System Dynamics (SD) Modelling for Carbon Emission Reduction in Building through Building Information Models (BIM) of Different Roof Insulation Systems

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

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CERTIFICATION OF APPROVAL

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(CIVIL)

Approved by,

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(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.

LIAU CHZEE JIE

ABSTRACT

The demand for carbon emission reduction in building design, construction and operations sector with negligible environmental impact is expanding. Increasing energy expenses and awareness of ecological issues are the impetuses for such high concern. The advantages of ecological and human wellbeing from sustainable approaches or green technology such as green buildings have been broadly perceived.

Thus, through this study, the author has investigated the effectiveness of the application of the cool roof insulation systems in reducing the carbon-emission in building. In achieving these goals, the author has utilized the application of Building Information Models (BIM) to analyse the energy-usage and carbon-emission reduction in building. In addition, the System Dynamics (SD) Modelling is incorporated to develop the simulation model for carbon-emission reduction in building with different roof insulation systems design.

Besides, this paper also presented the application of the SD method in making decisions corresponded to different roof insulation systems designs in carbon emission reduction of building. The SD model is utilized to simulate the interaction between different roof insulation systems design towards building carbon emission reduction, thus permitting different roof insulation systems designs to be compared in term of their effectiveness in reducing building cooling loads, energy consumption and carbon emission. The idea of directly integrating a BIM model with a SD model as decision-making tool also has been discussed.

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CHAPTER 1
INTRODUCTION

1.1. Background of Study

The concern of climate change and global warming has turned into an issue of intense attention everywhere throughout the globe since the most recent years. A decade ago, the global was still occupied with argument of uncertainty on climate change occurrence, and question on the probability that it was human-incited. Presently the level headed discussion has come to an end, and it has been presumed that climate change is true as well as created by human activities.

A roof can account for up to half of the heat load for buildings in hot atmospheres (Nahar et al., 2003). One of the main reasons for energy consumption in buildings is cooling or air conditioning, where it rises the crest of electricity demand with up to 25% (Santamouris et al,. 2001). The air conditioning utilization increase is joined by increase of contamination especially in urban areas and build-up of greenhouse gases (GHG) concentrations such as carbon dioxide (CO_2) emission, while carbon footprint of the urban areas is expanded (Santamouris, 2014).

Roof constitute a significant area in the cities, surfaces of building roof records for around 20 to 25% of the overall urban areas (Synnefa & Santamouris, 2012). Likewise, Urban Heat Island is frequently recorded effect of climate change and have been experienced in numerous urban places around the world. Urban Heat Island phenomenon is the impact from rising urban temperatures contrasted with the rural areas. Every day mean Urban Heat Index (UHI) commonly goes somewhere around 2 to 5 ^oC while UHI intensities up to 12 ^oC were enrolled under specific conditions (Zinzi & Agnoli, 2012). According to Akbari et al. (1992), for urban areas with more than 100,000 people in population, the peak electricity load increase up to 1.5 to 2% per every 1 ^oF incline in temperature.

Santamouris (2014) also stated that, thermal discomfort inside the building because of heat transferred from the building's roof during hot climate additionally is an issue too. Eventually the outside thermal conditions crumble, the indoor thermal stress on low salary level residents raised, and the building thermal comfort levels are genuinely diminished with the wellbeing issues among the residents also raised.

1.2. Problem Statement

Roofs contribute massively to building high temperature increase contrasted with vertical surfaces like walls, principally in light of the fact that the roofs are exposed to the solar radiation all through the daytime. Based on the study done by (Yew et al., 2013), conventional buildings in Malaysia, particularly the low cost residential buildings are indicated to experience high level of heat transferred into the building, in which the roof takes up to about 70% of the heat transmission. Temperature ascent builds the requirement for cooling and operational energy consumption. The utilization of electricity for cooling transmits the highest greenhouse gases for the whole lifecycle of a building. Cool roof insulation systems are an inexpensive method for electricity efficiency as well as to enhance the indoor thermal comfort of buildings located at hot climates (Yew et al., 2013).

Because of the increasing attention to climate change and carbon emission coming about building regulations around the world, building designers progressively need to consider the energy performance of their building plans. As of now, performance simulation is generally executed after the design stage and in this way not incorporated into design decision-making. With the specific end goal to assess the conditions of performance specification on structure, material and specialized frameworks, building performance appraisal must be flawlessly coordinated into the design process. In this approach, the reliability of Building Information Models (BIM) to store multi-disciplinary data is used to obtain parameters essential for performance evaluations. Notwithstanding the computation of energy balances, the idea of energy is utilized to assess the quality of energy sources, bringing about a higher adaptability of measures to streamline a building design (Schlueter & Thesseling, 2009).

The catalyst of global warming is the expanding centralization of greenhouse gases (GHG) in the ozone layer, whereby carbon dioxide (CO_2) is the major consisted gas that contributing to greenhouse effects. Subsequently, in order to take care of climate change phenomenon, it is key to set limit and minimize CO_2 emissions. In spite of the fact that building design, construction and operation industry is the main sources of CO_2 emissions, currently there are no particular approaches straightforwardly addressing the carbon emission issues in building design in Malaysia (Fong, Matsumoto, & Lun, 2009). Subsequently, in taking care of climate change, it is key to minimize and control CO_2 emissions. Thus, System Dynamics (SD) model is adopted as one of the decision making method in the reduction of carbon emission of building plans and designs, with particular considerations on the future CO_2 emission patterns.

1.3. Objectives

The objectives of this project are:

i. To evaluate the thermal resistance of existing roof insulation systems and their effect on indoor temperature of residential buildings.
ii. To determine the effect of roof insulation systems on energy consumption and carbon emission of residential buildings.
iii. To develop a system dynamics model that can assist decision makers to select the roof insulation systems with minimum energy consumption and carbon emission for residential buildings.

1.4. Scope of Study

In hot climates territory, modus operandi must be made to tackle solar heating problem. In such a way that it can helps to enhance thermal comfort in buildings, and eventually reduce the requirement for air conditioning, which is the contributing factor for substantial energy consumption. At the point where air conditioning was utilized broadly, especially in an indoor context, air conditioning contributes to a large amount of greenhouse gases (GHG) production such as the carbon dioxide (CO_2) and also increase pollution that responsible for the global warming (Miranville, Boyer, Lauret, & Lucas, 2008).

The fact that cool roof insulation systems is a low cost application to improve the comfort level and to save cooling energy in building located at hot climates, such as Malaysia, in-depth understanding of the conceptual and theoretical knowledge of thermal resistance and heat transfer is required.

Besides that, in order to develop a Building Information Models (BIM) to conduct a performance analysis of building with different roof insulation systems design, the practical and technical knowledge in operating the BIM based software such as Autodesk's Revit Architecture and Autodesk's Ecotect are necessary. In this study, Autodesk's Revit building program is used in creating the building model, while Autodesk's Ecotect for sustainable design analysis software is used in performing the analysis for energy use and carbon emission of building with different roof insulation systems design.

Furthermore, System Dynamics (SD) modelling method is used as a decision-making tool that allows building carbon emission reduction to be modelled as a feedback system. In this study, it is to simulate the interactions between the different roof insulation systems design towards the building carbon emission reduction. The SD building model is developed for simulation proposes using a SD software called "STELLA".

CHAPTER 2
LITERATURE REVIEW

2.1. Cool Roof Insulation Systems

Solar energy influences the entire building, particularly the roof. In light of the fact that the surface of roof is widely exposed to solar radiation from the sunlight. In the study done by Michels, Lamberts and Güths (2008), they indicated that when the solar radiation hits the roof surface, it is absorbed by the roof tiles and causing them to heat up. This heat is partially lost through convection and some portion is absorbed by the roof surface and then transmitted to the corresponding space in the attic. This absorbed heat transmits the heat through radiation and convection within the attic. Thusly, the ceiling absorbed the heat and causing the surface to heat up, followed by transmitting the heat to the interior envelope of the building (Michels, Lamberts, & Güths, 2008). The heat transfers in a roof are illustrated in Fig. 1.

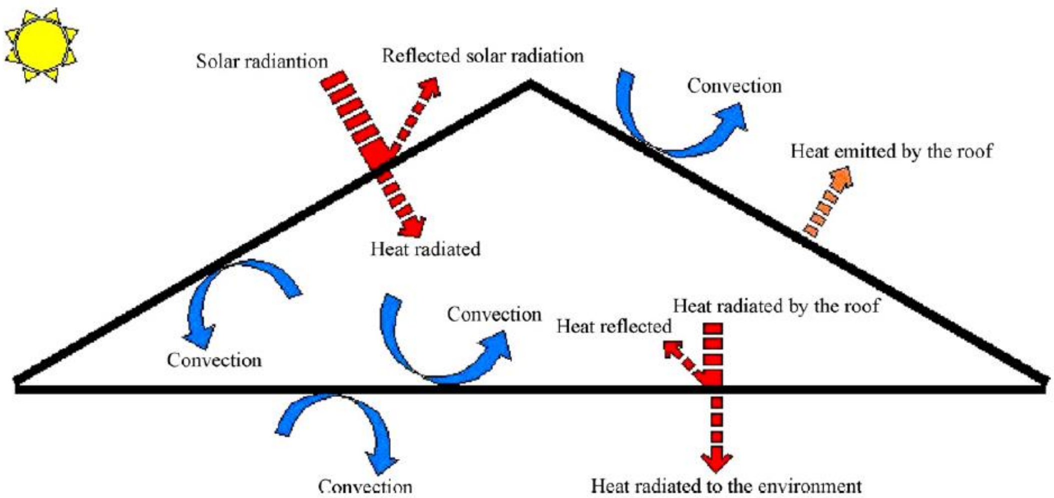


Figure 1: Heat transfer in a roof

According to Synnefa and Santamouris (2012), cool roofs is the roofs that keep cool below the sun through reducing the solar heat absorption and amplifying thermal reflection as well as reducing the transfer of heat from the roof into the building. Basically the cool surface of the roof is on top of the building envelope, where it would bring about declining of heat entering into the interior. In the urban area, this would help in reducing the temperature of the atmosphere and mitigate the UHI effect as the cooler surface brings down the heat.

In this case, to minimize the heat energy transmission from the roof, a few ways are conceivable, the regularly utilized method is insulation materials. Thermal insulation is largely utilized and features very low heat conductivity, which is $0.05Wm^{-1} K^{-1}$. Hence, heat gain because of thermal conduction is lessened. Mineral wool and expanded foam such as polystyrene and polyurethane are generally used materials for roof insulation systems.

Moreover, heat gain from the roof surface could be minimized basically by applying mass insulation as a conductive and radiant heat barrier (Ong, 2011). Based on the previous work done by Ong (2011), the author had developed a few roof insulation systems designs to justify the hypothesis. As an example, a typical tiled roof with ceiling is illustrated in Fig. 2a. While in cool roof designs, aluminium foil glued to surfaces of Rockwool or Fibreglass blanket could be attached directly underneath the roof tiles using wire mesh as illustrated in Fig. 2b. Whereas for old houses, the insulation blanket covered with aluminium foil could be installed simply on top of the ceiling board, Fig. 2c. Lastly, the metal deck roof illustrated in Fig. 2d could be improved by installing insulation on the underside of the roof tiles as proposed in Fig. 2e.

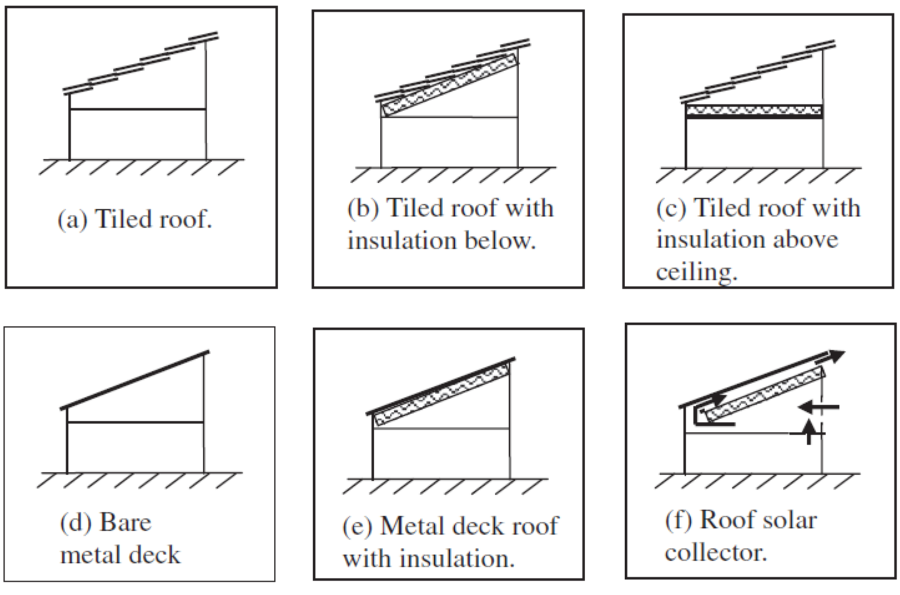


Figure 2: Solar passive roof designs

2.2. Building Information Models (BIM)

The conventional design, construction, and operation phases of buildings have been influenced by the consideration of sustainability, particularly the utilization of energy. A few methodologies and technologies have been developed to guarantee that focuses for energy savings and CO_2 emissions reduction can be attained by more sustainable design and more efficient utilization of energy. Then again, attaining the CO_2 emission target obliges better monitoring of building performance and offering exact information among the stakeholders. Among the practiced methodologies is the use of BIM to model energy usage, thermal flows, lighting patterns and other sustainability measures (Motawa & Carter, 2013).

According to Andrade and Ruschel (2001), BIM (Building Information Modelling) is an engineering advancement that enhances the procedure of building construction and its design. BIM enabling the collaboration and improvement of the techniques in design through the joint effort of multidisciplinary work in the group (stakeholders). Eastman et al. (2011) also mentioned that with a modification in the standard of the design flow, overall individuals work is included in a solitary virtual model that consists of detail data (non-geometrical and geometrical) that portrays the building model, with possible reduction of costs, time and quality revise simultaneously of the product introduced.

As indicated by Ruschel and Crespo (2007), BIM is an advanced program made by an information bank that permits modifying and creating data in the virtual environment of the building model for different assessment and with addition of rationalization and productivity gain in the design. It is the integration and utilization of a computational process to model the design and simulate the operation of an endeavour. Based on the study done by Nascimento et al. (2011), the BIM is a modelling of the building represented by a parameterized component that conceivable in controlling physical and technical data of which assistance the choices in design, maintenance and operation of the building model.

Currently, for the practices of sustainable design, the conventional computer-aided design (CAD) tools are utilized to model buildings. The design information is then entered into an energy simulation tool to analyse the building performance.

Energy simulation packages, for example EnergyPlus, Ecotect and IES Virtual Environment, consider the building design features, particularly in thermal insulation, climate response, coating, shading, solar gain, solar penetration, air tightness, natural ventilation, mechanical ventilation HVAC systems, building dynamics and thermal mass. As stated by Motawa and Carter (2013), the simulation engine of these packages runs the thermodynamic principles considering any assumptions to deliver the thermal loads and energy used in both text and graphical output.

2.3. System Dynamics (SD) Model

SD presented by Jay Forrester in the 1960s, is an entrenched system simulation methodology for understanding, visualizing and analysing complex dynamic feedback systems (Zhao et al., 2011). SD has been commonly utilized in a wide scope of applications, including in engineering and in social sciences (Thompson and Bank, 2009).

According to Monga (2001), SD is an arrangement modelling methodology focused around the fundamental of decision making, feedback systems, and computer simulation process. Decision making concentrates on how steps are to be taken by decision makers. Feedback manages with created data to generate insights into the subsequent decision making process in comparative future cases. Computer simulation furnishes decision makers by providing an apparatus to work virtually where they can see and analyse the impacts of different choices at any time, dissimilar to in a real social framework.

At present, building models represent the qualities of performance independently, for example temperature, light, energy, safety, fire, air quality and sound. As well as physical characteristics, for example mechanical frameworks, electrical frameworks, space, structure and building envelopes. The significant goal of the building performance simulation group is the combination of these discrete criteria into an individual solitary building model, and to idealize the utilization of the outputs of the models in decision-making (Augenbroe and Hensen, 2004). A SD model can give a structured framework to link these different models into a decision-making procedure, as showed in Fig. 3.

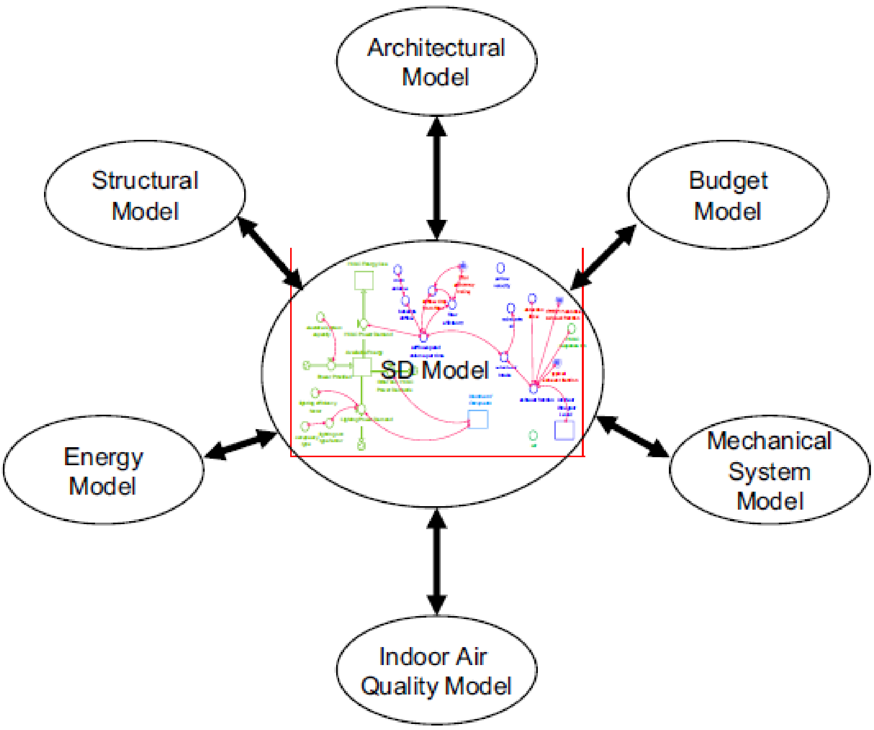


Figure 3: Using SD to link building simulation programs

In addition, the data of each system configuration and simulation models can be utilized to populate a SD model to assist the decision making in building design, operation or retrofit. What's more, a SD model can be utilized as a part of integration with different simulation models to identify favoured estimations values of parameters suitable in a design model to accomplish a general building system performance objective.

On the other hand, Homer and Hirsh (2006) also stated that SD is a modelling technique which permits a system to be populate as a feedback system. In this case, it refers to the building. The model is *''an interlocking set of differential algebraic mathematical equations created from a wide range of significant measured and experiential information''* (Homer and Hirsh, 2006). The equations are basically represented by a diagram, indicated in Fig. 4.

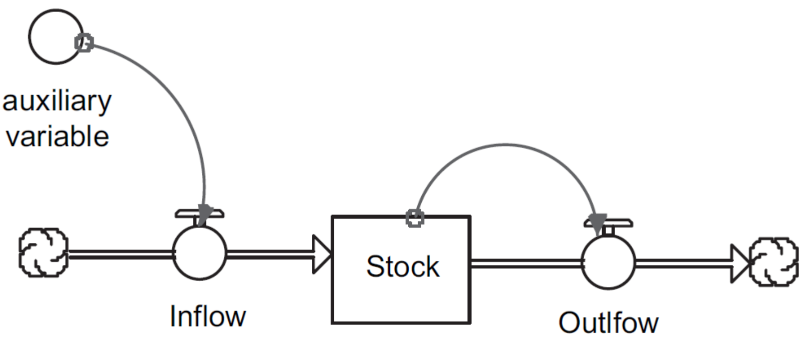


Figure 4: Schematic of a system dynamics model

However, a lot of efforts have been spent to model construction operations utilizing SD (Marzouk, Abdelhamid, & Elsheikh, 2013). In spite of the fact that these efforts model construction projects using system dynamics, there are no efforts that exist to model building carbon emission reduction through the SD approach. The table below indicate the research gap based on the studies done that are related to SD modelling.

Table 1: Research Gap

Reference	Construction Management	Building Structures	Building Carbon Emission Reduction
Lee et al. (2006)	●		
Pena-Mora and Li (2001)	●		
Taylor and Ford (2008)	●		
Thompson and Bank (2010)		●	
Marzouk et al. (2010)		●	

2.4. Integration of BIM model with SD model

In light of the study by Thompson and Bank (2010), with a specific end goal to populate the SD building model using the information require to represent the building model, an integration of building information modelling (BIM) program has been investigated. Particularly, a building is modelled using Autodesk's Revit Building program was incorporated to the SD decision-making model. The integration was fulfilled by making proper extraction of information from the Revit Building model, modifying these information as necessary to link the data needed for the SD model, and recording the data to a excel spreadsheet. Once the data were in the excel spreadsheet, they were assigned to the STELLA SD building model.

Presently, the BIM-SD link is conducted manually, but the likelihood of making an application programming interface (API) to transfer information straightforwardly from a BIM program to a SD program and also to return information from SD model over to BIM model exists (Thompson & Bank, 2010). An example of linking the data into SD model from the BIM model is illustrated graphically in Fig. 5.

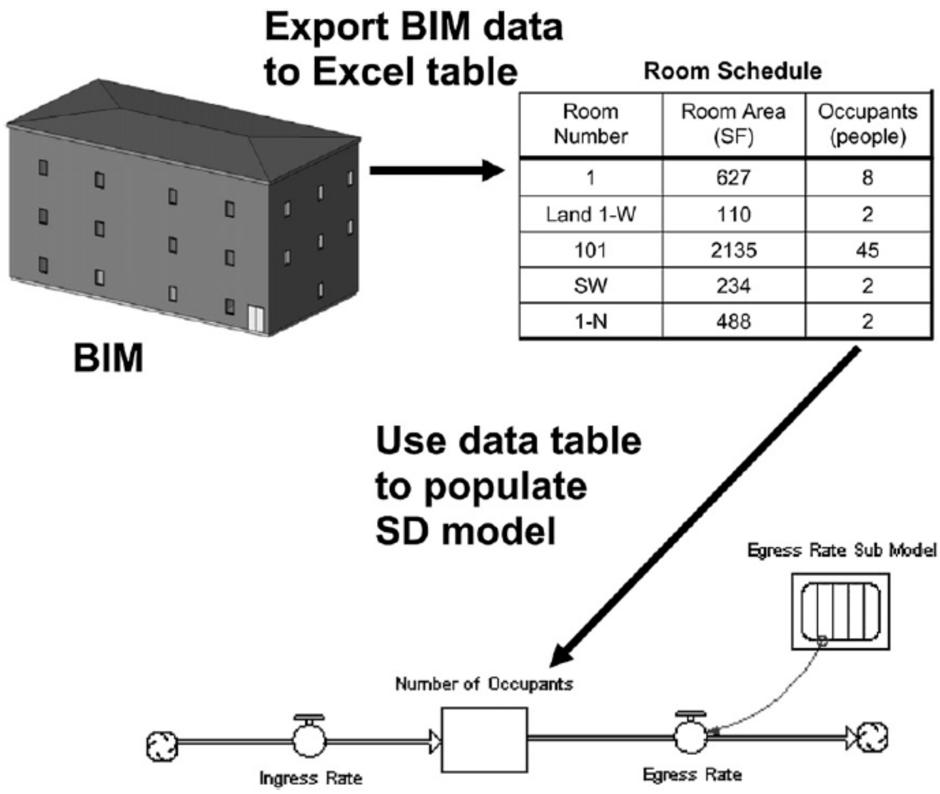
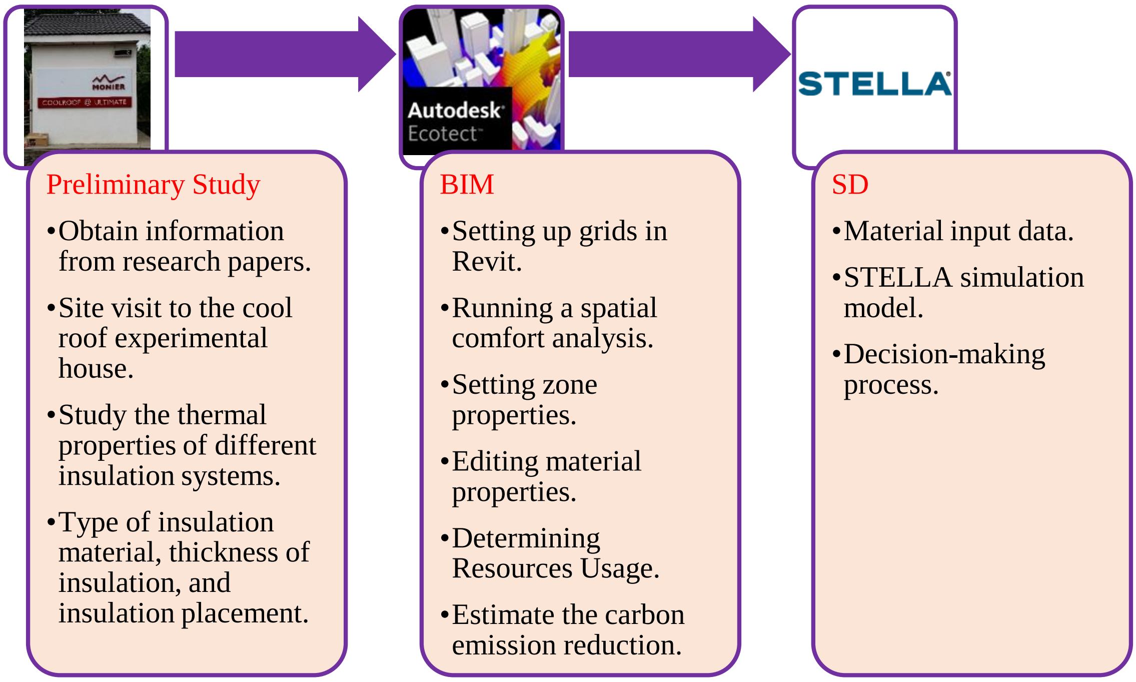


Figure 5: Linking BIM model with system dynamics building model

CHAPTER 3
METHODOLOGY

3.1. Research Methodology



As mentioned in the literature review, cool roof insulation systems assumes a critical part in improving the thermal comfort of tenants by decreasing the indoor temperature of the building. Heat gain through the roof can be lessened by using a thermal insulation layer under the roof in the attic. In this research, the study of the existing roof insulation systems is carried out and compared its thermal performance in reducing the heat load on the building. Basically, the roof insulation systems is evaluated in term of the insulation material types, thickness, and the area for installation of the insulation material.

Besides that, an understanding on the conceptual and theoretical knowledge of the thermal resistance and heat transfer of roof surface are required. The thermal resistivity of the existing roof insulation systems is tested and analysed using building information models (BIM) software, especially with a sustainability analyses based software. In addition, there is also a site visit being conducted to observe the experimental house for cool roof insulation systems.

So, in order to develop a site-interfaced BIM model to analyse the carbon emission reduction in building with different roof insulation systems design, one needs to first look for current technology help. As one of the few tools with focus on a more graphical interface and less exertion to conduct a performance analysis, Autodesk Ecotect is focused on the building design process. In this project, the model of the proprietary modelling editor "Ecotect" from Autodesk is used.

Ecotect for sustainable analysis software of building design is an extensive concept-to-detail device. Ecotect Analysis provides an extensive variety of building energy simulation functionality that can enhance performance assessment of building designs. Ecotect also integrates with programs that offer the user to simulate and visualize building overall performance within the context of its characteristic, such as online energy, water, and carbon-emission analysis capabilities (Autodesk, 2010). The few simulations and analysis that can be performed using the Autodesk, Ecotect software is as follows:

- Whole-building energy analysis, which is to calculate overall energy consumption and carbon emissions of the building by year, month, day, and hour, utilizing a worldwide information of climate database.
- Carbon Emission Analysis, which is to report carbon emissions for nearly all scopes of a designed building, including emissions from power plants as well as on-site fuel use.
- Thermal performance, which is to analyse heating and cooling loads for building design and investigate the impacts of internal gains, infiltration, occupancy, and equipment.
- Solar heating, which is to simulate occurrence of solar transmission on building opening and surfaces, visualizing differential impact of solar radiation over a period of time.

So, the step by step procedure for the BIM simulation is as follows:

1. Setting up grids in Revit Architecture, where the design of the building model is created using Autodesk's Revit building program and it is imported to Autodesk's Ecotect analysis software.
2. Running a spatial comfort analysis, where the climate data of the location is loaded, in order to check how hot or cool the room is and the comfort level of the room at the particular climate of the location.
3. Setting zone properties, which is to set the heat of the room, the comfort range, hours of operation and the type of cooling system used.
4. Editing material properties, which is to edit the material type for the roof and ceiling, as well as their thermal properties including the U-value of different materials, R-value of insulated materials, solar heat gain coefficient, etc.
5. Determining resources usage, which is to calculate the hourly temperature profile of the room and the resources consumption including all the energy loads.
6. Estimate the carbon emission reduction of the building model.

Besides, in creating the system dynamics (SD) model for carbon emission reduction in building with different roof insulation systems design. The systems thinking tool, STELLA by High Performance Systems Inc. is utilized here to develop a SD model for simulation. STELLA is the program, which executes the simulation model coded by visual programming focused on the SD for personal computer (PC). The module will comprises of three components, which include assigning material data, STELLA simulation modelling, and decision-making feedback.

The primary component of the SD module is material input data. Roof insulation systems is defined first to assign different type of material in a given system. The process followed by the first component of the SD module can be summarized as follows:

1. Roof insulation material should be defined in order to utilize them as part of mapping the simulation model;

2. Defining the roof insulation alternatives for each system, such as the different thickness and type of insulation material used;

3. Subsequently, assigning the required data that are utilized by the simulation module to perform its decision making tasks. These data include the thermal resistance of roof insulation systems, building energy consumption, as well as the carbon emission of the building to take its effect on the building carbon emission reduction;

4. Finally, the data can be changed and adjusted by the user or decision maker in any time and whenever it is necessary.

3.2. Key Milestones

- **December 2014** — Study the thermal resistance of existing roof insulation systems and their effect on cooling loads of building.
- **January 2015** — Create the building model using Building Information Modelling (BIM) software which is Autodesk's Revit Building program.
- **February 2015** — Perform the analysis for energy-use and carbon-emission of the building model with different roof insulation systems using Autodesk's Ecotect Analysis software.
- **March 2015** — Iterate the data of energy consumption and carbon-emission reduction in the building model with different roof insulation systems using Microsoft Excel.
- **April 2015** — Develop the simulation model for carbon emission reduction of building with different roof insulation systems using System Dynamics (SD) software called "STELLA".

3.3. Gantt-Chart

Activities (FYP 1)	Week													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of Project Topic	√													
Preliminary Research Work		√	√	√										
Preparation of Extended Report					√	√								
Study the thermal properties of roof insulation systems							√	√						
Proposal Defense									√					
Familiarize with the building information models (BIM) software										√	√	√		
Preparation of Interim Report													√	√

Activities (FYP 2)	Week													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Create the building model and input the required data	√	√												
Perform the analysis for building information models (BIM)			√	√										
Perform the simulation for system dynamics (SD) model					√	√								
Preparation of Progress Report							√	√						
Finalize the results and conclude the project									√	√				
Pre-SEDEX											√			
Preparation of Final Report												√	√	
Viva														√

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Theory in Thermal Properties of Insulation Materials

The R-value is a measurement of thermal resistance utilized in the building design process. Under uniform conditions, it is the factored value of the temperature difference over an insulator and the heat flux. Thermal resistance changes with temperature, yet it is basic practice in building design to regard it as a consistent factored value. The R-value is a unit thermal resistance of a specific material or combination of materials, like an insulation panel. The R-value represents the material's resistance towards conductive heat transfer. R is equals to the thickness of the material divided by thermal conductivity. The unit thermal conductivity of a material is the corresponding of the unit thermal resistance. This can likewise be known as the unit surface conductance. The higher the value, the better the building insulation effect theoretically.

$$R = \Delta T / \dot{Q}_A$$

R-value is the corresponding of U-factor.

The U-factor or U-value, is the general heat transfer coefficient that represents how well a building component conducts heat or the rate of transfer of heat (in watts) through one square metre of a structure partitioned by the distinction in temperature over the structure. The components are typically combining of numerous layers of materials, for instance those that make up roofs/walls/floors and et cetera. It quantifies the rate of heat transfer through a building component over a given area under a constant or fixed conditions. The general standard is at a temperature increment of 24 °C (75 °F), with humidity of 50% and no wind, in which a smaller U-factor is better at minimizing heat transfer. It is measured in watts per meter squared kelvin (W/m^2K). This infers that the higher the U value the lower the thermal performance of the building components. A lower U value usually shows high intensity of insulation. They are suitable as it is a technique for predicting the composite behaviour of an entire building component as opposed to relying upon the properties of single materials. The thermal conductivity (K-value) is the capacity of a material to conduct heat, so the lower the K-value, the better the material is for insulation.

U is the inverse of R with SI units of $W/(m^2K)$ and US units of BTU/(h °F ft^2);

$$U = \frac{1}{R} = \frac{\dot{Q}_A}{\Delta T} = \frac{k}{L}$$

where k is the material's thermal conductivity and L is its thickness.

Thermal conductivity expect that the heat transfer of the material is specifically identified with its thickness. Increasing the thickness of an insulating layer increases the thermal resistance. For example, doubling the thickness of fiberglass insulation will doubled its R-value, such as from 2.0 m^2K/W for 110 mm of thickness, to 4.0 m^2K/W for 220 mm of thickness. Heat transfer through an insulating layer is like adding resistance to an arrangement of circuit in series with a fixed voltage. In calculating the R-value of a multi-layered insulation, the R-values of the individual layers are summed up:

$$\text{R-value}_{(\text{outside air film})} + \text{R-value}_{(\text{brick})} + \text{R-value}_{(\text{sheathing})} + \text{R-value}_{(\text{insulation})} + \text{R-value}_{(\text{plasterboard})} + \text{R-value}_{(\text{inside air film})} = \text{R-value}_{(\text{total})}.$$

Table 2: Material properties of existing insulation materials

Insulation material	Thermal Conductivity (W/mK)	Mass Density (kg/m^3)
Organic/ Natural		
Cork	0.045-0.055	80-500
Wool	0.04	20-25
Cotton	0.04	20
Synthetic		
Polystyrene, EPS	0.035-0.04	15-30
Polystyrene, XPS	0.035-0.04	25-40
Polyurethane rigid foam	0.025-0.035	30
Inorganic		
Foam glass	0.04-0.0055	10-160
Mineral Fibre	0.035-0.05	15-80
Air, motionless	0.0025	1.2
Evacuated panel	0.006	

4.2. BIM simulation

In BIM simulation, since conventional bungalow houses are popular in Malaysia due to its tropical weather, a double story semi-detach house was modelled by using Autodesk Revit Architecture. The house's annual operational energy consumption was also calculated through Ecotect Analysis. However, only cooling load was considered in the calculation of the building annual operational energy consumption, since Malaysia is a tropical climate country.

As mentioned, a double story semi-detach house was chosen as the case study. It consisted of 682.461 m^2 of a functional area, including 4 bedrooms, 3 bathrooms, 1 kitchens and 1 living area for each house. The construction material was in-situ, reinforced concrete, and the exterior walls were plastered double brick walls. The windows were double-glazed glass with aluminum frames. The ceilings were suspended plaster tile. The floors were concrete slab and tiles. The doors were solid core timber. The roofs were clay tiled roof. These materials are considered as the study's baseline design. Fig. 6 and 7 shows the building's floor plans.

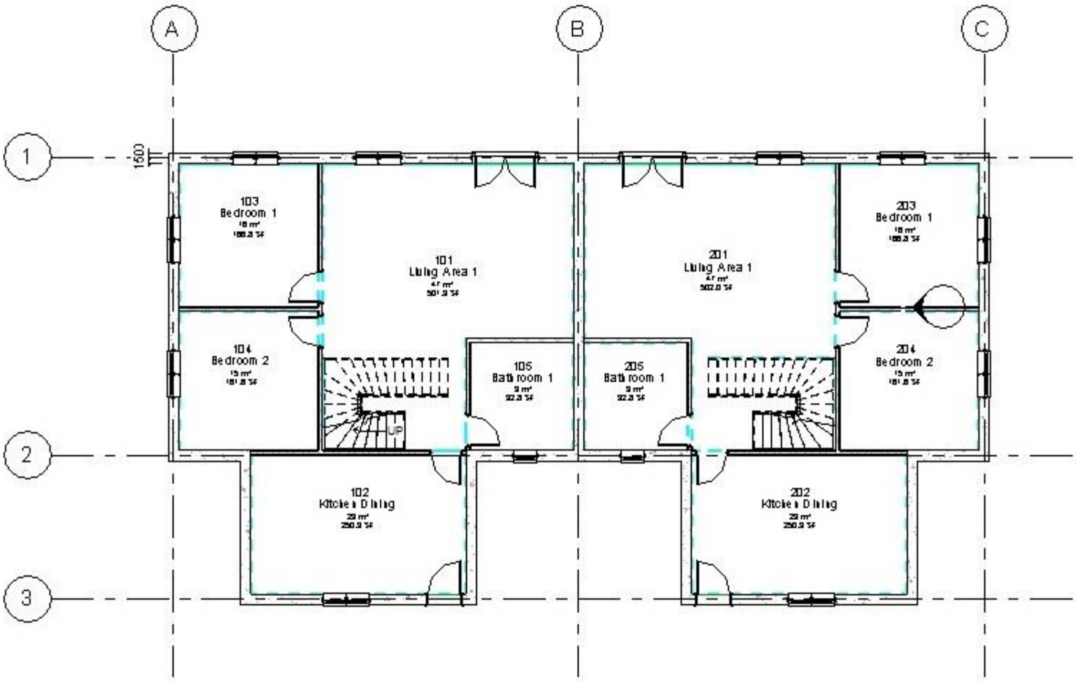


Figure 6: Ground floor plan of the house

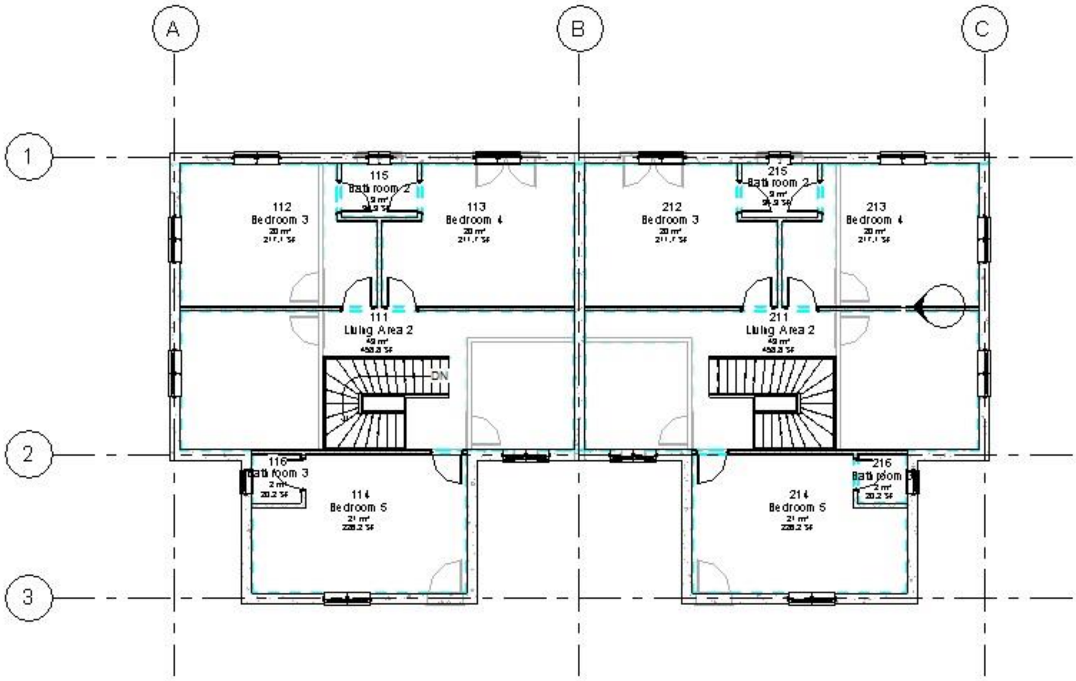


Figure 7: First floor plan of the house

All specifications of building components were simulated in Revit architecture software. As one of BIM tools, Revit architecture software can develop higher-quality, more-exact architectural designs .Fig. 8 shows the perspective and 3D views of the case-study building in two different elevations simulated in Autodesk Revit architecture.

Figure 8: 3D views of simulated building in two different elevations

After modeling, the results from Revit must be exported to Autodesk Ecotect analysis software, one of the largest energy simulation tools under the Autodesk umbrella, for energy modeling (Shoubi, Shoubi, Bagchi, & Barough).

. There are two types of imports to Ecotect, i.e., DXF and gbXML-based export from Revit architecture software. DXF is used primarily for geometry-based analysis, such as over shadowing, ventilation modeling, daylight analysis, and external solar availability. The gbXML is based more upon 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 Revit architecture to Ecotect analysis.

Before implementing the export process, rooms known as zones must be produced to separate operational spaces of the building required for energy simulation in Ecotect. The other application of the room element is to specify the area and volume of the spaces. In addition to room setting within BIM before exporting the energy model, the location and types of the building must also be defined, since they are significant factors in energy use and can affect the amount of energy consumed. Fig. 9 shows the perspective of an export gbXML file.

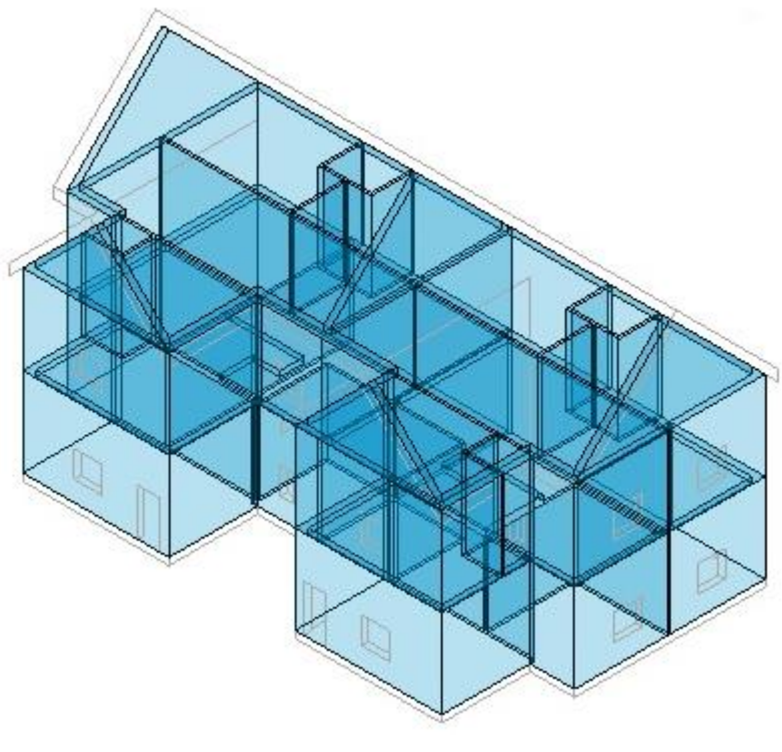


Figure 9: Perspective of export gbXML

4.2.1. Energy modelling

After entering to Ecotect, it could be seen that it has the ability to identify those elements simulated in Revit. It shows that these software products can be integrated to facilitate simulation and analysis. Before starting the analysis, we can evaluate the building's shadow on various days of the year and also various times of a specified day. First, weather specification of the building must be loaded based on its location, since different locations have different sun paths and conclusively dissimilar shadow positions. After considering the weather location of Malaysia, the daily and annual sun path can be visualized. This just allows the visual interpretation of exactly where the sun is and its impacts on the various parts of the building during different times of the day. It can also be helpful in visualizing the building's shadow throughout an entire day. Figs. 10 and 11 illustrate the spherical projection of the sun's position and the sun's daily and annual path on the building.

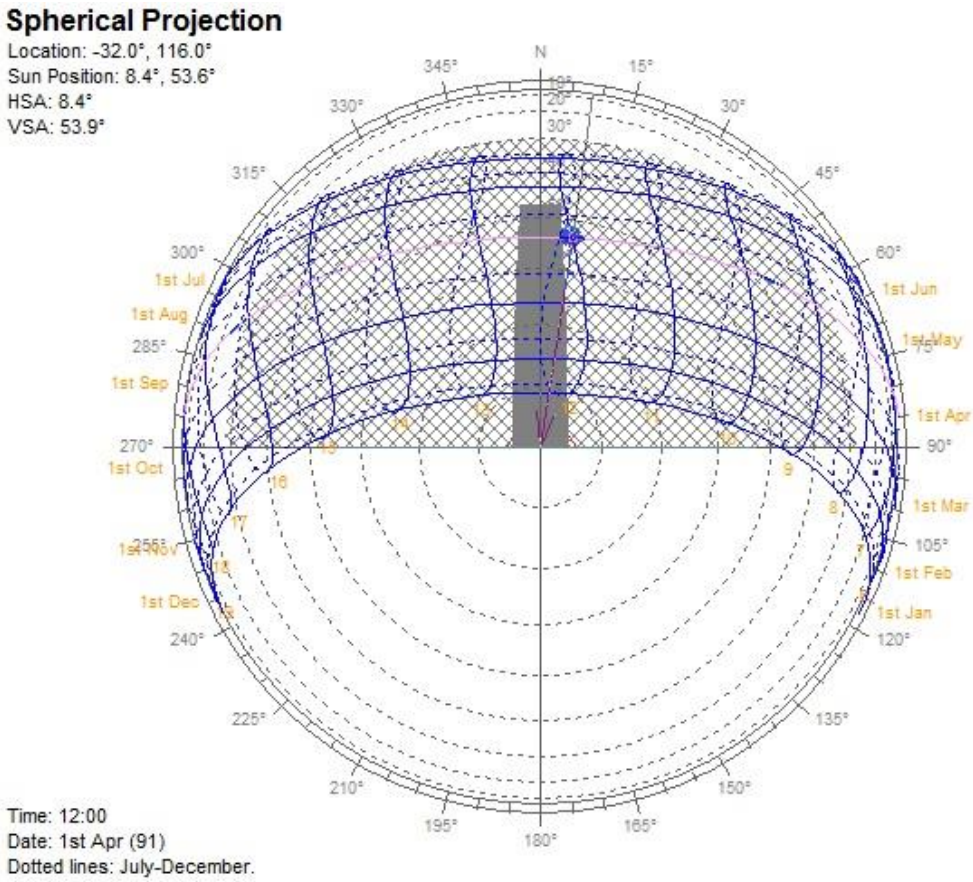


Figure 10: Spherical projection of sun's position

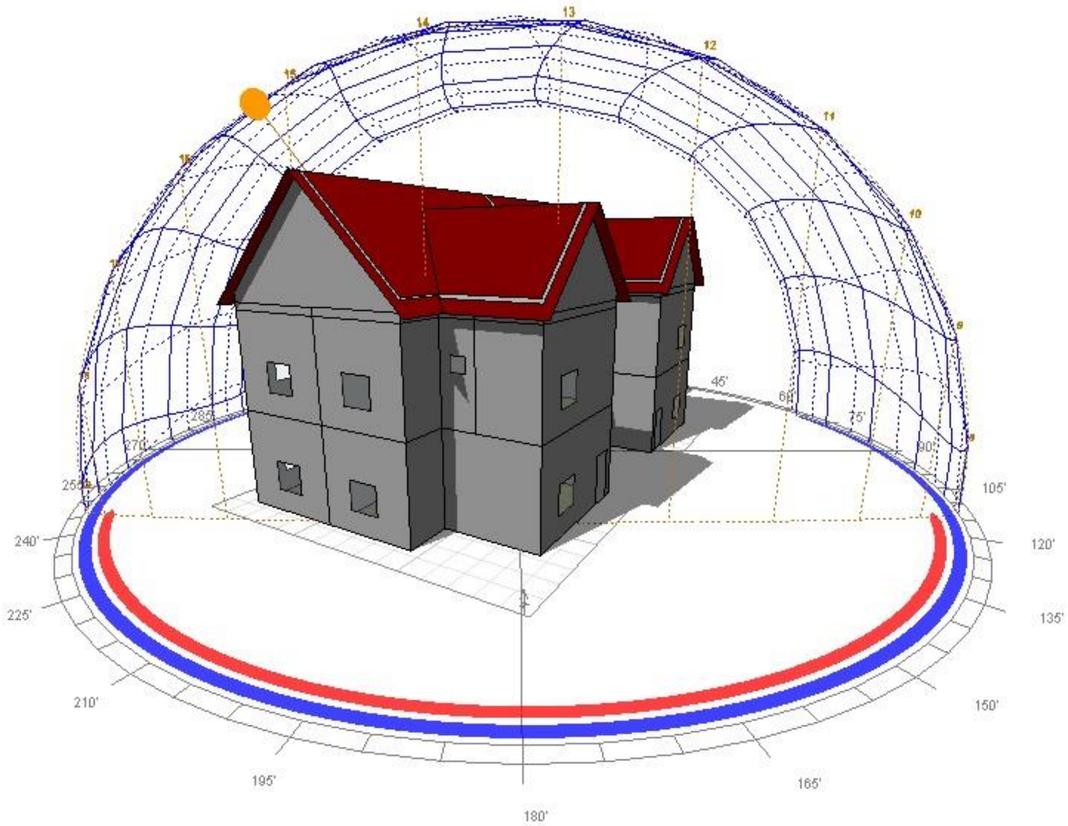


Figure 11: Daily and annual visualization of the sun's path

4.2.2. Analysis of solar energy absorption

Ecotect software can calculate how much solar energy will be absorbed by the surfaces of the building. After the calculations, the shape of the building is turned into a range of colors from yellow to blue, indicating the greatest and least solar energy absorption by the surfaces of the building. Figs. 12 show the degree of solar energy absorption by surfaces of the building in specified orientation and position. As can be seen in Fig. 12, the roof surface of the building is exposed to the greatest solar energy absorption, thus indicating that the roof contributed a large portion to the building total heat load. In which, it eventually promting the heat transfer into the building and builds the demand for cooling and energy consumption.

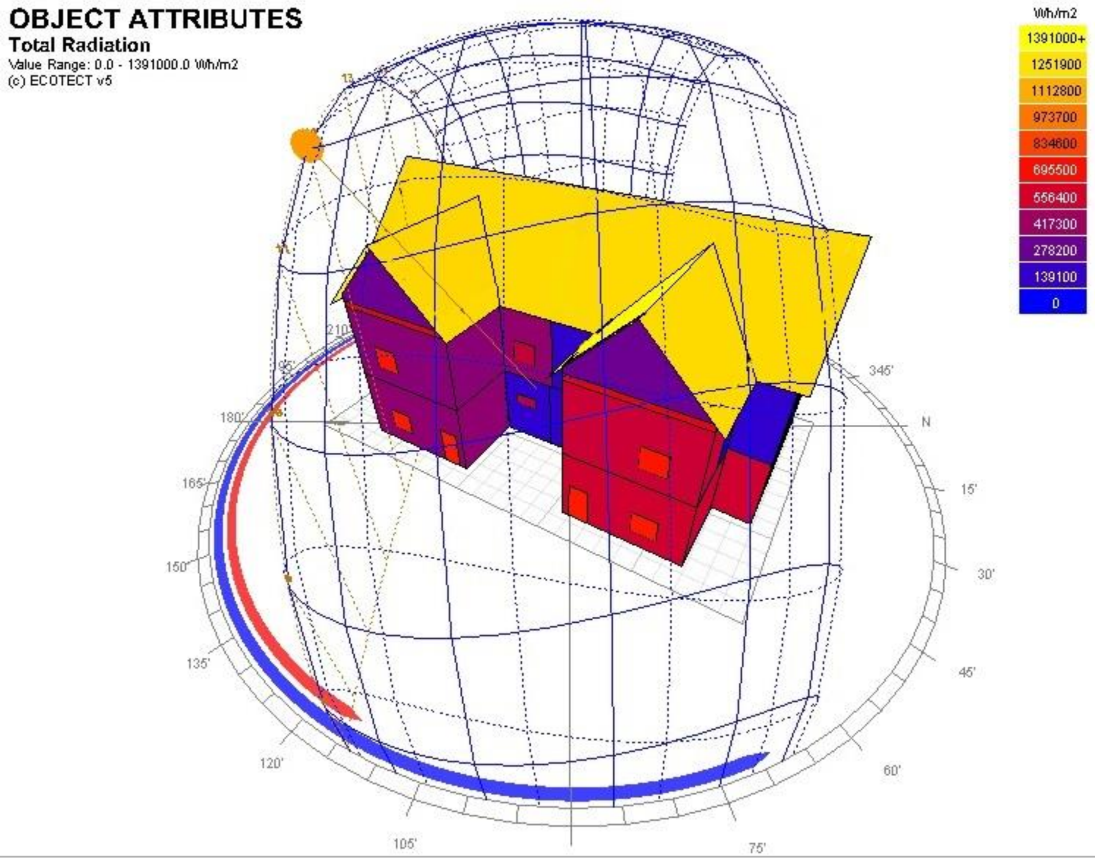


Figure 12: Solar energy absorption by surfaces of the building orientation

Besides, choosing the orientation is one of the effective issues that should be considered for enhancing solar energy absorption, and it is usually chosen during the preliminary design stage. The best choice of orientation in terms of solar energy absorption can lead to optimum solar energy absorption for the building. The best and worst orientation for the absorption of solar energy can be calculated through the Ecotect analysis software. Figs. 13 show the best and worst orientations of the buildings for solar energy absorption are shown in yellow and red lines, respectively. As shown in Fig. 13, the best and worst orientations were 150^{o} and 60^{o} from the north respectively. This means that, if the building were rotated 150^{o} from the north, it would absorb the most solar energy which could be so efficient when it is needed in providing a proportion of building's necessary energy.

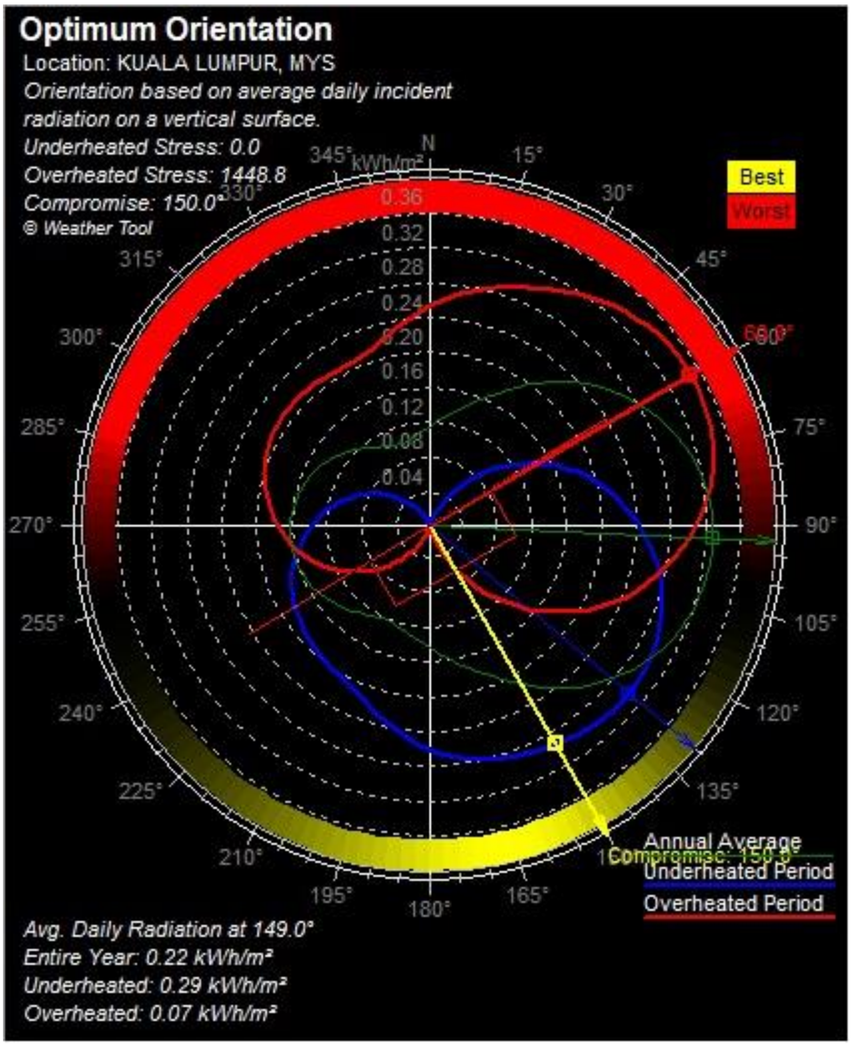


Figure 13: Calculation of the best and worst orientation

4.2.3. Analysis of annual operational energy consumption

In conducting the analysis, a few assumptions related to the building zones were made. The building was divided into 23 zones, including 8 single bedrooms, 2 master bedroom, 2 kitchens, 6 bathrooms, 2 dining rooms, 2 family rooms and 1 attic. It also was assumed that four people were going to live in the building. The HVAC system of the building was a singleroom cooling system. For each zone, including bedrooms, master bedroom, living room, family room, and kitchen, separate air conditioning systems were to be installed. After considering all assumptions and conducting the analysis of energy consumption, a calculation was done to determine the amount of cooling energy required to keep the temperature of the building between 22 and 26 ºC.

The energy consumption was determined based on the baseline design, including current material specifications of the building.

4.2.4. Baseline design cooling energy consumption

As mentioned, the baseline design of the case-study house involves double brick plaster for the wall, double-glazed aluminum frames for the windows, clay tiled for the roof, concrete ceramic tile for the floor, and solid core timber for the door. Fig. 14 shows the heating and cooling load required for each month of the year. By considering all months, it is seen that the energy used throughout the year to keep the building's temperature between 22 and 26 ^{o}C based on these materials was 41011 kWh. As shown in Fig. 14, there is just a cooling load for all months of a year due to the location of the building in Malaysia, which is a very hot and humid area. In Fig. 14, the blue color bar represent the cooling loads for each month of the year, respectively. It obviously shows that there is just a cooling load for this building. In fact, all months are warm in Malaysia. As can be seen, the highest amount of cooling energy consumption occurs from March to June, which is about 3600 to 3800 kWh. On the other hand, energy consumption in November and December is the lowest, at about 2900 and 3100 kWh, respectively.

Table 3 also shows the exact values of the building cooling load required for each month of the year that was generated in the Ecotect analysis. In fact, all of these analyses are based on the recent weather data of Kuala Lumpur, Malaysia. In which, the weather data file was basically obtained from the U.S Deparment of Energy website (energy.gov). They provide the weather data for more than 2100 locations in World Meteorological Organization region and Country. The weather data file is in EnergyPlus weather format that can be loaded in Ecotect Analysis software.

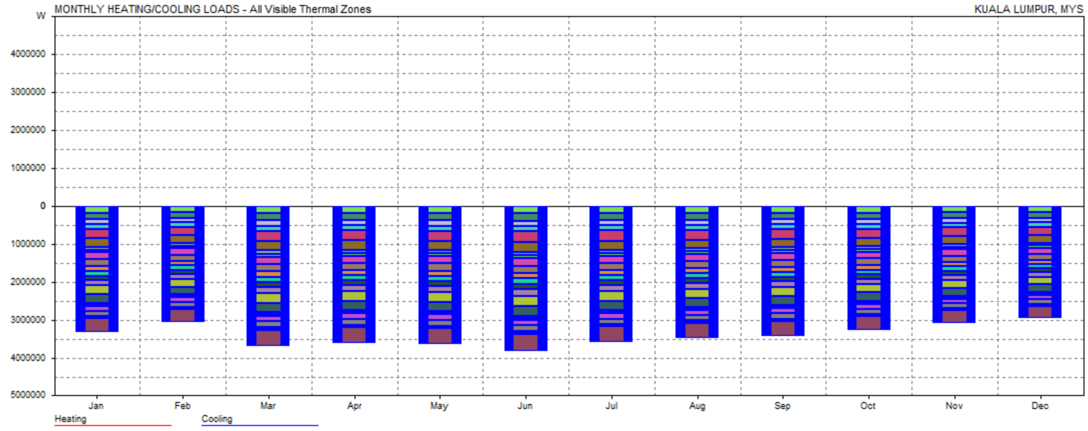


Figure 14: Monthly cooling loads energy consumption

Table 3: Monthly Heating/Cooling Loads

Max Heating: 0.0 C - No Heating.			
Max Cooling: 19328 W at 10:00 on 22nd April			
Month	**Heating (Wh)**	**Cooling (Wh)**	**Total (Wh)**
Jan	0	3337530	3337530
Feb	0	3068362	3068362
Mar	0	3700668	3700668
Apr	0	3623400	3623400
May	0	3650666	3650666
Jun	0	3825814	3825814
Jul	0	3592685	3592685
Aug	0	3478636	3478636
Sep	0	3426638	3426638
Oct	0	3261820	3261820
Nov	0	3096720	3096720
Dec	0	2948804	2948804
Total	0	41011744	41011744
Per m^2	0	60094	60094
Floor Area	682.461 m^2		

Conduction is a factor that may have a large impact on the loading values for the building. A breakdown of the passive gains was acquired from Ecotect as a visual sign of the contribution of each part of the building in load losses and gains. Fig. 15 shows the impact percentages of various factors on load losses and gains. It was calculated that, based on the baseline building design, 16.9% of the load gains is from conduction or fabric gains. It is clearly evident that conduction has a large impact on load gains.

Table 4 also shows the percentages of gains breakdown for six different types of heat load factors. It might be possible to reduce this to some extent by applying the roof insulation systems. Where as the baseline design will also be taken as the constant variables in investigating the cooling and energy consumption of the building with alternative roof insulation systems designs.

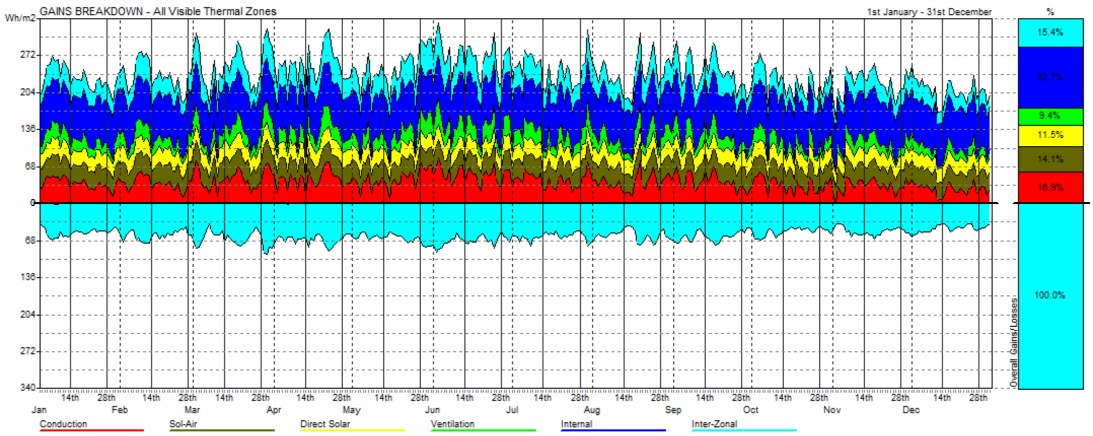


Figure 15: Breakdown of passive gains of the building based on the baseline design

Table 4: Gains Breakdown

Category	Losses	Gains
Fabric	0.00%	16.90%
Sol-air	0.00%	14.10%
Solar	0.00%	11.50%
Ventilation	0.00%	9.40%
Internal	0.00%	32.70%
Inter-zonal	100.00%	15.40%

4.2.5. Application of the cool roof insulation systems

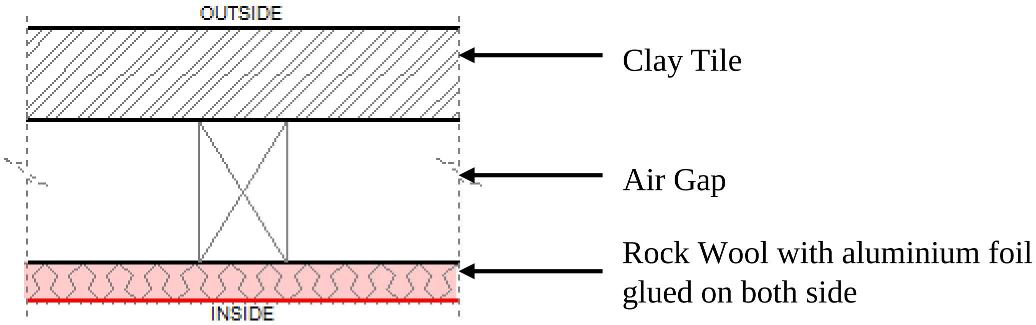
Then, alternative cool roof insulation systems designs were used to replace the baseline design of the roof to investigate their impacts on reducing and/or increasing energy consumption. Finally, a set of higher-performance materials was recommended for the purpose of reducing the energy consumption of the building, which will lead to decreases in the embodied energy and in carbon dioxide emissions as well as improving the building thermal performance.

In this study, 3 types of existing insulation materials or the generally known examples of roof insulation materials was chosen to conduct the investigation, which includes Rock Wool, Expended Polystyrene (EPS), and Glass Foam. Table 5 shows the material and thermal properties of the respective insulation materials used. Table 5 also indicates that Glass Foam has the highest thermal conductivity among the 3 types of material chosen with 0.052 W/mK, followed by Expended Polystyrene and Rock Wool with 0.035 W/mK and 0.034 W/mK respectively. The thermal conductivity (K-value) is the capacity of a material to conduct heat, so the lower the K-value, the better the material is for insulation.

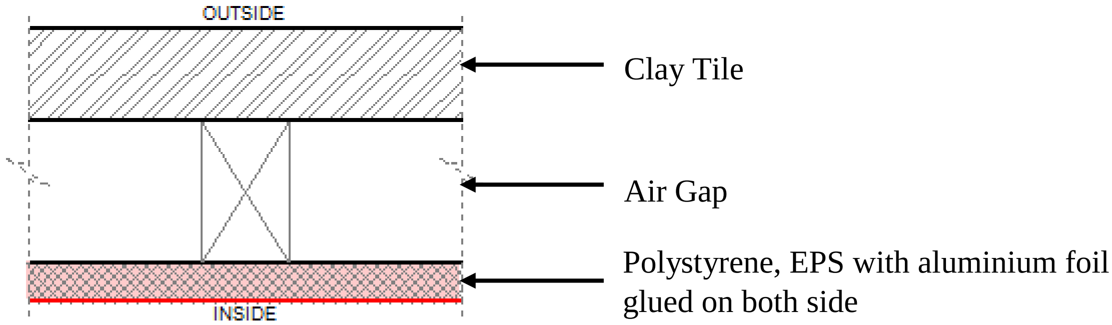
Table 5: Material properties of insulation material used

Material Name	Density (kg/m^3)	Specific Heat (J/kgK)	Conductivity (W/mK)
Rock Wool	200.0	710.0	0.034
Polystyrene, EPS	23.0	1470.0	0.035
Glass Foam	140.0	840.0	0.052

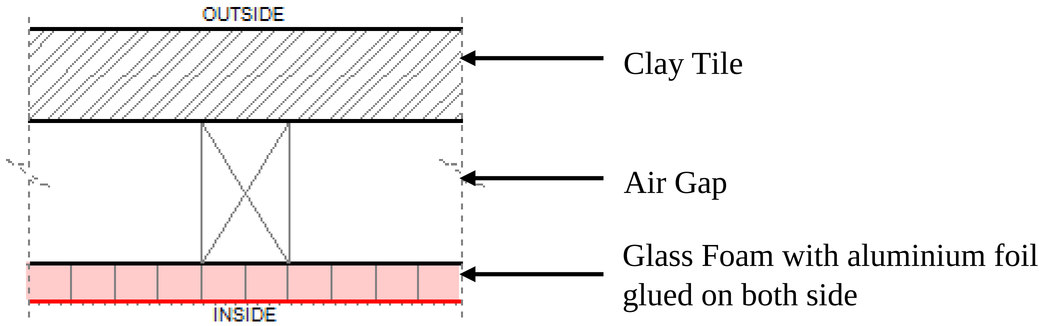
The insulation component is basically made up of a low conductivity mass insulation material with alluminium foil glued on both side of the material of a certain thickness to form a blanket. The insulation blanket is to be installed underneath the roof tile area and over the ceiling board area, thus making the entire roof structure and the attic to act as a cool roof insulation systems. Fig. 16 shows the sections of different roof and ceiling insulation systems designs with different insulation material used. While Table 6 shows the material and thermal properties of different insulation systems designs by its layer.



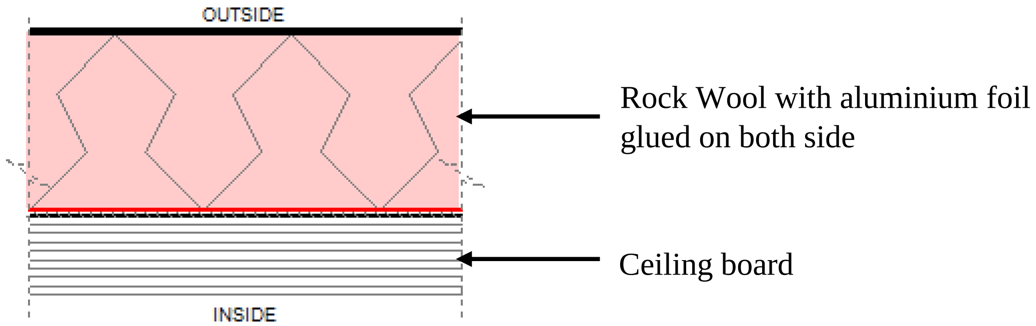
(a) Rock Wool insulated roof



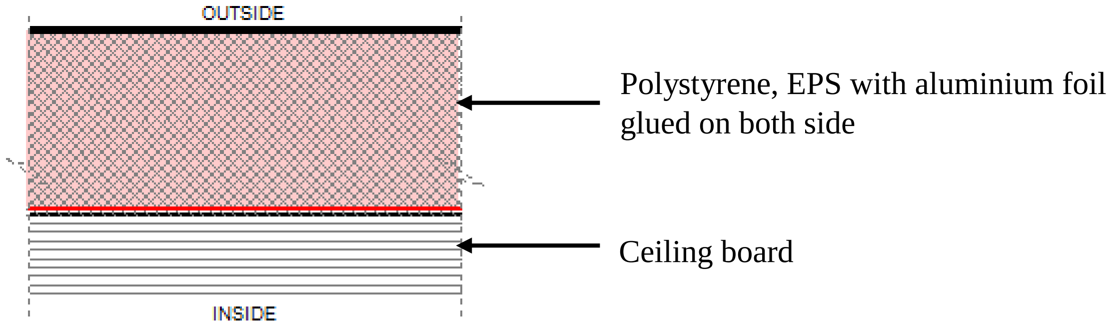
(b) Polystyrene, EPS insulated roof



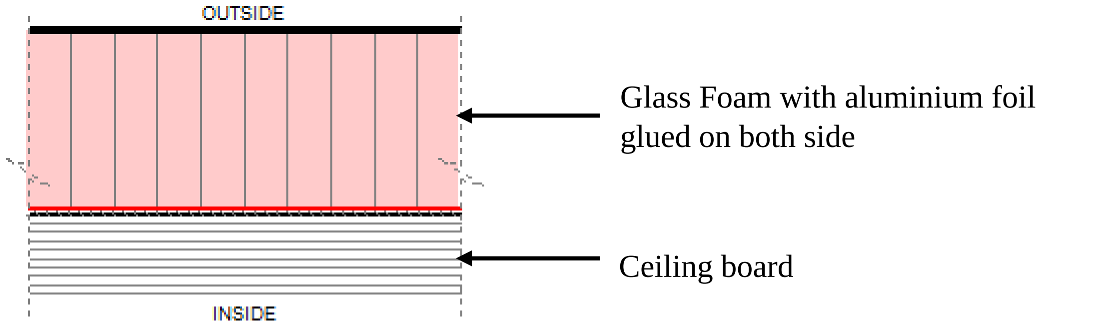
(c) Glass Foam insulated roof



(d) Rock Wool insulated ceiling



(e) Polystyrene, EPS insulated ceiling



(f) Glass Foam insulated ceiling

Figure 16: Cross-sections of roof and ceiling insulation designs

Table 6: Material properties of roof and ceiling insulation layer

Type	Layer Name	Thickness (mm)	Density (kg/m^3)	Specific Heat (J/kgK)	Conductivity (W/mK)
Roof insulation					
(a)	Clay Tiles	50.0	2760.0	836.8	18.828
	Air Gap	75.0	1.3	1004.0	5.560
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Rock Wool	**5.0-20.0**	**200.0**	**710.0**	**0.034**
	Aluminium Foil	0.6	2698.0	920.5	225.940
(b)	Clay Tiles	50.0	2760.0	836.8	18.828
	Air Gap	75.0	1.3	1004.0	5.560
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Polystyrene, EPS	**5.0-20.0**	**23.0**	**1470.0**	**0.035**
	Aluminium Foil	0.6	2698.0	920.5	225.940
(c)	Clay Tiles	50.0	2760.0	836.8	18.828
	Air Gap	75.0	1.3	1004.0	5.560
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Glass Foam	**5.0-20.0**	**140.0**	**840.0**	**0.052**
	Aluminium Foil	0.6	2698.0	920.5	225.940
Ceiling insulation					
(d)	Aluminium Foil	0.6	2698.0	920.5	225.940
	Rock Wool	**5.0-20.0**	**200.0**	**710.0**	**0.034**
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Plaster board	10.0	1250.0	1088.0	0.431
(e)	Aluminium Foil	0.6	2698.0	920.5	225.940
	Polystyrene, EPS	**5.0-20.0**	**23.0**	**1470.0**	**0.035**
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Plaster board	10.0	1250.0	1088.0	0.431
(f)	Aluminium Foil	0.6	2698.0	920.5	225.940
	Glass Foam	**5.0-20.0**	**140.0**	**840.0**	**0.052**
	Aluminium Foil	0.6	2698.0	920.5	225.940
	Plaster board	10.0	1250.0	1088.0	0.431

Besides, Table 7 basically shows the U-value of the different roof insulation systems configuration with different insulation material used and varying thickness. The insulation materials used is Rock Wool, Expended Polystyrene (EPS), and Glass Foam. While the thickness of the insulation materials applied is of 5mm, 10mm and 20mm. The U-value is basically obtained from the Ecotect software where it is used to calculate the thermal properties of the roof and ceiling layers with different insulation materials applied as well as for different thickness of insulation materials used. The U-factor or U-value is the general heat transfer coefficient of a building component, In this case, the building component refers to the roof and ceiling. This implies that the lower the U-value. the higher the amounts of insulation.

Based on the data, it also indicates that the incresed in the insulation materials thickness will lower the U-value of the insulation layer, thus incresing the thermal resistance of the overall insulation systems designs. Fig. 17 and Fig. 18 is the graphs that demonstrates the relationship between the U-value of the insulation layer against the thickness of the insulation material used.

Table 7: U-value for roof and ceiling insulation designs with different configuration

Type	Insulation Material	Thickness (mm)	U-Value (W/m^2K)
Roof Insulation			
(a)	Rock Wool	5	1.97
		10	1.53
		20	1.05
(b)	Polystyrene, EPS	5	1.99
		10	1.55
		20	1.07
(c)	Glass Foam	5	2.19
		10	1.81
		20	1.34
Ceiling Insulation			
(d)	Rock Wool	5	2.87
		10	2.02
		20	1.27
(e)	Polystyrene, EPS	5	2.91
		10	2.05
		20	1.29
(f)	Glass Foam	5	3.36
		10	2.54
		20	1.71

Figure 17: Graph of U-value against thickness of different roof insulation designs

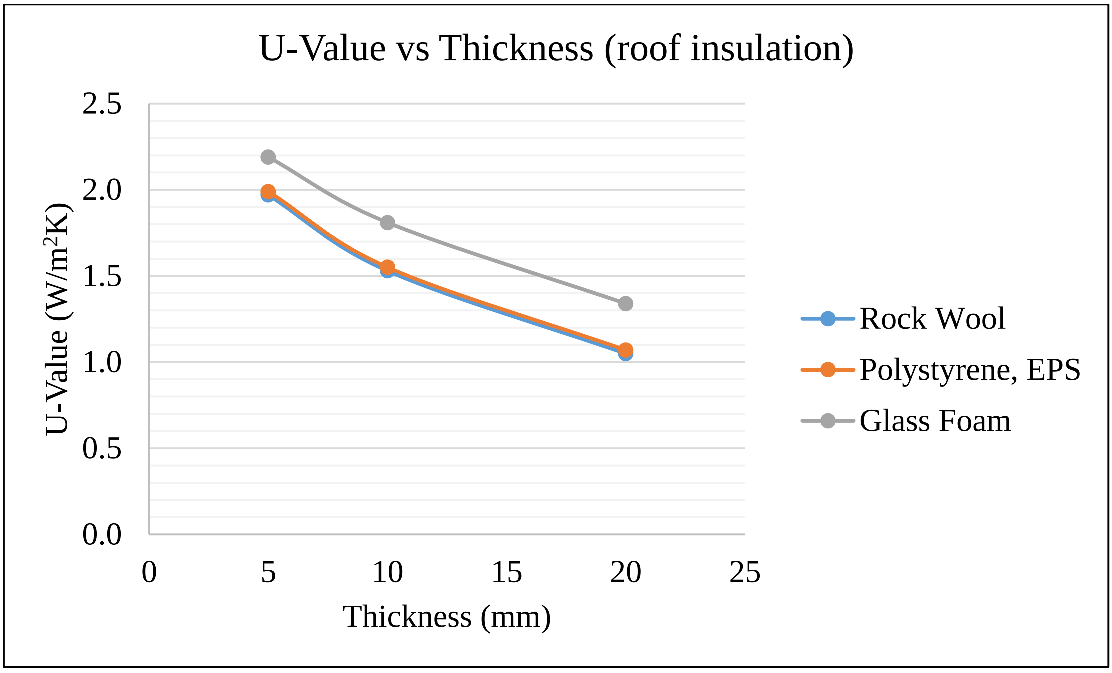
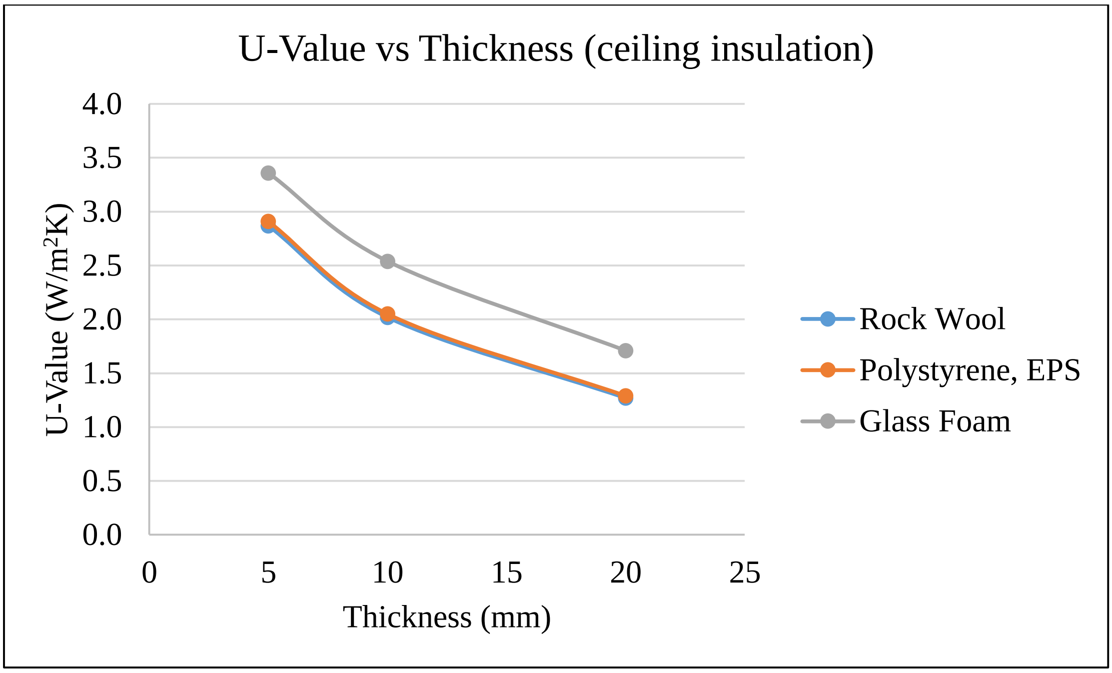


Figure 18: Graph of U-value against thickness of different ceiling insulation designs



By applying the insulation materials on the roof and ceiling to act as the insulation systems, it helps to reduce the solar radiation absorbtion from the roof as well as to reduce the heat transfer from the roof into the building. In fact, it eventually reduces the cooling energy required to keep the building's temperature between 22 and 26 ^{o}C, which is the average temperature for thermal comfort.

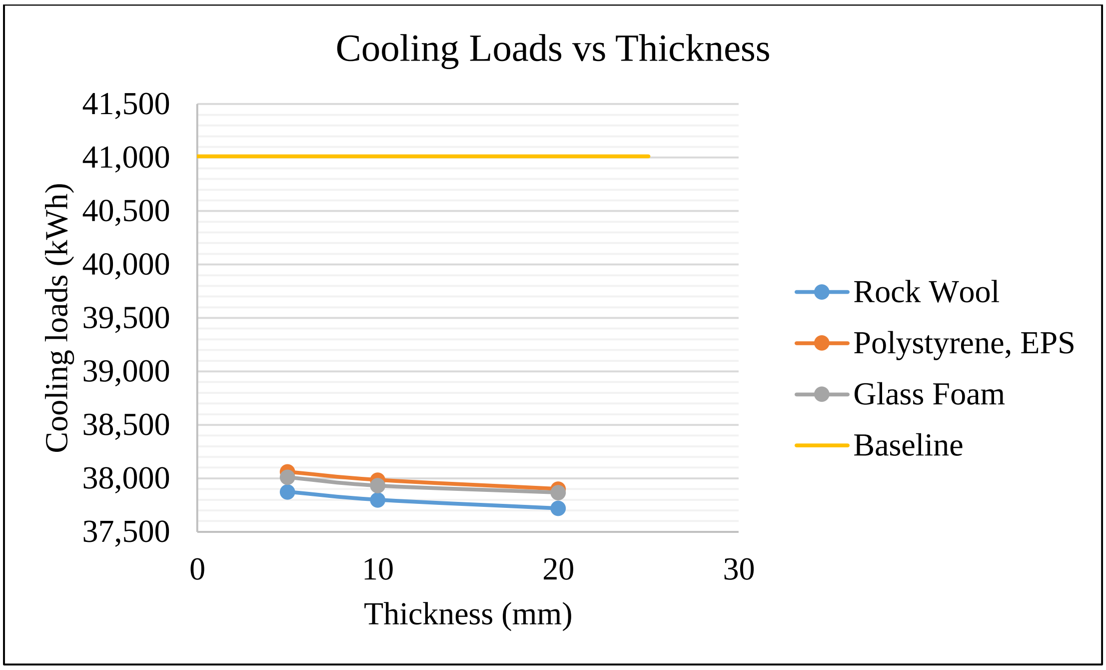
In Table 8, it shows the annual cooling loads and fabric gains of the building with different configuration of insulation systems in term of the material used and thickness. From the results shown, it indicates that the larger the thickness of the insulation material, the better the reduction in building annual cooling loads. The amount of cooling loads reduced annually in building with different roof insulation systems designs and baseline design have also been computed in Table 8. It can be seen that the operational energy consumption for cooling was reduced for about 2900 to 3200 kWh annually. The results also indicates that the fabric gains or the heat due to conduction was also reduced by 5% to 6% compared to of the baseline design.

Fig. 19 is the graph that demonstrates the different in annual cooling loads for different roof insulation systems designs including the baseline design. The graph also indicates the reduction gap of the annual operational energy consumption for cooling between the baseline design and the building with different roof insulation systems designs.

Table 8: Annual cooling loads and fabric gains of building with different roof insulation systems designs

Insulation Material	Thickness (mm)	Cooling Loads (kWh)	Fabric Gains (%)	Cooling Loads Reduction (kWh)	Fabric Gain Reduction (%)
Rock Wool	5.0	37874.82	16.2	3136.92	0.7
	10.0	37799.90	16.3	3211.84	0.6
	20.0	37719.54	16.4	3292.20	0.5
Polystyrene, EPS	5.0	38061.90	16.3	2949.85	0.6
	10.0	37985.88	16.3	3025.87	0.6
	20.0	37901.66	16.3	3110.08	0.6
Glass Foam	5.0	38010.11	16.3	3001.63	0.6
	10.0	37932.18	16.3	3079.56	0.6
	20.0	37867.77	16.3	3143.98	0.6
Baseline		**41011.74**	**16.9**		

Figure 19: Graph of cooling load against thickness of different roof insulation systems designs



4.2.6. Building carbon dioxide (CO_2) emission reduction

Table 9 shows the annual CO_2 emission reduction for building with different roof insulation systems designs. It is clearly shown that the total amount of CO_2 emission that can be reduces annually with the application of roof insulation systems designs is about 1.9 to 2.1 tonnes. Basically, from the amount of cooling load reduction that was computed for different roof insulations systems design, the CO_2 emissions reduction due to cooling or air-conditioning was calculated using the equation below:

$$Electricit\,yConsumption(Kwh)\times\left(1.486\frac{lbsCO_2}{Kwh}\right)\div 2204.6 = CO_2Emissions(tonnes)$$

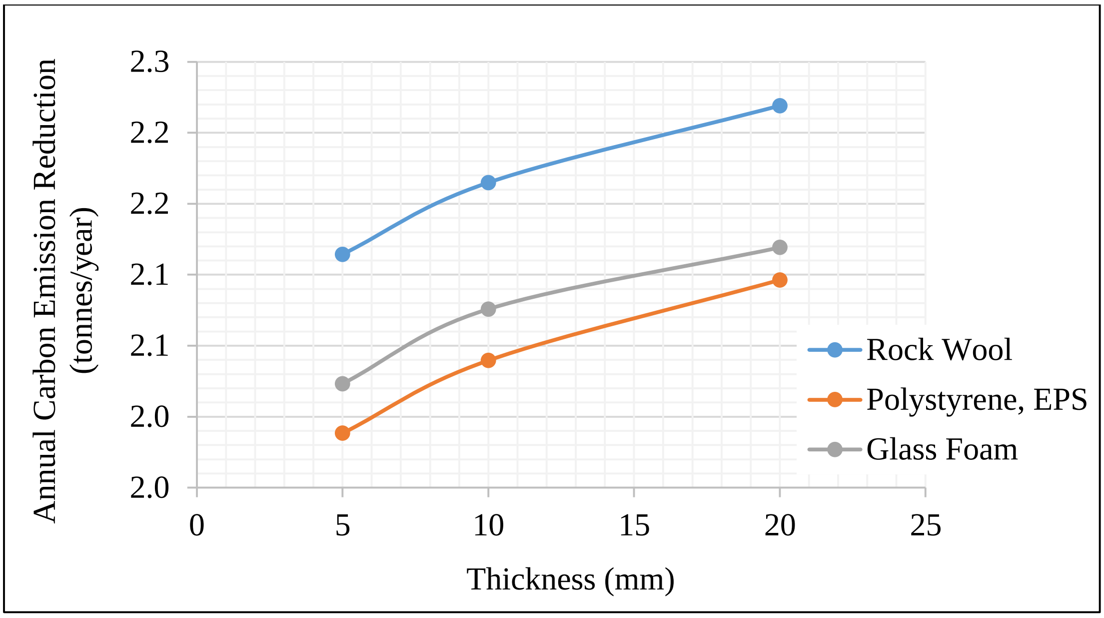
Table 9: Annual CO_2 emissions reduction of building with different roof insulation systems designs

Insulation Material	Thermal Conductivity (W/mK)	Thickness (mm)	U-Value (W/m^2K)	Cooling Loads Reduction (kWh)	CO_2 Emissions Reduction (tonnes)
Rock Wool	0.034	5.0	4.84	3136.92	2.1144
		10.0	3.55	3211.84	2.1649
		20.0	2.32	3292.20	2.2191
Polystyrene, EPS	0.035	5.0	4.90	2949.85	1.9883
		10.0	3.60	3025.87	2.0396
		20.0	2.36	3110.08	2.0963
Glass Foam	0.052	5.0	5.55	3001.63	2.0232
		10.0	1.81	3079.56	2.0758
		20.0	1.34	3143.98	2.1192

Based on all of the results above, it has been proven that the thermal conductivity (K-value) is directly related to the thickness of the insulation materials used. Increasing in the thickness of the insulation materials used will increase the thermal resistance of the insulation systems due to the lowered in U-value of the insulation layer. With the insulation systems that has a lower U-value, it basically reduces the heat transfer from the roof into the building. Hence, it eventually resulted in the reduction of the building energy consumption for cooling.

From the investigation conducted on different insulation material used with different thickness, 20mm of Rock Wool was found to be the best insulation combination in developing the cool roof insulation systems for residential building as per illustrated in Figure 20. Not only it helps to reduce the building energy consumption for cooling, but it also contributes to the carbon emission reduction of the building.

Figure 20: Graph of building annual carbon emission reduction for different roof insulation designs



4.3. Excel Data Analysis

The data obtained from the BIM simulation was then exported and recorded to a spreadsheet in Microsoft Excel. The information and data of the annual carbon emission reduction of building with different roof insulation systems was used to generate the mathematical equation required for SD modelling. The data was used to perform a regression analysis in Excel and the Summary Output is shown in Figure 21 and Figure 22. The regression analysis basically generated the mathematical equation to interpret the relation on how the roof insulation systems affecting the building cooling loads. In other words, the equation can be used to predict the building cooling loads based on the thickness and thermal conductivity of different roof insulation systems.

Figure 21: Results of regression analysis in excel for U-value in term of thickness and thermal conductivity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.983360071
R Square	0.966997029
Adjusted R Square	0.955996039
Standard Error	0.241171014
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	2	10.225241	5.112621	87.900907	0.000036
Residual	6	0.348981	0.058163		
Total	8	10.574222			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	4.060867	0.428000	9.487997	0.000078	3.013587	5.108146	3.013587	5.108146
Conductivity	41.259501	9.732870	4.239192	0.005445	17.444026	65.074976	17.444026	65.074976
Thickness	-0.161952	0.012891	-12.563084	0.000016	-0.193496	-0.130409	-0.193496	-0.130409

RESIDUAL OUTPUT

Observation	Predicted U-value	Residuals
1	4.653928	0.186072
2	3.844166	-0.294166
3	2.224642	0.095358
4	4.695187	0.204813
5	3.885426	-0.285426
6	2.265902	0.094098
7	5.396599	0.153401
8	4.586837	-0.236837
9	2.967313	0.082687

Figure 22: Results of regression analysis in excel for cooling loads in term of U-value

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.671013494
R Square	0.450259109
Adjusted R Square	0.371724696
Standard Error	84.39092022
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	1	40831.369886	40831.369886	5.733271	0.047857
Residual	7	49852.791906	7121.827415		
Total	8	90684.161792			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	37667.631082	103.438986	364.153137	0.000000	37423.036749	37912.225416	37423.036749	37912.225416
U-Value	62.140216	25.952040	2.394425	0.047857	0.773392	123.507040	0.773392	123.507040

RESIDUAL OUTPUT

Observation	Predicted Cooling Loads	Residuals
1	37968.389728	-93.569728
2	37888.228849	-88.328849
3	37811.796384	-92.252384
4	37972.118141	89.777859
5	37891.335860	94.540140
6	37814.281992	87.382008
7	38012.509281	-2.397281
8	37937.941022	-5.761022
9	37857.158741	10.609259

Excel produces the following Summary Output:

i. **R Square**

The R Square is equals to 0.96, which is a very good fit. 96% of the variation in U-value is explained by the independent variables Conductivity and Thickness. The closer to 1, the better the regression line (read on) fits the data.

ii. **Significance F and P-values**

To check if the results are reliable (statistically significant), look at Significance F. If this value is less than 0.05, then it is okay. If Significance F is greater than 0.05, it's probably better to stop using this set of independent variables or to delete a variable with a high P-value (greater than 0.05) and rerun the regression until Significance F drops below 0.05.

iii. **Coefficients**

The regression line is: y = Intercept + Coefficients*Variables (y = mx + c). From the analysis, the equation obtained was as follow:

*U-Value = 4.060867 + (41.2595*Conductivity) – (0.16195*Thickness)*

*Building Cooling Loads = 37667.63 + (62.14022*U-value)*

It is a valuable information and these equation can be used to do a forecast. For example, by varying the value of the variable such as the thickness and conductivity in order to find out effect on the building cooling loads.

iv. **Residuals**

The residuals shown how far away the actual data points are from the predicted data points (using the equation).

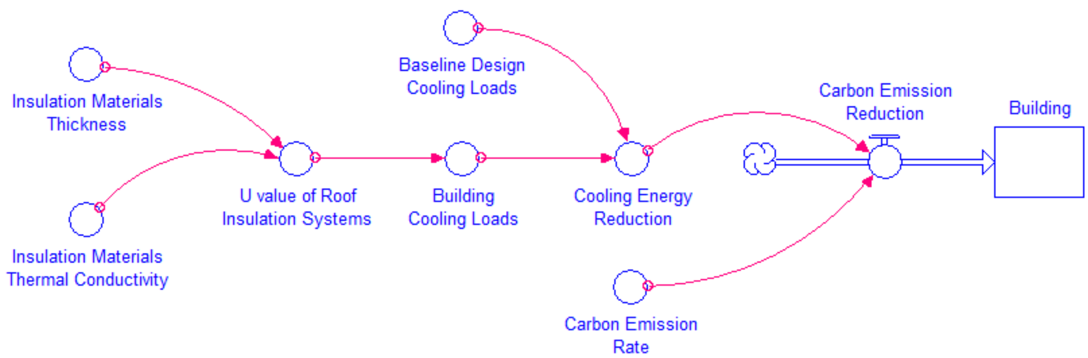
4.4. SD Modelling and Simulation

SD modelling using STELLA software is part of the module in developing SD simulation model. The model was populated to estimate the carbon emission reduction of residential building with different roof insulation systems designs. STELLA software is an icon-based modelling 'language' that allows simple and user friendly generic building blocks through which particular components of roof insulation material selection systems for building can be populated or modelled.

The generic parameters of STELLA items can be utilized for modelling of numerous dynamics systems. For instance, a stock can be model to represent the capacity of variety of intangible or tangible quantities; a flow can be utilized to model whenever time series of flow of quantities. Also, a connector can convey data of variables while a converter can be utilized to model functional connection of relationships. STELLA can likewise provide some built-in functions (mathematical, logical, if-then-else, random, delay) and graphical interface (Graphs, Tables, Sliders, Sectors).

To populate a SD simulation model using STELLA and form this model, it is obliged to define the items that are utilized as part of the model. In this model, the building roof insulation systems includes a few option designs, and every designs has two types of materials information: thermal conductivity and thickness. For defining the items that are utilized as part of the model, the process of building model network is performed, as portrayed in Figure 23.

Figure 23: SD Mapping model network



The mapping process can be described as follows:

1) Draw one stock block for building that has one inflows (Carbon Emission Reduction);
2) Draw one inflow blocks (flow blocks) that gather information from converters to model any time series of quantities' flows;
3) Draw two converter blocks to hold the two criteria (Cooling Energy Reduction and Carbon Emission Rate);
4) Draw the baseline design cooling loads, building cooling loads and roof insulation systems in converter blocks. Roof insulation systmes have two converters related to the alternatives materials that are used in the systems design;
5) Connect all converters with suitable blocks by connectors.

Then, insert the data or information obtained from excel into each converter to populate the SD model. The required mathematical equation for each converter in order simulate the SD model is as follow:

- **Thermal Conductivity** ***(W/mK)*** *= k*
- **Thickness** ***(mm)*** *= t*
- **U-Value** ***(W/m²K)*** *= 4.060867 + (41.2595*k) – (0.16195*t)*
- **Baseline Design Cooling Loads** ***(kWh)*** *= 41011.744*
- **Building Cooling Loads** ***(kWh)*** *= 37667.63 + (62.14022*U-value)*
- **Cooling Loads Reduction** ***(kWh)*** *= Baseline Design – Cooling Loads*
- **CO_2 Emission Rate** ***(tonnes/kWh)*** *= 1.486/2204.6*
- **Building Carbon Emission Reduction** ***(tonnes)*** *= Cooling Energy Reduction*CO_2 Emission Rate*

Finally, after inserting all data of materials according to the chosen group of alternatives roof insulation systems designs, the simulation model was executed. The generated results is the amount of carbon emission reduction in building with different alternatives of roof insulation systems designs. In addition, the charts of building carbon emission reduction vs time for over the spent of 20 years was generated as shown in Figure 25. The charts depict all results for each of the alternatives roof insulation systems design provided in Figure 24.

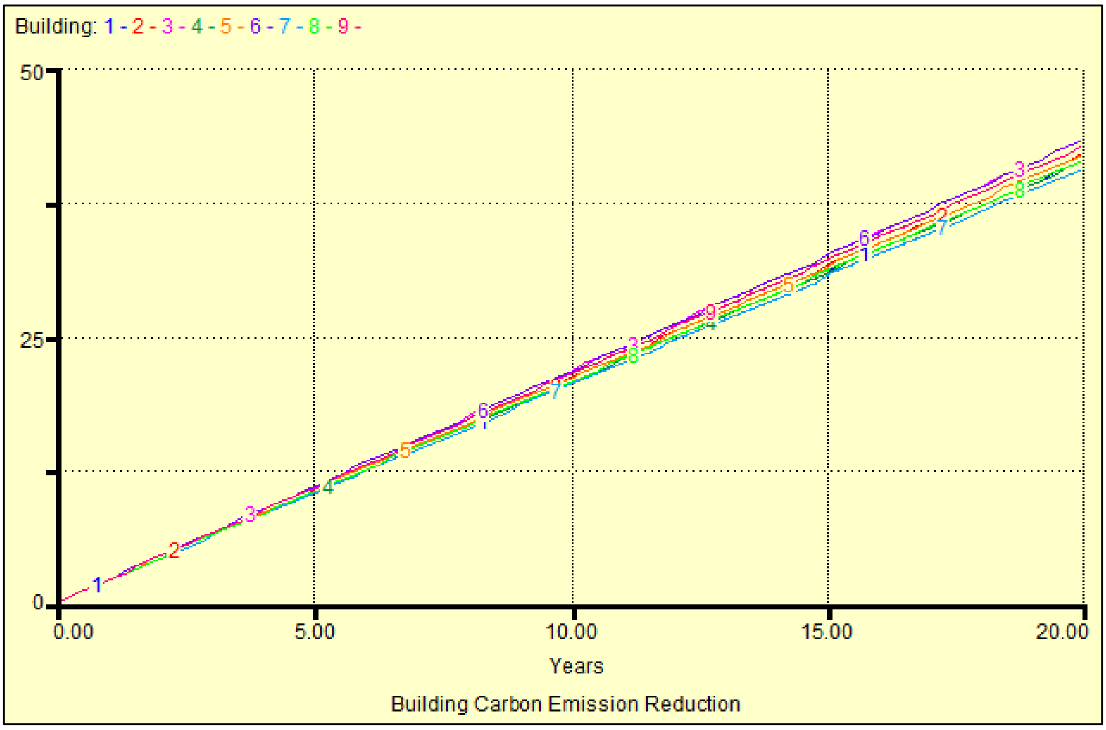
Figure 24: SD simulation for different roof insulation systems designs

Setup #1 22 Mar 2015 3:04 PM

Input Variables

Run #	Materials ...onductivity	Materials Thickness
1	0.034	5.00
2	0.034	10.0
3	0.034	20.0
4	0.035	5.00
5	0.035	10.0
6	0.035	20.0
7	0.052	5.00
8	0.052	10.0
9	0.052	20.0

Figure 25: Graph of SD simulation for building carbon emission reduction with different roof insulation systems designs



CHAPTER 5
CONCLUSION AND RECOMMENDATION

Based on the progress work that have been discussed in Chapter 4, the author is basically trying to achieve the first and second objective of this study. The first objective is basically to evaluate the thermal resistance of existing roof insulation systems and their effect on indoor temperature of residential buildings. So, in order to achieve that objective, the author has studied the concept of roof insulation systems in term of their thermal properties. In these contexts, the thermal properties of roof insulation materials basically consist of thermal resistance, thermal transmittance and thermal conductivity, where these are the parameters of roof insulation systems that will contribute to the effect of indoor temperature in buildings.

Besides that, the author has also made a visit to the location of the experimental houses which belong to Monier Sdn. Bhd. that are located at Bukit Kemuning, Klang. The purpose of the visit is to observe the utilization of experimental houses in conducting the test for the performance of cool roof insulation systems. The calibration of the experimental houses also has been conducted on the same day. Hence, it can be concluded that the first key milestone of this research has been met, which is to study the thermal resistance of existing roof insulation systems and their effect on indoor temperature of the building as well as to conduct experiments to validate the data obtained.

Furthermore, the second objective of this study which is to determine the effect of roof insulation systems on energy consumption and carbon emission of residential building in Malaysia has been achieved. In fact, the second, third and fourth milestones of this study also has been meet, where the purpose is to investigate the potential of BIM in assessing the effectiveness of different combinations of roof insulation systems designs in building to decrease the annual operational energy consumption and carbon emission of the building.

Finally, the third objective of this study has also been achieved, which is to develop a system dynamics model that can assist decision makers to select the roof insulation systems with minimum energy consumption and carbon emission for residential buildings. Not only that, but this objective also marks the end of the project milestones which is to develop the simulation model for carbon emission reduction of building with different roof insulation systems using System Dynamics (SD) software called "STELLA".

On the other hand, the study also suggested a sustainable solutions that have been proven to be effective in reducing the energy consumption of the building. In fact, this study showed that considering traditional practices, as well as new technologies, can be an effective approach. After the essential data required for the simulation had been gathered and after importing the data to the energy analysis software, the building was simulated using the BIM tool, and the annual energy consumption of the building was estimated. In doing so, considerable energy can be saved during the building's lifecycle, resulting in reducing operational energy usage and CO_2 emissions, thereby contributing to the achievement of a sustainable, green building.

Moreover, building is an entangled system made out of bunches of building materials and component subject. It is believed that in the demonstrating of SD, the development and change of the system model are feasible, especially for effectiveness and affectability analysis of different parameters likewise can be completed. To make a thorough SD model, it is essential to comprehend the real system and model it correctly. At that point it is important to complete the sufficient verification.

In addition, the author foresees that the system dynamics method will discover an extensive variety of other uses in the field of building design and operation. Principal among these uses will be the idea of creating a system dynamics building model suitable for examination of a building as far as sustainable design. The system dynamics model will keep on being created and enhanced, and will in the end expanded to incorporate different sorts of building materials or designs, and be helpful for discovering the most sustainable configuration of building design.

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