buildings have a low running cost compared to conventional buildings. As a result, Murdoch University is interested in upgrading the building and facilities by proposing the new MEB to be more energy and water efficient, which would greatly reduce the cost of the monthly energy and water bills.

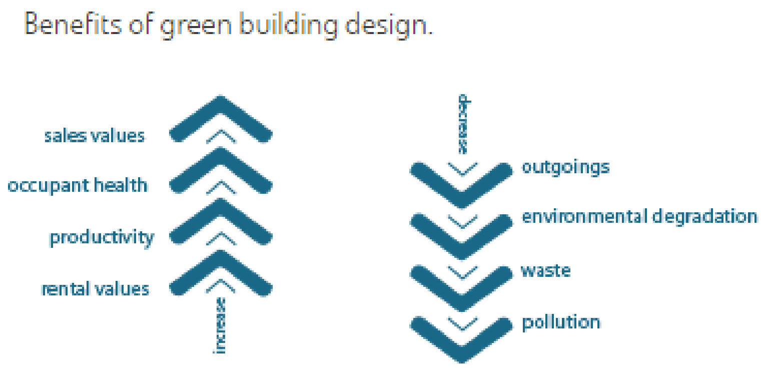


Figure 5: Benefits of green building design.

organized mechanism used to measure, rate and evaluate the building's design and performance – the NABERS rating tool. NABERS as known as National Australian Built Environment Rating System is a comprehensive, national, voluntary environmental rating system that evaluates the energy consumption of a building and its environmental impact. In order to achieve a wide-ranging green building approach, the cooperation between stakeholders and the government is crucial along with education being a significant aspect in conveying the knowledge and understanding among students.

1.3 PROJECT SCOPE

- **Working towards achieving Murdoch University's objective**
  - The Green Building Program is fundamental to create an environmentally sustainable community within Murdoch University.

- **Business benefits**
  - Significantly reduce costs by minimising energy consumption and waste production and promote recycling activities.
  - Considerably reduce water usage by implementing water efficient appliances and fixtures.
  - Greatly reduce the volume of effluent that goes into the sewer by introducing wastewater treatment technologies.
  - Substantially reduce energy consumption and its negative impacts on our climate by using alternative renewable resources.

- **Protect our environment**
  - Green building is designed to reduce global warming, preserve resources, improve air and water quality, protects flora and fauna and reduces landfills.
  - Provide a comfortable learning environment for the Mechanical Engineering students in the near future.

- **Enhance Murdoch University's image**
  - Environmental stewardship: Universities are expected to be leaders in conducting, supervising and managing sustainable practices and education.
  - Corporate image: Improve reputation by adopting sustainable practices, attract positive media coverage, improve goodwill and captivate more students and staff. (The University of Western Australia 2012).

1.4 OBJECTIVES

- **Identify the annual energy consumption of the existing building**

  The energy sources and consumption by appliances is significant and needs to be investigated by implementing IES-VE, Integrated Environmental Solution-Virtual Environment modelling tool in order to set up a new benchmark for the new green building.

- **Diagnose the major energy efficiency issues in the existing building**

  By understanding the different types of material used and operating issues, energy efficiency strategies can be established.

- **Classify the net energy consumption measures to achieve the green building guideline**

  Fulfil the essential requirements for green building standard by getting familiarised with the mechanisms of NABERS self-rating tool.

- **Design a green Mechanical Engineering building structure**

  Recognise the essential services and appliances that are required for mechanical engineering purposes and outline the building structure.

- **Propose possible low energy building strategies**

  Review and suggest possible energy efficient strategies by determining the new green building concept and materials.

- **Integrate green building design and strategies**

  Recommend potential integration strategies such as rain water harvesting, wastewater treatments, renewable materials for construction and green roof garden for sustainable community purpose and enhancement of Murdoch University's image.

1.5 STRUCTURE OF PROJECT

The structure of this study is as follows:

Chapter 2: Literature review is carried out to gain a basic understanding of the current development of green buildings and gain insights into some of the well-known eco-architecture projects around the world.

Chapter 3: Introduce the methodology that has been followed in this research project which includes:-

I. The use of IES-VE modelling tool for existing building energy simulation in order to get familiarised with the energy sources and consumption.

II. NABERS self-rating tool which is used to identify the major issues of the building's energy consumption.

III. 3D drawing tool named SketchUp that is used to outline the structure and design of the new MEB.

Chapter 4: Results based on the implementation tools described in Chapter 3 which include:-

I. The energy simulation results of the existing building that was obtained using the IES-VE modelling tool.

II. Evaluation of the existing building's environmental performance results using NABERS rating tool which was also used to calculate the net energy consumption for the new MEB design.

III. Outcomes of the new building's 3D drawing by using SketchUp.

Chapter 5: Discussion based on all results obtained and described in Chapter 4.

I. Identify major inefficiency issues from the existing building energy use that was simulated using IES-VE and suggest possible strategies that could be used to reduce the annual energy consumption.

II. Propose low energy building strategies based on evaluating the NABERS rating results generated.

III. Review the structure and measurement of the new MEB. The suggested use of each floor is analysed and summarised.

Chapter 6: Suggestions on potential integration strategies for green building design.

Chapter 7: Summary of the issues that were diagnosed and possible strategies that could be implemented.

Chapter 8: Record of lessons learnt through this project and other remedial recommendations that could be useful for further research.

CHAPTER 2: LITERATURE REVIEW

Green building is known as environmentally sustainable building. It is designed, constructed and operated in order to reduce the total environmental impacts example like greenhouse gases emission that will lead to global warming. A green building integrates with environmental considerations into every phases of the building construction and focus on the design, construction, operation and maintenance phases. (EcoMENA) Elements of green building included a development of a sustainable site; water conservation and savings purposes; energy efficiency strategies implementation and resource efficient materials adoption. On top of that, healthy indoor environmental quality is required to maintain to achieve green building standard.

With new technologies on the rise, retrofitting older buildings to create greener and more environmental friendly structures will lead to a range of environmental, economic and social benefits. For instance, not only can green buildings reduce waste production, but they can also simultaneously improve air and water quality. Therefore, designing green buildings for Murdoch University does not only lead to potential health improvements of university staff and students, but also reduction of environmental impacts. According to Kibert (2012) and Judelson (2007), green buildings could be made possible by implementing and practising basic principles and methodologies for sustainable construction resulting in energy-efficient, healthy and environmentally friendly construction.

The ever-increasing growth in population and subsequently human consumption may have serious impacts on urban development with regards to constructing, operating and maintaining buildings. These activities are said to account for about 40% to 50% of all energy usage and anthropogenic greenhouse gas emissions globally. One of the key reasons for constructing green public buildings is to enable constructors to demonstrate innovative sustainable designs which can reduce energy consumption and greenhouse gas emissions (Deng et al. 2011). One particular case study, which was on a multi-functional green building in Shanghai Jiao Tong University, emphasised energy systems design and GHG emission reduction (Deng et al. 2011). Henceforth, the use of green buildings is becoming an essential phase that must be considered for environmental sustainability (Asif 2013). Subsequently, studies on different role models like Eco architects who design sustainable buildings can be carried out in order to gain a deeper understanding on the structure and requirements that enable buildings to be classified as 'green'. Ken Yeang, a Malaysian architect and a famous ecolologist, has published his initiative on ecomasterplans and ecoarchitecture design. He is also famous for bioclimatic skyscrapers and sustainable design which were implemented in various projects in South-East Asia (Hamzah and Yeang 2015). Yeang contributes greatly towards a sustainable living environment by designing sustainable intensive buildings, in which he explains extensively about designing high-rise buildings in a green way, also mentioning some of his concerns on ecological designs.

In Yeang's design project, the National Singapore library received the highest accreditation from the Building and Construction community and the Singaporean government authorities. The objective of the library design is to offer a comfortable and favourable environment for Singaporeans. Yeang's proposed idea was to design a Green Library Building that would stand out in that specific region.

The passive design that was integrated in the library included:

- Good solar direction and building design
- Appropriate natural ventilation structure
- Day lighting system improvement
- Excellent design for solar facade
- Adequate sun shading mechanisms
- And application of suitable building colour courts (Culture for Friends 2015).

On the other hand, the roof top garden that was located on top of the National Singapore library provided a pleasant working and study environment. The design methodology towards achieving the green building benchmark may have to cover the all-inclusive concern of smart selection of low energy consumption building material. Hence, the application of reused and recycled materials would be favouredFor example, wall fabrics, sustainable timber construction and the use of carpet to reduce heat loss. The utilisation of these materials as components of a low impact design would be profitable. These sustainable features were used in tandem to create a comfortable, low energy consumption and delightful study environment for all students.

The Solaris building in Singapore designed by Yeang had side glazed-walls at the ground floor's frontages which are facing a non-air-conditioned area. The Solaris building has a central hall with glass-window blinds over the hall equipped with sensors that detects ventilation conditions and automatically make adjustments. Solaris' roofs are improved to promote biodiversity. The roof structure also delivers an outstanding insulation effect and reduces the sunlight's radiation into the building. Most importantly the Solaris building green building design and structure also receive the utmost recognition for being one of the most sustainable buildings in Singapore.

Arno Schlueter is another person that has played a key role in sustainable building technologies used at the Swiss Federal Institute of Technology (ETH) which is the advanced technology and research centre located in Zurich. Arno Schlueter was also involved in the design and construction of Singapore's most energy efficient workplace. This energy efficient office has featured an advanced construction design named SEC FCL's '3for2' technology. This energy efficient office is developed with an innovative strategy that enables builders to reduce the use of space, cost and energy consumption. Simultaneously, this cutting edge concept contributes in the reduction of the carbon footprint. The design of the building is constructed with three floors within the height that is normally needed for two levels in any other conventional structure (Eco Business 2015). Moreover, sloped windows were one design feature that was used to enhance the daylight's quality while reducing heat gain.

NABERS rating tool is chosen to identify the designed building environmental performance, NABERS Energy ratings recognise that increasing energy efficiency and also the decreasing of the greenhouse gas intensity of grid electricity. These both effective approaches aim to reduce the overall environmental impact of a building. NABERS Energy ratings provide rated buildings with two different star rating results: one measures the energy efficiency of a building, and the other measures its greenhouse gas performance by taking into consideration the fuel source of externally supplied grid electricity. By implementing NABERS rating tool in this project, it can simultaneously lead our green building design towards environmental friendly community.

In order to design a sustainable building, low energy consumption and high energy use efficiency are two crucial aspects that should be analysed in detail.

Building a sustainable community has several advantages:

- Contributes to lower cost and is one of the most efficient ways towards achieving a carbon neutral community by minimising the annual greenhouse gas emissions.
- Links the issue of fossil fuel deficiency by implementing renewable energy resources.
- Improves the worldwide energy supply by implementing energy efficient appliances.
- Generates jobs opportunities and maximise occupants' income.
- Inspires people to make an improvement in building facilities and promote education for behavioural change.
- Shortens the payback time for energy efficient appliance investment

CHAPTER 3: METHODOLOGY

This research report is carried out using three different theoretical and analytical tools which are described in more detail below.

1. **Energy simulation using IES-VE modelling tool**

   The annual energy consumption of the existing building is evaluated using IES-VE modelling tool by importing the structural floor plan of the existing building. The materials (building embodied energy), building working hours and infrastructural activities (operational energy) in the existing building are identified are identified as they are major components that consume energy.

2. **Identify the NABERS scores for the existing building and used as a benchmark**

   NABERS is an environmental rating system that evaluates the building energy consumption. NABERS rating tool is suggested to demonstrate the effectiveness of the building energy performance and determine the total carbon footprint that is created. By getting familiarised with the mechanisms of NABERS self-rating tool, the necessary requirements that would be needed to achieve the green building standard could be met.

3. **Sketch Up drawing tools for the building design and structure**

   A 3D Drawings tool is used to design the new MEB following the building infrastructure requirements. For instance, total surface area and working purpose of each floor are illustrated.

3.1 ENERGY SIMULATION USING IES-VE MODELLING TOOL

In recent decades, PC re-enactments of complex designing frameworks have developed as a promising methodology (Nguyen and Reiter 2015). In building science, scientists and architects regularly utilise dynamic thermal re-creation projects to investigate thermal and vitality practices of a building to accomplish particular targets through the reduction of energy consumption and also enhance the indoor environment. (Garber 2009). For the purpose of building energy consumption reduction purpose, energy simulation process and analysis program is decisive in order to design a low carbon footprint building. Energy analysis programs used to study vitality execution and thermal condition along with the building life cycle assessment. Various tools are accessible and differ in their thermodynamic models, their graphical client interfaces, their motivation of utilisation, their life cycle pertinence and their capacity to trade information with other programming applications.

Since that the new Mechanical Engineering Building will be an extension of the current Science and Computing building, we decided to simulate the Science and Computing Building and then design an analogous yet energy efficient building by investigating the major energy consumption sectors and evaluate possible strategies and technologies for implementation purposes.

By considering the fact that existing buildings are generally in operation for 30 to 50 years and will account for approximately 70% of the total building stock by 2050 (Kelly 2010), investigating ways to reduce the energy consumption of these existing buildings and also identify the limitation of building design would be a starting point to put in place energy reduction strategies for newly proposed building design. Energy modeling which uses visual and computerised tools to estimate and evaluate energy performance focuses on energy consumption, utility bills and life cycle costs of different energy integrating activities in a particular building. It is also used to evaluate the payback renewable energy technologies which include solar panels and adaptive solar facade, wind turbines and high energy efficient appliances (Energy Models 2013).

3.1.1 INTRODUCTION TO THE IES-VE MODELLING TOOL

IES-VE is used to simulate the energy consumption of a specific building based on its basis activities. IES-VE is known as a dynamic building energy simulation software which consists of a suite of integrated analysis tools. These integrated analysis tools can review the performance of a building either reflectively or during the outline stages of a development scheme.

The IES-VE suite of devices offers alternatives for precise and accurate simulation process, top-level investigation through building structures and designs. Areas for investigation would include atmosphere, theoretical building measurements, shading, orientation, lighting, sun shading, LEED, vitality, carbon emanations, wind assessment and others (Kegel 2015).

3.1.2 VIRTUAL ENVIRONMENT MODULES AND COMPONENTS

Table 1 illustrates the modules and components that are functional in the IES-VE modelling software.

Table 1: The virtual environment modules and components.

Virtual Environment Modules	Functions
ModelIT	Geometry creation and editing
ApacheCalc	Data analysis load
ApacheSim	Thermal simulation
MacroFlo	Natural ventilation
Apache HVAC	HVAC's components
SunCast	Shading visualisation and investigation
MicroFlo	The fluids dynamics in 3D form
FlucsPro/Radiance	Design of the lightning and efficiency
DEFT	The optimisation of the model
LifeCycle	Cost analysis and the total building's life cycle energy calculation
Simulex	The evacuation of the specific building

The program provides an environmental analysis for the detailed evaluation of building and system designs, allowing them to be optimised with regards to comfort criteria and energy use.

3.1.3 IES-VE MODELLING TOOL IMPLEMENTATION PROCEDURES

Initially, at the start-up of the Virtual Environment programme, a clear model space is initialised (Figure 6; *The IES Virtual Environment-User Guide* 2015).

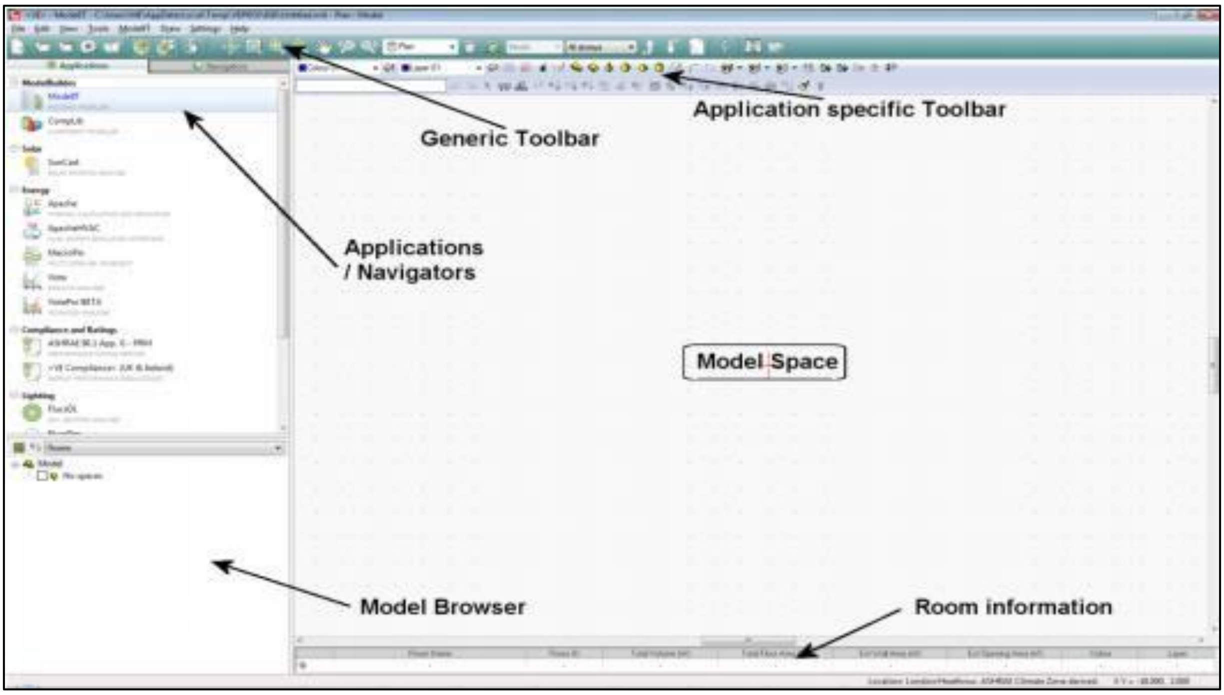


Figure 6: The IEC Virtual Environment start-up page

(*The IES Virtual Environment-User Guide* 2015).

The section of the screen as shown below (Figure 7) enables a specific selection of the required application to be made in the Virtual Environment software.

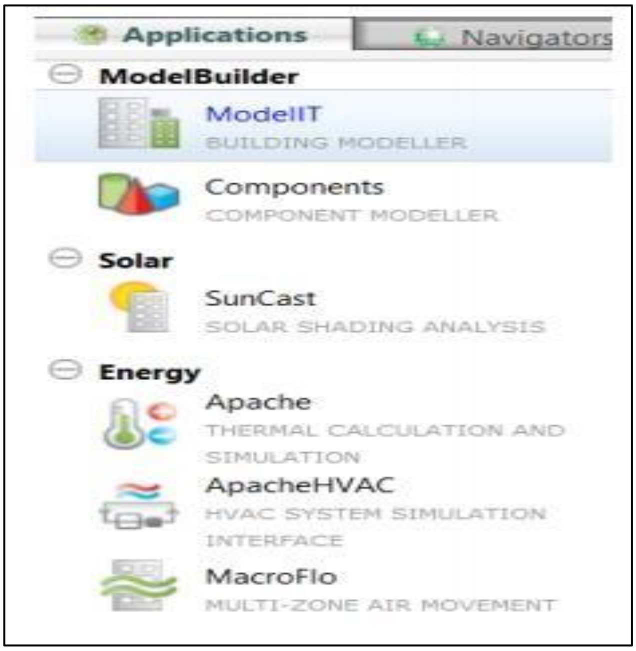


Figure 7: The application section in the IES-VE

(*The IES Virtual Environment-User Guide* 2015).

The modeling simulation process is described in bullet points as below.

- Two-dimensional models (from DXF) and 3D gbXML data are directly imported into the IES software and facilely used to simulate a three-dimensional model using the IES ModelIT application (Kegel 2015).
- The floor plans of the Science and Computing Building in DXF form is used as an input and imported to the IES-VE software in order to manually sketch out the structure of the building.
- The height of the building has to be inserted accurately in order to produce a similar building structure.
- The PDF form of the Science and Computing' floor plans are attached in the appendix which are figure 32, figure 33, and figure 34.

- The outcome of the Science and Computing Building floor plan in DXF form when imported into IES software is shown below (Figure 8).

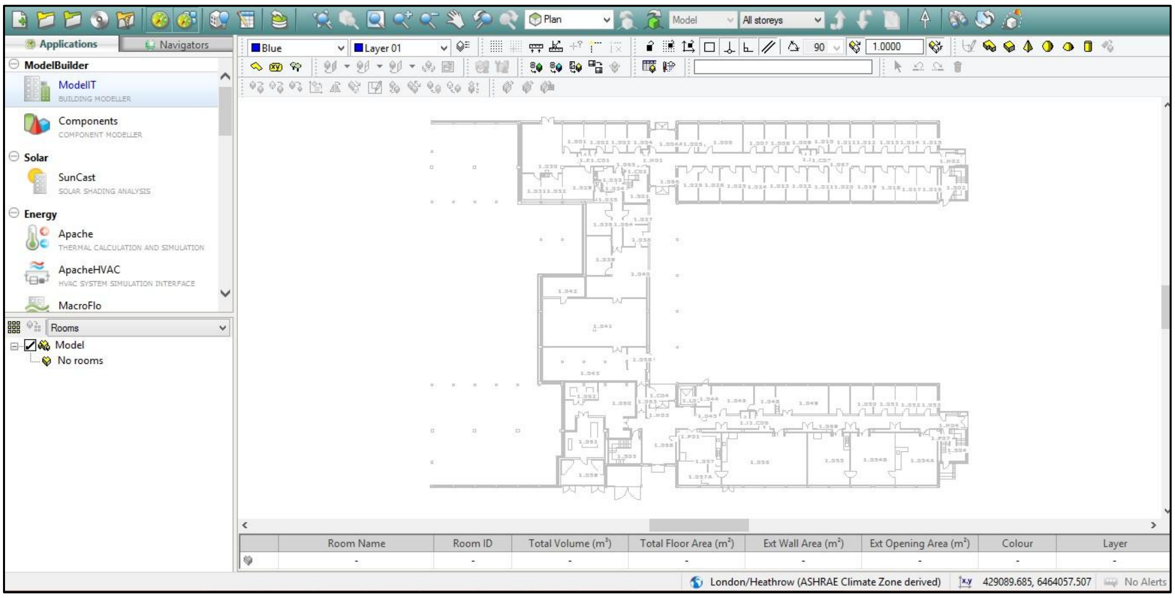


Figure 8: Floor plans in DXF form which are imported into the IES software.

- All the rooms can be created using the 'partition of the site' icon and drawn out manually according to the floor plan outline.
- The main way a wall is differentiated as an outside versus an inside wall is by their adjacencies. For a component to be characterized as a ground floor piece, it is a flat surface nearby a room (else it is a shading gadget) that is not in contact with any room underneath. For a story, it's a flat surface that is in contact with a room above as well as underneath. For a rooftop, it's a flat surface that is not in contact with any room above. Exterior dividers are vertical surface that is not in contact with a neighbouring room on one side (A and M 2015).

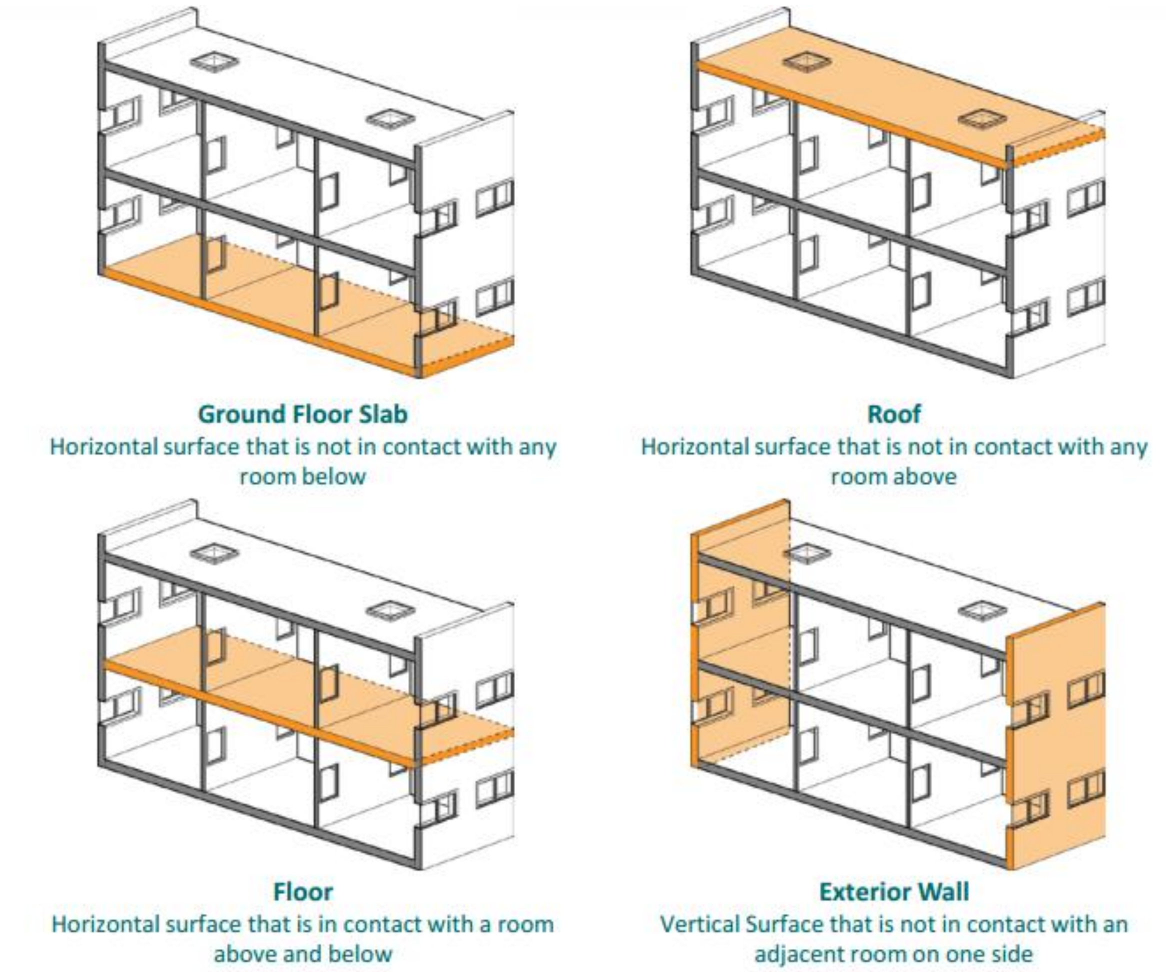


Figure 9: The differentiation and description of each component used in the design of the new MEB (A and M 2015).

- To identify as an interior wall, it's a vertical surface and it is connected with the rooms beside. Exterior Windows are known as windows on the exterior wall, interior windows are windows on an interior wall, and lastly skylights are windows on a roof (A and M 2015).

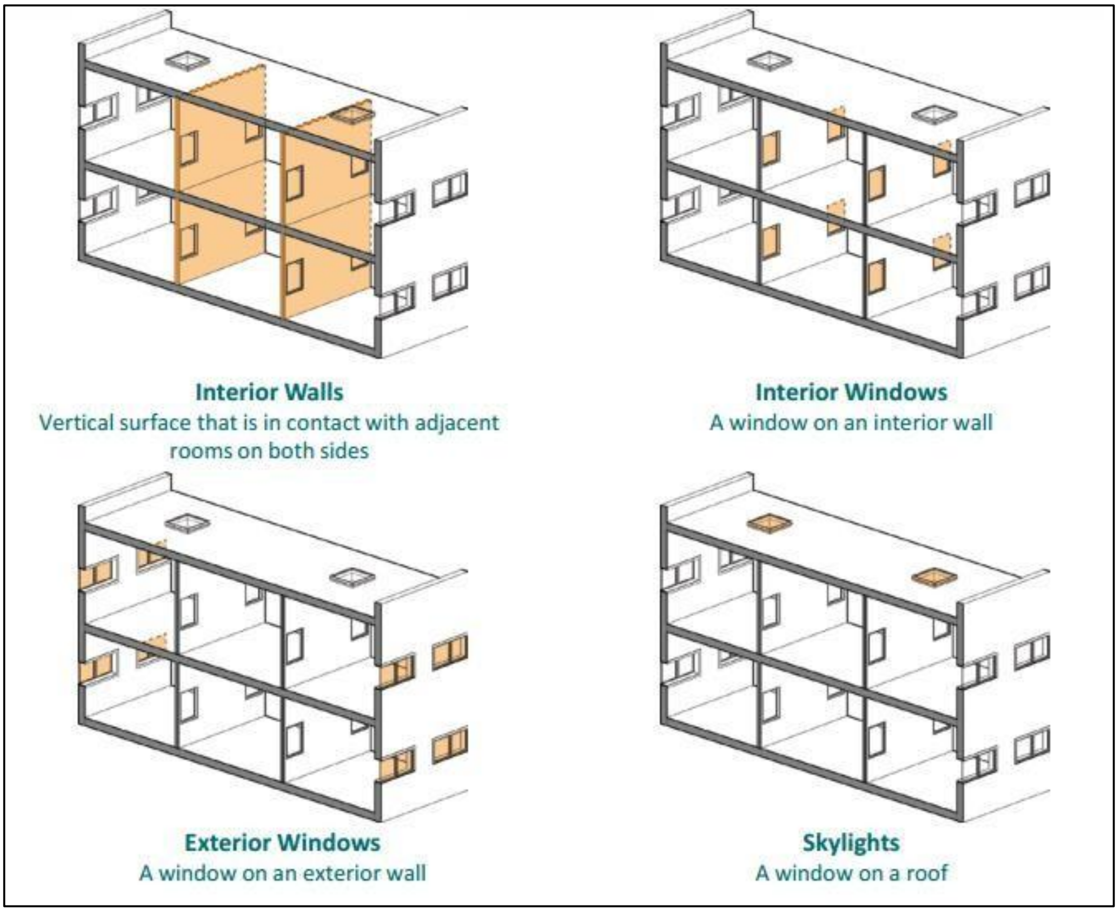


Figure 10: The differentiation and description of each component (A and M 2015).

- The size and number of the doors and windows are identified and inserted as input data in order to achieve a higher similarity of the building model to reality
- The existing building energy simulation is generated based on the location of the building, annual weather of the specific location, existing building construction materials and the working hours of the building, which may differ from time to time.

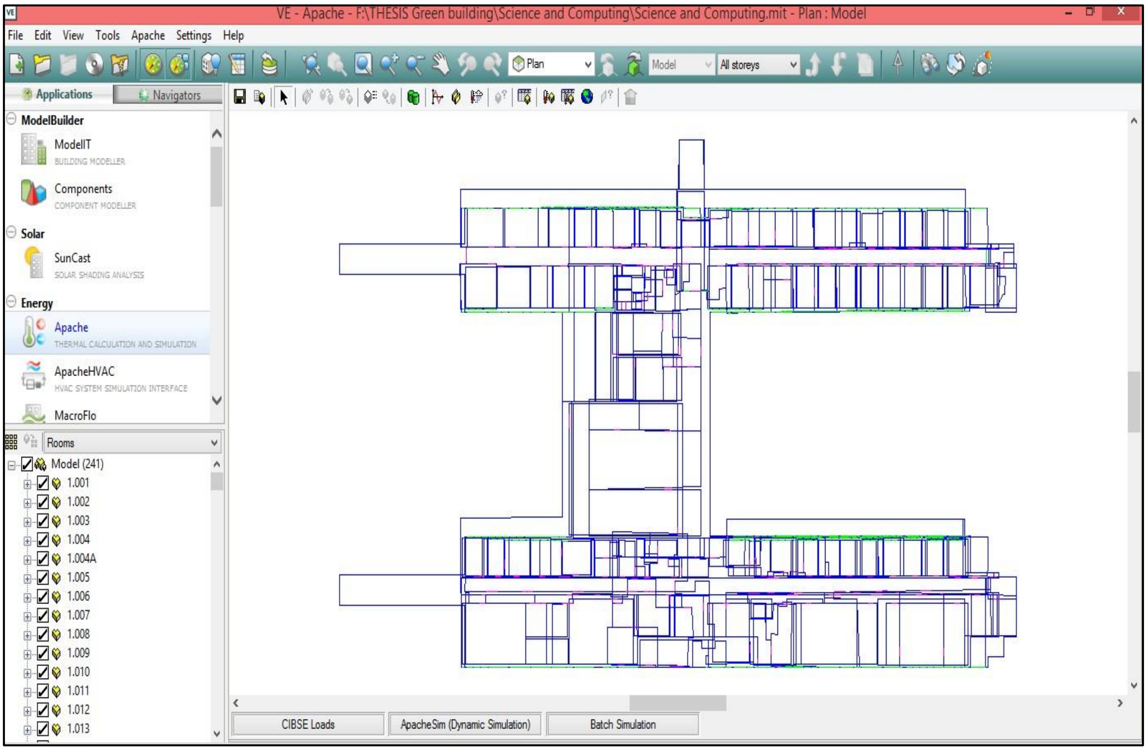


Figure 11: The final outcome after all the data is inserted into the Virtual Environment software.

Once all the input information is imported into the IES-VE software, the final outcome of the existing building is given as an output as shown (Figure 11).

3.1.4 Input Information for the Existing Building Energy Simulation

The Science and Computing building location information is attached in appendix figure 36 and the Science and Computing building weather information is attached in appendix figure 25. All input information for the existing building energy simulation is tabulated (Table 2).

Table 2: Input information for the Science and Computing building energy simulation.

Location	Perth Airport, Australia
Latitude	31.93
Longitude	115.97
Altitude (m)	20
Time zone (hours ahead of GMT)	8

The existing building materials are attached in the appendix Figure 35.

All relevant information regarding the existing building materials are tabulated (Table 3).

Table 3: Important information and description based on different categories in the existing building

Category	Description	U value (W/m^2k)	Thickness (mm)
External Wall	Brick/Block wall	0.4396	323
Door	Wooden door	2.1944	40
Internal ceiling / Floor	Concrete slab internal ceiling	1.0687	420
Roof	Sloping roof included loft	0.1589	1078
External Window	Large Single glazed window	5.5617	6
Ground / Exposed floor	Standard floor construction (2002)	0.2499	1198
Internal Partition	115mm single-leaf brick	2.2448	115

3.1.5 EXISTING BUILDING IN 3D VIEW FROM IES-VEMODELLING TOOL

- A 3D model of the existing building is generated (Figure 12)
- The area and volume of the whole building is calculated

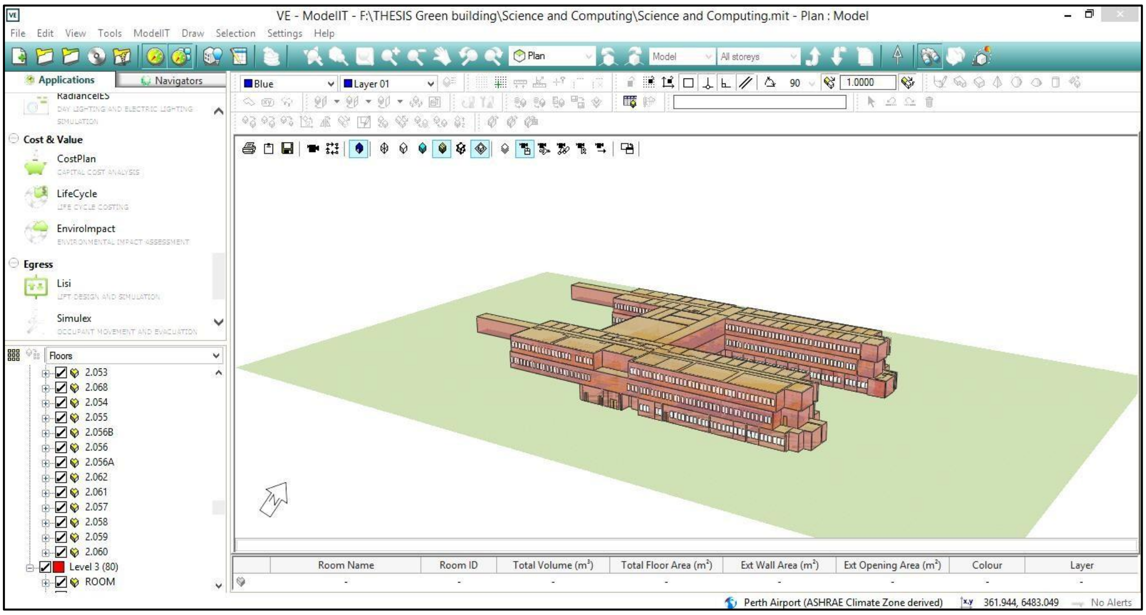


Figure 12: The existing building output in a 3D view.

The 3D view of the Science and Computing Building using ModelViewer which is a component of the IES-VE software is shown below (Figure 13).

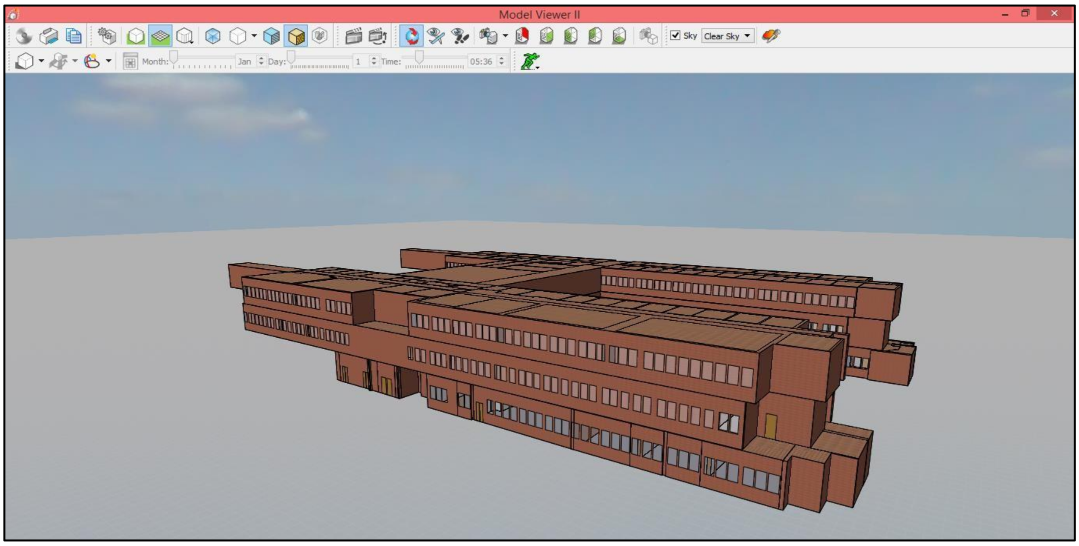


Figure 13: 3D view of the Science and Computing Building using ModelViewer.

3.2 INTRODUCTION TO NABERS RATING TOOL

In this modern era, the extensive load of energy consumption has led to environmental concerns including ozone layer depreciation, global warming, and negative impacts on organisms natural habitat (Pérez-Lombard, Ortiz and Pout 2008). Hence, it is important to highlight and evaluate several solutions for minimizing the energy consumption of buildings and integrating new strategies for achieving sustainability in built environments. Additionally, the proposed strategies promote energy conservation awareness could be used as education tools for the future students. The NABERS rating tool is implemented to investigate a building's performance towards environmental sustainability.

The NABERS rating tool demonstrates the effectiveness of the building energy management system, which also indicates the efficiency of the building design. NABERS also helps evaluate the existing building's operational efficiency. In other words, it determines how the building is utilised during usual activity rather than just depending on the design structure of the building. Wong et al. (2015) stated that the estimation results are assessed under four headings: energy, water, indoor environment and waste (Table 10).

The building rating tool can contribute to the sustainability of Australia's built form and resultant communities as when used as a leading guide for contractors or builders. It is innovative and persuasive which enables construction practitioners to understand the function of the tool. These findings will help develop outcomes and practices that encourage behavioral change among construction stakeholders and people within the construction industry and thus driving towards a reduction in carbon emissions.

The building energy consumption is documented and shown as carbon emissions per square metre of the floor area of the building (kg CO_2/m^2) in a 12-month period. In the end, the building receives the NABERS star rating that follows a ranking from one to five, which symbolises the carbon emission results based on per square metre of the building throughout the entire period of assessment. The lesser the carbon emissions that are generated by the specific building, the higher the rating it will receive. This gives an indication of the status of the building's performance towards sustainability (Wong et al. 2015). Even though NABERS is not a legal requirement during the design phase of building construction and development in Australia (Mitchell 2009), it is highly recommended in order to reduce the operational and energy cost

In the new MEB design, experimentation and research labs are included. In order to accomplish the daily experimentation basis, it is important to point out that laboratories often consume 3 to 4 times more energy compared to a standard office operation. Their complex structures are recognised as a challenge in understanding the energy sources and implementation, and therefore it is significant to diagnose and identify possible opportunities for improvement.

3.2.1 NABERS ASSESSMENT DESCRIPTION

Table 4: Description of NABERS assessment (adapted from NABERS 2014).

Item	Description of assessment
Energy	Monitoring individual energy types (coal, oil, gas, and electricity) expelled by the building over a 12-month period. Consideration is also given to the amount of energy that is sourced from "green power" supplies.
Water	Observing water usage of a 12-month period, with consideration to the external supply of recycled water.
Indoor environment	An assessment of indoor air quality, lighting, thermal comfort, acoustic levels, and office plan.
Waste	An evaluation of the total amount of waste generated by each person, each day. Consideration is given to materials that are recycled and reused.

By utilizing the rating scores and carbon emission benchmark that is set by NABERS, we can identify the building's major energy sources and thus generate effective energy saving plans which would simultaneously improve energy supply security and help mitigate fluctuations of energy prices. On top of that, water usage can be reduced by implying water reduction strategies and also mitigate massive wastewater generation.

3.2.2 THE SCIENCE AND COMPUTING BUILDING INPUT DATA FOR NABERS RATING

There are several assumptions made:

- The total hours that 60% of the total staff have occupied the Science and Computing building in a week is approximately 30 hours.
- There are 150 computers being used during working hours within the building.
- The electricity and natural gas input data is based on the IES-VE energy simulation result.

Table 5: Other important information from the Science and Computing building for self-rating purposes.

Premise types	Office
Premises scope	Whole Building
Building details	Murdoch Science and Computing Building
State and postcode	Murdoch 6150
Areas of office	10956 m^2
Hours of occupancy	40
Number of computers	150

The relevant input information of the existing building that is required to be imported into the IES-VE software for the simulation process is given in (Tables 5 and 6).

Table 6: The energy data input from the Science and Computing building.

Fuel type	Quantity	Unit
Electricity	3746000	kWh
Gas	12744	MJ

3.2.3 THE NEW BUILDING DESIGN INPUT DATA FOR NABERS RATING

In order to identify the sustainability performance of the future Mechanical Engineering Building towards our environment, NABERS rating tools is implemented at the same time to achieve the green building standard. The relevant information on the new MEB that is required for NABERS rating is tabulated below (Table 7).

Table 7: Input information of the new MEB that is used in NABERS rating.

New Building Total Area (m^2)	**2800**
Building Location and Postcode	**Murdoch, 6150**
Working Hours per week	**40**
Number of computers and appliances switched on during working hours	**100**

Assumptions

- The New Mechanical Engineering Building is designed to have 4 levels and each level has approximately 700 m^2 which makes up to a total whole building area of 2800 m^2
- Due to the reason that the New Mechanical Engineering Building will be consisting of workshops, offices and computer laboratories, therefore, approximately 100 computers will be installed within the building.
- Total of 40 working hours per week = 5 days of working days per week × 8 hours of working hours per day

3.3 INTRODUCTION TO SKETCHUP PROGRAMME

SketchUp Pro programme is used after obtaining several estimations and considerations. It is accessible and straightforward. The SketchUp Pro programme is specialized. It is a useful mechanism for architects and building constructors to gather their drawings, develop their concepts and thus proceed to the planning stage. SketchUp Pro acts as a visualisation and communication tool between designer and the clients. SketchUp Pro is known to be a convincing tool and practice because it is intuitive and simple. It empowers project designers to evolve their ideas and also report their modelling concepts in both 2D and 3D formats

SketchUp Pro programme is widely utilised over all periods of Design-Build-Operate as it encourages everyone that is working on that programme to talk the same motives and be on the same page (Building Point Australia 2015). One of the merits of 3D modelling is that the type, breadth and source of the building material can be imported into the 3D modelling mechanism, a vital component in the 3D building model. In addition, it is generally recognised that a 3D computerized model incorporates three parts: geometry, topology and semantics. Geometry characterizes shape and measurements, topology characterizes spaces and their connections, and semantics portrays extra qualities, for example, room capacities, typically with devoted traits (Gimenez et al. 2015).

In order to assist the drawing and modelling mechanisms, general research such as the area, the location and the height of the new mechanical engineering building design is briefly evaluated in advance.

3.3.1 SKETCHUP MODELLING TOOL DRAWING PROCESS

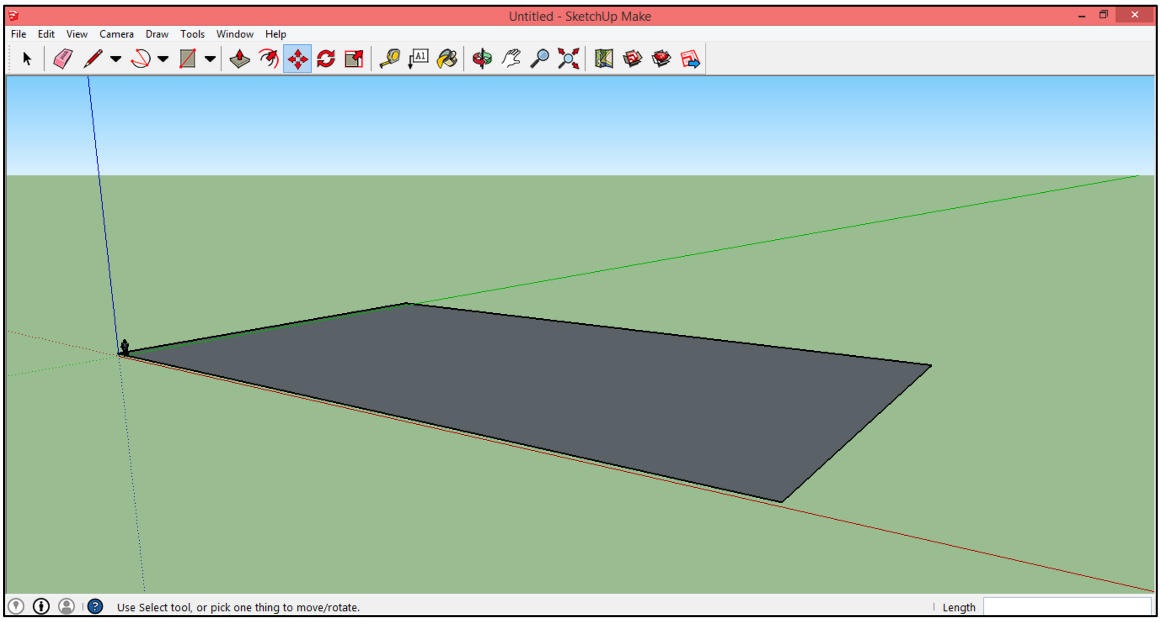


Figure 14: Demonstration of the base structure development.

The rectangular base structure of the new MEB generated using SketchUp (Figure 14).

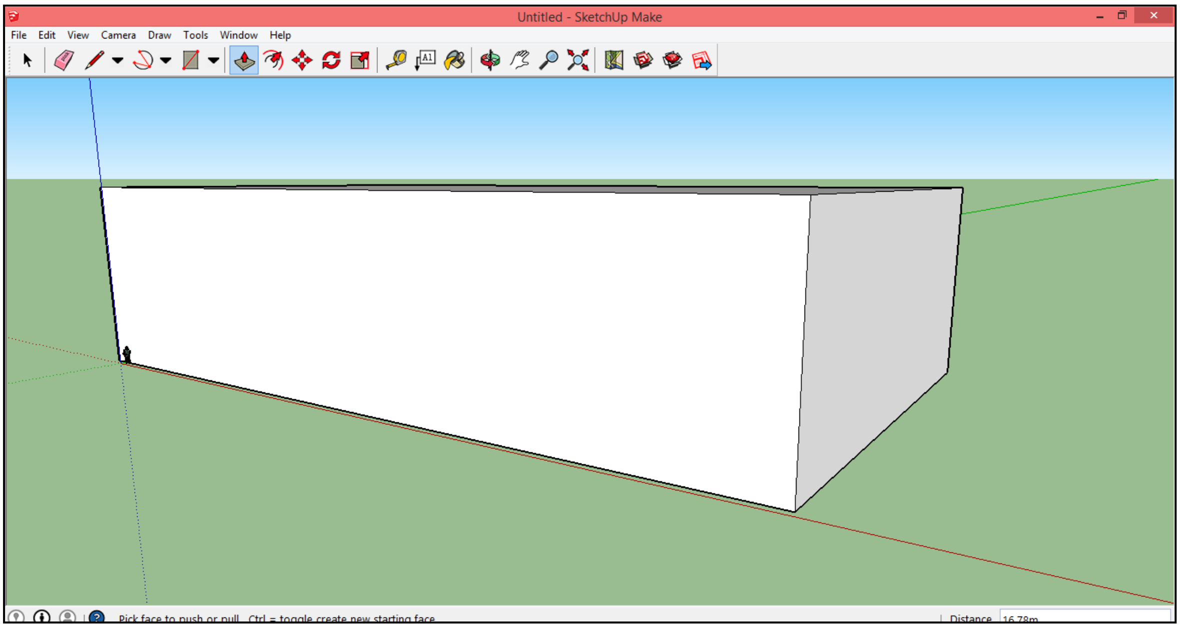


Figure 15: Demonstration of the pulling up the sculpt function.

Demonstrated progression of setting up an entire building structure outline by pull the sculpt of the 3D model to a certain height (Figure 15).

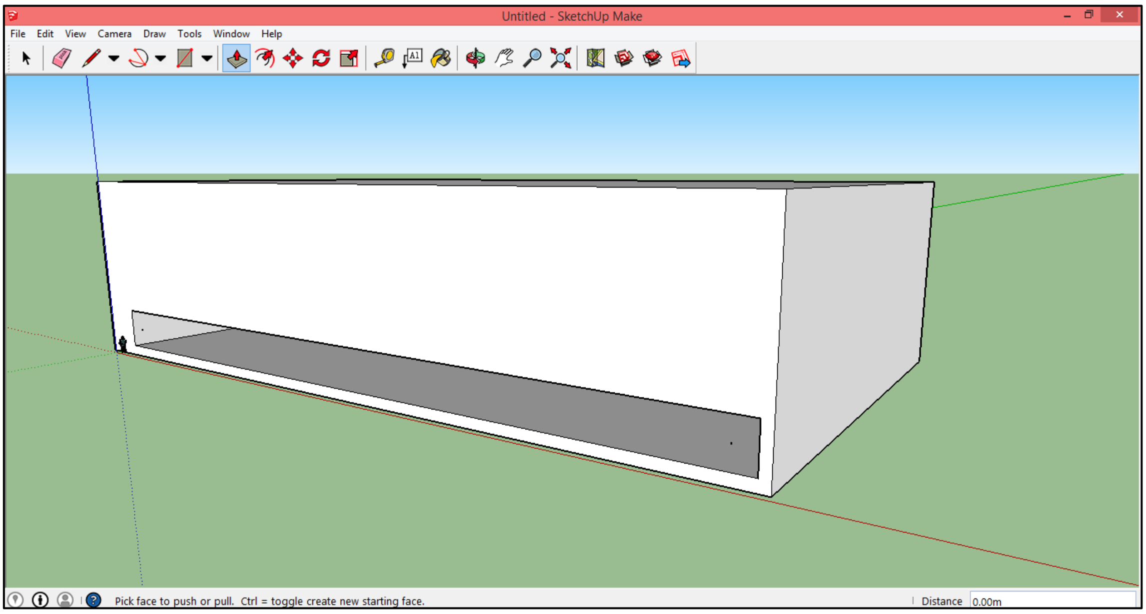


Figure 16: Demonstration of the ground floor structure.

The operation of constructing the new MEB floor layout is shown above (Figure 16)

CHAPTER 4: RESULTS

4.1 RESULTS OF THE EXISTING BUILDING ENERGY SIMULATION BY USING IES-VE

There are several energy simulation results generated which included:

- 4.1.1 Total Natural Gas consumption
- 4.1.2 Total Electricity consumption
- 4.1.3 Total Energy Consumption
- 4.1.4 Annual HVAC consumption

However, lightning consumption is not included as input data due to the lack of lightning information. The types of lightings and the total quantities used is not recorded by Murdoch University. As a result, the total energy consumption tabulation data is based on the total electricity usage which excluded lighting consumptions and also natural gas usage throughout the year.

4.1.1 RESULTS OF THE TOTAL NATURAL GAS CONSUMPTION IN THE SCIENCE AND COMPUTING BUILDING

Table 8: Results of the total natural gas consumption in the Science and Computing Building which simulated through IES-VE program.

	Total nat. gas (MWh)
Date	Science and Computing1.aps
Jan 01-31	0.0000
Feb 01-28	0.0000
Mar 01-31	0.0000
Apr 01-30	0.0000
May 01-31	0.0173
Jun 01-30	0.7883
Jul 01-31	2.0979
Aug 01-31	0.6313
Sep 01-30	0.0055
Oct 01-31	0.0000
Nov 01-30	0.0000
Dec 01-31	0.0000
Summed total	3.5404

The total natural gas consumption throughout the whole year is 3.5404 Mwh which is relatively low compared to the total electricity consumption for the Science and Computing Building.

In order to determine the energy consumption in MJ, we calculate it according to the following equation

$$3.5404 \text{ MWh} \times 3600 = 12745.44\text{MJ}$$

(1 MWh = 3600 MJ)

The total Science and Computing building has total area of 10967 m^2, therefore the natural gas energy consumption for the existing building is

$$\frac{12745.44 \text{ MJ}}{10956 \text{ m}^2} = 1.163\text{MJ/m}^2$$

4.1.2 RESULTS OF THE TOTAL ELECTRICITY CONSUMPTION IN THE EXISTING BUILDING

Table 9: Results of the total electricity consumption which excluded the lighting consumption in the Science and Computing Building and simulated through IES-VE modeling system

	Total electricity (MWh)
Date	Science and Computing1.aps
Jan 01-31	326.6673
Feb 01-28	294.7263
Mar 01-31	327.3864
Apr 01-30	312.4130
May 01-31	314.1290
Jun 01-30	298.6304
Jul 01-31	306.9912
Aug 01-31	308.0859
Sep 01-30	303.2524
Oct 01-31	314.9392
Nov 01-30	310.4376
Dec 01-31	325.6020
Summed total	3743.2607

The total electricity used in Science and Computing Building is 3743.3 MWh which is simultaneously equals to 13475880 MJ

$$3743.3\ \mathrm{MWh}\ \times 3600\ =\ 13475880\mathrm{MJ}$$

(1 MWh = 3600 MJ)

The total Science and Computing building has total area of 10967 m^2 which would result in the electricity energy consumption for the existing building to be

$$\frac{13475880\ \mathrm{MJ}}{10956\ \mathrm{m}^2}\ =\ 1230\mathrm{MJ/m}^2$$

4.1.3 RESULTS OF THE TOTAL ENERGY CONSUMPTION IN THE EXISTING BUILDING

Table 10: The results of the total energy consumption in the existing building which simulated through IES-VE program.

	Total energy (MWh)
Date	Science and Computing1.aps
Jan 01-31	326.6673
Feb 01-28	294.7263
Mar 01-31	327.3864
Apr 01-30	312.4130
May 01-31	314.1463
Jun 01-30	299.4185
Jul 01-31	309.0889
Aug 01-31	308.7171
Sep 01-30	303.2580
Oct 01-31	314.9392
Nov 01-30	310.4376
Dec 01-31	325.6020
Summed total	3746.8008

The total energy used in the existing building = the total electricity used + the total natural gas; which sum up to a total of 3746.8 MWh as known as 13488480 MJ.

$$3746.8 \text{ MWh} \times 3600 = 13488480\text{MJ}$$

The total Science and Computing building has total area of 10967 m^2, therefore the energy consumption for the existing building is

$$\frac{13488480 \text{ MJ}}{10956 \text{ m}^2} = 1231.15\text{MJ/m}$$

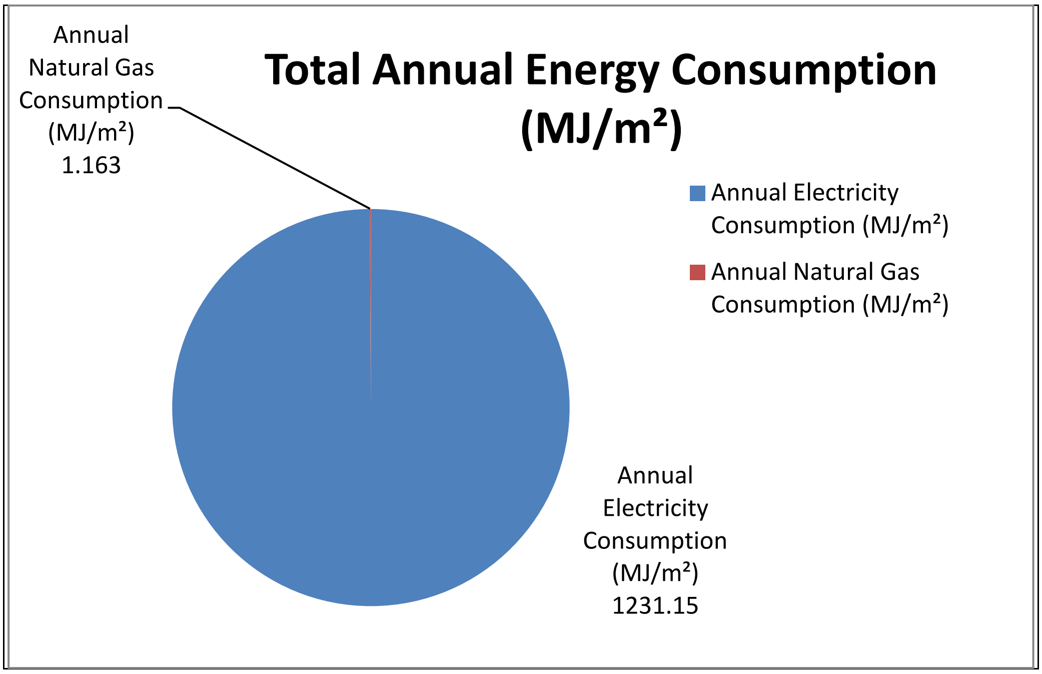


Figure 17: Total annual energy consumption in pie chart form.

Figure 17 illustrated the total annual energy consumption of the building which consists of annual electricity consumption and annual natural gas consumption. Annual electricity consumption has almost taken 100% of the total energy use.

4.1.4 ANNUAL HVAC CONSUMPTION

The annual HVAC consumption is made up of two main components:-

- Annual Boiler Load
- Annual Chiller Load

4.1.4.1 RESULTS OF THE ANNUAL BOILER LOAD IN THE SCIENCE AND COMPUTING BUILDING

Table 11: The results of the annual boiler load in the Science and Computing building which simulated through IES-VE modeling system.

	Boilers load (MWh)
Date	Science and Computing1.aps
Jan 01-31	0.0000
Feb 01-28	0.0000
Mar 01-31	0.0000
Apr 01-30	0.0000
May 01-31	0.0140
Jun 01-30	0.6385
Jul 01-31	1.6993
Aug 01-31	0.5114
Sep 01-30	0.0045
Oct 01-31	0.0000
Nov 01-30	0.0000
Dec 01-31	0.0000
Summed total	2.8677

Table 11 illustrates the total boiler load throughout the year and the boiler is not used from January to March and September to December due to the summer and hot season. However, heaters are used during winter season (June to August) in order to keep the warmth of the office.

On the other hand, there's plenty of experimentation labs used and therefore boiler is being implemented to operate the mechanisms and appliances like provide hot water for experimentation purposes.

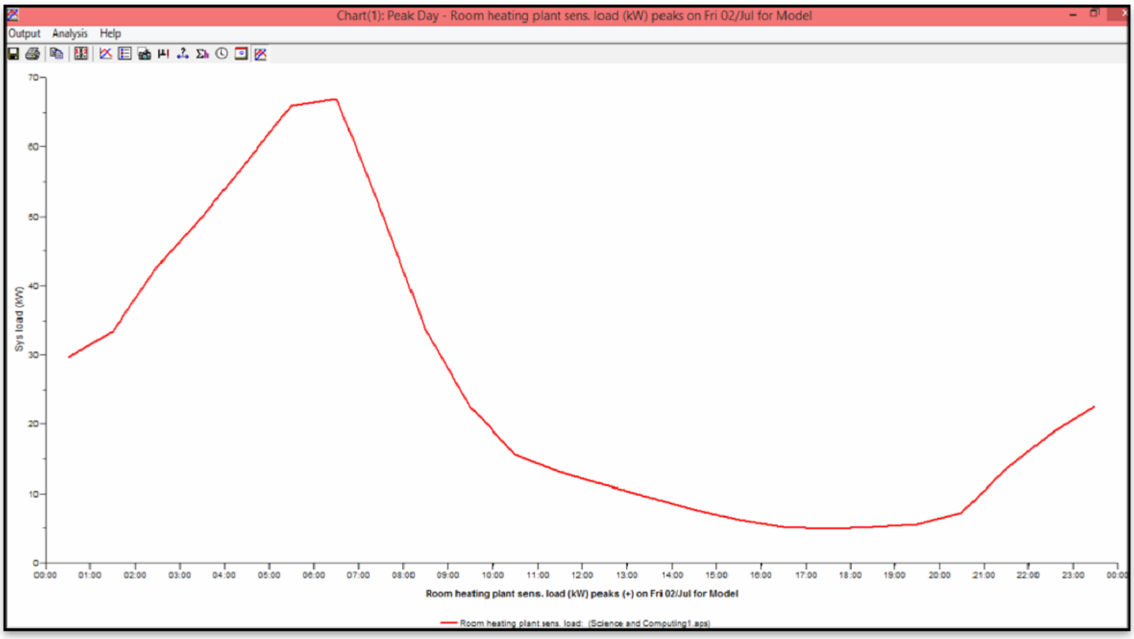


Figure 18: Peak day load of boiler in the Science and Computing building on 2 of July 2015 that simulated through IES-VE modeling system

Figure 18 explained the peak day boiler use. The boiler has the highest energy consumption from 6.00am to 7.00am on Friday 02/July in order to warm up the boiler system for its functionality throughout the day.

4.1.4.2 RESULTS OF THE ANNUAL CHILLER LOAD IN THE SCIENCE AND COMPUTING BUILDING

Table 12: The result of the annual chiller load in the Science and Computing building which simulated through IES-VE modeling tool

	Chillers load (MWh)
Date	Science and Computing1.aps
Jan 01-31	82.8408
Feb 01-28	73.7309
Mar 01-31	85.2383
Apr 01-30	67.7797
May 01-31	41.0467
Jun 01-30	21.8376
Jul 01-31	17.2537
Aug 01-31	20.9025
Sep 01-30	37.2448
Oct 01-31	43.7478
Nov 01-30	61.1958
Dec 01-31	79.2911
Summed total	632.1099

The chiller had the highest consumption load during summer season (January to March) which have achieved more than 80 MWh of chiller load for cooling purposes (Table 12). On the other hand, the chiller's consumption is comparatively higher than boiler load which indicates that most of the energy consumed by the chiller system.

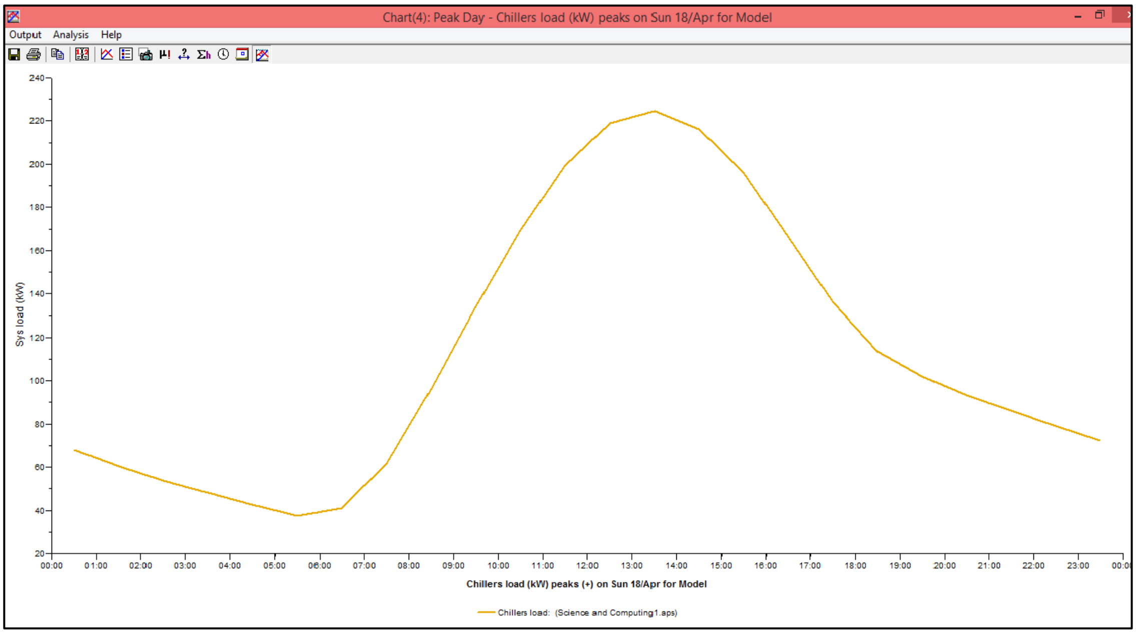


Figure 19: Peak day load of the chiller system at the Science and Computing building on 18 of April 2015 which simulated through IES-VE modeling system

The chiller load reaches its peak during midday (12pm to 1pm) on 18 of April 2015 due to the reason it has the highest temperature throughout the whole day (Figure 20). Hence, by implementing high efficiency chiller system, it can maintain the indoor temperature, and also educating workers' behavior, the indoor temperature for comfort can be maintained while reducing the total carbon emission.

4.2 NABERS RATING CALCULATOR RESULTS

The NABERS rating calculator results consist of:

- 4.2.1 Science and Computing Building NABERS rating scores;
- 4.2.2 The estimated energy consumption for the new building with same design and energy performance as the existing building; and
- 4.2.3 The estimated energy consumption for the new building with NABERS Ratings 4, 5 and 6.

4.2.1 THE SCIENCE AND COMPUTING BUILDING NABERS RATING SCORE

Nabers rating calculator results

NABERS

Premise type	Office			
Premise scope	Whole building			
Building details	Murdoch Science and Computing, South Stn			
State and postcode	MURDOCH 6150	**Hours of occupancy**	30	hrs/week
Area of office	10956 m^2	**Number of computers**	150	

Energy Star rating (Calculator version number: 10.0)

Very poor performance

Your office has very poor greenhouse performance and lies outside the rating scale .Some simple initiatives will likely to improve your greenhouse/energy efficiency significantly and bring your office within the rating scale .

Results for the 12 months rating period	**Nabers energy rating**		**Nabers energy rating without GreenPower**	
Star rating	0 star		0 star	
GreenPower included	0	%	0	%
Energy intensity	1232	MJ/m^2	1232	MJ/m^2
Total greenhouse gas emissions (Full fuel cycle - scope 1 & 2)	2847614	kg CO_2-e p.a.	2847614	kg CO_2-e p.a.
Total greenhouse gas emissions (Full fuel cycle - scope 1,2 & 3)	3109885	kg CO_2-e p.a.	3109885	kg CO_2-e p.a.
Greenhouse gas intensity (Scope 1 & 2)	260	kg CO_2-e/m^2 p.a	260	kg CO_2-e/m^2 p.a
Greenhouse gas intensity (Full fuel cycle - scope 1,2 & 3)	284	kg CO_2-e/m^2 p.a	284	kg CO_2-e/m^2 p.a
Benchmarking factor (previously known as Normalised Emissions)	418		418	

Your energy data source input

Fuel type	**Quantity**	**Unit**	**Emissions (Full fuel cycled - Scope 1,2 & 3)**		**GreenPower**	
Electricity	3746000.0	kWh	3109180	kg CO_2-e p.a.	0	%
Gas	12744.0	MJ	705	kg CO_2-e p.a.	Not applicable	
Deisel	-	L	-		Not applicable	
Coal	-	T	-		Not applicable	

Figure 20: Science and Computing building's NABERS rating score.

Based on the results that presented in Figure 22, the Science and Computing building achieved 0 stars which indicated that there is a major effort necessary to reduce its total energy consumption and also reduce the green house emission. On the other hand, the existing building is consuming energy based on the offices purpose as well as the laboratory operation for experimentation purpose. In addition, green power rating is low due to the reason that renewable energies are not undertaken as part of the existing building's facilities to generate energy. GreenPower is a voluntary measure that households and organisations used to increase renewable energy generation (Thefifthestate.com.au 2016) (and it comes from energy sourced from the sun, wind, water and waste which produce no greenhouse gas emissions. (The Facts On Greenpower, 2015)

In conclusion, the NABERS data tabulation and results showed the major issues which had led to the inefficiency of building energy use. These results are identified as benchmarks towards the journey on designing the new Mechanical Engineering Building. The energy simulation results and NABERS rating results can be used as an effective referencing tool which can provoke the new mechanical engineering building's design and operational use to at least achieve NABERS 4 star ratings.

4.2.2 THE ESTIMATED ENERGY CONSUMPTION FOR THE NEW BUILDING WITH SAME DESIGN AND ENERGY PERFORMANCE AS THE EXISTING BUILDING

An estimation of yearly Energy Consumption for the new Mechanic al Engineering building based on the same energy sources and building design as Science and Computing building is calculated as below

$$\frac{3746800\ \text{kWh}}{10956\text{m}^2} \times 2800\text{m}^2 = 957561.15\text{kWh/year}$$

In order to calculate the Max total energy use in MJ per annum

$$\frac{957561.15\text{kWh}}{\text{year}} \times 3.6 = 3447220.153\text{MJ}$$

Table 13: The estimated energy consumption for new building based on the same design and energy performance as the existing building.

	The new Mechanical Engineering building with same design and energy performance as Science and Computing building	**The new Mechanical Engineering building with good high energy efficiency design**
Estimation of yearly Energy Consumption (kWh/year)	**957,561.15**	**574,414.02**
Max total energy use in MJ per annum	**3447,220.153**	**2037,890.47**

4.2.3 THE ESTIMATED ENERGY CONSUMPTION FOR THE NEW BUILDING WITH NABERS RATINGS 4, 5 AND 6

The calculation tabulated sheets for the higher NABERS ratings are attached in the appendix Figure 42 (NABERS 4 rating calculation), Figure 43 (NABERS rating 5 calculation), and Figure 46 (NABERS rating 6 calculation).

Table 14: The estimated energy consumption for the new Mechanical Engineering building in order to achieve NABERS Ratings 4, 5 and 6.

	The new building with NABERS 4 ratings	**The new building with NABERS 5 ratings**	**The new building with NABERS 6 ratings**
Estimation of yearly Energy Consumption (kWh/year)	**412,323**	**293,231**	**146,615**
Max total energy use in MJ per annum	**1484,363**	**1055,632**	**527,814**

4.3 FINAL RESULTS OF MECHANICAL ENGINEERING BUILDING 3D DRAWINGS

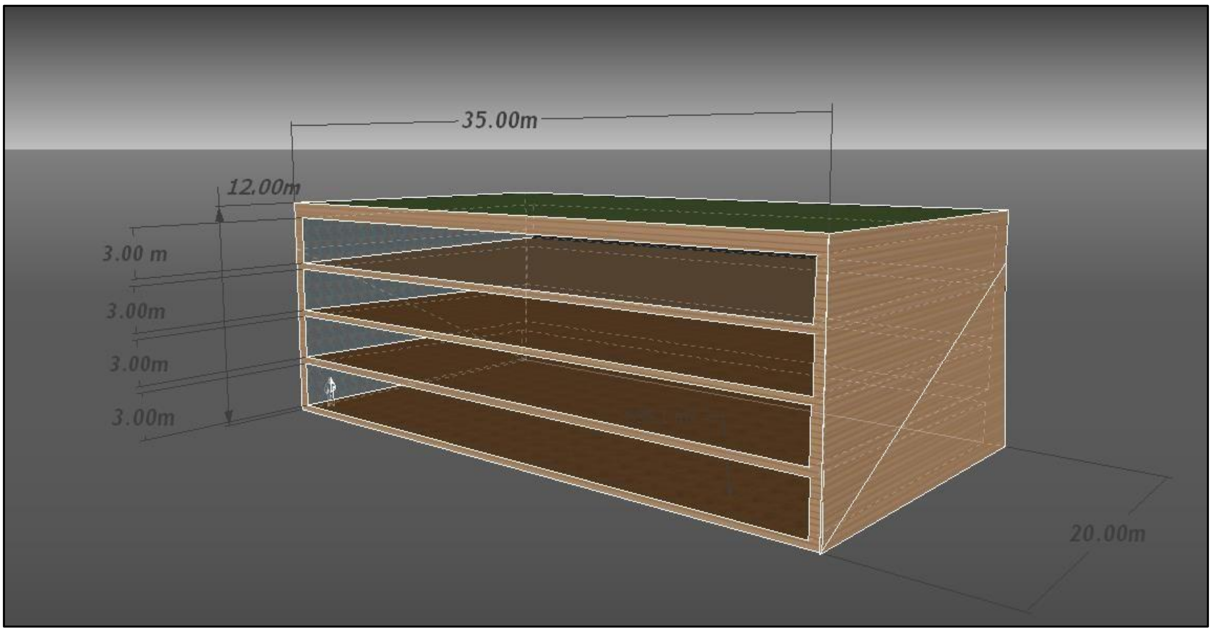


Figure 21: Final 3D drawing of the new Mechanical Engineering Building.

	New Murdoch Mechanical Engineering Building
Total Height of the building	Each floor with 3m height which make up to a total of 12m height
Total Length of the building	35m long
Total Width of the building	20m width
Total Area of the Building	2800m^2 in total area

CHAPTER 5: DISCUSSION

5.1 DISCUSSION OF THE BUILDING ENERGY SIMULATION USING IES-VE MODELING TOOL

Due to the economic advancement and irresponsible acts of mankind, our environment and climatic system is affected by greenhouse gas emissions which lead to the issue of global warming (Prato 2008). In particular, buildings, which are one of the major components that consume energy, lead to air contamination and carbon outflow (You et al. 2011). Embodied and Operational energy are known as the biggest energy consumption in a building’s life cycle. Besides, maintenance acts, demolition work and disposal activities are major contributors towards building energy consumption and emission of carbon dioxide. Hence, in order to reduce the total energy consumption in a specific building, the effort to reduce the embodied energy and operational energy has to be taken into account and evaluated.

Embodied energy (EE) is carried out during the construction stage of the building development, which includes the total embodied energy of building materials, transportation energy of materials and building construction energy. Specifically, embodied energy of building materials makes up a large percentage of embodied energy in buildings.

South Korea is widely known as a developed country and has introduced advanced technologies for motor manufacturing and building development. Each year South Korea generated about 27 % of the total global energy consumption and also emit about 25% of total GHG emissions. Accordingly, the government sector played a major role in reducing the energy use in there sectors which simultaneously reduces the carbon emission.

To obtain more specific outcomes via these efforts to achieve the carbon- reduce framework, it is mandatory and important to clearly identify the sources of the building energy use. Similarly, energy simulation of the existing building is undertaken in order to identify the building material and this will help in design of the new mechanical engineering building with more environmental-friendly building materials (Kim et al. 2012).

Based on the existing building's IES-VE energy simulation results, the building materials that are used for the Science and Computing building contribute a relatively huge amount of carbon emission to our environment, because use of energy intensive materials such as brick, cement, steel, glass results in high embodied energy. Appropriate selection of building materials and in depth research with regard to their embodied energy is crucial for limiting embodied energy of buildings (Praseeda, Reddy and Mani 2015).

The type of building materials and also the U-value of the material are tabulated (Table 15). U-values, known as heat transfer coefficient, are used to identify the insulation effectiveness of the building's materials and components. In another word, it characterizes the specific building material's resistance to heat transmitting between the inside and the outside of a building. The lower the U-value of the building material, the harder for the heat to pass through from the outdoor into the indoor, therefore, the higher the insulation efficiency (Designing Buildings 2015).

Table 15: The building material types and their associated U-value.

Category	**Description**	**U value (W/m^{2}k)**
External Wall	Brick/Block wall	0.4396
Door	Wooden door	2.1944
Internal ceiling/Floor	Concrete slab internal ceiling	1.0687
Roof	Sloping roof included loft	0.1589
External Window	Large Single glazed window	5.5617
Ground/ Exposed floor	Standard floor construction (2002)	0.2499
Internal Partition	115mm single-leaf brick	2.2448

5.1.1 LOW EXISTING BUILDING EMBODIED ENERGY BUILDING MATERIALS INVESTIGATION

Low energy building materials with low U value can be used to replace these traditional building materials that implemented in the existing building.

Table 16: The existing building materials and recommended low energy building materials

Existing Building Material			Low Energy Building Material		
Category	**Description**	**U value (W/m^2k)**	**Category**	**Description**	**U value (W/m^2k)**
External Wall	Brick/Block wall	0.4396	External Wall	Lightweight aggregates from recycled masonry rubble	0.28
Door	Wooden door	2.1944	Door	NZ Generic Door R0.88	0.9972
Internal ceiling/Floor	Concrete slab internal ceiling	1.0687	Internal ceiling/Floor	Timber Frame Attic Ceiling	0.5255
Roof	Sloping roof included loft	0.1589	Roof	Sloping roof included loft	0.1589
External Window	Large Single glazed window	5.5617	External Window	Double Glazed with 16mm argon with aluminium spacer bar	1.5
Ground/ Exposed floor	Standard floor construction (2002)	0.2499	Ground/ Exposed floor	2013 exposed floor	0.22
Internal Partition	115mm single-leaf brick	2.2448	Internal Partition	Wood made production	1.4615

5.1.1.1 LIGHTWEIGHT AGGREGATES FROM RECYCLED MASONRY RUBBLE

For the external wall section, lightweight aggregates from recycled masonry rubble are one of the preferable options because these lightweight construction aggregates manufactured from construction waste. They can be re-used again and fabricated into lightweight mortars and concretes (Mueller, Schnell and Ruebner 2015). By implementing lightweight aggregates from recycled masonry rubble, construction energy and waste can be significantly reduced. In the future, strict closed-loop construction waste recycling on site will be undertaken by government and authorities in order to avoid excessive construction waste that will end up in landfill. Hence, limited landfill capacity will be recognised as a future plan from the state government to prevent the disposal or operation of these construction wastes.

20 million tonnes of masonry rubble is generated every year from demolition and rehabilitation phase of buildings This recycled masonry rubble is unquestionably a notable potential source of raw material that can be used to construct walls, which would in turn address construction demands. The lightweight aggregates could also be used use as a bulk insulation material because of their low thermal conductivity.

The biggest achievement of the lightweight aggregate manufactured from masonry rubble is that the production process involves nearly zero primary resources. Manufacturer production of lightweight aggregates from recycled masonry rubble could take the opportunity to replace natural pumice and expanded clays which will keep the use of natural resources to a minimal (Mueller, Schnell and Ruebner 2015).

Figure 22: Image of lightweight aggregates from masonry rubble.

The production of lightweight concrete blocks, refulting in a concrete block of lightweight aggregates from masonry rubble (left) and from expanded clay (right).

5.1.1.2 DOUBLE GLAZING

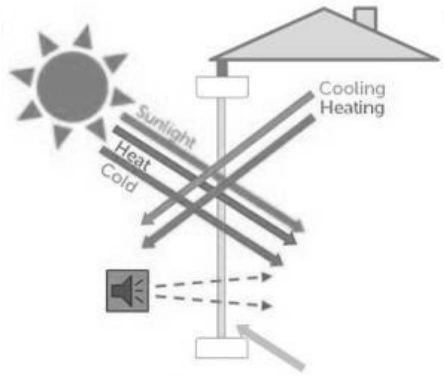
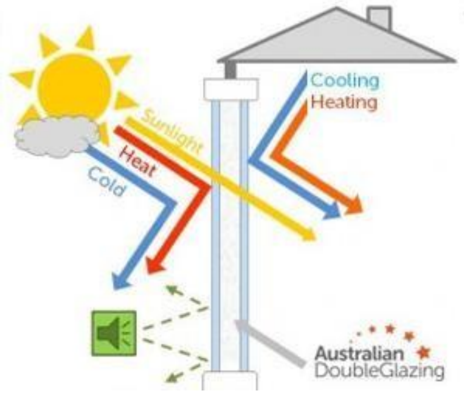
Single Glazing Properties	Double Glazing Properties
(a) 	(b) 
• Only one pane that leads to low efficiency • Creates noise pollution	• Dual panes of glass and 20mm gas filled cavities to provide insulation and thus improve the energy efficiency • Reduces external noise by up to 80%

Figure 23: (a) Single glazing properties and (b) Double glazing properties (Australian Double Glazing 2015).

Minimising energy use in building is one of the main considerations that can be taken to reduce the operational cost. Pérez-Lombard et al (2009) stated that the energy consumption by both residential and commercial buildings, in developed countries accounts for abour 20–40% of the total energy consumption. Windows influence the energy balance in a building in two ways: the solar radiation and thermal transfer performance. A window transmits sun based radiation and emanates long-wave solar radiation producing heat between the indoor and outdoor environment (Long et al. 2015). Subsequently, double glazing windows with better solar radiation are recommended as the low U value enhances the insulation purpose of the room.

For an example, in order to achieve the maximum daylight penetration and thus to reduce the use of lighting, the building at 40 Albert Road, South Melbourne has installed floor to ceiling high performance double glazing windows. It can also accomplish several other outcomes like enabling and preventing excessive heat loss from the building. This particular double glazing window installation also promotes natural ventilation. This feature can results in lower energy consumption by air conditioning. Full length shading curtains to the eastern façade along with operable internal blinds may assist in reducing heat entering the building (Energy Efficient Glazing 2015).

A major part of the energy consumption in the existing building is due to the boiler and chiller systems that function to keep a constant temperature throughout the day. Thus, the type of window selection is one of the key considerations in order to decrease the HVAC system operational cost

5.1.1.3 WOOD MADE PRODUCTION

Proper choice of building materials and basic frameworks may results in a significant decrease the essential energy use and atmosphere effect of structures. (Buchanan and Honey 1994) Reviews of lifecycle surveys on material structures have highlighted the energy and atmosphere advantages of wood-based building materials (Lippke et al. 2011). Several surveys have considerable reduction in embodied energy in a specific building (Buchanan and Honey 1994; Reddy and Jagadish 2003). Additionally, a few studies advocate ideal utilisation of materials or assets and that of locally accessible materials as methods used for conserving energy consumption (Morel et al. 2001; Kofoworola and Gheewala 2009).

Wood based products are carbon-neutral, and act as a repository of carbon which can reduce the amount of carbon emitted into the environment (Oneil and Lippke 2010). Trees can effectively store carbon (Lehmann and Hamilton 2011), which is widely known as carbon sequestration. It is roughly estimated that 1.1 tonnes of carbon dioxide can be stored in 1 square m^3 of wood product which contemporaneously conserve our environment (Puettmannand and Wilson 2005). Research also showed that wood-based products consumed 15% less energy as compared to concrete.

Chen (2012) calculated the operational energy that is used for heating, ventilation, air conditioning, lighting, and appliances of a five-story office building by comparing timber based products and concrete. He concluded that wood based buildings have a 10% lower operational energy demand with the integration of design optimisation and the use of advanced technologies. Another research from a comparative study of two mid-rise office buildings that was conducted by John et al. (2009) also indicated that timber products have better environmental performance, covering several environmental aspects (ozone depletion, global warming potential, eutrophication), compared to a building built using concrete.

5.1.2 SCIENCE AND COMPUTING BUILDING OPERATIONAL ENERGY REDUCTION STRATEGIES

By evaluating the results from the existing building energy simulation, we can identify the issues that lead to the massive annual energy consumption in that building.

Table 17: Australian Average Energy Intensity Trends by Building types, 1999-2020 (Department of Climate Change and Energy Efficiency 2015).

Units: MJ/ m^2.a	1999	2009	2020
Office - Tenancies	400	385	368
Office - Base Buildings	594	532	465
Office - Whole Buildings	994	917	833
Hotels	1209	1420	1652
Shopping Centres - Base Buildings*	403	403	403
Shopping Centres - Tenancy*	-	1202	1202
Shopping Centres - Base +Tenancy*	-	1605	1605
Supermarkets (Whole) *	-	3375	3375
Hospitals	1420	1542	1676
Schools	166	178	191
VET buildings	368	367	366
Universities	780	868	965
Public Buildings#	1111	947	768
Law Courts	467	550	642

By 2020, an office, which is the whole building, would require approximately 833 MJ/m2 of energy consumption per annum. However, based on the existing building energy simulation that was estimated using the IES-VE modelling tool, there is a total of 1230MJ/m^2 of energy used annually. The existing Science and Computing building daily operation consumes a large quantity of energy. At the same time it has contributes to a large amount of carbon emission into the environment. In order to reduce these total energy consumption as well as electricity cost, strategies to minimise the operational energy should be reviewed and also high efficiency appliances should be considered.

Existing Science and Computing building operational energy can be reduced by

- Workers behaviour change
- Appliances Efficiency Improvements and Energy Saving Strategies

5.1.2.1 WORKERS' BEHAVIOUR CHANGE

In order to effectively reduce the operational energy of the appliances, workers behaviour needs to be analysed. Work styles allude to a heap of dispositions and practices in the work environment. A specific work style may occur as a result of business exercises, workplace types, standards and rules characterised by upper administration and the general working environment and interaction. These are the components that will determine the energy consumption in a particular building (Bin 2012). In another words, workers improvement in conserving the environment can decide the aspiration and accomplishment of an organisation's objectives. Work environment conduct and practices can decide levels of asset consumption, and the working society may be influenced by a minimal slender or wide consideration of sustainability (McElligott et al. 2013).

Employees are encouraged to spare PC settings, implement office shut down strategies after office hours, utilize of electrical extensions for hardware that can be switched off when not being used and cooperate in lighting decrease programs. Likewise, transportation to and from work creates GHG emission and consumes a huge amount of energy. Workers can consider carpooling, biking, or taking public transportation (Institute for Building Efficiency 2013).

Moreover, in order to reduce the heating and cooling load of the building, staffs have an important role to play.

Actions to reduce the heating and cooling load should be encouraged. Some of these are listed below:-

- Watch all signage and conventions for heating and cooling operation
- Ensure heating and cooling indoor appliances are set to the predefined temperatures for the particular territory – not all zones should be at the same temperature
- Wear appropriate clothing that according to the seasonal weather to keep yourself comfortable
- Use a local fan instead of relying the function of air conditioners and
- Ensure that all windows and doors are closed if running an air conditioner appliances (Australian Hotel Association 2006)

Communication is an important tool that is used to convey information as well as educate workers. Through communication, workers would be able to find out the impact of their behaviours and how they can follow environmental sustainable practices.

There are many communication tools that are useful for energy conservation purposes. Three of the common ones are detailed below.

- Emails and websites: Suggestions promote any specific conservation activities and gather feedback and comments from staff.
- Public meetings: Building occupants obtain useful knowledge on energy efficient practices and participate in energy conservation programs.
- Prompts: Used as a visual reminders that attract attention of employees to energy savings activities (Bin 2012).

Figure 24: Example of prompts (Bin 2012).

5.1.2.2 APPLIANCES EFFICIENCY IMPROVEMENTS AND ENERGY SAVING STRATEGIES

To maintain an acceptable temperature inside a particular building, the HVAC framework must be able to handle all different kinds of loads. Practices to enhance the effectiveness in a building's HVAC framework can be separated into two classifications.

- Reduced of the HVAC loads
- Improved efficiency of the HVAC mechanisms (Department of Industry, Innovation and Science 2013)

5.1.2.2.1 REDUCTION OF THE HVAC LOADS

- Reduce Equipment Load – Decreasing the usage of electricity driven appliances, such as PCs, printers and lights will reduce a HVAC system's loads
- Demand Based Ventilation – Turning on the air conditioner only when required. A low amount of fresh air is required in a space based on the number of workers in accordance with the Australian Standards. Carbon dioxide sensors can be used to decide the base measure of outside air required and to reduce the amount of natural air supplied (Department of Industry, Innovation and Science 2013)

5.1.2.2.2 IMPROVE EFFICIENCY OF THE HVAC MECHANISMS

- System Selection – Select the suitable system which can reduce the energy usage and maximise energy savings. For an instance, a Variable Air Volume (VAV) AHU will adjust the volume of the incoming air to the spaces depending on the required demand. This enables for better control and reduces airflow rates, which simultaneously minimises the energy.
- Plant Selection –The total energy consumption of a building can be affected by the selection of HVAC plants. For example, condensing boilers implemented for producing hot water can improve its efficiencies for more than 90%. Accurate plant sizing also has a large impact on energy efficiency.

5.2 DISCUSSION ON THE NABERS RATING TOOLS - LOW ENERGY BUILDING PROPOSED STRATEGIES

In order to design a new mechanical engineering building that can at least achieve 4 star ratings; energy consumption has to be reduced by constructing energy efficient building design structure, implementing energy efficient strategies and also integrating with renewable energy technologies.

5.2.1 ENERGY EFFICIENCY DESIGN

To design a low energy building, on-lot demand management and high energy efficiency measure should be undertaken. A building designed based on the key principles of climate sensitive design as it can reduce thermal loads and energy losses.

- North facing double glazed windows recommended to reduce the summer heat and also achieve a better insulation
- All windows and doors that are adjacent to air-conditioned spaces are high performance double glazed, which will be build up based on the sun orientation in order to avoid heat gain.
- The interior lighting of the building will mainly consist of fluorescent lamps with dimmable daylight harvesting controls and motion sensors in less frequently used areas.

- Lighting is grouped in zones and local dimmer controls are provided to suit usage and prevailing conditions.
- External LED and metal halide lights with photo sensor control will reduce energy use.
- On the other hand, a transparent roof window is implemented to enable roof light to penetrate for the tutorial rooms and workshops purpose which are located at the Mechanical Engineering building Level 2
- Low VOC products are used, where possible, to replace high VOC products in paint finishes, and laminates.

Insulation is used to ensure the comfort in the building throughout the year by maintaining consistent indoor temperature. With suitable insulation to implemented extra heat loss and heat gain can be mitigated thus reducing the energy consumption of the HVAC system. Different types of materials can be used for insulation and these include wood fibre, plant fibre, rock wool, glass wool, and so on. The quantity of insulation that required may depend on the building plan, budgets and climate. Compared to heating and cooling tools, insulation is undeviating and doesn't involve much maintenance (Insightprojects.com.au)

5.2.2 ENERGY EFFICIENT TECHNOLOGIES

The variety of engineering structures, equipment and mechanisms are considered to manage the net energy demand of the building (Pantelic 2014).

- Appropriate scale and type of HVAC systems

  It is desirable to invest in an efficient and proper size of HVAC system that is well maintained and has a good warranty. HVAC consume the majority of the total energy in a specific workplace. Installing an energy efficient HVAC system can save up to 40% of the energy operating cost (Admin 2015).

- Energy meter used to monitor the appliances' energy efficiency
- Use of energy efficient office/ laboratory/ research equipment that labelled energy rating labels that illustrate the energy efficiency of the mechanisms
- Use of Building Management System to monitor and maintain the building energy use.

  Building Management System is a computer based system that delivers integrated control and monitoring of a building's electrical appliances and mechanical system. By using BMS in a new or existing building, its leading edge technology can used to monitor the ventilation heating, and HVAC systems. Further than that, BMS can also include fire alarm systems, lighting, security, plumbing and water monitoring.

Building Management System is capable to record and arrange the maintenance of the building. A system can use exclusive controls or, as is progressively to open standard controls. A BMS can deliver early detection of problems with electrical power via basic alarm and control notification (Data Center Knowledge 2014).

5.2.3 RENEWABLE ENERGIES

Advantages of local renewable energy generation include integration with existing building structures (no additional land or material use) and reduction of grid transmission losses and grid congestion issues. Determining the potential and calculating the performance of renewables in an urban environment is important for the design of future urban areas and the retrofit of existing structures.

- Integration of Solar Photovoltaic system with solar battery storage

- Adaptive Solar Facade

5.2.3.1 INTEGRATION OF SOLAR PHOTOVOLTAIC SYSTEM WITH SOLAR BATTERY STORAGE

Solar photovoltaic (PV) system is installed on the roof of the design building to supply part of the building's power needs. Photovoltaic cells have the potential to provide a significant amount of electrical energy (Gregory et al. 1997). Photovoltaic cells generate power by converting light from the sun into electricity. Most auspicious photovoltaic cells in terms of mass production, standard of efficiency and affordability are made from silicon. High efficiency mono-crystalline silicon panels are proposed for installation on top of the roof. The solar panel will be mounted at a north-facing angle of 25° to 30° to maximise power productivity.

Moreover, locating the photovoltaic cells on the roofs of homes, industries, and other buildings would reduces the requirements for extra land by an estimated 20% and reduces transmission costs. An inverter changes the direct current (DC) electricity from the panels into alternating current (AC), which can then be used to power the fixtures and appliances in a building, with any excess energy stored in a battery.

Solar energy storage using new innovation technology lithium iron phosphate ($LiFePO_4$) batteries is rising as a possible solution to this inconvenient issue (Josh's House 2015). The battery stores excess solar power generated during the day so the stored solar energy can be used during the night time. The surplus power that generated from the solar PV is redirected back to the grid once the batteries are full.

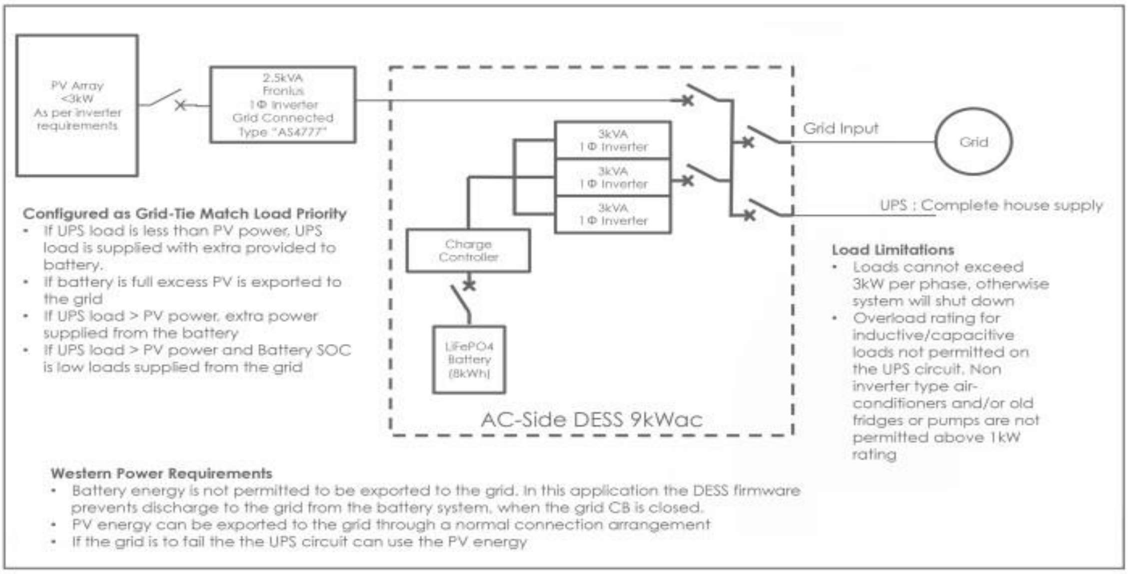


Figure 25: Schematic detailing of the solar energy storage system at Josh's House (Solar Balance 2015).

5.2.3.2 ADAPTIVE SOLAR FAÇADE

In modern Australia, solar gains intensity due to glazed conditions and structures is suggested that has significantly lead to the issue of global warming. Solar energy gains are also provided by other alternative ways such as transparently insulated walls and solar photovoltaic system. A beneficial system reinforcing the direct gains through glazed areas included indirect gains using translucent insulation methods on solid walls. All these solar energy gains can be collected to generate electricity (Raicu et al. 2000). Therefore the Adaptive Solar façade is considered as one of the options of the system integration to reduce energy loss. The Adaptive Solar Facade (ASF) is a useful facade that integrates photovoltaic modules with soft inflated actuators for daylight control and also solar detecting. The adaptive solar façade enables shading, solar energy generation, and also control of the level of exposure and transparency. The dynamic feature can rotate after responding to the alterations of the outside environment and the occupants comfort needs (Architecture and Building Systems 2015)

5.3 DISCUSSION ON THE MECHANICAL ENGINEERING BUILDING STRUCTURE DESIGN AND MEASUREMENTS

In modern days like this that emphasize the effectiveness of instruments and appliances usage, it is today conceivable to build a definite yet simple way to utilise 3D models in an expense effective way. As a result, in this project, we intend to discover an effective 3D drawing tools to illustrate the animated diagram of the new mechanical engineering building for the purpose of better understanding.

As needs be, expansive corpora of 3D models, for example, the Google 3D Warehouse, are currently turning out to be unreservedly accessible on the web. (Zhang et al. 2013) It is likewise noticed that for quite a while now mapping mechanisms, similar to Google Earth, have been utilizing 3D models of urban communities as a part of their perceptions. Such technique can thus accomplish noteworthy results for demonstrating substantial regions with consistent improvement and outcomes (Frahm et al. 2010)

Due to the reason that the new Mechanical Engineering Building will be the extension of the current Murdoch Science and Computing Building, therefore the layout plan of the new Mechanical Engineering Building will be constructed based on the existing building's design layout.

The new engineering building is designed to have 4 levels and each floor consists of different teaching purpose which sums up to a total area of 700m^2. The measurements of building partitions are listed below (Table 17).

Table 18: Measurement of the new Mechanical Engineering Building.

Total Height of the building	Each floor with 3m height which make up to a total of 12m height
Total Length of the building	35m long
Total Width of the building	20m width
Total Area of the Building	2800m^2 in total area

5.3.1 GROUND FLOOR OF THE BUILDING

The ground floor of the Mechanical Engineering Building consists of six different experimentation laboratories with a total area of 600 m^2. Consequently, a brief survey of mechanical engineering experimentation laboratories requirements is carried out in order to get acquainted with the facilities that may recommend establishing. These laboratories cover an extensive variety of mechanical building administrations, permitting the future mechanical students to test, assess, and show an assortment of physical standards (University of Technology Sydney 2015). The experimentation laboratories are designed to be located on the ground floor in order for the piping network to be constructed uncomplicatedly and to improve the efficiency of the maintenance work.

A complete list of the Mechanical Engineering Building facilities' strategies is recommended, with top 10 Mechanical engineering programs around the world reviewed below (Table 18).

Table 19: Top 10 world-wide Mechanical Engineering programs

<table>
<tr><th>Rank</th><th>Name of Institution</th><th>Location</th><th>Experimental Labs</th><th>Computational Labs</th></tr>
<tr><td>1</td><td>Massachusetts Institute of Technology (MIT)</td><td>United States</td><td rowspan="10">• Mechanics of solid Laboratory
• Engineering Thermodynamics
• Automated Modeling Laboratory
• Fluid Mechanics Laboratory
• Bio-MicroElectro Mechanical Systems Lab
• Heat Transfer laboratory</td><td rowspan="10">• Computational Flow Physics Laboratory
• Computational Mechanics Laboratory
• Computational Physics Group</td></tr>
<tr><td>2</td><td>Stanford University</td><td>United States</td></tr>
<tr><td>3</td><td>University of Cambridge</td><td>United Kingdom</td></tr>
<tr><td>4</td><td>University of California, Berkeley (UCB)</td><td>United States</td></tr>
<tr><td>5</td><td>University of Michigan</td><td>United States</td></tr>
<tr><td>6</td><td>Imperial College London</td><td>United Kingdom</td></tr>
<tr><td>7</td><td>Georgia Institute of Technology</td><td>United States</td></tr>
<tr><td>8</td><td>National University of Singapore (NUS)</td><td>Singapore</td></tr>
<tr><td>9</td><td>University of Oxford</td><td>United Kingdom</td></tr>
<tr><td>10</td><td>Harvard University</td><td>United States</td></tr>
</table>

5.3.1.1 MECHANICS OF SOLID LABORATORY

Mechanical Engineer utilizes, study and develop apparatus, machines, and structures, extending from wrenches to autos to rockets. The instructive foundation for this incorporates courses in statics, motion, mechanics of materials, and other related subjects. For instance, knowledge of unbending bodies is required in summing up the range of burdens on an auto, which is vital in characterising the vehicle's distortions and long haul solidness (Kreith 1999). Various equipment and instruments are essential in a mechanics of solid laboratory. A few examples include Universal testing machine, Torsion testing machine, Impact testing machine, Brinell hardness testing machine, Rockwell hardness testing machine. These equipment demonstrate the fundamental the quality and mechanics of materials to prospective students. The material properties of interest include sway quality, elasticity, compressive quality, hardness, flexibility and so on (ACE College of Engineering 2015).

Figure 26: Mechanics of Solid Laboratory in Curtin University.

5.3.1.2 THERMODYNAMICS LAB

Thermodynamics is both a branch of material science and a designing science. Mechanical Engineer are typically keen on picking up an essential comprehension of the physical and compound conduct of fixed, tranquil amounts of substances and uses the standards of thermodynamics to relate the properties of matter.

Engineers are by large keen on considering thermodynamics frameworks and how they communicate with the environment. To encourage this, engineers have extended the subject of thermodynamics to investigate the frameworks through which matter streams. (Keith 1999). Thermodynamics laboratory may consists of different equipment's such as turbo charged diesel motor or generator station, calorimeter for fuel examination, air heat-recuperation ventilator (white nook) that is used to test the indoor air quality and motor dynamometer. Students are acquainted with the weight, temperature, and humidity of the testing appliances, for example, transducers, vacuum gauges, thermocouples, and other gauges. Motor proficiency and execution tests are led, whereby students learn the fundamental properties of different liquids (Wentworth Institute of Technology 2015).

5.3.1.3 HEAT TRANSFER LABORATORY

The heat transfer laboratories are utilised for trial research on heat exchange and heat hydrodynamics. The experimentation laboratories is normally equipped with a few stream circles, high current power and flow force supplies, high recurrence instigation force supplies, holography and hot wire anemometry setups (UCLA Engineering 2015). There are additionally types of appliance and sensors that enable future students to get familiarised with and this include the transient heat exchange and lumped system examination, radiation successes, heat sink, and heat channels (Wentworth Institute of Technology 2015).

5.3.1 1ST FLOOR OF THE BUILDING

Laboratories and undergraduate workshops consists a total area of 600m^2. This enables a stronger engagement between tutors and students and thus improves the interaction between one another. Research laboratories may consist of computers and other electronic appliances that would assist students in conducting their research for projects and assignments by sourcing information from journals and other resources online.

5.3.2 2ND Floor of the Building

There would be computer labs on the 2nd floor of the building, which would have approximately 60 computers. A common area as well as a study area will also be included on this floor.

5.3.3 3RD Floor of the Building

The 3rd floor of the building would be designed as offices spaces. There will be 30 small offices which make up to a total area of 600 square meters. The offices are designed with double glazing windows with suitable insulation materials for the staff's comfort. Waterless urinals are implemented in the office's toilet in order to reduce water usage.

CHAPTER 6: NEW BUILDING INTEGRATION STRATEGIES REVIEW

In order to achieve sustainability purpose, most green building designers utilise technologies and computer simulations based on building information modelling (BIM) during the first stage of the project. BIM analyses and simulates options during the design development of a green building to optimise the building energy consumption through energy use simulation. (Lee 2011). It is becoming an essential part of the project implementation practice in the architecture and development industry due to the reason that BIM technology addresses the major input elements of a building. This modelling tool favours the developers because it integrates all building performance modeling and enables them to implement effortlessly (Khemlani 2009). Essentially, building information modelling (BIM) is a new approach of gathering the layout and information of building projects.

- Building - the whole lifecycle of the building is well thought-out (drawing, manufacture, performance)
- Information - all details about the building and its lifecycle are integrated
- Modelling – characterising and simulating the building, its delivery, and procedure using incorporated tools (Bentley System 2011)

According to the National Institute of Building Sciences (2011), BIM is not simple 3D modelling of a building but rather attribute to ‘‘an automated demonstration of physical and practical components of a facility based on contemporary communication technique of digital modelling system.’’

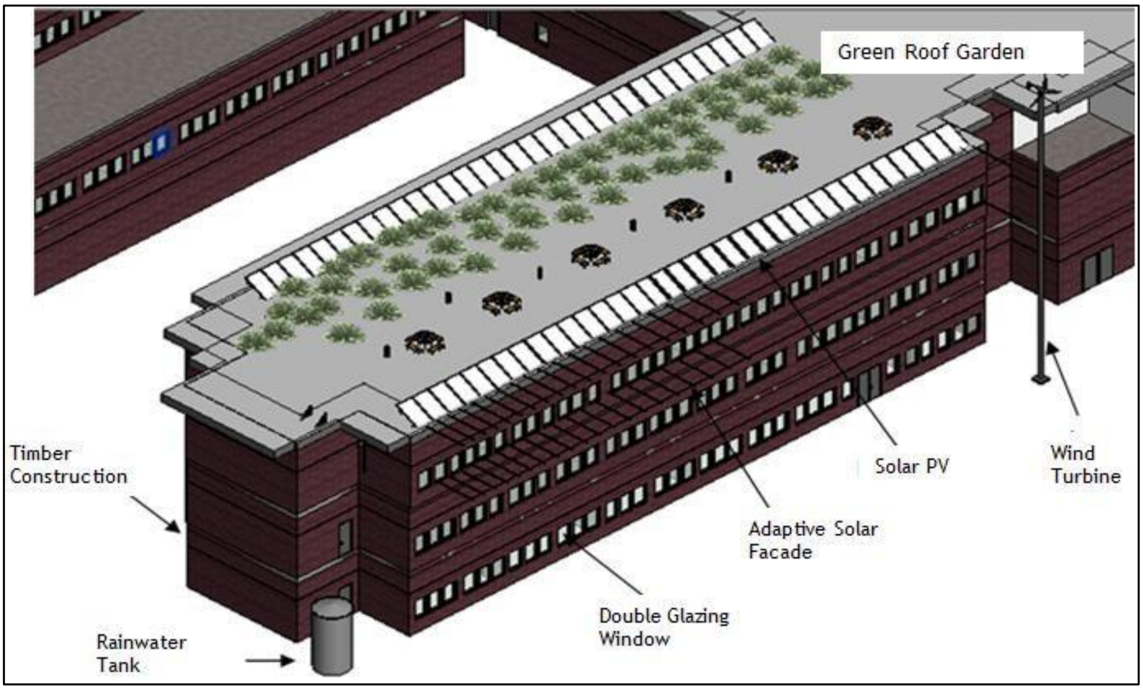


Figure 27: The 3D drawing of the new building with integrated sustainable strategies.

In a nutshell, (BIM) technology provides a new wide range of evaluating, managing and auditing on the environmental impacts of project construction and development through virtual prototyping/visualisation technology. Alawini et al. (2008) also emphasize that BIM is a tool that is used to create and to help building design industry efficiently integrate sustainable components like solar panel and construction materials, especially in energy efficiency application. It can thus evaluate and monitored into the building project lifecycle.

6.1 RAINWATER HARVESTING FOR LABORATORY PURPOSE

The use of rainwater harvesting in conjunction with other water supplies and a rooftop garden including rainwater harvesting system is functional for laboratory use. Onsite rooftop rainwater with minimum treatment has been employed as a cost-effective and alternative water resource (Ahmed et al. 2014; Zhang et al. 2009). Harvesting rainwater can simultaneously reduce water stress and environmental pollution, help to prevent floods created by low soil permeability and is recognised as a flexible strategy to deal with the reduction of water availability due to climate change (Angrill et al. 2011; Schudel 1996). Rainwater can be conveyed and distributed to rain water storage tanks. Water leaving the tank will be filtered, disinfected and distributed back to the Mechanical Engineering Building to supplement specific indoor potable demands, such as laboratory uses (deionised water) and/or cooling tower make-up water.

In research laboratories rainwater is estimated to be mainly used as a supply of deionised (DI) water. DI water has the mineral ions removed (demineralised water) compared to scheme water. Many laboratory procedures use deionised water including preparation of various reagents, preparation of calibration standards or analytic blanks, and cleaning of laboratory equipment. Due to the reason that rainwater contains fewer impurities than treated wastewater, it requires less filtration for high end research purposes and consequently less energy for its treatment. This makes the business case for rainwater harvesting and reuse attractive for laboratory purposes (Pantelic 2014).

6.2 WASTEWATER TREATMENT PLANT

According to the recent research, irrigation demand in Murdoch University is currently met by groundwater level and the groundwater safety measures is a key sustainable water driver, fully offsetting or greatly contributing to the irrigation requirement via use of recycled water is a major sustainable water management proposal. All the wastewater generated from the new MEB will be directed to the proposed wastewater treatment plants located underground that right beside the Green Mechanical Engineering building. Overflows and emergency flows from the Wastewater Treatment plant will be sent back to the Water Corporation gravity sewer. The collected raw wastewater will be treated in a WWTP that will be most likely be a type of Membrane Bioreactor (MBR) sized to accommodate maximum development flows (Pantelic 2014).

The Membrane Bioreactor system components are expected to include:

- Inlet mechanical screen;
- Balancing /Settling tank;
- Anoxic/ Aeration tanks;
- Membrane system (ultrafiltration);
- Disinfection systems which includes UV disinfection + chlorine dosing;
- SCADA telemetry; and
- Treated effluent tanks (Pantelic 2014).

6.3 TIMBER PREFABRICATED CONSTRUCTION

Cross Laminated Timber (CLT) panels were developed in Austria in 1995. By description a CLT panel consist of waste strips of structural grade timber compressed and bonded using a biodegradable structural adhesive. These two elements are fixed together by compressing and laminating them alternating between longitudinal and transverse lines, which are comparable to strengthen concrete (Lehmann 2012; Lehmann *et al.* 2012). The lifecycle of a CLT panel is shown below (Figure 33).

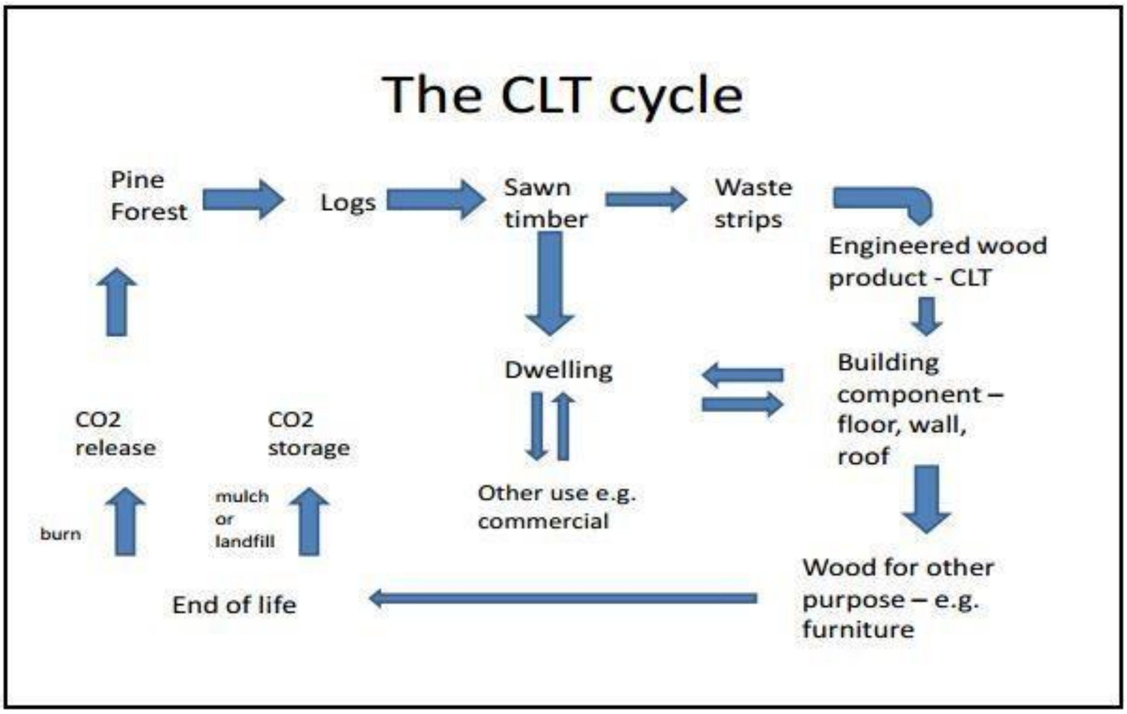


Figure 28: The CLT lifecycle form (Lehmann et al. 2012).

If managed properly, CLT panels can be an efficient and sustainable building alternative.

One of the more innovative features of CLT technologies is the reduction in construction time, this varies anywhere between 15 to 30% reduction in the total time which includes the design and procurement phases compared to a concrete constructed building (Hayball 2014). In some cases it has been documented up to 50% faster than conventional construction times (Lehmann 2012). An example Gantt diagram can be seen in the Appendix A comparing construction times of a conventional construction vs. CLT construction. The material costs are currently only around 4% cheaper than conventional construction materials (Hixon 2014; CLT Feasibility Study 2014). As industry accepts CLT and other timber construction materials and becomes more common, material costs and labour costs will decrease as well.

In comparison to conventional construction methods, CLT constructed buildings can reduce the embodied energy of buildings from roughly 550 kg CO_2/sqm to around 300 kg CO_2/sqm. This is a combination of prefabrication of the CLT panels that are made to exact dimensions with minimal waste and the use of low-impact finishes. The material is highly efficient with around a 0.75 m3 of CLT per sqm of apartment space (Lehmann et al. 2012).

A brief summary table of CLT panels in a comparison with conventional concrete construction can be seen below (Table 19).

Table 20: Comparison of CLT panels and conventional concrete construction.

	CLT	**Conventional Construction**
Material Cost	4% Cheaper than BAU (Hixon 2014, CLT Feasibility Study 2014)	n/a
Time	up to 30% Faster (Hayball 2015)	n/a
Embodied Carbon	300kg CO_2 per sqm. (Lehmann *et al.* 2012)	550kg CO2 per sqm. (Lehmann *et al.* 2012)
Carbon Capture Potential	0.25 to 0.8 tonne per cubic meter (Smith 2013; Lehmann *et al.* 2012)	0
Heating and Cooling	25% reduction (Lend Lease 2012)	n/a

Other benefits of CLT include:

- Building design and modelling done before CLT is manufactured, so there is minimal waste.
- Timber constructions are light weight, about 20% the weight of concrete which reduces the foundation requirements.
- High thermal performance of the panels, increased air tightness of the building which reduces the amount of insulation required for high energy efficiency.

6.4 GREEN ROOF GARDEN

Urban green infrastructures like vegetative roof top garden played as a vital part of water management and also promotes towards environmental sustainability (Gill, Handley, Ennos and Pauleit 2007; Schmidt 2010). Green roofs provide many ecosystem processes and services, including stormwater management, cooling and insulation of buildings, mitigation of the urban heat island effect, contribution to human health and habitat provisioning (Oberndorfer et al. 2007). Green roof gardens are designed to be situated on the top of the 4th floor and includes local natives' plants which provide creative purpose and habitat for various species. It also acts as an effective education and awareness tools. Green roof garden enable direct public viewing and are an obvious and effective way to educate and raise awareness about sustainability and resource conservation. In addition to extenuating urban heat islands, the advantage of green roofs includes:

- Reduced air pollution and carbon emission because plants can also remove air pollutants and carbon emissions through dry deposition and carbon sequestration and storage.
- Green roof garden will be able to reduce heat transfer through the building roof which simultaneously improving the indoor comfort and human health.
- Green roof garden mitigate as well as reduce storm water runoff in the urban environment- dampening of peak velocity run off during storm events.

- Improvement in remnant vegetation connectivity and private open space provision in the development, including provision of a ‘third dimension’ to a biodiversity link.

CHAPTER 7: CONCLUSION

By producing this thesis report, IES-VE modelling tools are useful to simulate the energy consumption based on the whole building materials and operation procedures which included the staff working hours and also the building's location and its topography information. The 3D modelling drawing is also generated from IES-VE drawing tool to identify the existing building structure. The 3D drawing results enable the establishment of the new building design strategies.

Based on the results shown, the existing Science and Computing building consume a relatively large energy demand due to the reason that existing building materials are not sustainable which have created large carbon footprint to our environment. On top of that, lack of annual system maintenance and energy audit are carried out to improve the building energy use efficiency. Throughout the energy simulation process, the existing building material types and operating issues are identified and therefore energy efficiency strategies is discussed to reduce the total energy consumption and total carbon footprint.

NABERS rating tools, a new environmental performance evaluation tool are carried out by embedded the existing building total energy consumption. The NABERS ratings enable stakeholders to classify their building net energy consumption in order to achieve green building criteria. On the other hand, NABERS self-rating tools provide an interpretation function which enable to calculate the allowance of maximum energy consumption for a new design building in order to improve its sustainable achievement. The existing Science and Computing building receive 0 stars from NABERS rating results which indicate that building energy use is significant for improvement and building management is necessary to enhance the building operational performance.

In this thesis report, analysis and in depth research based on the essential requirement for Mechanical Engineering building is accomplished in order to fit for itspurpose. On the other hand, a 3D drawing for the future Mechanical Engineering building is sketched out like the buildings' dimensions and structure description in order to use as a reference tool for stakeholders for future design project and also gain for public understanding.

The new Mechanical engineering building is suggested with low energy strategies in order to upgrade its sustainable performance, which can improve University's reputation. The possible energy efficient strategies will be mainly focus on the building concept and the material used. Moreover, for the purpose to lead the new Mechanical Engineering building towards the greener community, some of the potential sustainable integration strategies are recommended for implementation especially the renewable resources strategies in order to preserve our environment.

CHAPTER 8: RECOMMENDATION AND FUTURE WORK

- In depth investigation and design structure of the new Mechanical Engineering building is significant for development based on the building's function and its extended use.

- Retrofit the green building design and purpose to the new building development in order to achieve a sustainable community

- The energy simulation and reduction strategies like building management system is suggested in order to monitor the future mechanical engineering building energy use and identify any electricity power issue.

- Benchmarking on the performance of the new building is significant after the building design phase to determine their current performance and also figure out the low energy use operation strategies. . Performing benchmarking may enhance the pathway for attaining Green Star-Performance (GBCA, 2013) and NABERS rating (NABERS, 2013)

- In-depth or further research is crucial to identify the most efficient and sustainable building materials and cost analysis is crucial to carry out in order to evaluate its life time performance

- Integrated strategies like rainwater treatment, wastewater treatment and stormwater treatment plants should be evaluated based on the cost analysis and operation performance in order to reduce water use and improve the wastewater quality before it discharge.

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APPENDICES

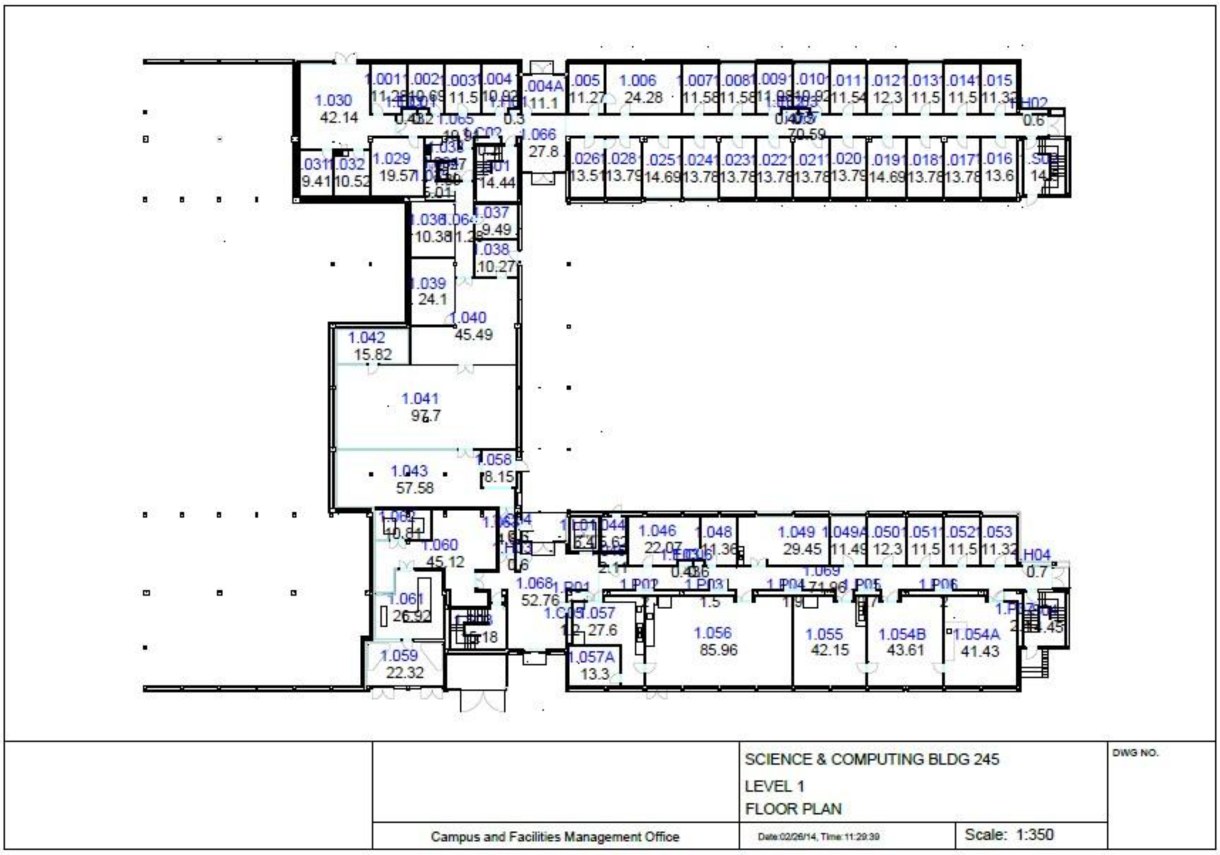


Figure 29: Science and Computing Building level 1 floor plan

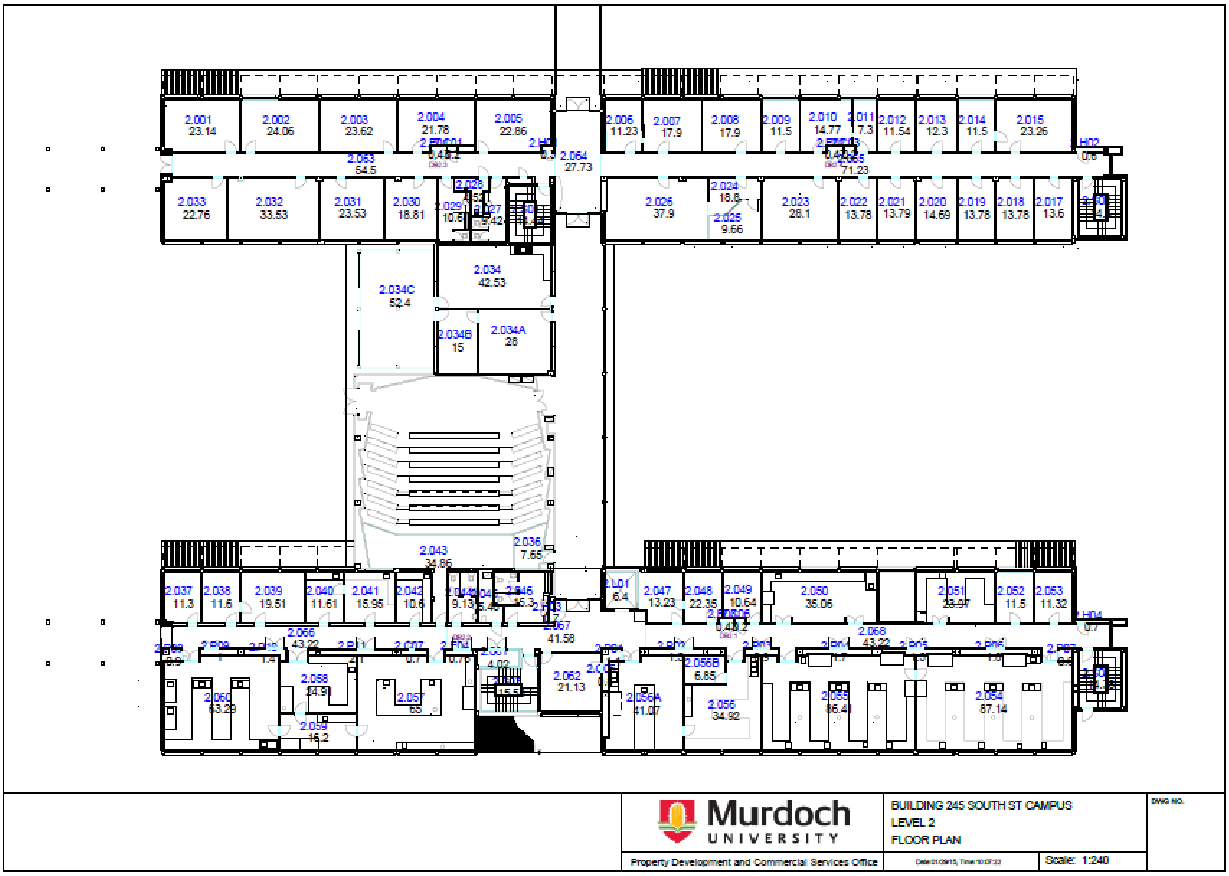


Figure 30: Science and Computing Building level 2 floor plan

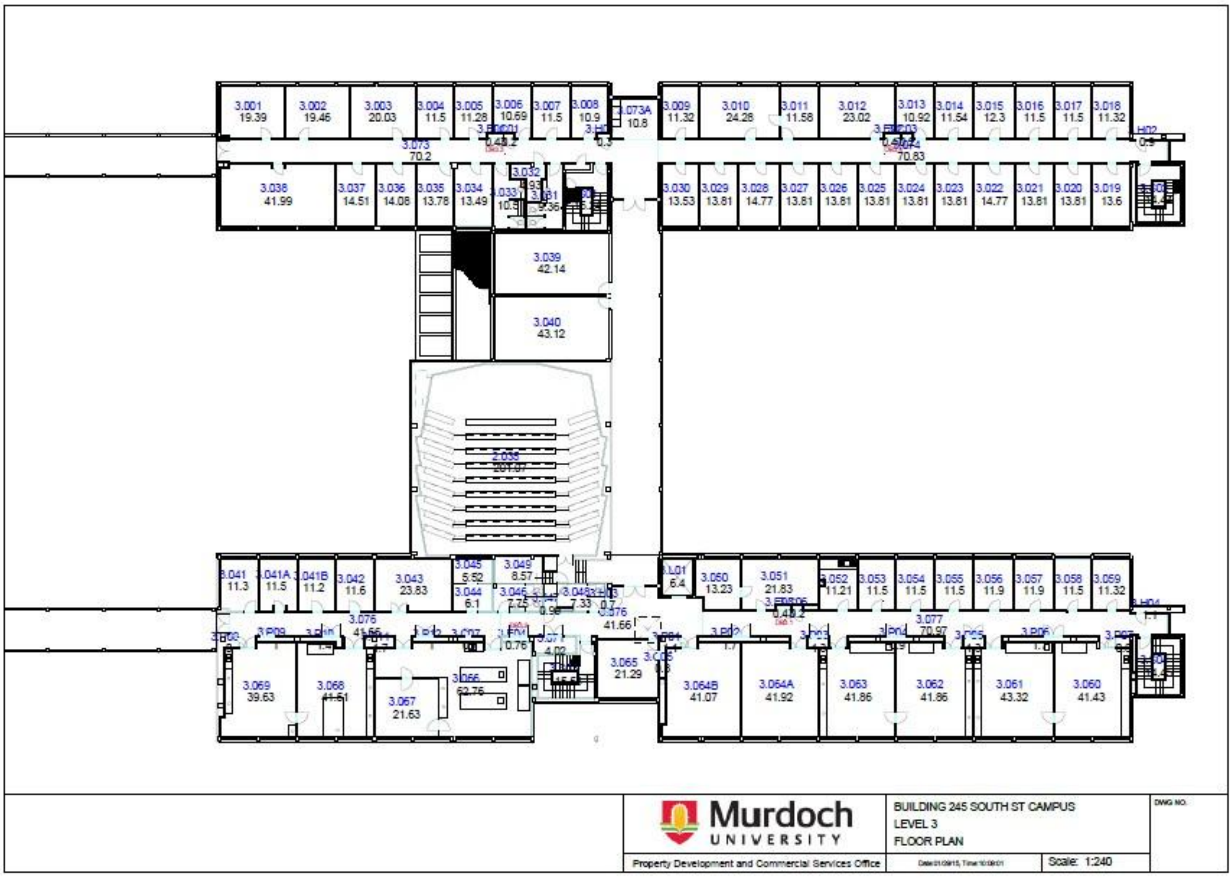


Figure 31: Science and Computing Building Level 3 floor plan.

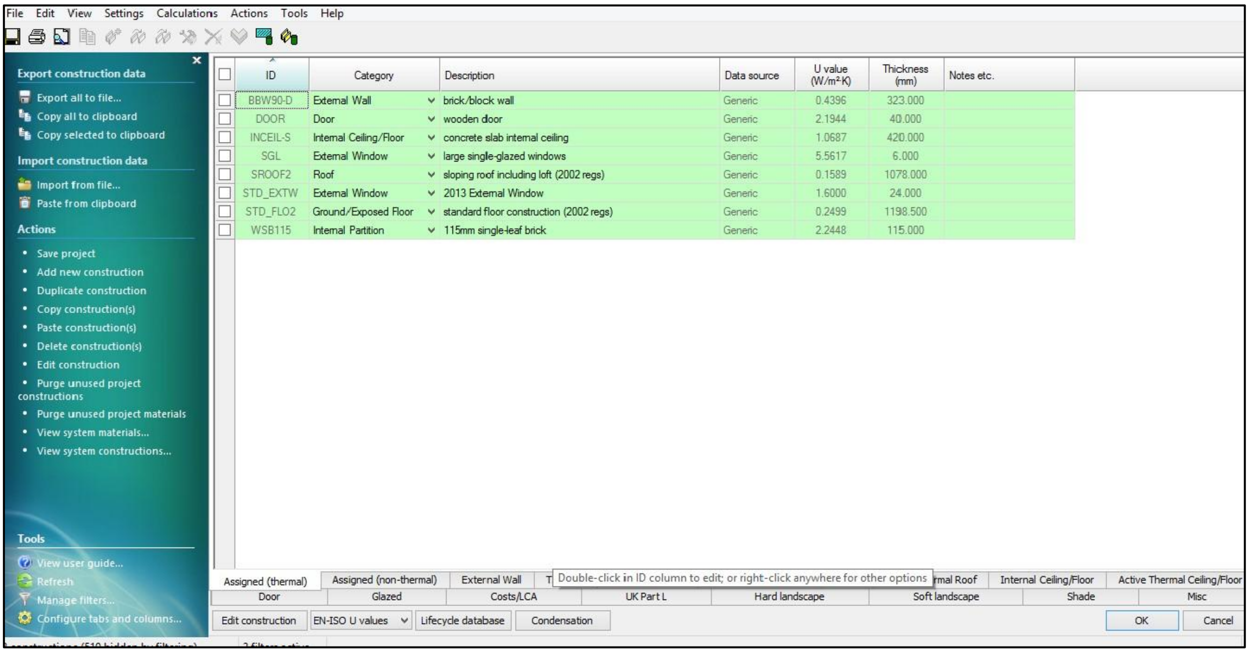


Figure 32: Existing Building material information for IES-VE simulation.

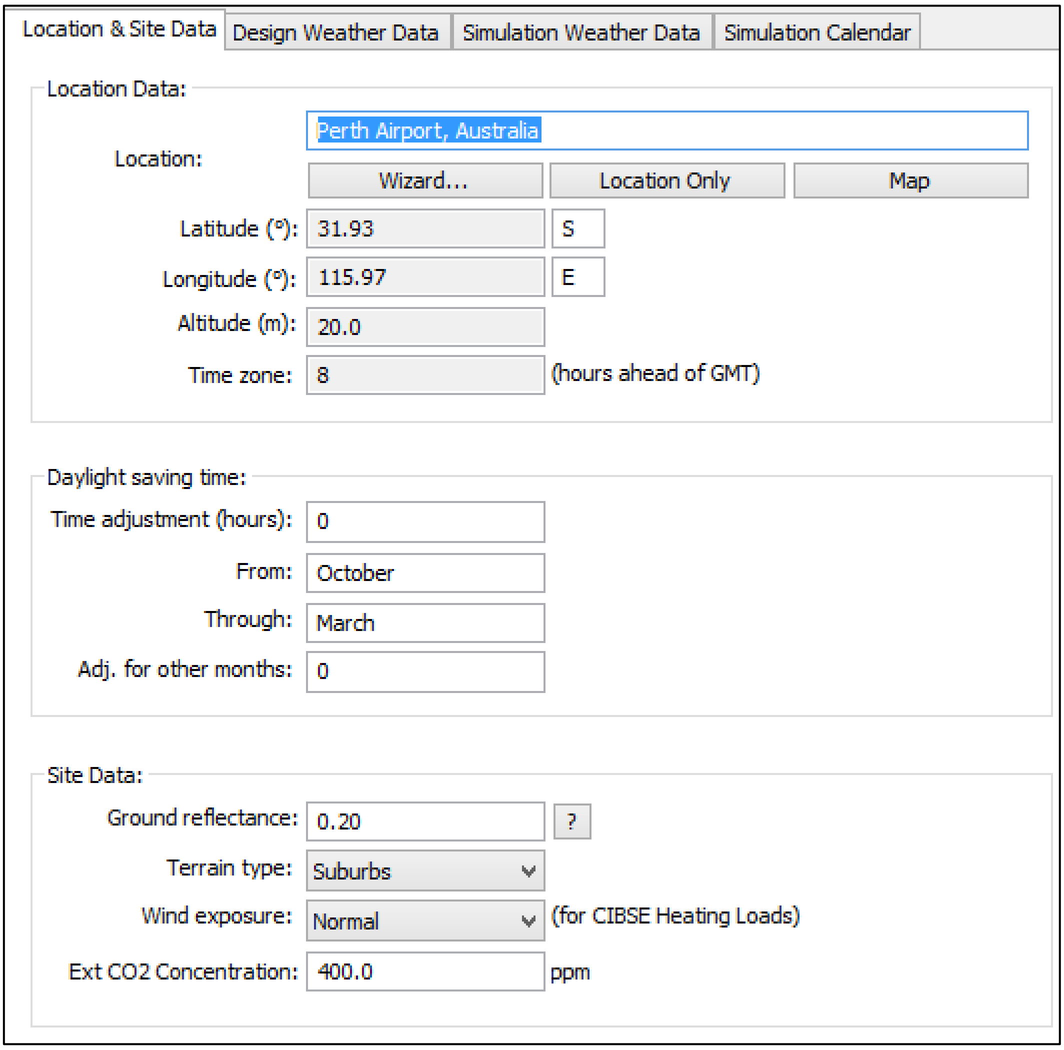
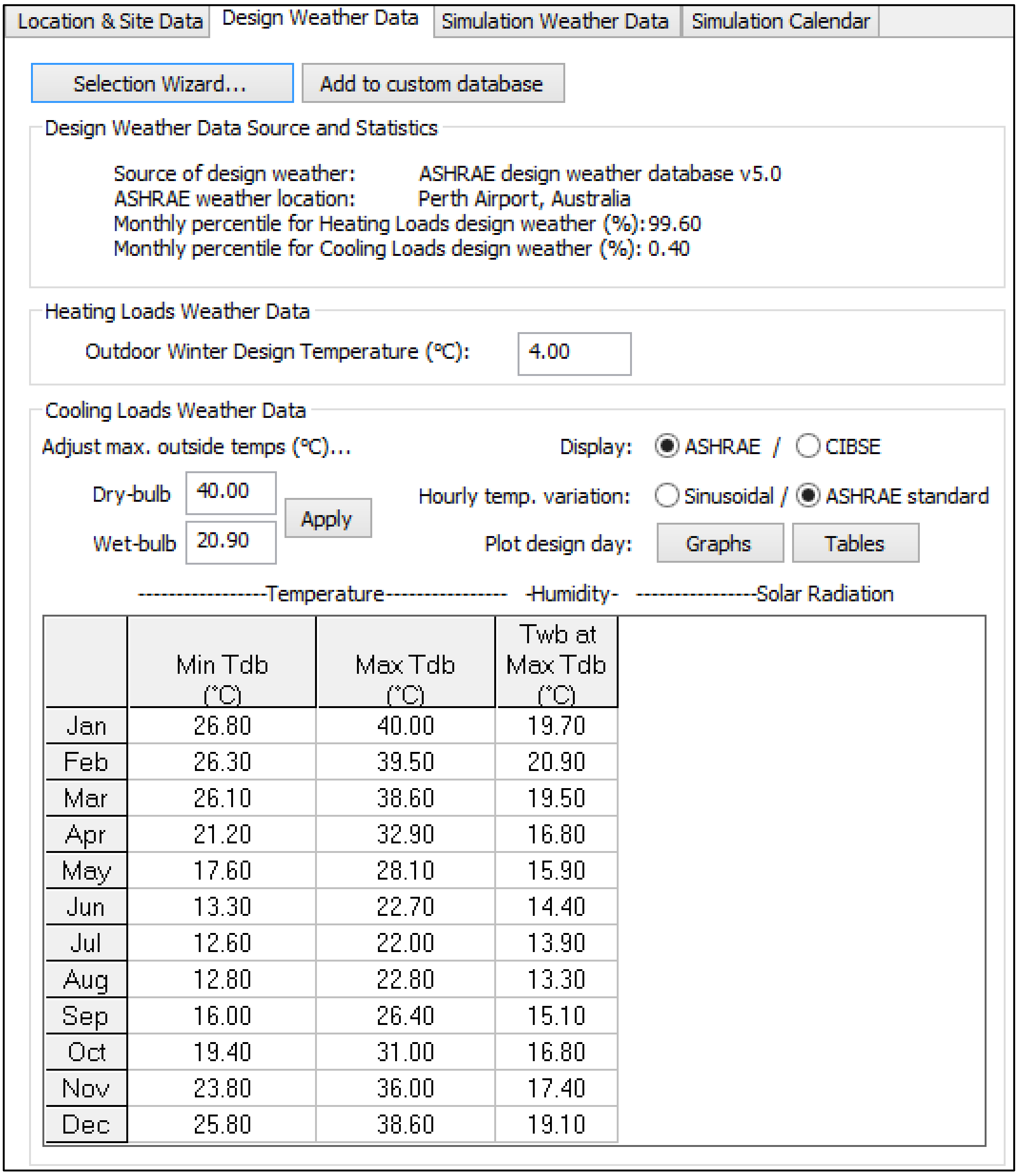


Figure 33: Input information (LOCATION) for the existing building.



	Min Tdb (°C)	Max Tdb (°C)	Twb at Max Tdb (°C)
Jan	26.80	40.00	19.70
Feb	26.30	39.50	20.90
Mar	26.10	38.60	19.50
Apr	21.20	32.90	16.80
May	17.60	28.10	15.90
Jun	13.30	22.70	14.40
Jul	12.60	22.00	13.90
Aug	12.80	22.80	13.30
Sep	16.00	26.40	15.10
Oct	19.40	31.00	16.80
Nov	23.80	36.00	17.40
Dec	25.80	38.60	19.10

Figure 34: Input information (WEATHER) for the existing building..

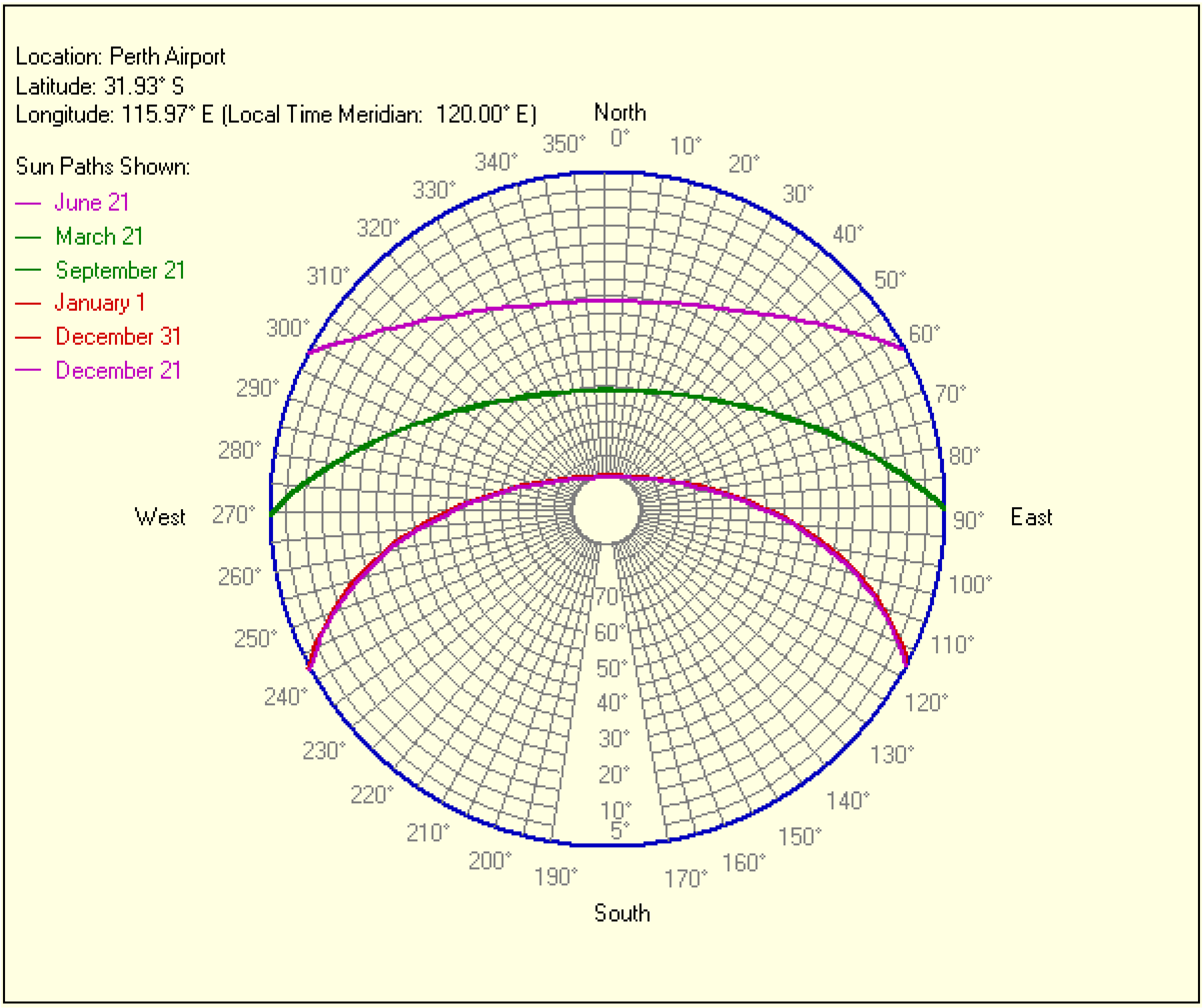


Figure 35: Existing building Sun Path diagram.

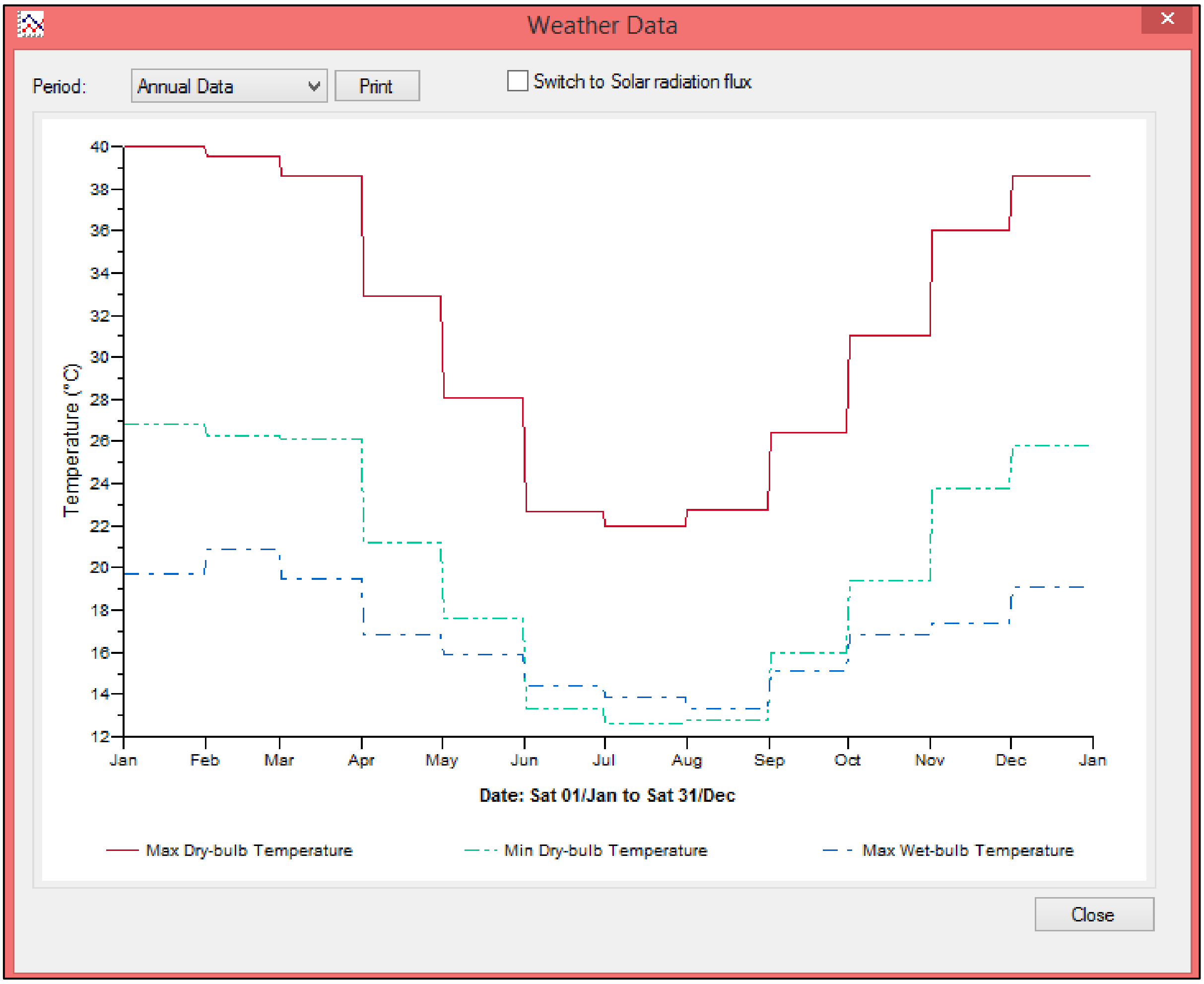


Figure 36: Existing Building Weather Data.

Building systems energy

Month	Heating (boilers etc.)	Cooling (chillers etc.)	Fans, pumps and controls	Lights	Equip.
A-Z	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo	Hi/Lo
Jan	0.0	15.1	311.6	0.0	0.0
Feb	0.0	13.4	281.3	0.0	0.0
Mar	0.0	15.5	311.9	0.0	0.0
Apr	0.0	12.3	300.1	0.0	0.0
May	0.0	7.5	306.7	0.0	0.0
Jun	0.8	4.0	294.7	0.0	0.0
Jul	2.1	3.1	303.9	0.0	0.0
Aug	0.6	3.8	304.3	0.0	0.0
Sep	0.0	6.8	296.5	0.0	0.0
Oct	0.0	8.0	307.0	0.0	0.0
Nov	0.0	11.1	299.3	0.0	0.0
Dec	0.0	14.4	311.2	0.0	0.0
Total	3.5	114.9	3,628.3	0.0	0.0

Summary

MWh

The maximum value in each column is highlighted in red. The minimum value in each column is highlighted in blue. More than one value may be highlighted

Total Yearly Energy Consumption = 3,746.8MWh

Total Yearly Energy Consumption per Floor Area = 341.9kWh/m²

Figure 37: Existing Building systems energy report.

Table 1 Engagement Methods for Workplace Environmental Sustainability Programs

Engagement Methods	
Employee Acknowledgement	Activities that engage and incentivize employees to consider sustainable choices. This includes employee discounts, rewards and recognition, personal sustainability planning, and pledges.
Team Activities	Activities employees can do together to promote sustainability in their workplaces and communities. This includes volunteerism, green teams or leaders, challenges and competitions, and fundraising campaigns.
Communications	Online communications and assessment tools that inform employees of sustainability initiatives and allow them to provide feedback or suggest new activities. Examples include websites, e-newsletters, feedback programs, and social media or knowledge-sharing networks.
Education	Opportunities for employees to learn more about sustainability. This includes tours, interactive kiosks, interactive games, and personal environmental footprinting tools.
Training	Opportunities for employees to learn about sustainability. This includes training in energy efficiency, water conservation, efficient driving and transportation, and waste, recycling and material use.

Source: Institute for Building Efficiency, Johnson Controls, Inc. (2013)

Figure 38: Engagement Methods for workplace environmental sustainability programs

NABERS Energy for Offices
Reverse Calculator

Version 11.0

Updated on 21 January 2015 with NGA Factor released in December 2014

The NABERS Energy for offices reverse calculator helps you calculate the maximum amount of energy an office building can use to achieve a star rating that you specify. To ensure you achieve the rating, you should allow a factor of safety, and not design to the minimum figure for each star band. The output is the maximum amount of energy allowed to be used to achieve the rating you nominate.

Whole Building

1. ENTER THE STAR RATING YOU WISH TO ACHIEVE

NABERS ENERGY **4** STARS

2. ENTER THE WHOLE BUILDING INFORMATION

Building Postcode	6150
Hours each week with occupancy levels of 20% or more (hrs/week)	40
Net Lettable Area of the building (m2)	2800
Number of computers that are normally switched on when the building is occupied	100

Percentage Breakdown of Energy Consumption:	Electricity	100%
	Gas	0%
	Coal	0%
	Diesel	0%

RESULTS

Benchmarking factor at selected rating 158

Maximum Allowable Energy Consumption

Electricity	412,323	kWh per annum
Gas	-	MJ per annum
Coal	-	kg per annum
Diesel	-	L per annum

Max total energy use in MJ	1,484,362	MJ per annum
Max total energy intensity	530	MJ/m2 per annum
Electricity energy intensity	530	MJ/m2 per annum
Gas energy intensity	-	MJ/m2 per annum
Coal energy intensity	-	MJ/m2 per annum
Diesel energy intensity	-	MJ/m2 per annum
Max total greenhouse emissions (raw), Scope 1, 2 & 3	342,228	kg CO2 per annum
Max greenhouse emissions intensity (raw), Scope 1, 2 & 3	122	kg CO2/m2 per annum
Electricity greenhouse emissions (raw), Scope 1, 2 & 3	342,228	kg CO2 per annum
Gas greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Coal greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Diesel greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum

Figure 39: NABERS reverse calculator result for 4 star ratings.

NABERS Energy for Offices
Reverse Calculator

Version 11.0

Updated on 21 January 2015 with NGA Factor released in December 2014

The NABERS Energy for offices reverse calculator helps you calculate the maximum amount of energy an office building can use to achieve a star rating that you specify. To ensure you achieve the rating, you should allow a factor of safety, and not design to the minimum figure for each star band. The output is the maximum amount of energy allowed to be used to achieve the rating you nominate.

Whole Building

1. ENTER THE STAR RATING YOU WISH TO ACHIEVE

NABERS ENERGY **5** STARS

2. ENTER THE WHOLE BUILDING INFORMATION

Building Postcode	6150
Hours each week with occupancy levels of 20% or more (hrs/week)	40
Net Lettable Area of the building (m2)	2800
Number of computers that are normally switched on when the building is occupied	100

Percentage Breakdown of Energy Consumption:	Electricity	100%
	Gas	0%
	Coal	0%
	Diesel	0%

RESULTS

Benchmarking factor at selected rating 116

Maximum Allowable Energy Consumption

Electricity	293,231	kWh per annum
Gas	-	MJ per annum
Coal	-	kg per annum
Diesel	-	L per annum

Max total energy use in MJ	1,055,631	MJ per annum
Max total energy intensity	377	MJ/m2 per annum
Electricity energy intensity	377	MJ/m2 per annum
Gas energy intensity	-	MJ/m2 per annum
Coal energy intensity	-	MJ/m2 per annum
Diesel energy intensity	-	MJ/m2 per annum
Max total greenhouse emissions (raw), Scope 1, 2 & 3	243,382	kg CO2 per annum
Max greenhouse emissions intensity (raw), Scope 1, 2 & 3	87	kg CO2/m2 per annum
Electricity greenhouse emissions (raw), Scope 1, 2 & 3	243,382	kg CO2 per annum
Gas greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Coal greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Diesel greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Max total greenhouse emissions (raw), Scope 1 & 2	222,856	kg CO2 per annum
Max greenhouse emissions intensity (raw), Scope 1 & 2	80	kg CO2/m2 per annum
Electricity greenhouse emissions (raw), Scope 1 & 2	222,856	kg CO2 per annum
Gas greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum
Coal greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum
Diesel greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum

Figure 40: NABERS reverse calculator result for 5 star ratings.

NABERS

NABERS Energy for Offices
Reverse Calculator

Version 11.0

Updated on 21 January 2015 with NGA Factor released in December 2014

The NABERS Energy for offices reverse calculator helps you calculate the maximum amount of energy an office building can use to achieve a star rating that you specify. To ensure you achieve the rating, you should allow a factor of safety, and not design to the minimum figure for each star band. The output is the maximum amount of energy allowed to be used to achieve the rating you nominate.

Whole Building

1. ENTER THE STAR RATING YOU WISH TO ACHIEVE

NABERS ENERGY **6** STARS

2. ENTER THE WHOLE BUILDING INFORMATION

Building Postcode	6150
Hours each week with occupancy levels of 20% or more (hrs/week)	40
Net Lettable Area of the building (m2)	2800
Number of computers that are normally switched on when the building is occupied	100

Percentage Breakdown of Energy Consumption:		
	Electricity	100%
	Gas	0%
	Coal	0%
	Diesel	0%

RESULTS

NABERS ENERGY

Benchmarking factor at selected rating N/A

Maximum Allowable Energy Consumption

Electricity	146,615	kWh per annum
Gas	-	MJ per annum
Coal	-	kg per annum
Diesel	-	L per annum

Max total energy use in MJ	527,814	MJ per annum
Max total energy intensity	189	MJ/m2 per annum
Electricity energy intensity	189	MJ/m2 per annum
Gas energy intensity	-	MJ/m2 per annum
Coal energy intensity	-	MJ/m2 per annum
Diesel energy intensity	-	MJ/m2 per annum
Max total greenhouse emissions (raw), Scope 1, 2 & 3	121,690	kg CO2 per annum
Max greenhouse emissions intensity (raw), Scope 1, 2 & 3	43	kg CO2/m2 per annum
Electricity greenhouse emissions (raw), Scope 1, 2 & 3	121,690	kg CO2 per annum
Gas greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Coal greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Diesel greenhouse emissions (raw), Scope 1, 2 & 3	-	kg CO2 per annum
Max total greenhouse emissions (raw), Scope 1 & 2	111,427	kg CO2 per annum
Max greenhouse emissions intensity (raw), Scope 1 & 2	40	kg CO2/m2 per annum
Electricity greenhouse emissions (raw), Scope 1 & 2	111,427	kg CO2 per annum
Gas greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum
Coal greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum
Diesel greenhouse emissions (raw), Scope 1 & 2	-	kg CO2 per annum

Figure 41: NABERS reverse calculator result for 6 star ratings.

CASE STUDIES

PROJECT OVERVIEW FOR GREENSKILLS BUILDING

- Central Institute of Technology, East Perth houses the GreenSkills Training Centre which has achieved the first GBCA 6 star-rating for a public building in Western Australia and is used as a teaching facility for students studying environmental monitoring and technology.
- The estimated $17million GreenSkills Training Centre (figure 1) is located on the western side of the East Perth campus central courtyard. The ground level landscaping ties in with the existing courtyard with an existing artistic feature fountain is merged within the new landscaping works. Sustainable technology is demonstrated within architecture, construction, landscaping and engineering principles.
- Formal spaces within the GreenSkills Training Centre include 11 teaching classrooms, a teaching wet lab and two meeting rooms. There is a large, double height demonstration space on the entry level for functions and informal teaching opportunities and an open roof deck.

Figure 1. GreenSkills Training Centre. Source WAMC.

- The 6 Star Green Star – Education Design v1 rating represents world leadership in environmentally sustainable design and was achieved with use of building information modelling (BIM) software used from design through to operation.
- The BIM design software, which produces 3D imagery, allowed for the efficiency of the building to be determined before construction and gave architects and engineers the opportunity to improve or change the design to achieve optimal outcomes. It is expected that there would be greenhouse gas savings of 134495kg Co2/year.
- The building is comprised of a structural steel skeleton with an in-situ concrete ground slab and pre cast flooring. Footings were constructed to accommodate shear walls which tie in the flooring and the structural steel. The roof is comprised of metal sawtooth roof panels so solar panels can be perfectly aligned to capture the sun. The building also embraces biophilic urbanism with its green rooftop design.

- Real time data on buildings performance, energy generation and consumption are displayed in the building foyer systems and technologies are visible to students and visitors throughout the building.
- Sustainable and renewable materials were used for the building construction, claddings, fixtures, fittings and furniture. The structural steel and reinforcement steel are certified to ISO 14001 standards to enable reuse at end of life. Use of PVC materials were limited and had to meet the best practice guidelines for PVC in the built environment when used. Timber used in the project (including cladding timbers, joinery and furnishings, internal and external seating and concrete formwork) was sourced from forest certification schemes or re-used.
- Building elements, structure and technologies were left exposed for viewing to create a learning tool to show students and visitors how components of the building fit together and to demonstrate sustainable technologies (figure 2).
- Mechanical building systems are automated with aid of building management system (BMS) that is linked to the campus room booking system which turns on and off air conditioning so that rooms are cooled when used.

Figure 2. Exposed structural steel and building elements.

- Continuous data on the building's energy and environment status can be view on the LED screen in the entrance foyer. The BMS gathers information from meters throughout the building and provides real time information on energy and water consumption, solar power generation, savings from solar generated power and the water recycling system.
- The lighting system has been installed with high efficiency LED fittings, multiple lighting zones and a lighting control system to allow use of lighting only in the areas requiring it and at required levels. The lighting system turns off when rooms are not in use and light fittings can be lowered to ground level by remote control for servicing.
- Active controls switch off lighting and air-conditioning when the building is not in use, and active heat recovery technology has been installed in the classroom and atrium air conditioning systems to reduce energy usage.
- A building disassembly plan was created to meet the GBCA 6 star criteria and the structure of the building is designed to be disassembled at the end of its life and components to be recycled.

Figure 3. Roof Solar PV.

- Solar photo voltaic (PV) system was installed to offset the buildings energy use. 212 high-efficiency 327-watt solar panels were installed on the roof of the campus (figure 3). 130 custom made 87W solar panels were also installed on the building's façade (figure 4) for additional solar gain as well as shading the building's north face from summer sun.
- Electricity generated from the solar system is used to power the building and excess is fed back to building of the campus via a connection system. The solar system is expected to produce 112MWHa of electricity annually and it is estimated that it will offset more than 76 tonnes of carbon emissions.

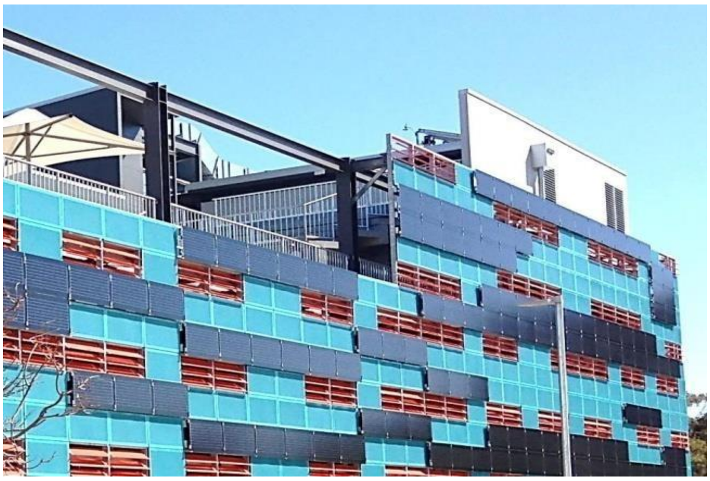


Figure 4. Façade integrated solar PV

- The inclusion of a blackwater treatment plant (figure 5) reduces the amount of sewage discharge from site. All of the building's blackwater is captured in an 11 kilolitre in-ground collection tank and is then treated in a plant that has a processing capacity of up to 10 kilolitres per day. Treated water is held in two inground storage tanks with a combined capacity of 38 kilolitres.

Figure 5. Exposed blackwater treatment system.

- The blackwater system is designed to take water from the building flows to a collection tank where it is pumped into the aerobic screening module that reduces insoluble material to a negligible residue which is discharged to sewer.
- Biological treatment then occurs with the aid of air diffusion into the water to create ideal conditions for bacteria to consume impurities and maintain a sustainable biomass concentration which metabolises all the incoming waste. This results in negligible sludge and allows for 99.9 per cent of the incoming water to be re-used.

- Ultrafiltration occurs through membranes that contain microscopic pores that stop particles, bacteria and viruses from passing through. The membranes are cleaned by air scouring to make sure no wastewater is produced.
- The resulting water is then pumped through activated carbon filter and UV unit for purification and sterilisation before further disinfection by chlorination to protect the water while in storage and the reticulation system.
- Online instrumentation monitors conditions of the recycled water and critical alarms will shut the system down or divert effluent to sewer via the sludge tank if there is an issue. When treated water exceeds demand excess water is diverted back to the sludge tank.
- The system offers high recovery rates without backwashing, negligible residue and low energy usage. These features provide maximum credits for Green Star or environmentally sustainable design projects.
- The treated water is used for buried dripper irrigation to the ground level landscaped area and also feeds four raised orb planter beds as a demonstration of a natural nutrient stripping process.
- Rainwater is collected via the buildings downpipes and stored in two underground water tanks (figure 6), with a total capacity of 150 kilolitres. The rainwater is put through a sterilisation unit and then a pressure system sends the water throughout the building for flushing of the toilets and urinals.

Figure 6. Rainwater tank underground water tank storage area.

- Classrooms are equipped with individual CO2 and VO2 outside air controls with heat exchangers to incorporate ventilation and outside air rates based on the level of occupancy and rates of carbon dioxide detected through monitoring sensors. The building is also designed to achieve selected thermal and acoustic comfort levels. Materials used in construction were chosen to ensure reduced levels of volatile organic compounds and formaldehyde.
- An underfloor displacement air-conditioning system used in the demonstration area is designed to distribute supply air from under the floor via ducted main trunk lines and a heat exchanger on the chiller system requires no maintenance and reduces the amount of air that has to be cooled in summer or warmed in winter.

- The underfloor heating structure was constructed using 250mm thick pre-stressed floor panels bearing on structural steel beams. A 60mm thick in-situ concrete structural topping was poured on these to complete the floor structure. To insulate for the in-floor heating, a 100mm layer of high density foam was then laid across the structural floor, covered with waterproof membrane and the in-floor heating pipework laid within the 50mm concrete topping.
- The fire system is a high efficiency fine mist fire sprinkler system which is waterwise even when extinguishing fires.
- The rooftop garden is landscaped with composite timber decking, fine gravel pavement and beds of waterwise plants and fruit trees and is used to demonstrate the building's energy and water systems. The rooftop covers more than 200sqm and sits atop the demonstration space on the north-east corner of the building. High density foam between 75mm to 230mm was installed between the structural slab topping and the final concrete topping to reduce weight and help achieving the falls required to the drainage points.
- Zephyrus, the Greek God of the West Wind, is the title of the artwork installed on the north facing façade of the building. Inspired by the environment the commissioned artists added to the visual language of the building's architecture by integrating powder-coated aluminium panels into the shading panels. LED lights located behind each of the artwork panels uses real-time wind direction data to change panels colour. Local speed and wind direction is recorded by a rooftop anemometer and an electronic sensing

system feeds the collected data into the artwork and changing colours indicate changing wind direction.

Case Study Implications

Sustainable design increases the efficiency in which buildings use energy, water and materials and reduces the building impacts on human health and the environment over the entire life of a building. Officially opened in February 2015 the GreenSkills Training Centre is still in its infancy and performance over the long term is yet to be shown, however the building has already demonstrated many positive implications of the uptake of sustainable design and provides a hands-on example of world leading sustainability practices that can be adapted for application in commercial and residential design.

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