System Dynamics Modelling of Carbon Emission Reduction of Building Information Model (BIM) with Different Roof Design Configurations

by

Fong Kah Soon

15942

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil)

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

____
(Prof. Dr. Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(FONG KAH SOON)

ABSTRACT

This paper aims to develop an optimum roofing system for hot climate by introducing different roof design configuration with the aid of Building Information Modelling and System Dynamics Modelling. Tropical climate with high ambient temperature and humidity caused the residential buildings in Malaysia experienced overheating roof space, where roof contributes up to 70% of heat gain. Heat absorbed radiates to living space beneath and caused thermal discomfort to the occupants. However, the roofing system in Malaysia is not well investigated and applied. Adoption of air conditioning system to reduce thermal discomfort increased energy consumptions and contributes to carbon emission. In this research, energy consumption and carbon emission reduction of a single storey residential house in Malaysia were evaluated based on different roof design configuration, which included roof surface colour and air gap thickness by using Autodesk Revit Architecture and Autodesk Ecotect. System dynamic model was developed to help in decision making to develop an optimum roofing system by using STELLA. The results suggested that white roof is the better alternative compared to other colour roof such as brown, red, and black. The presence of air gap showed the reduction in carbon emission. However, varying the thickness of air gap did not reduce carbon emission due to the limitation of software.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude to Universiti Teknologi PETRONAS (UTP) to include Final Year Project as part of the requirement for Bachelor of Engineering (Hons) in Civil Engineering as a platform to learn as a researcher.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia’s climate with high ambient temperatures and high humidity lead to uncomfortable condition that are non-conducive for human comfort and productivity [1]. In order to maintain a comfortable indoor environment, approximately 75% of the Malaysian population choose to use air conditioning [2]. According to Zain-Ahmed [3], air conditioning contributes 60% of building energy consumption. In building sector, energy demand increases tremendously from 2914 Mtoe in 2005 to 5,257 Mtoe in 2050 in the base line scenario and residential sector contributes 60% of the growth rate. Generation of electricity from fossil fuels is the largest producer of global CO_2 emissions, which accounted for 42% of the world CO_2 emissions in 2011. The International Energy Agency [4] highlighted in his 2013 edition report that CO_2 emission in Malaysia has increased dramatically since 1970. The increment of CO_2 emission from year 1990 to year 2011 is 290.7%, which represents as one of the highest carbon emitter compared to other countries in Southeast Asia.

Therefore, the demand for sustainable development is on rising especially in hot humid climate countries like Malaysia in order to reduce the carbon emission and achieve comfortable indoor environment. Cool roof with different roof design configuration is a good alternative solution to reduce the energy need for mechanical cooling system such as air conditioning. Cool roof systems are an inexpensive alternative to save building energy consumption and enhance the comfort level in the building by reducing the attic temperature [5]. Numerous studies has successfully proven the benefit of ventilation on the thermal load in roof. Airflow in the ventilation layer can transmit the heat and moisture effectively to the outside and keep the internal part of the roof cool and dry. In this research, the study will emphasize on roof design configurations i.e. (1) Air Gap ventilation layer, and, (2) Roof surface colour. Unlike previous research, building information modelling (BIM) and systemic dynamics modelling (SDM) are integrated in the research to perform energy analysis and decision making.

1.2 Problem Statement

Being a tropical country, Malaysia exposes to tropical climate with high ambient temperature and high humidity throughout the year. Its ambient temperatures range from 26ºC to 40 ºC and relative humidity from 60 % to 90% [1]. High ambient temperature and high humidity lead to uncomfortable condition that are unconducive for human comfort. During daytime, the heat is absorbed by the roof, transmitted through and trapped in the attic resulting in a hot ceiling. Heat from the hot ceiling radiates to the occupants in the living space beneath and cause thermal discomfort.

According to Vijaykumar, Srinivasan [6], the heat transmission for residential buildings across the building roof is about 50% - 70% of the total heat entry for the rooms below the exposed roof. Jayasinghe, Attalage [7] added that roof contributes more in heat gaining compared to the vertical surface such as walls due to direct exposure to sunlight throughout the daylight. Therefore, thermal performance of building envelope like roof is significant for guaranteeing a comfortable interior environment. However, roofing system in Malaysia is not well investigate and applied [8]. In recent year, air conditioning is adopted as an alternative to overcome thermal discomfort. However, this alternative is not sustainable due to high energy consumption and carbon emission. Consequently, leading to global warming and urban heat island phenomena. Besides, low income family could not afford mechanical air conditioning due to financial constraint.

1.3 Objective

- To simulate a real case study building based on the drawing plans and material specifications of the building with the aid of Building Information Modelling (BIM) based software, Autodesk Revit Architecture.
- To perform sustainability analysis and evaluate building energy performance as well as building's carbon footprint by using Building Information Modelling (BIM) based software, Autodesk Ecotect.
- To develop a system dynamic model as a decision making tool for carbon emission reduction of building information model by using system dynamic modelling software, STELLA.

1.4 Scope of Study

The scope of the research can be divided into three phrases:

1. Modelling of single storey residential house by using computer software, Autodesk Revit Architecture.
2. Analysing of building energy performance of the single storey residential house by using Building Information Modelling (BIM) based sustainability analyses software, Autodesk Ecotect.
3. Making of decision with the aid of system dynamic model developed by using system dynamic modelling software, STELLA.

CHAPTER 2

LITERATURE REVIEW

2.1 Cool Roof System

With the increasing public awareness on the global warming and greenhouse effect issues, international conferences are pressurizing the construction industry, and particularly roofing industry, to reduce energy consumption through sustainable roof [8]. Sustainable roof is defined as a roofing system that is designed, constructed, maintained, rehabilitated and demolished with an emphasis throughout its life cycle on using natural resources efficiency and preserving the global environment.

2.1.1 Ventilation layer

Numerous experimental and theoretical studies have been carried out to evaluate the thermal behaviour of naturally ventilated roof. Most experimental research on the ventilated roofs involve the measurement of roof surface temperature, airflow temperature and heat flux transmission across the upper and lower slab [9]. For example, Lee, Park [10] performed an experiment using a different roof model in 2009. They examined the effect of roof ventilation on roof heat gain. It was concluded that thermal accumulation in the roof can be minimized by employing a ventilated layer in the roof. During summer of Greece in 2006, Dimoudi, Androutsopoulos [11] conducted an experiment to investigate the effect of roof ventilation and radiant barrier on the roof heat gain. Through the experiment, they found out that 6cm ventilated cavity reduced 56% of roof heat gain during the daytime compared to typical unventilated roof. Besides, Gagliano, Patania [12] found out that ventilated roof as shown in **Figure 1** can reduce significantly the heat flux up to 50% during summer season.

Theoretical studies on thermal performance of naturally ventilated inclined roof were conducted as well. The computational fluid dynamic (CFD) technique was often adopted to estimate the induced airflow temperature and velocity in the ventilated roof. In 2007, Biwole, Woloszyn [13] numerically simulated the model of a double-skin roof and the associated governing equation. They validate the model using field experiment and investigate the impact of various parameters on the energy efficiency of ventilated roof. In 2014, Tong & Li adopted CFD technique to analyse the airflow movement and connective heat transfer in the inclined roof cavity. Laboratory experiment is carried out to validate the CFD model through the study of airflow movement and convective heat transfer in the inclined roof.

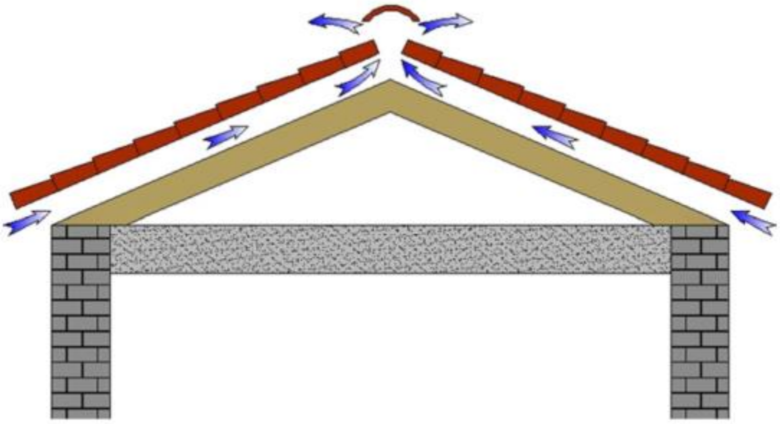


FIGURE 1 SCHEME OF VENTILATED ROOF (SOURCE: GAGLIANO,A.,ET ALL[12])

2.1.2 Roof Surface Colour

Cooling energy consumption of a building can be reduced significantly by limiting the solar heat gain through roof, which depends on the intensity of impinging solar radiation and the absorptivity (colour) of the external surface [14]. In their research, a testing facility has been set up in Chinese University of Hong Kong to study the effect of various building design features such as envelope colour on indoor temperature. They found out that the maximum air temperature inside black test cell was about twelve degrees higher than the white test cell. They concluded that the influence of colour was dependent of solar radiation and darker surface has higher absorptivity. The absorbed heat was transmitted to indoor surface by conduction and heated up indoor air through convection.

According to Suehrcke, Peterson [15], the thermal performance of a building is affected by the solar absorptance of the roof and there are significant differences in heat gain between light and dark coloured roof surface. In their research, a classification of roof colours with different solar absorptance (dark, medium, light, and reflective) was proposed to enable a fast assessment of the effect of roof colour on the heat gain and R-value. The calculations show that the use of light roof colour can significant reduce downward heat flow to the building and reduce air conditioning load in hot climate. Thus, increasing the thermal comfort of the occupants.

In year 2003, the influences such as roof orientation, roofing materials, and roof surface colour on indoor thermal comfort in warm humid climates were investigated through computer simulations [7]. A series of computer simulations were conducted to determine the influences on indoor thermal comfort of a single-storey house subjected to warm humid climate. They found out the absorptances of blackish grey cement fibre sheet, light grey cement fibre sheet, and off-shite cement fibre sheet are 80%, 60%, and 40% respectively. Light colour roof surface can achieve indoor thermal conditions comparable to those insulation material.

Suehrcke, Peterson [15] have demonstrated numerical simulation and deriving equation to suggest that a significant reduction in downward heat flow can be achieved in hot climate using light or reflective roof colour instead of dark one. In year 2011, Yacouby, Khamidi [2] designed two models based on the dimension of existing experimental house. The experimental data shows that white roof reflects 700% more sunlight than the dark one.

2.2 Building Information Modelling

Building Information Modelling (BIM) is a simulation of construction project in a virtual environment [16]. A simulation has the advantages of taking place in a computer through the use of a software package. Therefore, virtual building implies the possibility of practice construction, experiment, and adjustment in the project before it is actualized. Building information model is simulating project which consist of the 3D models of the project component with links to all the required information connected with the project’s planning, construction or operation, and decommissioning. A Building Information Model is a data rich, object orientated, intelligent and parametric digital representation of the facility, which the data can be extracted and analysed to generate information that used for decision making and enhance the process of delivering the facility [17]. Unlike the computer aided drafing (CAD), BIM model contains the actual construction of the building and assemblies rather than two dimensional representation of building [18]. The design process through BIM is faster by allowing parametric changes to the building design

According to Azhar, Brown [19], Building Information Modelling allows multi-discipline information to be superimposed within one model and helps in performing complex building performance analyses to ensure an optimized sustainable building design. There are three BIM-based sustainability analyses software commonly used in design and construction firms in the United States, which are Autodesk Ecotect ™ , Autodesk Green Building Studio ™ (GBS) and Virtual Enviroment ™ (VE). Kriegel and Nies [20] added that BIM-based sustainability analyses software can used in the following aspect:

- Building orientation (Selection of best building orientation which result in minimum energy cost.)
- Building massing (Analysis of building form and optimise the building envelope.)
- Daylighting analysis
- Energy modelling (Reduction of the energy need and analyse of renewable energy option.)

In this research, Autodesk Ecotect ™ will be used as environmental analysis software. Autodesk Ecotect ™ is a BIM environmental simulation tool that is capable of analysing the thermal load, lighting design, shadows and reflections, shading devices, and solar radiation [18]. This software is developed by architects and widely used by the engineer, environmental consultants and building designers due to its application in architecture and the design process in mind. Based on the survey carried out by Attia, Beltrán [21], up to 64% of architects used Autodesk Ecotect ™ as building performance simulation tool.

Shoubi, Shoubi [22] have investigated various combination of materials using BIM and identify sustainable alternatives to reduce building energy consumption. A case study building, double story bungalow was modelled and simulated in Autodesk Revit and exported to Autodesk Ecotect for energy modelling and analysis. At the end of their research, sustainable designs in term of energy savings have been suggested. The results of the study will be useful to the architect and structural designer because of the growing development of energy efficient building in future using BIM concept [22].

2.3 System Dynamic Modelling

System Dynamics is a methodology developed by Jay W. Forrester of the MIT Sloan School of Management for studying and managing complex feedback system [23]. It has been used to address practically almost all feedback systems. It is often based on formal mathematical model and computer simulations for the learning of dynamic complexity, understanding of policy resistance, and designing more effective policies [24].

System dynamics modelling allows a system to be represented as a feedback system based on the work of Forrester, who defined it as “the investigation of the information-feedback character of industrial systems and use of models for the design of improved organizational form and guiding policy”[25]. The model is an interlocking set of differential algebraic equation developed from relevant measured and experimental data. The equation comprise of three element types: (1) Stock, (2) Flow element, and (3) Auxiliary variables and constants as shown in **Figure 2.** System dynamic models can used to examine the long term behaviour of complex system [26]. The true value of using system dynamics method is to model building design, operation, and retrofit problems before implementation and allocation of time, budget and resources to solve problem [25].

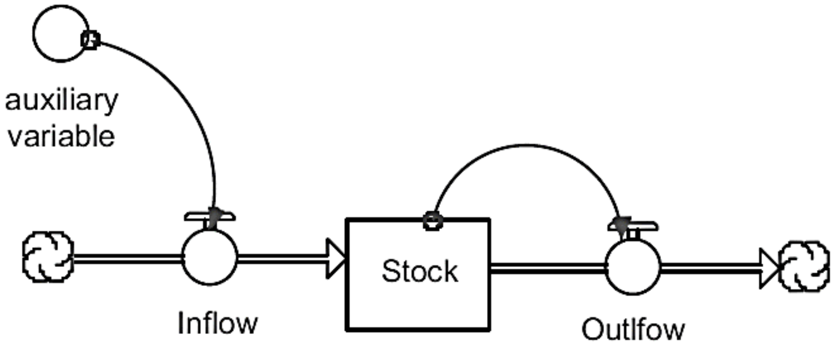


FIGURE 2 SCHEMATIC OF SYSTEM DYNAMICS MODEL

2.3.1 Application of System Dynamic

The system dynamics modelling has been used widely in the application of social sciences and engineering [25]. This method has been used to model environmental system. For example, Ford [27] includes the examples of salmon migration, fisheries management, wildlife population dynamics, air pollution, vehicle emissions, and environmental policy. It could be also used in military and defence modelling such as preparedness and training, and capital equipment management. For example, Smith [28] make the case that SD methods could and should be used for counter-terrorism simulations. In 2009, Fong, Matsumoto [23] applied system dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emission from cities. He presented the projections of future CO2 emission trends for IDR under various options of urban policies using the FML model and showed that it can be used as decision making tool in urban planning process.

In civil and environmental engineering industry, system dynamics has also been widely used especially in construction project management [25]. For example, it is used to study the performance enhancement of a construction organization, effect of project personnel changes, delay and disruption claims, quality management, rework, the design-build process, conflict management, and road maintenance budgeting. Other than that, system dynamics modelling has been used to study the sustainable construction. For example, Shen, Wu [29] developed a system dynamics model to assess the sustainable performance of projects using a triple bottom line of economic, social and environmental performance. Study of infrastructure systems as well as disruption to those system has been done by applying system dynamic modelling. For example, Chasey, Garza [30] examined highway management using system dynamic model. In 2009, system dynamic is used and applied to building design and simulation. Thompson and Bank [25] developed a system dynamic model which used to simulate a building subjected to a bioterrorist attack. It was tested for proof-of-concept and the testing gave positive result.

2.4 Governing Equation

2.4.1 Heat Transfer Mechanism in Ventilated Roof

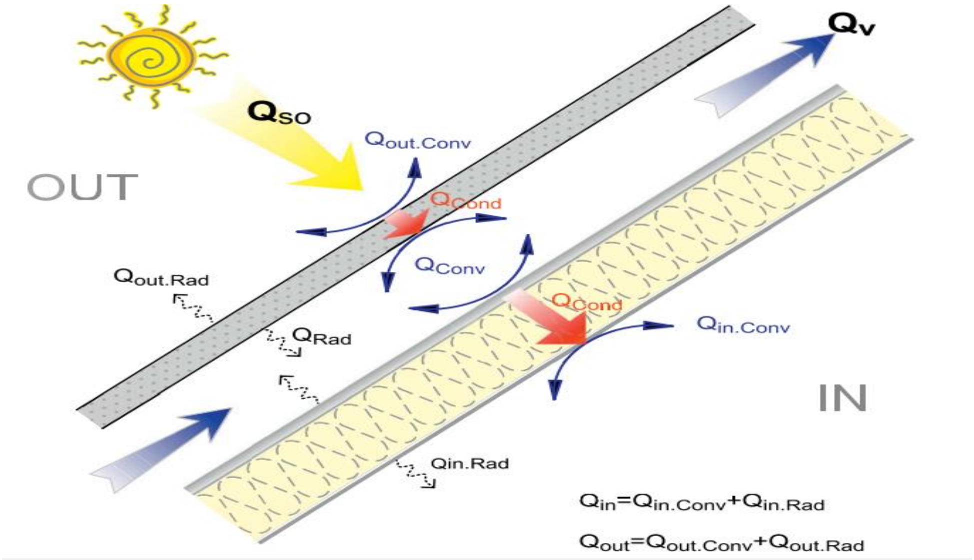


FIGURE 3 MECHANISM OF HEAT TRANSFER IN A VENTILATED ROOF (SOURCE: LEE, PARK [10])

According to Lee, Park [10], the balance of heat transfer in a ventilated cool roof includes conductive heat transfer from the outside to the inside due to the temperature difference across the roof, radiation heat gain from the outer surface, together with convective heat transfer, when outdoor air passes through the ventilated cavity.

The thermal performance of the ventilated roof can be analysed by estimating the amount of exhausted heat by the equation:

$$\mathrm{Q_{so}} = \mathrm{Q_{out}} + \mathrm{Q_{in}} + \mathrm{Q_v} \qquad \text{adopted from [10]}$$

Where: $\mathrm{Q_{so}}$= heat gain from solar radiation (W)

$\mathrm{Q_{out}}$= heat flow back to the outside (W)

$\mathrm{Q_{in}}$ = heat flow back to the interior (W)

$\mathrm{Q_v}$ = exhausted heat via the cavity (W)

$\mathrm{Q_v}$ can be calculated from the equation:

$$\mathrm{Q_v} = \dot{\mathrm{m}}\mathrm{c_p}(\mathrm{T_{out}} - \mathrm{T_{in}})$$

Where: $\dot{\mathrm{m}}$= mass flow rate (kg/s)

$\mathrm{c_p}$= air specific heat at constant pressure (J/kg K)

$\mathrm{T_{out}}$= Outside air temperature in the shade (K)

T_{in}= Indoor Air Temperature (K)

The exhausted heat flux can be estimated from the cavity as the thermal performance of the ventilated roofs [10]. If the heat flux from the cavity to the outside Q_v is increased, heat flow from the cavity to the interior Q_{in} would be decreased.

2.5 Critical Analysis

In previous research, the effectiveness of cool roof is proven as shown in Table 1 and Table 2. Table 3 shows the general application of Building Information Model and System Dynamic Model. Although system dynamic has been used widely in various disciplines, its use in design of buildings has been very limited. None of the researchers apply system dynamic method to the problem related to roof. Therefore, the application of system dynamic method to roofing system is a huge research gap.

Therefore, in present work, optimum roofing system with different roof design configuration such as ventilation layer, and roof surface colour will be developed and analysed using building information modelling software and system dynamic modelling. The experimental works will be conducted to validate the computational results.

2.5.1 Cool Roof

a. Air Gap Ventilation Layer

No.	Year	Author	Title of Research	Findings
1.	2012	Gagliano, Patania, Nocera, Ferlito, & Galesi	Thermal performance of ventilated roof during summer period	(i) Ventilation of roofs can reduce significantly the cooling load up to 50% during summer season
2.	2009	Lee et al.	An experimental study on airflow in the cavity of a ventilated roof.	(i)The temperature difference between the ventilated cavity and the non-ventilated cavity at the middle cavity was 37.5 ºC. (ii)By employing a ventilated layer in the roof, thermal accumulation in the roof can be prevented and cooling load can be decreased.
3.	2006	Dimoudi et al.	Summer performance of a ventilated roof component	(i) 6cm ventilated cavity reduced 56% of roof heat gain during the daytime compared to typical unventilated roof.

TABLE 1 PREVIOUS RESEARCH ON CAVITY VENTILATION

b. Roof Surface Colour

No.	**Year**	**Author**	**Title of Research**	**Findings**
1.	2011	Yacouby et al.	Study on Roof Tiles's Colors in Malaysia for Development of new Anti-warming Roof Tiles with Higher Solar Reflection Index (SRI)	(i)White roof reflects around 700% more sunlight than the black roof. (ii)Indoor temperature of white roof was 1.7ºC cooler than black roof , thus better indoor thermal comfort and lesser energy consumption
2.	2005	Cheng et al.	Effect of envelope colour and thermal mass on indoor temperatures in hot humid climate	(i) The maximum air temperature inside black test cell was 12 ºC higher than that of white test cell. (ii) Application of light surface colour is effective and economical in reducing indoor temperature.
3.	2003	Jayasinghe et al.	Roof Orientation, roofing materials and roof surface colour: their influence on indoor thermal comfort in warm humid climate	(i) Light colour roof surfaces (eg., off-white) can achieve indoor thermal conditions comparable to those of the insulation material. (ii)Cement Fibre Sheet Roof: (a) Blackish Grey-80% absorptance (b) Light Grey-60% absorptance (c) Off-white-40% absorptance

TABLE 2 PREVIOUS RESEARCH ON ROOF SURFACE COLOUR

2.5.2 System Dynamic Modelling and Building Information Modelling

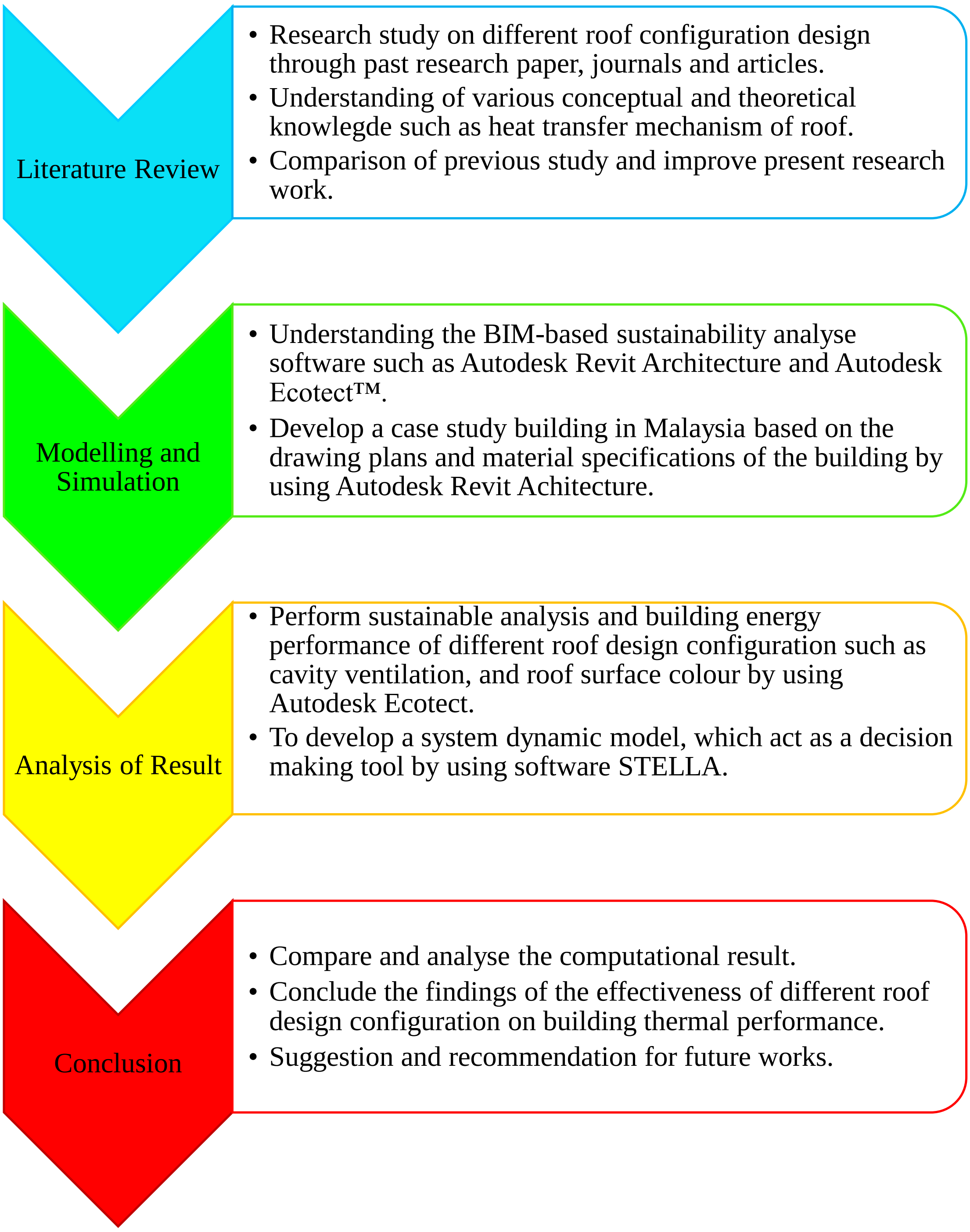
No.	**Year**	**Author**	**Title of Research**	**Remarks/ Application**
1.	2014	Shoubi et al.	Reducing the operational energy demand in buildings using building information modelling tools and sustainability approaches.	(i) BIM was used to assess the effectiveness of different combinations of materials in various components of the building to decrease annual operational energy consumption of the building. (ii) It is proven effective in reducing the energy consumption of the building.
2.	2013	Marzouk, Abdelhamid, & Elsheikh	Selecting sustainable building materials using system dynamics and ant colony optimization	(i) Proposed framework for green selection of building materials
3.	2010	Thompson & Bank	Use of system dynamics as a decision making tool in building design and operation	(i) Present a decision making tool for building design and operation, and analysis of building subjected to a bioterrorist attack.
4.	1999	Matsumoto	System dynamics model for life cycle assessment (LCA) of residential buildings	(i) Used to evaluate the life cycle energy and CO2 of houses (ii) Effectiveness was confirmed by the application of system dynamic method for life cycle inventory (LCI)
5.	2009	Fong et al.	Application of system dynamics model as decision making tool in urban planning process toward stabilizing carbon dioxide emission from cities	(i) Shed new light in the urban planning sector in Malaysia by system dynamic method as decision making tool in the planning process. (ii) Provide quantitative assessment of the option of development proposals or urban policies on the long term CO2 emission trends of a city as a whole

TABLE 3 PREVIOUS RESEARCH OF BIM AND SDM

CHAPTER 3

METHODOLOGY

3.1 Research Methodology



Literature Review

- Research study on different roof configuration design through past research paper, journals and articles.
- Understanding of various conceptual and theoretical knowlegde such as heat transfer mechanism of roof.
- Comparison of previous study and improve present research work.

Modelling and Simulation

- Understanding the BIM-based sustainability analyse software such as Autodesk Revit Architecture and Autodesk Ecotect™.
- Develop a case study building in Malaysia based on the drawing plans and material specifications of the building by using Autodesk Revit Achitecture.

Analysis of Result

- Perform sustainable analysis and building energy performance of different roof design configuration such as cavity ventilation, and roof surface colour by using Autodesk Ecotect.
- To develop a system dynamic model, which act as a decision making tool by using software STELLA.

Conclusion

- Compare and analyse the computational result.
- Conclude the findings of the effectiveness of different roof design configuration on building thermal performance.
- Suggestion and recommendation for future works.

3.1.1 Modelling and Simulation

3.1.1.1 Overview

In the research, Building Information Modelling (BIM) software and System Dynamic Modelling (SDM) were used to perform sustainability analysis, evaluate building energy performance and develop an optimum roofing system for hot humid climate like Malaysia. BIM based software. A case study building was simulated by using Autodesk Revit. The sustainability analysis such as operational energy consumption and daylight analysis was performed using Autodesk Ecotect. The data from BIM based software will then export to Excel table and imported to the system dynamic modelling software, STELLA. The data was used to populate SD model. **Figure 4** shows the overview of the software used in the research. Figure 5 shows the overview of the modelling and simulation technique adopted in the research.

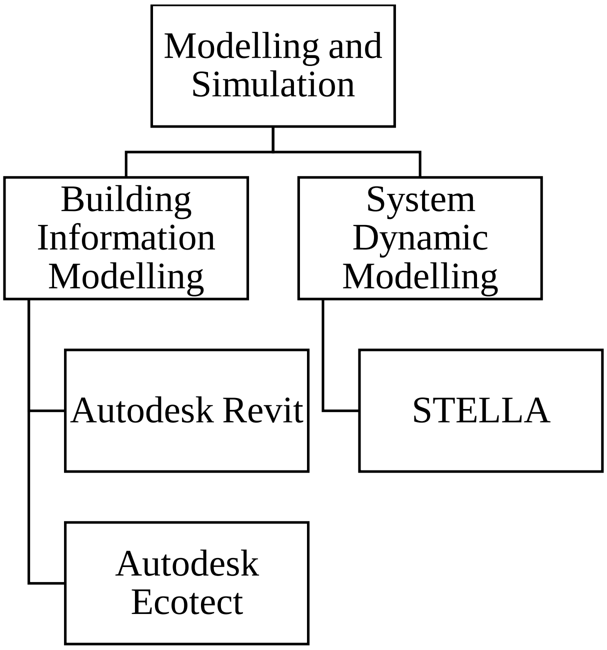


FIGURE 4 OVERVIEW OF SOFTWARE USED IN THE RESEARCH

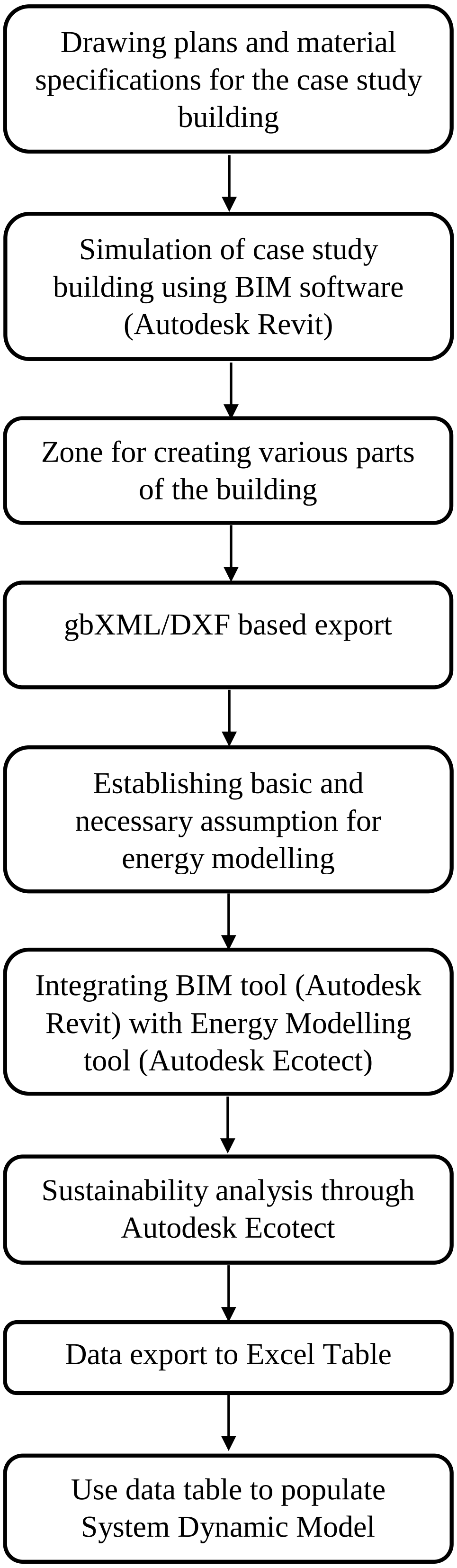


FIGURE 5 OVERVIEW OF THE MODELLING AND SIMULATION

3.1.1.2 Building Information Modelling (BIM) Simulation

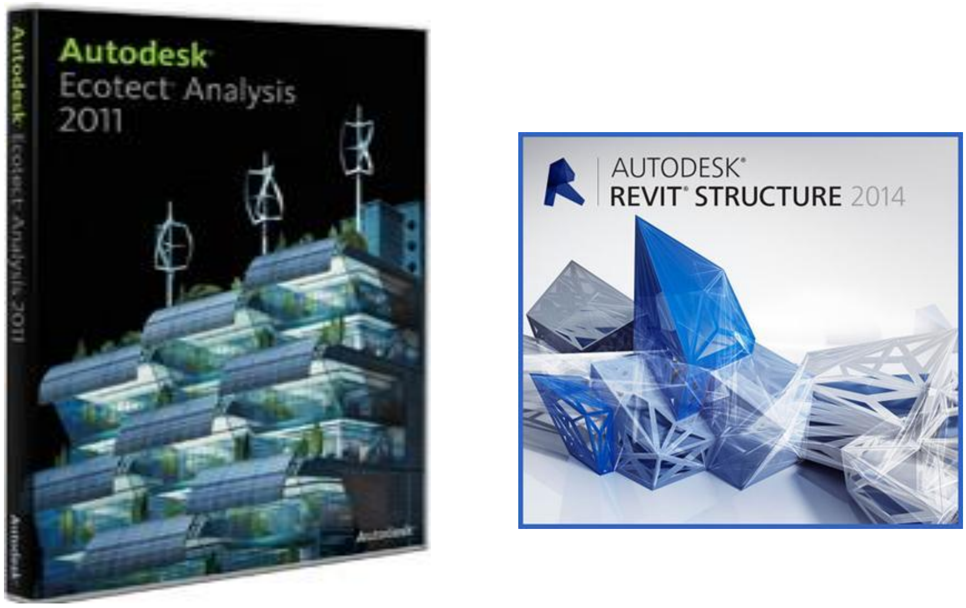


FIGURE 6 BIM SOFTWARE: AUTODESK ECOTECT ANALYSIS & AUTODESK REVIT

According to **Figure 5**, after the drawing plans and material specifications of the case study building are prepared, the building can be simulated and modelled using BIM software called Autodesk Revit. After simulation, for integrating between Autodesk Revit and Autodesk Ecotect, a zone must be formed to create various part of the building [22]. Energy modelling cannot be proceeded without creating the zones in Autodesk Revit. In fact, the file cannot be exported to Autodesk Ecotect. After creating the zones, for exporting the simulation file from Revit to Ecotect, the gbXML based export way explained in the next parts must be used. It can define the exportation of all building specification in Revit to Ecotect.

There are two types of import from Autodesk Revit to Autodesk Ecotect: (1) DXF, and (2) gbXML based export. DXF is primarily used for geometry based analysis such as over shadowing analysis, ventilation modelling, daylight analysis, and external solar availability. The gbXML is mainly used for space-based concerns such as thermal performance, solar radiation, and energy demands. Based on the study and the type of analysis that is to be performed, gbXML based export must be chosen to import the simulated file from Autodesk Revit to Autodesk Ecotect. By choosing gbXML, some basic and necessary assumptions for energy modelling such as location and types of building must be established. After that, the file is exported to Ecotect for energy modelling and analysis. In Ecotect, after establishing additional assumptions such as activity, type of system, and environmental temperature range for comfort of the building baseline, building operational energy use can be calculated. The relationship between the cooling load energy consumption and carbon emission will be established as shown in **section 3.1.2.**

3.1.1.3 Integration of BIM Model and System Dynamic Model

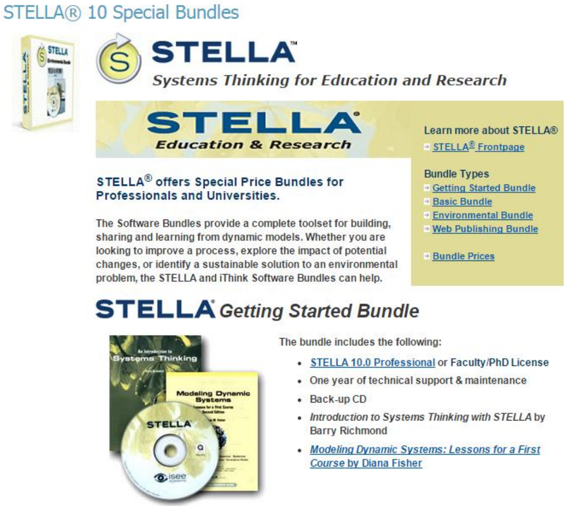


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FIGURE 7 STELLA® SOFTWARE

In order to populate the system dynamic model with necessary data to represent the building, integration of BIM model with system dynamic model is necessary[25]. A case study building created with BIM software is linked to SD decision making model, STELLA ®. The link can be created by creating appropriate schedules within the BIM model and modifying the needed schedules to match the input requirements of the SD model, and exporting the data to the spreadsheet. Once the data are in the form of spreadsheet, it can be imported to the system dynamic software, STELLA ®. The final product of produced by system dynamic software, STELLA should be as illustrated in **Figure 8**.

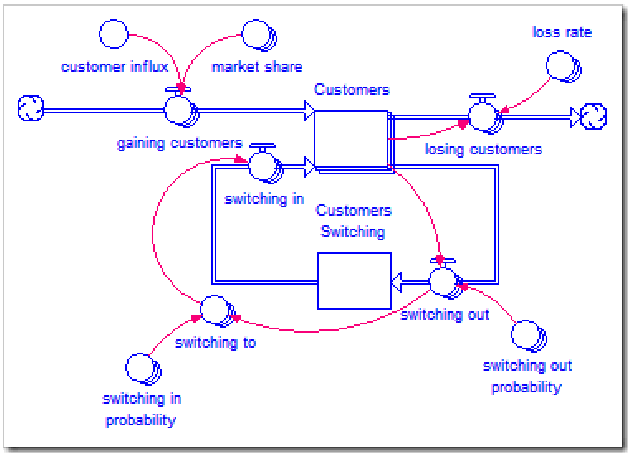


FIGURE 8 SYSTEM DYNAMIC MODEL

3.1.2 Formulations of carbon emission associated with the energy consumption

The estimation of carbon emissions from the cooling load energy consumption is based on the carbon emission baselines of power generation for Peninsular Malaysia [31] . It used the CDM Executive Board approved methodologies of the emission factor to determine the CO_2 emission factor for the displacement of electricity generated by power plants in an electricity system. The method involves the calculation of combined margin (CM) emission factor of the electricity system.

Combined margin is defined as the result of a weighted average of two emission factor, which are operating margin (OM), and build margin (BM) pertaining to the electricity system. In the research, the CO_2 emission was calculated using a conservative method where the average efficiency for specific power plants was used as the determinant.

3.1.2.1 Calculation of Simple Operating Margin

The operating margin was calculated as the generation-weighted emissions per electricity unit of all generating units serving the system. It was calculated based on the net electricity generation and CO_2 emission factor of each power unit. The formula was:

$$EF_{grid,OMsimple,y} = \frac{\sum_m EG_{m,y} \, . \, EF_{El,m,y}}{\sum_m EF_{m,y}}$$

Where:

$EF_{grid,OMsimple,y}$ = Simple operating margin CO_2 emission factor in year y (tCO_2/MWh)

$EG_{m,y}$ = Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)

$EF_{El,m,y}$ = CO_2 emission factor of power unit m in year y (tCO_2/MWh)

m = All power units serving the grid in year y except low-cost/ must run power unit.

y = The relevant year as per the data vintage

The emission factor of each power unit m are determine using:

$$EF_{EL,m,y} = \frac{EF_{CO_2,m,i,y} \, . \, 3.6}{\eta_{m,y}}$$

Where:

$EF_{El,m,y}$ = CO_2 emission factor of power unit m in year y (tCO_2/MWh)

$EF_{CO_2,m,i,y}$ = Average CO_2emission factor of fuel type *i* used in power unit *m* in year *y* (tCO_2/GJ)

$\eta_{m,y}$ = Average net energy conversion efficiency of power unit *m* in year *y* (ratio) m = All power units serving the grid in year y except low-cost/ must run power unit.

y = The relevant year as per the data vintage

Operating Margin was calculated based on the generation-weighted emissions per electricity unit of all power plants generating units serving the grid system in Peninsular Malaysia. **Table 4** shows the data available for years 2010, 2011, and 2012 for calculating the simple operating margin for year 2012.

Years	**Generation (MWh)**	**CO_2 emission (tonnes)**	**Baselines(tCO_2/MWh)**
2012	108,642,040	75,706,047	0.697
2011	97,372,020	70,285,043	0.722
2010	100,510,460	72,362,929	0.720
Average Operating Margin for 3 years			**0.713**

Source: Energy Commision, 2012

TABLE 4 SIMPLE OPERATING MARGIN FOR PENINSULAR MALAYSIA 2012

3.1.2.2 Calculation of Build Margin

The calculation of Build Margin was based on the set of power units that comprises the larger annual generation as shown in **Table 5** .

Power Plants and Fuel Types	Year of Operation	Capacity (MW)	Total Generation (MWh)	CO_2 Emission (tCO_2)
1. Plant A(Coal)	2003	2,100	15,933,450	14,260,428
2. Plant B (Gas & Distillate)	2003	720	4,305,530	1,768,425
3. Plant C (Gas & Distillate)	2005	1,423	10,589,080	4,376,773
4. Plant D (Coal)	2007	2,100	15,265,830	13,662,918

5. Plant E (Coal)	2009	1,400	10,967,400	9,815,823
Total			**57,061,290**	**43,884,377**

Source: Energy Commission, 2012

TABLE 5 BUILDING MARGIN FOR PENINSULAR MALAYSIA 2012

Build Margin for Peninsular Malaysia 2012:

$\mathrm{CO_2}$ Emission divided by the total generation

$$= \frac{43{,}884{,}377 \text{ tonnes } \mathrm{CO_2}}{57{,}061{,}290 \text{ MWh}} = 0.769 \text{ tonnes } \mathrm{CO_2}/\mathrm{MWh}$$

3.1.2.3 Calculation of Combined Margin

The calculation of combined margin emission factor was calculated as the weighted average of emission factor of OM and BM by using the formula:

$$\mathrm{EF_{grid,CM,y}} = \mathrm{EF_{grid,OM,y}} \times \mathrm{W_{OM}} + \mathrm{EF_{grid,BM,y}} \times \mathrm{W_{BM}}$$

Where:

$\mathrm{EF_{grid,BM,y}}$ = Build margin $\mathrm{CO_2}$ emission factor in year y ($\mathrm{tCO_2/MWh}$)

$\mathrm{EF_{grid,OM,y}}$ = Operating margin $\mathrm{CO_2}$ emission factor in year y ($\mathrm{tCO_2/MWh}$)

$\mathrm{W_{OM}}$ = Weighting of operating margin and emission factor (%)

$\mathrm{W_{BM}}$ = Weighting of built margin and emission factor (%)

$$\begin{aligned}\mathrm{EF_{grid,CM,y}} &= 0.713\mathrm{tCO_2/MWh} \times 0.5 + 0.769\mathrm{tCO_2/MWh} \times 0.5 \\ &= \mathbf{0.741\ tCO_2/MWh}\end{aligned}$$

3.1.2.4 Calculation of Carbon Emission

The calculation of carbon emission of the research paper was from the cooling load energy consumption based on the carbon emission baselines of power generation in Peninsular Malaysia. 0.741 tonnes of CO_2 will be emitted for one unit MWh of electricity consumption.

3.1.3 Development of System Dynamic Model

In the research, system dynamic model has been developed to analyse the carbon emission reduction of building information model, which was a single storey house in Malaysia with different roof design configurations. A system dynamic model was developed by the building blocks categorize as stocks, flows, connector and convertors as shown in **Figure 9** [32]. Stock variables (symbolized by rectangles) are the state variable of interest and represent major accumulation in the system. Flow variables (symbolized by valve) are the rate of change in stock variable and it is what makes the stock bigger or smaller. They either flow into a stock (causing it to increase) or flow out of a stock (causing it to decrease). Converter (represented by circle) is the change relationship between stock and flow and they are some factors that control the flow. Connector (represented by arrow) are arrow indicating that one element controls another and allow information to be passed between variables. In the research, system dynamic model was presented to identify and capture feedback loops affecting the carbon emission reduction.

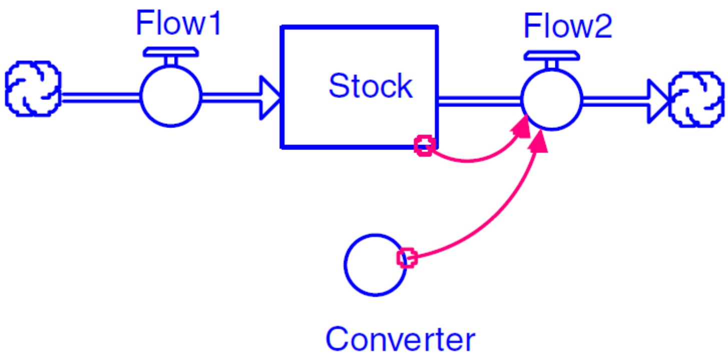


FIGURE 9 BASIC ELEMENT OF SYSTEM DYNAMIC MODEL

The entire model of the research was divided into three sub-system causal loop diagram as shown in the following section:

1. Energy Consumption with different roof design configuration
2. Energy Saving due to roof design configuration
3. Carbon Emission Reduction due to amount of energy saving

The causal loop diagram below were then converted into stock and flow diagram and appropriate mathematical formulas as a relationship link were applied to obtain the simulation result. The overall stock and flow diagram will be shown in **Result and Discussion** section.

3.1.3.1 Energy Consumption with Different Roof Design Configuration

The structure of energy consumption due to different roof design configuration is presented in **Figure 10**. By changing the different roof design configuration such as roof colour has changed the energy consumption of the case study building, which was a single storey house. The higher the solar absorptance, the higher demand of cooling load energy consumption to maintain the indoor thermal comfort. Besides, the solar absorptance of the roof is dependent with the surface reflectivity and emissivity of the roof. In the research, different roof colours have different surface reflectivity. Therefore, energy consumption with different roof design configuration is the function of solar absorptance and the solar absorptance is the function of surface reflectivity and emissivity.

$$\text{Solar Absorptance} = 100 - 0.9 \times \text{Emissivity}$$

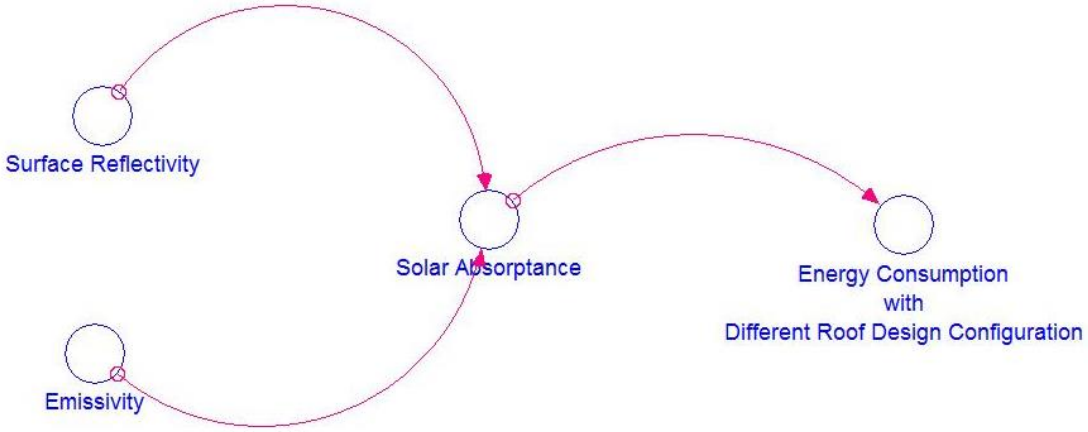


FIGURE 10 THE STOCK AND FLOW DIAGRAM FOR ENERGY CONSUMPTION WITH DIFFERENT ROOF DESIGN CONFIGURATION

3.1.3.2 Energy Saving due to Different Roof Design Configuration

The structure of energy saving due to different roof design configuration is illustrated in **Figure 11** . In the research, different roof design configuration such as colour has result in energy consumption variation. In order to determine the energy saving, energy consumption with different roof design configuration was compared to the baseline cooling load energy consumption. Therefore, cooling load energy saving is a function of baseline cooling load energy consumption and energy consumption with different roof design configuration.

$$\begin{aligned} &\text{Cooling Load Energy Saving} \\ &\qquad\qquad = \text{Baseline Cooling Load Energy Consumption} \\ &\qquad\qquad - \text{Energy Consumption with Different Roof Design Configuration} \end{aligned}$$

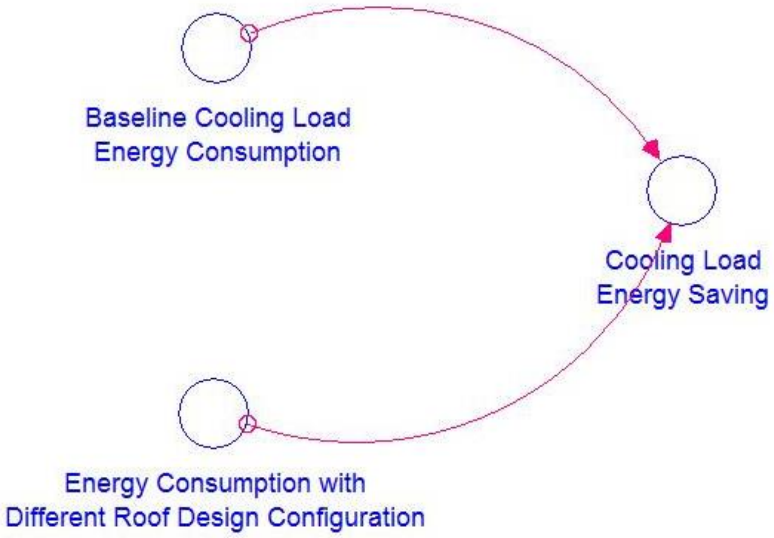


FIGURE 11 COOLING LOAD ENERGY BY DIFFERENT ROOF DESIGN CONFIGURATION

3.1.3.3 Carbon Emission Reduction due to Amount of Energy Saving

The structure of carbon emission reduction of the building is shown in **Figure 12**. The quantity of carbon particulates emitted is directly proportional to the amount of cooling load energy saved. The amount of cooling load energy saved will be the difference between baseline cooling load energy consumption and energy consumption with different roof design configuration. Therefore, the building carbon emission reduction is the function of cooling load energy saving and CO2 emission factor.

$$\begin{aligned}&\text{Building Carbon Emission Reduction}\\&\qquad\qquad = \text{Cooling Load Energy Saving} \times \text{CO}_2\ \text{Emission Factor}\end{aligned}$$

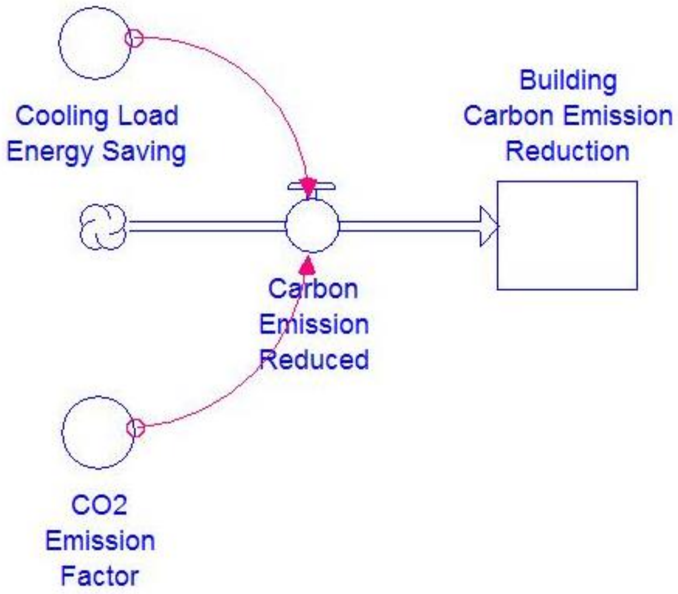
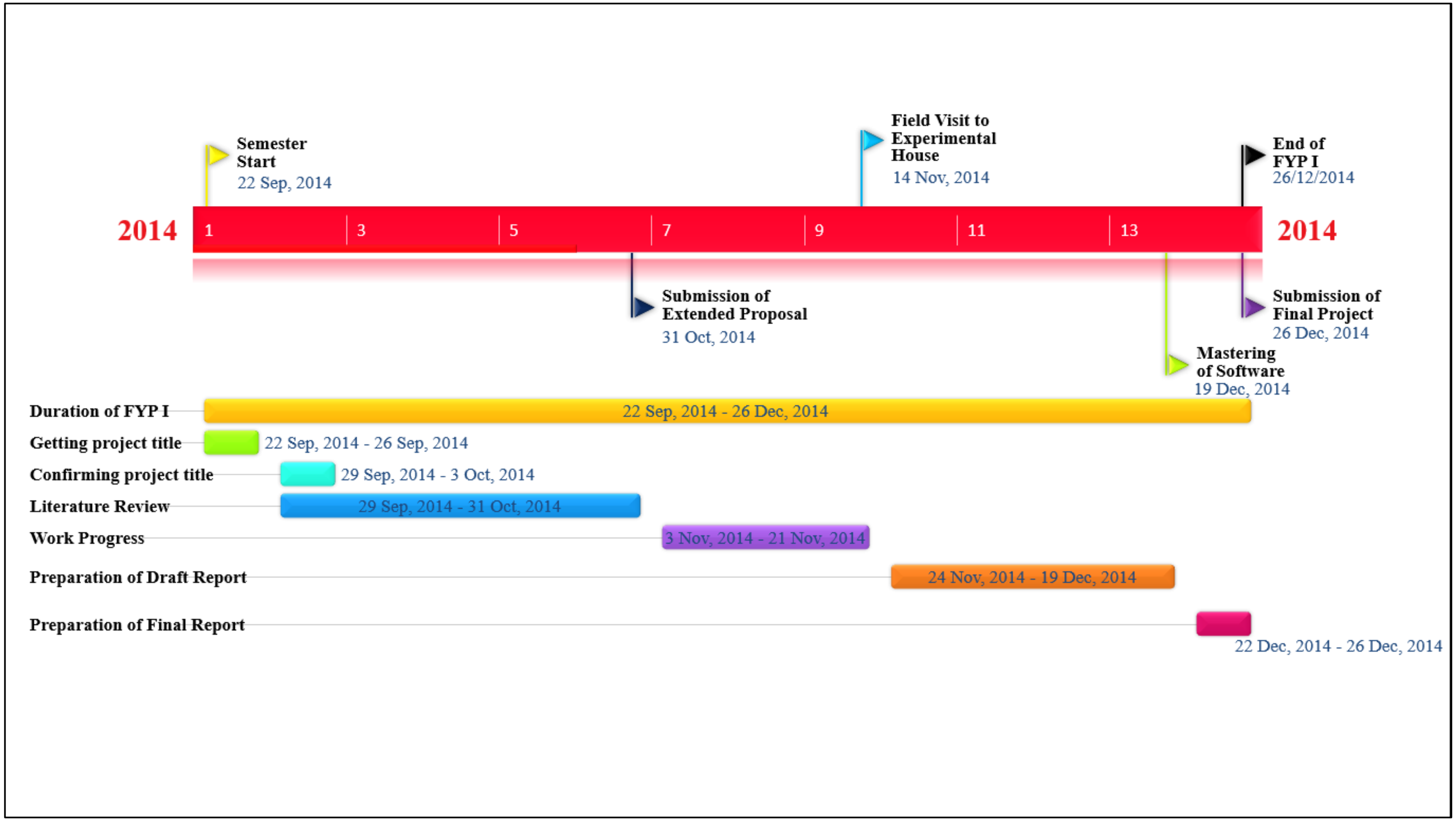


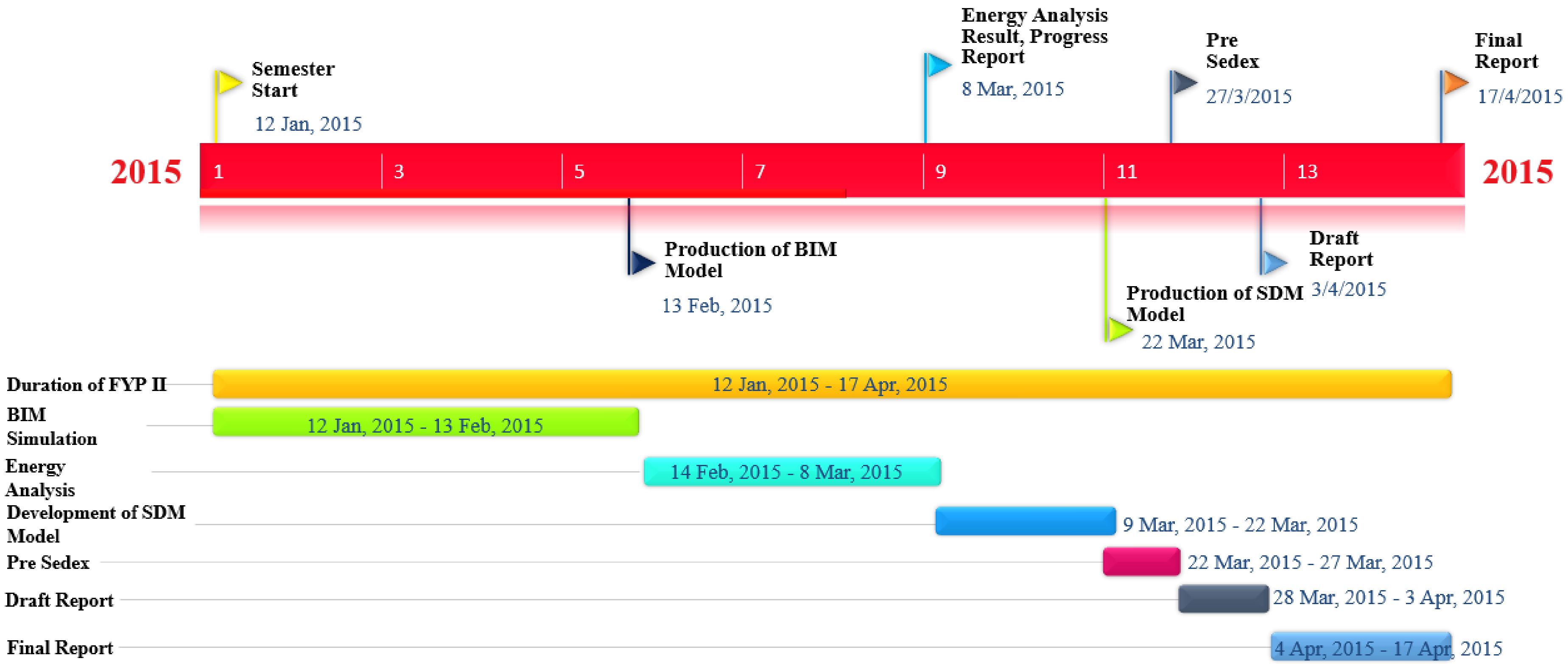
FIGURE 12 BUILDING CARBON EMISSION REDUCTION

3.2 Project Key Milestone

3.2.1 FYP I

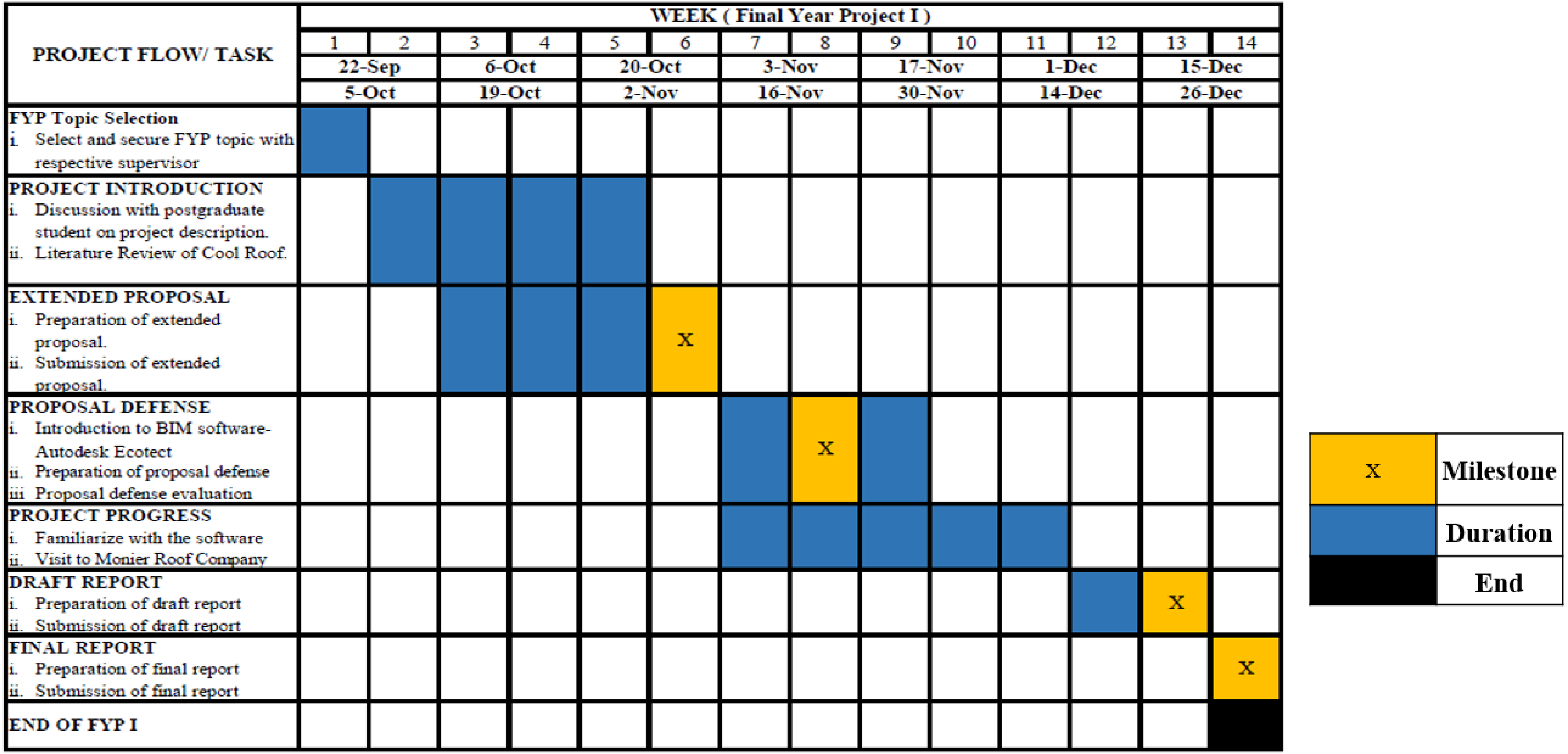


3.2.2 FYP II


Energy Analysis Result, Progress Report
8 Mar, 2015
Pre Sedex
27/3/2015
Final Report
17/4/2015
Semester Start
12 Jan, 2015
2015
1
3
5
7
9
11
13
2015
Production of BIM Model
13 Feb, 2015
Draft Report
3/4/2015
Production of SDM Model
22 Mar, 2015
Duration of FYP II
12 Jan, 2015 - 17 Apr, 2015
BIM Simulation
12 Jan, 2015 - 13 Feb, 2015
Energy Analysis
14 Feb, 2015 - 8 Mar, 2015
Development of SDM Model
9 Mar, 2015 - 22 Mar, 2015
Pre Sedex
22 Mar, 2015 - 27 Mar, 2015
Draft Report
28 Mar, 2015 - 3 Apr, 2015
Final Report
4 Apr, 2015 - 17 Apr, 2015

3.3 Gantt Chart

3.3.1 FYP I



PROJECT FLOW/ TASK	WEEK (Final Year Project I)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	22-Sep		6-Oct		20-Oct		3-Nov		17-Nov		1-Dec		15-Dec	
	5-Oct		19-Oct		2-Nov		16-Nov		30-Nov		14-Dec		26-Dec	
FYP Topic Selection i. Select and secure FYP topic with respective supervisor	🟦													
PROJECT INTRODUCTION i. Discussion with postgraduate student on project description. ii. Literature Review of Cool Roof.		🟦	🟦	🟦	🟦									
EXTENDED PROPOSAL i. Preparation of extended proposal. ii. Submission of extended proposal.			🟦	🟦	🟦	X								
PROPOSAL DEFENSE i. Introduction to BIM software- Autodesk Ecotect ii. Preparation of proposal defense iii Proposal defense evaluation							🟦	X	🟦					
PROJECT PROGRESS i. Familiarize with the software ii. Visit to Monier Roof Company							🟦	🟦	🟦	🟦	🟦			
DRAFT REPORT i. Preparation of draft report ii. Submission of draft report												🟦	X	
FINAL REPORT i. Preparation of final report ii. Submission of final report														X
END OF FYP I														⬛

X	**Milestone**
🟦	**Duration**
⬛	**End**

3.3.2 FYP II

PROJECT FLOW/ TASK	WEEK (Final Year Project II)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	12-Jan		26-Jan		9-Feb		23-Feb		9-Mar		23-Mar		6-Apr	
	25-Jan		8-Feb		22-Feb		8-Mar		22-Mar		5-Apr		19-Apr	
PROJECT PROGRESS I i. Develop Architecture Drawing of single storey house. ii. Simulation and Modelling of single storey house using Autodesk Revit. iii. Exporting BIM model to Autodesk Ecotect.	🟦	🟦	🟦	🟦	X									
PROJECT PROGRESS II i. Energy Modelling and Analysis by using Autodesk Ecotect. ii. Preparation and Submission of Progress Report.						🟦	🟦	X						
PROJECT PROGRESS III i. Determination the relationship between the cooling load energy consumption and carbon emission. iii. Development of SDM Model using STELLA.								🟦	🟦	X				
PRE SEDEX i. Preparation of Poster Presentation.										🟦	X			
DRAFT REPORT i. Preparation of draft report ii. Submission of draft report											🟦	X		
FINAL REPORT i. Preparation of final report ii. Submission of final report											🟦	🟦	X	
END OF FYP I														⬛

X	**Milestone**
🟦	**Duration**
⬛	**End**

CHAPTER 4

RESULT AND DISCUSSION

4.1 Building Information Modelling (BIM) Simulation

As mentioned in Chapter 3, Methodology, a single story bungalow house was chosen as the case study in the research paper. The architecture drawing of the single storey house consists of 107m^2 floor area, including 3 bedrooms, 2 bathrooms, 1 dining room, 1 living room, 1 kitchen, and 1 yard as shown in **Figure 13.**

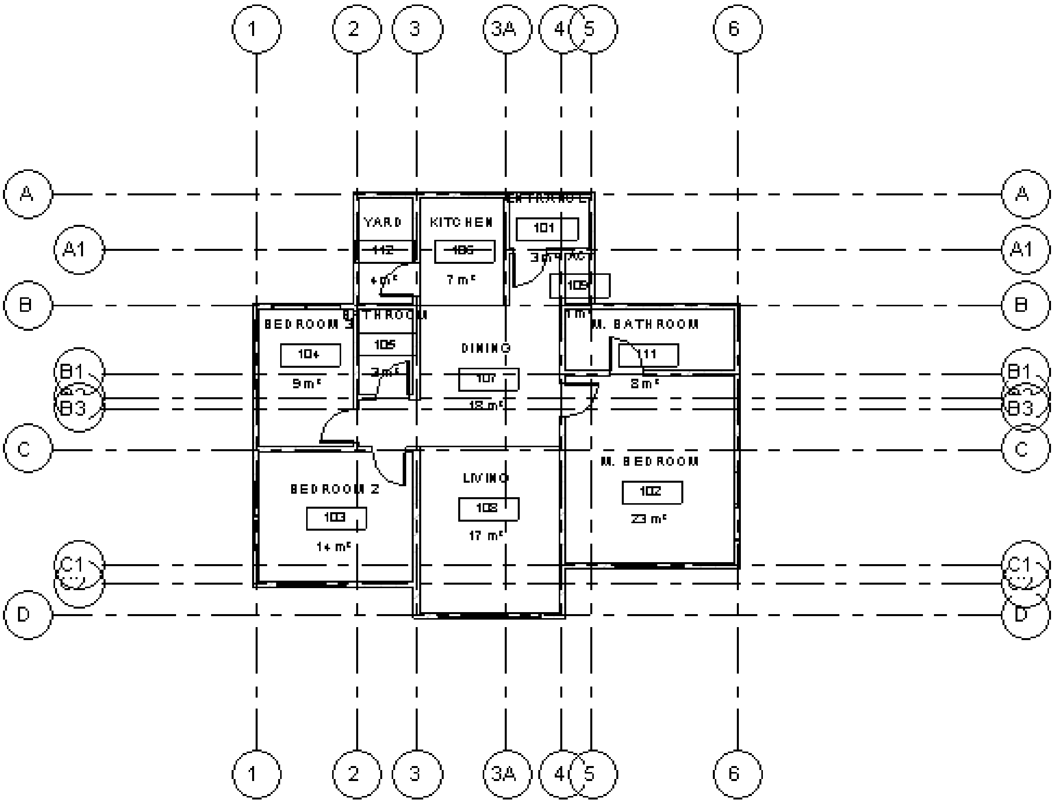


FIGURE 13 GROUND FLOOR PLAN OF SINGLE STORY HOUSE

All specifications of building components were simulated in a virtual environment by using Building Information Modelling based software, Autodesk Revit Architecture. Typical reinforced concrete structure frame has been adopted in the construction of the single storey house. The building components of the house such as wall, door, window, roof, ceiling and floor were chosen from the building component grouped in term of categories, types, and families within the Revit

Architecture's built in library. The building information model (BIM) created by Autodesk Revit Architecture is shown in **Figure 14**, **Figure 15, Figure 16,** and **Figure 17**.

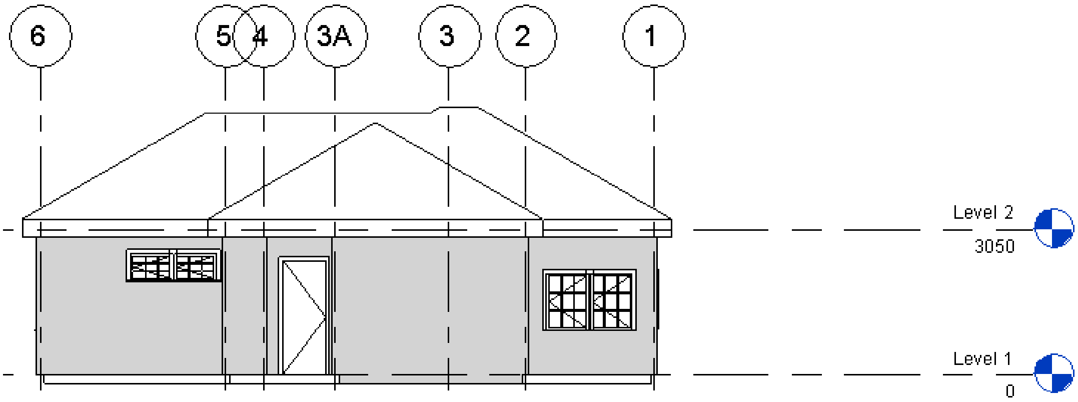


FIGURE 14 FRONT ELEVATION OF THE MODEL

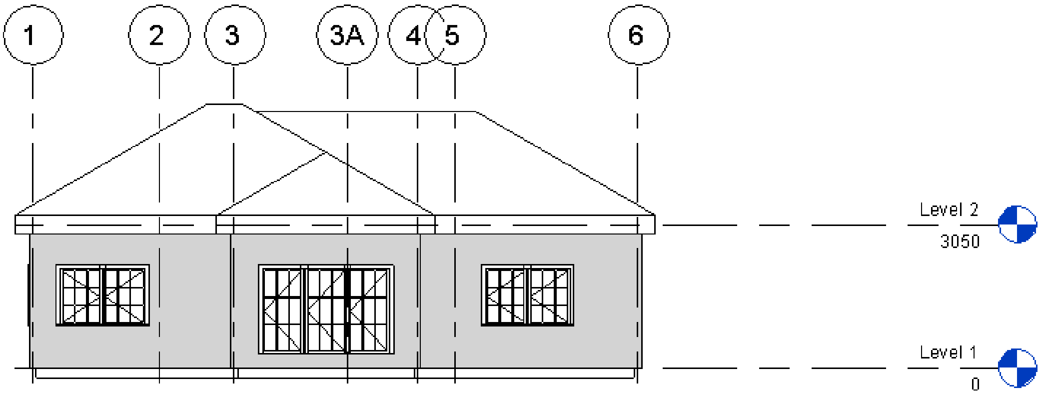


FIGURE 15 REAR ELEVATION OF THE MODEL

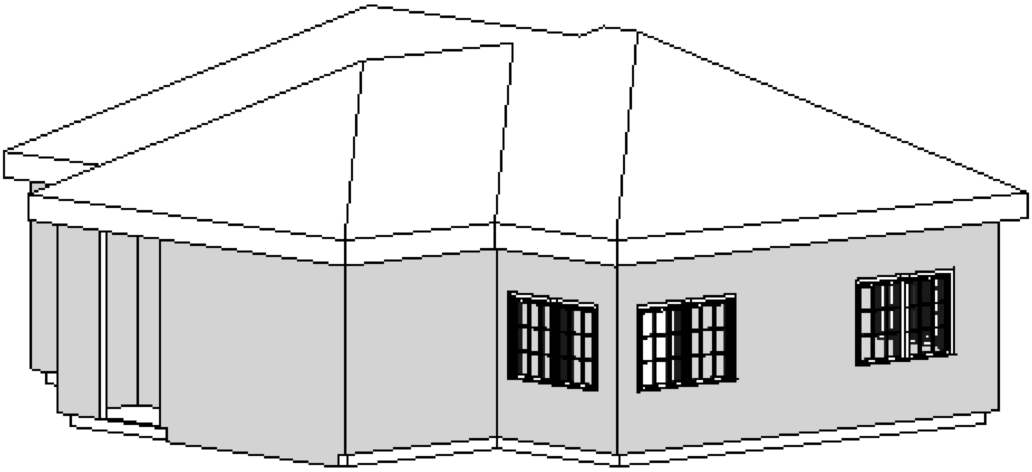


FIGURE 16 3D VIEW OF THE MODEL

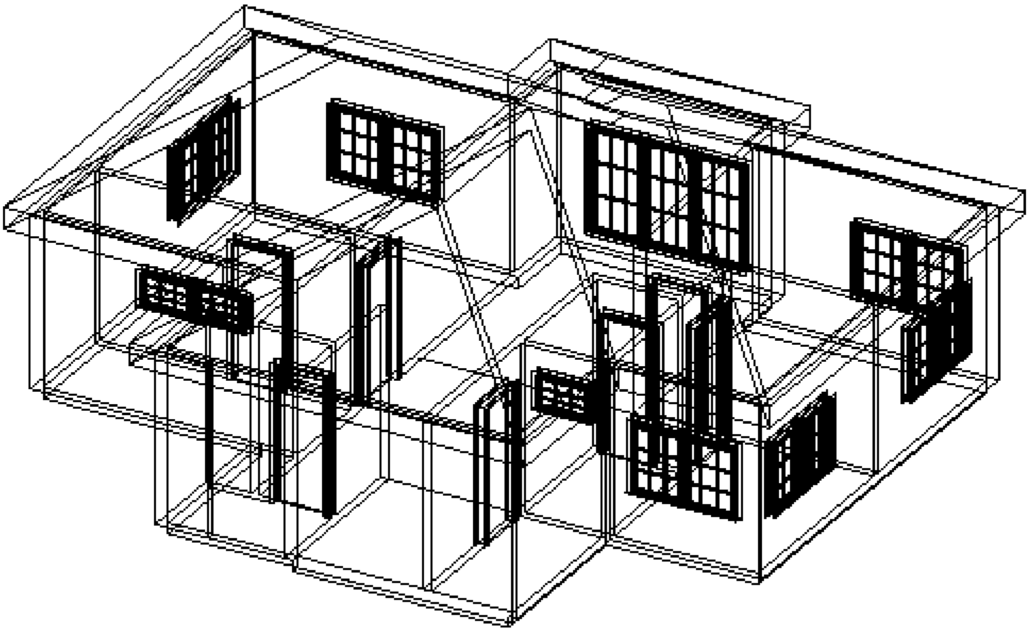


FIGURE 17 WIREFRAME VIEW OF THE MODEL

4.2 Energy Modelling

After the case study building modelling, the output from the Autodesk Revit Architecture must be exported to Autodesk Ecotect for energy modelling. The gbXML based export from Autodesk Revit Architecture is more suitable in the case as the gbXML is based more upon space-based concerns, such as thermal performance, solar radiation and energy demands. **Figure 18** shows the perspective of export gbXML to import the simulated file from Autodesk Revit Architecture to Autodesk Ecotect software for energy modelling. Zones must be produce to separate operational spaces of the building required for energy simulation in Ecotect before implementing the export process. Before the energy analysis, weather specification was loaded from weather data library in Ecotect based on the location. Different location have different sun paths and shadow position. The weather data from Malaysia was found from US Department of Energy and loaded to Ecotect software as shown in **Figure 19**. After loading the Malaysia's weather data, the daily and annual sun path can be visualized to interpret their impact on the various part of the building during different times of the day. **Figure 20** illustrates the daily and annual visualizations of the sun's path.

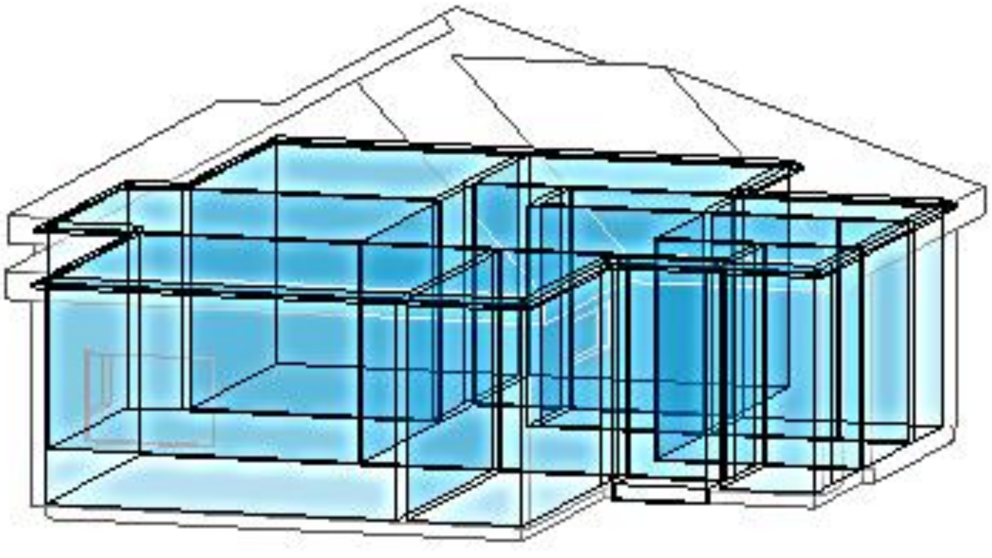
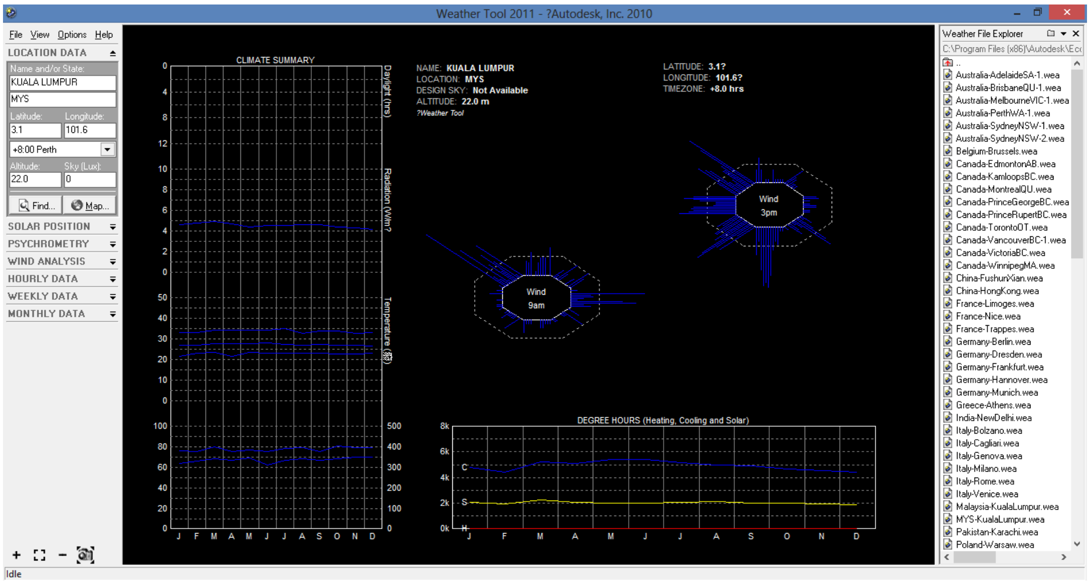


FIGURE 18 PERSPECTIVE OF EXPORT GBXML



Name and/or State: KUALA LUMPUR
MYS
Latitude: 3.1
Longitude: 101.6
+8:00 Perth
Altitude: 22.0
Sky (Lux): 0

NAME: **KUALA LUMPUR**
LOCATION: **MYS**
DESIGN SKY: **Not Available**
ALTITUDE: **22.0 m**
?Weather Tool

LATITUDE: **3.1?**
LONGITUDE: **101.6?**
TIMEZONE: **+8.0 hrs**

C:\Program Files (x86)\Autodesk\Ec
..
Australia-AdelaideSA-1.wea
Australia-BrisbaneQU-1.wea
Australia-MelbourneVIC-1.wea
Australia-PerthWA-1.wea
Australia-SydneyNSW-1.wea
Australia-SydneyNSW-2.wea
Belgium-Brussels.wea
Canada-EdmontonAB.wea
Canada-KamloopsBC.wea
Canada-MontrealQU.wea
Canada-PrinceGeorgeBC.wea
Canada-PrinceRupertBC.wea
Canada-TorontoOT.wea
Canada-VancouverBC-1.wea
Canada-VictoriaBC.wea
Canada-WinnipegMA.wea
China-FushunXian.wea
China-HongKong.wea
France-Limoges.wea
France-Nice.wea
France-Trappes.wea
Germany-Berlin.wea
Germany-Dresden.wea
Germany-Frankfurt.wea
Germany-Hannover.wea
Germany-Munich.wea
Greece-Athens.wea
India-NewDelhi.wea
Italy-Bolzano.wea
Italy-Cagliari.wea
Italy-Genova.wea
Italy-Milano.wea
Italy-Rome.wea
Italy-Venice.wea
Malaysia-KualaLumpur.wea
MYS-KualaLumpur.wea
Pakistan-Karachi.wea
Poland-Warsaw.wea

FIGURE 19 WEATHER DATA FILE OF MALAYSIA

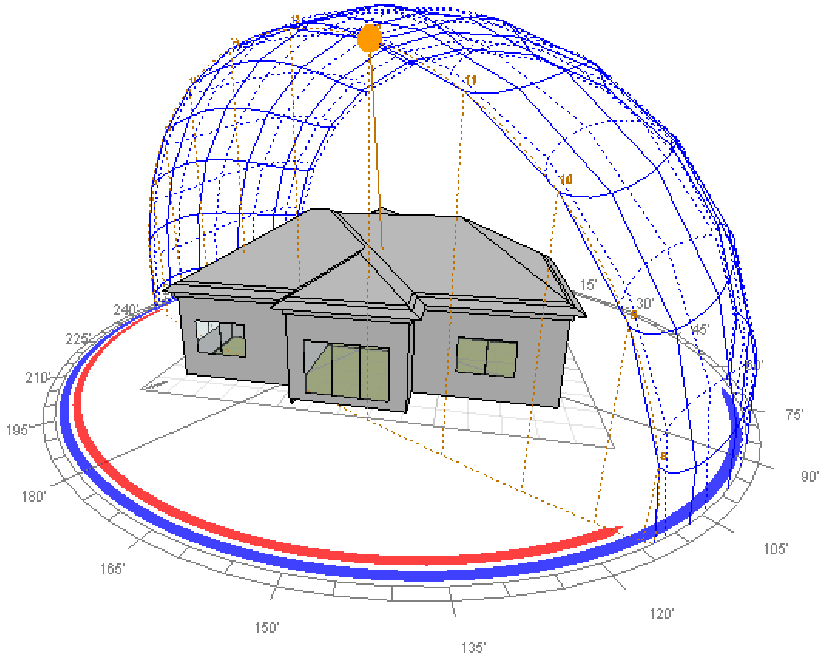


FIGURE 20 DAILY AND ANNUAL VISUALIZATIONS OF THE SUN'S PATH

4.2.1 Analysis of solar energy absorption

Ecotect can perform solar access analysis where incident solar radiation was mapped onto a surface to calculate total, direct and diffuse solar radiation on object. It used hourly recorded direct and diffuse radiation data from the weather file. After the calculation, the surface of the building was changed to a range of colours from yellow to blue as illustrated in **Figure 21 and Figure 22**. The yellow colour indicates the greatest solar energy absorption and blue colour indicates the least solar energy absorption. To enhance the solar energy absorption, selection of the orientation is one of the important criteria. The best and worst orientation of the building for solar energy absorption were calculated as shown in **Figure 23**. The best orientation of the building was 150º from the north and the worst orientation was 60 º from the north.

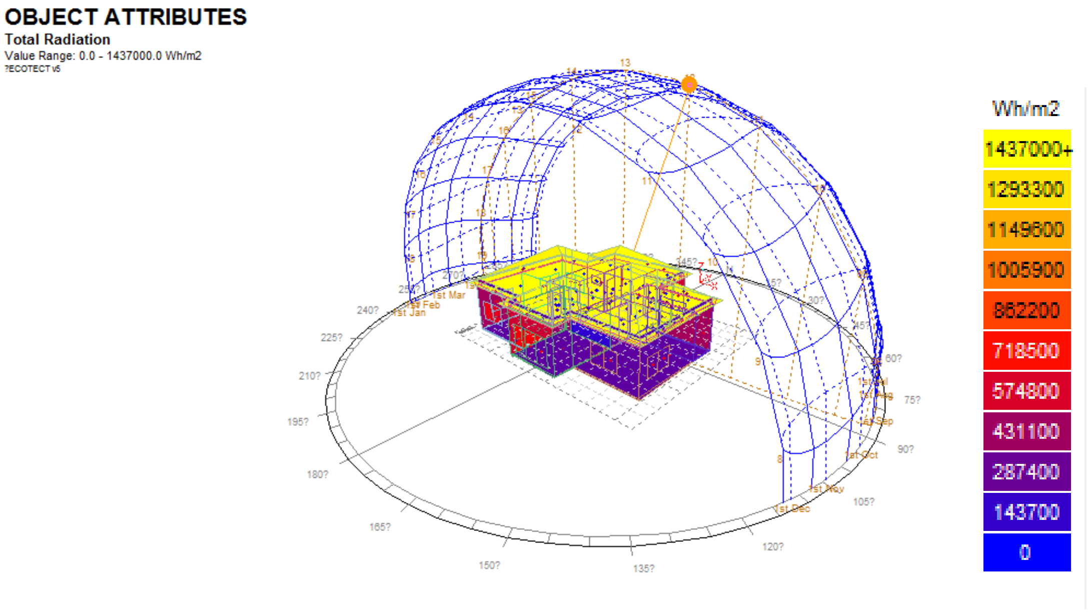


FIGURE 21 SOLAR ENERGY ABSORPTION BY SURFACE OF THE BUILDING

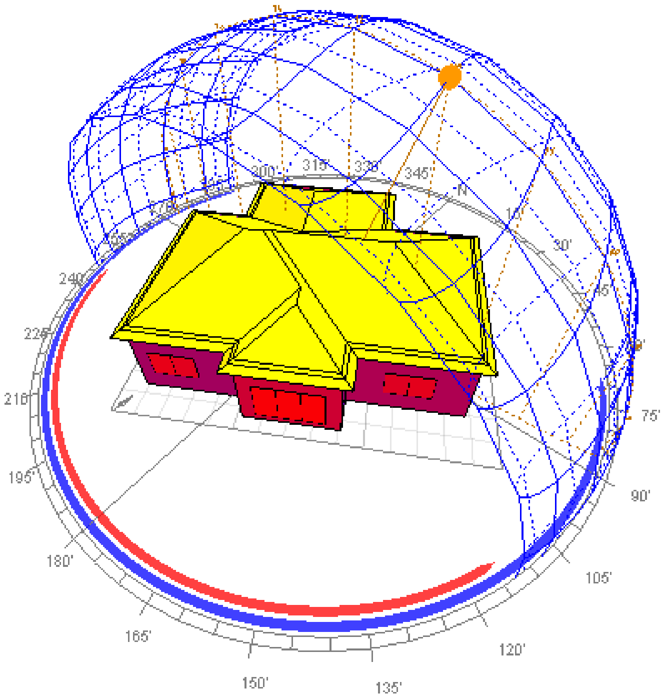
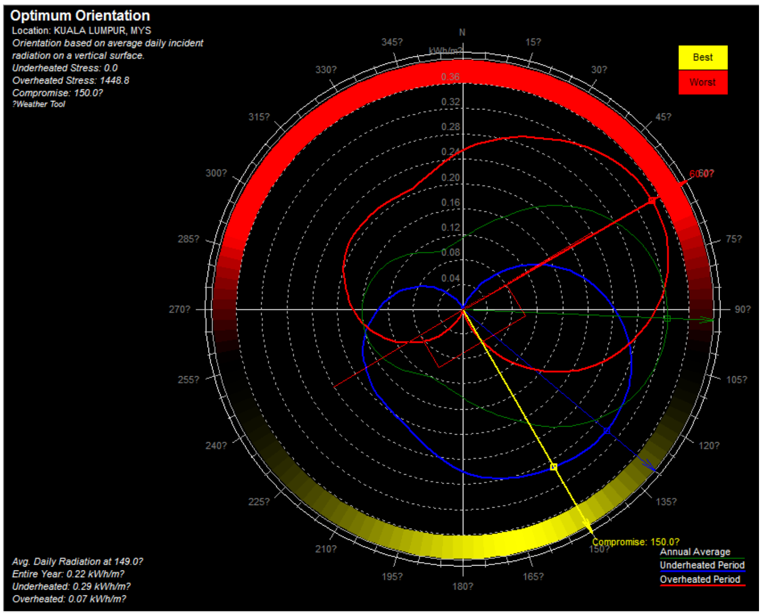


FIGURE 22 VISUALIZED SOLAR ENERGY ABSORPTION OF MODEL



Optimum Orientation
Location: KUALA LUMPUR, MYS
Orientation based on average daily incident radiation on a vertical surface.
Underheated Stress: 0.0
Overheated Stress: 1448.8
Compromise: 150.0?
?Weather Tool

Avg. Daily Radiation at 149.0?
Entire Year: 0.22 kWh/m?
Underheated: 0.29 kWh/m?
Overheated: 0.07 kWh/m?

Compromise: 150.0?

FIGURE 23 BEST AND WORST ORIENTATION OF THE BUILDING

4.2.2 Analysis of annual operational energy consumption

During the energy analysis, several assumptions related to the building zones were made. The building model was divided into 12 zones, which includes three bedrooms, two bathroom, one kitchen, one dining room, one living room, one AC, one yard, one entrance, and one attic. Typical family number of 5 persons were assumed to live in the building. After the assumptions were made as shown in **Table 4**, thermal analysis was performed to determine the energy consumption of the building with 5 occupants. The amount of cooling load was calculated to keep the indoor temperature between 22 ºC and 26 ºC. The energy consumption of the building was calculated based on the baseline design, with material specification shown in **Table 6**. Different roof design configuration such as roof surface colour and ventilation gap were changed to determine their effect on energy consumption, which will affect the carbon dioxide emission.

Zone	**Assumptions**				
101 Entrance	Number of people involved		: 5		
	Activity	: Walking	; Average biological heat oupput		: 80W
	Lighting Level	: 500 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				: 22˚C - 26˚C
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
102 M Bedroom	Number of people involved		: 2		
103 Bedroom 2	Activity	: Sleeping	; Average biological heat oupput		: 40W
104 Bedroom 3	Lighting Level	: 200 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				: 22˚C - 26˚C
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
105 Bathroom	Number of people involved		: 1		
111 M Bathroom	Activity	: Sedentary	; Average biological heat oupput		: 70W
	Lighting Level	: 500 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				: 22˚C - 26˚C
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
106 Kitchen	Number of people involved		: 5		
	Activity	: Cooking	; Average biological heat oupput		: 95W
	Lighting Level	: 500 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				: 22˚C - 26˚C
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
107 Dining Room	Number of people involved		: 5		
108 Living Room	Activity	: Resting	; Average biological heat oupput		: 45W
	Lighting Level	: 500 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				:
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
109 AC	Number of people involved		: 5		
	Activity	: Walking,Slo	; Average biological heat oupput		: 115W
	Lighting Level	: 50 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				:
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day

112 Yard	Number of people involved		: 5		
	Activity	: Resting	; Average biological heat oupput		: 45W
	Lighting Level	: 500 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				:
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day
113 Attic	Number of people involved		: 0		
	Activity	: Sedentary	; Average biological heat oupput		: 70W
	Lighting Level	: 50 lux			
	Type of system	: Cooling			
	Environmental temperature range for comfort of the building				:
	Standard Weekday	: Mon - Fri		Hour of Operation	: 12h/day
	Standard Weekend	: Sat - Sun		Hour of Operation	: 12h/day

TABLE 6 BASIC ASSUMPTIONS OF THE ZONES

Component	Type of Materials
Walls	Brick Plaster
Windows	Single Glazed Aluminium Frame
Roof	Clay Tiles
Ceiling	Plaster Insulation Suspended
Floor	Concrete Slab Tiles On Ground
Door	Solid Core Pine Timber

TABLE 7 TYPES OF MATERIAL USED FOR EACH BUILDING COMPONENTS

4.2.2.1 Baseline design cooling energy consumption

In order to determine the effect of different roof design configuration on the energy consumption and carbon emission, other building components were remained unchanged. As mentioned in **Table 7**, the baseline design house involves brick plaster for the wall, single glazed aluminium frame for window, plaster insulation suspended for the ceiling, concrete slab tiles on ground for the floor, solid core pine timber for the door, and clay tiles for the roof. However, different roof colour and ventilation gap were changed to determine their effect on energy consumption and carbon emission. For the baseline design, black roof with the solar reflectance of 4.3% was selected. No air gap was provided in baseline design. **Figure 24** illustrates the monthly cooling load energy consumption throughout the year in Malaysia to maintain the temperature of between 22 ºC and 26 ºC. Since Malaysia is a tropical country, no heating load was considered in the research paper. The highest of energy consumption occurs in March, June, and May whereas the lowest of energy consumption occurs in February, December, and November. Table 6 shows the value of monthly cooling load energy consumption of baseline design. The maximum cooling load was 14832W at 10.00 on 29th March. The analysis was supported by strong database in Ecotect analysis software in which the weather specification of different country have been well established.

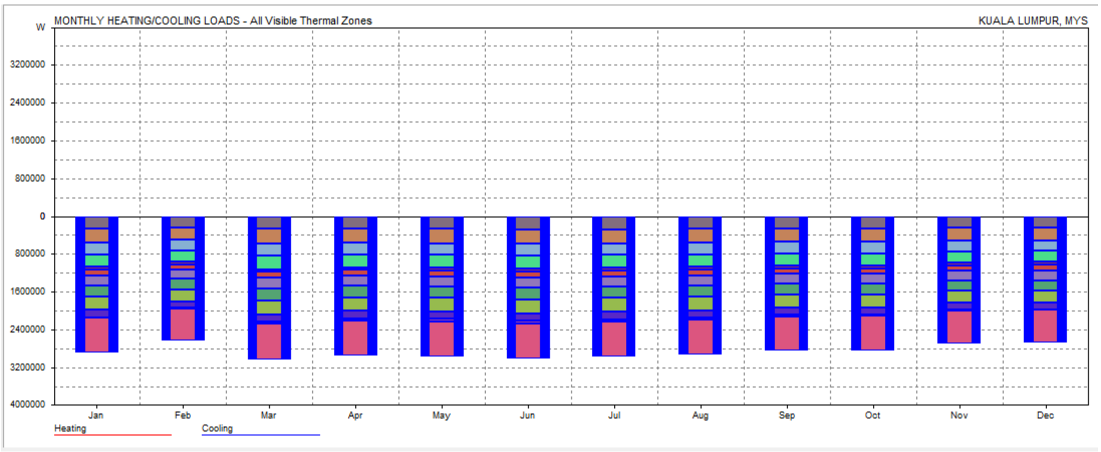


FIGURE 24 MONTHLY COOLING LOAD ENERGY CONSUMPTION

MONTH	**HEATING (Wh)**	**COOLING (Wh)**	**TOTAL (Wh)**
Jan	0	2888495	2888495
Feb	0	2636226	2636226
Mar	0	3040514	3040514
Apr	0	2948374	2948374
May	0	2973123	2973123
Jun	0	3009093	3009093
Jul	0	2970673	2970673
Aug	0	2932150	2932150
Sep	0	2852948	2852948
Oct	0	2839274	2839274
Nov	0	2703524	2703524
Dec	0	2683654	2683654
TOTAL	0	34478048	34478048

TABLE 8 MONTHLY COOLING LOAD ENERGY CONSUMPTION

The passive gain breakdown chart was calculated to know the contribution of each building component in load losses and gain as shown in **Figure 25**. The load gains for the baseline design building mainly come from internal load, which contribute 44.4% of load gains. The impact percentages of various factors on load losses and gains was shown in **Table 9**.

CATEGORY	LOSSES	GAINS
FABRIC	0.00%	11.50%
SOL-AIR	0.00%	9.30%
SOLAR	0.00%	16.00%
VENTILATION	0.00%	2.60%
INTERNAL	0.00%	44.40%
INTER-ZONAL	100.00%	16.20%

TABLE 9 PERCENTAGE OF VARIOUS FACTORS ON LOAD LOSSES AND GAINS

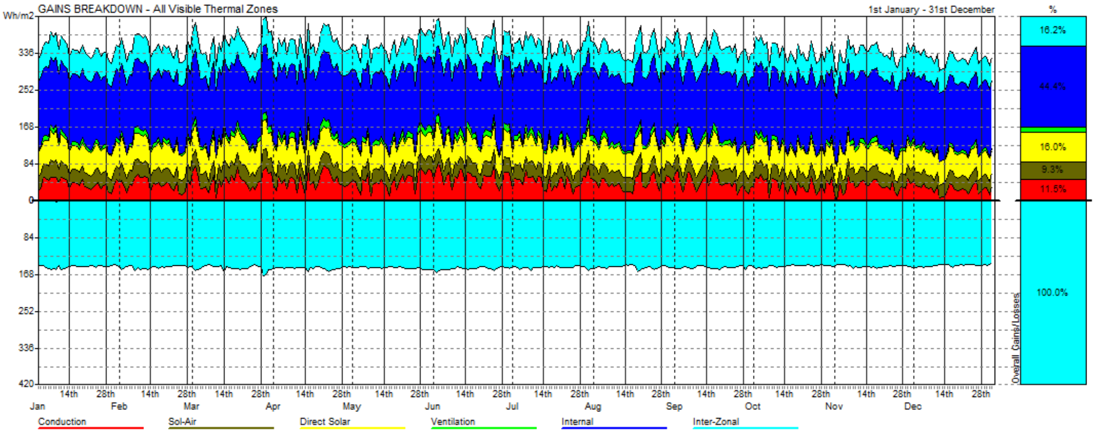


FIGURE 25 BREAKDOWN OF PASSIVE GAIN OF THE BUILDING

4.2.2.2 Effect of different roof design configuration

In the study, all the building components such as wall, window, roof, ceiling, floor, and door were remained unchanged except for roof component. The roof material used for the study was clay tiles and the baseline design selected in the case study is black roof without air gap. Different colours with different intensity and solar reflectance index such as red, brown, and white were replaced to investigate their capability for energy consumption reduction. The presence of air gap with different thicknesses were also replaced to determine their effectiveness in reducing energy consumption. Thus, reducing carbon emission. **Table 10** shows the impact of the use of alternative colours and air gap thickness on the amount of cooling load energy consumption. Generally, it can be concluded that lighter roof colour with the presence of air gap can reduce the cooling load energy consumption and carbon emission. Detailed explanations and interpretations of the result are shown in (a) and (b) in the following section.

	Roof Colour	**Air Gap**	**Annual Cooling Load (Wh)**	**Annual Cooling Load Reduction (Wh)**
Baseline Design	Black Roof	No	34478048	-
Alternative 1.0	Red Roof	No	33996296	481752
Alternative 1.1	Red Roof	3cm	31354454	3123594
Alternative 1.2	Red Roof	6cm	31354454	3123594
Alternative 1.3	Red Roof	9cm	31354454	3123594
Alternative 2.0	Brown Roof	No	33626940	851108
Alternative 2.1	Brown Roof	3cm	31342430	3135618
Alternative 2.2	Brown Roof	6cm	31342430	3135618
Alternative 2.3	Brown Roof	9cm	31342430	3135618
Alternative 3.0	White Roof	No	32790666	1687382
Alternative 3.1	White Roof	3cm	31314776	3163272
Alternative 3.2	White Roof	6cm	31314776	3163272
Alternative 3.3	White Roof	9cm	31314776	3163272

TABLE 10 USE OF DIFFERENT ALTERNATIVE OF ROOF COMPONENT ON ANNUAL COOLING LOAD

(a) Roof Surface Colour

Table 11 shows the impact of roof surface colour on annual cooling load energy consumption. It can be seen the relationship between the roof colour and surface reflectivity. Darker roof colour intensity has lower surface reflectivity and higher solar absorption. Lighter roof colour intensity has higher surface reflectivity and lower solar absorption. Black colour roof has the lowest surface reflectivity, which was capable of reflecting 4.3% of sunlight. White colour roof has the highest surface reflectivity, which was capable of reflecting 72.5%. Therefore, a roof with higher surface reflectivity and lower solar absorption (typically lighter colour) will reflect more solar radiation and keep the roof space cooler during the hot day, hence lesser cooling load energy consumption.

	Roof Colour	**Surface Reflectivity (%)**	**Emissivity**	**Solar Absorption (%)**	**Annual Cooling Load (Wh)**
Baseline Design	Black	4.3	0.9	96.1	34478048
Alternative 1.0	Red	23.9	0.9	78.5	33996296
Alternative 2.0	Brown	38.8	0.9	65.1	33626940
Alternative 3.0	White	72.5	0.9	34.7	32790666

TABLE 11 THE EFFECT OF ROOF COLOUR

Figure 26 illustrates the effect of different roof colour on monthly cooling load. White roof has the least cooling load consumption compared to other colours roof such as black, red, and brown. Therefore, it can be concluded that darker roof colour will consume more cooling load energy consumption than the lighter roof. **Figure 27** and **Figure 28** shows the relationship between the surface reflectivity (%) and solar absorptance with annual cooling load. White roof has the highest surface reflectivity, which was 72.5%. Therefore, white roof is able to reflect 72.5% of sunlight, therefore the cooling energy consumption is the least. It means that lesser cooling load energy required to maintain the temperature of 22 °C and 26 °C indoor temperature since white roof able to reflect 72.5% sunlight and reduce the heat gain to the building. The relationship between surface reflectivity and solar absorption was also established as shown in **Figure 29**. The higher the surface reflectivity, the lower the solar absorption. Thus, lower cooling load energy consumption.

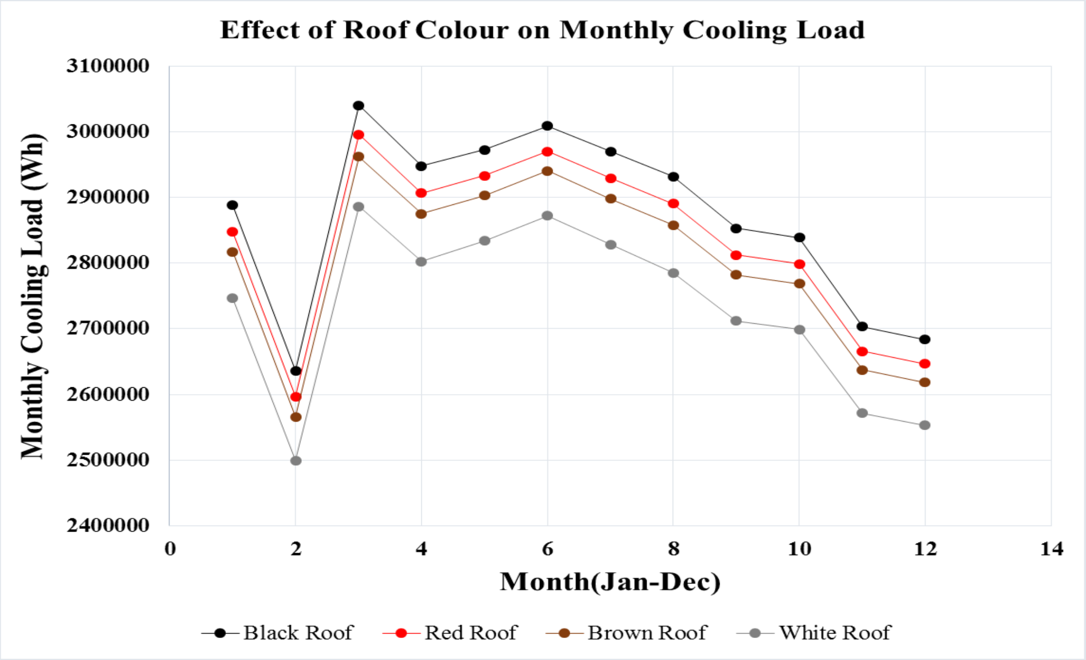


FIGURE 26 GRAPH OF MONTHLY COOLING LOAD VS MONTH

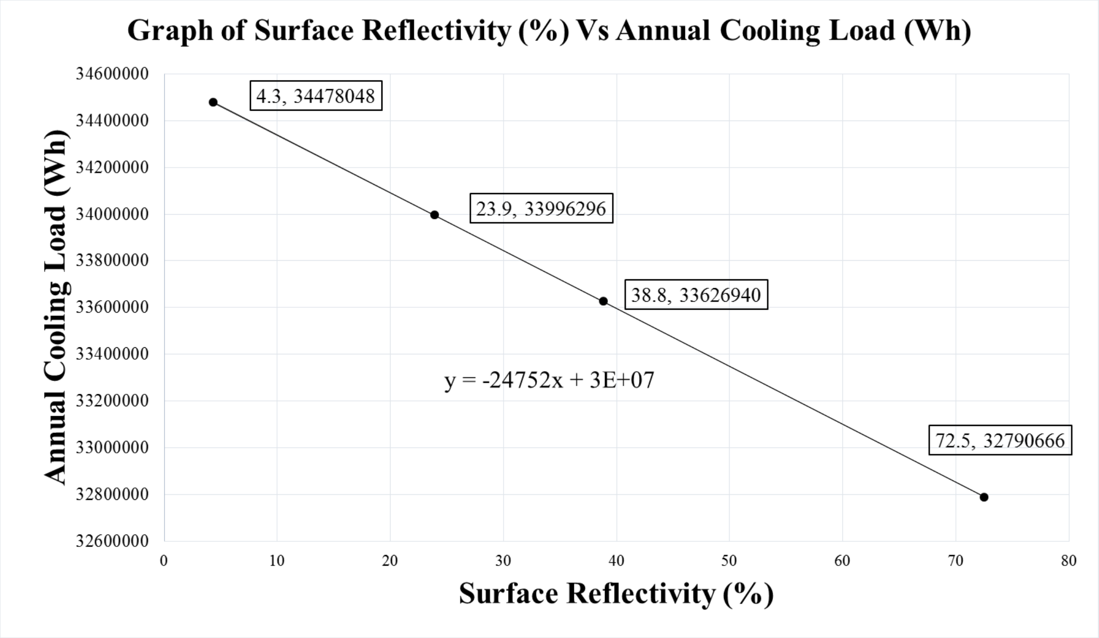


FIGURE 27 GRAPH OF SURFACE REFLECTIVITY VS ANNUAL COOLING LOAD

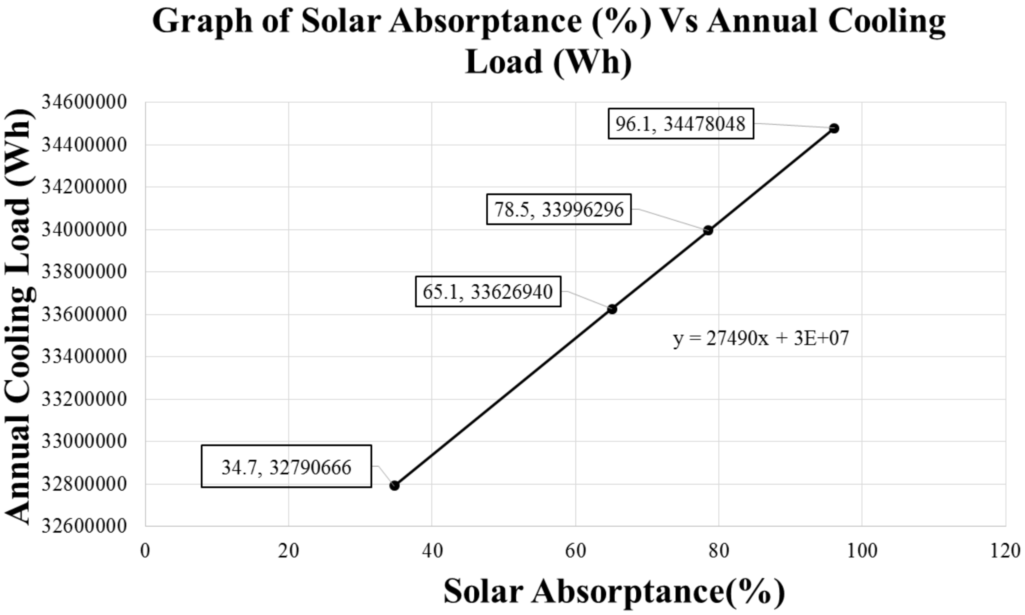


FIGURE 28 GRAPH OF SOLAR ASORPTANCE VS ANNUAL COOLING LOAD

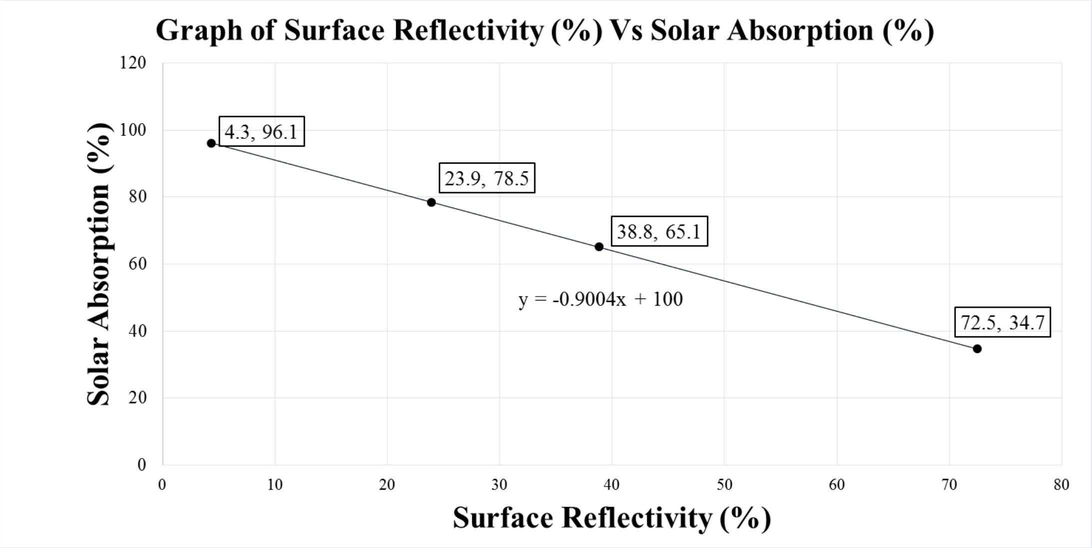
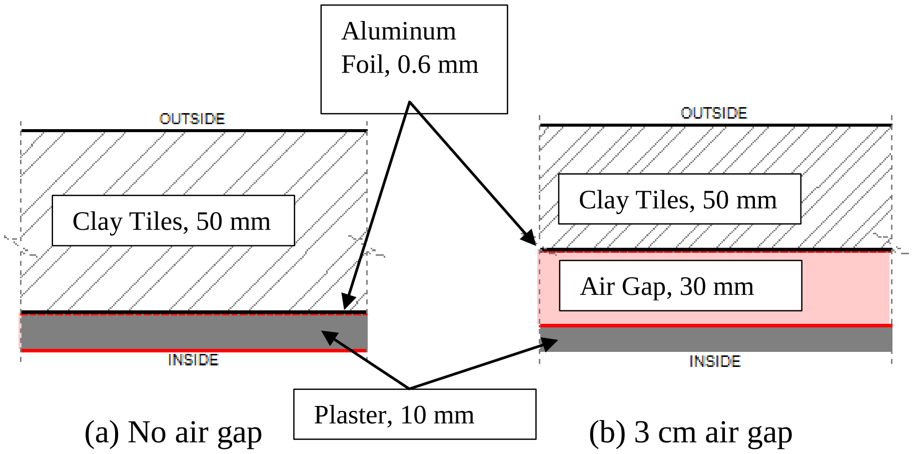


FIGURE 29 GRAPH OF SURFACE REFLECTIVITY VS SOLAR ABSORPTION

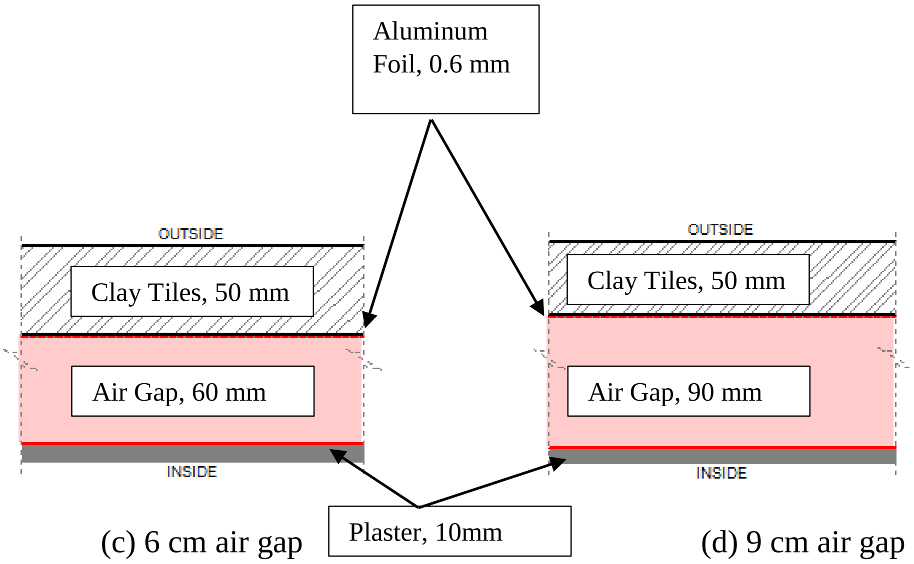
(b) Ventilation layer

Table 12 shows the properties of the layer used in the case study, which includes width, density, specific heat, and thermal conductivity. The baseline design was the black roof without any air gap. To determine the effectiveness of air gap on cooling load energy consumption, different thickness of air gaps were applied to each colour roof. The thickness varied from 3cm, 6cm and 9cm. **Figure 30** shows the section of different roof components. Other layer such as clay tiles, aluminium foil, and plaster were remained unchanged in term of the properties and thickness except for air gap.



(a) No air gap

(b) 3 cm air gap



(c) 6 cm air gap

(d) 9 cm air gap

FIGURE 30 SECTION OF DIFFERENT ROOF COMPONENT

Layer Name	Width (mm)	Density (kg/m3)	Specific Heat (J/kg.K)	Thermal Conductivity (w/m.k)
Clay Tiles	50	2760	836.8	18.828
Aluminium Foil	0.6	2698	920.5	225.94
Plaster	10	1250	1088	4.31
Air Gap 3 cm	30	1.3	1004	5.56
Air Gap 6 cm	60	1.3	1004	5.56
Air Gap 9 cm	90	1.3	1004	5.56

TABLE 12 PROPERTIES OF LAYER

Table 13 shows the result of different thickness of air gap applied to different roof colour. The U-value and Admittance changed in the presence of air gap. Without the presence of air gap, the U-value and Admittance is 5.47W/m2.k and 5.83W/m2.K respectively. In **Figure 31**, it was obviously seen, with the presence of air gap, the cooling load energy consumption reduces dramatically compared to the roof without air gap. The cooling load energy reduction for red roof, brown roof, and white roof were 2641842Wh, 2284510Wh, and 1475890Wh respectively.

With the presence of air gap, the U-value reduced from 5.47W/m2.K to 2.76W/m2.K, whereas the admittance value reduced from 5.83 W/m2.K to 0.98 W/m2.K. U-value is defined as the measure of the rate of heat loss or gain through a material or assembly. It can be determined by the formula U=1/R, where R is the thermal resistance of the material. Thermal resistance is a measure of a material’s ability to resist heat transfer. Therefore, the presence of air gap increase the thermal resistance of the roof, thus reducing the U-value. Lower U value will result in lower cooling load energy consumption.

However, varying the thickness of the air gap did not affect the cooling load energy consumption, U-value, and admittance of the roof as illustrated in **Figure 31**. This is because the behaviour of air is unlikely the same as other material properties when computing thermal process. When the air gap beyond a certain thickness, 25mm, thermal convection occurred in the air gap. The radiation from the adjoining surface played an important role in the performance of the air gap. Therefore, in Ecotect, thermal conductivity of 5.56W/m.K and thermal resistance of 0.18m2K/W were used due to different behaviour of air during construction. Varying the thickness of air gap did not change the thermal resistance, U-value, and admittance. Thermal conductivity of 5.56W/m.K and thermal resistance of 0.18m2K/W will be used in the calculation regardless the thickness of the air gap due to the limitation of the software. However, in real situation, thickness of air gap will affect the cooling load energy consumption due to convection process taking place.

	Roof Colour	**Air Gap**	**Annual Cooling Load (Wh)**	**U-Value (W/m2.K)**	**Admittance (W/m2.K)**
Baseline Design	Black Roof	No	34478048	5.47	5.83
Alternative 1.0	Red Roof	No	33996296	5.47	5.83
Alternative 1.1	Red Roof	3cm	31354454	2.76	0.98
Alternative 1.2	Red Roof	6cm	31354454	2.76	0.98
Alternative 1.3	Red Roof	9cm	31354454	2.76	0.98
Alternative 2.0	Brown Roof	No	33626940	5.47	0.98
Alternative 2.1	Brown Roof	3cm	31342430	2.76	0.98
Alternative 2.2	Brown Roof	6cm	31342430	2.76	0.98
Alternative 2.3	Brown Roof	9cm	31342430	2.76	0.98
Alternative 3.0	White Roof	No	32790666	5.47	5.47
Alternative 3.1	White Roof	3cm	31314776	2.76	0.98
Alternative 3.2	White Roof	6cm	31314776	2.76	0.98
Alternative 3.3	White Roof	9cm	31314776	2.76	0.98

TABLE 13 U-VALUE AND ADMITTANCE WITH RESPECT TO DIFFERENT AIR GAP

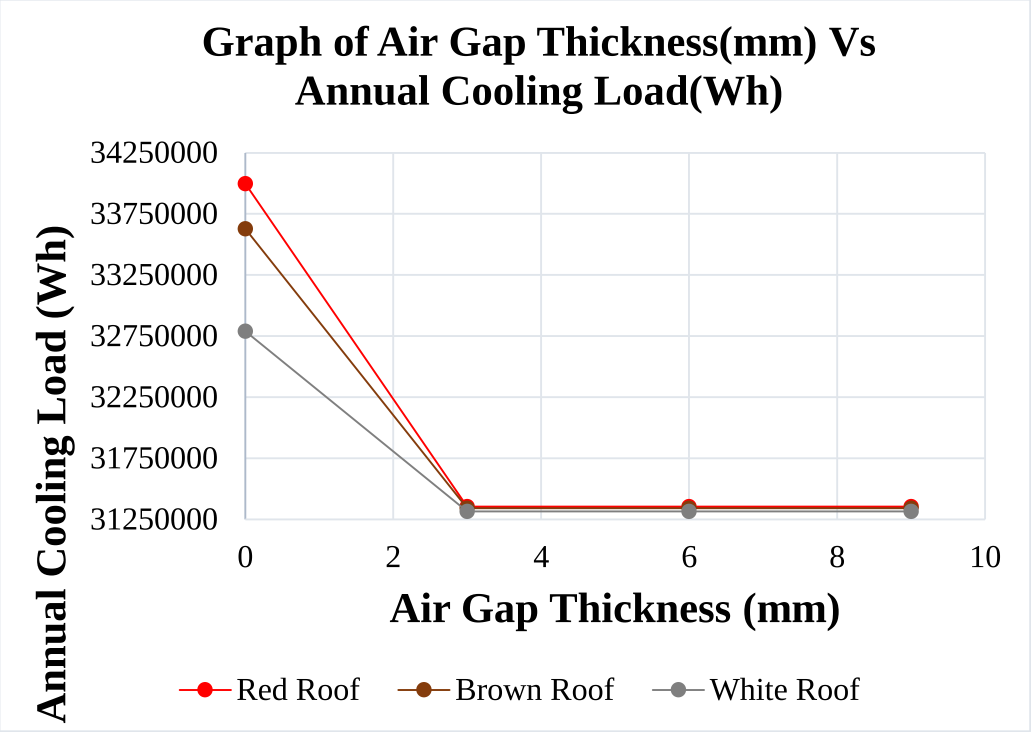


FIGURE 31 GRAPH OF ANNUAL COOLING LOAD VS AIR GAP THICKNESS

4.2.3 Formulations of carbon emission reductions associated with the energy saving

Table 14 shows the energy saving and carbon emission reduction with different roof design configuration. It can be seen obviously white roof with air gap is the most effective among other alternatives in reducing carbon emission. It reduces 2.344 tonnes of the carbon emission. The second most effective alternative is brown roof with air gap, with the reduction of 2.323 tonnes of carbon emission. The least effective method is red roof without the presence of air gap. It only reduce 0.357 tonnes of carbon emission compared to the baseline design. **Figure 32** illustrates the relationship between annual cooling load energy reduction and carbon emission reduction. It can be concluded that larger energy saving can result in greater carbon emission reduction.

	Roof Colour	Air Gap	Annual Cooling Load (Wh)	Annual Cooling Load Reduction (Wh)	Carbon Emission Reduction (tonnes)
Baseline Design	Black Roof	No	34478048	-	-
Alternative 1.0	Red Roof	No	33996296	481752	0.357
Alternative 1.1	Red Roof	3cm	31354454	3123594	2.315
Alternative 1.2	Red Roof	6cm	31354454	3123594	2.315
Alternative 1.3	Red Roof	9cm	31354454	3123594	2.315
Alternative 2.0	Brown Roof	No	33626940	851108	0.631
Alternative 2.1	Brown Roof	3cm	31342430	3135618	2.323
Alternative 2.2	Brown Roof	6cm	31342430	3135618	2.323
Alternative 2.3	Brown Roof	9cm	31342430	3135618	2.323
Alternative 3.0	White Roof	No	32790666	1687382	1.250
Alternative 3.1	White Roof	3cm	31314776	3163272	2.344
Alternative 3.2	White Roof	6cm	31314776	3163272	2.344
Alternative 3.3	White Roof	9cm	31314776	3163272	2.344

TABLE 14 RELATIONSHIP BETWEEN ENERGY SAVING WITH CARBON EMISSION REDUCTION

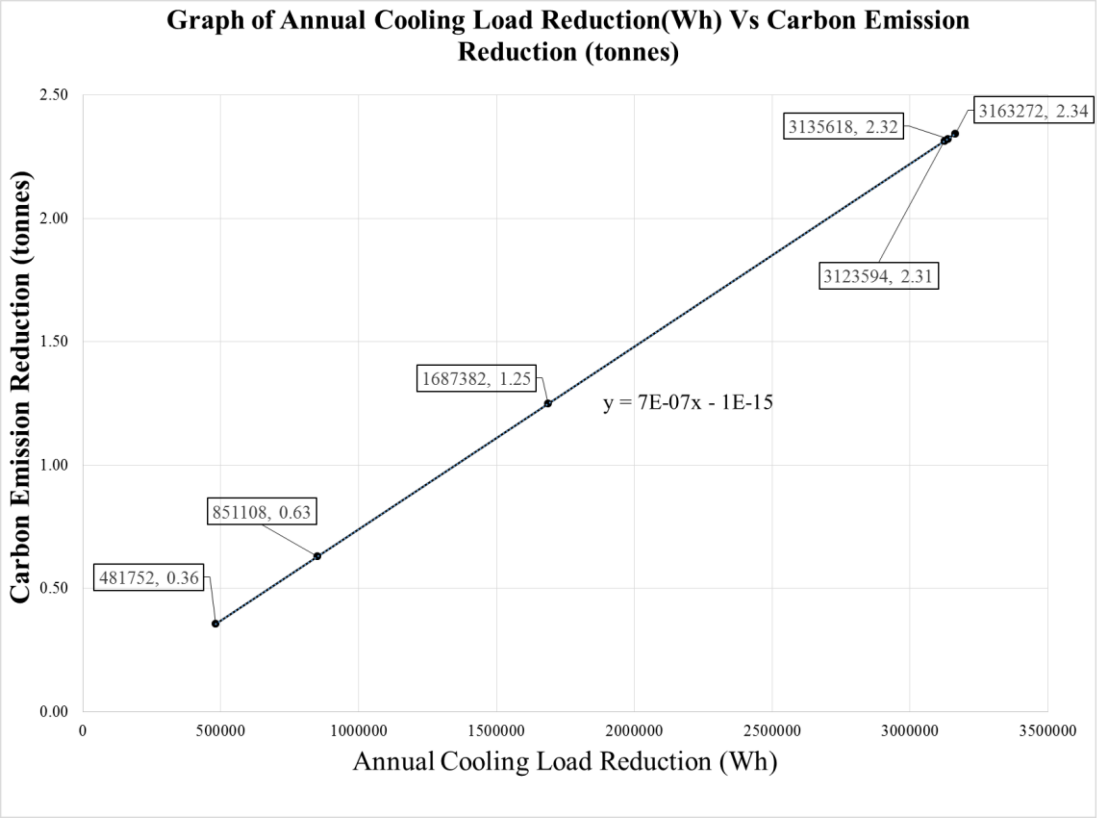


FIGURE 32 GRAPH OF ANNUAL COOLING LOAD REDUCTION VS CARBON EMISSION REDUCTION

Table 15 shows the carbon emission reduction with respect to different roof colour. White roof with the surface reflectivity has greater carbon emission reduction compared to other colour such as red and brown. This is because white roof reflect more sunlight, thus lower heat gain in the single storey residential house. Lower heat gain will require lesser cooling load energy consumption and thus saving more carbon emission as the generation of electricity in Malaysia by fossil fuel is the largest producer of carbon emission. **Figure 33** and **Figure 34** shows the effectiveness of different roof design configuration on carbon emission reduction. It can be concluded that larger surface reflectivity and presence of air gap can reduce more carbon emission.

	Roof Colour	**Surface Reflectivity (%)**	**Solar Absorption (%)**	**Carbon Emission Reduction (tonnes)**
Baseline Design	Black	4.3	96.1	-
Alternative 1.0	Red	23.9	78.5	0.357
Alternative 2.0	Brown	38.8	65.1	0.631
Alternative 3.0	White	72.5	34.7	1.250

TABLE 15 CARBON EMISSION REDUCTION WITH DIFFERENT ROOF COLOUR (WITHOUT AIR GAP)

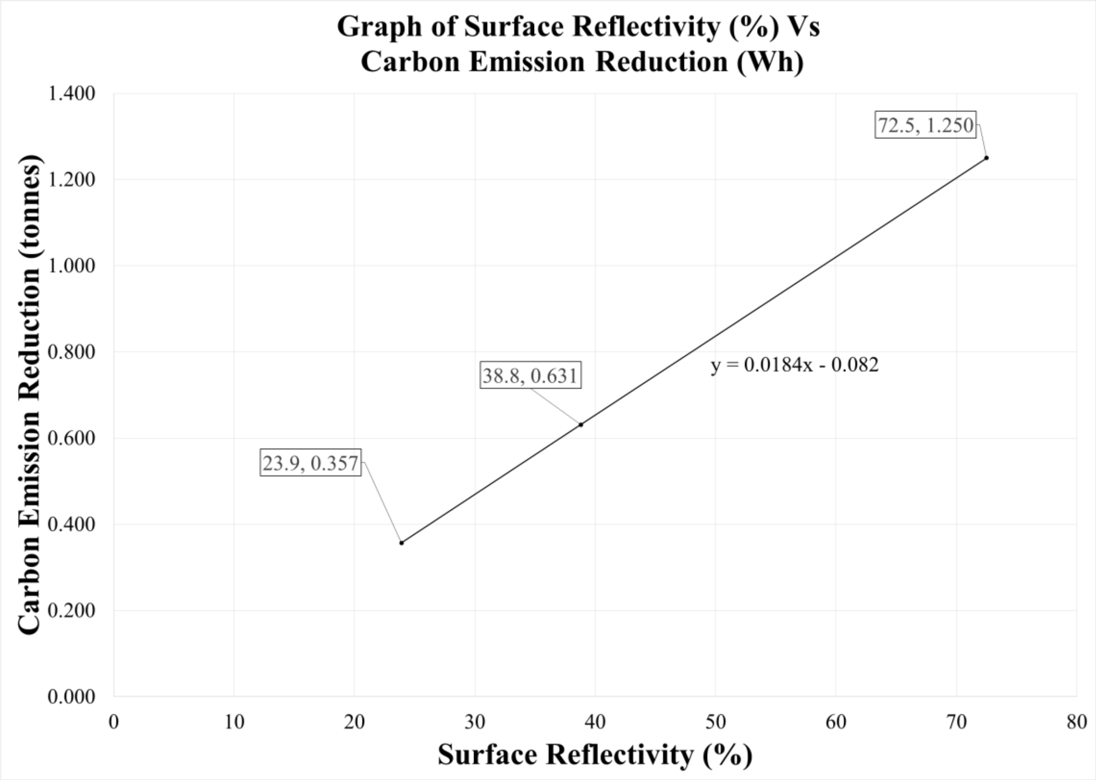


FIGURE 33 GRAPH OF SURFACE REFLECTIVITY VS CARBON EMISSION REDUCTION

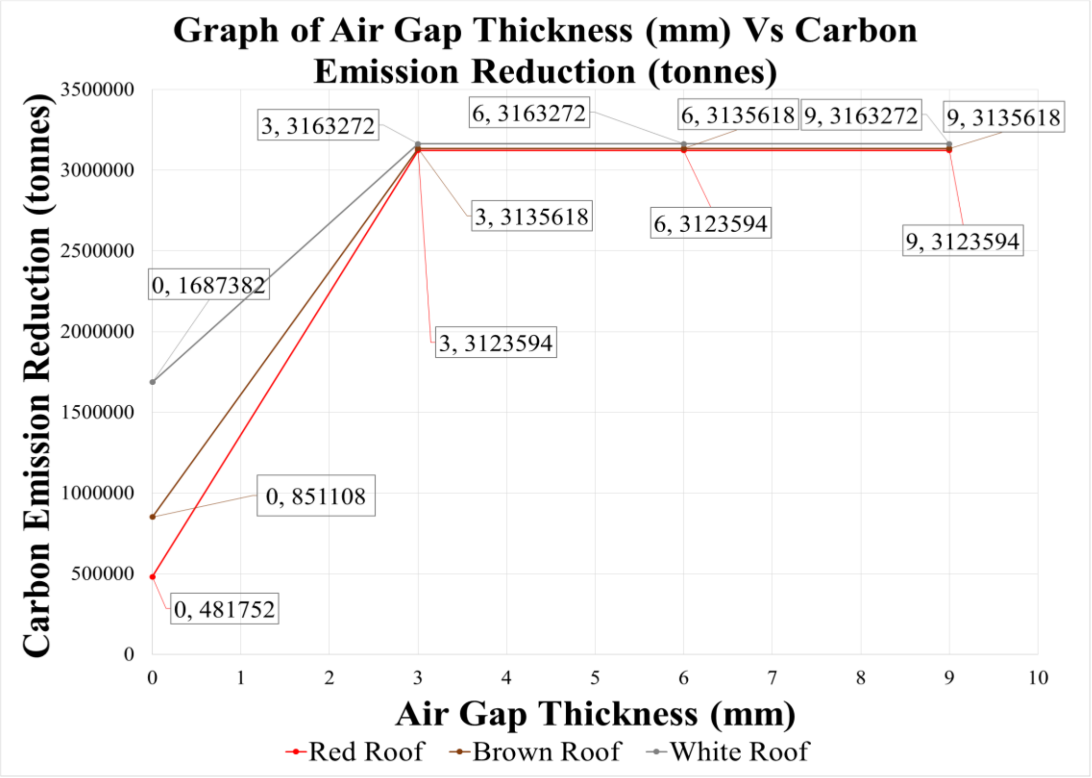


FIGURE 34 GRAPH OF AIR GAP THICKNESS VS CARBON EMISSION REDUCTION

4.3 System Dynamic Model

As mentioned in Chapter 3, **Methodology**, a case study was presented to demonstrate the proposed framework. The study concerns with the issues of different roof design configurations related to carbon emission reduction of a building information model, which is a single storey residential house. It needs to emphasize that the amount of carbon emission reduced as a result of carbon emission factor and cooling load energy saving, which depend on the characteristic of different roof design configuration.

Figure 35 shows the system dynamic model of the research, which combined three subsystem causal loop diagram explained in the **Methodology**. The model in **Figure 35** has the capability to estimate the amount of carbon emission reduction based on the variables concerned in the research such as surface reflectivity. In other term, different roof colour has different surface reflectivity.

System dynamic model in **Figure 35** represent a complex system that are interrelated and interdependent on one another. However, the limitation of the Ecotect software in determining the relationship of between the air gap thickness and annual cooling load energy consumption has resulted in the exclusion of air gap thickness as a variable in system dynamic model. Varying the thickness of the air gap did not change the parameter such as thermal resistance, U value and admittance. Therefore, a relationship with annual cooling load energy consumption is not established. System dynamic model in the research will only focus on the variable such as surface reflectivity. The mathematical formulation in the system dynamic model is shown in **Figure 36**.

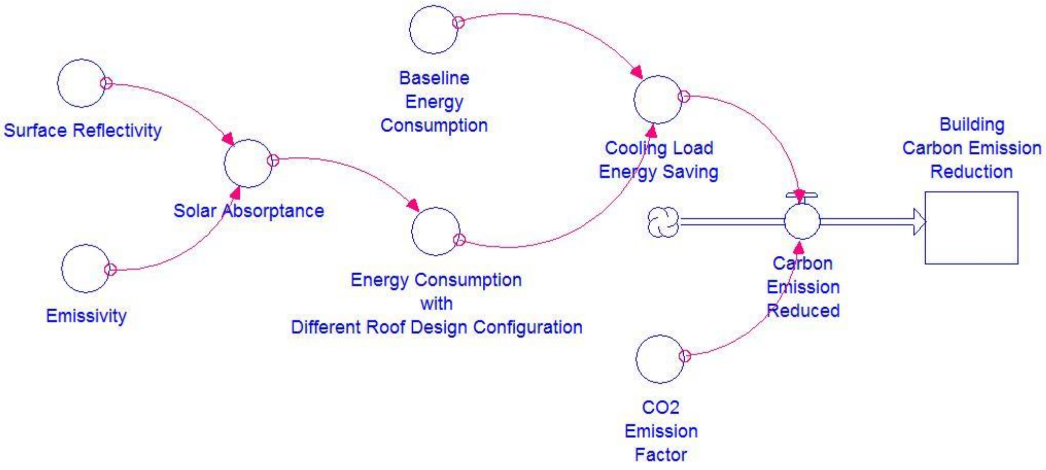
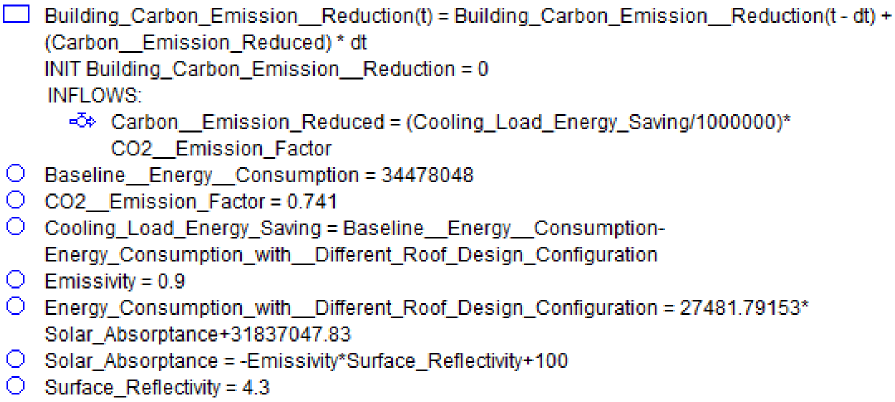


FIGURE 35 STOCK AND FLOW MODEL (SYSTEM DYNAMIC MODEL)



```
Building_Carbon_Emission__Reduction(t) = Building_Carbon_Emission__Reduction(t - dt) +
(Carbon__Emission_Reduced) * dt
INIT Building_Carbon_Emission__Reduction = 0
 INFLOWS:
    Carbon__Emission_Reduced = (Cooling_Load_Energy_Saving/1000000)*
    CO2__Emission_Factor
Baseline__Energy__Consumption = 34478048
CO2__Emission_Factor = 0.741
Cooling_Load_Energy_Saving = Baseline__Energy__Consumption-
Energy_Consumption_with__Different_Roof_Design_Configuration
Emissivity = 0.9
Energy_Consumption_with__Different_Roof_Design_Configuration = 27481.79153*
Solar_Absorptance+31837047.83
Solar_Absorptance = -Emissivity*Surface_Reflectivity+100
Surface_Reflectivity = 4.3
```

FIGURE 36 THE STOCK EQUATION OF BUILDING CARBON EMISSION REDUCTION

The system dynamic model was simulated to see how the system would behave for a time span of 50 years. The simulation result for carbon emission reduction of the single storey residential house is shown in **Figure 37** and the data is shown in **Table**

16. The variables of surface reflectivity were changed accordingly with respect to the roof colour, which were 23.9% for red roof, 38.8% for brown roof, and 72.5% for white roof. The carbon emission reduction for a single storey residential house will go to 17.93 tonnes, 31.58 tonnes, and 62.47 tonnes for red roof, brown roof and white roof respectively. White roof can reduce 97.8% more carbon emission compared to brown roof and 248% more carbon emission reduction than red roof in 50 years. The simulation results clearly indicate the direct relationship between the roof colour (surface reflectivity) and carbon emission reduction. Therefore, the result of the simulation have the implication on the architects or developer to choose lighter roof colour instead of darker roof colour as white roof can reduce the carbon emission of a single storey residential house up to 62.47 tonnes in 50 years, which reduce the most carbon emission reduction compared to other roof colour.

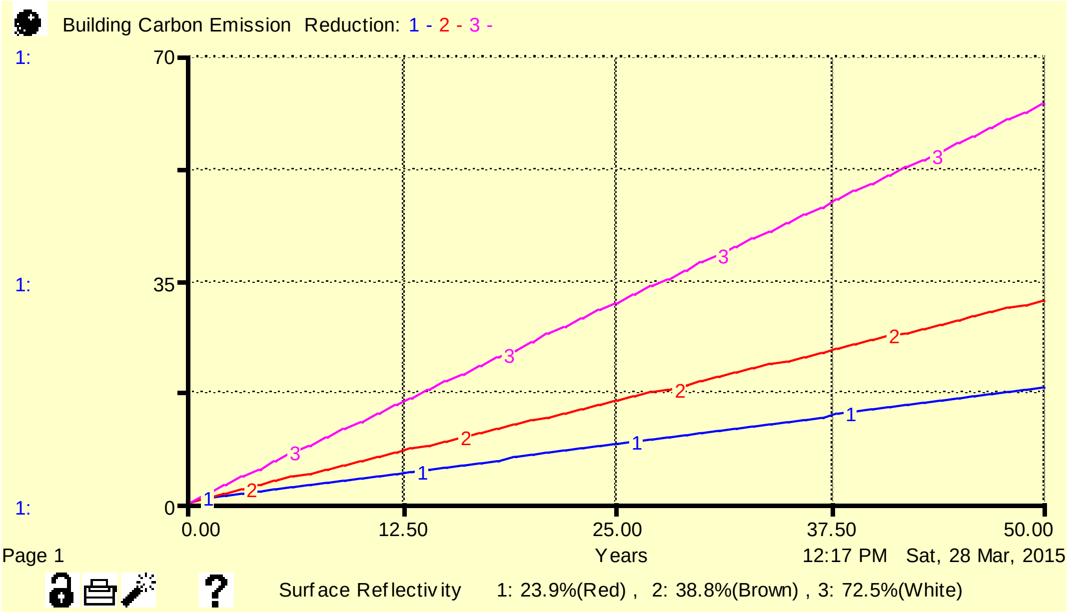


FIGURE 37 SIMULATION RESULTS FOR BUILDING CARBON EMISSION REDUCTION

Surface Reflectivity 1: 23.9%(Red) , 2: 38.8%(Brown) , 3: 72.5%(White)			
Year	1: Building Carbon Reduction	2: Building Carbon Reduction	3: Building Carbon Reduction
0	0.00	0.00	0.00
1	0.36	0.63	1.25
2	0.72	1.26	2.50
3	1.08	1.90	3.75
4	1.43	2.53	5.00
5	1.79	3.16	6.25
6	2.15	3.79	7.50
7	2.51	4.42	8.75
8	2.87	5.05	9.99
9	3.23	5.69	11.24
10	3.59	6.32	12.49
11	3.94	6.95	13.74
12	4.30	7.58	14.99
13	4.66	8.21	16.24
14	5.02	8.84	17.49
15	5.38	9.48	18.74
16	5.74	10.11	19.99
17	6.10	10.74	21.24
18	6.45	11.37	22.49
19	6.81	12.00	23.74
20	7.17	12.63	24.99
21	7.53	13.27	26.24
22	7.89	13.90	27.49
23	8.25	14.53	28.73
24	8.61	15.16	29.98
25	8.97	15.79	31.23
26	9.32	16.42	32.48
27	9.68	17.06	33.73
28	10.04	17.69	34.98
29	10.40	18.32	36.23
30	10.76	18.95	37.48
31	11.12	19.58	38.73
32	11.48	20.21	39.98
33	11.83	20.85	41.23
34	12.19	21.48	42.48
35	12.55	22.11	43.73
36	12.91	22.74	44.98
37	13.27	23.37	46.23
38	13.63	24.00	47.47
39	13.99	24.64	48.72

40	14.34	25.27	49.97
41	14.70	25.90	51.22
42	15.06	26.53	52.47
43	15.42	27.16	53.72
44	15.78	27.79	54.97
45	16.14	28.43	56.22
46	16.50	29.06	57.47
47	16.85	29.69	58.72
48	17.21	30.32	59.97
49	17.57	30.95	61.22
Final	17.93	31.58	62.47

TABLE 16 CARBON EMISSION REDUCTION OVER 50 YEARS

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The paper has reviewed the research on low carbon building with the application of Building Information Modelling (BIM) and described the use of system dynamic method (SDM) as decision making tool related to building design, operation and retrofit for the case study building. The information and results produced will be useful to architects and engineers to develop more energy efficient building in the goal of achieving sustainable development of the society by using Building Information Modelling (BIM). Previous researches of using BIM and SDM have been reviewed and the case laid out why these methods could be applicable to building design. The integration of the BIM technique into design stage can be used to select the best green building designs and reduce the extra operation cost and time caused by the design modification. Therefore, government should encourage and provide incentives for designers and engineers to use BIM and SDM in the preliminary stage to investigate the problem such as energy consumption and carbon emission. Applying these method enables the engineers and designers to make decision on which specification has the least impact to the environment.

The case study building used in the research was a simple single storey residential building and simulated with the aid of Building Information Modelling (BIM) based software, Autodesk Revit Architecture. By using Autodesk Ecotect, sustainability analysis and building energy performance analysis such as cooling load energy consumption was performed and identified with different roof design configurations such as roof color and ventilation layer. It was also found out that huge amount of energy consumption can be saved by applying lighter roof colour and air gap ventilation layer to the roof. The relationship between the energy saving and carbon emission reduction was also established.

In the research, system dynamic model was developed for the time span of 50 years by using STELLA to act as decision making tool for the architect or developer to choose the roof design configuration in order to reduce the carbon emission reduction. The result produced by the system dynamic model indicates that by applying ligher roof colour with higher surface reflectivity can reduce more carbon emission compared to lower surface reflectivity. The objectives as stated in **Chapter 1**, **Introduction**, this study aims to determine the effectiveness of different roof design configuration on carbon emission reduction by using Buildnig Information Modelling (BIM) and System Dynamic Modelling (SDM) as decision making tool. All three objectives were achieved in the research.

Based on the current state of the research, the following areas are highlighted as the research gap to be filled in the future research:

1. Investigation on the use of different BIM based sustainability software to determine their variation, accuracy, and reliability.
2. Investigation on applying the research work on the real scale experimental house and validate the computational result.
3. Investigation on the impact of adopting different roof insulation material or low carbon emission on the carbon emission reduction.
4. Investigation on the embodied carbon emission emitted by the building envelop material.

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