Transient Simulation of Energy in a Terraced House Using TRNSYS

by

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Dissertation submitted in partial fulfilment of
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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Syed Ihtsham Ul Haq Gilani)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2010

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.

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NUR AIN BINTI SULAIMAN

ABSTRACT

Economic and industrial development in Malaysia has led to an increasing demand of energy. Reduction of energy consumption in building is a major aim worldwide. In this study an attempt is made to help in understanding the energy flow within a terraced house, using the transient simulation technique and eventually, helping in reducing the energy needs of the house. Some major factors that influenced the energy flow in a terraced house are size and shape; thermo physical properties, window systems and orientation. A well known TRNSYS (Transient Systems Simulation Program) would be used for the modelling and simulation of the energy flows of the house to examine measures to reduce the thermal load. For a single-storey house selected for this study, the parameters used are the actual or a typical standard Malaysian house. The results show the effect of occupancy and electrical appliances, window system and U-value of the materials construction to the inside temperature. This study is focusing more on the choice of constructional materials so that good temperature and lower cooling load is attained. The cost effectiveness of the design modification on cooling load is calculated and it is definitely help in providing a better solution for sustainable future.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Malaysia is located in a tropical region and is subjected to hot and humid climate. Inside temperature of buildings in Malaysia is greatly determined by local weather conditions, i.e. the sun radiation, ambient temperature and humidity. Consumption of energy however produces some undesirable impacts on the environment and climate. Each year, the energy demand is kept on increasing [1] and one of the strategies of the energy sector that mentioned in the 9th Malaysia Plan [2] is:

> "Energy efficiency measures will be intensified in the industrial, transport and commercial sectors as well as in government buildings". The implementation of energy efficiency (EE) programmes will focus on energy saving features in the industrial and commercial sectors. In this regard, EE features such as efficient lighting and air conditioning systems as well as establishing a comprehensive energy management system will be encouraged.

In Malaysia not much published data is available yet on the energy performance or actual annual energy consumption of buildings. Therefore, this paper will discuss the energy behaviour of a residential building to increase understanding in building management.

A 2006 study of Household Energy use by Center for Environment, Technology & Development, Malaysia (CETDEM) headed by Ir Gurmit Singh in cooperation with Majlis Bandaraya Petaling Jaya (MBPJ) and funded by Exxon Mobil found the following:

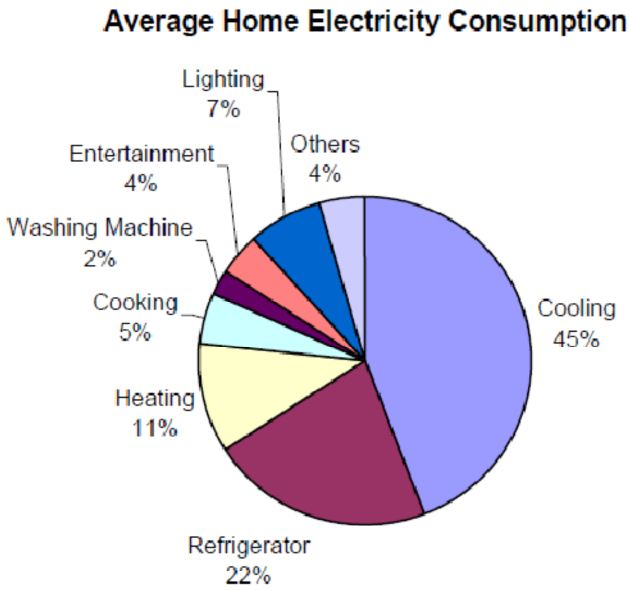

Figure 1.1: Average home electricity consumption [3]

Air conditioning and the refrigerator take up nearly 70% of the average household electricity consumption and air conditioning is the largest consumer of electricity in the home. With the threat of "Global Warming" and increasing energy cost, keeping the home cool will become increasingly important in the future.

There are several major factors that influenced the energy flow in a terraced house, i.e. size and shape; thermo physical properties, window systems, orientation, etc. The average outdoor air temperature in Malaysia is only about 4 degrees above the comfort range.

1.2 PROBLEM STATEMENT

Due to the tropical nature of weather in Malaysia, the flow of energy in and around the terraced houses should be low. A lot of air conditioning is used to maintain the temperature and humidity within the house. Many studies have been made to calculate the cooling load using steady state conditions but they may not accurate because of ever changing input parameters.

This project will help in understanding the energy flow within a terraced house, using the transient simulation technique and eventually, helping in reducing the energy needs of the house. In Malaysia, terraced house holds the biggest fraction of residential units.

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives

The objectives of this project are:

1. To select a terraced house in Perak and gather all parameters needed to run the simulation (weather data, building specifications, materials, etc.)
2. To develop a simulation model using Transient Systems Simulation Program, TRNSYS.
3. To understand the inter-relation between design and parameters to identify potential problem areas and so implement and test appropriate design modification that will reduce the cooling load of the house.

1.3.2 Scopes of Study

The scopes of study for this project are:

1. A single storey terrace house located in Perak is selected for the project.
2. The representative house model includes three rooms, a kitchen, two toilets and a living room.
3. The house is occupied by a family composed of two adults and two children.
4. Steady state flow of energy would not be evaluated.
5. TRNSYS software would be used for simulation.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

In order to fully understand the project, the study has been done on energy simulation of buildings and TRNSYS from various sources such as journals, articles, books, internet, previous report and etc. It is also important to know calculation methods on energy performances of buildings.

2.2 ENERGY SIMULATION OF BUILDINGS

Energy simulation of a building is done in order to understand the thermal behaviour of the building and seek solutions to minimize the effects on environment. A normal work flow (manual approach) for getting knowledge about thermal building performance is time consuming but with the used of model simulation, it saved compute and operator (engineer) time [4]. Buildings are complex artefacts involving 'hard' and 'soft' aspects such as transient energy flows and stochastic occupants' interactions respectively.

Figure 2.1 shows the flowpaths encountered within and outwith buildings which interact in a dynamic manner to dictate comfort level and energy demands. Constructional elements, room contents, glazing systems, plant components, renewable energy devices may be treated as network 'nodes' and characterized by capacitance with the inter-node connections characterized by conductance. The stage (Figure 2.2) of predicting energy consumption is concerned with predicting the energy requirement to satisfy the demands of the building activities. This is found by modifying the various instantaneous heat gains and losses as a function of the distributed thermal capacities. It is concerned with the design of the building to reduce the energy requirement. [5]

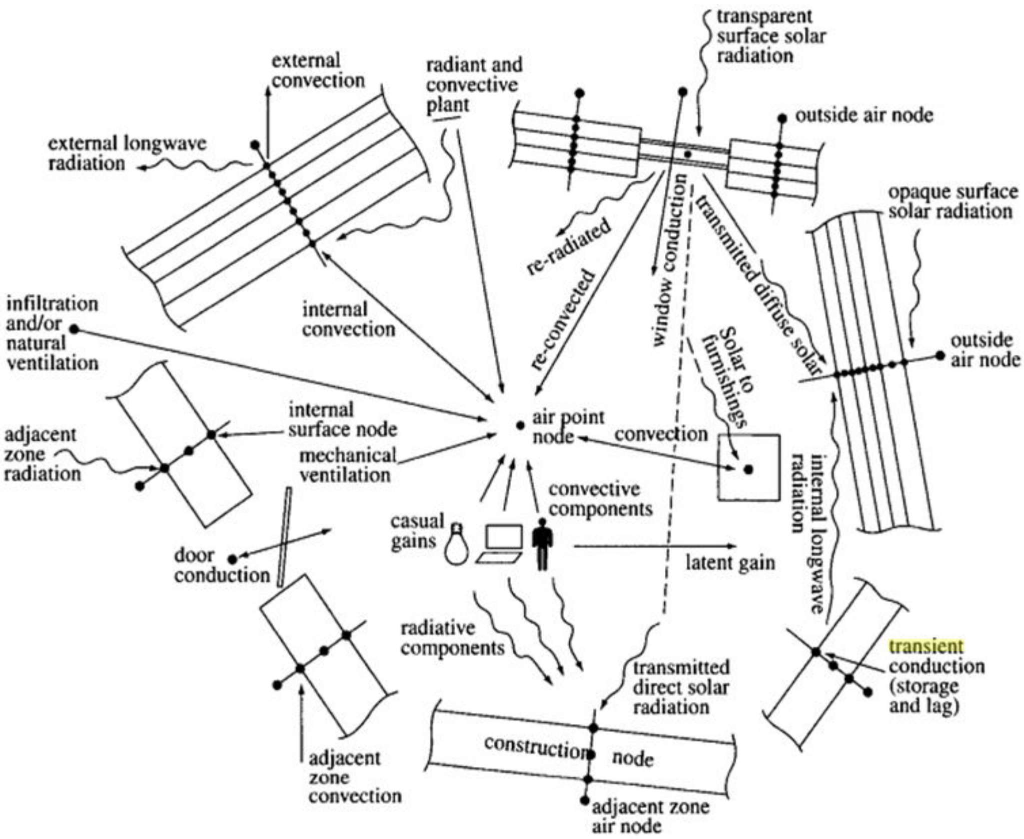

Figure 2.1: Building energy flowpaths [5]

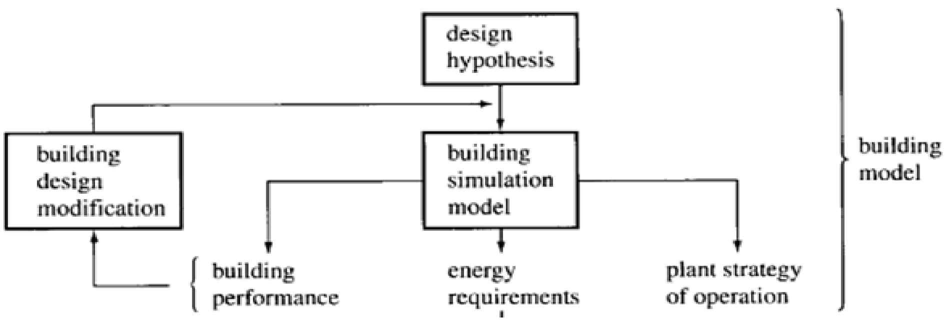

Figure 2.2: Building model [5]

From mathematical viewpoint, several complex equation types must be solved to accurately represent such a system and because these equations represent heat transfer processes that are highly inter-related, it is necessary to apply simultaneous solution techniques if the performance prediction is to be both accurate and preserve the spatial and temporal integrity of the modelled system. The simulation is used to determine optimum combination of zone layout and constructional scheme that will provide a climate responsive solution and so minimize the need for mechanical plant.

Simulation focus on the choice of constructional materials and their relative positioning within multi-layered constructions so that good temperature and load levelling is attained. The alternative daylight capture and shading strategies might be investigated to ensure glare avoidance, excess solar gain control and minimum luminance usage. Simulation also allows users to understand the inter-relation between design and parameters to identify potential problem areas and so implement and test appropriate design modification. The design result would be more energy conscious. Specifically, this representation includes models of the heat, air, moisture, light and electricity flows as they occur within a building/plant system when subjected to weather factors and influenced by distributed control action and occupant interactions.

2.3 FACTORS AFFECTING ENERGY USE IN BUILDINGS

The amount of energy used in buildings depends firstly on what it is used for. Thus the initial and most important steps in isolating the factors affecting energy use are to determine its end-use. To engineers and architects, the category of use or building type will be the first factor to consider. The following were found to have a significant impact on energy consumption in buildings. [3]

2.3.1 Occupancy and Management

It should be emphasized that people use energy. The building itself does not use much energy. The amount of energy used will generally be directly proportionate to the intensity of building occupancy. The level of physical activity, the clothing worn, the duration of occupancy and age, size and background of the occupant will also affect the cooling / heating requirement. These factors will affect cooling requirements by influencing the preferred air temperature.

Fanger and Kowakzewski's work show for example that a person wearing light clothes and doing light desk work seated will feel comfortable at 25 degrees centigrade while he will only feel comfortable at 21 degrees centigrade with a light business suit. This 4 degrees difference can mean a 100% difference in the air conditioning energy requirement of a room. The attitude of the occupants towards energy use has significant consequences. They are influenced by the aims and goals of the uses, the penalties and benefits to the user of conserving energy, expectations of the user and weather the users are aware of the relationship of their actions to the amount of air conditioning of heating energy used. Finally, the organization and management of the building and its air conditioning equipment in terms of operation and maintenance will reflect on its efficiency and thus the energy used. [3]

Study on Optimal Energy System Design for Apartment House [6] is about an optimal design method for the energy system of the apartment house using both genetic algorithm and data of cooling/heating demand load simulated by TRNSYS. It controlled a resident pattern and the results showed that energy in apartment house can be saved by using management.

2.3.2 Building Design and Construction

The building layout, planning, design, shape, fabric and construction cover a wide number of variables that affect building energy requirements. This the area where the basic decisions of the architect will have the most influence on the building's energy use. The following sets of estimates by Givoni should serve to illustrate a building's influence on its indoor environment and thus air conditioning or heating requirement. Depending on the design; [3]

i. The indoor air temperature amplitude – swing from lowest to highest – can vary from 10% to 150% of outdoor amplitude
ii. The indoor maximum air temperature can vary by -10 to +10 ^{0}C from outdoor maximum
iii. Indoor minimum air temperature can vary by 0 to +7 ^{0}C from outdoor minimum
iv. Indoor surface temperature can vary by +8 to +30 ^{0}C from outdoor maximum and minimum.

The building related factors influencing energy requirements are numerous and complex. They can be classified under the following headings. [3]

i. Size and Shape
ii. Orientation
iii. Roof System
iv. Planning and Organization

v. Thermo physical properties – thermal resistance & thermal capacity
vi. Window systems
vii. Construction detailing

There are several papers that study these factors which are:

i. The Minimisation of Life Cycle Cost of a Detached House Using Combined Simulation and Optimisation [7] study the selected design variables in the building construction (insulation thickness of the external wall, roof, floor and U-value of the windows) and HVAC system which achieved minimum LCC values for the studied cases. The solution suggests lowering the U-values for the external wall, roof, floor and the window from their initial values.
ii. Energy Simulation for a Typical House Built with Different Types of Masonry Building Materials [8] paper shows that the thermal transmission through walls and roof constitute more than half of the total peak cooling load and insulating (walls and roof) the base house results in a reduction of the air-conditioning equipment capacity.
iii. The Energy-efficient Terrace Houses in Sweden Simulations and Measurement [9] paper show parametric studies on the indoor temperature, solar gains, air-tightness, window type and occupancy. Simulations showed that energy-efficient windows are essential to reduce thermal loss and occupancy behaviour was highly influenced the space heating demand and also the reduction of energy in houses compared to normal standard was about 60%.
iv. Two papers, Measures Used to Lower Building Energy Consumption and Their Cost Effectiveness [10] and Modelling of the Modern Houses of Cyprus and Energy Consumption Analysis [11] used similar approach but different backgrounds. The project was done to analyse the energy consumption of modern house by examined the natural and controlled ventilation, solar shading, various types of glazing, orientation, shape of buildings and thermal mass. Both papers indicated that construction type (better insulated house), low-emissivity double glazing windows and square-shaped house can help in lowering energy consumption. For hot climate, roof

is the most important structural element because increasing roof insulation pay back in short period of time compared to increasing wall insulation.

2.3.3 Mechanical and Electrical Equipment

Electrical equipment and plant also play an important role in energy buildings. Low energy equipment and plant will not only save electricity but also help the earth. The study [6] shows lighting, heat emitted from electrical appliances, heating and cooling can be controlled. The results showed that energy for equipment systems in apartment house can be saved by using operation plan of building equipment systems.

2.4 TRANSIENT SYSTEM

Transient convection is of fundamental interest in many industrial and environmental situations such as air conditioning systems, human comfort in buildings, atmospheric flows, motors, thermal regulation process, cooling of electronic devices, security of energy systems, etc. Many works reported in literature deal with stationary velocity and temperature fields, but only a small number deal with time – variable boundary conditions (1, 2, 3, 4), either in forced, natural or mixed convection. Among the three types of convective transfers, forced convection is often used because of its efficiency. A contrario, natural convection has the advantage to be free in terms of energy expense but generates low heat transfer coefficient. Thus it will be interesting to improve free convection heat transfer, by the mean of time-dependent boundary conditions. [12]

Transient conduction is the process by which a fluctuation of heat flux at one boundary of a solid material finds its way to another boundary, being diminished in magnitude and shifted in time due to the material's thermal inertia. Within the building fabric, transient conduction is a function of the temperatures and heat flux excitations at exposed surfaces, the possible generation of heat within the fabric, the temperature and moisture dependent (and therefore time dependent) hygro-thermal properties of the individual materials, and the relative position of these materials. With the external weather excitations declared as known time-series data, the modelling is to determine the intra-fabric temperature and moisture distribution and hence the dynamic variation of heat flux at the exposed surfaces. [5]

The thermophysical properties of interest include:

1. Conductivity, k (W/mK)
2. Density, ρ (kg/m^3)
3. Specific heat capacity, c (kJ/kgK)

These properties are time dependent because of material temperature and/or moisture fluctuations and may be positioned or direction dependent if the material is non-homogenous or anistrophic respectively. In some applications such dependencies may be ignored and the thermal properties assumed constant.

The U-value (or U-factor), more correctly called the overall heat transfer coefficient, describes how well a building element conducts heat. It measures the rate of heat transfer through a building element over a given area, under standardized conditions. The overall thermal transmittance or U-value (W/m^2K) is given by:

$$U = \frac{1}{\sum_{i=1}^{N} \frac{x_i}{k_i} + R_{si} + R_{so} + R_c} \quad (2 - 1)$$

N = number of layers

x_i = thickness of layer i

R = the combined radiative and convective thermal resistance, m^2K/W

(si, so and c are innermost surface, outermost surface and cavity)

The steady state concept approach does not preserve spatial integrity since different constructional arrangements will preform differently even though each may have the same U-value. By proper design, this stored energy can later be harnessed passively (rather than by mechanical means) to minimise heating or cooling requirements.

In summary, transient conduction will affect energy requirements, load diversity, peak plant demand, load levelling, plant operating efficiency and condensation potential. The thermophysical properties of interest include shortwave absorptivity for opaque elements and absorptivity, transmissivity and reflectivity for transparent elements. The magnitude of these properties is dependent on the angle of incidence of the shortwave flux and on its spectral composition.

2.5 TRANSIENT SYSTEMS SIMULATION PROGRAM, TRNSYS

TRNSYS is a transient systems simulation program with a modular structure. It is an equation solving program based on standard numerical techniques. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. TRNSYS has become reference software for researchers and engineers around the world. Main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells [13].

The main inputs to the programme are the following:

1. The building's construction elements
2. The building's geometric elements
3. Meteorological parameters (ambient temperature, relative humidity, diffuse and global radiation, wind speed and direction)
4. The building's internal gains
5. The building's infiltration, ventilation, etc.

The main outputs of TRNSYS programme are the indoor air temperature at each building's thermal zone and the heating and cooling load [14].

The TRNSYS engine calls the system components based on the input file and iterates at each time-step until the system of equations is solved [10]. TRNSYS is the program with the longest and perhaps most wide spread usage, employs a "block iterative" strategy, calling the component subroutines in a sequence largely determined by the order in which they appear in the user's problem definition. TRNSYS has recently been modified to allow “reverse solving” [15].

2.5.1 Multizone Building Modeling (Type 56)

The building model in Type 56 is a non-geometrical balance model with one air node per zone, representing the thermal capacity of the zone air volume and capacities which are closely connected with the air node. Thus the node capacity is a separate input in addition to the zone volume.

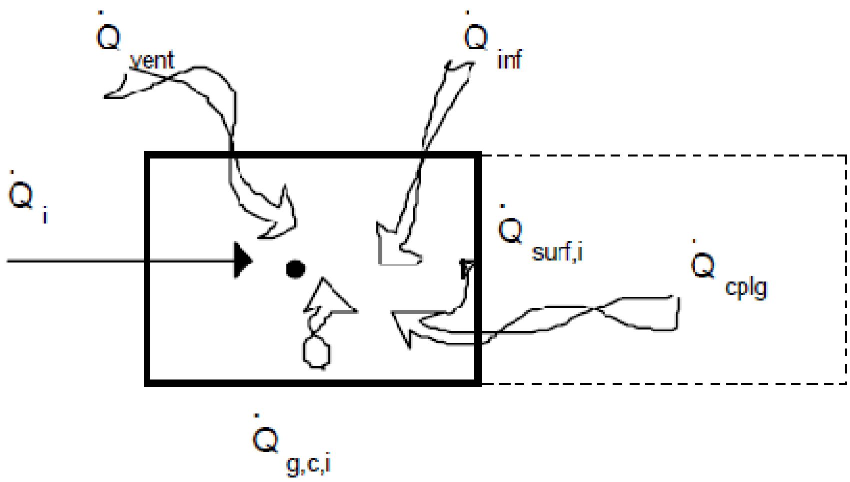

Figure 2.3: **Heat balance on the zone air node** [16]

i. Convective Heat Flux to the Air Node:

$$\dot{Q}_i = \dot{Q}_{surf,i} + \dot{Q}_{inf,i} + \dot{Q}_{vent,i} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i} \qquad (2 - 2)$$

Where $\dot{Q}_{inf,i}$ is the infiltration gains (air flow from outside only), given by;

$$\dot{Q}_{inf,i} = V.\rho.c_p.(T_{outside} - T_{air}) \qquad (2 - 4)$$

$\dot{Q}_{vent,i}$ is the ventilation gains (air flow from a user-defined source), like an HVAC system, given by;

$$\dot{Q}_{vent,i} = V.\rho.c_p.(T_{ventilation,i} - T_{air}) \qquad (2 - 5)$$

$\dot{Q}_{g,c,i}$ is the internal convective gains (by people, equipment, illumination, radiators, etc.), and $\dot{Q}_{cplg,i}$ is the gains due to (connective) air flow from zone I or boundary condition, given by;

$$\dot{Q}_{cplg,i} = V.\rho.c_p.(T_{zone,i} - T_{air}) \quad (2 - 6)$$

ii. Radiative Heat Flows (only) to the Walls and Windows:

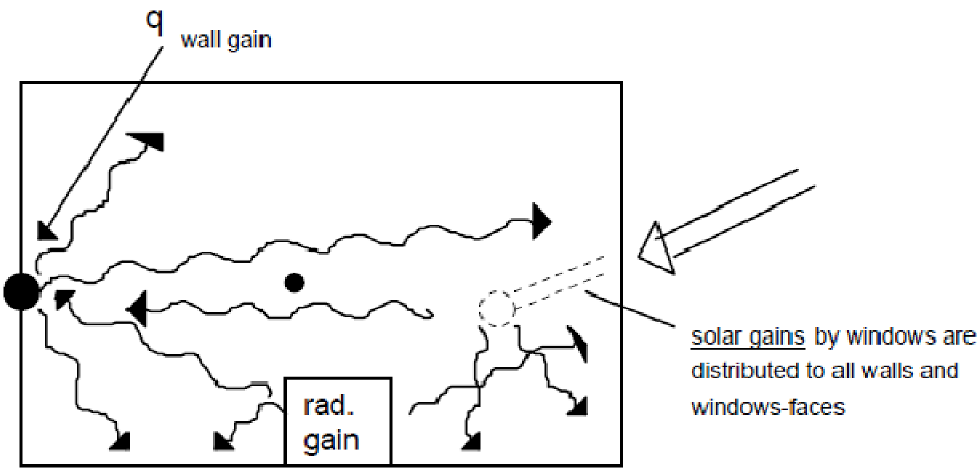

Figure 2.4: Radiative energy flows considering one wall with its surface temperature node [16]

$$\dot{Q}_{r,w_1} = \dot{Q}_{g,r,i,w_1} + \dot{Q}_{sol,w_1} + \dot{Q}_{long,w_1} + \dot{Q}_{wall-gain} \quad (2 - 7)$$

where $\dot{Q}_{r,w_1}$ is the radiative gains for the wall surface temperature node, $\dot{Q}_{g,r,i,w_1}$ is the radiative zone internal gains received by wall, $\dot{Q}_{sol,w_1}$ is the solar gains through zone windows received by walls, $\dot{Q}_{long,w_1}$ is the longwave radiation exchange between this wall and all other walls and windows (εi =1), and $\dot{Q}_{wall-gain}$ is the user-specified heat flow to the wall or window surface. All of these quantities are given in kJ/h.

iii. The long-wave radiation

The long wave radiation exchange between the surfaces within the zone and the convective heat flux from the inside surfaces to the zone air using the star network as represented in **Figure 2.5**.

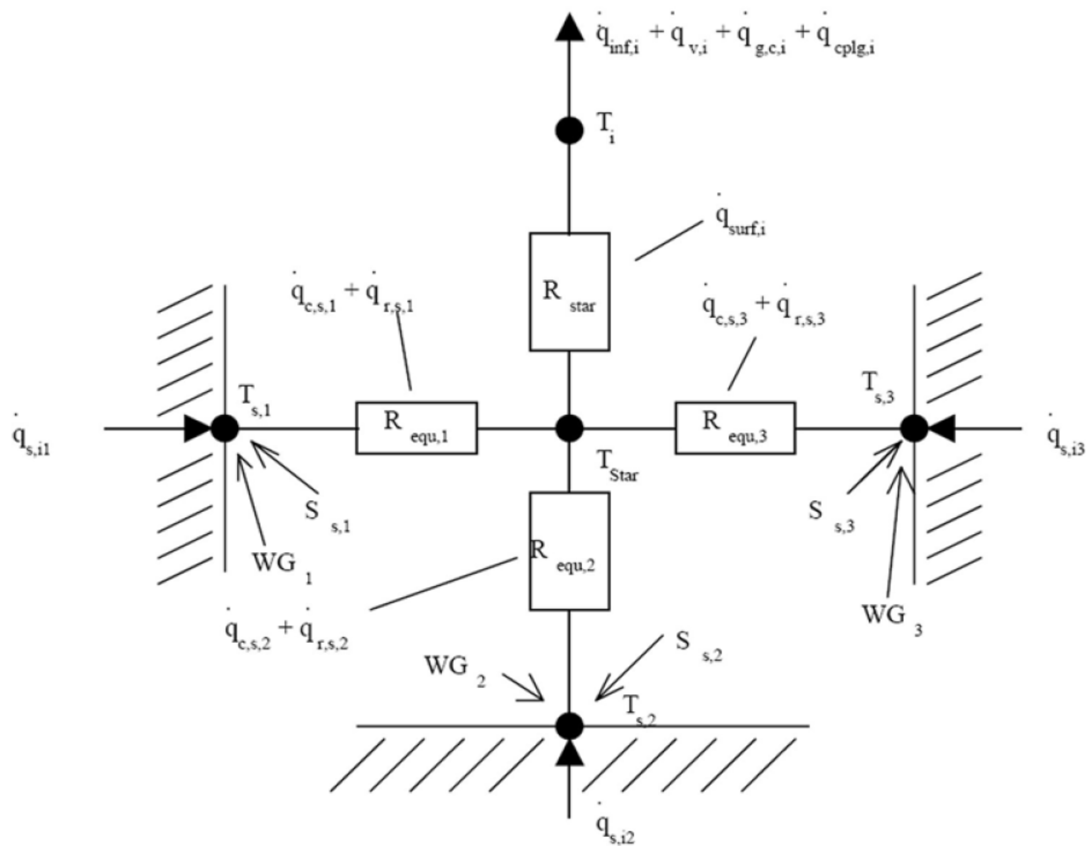

Figure 2.5: Star network for a zone with three surfaces [16]

For external surfaces, the long wave radiation exchange at the outside surface is considered explicitly using a fictive sky temperature, T_{sky} which is an input for Type 56 model and a view factor to the sky, f_{sky} for each external surface. The total heat transfer is given as the sum of convective and radiative heat transfer:

$$\dot{q}_{comb,s,o} = \dot{q}_{c,s,o} + \dot{q}_{r,s,o} \quad (2 - 8)$$

$$\dot{q}_{c,s,o} = h_{conv,s,o}(T_{a,s} - T_{s,o}) \quad (2 - 9)$$

$$\dot{q}_{r,s,o} = \sigma\varepsilon_{s,o}(T_{s,o}^4 - T_{sky}^4) \quad (2 - 10)$$

$$T_{fsky} = (1 - f_{sky})T_{a,s} + f_{sky}T_{sky} \quad (2 - 11)$$

where, $\dot{q}_{comb,s,o}$ Combined convective and radiative heat flux to the surface

$\dot{q}_{c,s,o}$ Convective heat flux to the surface

$\dot{q}_{r,s,o}$ Radiative heat flux to the surface

$h_{conv,s,o}$ Convective heat transfer coefficient at the outside surface

f_{sky} Fraction of the sky seen by the outside surface**1**

T_{sky} Fictive sky temperature used for long-wave radiation exchange

$\varepsilon_{s,o}$ Long-wave emissivity of outside surface (ε =0.9 for walls; value read from window library for windows)

σ Stephan-Boltzmann constant

iv. Infiltration and ventilation

Infiltration and ventilation rates are given in terms of air changes per hour for each zone. The mass flowrate is the product of the zone air volume, air density, and air change rate. Infiltration occurs always from outdoor conditions while ventilation occurs from a specified temperature. Equal amounts of air are assumed to leave the zone at the zone temperature. The energy gains to any zone i due to infiltration and ventilation are:

$$\dot{Q}_{inf,i} = \dot{m}_{inf,i} C_p (T_a - T_i) \quad (2 - 8)$$

$$\dot{Q}_{v,i} = \sum_{k}^{nvent} \dot{m}_{v,k,i} C_p (T_{v,k} - T_i) \quad (2 - 9)$$

where, $\dot{m}_{inf,i}$ mass flow rate of infiltration air

$\dot{m}_{v,k,i}$ mass flow rate of ventilation air of ventilation type k

Cp specific heat of the air

Tv,k temperature of ventilation air of ventilation type k

Ta ambient air temperature

CHAPTER 3
METHODOLOGY

3.1 WORKFLOW OF PROJECT

The workflow diagram is developed to show the flow of this project to meet the objectives. The overall steps involved are shown in figure 3.1. This project is divided into two intervals time. First interval is for Final Year Project I (FYP I) and second interval is for Final Year Project II (FYP II).

For the first interval (FYP I), the first step involve is to understand the problem identified and then underline the objectives to be achieved. After that, a research has to be done regarding energy simulation of buildings and the software that will be used throughout this project which is TRNSYS. The sources that can be used are journals, books, articles, previous reports, internet, etc. Then, a house must be selected according to the limitations stated in the scope of study. Data needed to run simulation are gathered and weather data closest to the site should be prepared as well. Since the author has never been exposed to TRNSYS before, there will be need to study the software for some period of time. This software can be learned by using manual and a simple model will be developed for testing. A TRNSYS model of the selected house is then being developed and the simulation is interpreted bit by bit.

For the second interval (FYP II), the simulation data is being analysed and evaluated in terms of energy flow and requirements. Then, the factors that influence energy requirement inside the house are identified and the effect of various design parameters will then be evaluated. Finally, a written report of this project is produced after all steps successfully conducted.

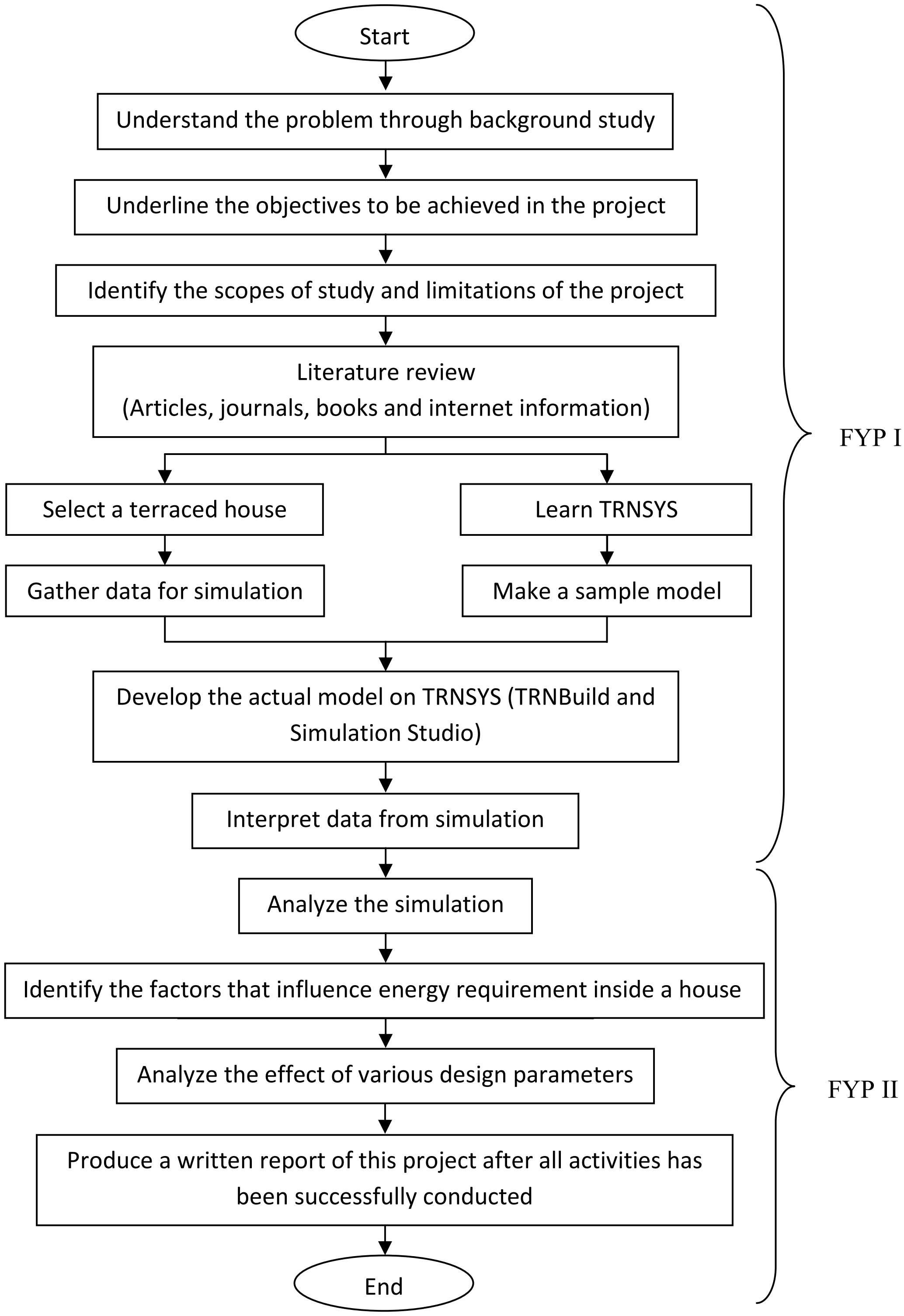

Figure 3.1: Workflow Diagram of the Project

3.3 TOOLS/EQUIPMENT REQUIRED

1. TRNSYS software.

3.4 FLOW DIAGRAM TO WORK WITH TRNSYS

There are several steps that need to be followed to work with TRNSYS. The steps are as shown in **Figure 3.2**.

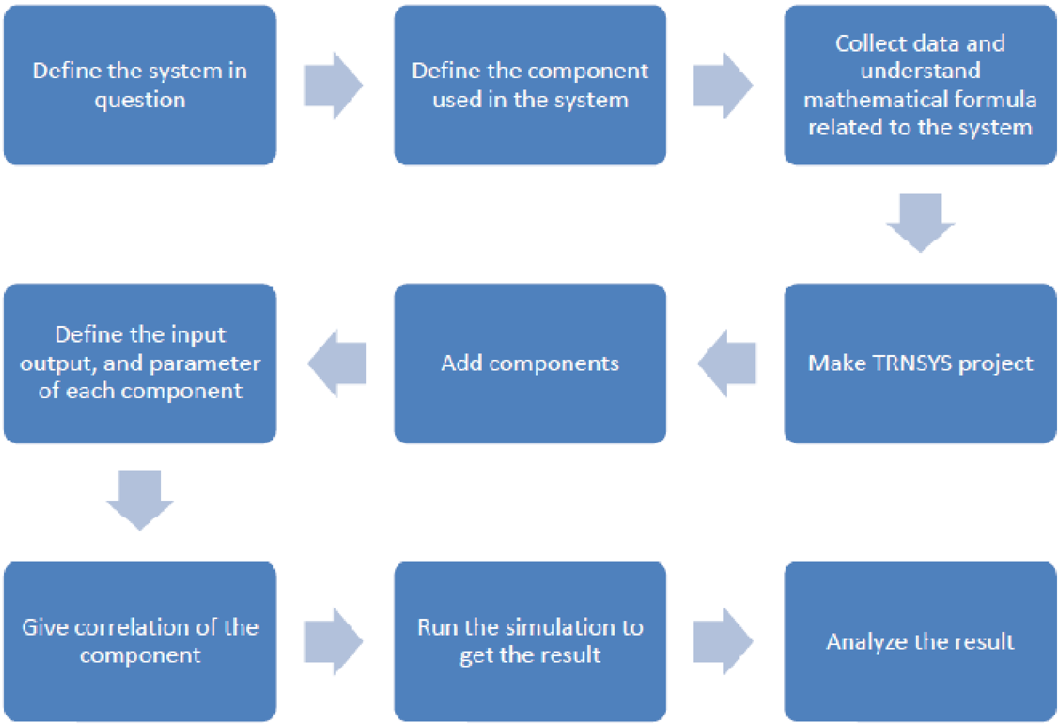

Figure 3.2: Flow diagram of working with TRNSYS

For multizone building modelling, there are four main parts for data describing a zone that are very important to run the simulation which are:

1. The required regime data (zone volume, capacitance, initial temperature, initial relative humidity and humidity model)
2. The walls of the zone (wall type, area, category, geosurf, surface number and wall gain)
3. The windows of the zone (window type, area, category, geosurf, surface number, gain, orientation, shading device)
4. Optional equipment data and operating specifications including infiltration, ventilation, cooling, heating, gains and comfort.

The overall methodology of working with TRNSYS is shown in detail on **Chapter 4** of this report.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 LOCATION OF CASE STUDY HOUSE

A single storey terraced house (**Figure 4.1**) located in Bandar Seri Botani, Ipoh, Perak is selected as an objective building. The location map is as shown in **Figure 4.2**.

Figure 4.1: Actual house

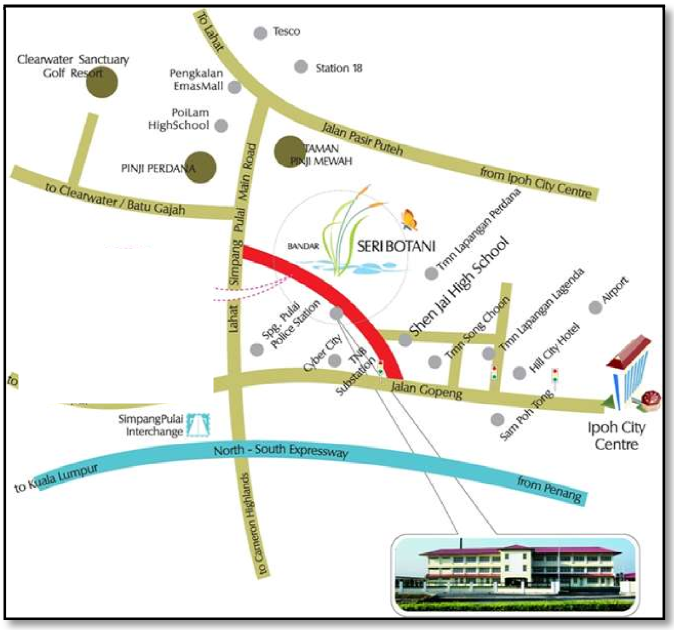

Figure 4.2: Location map of Bandar Seri Botani

4.2 DATA GATHERING AND ANALYSIS

The floor plan of the house is as shown in **Figure 4.3**. The representative family house model includes eight zones: the living room, the dining room, the kitchen, three bedrooms and two bathrooms. A family is composed of father, mother and two children.

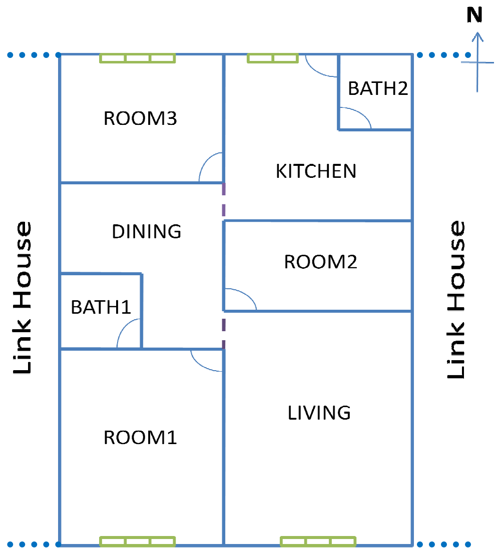

Figure 4.3: Model of a single storey house

The living space is about 90m^2 with a height of 2.7m. Analysis for this study is done on the house in the center of the link house, because the result of the simulation can be transferred easily to other 'center' units, where both ends of the array are considered similar to semi-detached houses and hence not practical. The house faces directly south and data concerning the single-storey terraced house is as follows:

i. Height of ceiling: 2.7 m
ii. Floor area:
  - Bedroom 1: 16.71 m^2 (3.05 m x 5.48 m)
  - Bedroom 2: 8.32 m^2 (2.28m x 3.65 m)
  - Bedroom 3: 12.57 m^2 (4.12 m x 3.05 m)
  - Living room: 22.77 m^2 (3.65 m x 6.24 m)
  - Kitchen: 14.92 m^2
  - Dining: 9.04 m^2
  - Bathroom 1: 2.55 m^2 (1.52 m x 1.68 m)

- Bathroom 2: 2.89 m^2 (2.14 m x 1.35 m)

iii. Window area, One panel: 0.74 m^2 (0.61 m x 1.22 m)

iv. Door area:

- Entrance: 1.64 m^2
- Bedrooms: 1.55 m^2
- Kitchen: 1.55 m^2
- Bathrooms: 1.55 m^2

Properties of building materials are as **Table 4.1**.

Table 4.1: Building specifications [17]

	Materials	Heat Transfer Coefficient (U-value), W/m^2K
Structure	Reinforced concrete frame	
Walls	Brickwork	2.683
Roof	Cement roofing tiles	1.943
Windows	Single glazed clear	5.680
Doors	Plywood/PVC	
Floor	Ceramic tiles Cement	3.998

4.3 TRNSYS SIMULATION

4.3.1 TRNBuild/TRNSYS Type 56

The simulation on a real model has been completed using TRNSYS type 56, which is one of the components to simulate building thermal balance of the multi-zone is used. The building model of Type 56 is non-geometrical balance model with one air node per zone. Thermal properties of building materials and input data are shown in **Table 4.1**. **Figure 4.4** is the interface of the TRNSYS Type 56.

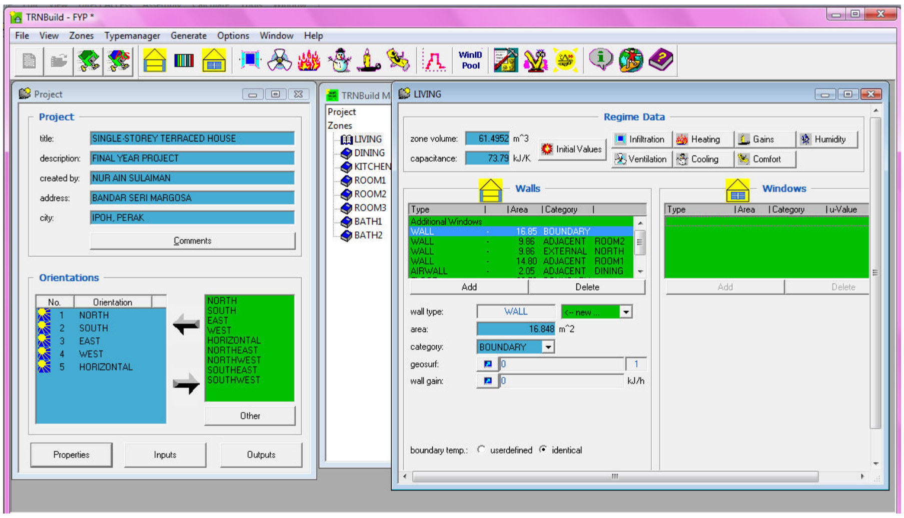

Figure 4.4: Screenshot of TRNSYS module (type 56)

The Ipoh weather data is used for this simulation and the meteorological data such wind direction and speed, air temperature, humidity and sunshine duration are used. $0.5h^{-1}$ of infiltration of air exchange by natural ventilation is assumed.

4.3.2 Simulation Studio

TRNSYS need three main parts before it can simulate the system in question, they are the model of the system, input/output parameters, and correlation of each part within the model. For this project, the following components are used in the simulation as shown in **Figure 4.5**:

i. Type 109 Weather data reader and processor

   This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces.

ii. Psychrometrics: Dry Bulb and Relative Humidity Known

   This component takes as input the dry bulb temperature and relative humidity of moist air and calls the TRNSYS Psychrometrics routine, returning the following corresponding moist air properties: dry bulb temperature, dew point temperature, wet bulb temperature, relative humidity, absolute humidity ratio, and enthalpy.

iii. Effective sky temperature for long-wave radiation exchange

This component determines an effective sky temperature, which is used to calculate the long-wave radiation exchange between an arbitrary external surface and the atmosphere. The effective sky temperature is always lower than the current ambient temperature. The black sky on a clear night for example, is assigned a low effective sky temperature to account for the additional radiative losses from a surface exposed to the sky. In this instance of Type69, the cloudiness of the sky is calculated based on user provided dry bulb and dew point temperatures.

iv. Multi-Zone Building

This component models the thermal behaviour of a building having up to 25 thermal zones. The building description is read by this component from a set of external files having the extensions *.bui, *.bld, and *.trn. The files can be generated based on user supplied information by running the preprocessor program called TRNBuild (known as Prebid in TRNSYS versions prior to the release of v. 16.0). This instance of Type56 generates its own set of monthly and hourly summary output files.

v. Online graphical plotter

The online graphics component is used to display selected system variables while the simulation is progressing. This component is highly recommended and widely used since it provides valuable variable information and allows users to immediately see if the system is not performing as desired. The selected variables will be displayed in a separate plot window on the screen.

vi. Printer: TRNSYS-supplied units printed to output file

The printer component is used to output (or print) selected system variables at specified intervals of time. In this mode, TRNSYS supplied units descriptors (kJ/hr, degC, W, etc.) if available, are printed to the output file along with each column heading. Output can be printed in even time intervals starting relative to the simulation start time or can be printed in absolute time.

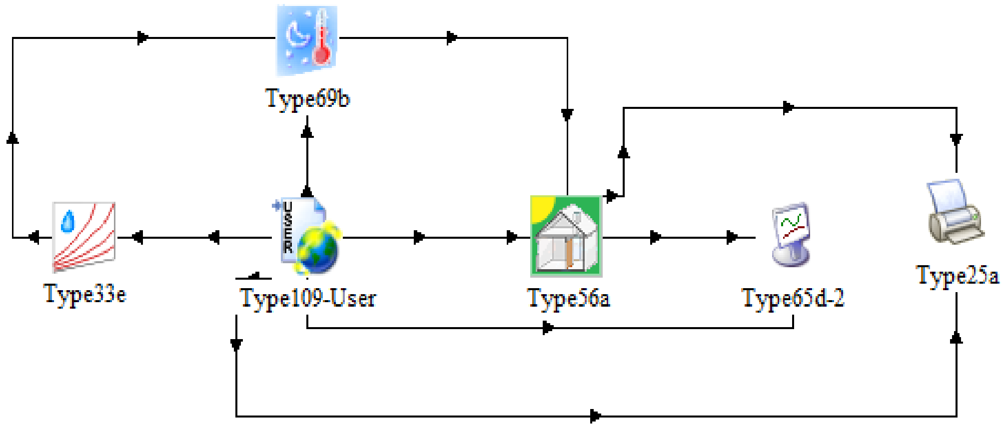

Figure 4.5: Simulation system

4.4 RESULTS AND DISCUSSIONS

The eight zones in the simulation will be defined as **Table 4.2** which are according to the zones' positions. But the author will only focusing on Living Room, Kitchen, Bedroom1 and Bedroom3 for the evaluation of energy flow as shown in **Figure 4.6**.

Table 4.2: Name of the zones in simulation system

Living	Living_S
Dining	Dining_M
Kitchen	Kitchen_N
Room1	Room1_S
Room2	Room2_M
Room3	Room3_N
Bath1	Bath1_M
Bath2	Bath2_N

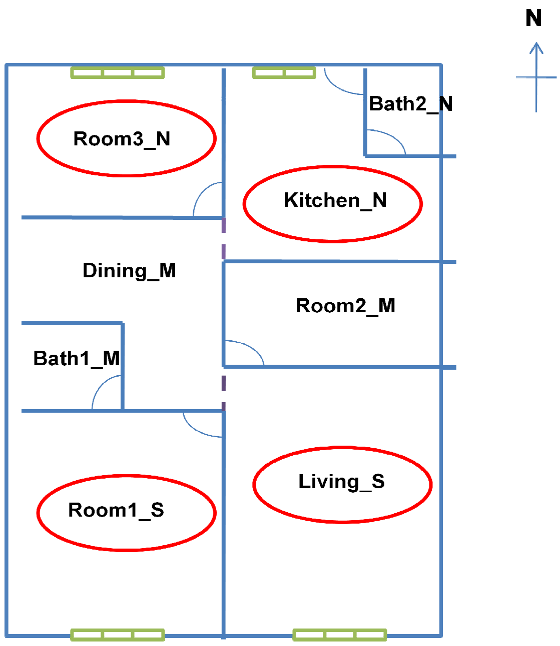

Figure 4.6: North and south zones under study

Inside the thermal zones, a change in thermal energy of a given mass results in a change of temperature. Thus, temperature is a good representative of thermal energy. Therefore, the author will use temperature graphs mostly to represent the thermal energy of the house.

The graph from **Figure 4.7** shows the relationship between relative humidity, ambient temperature and zones temperature of the house in January. The graphs shows that the inside temperature is slightly lower most of the time compared to the outside temperature. The zone temperature followed the same pattern with the ambient temperature but the temperature intervals within the zones are slightly smaller. The ambient temperature difference is about 12^{o}C which is three times greater than the temperature difference inside the house in January which is 3^{o}C. The temperature is high when the relative humidity is low and vice versa. The pattern is about the same for other months. The highest ambient temperature through out the year is 35^{0}C and the minimum is 21^{0}C. Inside the house, the temperature varies between 23^{0}C to 29^{0}C. The outside temperature difference is 14^{0}C while it is only 6^{0}C difference inside the house.

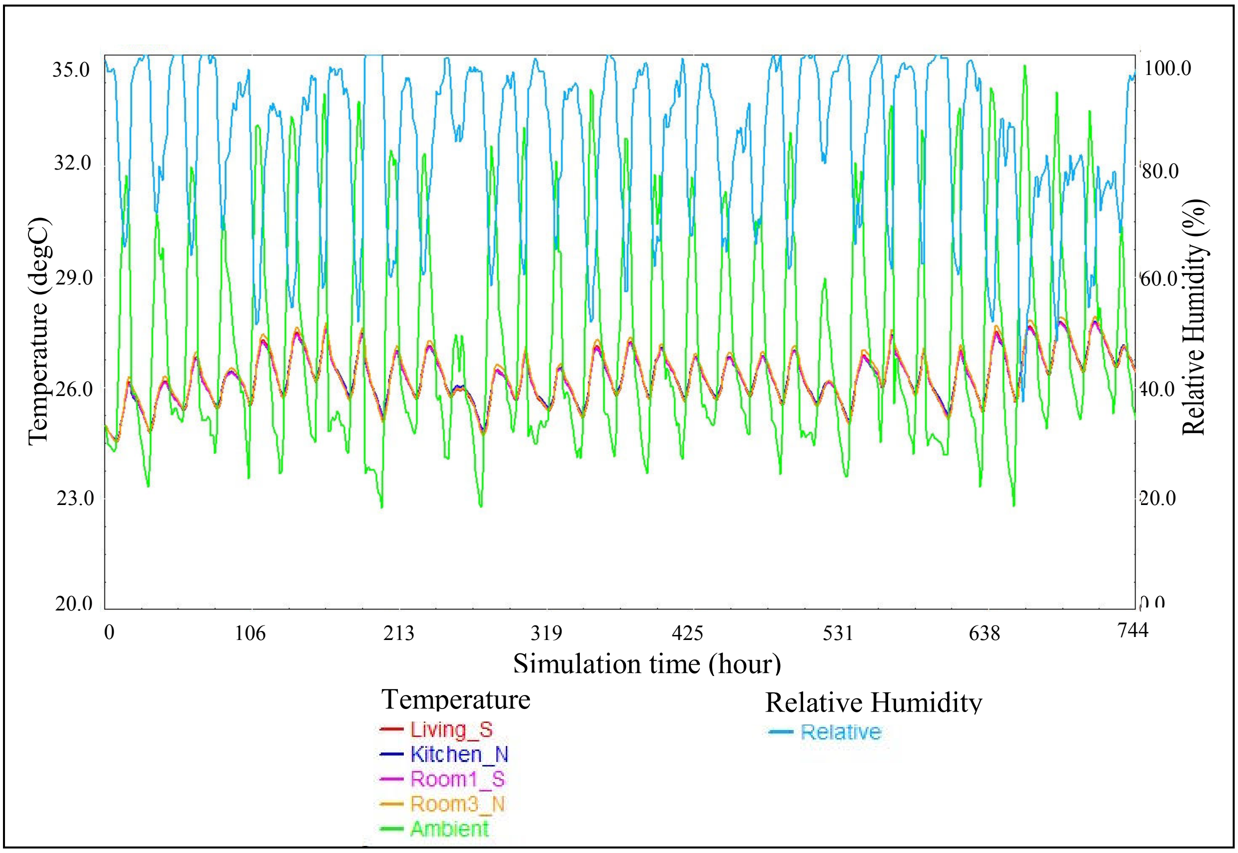

Figure 4.7: Relative Humidity, Ambient Temperature and Zones Temperature in January

The following **Figure 4.8** shows the temperature trend for each quarter of the year. The graphs show that the temperature is the lowest on December and the highest on March. It can be seen clearly from the graph plotted for a day in each quarter of the year (**Figure 4.9**).

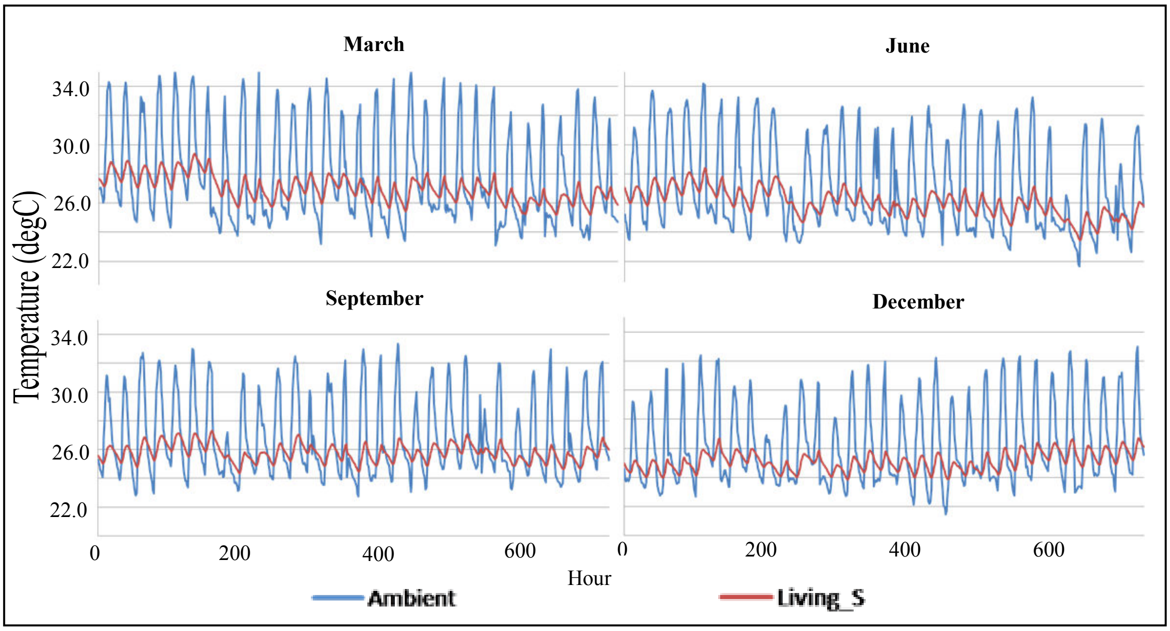

Figure 4.8: Temperature trend for a month in each quarter of the year

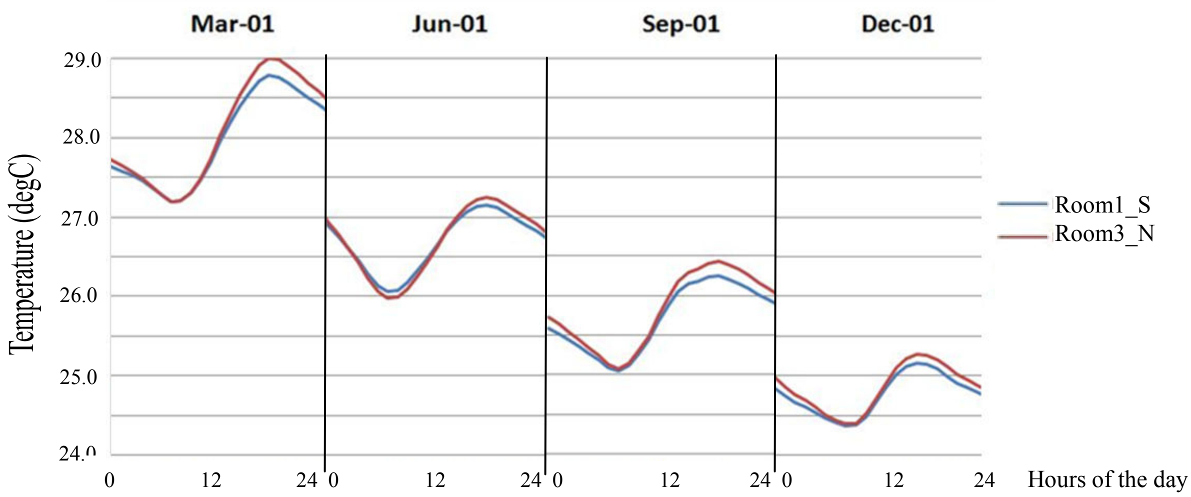

Figure 4.9: Temperature difference in north and south room

It can be seen that the temperature in the south room is slightly lower most of the time compare to the north room. From the graph, it can be said that north zone is cooler in the morning compare to south zone but in the evening, south zone is cooler than north zone.

When the house is empty and unoccupied, the monthly average temperature for each zone is lower than the ambient temperature for about 1^{0}C. It shows that to be inside the house is more comfortable than to be outside the house. Later in the report shows that these will change due to several factors that affect the energy flow inside the building.

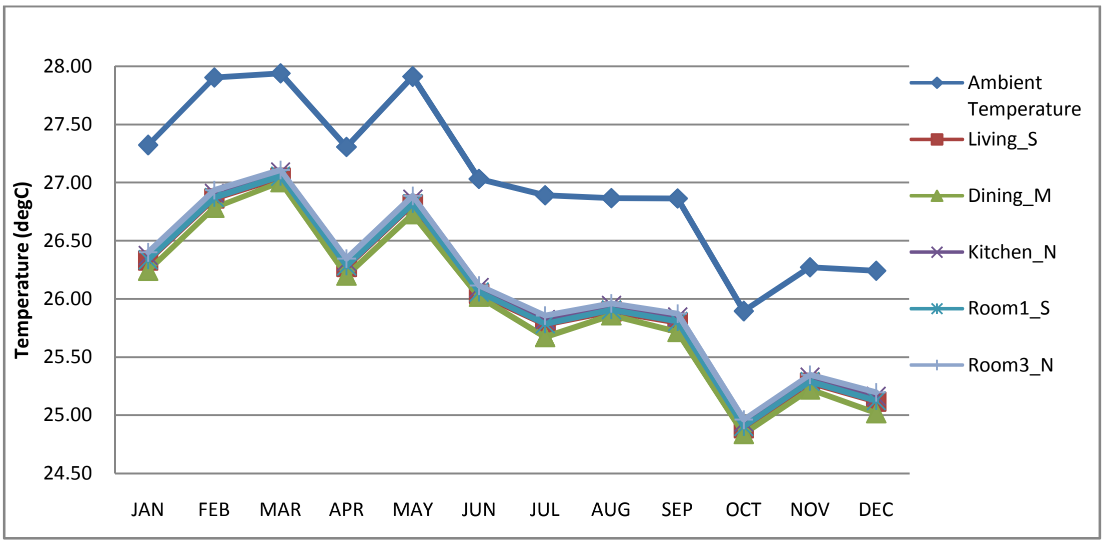

Figure 4.10: Monthly Average Temperature of the House

4.4.1 Factors Effecting Thermal Energy in the House

4.4.1.1 Occupancy and Electrical Appliances

The author studies the effect of occupancy and electrical appliances to the thermal energy inside the house using scheduling. A resident pattern, lighting and the heat emitted from electric appliances are controlled as shown in **Figure 4.11**, **Figure 4.12** and **Figure 4.13**.

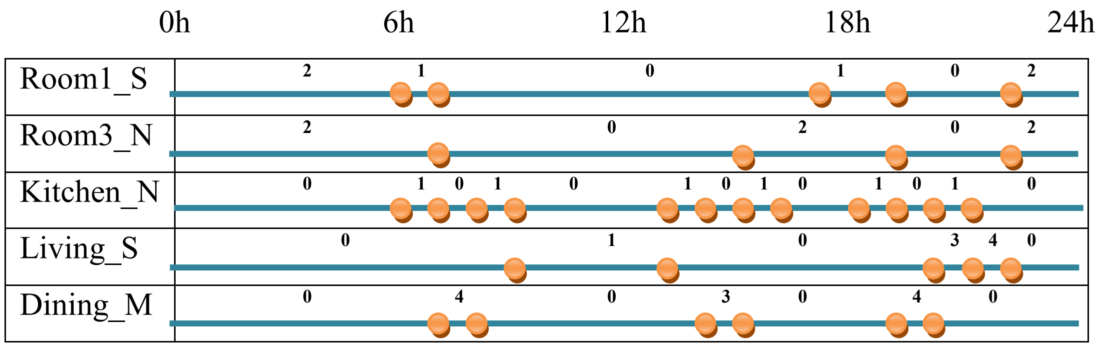

Figure 4.1: Occupancy schedule (Number of occupants in the zone)

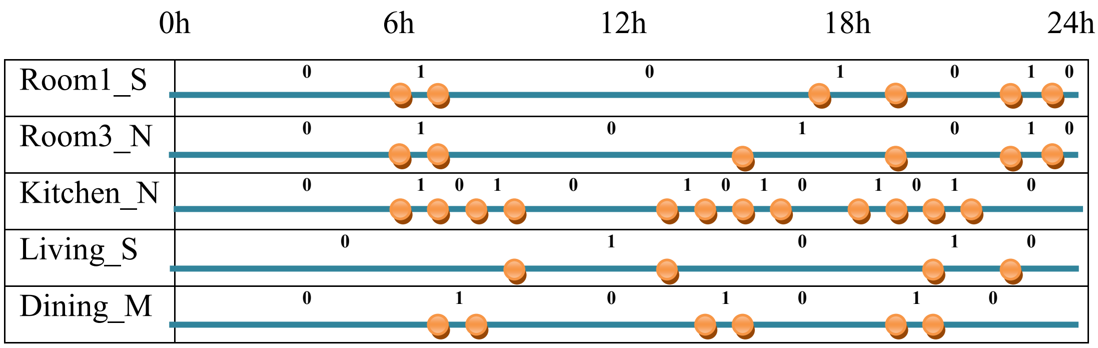

Figure 4.12: Lighting schedule (0 = Off, 1 = On)

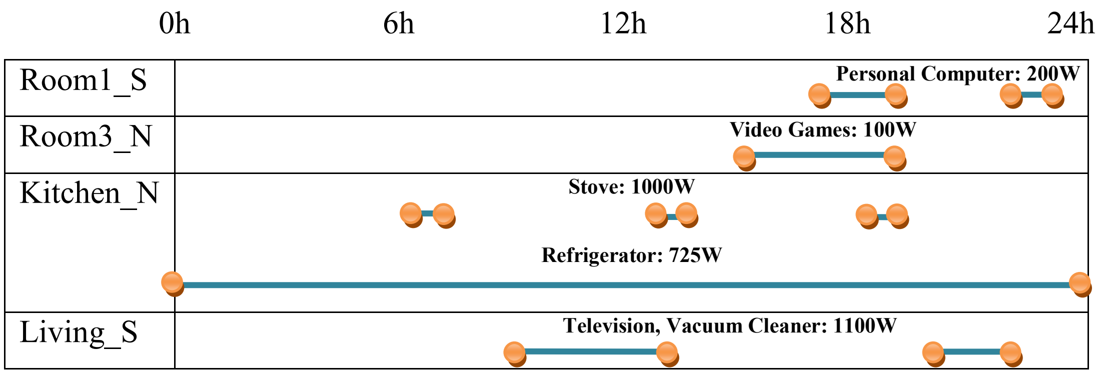

Figure 4.13: Electrical Appliances schedule

When there is an operation or activities within the house as specified earlier in terms of scheduling, the inside temperature increase about 1.5^{o}C from the temperature without any operation as shown in **Figure 4.14**. The temperature range becomes larger which is from a range of 2^{0}C to a range of 5.5^{0}C. The temperature inside the living room can go up until 33^{0}C when there are activities inside the house, which without any activities the temperature is only up until 29^{0}C.

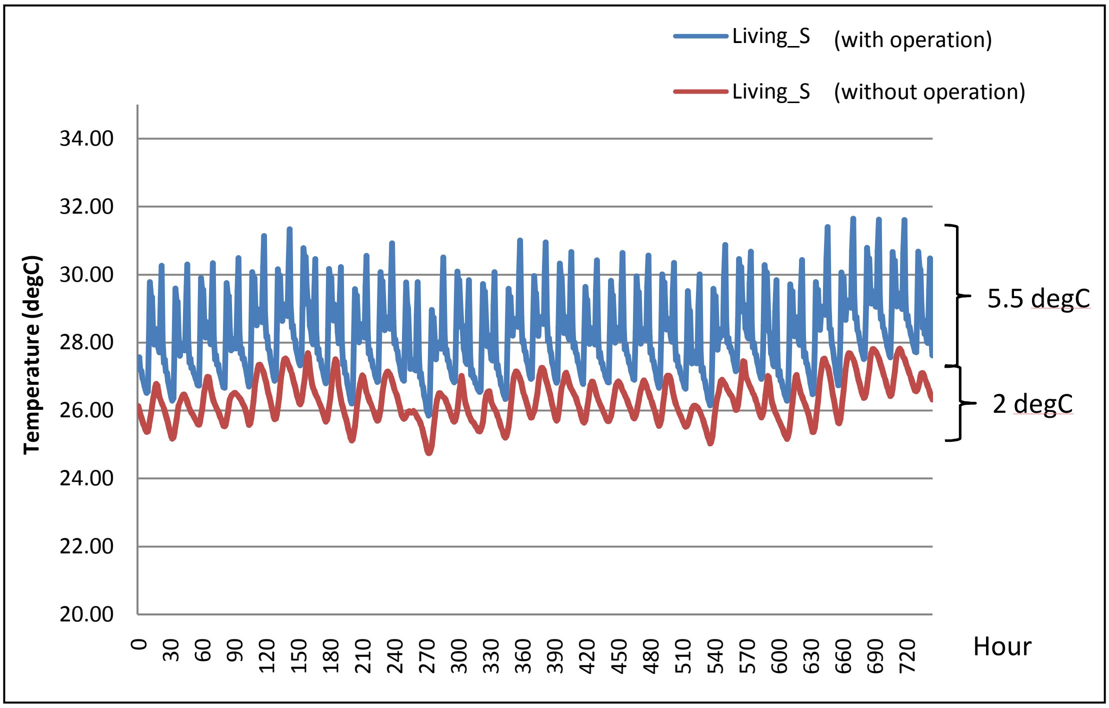

Figure 4.14: Temperature difference between no operation and with operation

Figure 4.15 shows a relation between electrical appliances and the temperature in the kitchen. The temperature rise when there is electrical appliance being used in the zone. The temperature increase is quite high which can go up to 3^{0}C.

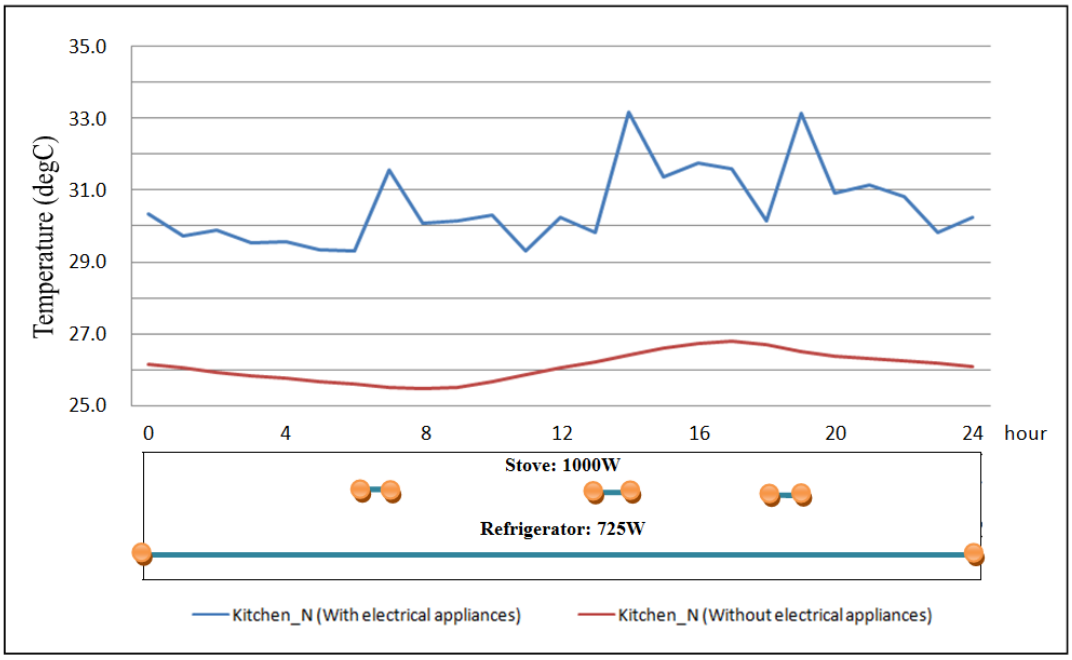

Figure 4.15: Relations between electrical appliances and zone temperature

Figure 4.16 shows the variations of temperature from outside (ambient) through the wall and to inside of the house. From the graph, the turning point of convective energy is at hour 1000 and hour 1800. The heat transfer through the wall can be seen clearly in **Figure 4.17** where it shows the cross section of the wall.

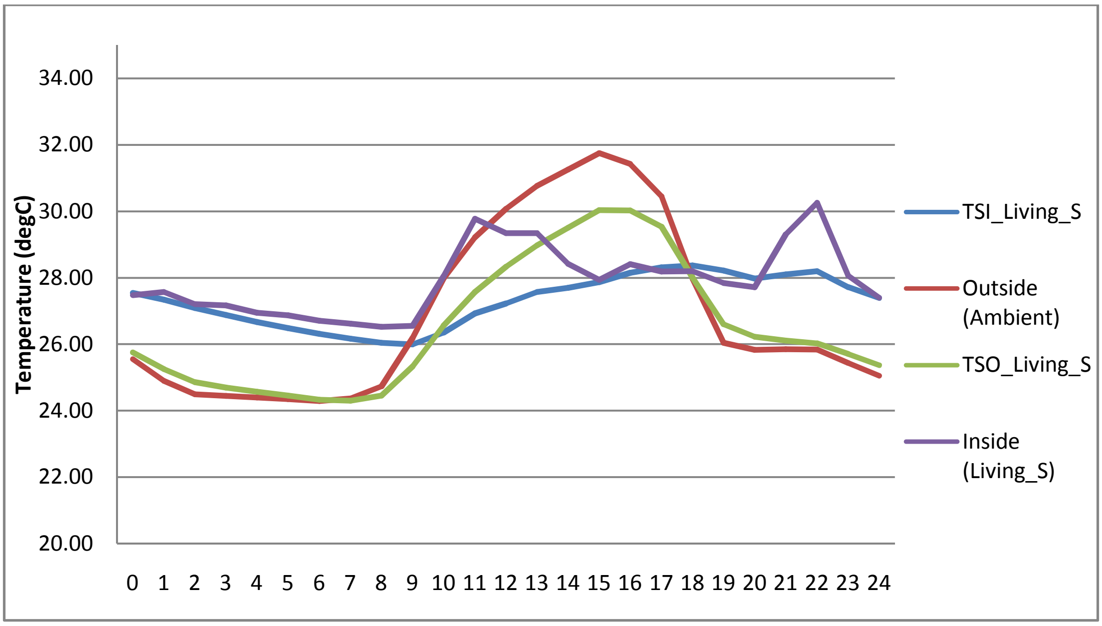

Figure 4.16: Temperature at outside, outer-wall, inner-wall and inside the house

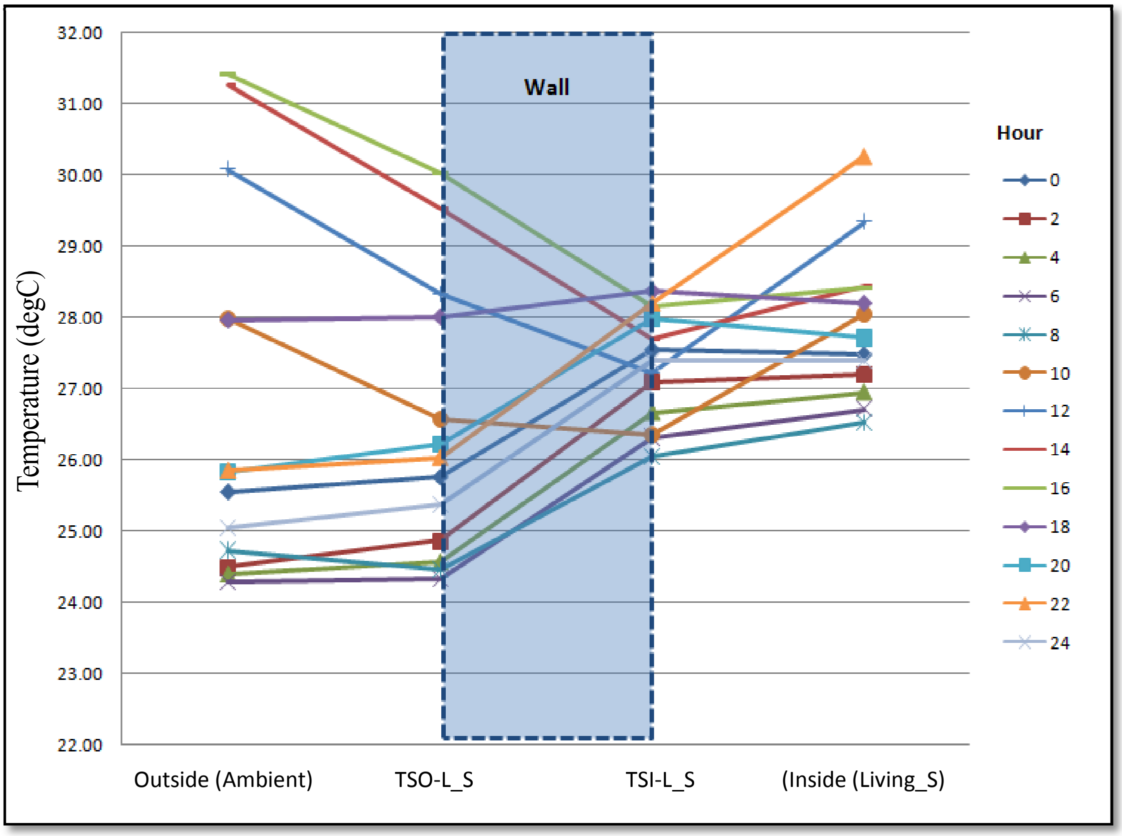

Figure 4.17: Temperature across the wall

There is a significant change in the monthly average temperature when the house is filled with two adults and two children along with the electrical appliances as shown in **Figure 4.18**. The temperature inside the house increases 1-3^{0}C above the ambient temperature. It shows that outside the house is cooler than inside the house. This is one of the possible causes for the increase in demand of air conditioning system in the house.

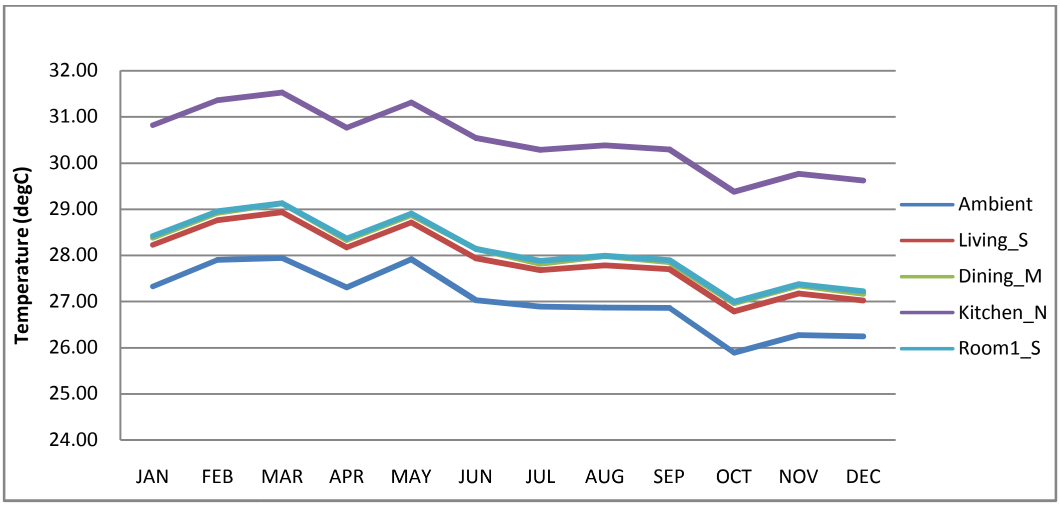

Figure 4.18: Monthly average temperature (with occupancy & electrical appliances)

The internal gain of zone is very high in the kitchen due to the used of electrical appliances as seen in **Figure 4.19**. The positive value indicates that the thermal energy flow around the house is higher than the energy flow out the house.

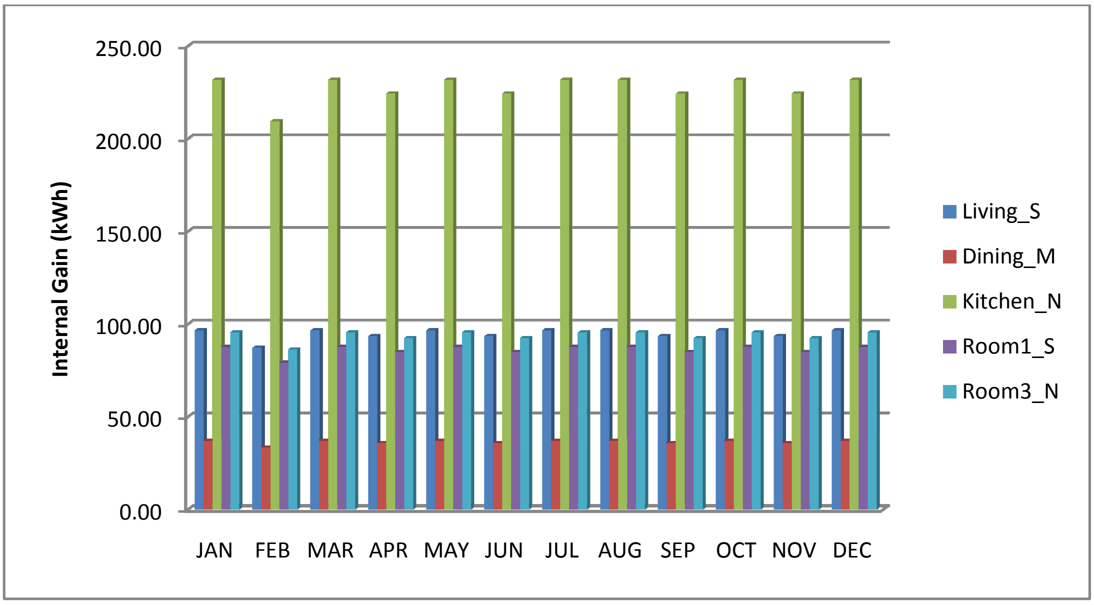

Figure 4.19: Internal Gain of zone

After the operating specification is brought into the simulation, the interval temperature within the house becomes 5-9^{0}C and the average temperature increases about 1.5^{0}C. It makes the inside temperature far above the comfort range and using air conditioning in this condition will increase the mechanical power of the machine resulting an increase in energy used.

Table 4.3: Maximum, minimum, median and average temperature

	Ambient	Living_S	Dining_M	Kitchen_N	Room1_S	Room2_N
Max (°C)	35.17	33.08	32.87	36.02	33.68	33.50
Min (°C)	21.48	24.54	25.34	27.21	25.17	25.07
Median (°C)	27.98	28.26	28.32	28.39	28.11	28.27
Average (°C)	27.03	27.90	28.07	30.50	28.10	28.51

The comfortable temperature in Malaysia is about 24^{0}C and based on **Table 4.3**, it shows that the average indoor air temperature is only about 4^{0}C above the comfort range.

4.4.1.2 Window System

The temperature inside the house is also affected by the time when the window is open or close. In this study, the author runs the simulation in two states which are:

i. State 1: Windows open at 7.00am until 7.00pm (day)
ii. State 2: Windows open at 7.00pm until 7.00am (night)

Figure 4.20 shows the effect of different opening time of windows to the inside temperature. At night, the heat usually flow from inside house to the outside house due to the outside temperature at night is lower than the inside temperature. Therefore, by opening the window at night make it easier for the air to flow inside the house. But since the weather in Malaysia is not extreme, window opening schedule does not give a big impact on temperature around the house.

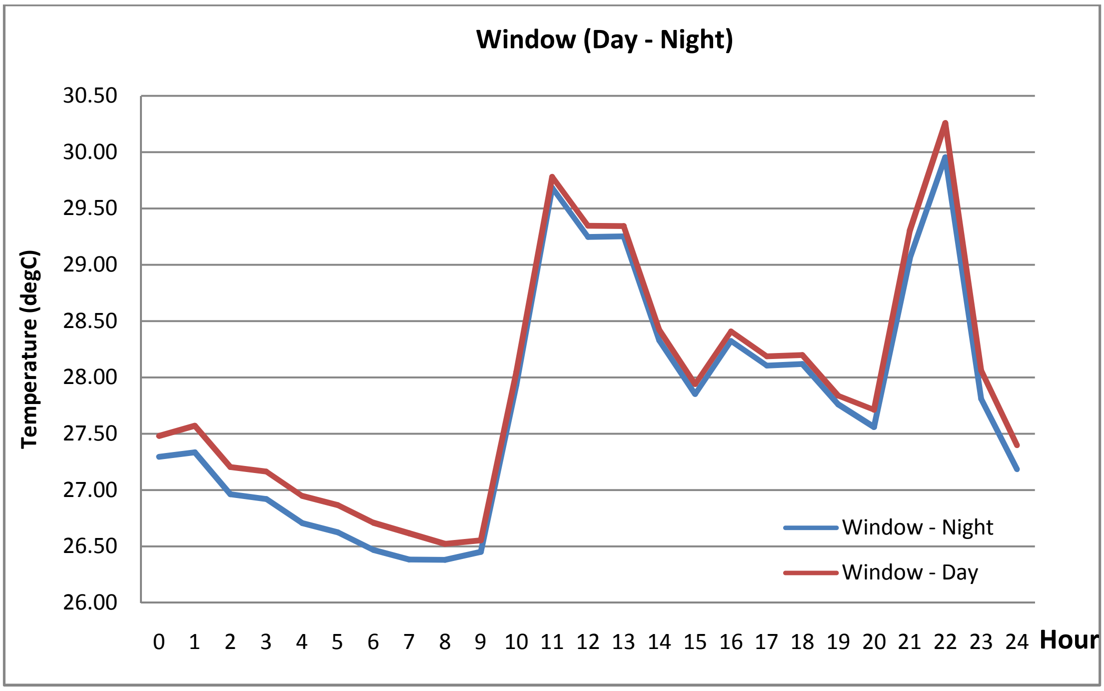

Figure 4.20: Effect of different windows opening time

The window area also affects the temperature inside the house. The author had set two (2) different window areas (**Table 4.4**) in the living room to check which area is giving a better result.

Table 4.4: Window areas

Original value (22.5% of wall area)	**2.22 m^2**
50% of wall area	4.94 m^2
75% of wall area	7.41 m^2

The graph comparing these three (3) different window areas is plotted as shown in **Figure 4.21**. From the graph it shown that the larger the window area, the greater the temperature during the daylight, while at night the larger window area give some advantage because the temperature drop a little. But, the temperature drop at night is smaller compared to the temperature rise during the day. Therefore, the smaller window area should be preferred for a house.

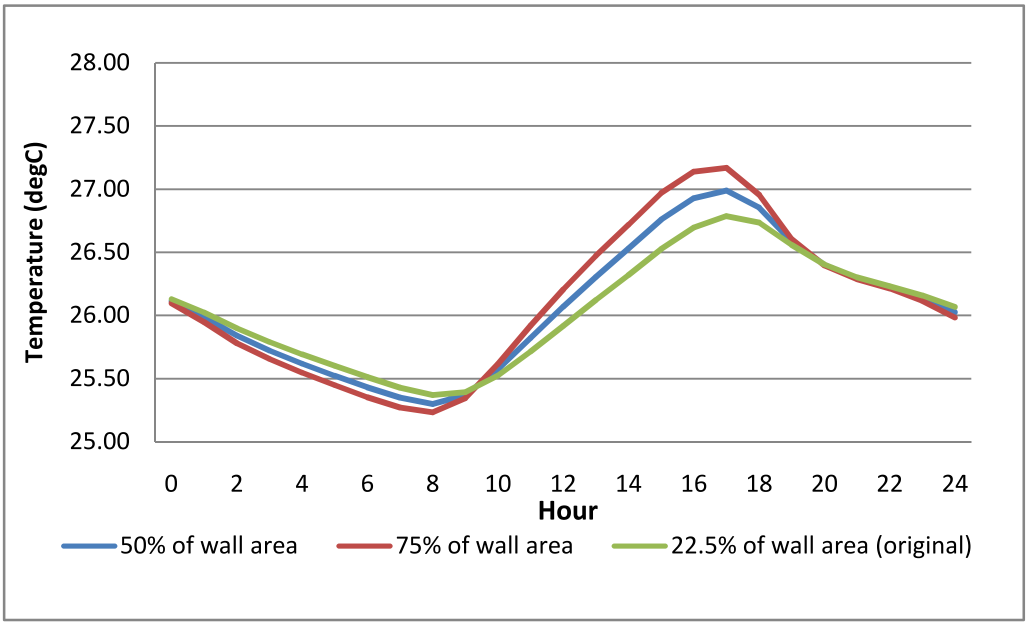

Figure 4.21: The differences in temperature for three different window areas

4.4.1.3 U-value

The author also study the effect of different U-value to the inside temperature. **Table 4.5** shows the design modification that has lower U-value.

Table 4.5: Building modification [17]

	Materials	Heat Transfer Coefficient (U-value), W/m^{2}K
Structure	reinforced concrete frame	
Walls	concrete	0.805
Roof	cement roofing tiles with insulation	0.987
Windows	single glazed clear	5.680
Doors	plywood/PVC	
Floor	ceramic tiles cement	1.223

Figure 4.22 shows the cross-section of the wall made of concrete. The temperature distribution inside the house is smaller. It shows that by lowering the U-value, it will help in maintaining a smaller range of temperature in the house.

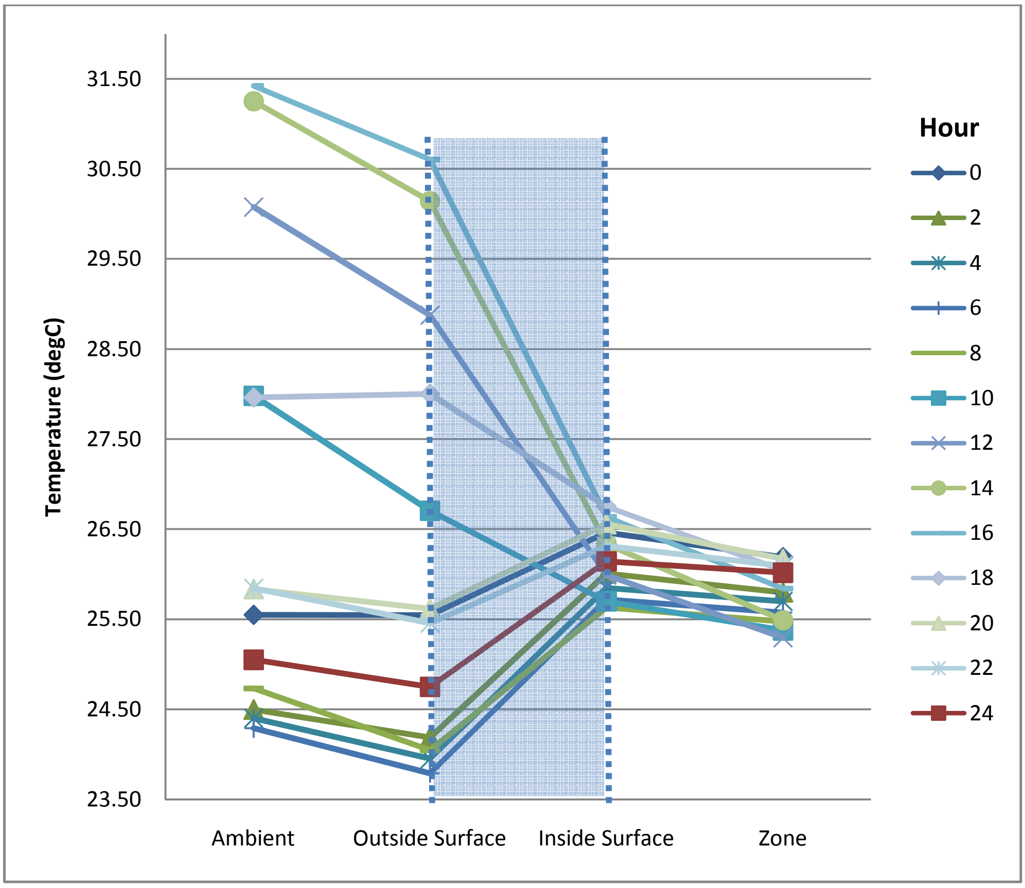

Figure 4.22: Cross-section of the alternate wall

This design modification is only applied to the external wall, the wall that is hit by solar radiation. The internal wall is the same as the original design.

4.4.2 Cooling Load

As stated before, the comfortable temperature is about 24^0C. The author will now compare the cooling load require in maintaining the house at 20^0C to 24^0C. The comparison will be between the original design and the modify design to find the design that is more energy conscious.

Figure 4.23 shows the cooling load at different temperature (20^0C – 24^0C) for both, original design and modify design. This cooling load is only applied to one zone which is the living room. The graph shows that the cooling load is increased when the temperature is decrease. It shows that to keep the room cooler required more work from the air conditioning resulting in higher cooling load. But, with the design modification, the cooling load is reduced. The differences between the cooling load for original design and modify design is quite big and in a long term, it will benefits the user more.

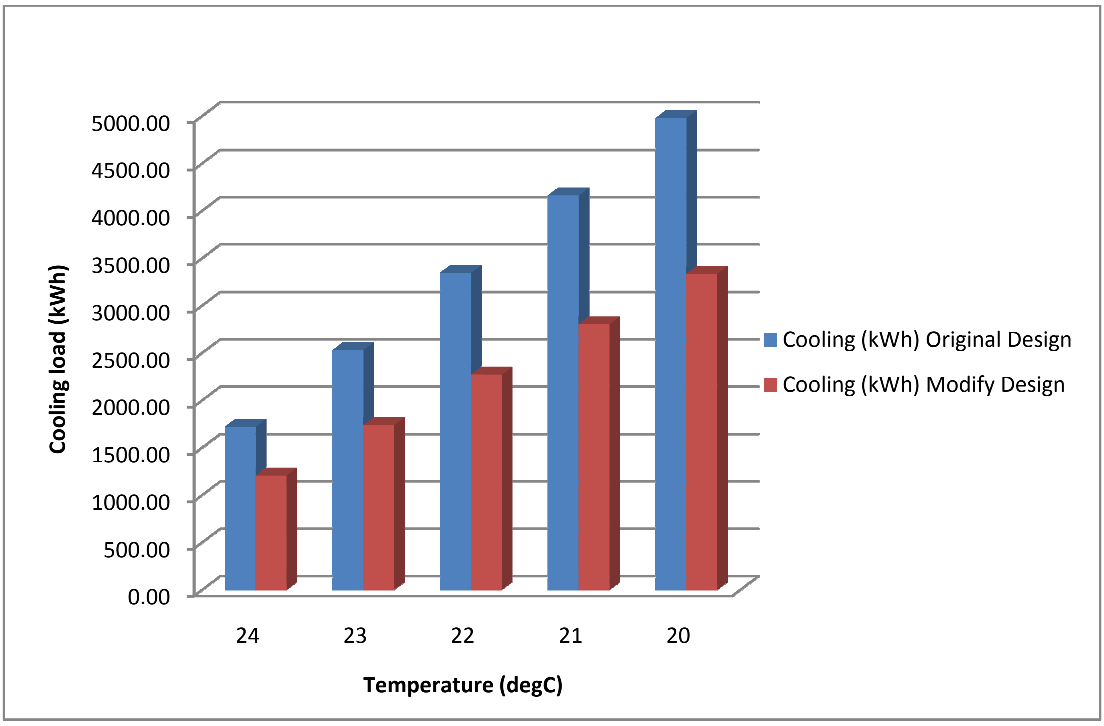

Figure 4.23: Cooling load at different temperature

Maintaining the house at 24^0C is the best way to reduce the energy consumption inside the house.

4.4.2.1 Cost Effectiveness

This section presents a feasibility study on the cost that can be saved by implementing the design modification. **Table 4.6** shows annual cooling load and energy saving at different temperatures. The annual energy saving is calculated as below:

- Energy saving = Cooling load (original design) – Cooling load (modify design)

Table 4.6: Cooling load at different temperature

Temperature (^{0}C)	24	23	22	21	20
Cooling (kWh) Original Design	1723.39	2532.50	3348.60	4165.00	4981.10
Cooling (kWh) Modify Design	1208.62	1740.37	2272.50	2804.90	3336.80
Energy saving (kWh)	514.77	792.13	1076.10	1360.10	1644.3

The tariff rates by Tenaga Nasional Berhad, Malaysia for the year 2010 for domestic consumer is as following for monthly consumption between 0-400 kWh/month:

i. For the first 200 kWh (1 - 200 kWh) per month: 21.8 sen/kWh
ii. For the next 200 kWh (201 -400 kWh) per month: 33.0 sen/kWh

Assuming that the monthly consumption is between 1-200 kWh, the cost saving for each of the temperature alternatives are:

Table 4.7: Cost saving

Temperature (^{0}C)	24	23	22	21	20
Annual Energy saving (kWh)	514.77	792.13	1076.10	1360.10	1644.3
Cost saving, Energy x RM 0.218/kWh (RM)	112.22	172.68	234.59	296.50	358.46

As shown in the above table, the consumers can save up to RM 358.50 per year. The number might be small but in a long term it will save a lot of money and also save the environment.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

5.1 CONCLUSSIONS

There are a lot of methods that can be used to reduce the energy consumption of the house. By performing transient simulation, several factors have been identified to be implemented for energy saving. Understanding these factors will help in finding the low energy design strategies and it is a better solution for a sustainable future.

Originally, the inside temperature of the house is smaller than the outside temperature making it a comfort place to stay than staying outside. But, the need of doing some activities and having some electrical appliances at home has made the temperature inside the house increased insignificantly. Everyday, there are new technology being developed and choosing the right equipment that is using lower energy is important in determining the condition inside the house because clearly the temperatures inside the house is greatly determined by the activities and operating conditions of the house.

Correct opening schedules of windows will help in getting lower temperature inside the house. Windows area also gives some impact on the inside temperature. Furthermore, finding the thermally efficient construction that has lower U-value will definitely help in increasing the comfort.

The comfortable temperature is about 24°C and the average indoor air temperature is only about 4°C above the comfort range. As Malaysians, being acclimatised to hot and humid climates are able to tolerate much higher temperatures and by increasing the upper limit of the comfort range would result in greater energy savings. Therefore, higher set point temperatures of air conditioning will very much help in energy saving.

5.2 RECOMMENDATIONS

For future improvement, further analysis should be done on other non-design factors such as occupancy and management; site planning and microclimate; and plantation. By combining both the design and non-design factors in the studies, it will help in developing a passive design that will maximize the use of natural and fan assisted ventilation and friendlier methods for sustainable future. To test the effectiveness of the design modification, the physical monitoring should be done to both the typical Malaysian house and the designing house. Finally, a smart control system of the energy use in the house can be developed after all the factors have been taken into consideration.

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APPENDICES

APPENDIX A

User Information (TRNSYS-TRNBuild)

```
**************************************************************************************************
**************************************************************************************************
*  TRNBuild   1.0.94
**************************************************************************************************
**************************************************************************************************
*   BUILDING DESCRIPTIONS FILE TRNSYS
*   FOR BUILDING:   C:\Users\ain\Desktop\1 year simulation\FYP Single Storey House (Ipoh) 1 year without any
operation\FYP Single Storey House.inf
*   GET BY WORKING WITH TRNBuild 1.0 for Windows
**************************************************************************************************
**************************************************************************************************
*
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
* C o m m e n t s
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
* P r o j e c t
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
*+++ PROJECT
*+++ TITLE=FYP SINGLE STOREY HOUSE
*+++ DESCRIPTION=TEST - 10
*+++ CREATED=NUR AIN BINTI SULAIMAN
*+++ ADDRESS=IPOH
*+++ CITY=IPOH
*+++ SWITCH=UNDEFINED
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
* P r o p e r t i e s
*---------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------
PROPERTIES
 DENSITY=1.204 : CAPACITY=1.012 : HVAPOR=2454.0 : SIGMA=2.041e-007 : RTEMP=293.15
*--- alpha calculation -------------------
 KFLOORUP=7.2 : EFLOORUP=0.31 : KFLOORDOWN=3.888 : EFLOORDOWN=0.31
 KCEILUP=7.2 : ECEILUP=0.31 : KCEILDOWN=3.888 : ECEILDOWN=0.31
 KVERTICAL=5.76 : EVERTICAL=0.3
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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TYPES
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*
*---------------------------------------------------------------------------------------------------------------------------------------------------
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* L a y e r s
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---------------------------------------------
LAYER PLASTER_CE
 CONDUCTIVITY=   1.26 : CAPACITY=   0.84 : DENSITY=   1200
LAYER BRICKS
 CONDUCTIVITY=   4.68 : CAPACITY=   0.84 : DENSITY=   2000
LAYER CONCSLAB
 CONDUCTIVITY=   4.07 : CAPACITY=      1 : DENSITY=   1400
LAYER TILE
 CONDUCTIVITY=    3.6 : CAPACITY=      1 : DENSITY=   2000
LAYER PLASTERBRD
 CONDUCTIVITY=   0.58 : CAPACITY=   0.84 : DENSITY=    950
LAYER AIRSPACE
 RESISTANCE=    0.044
LAYER CLAY_TILES
 CONDUCTIVITY=      3 : CAPACITY=   0.84 : DENSITY=   1700
LAYER AIRWALL
 CONDUCTIVITY=   0.03 : CAPACITY=      1 : DENSITY=    1.2
```

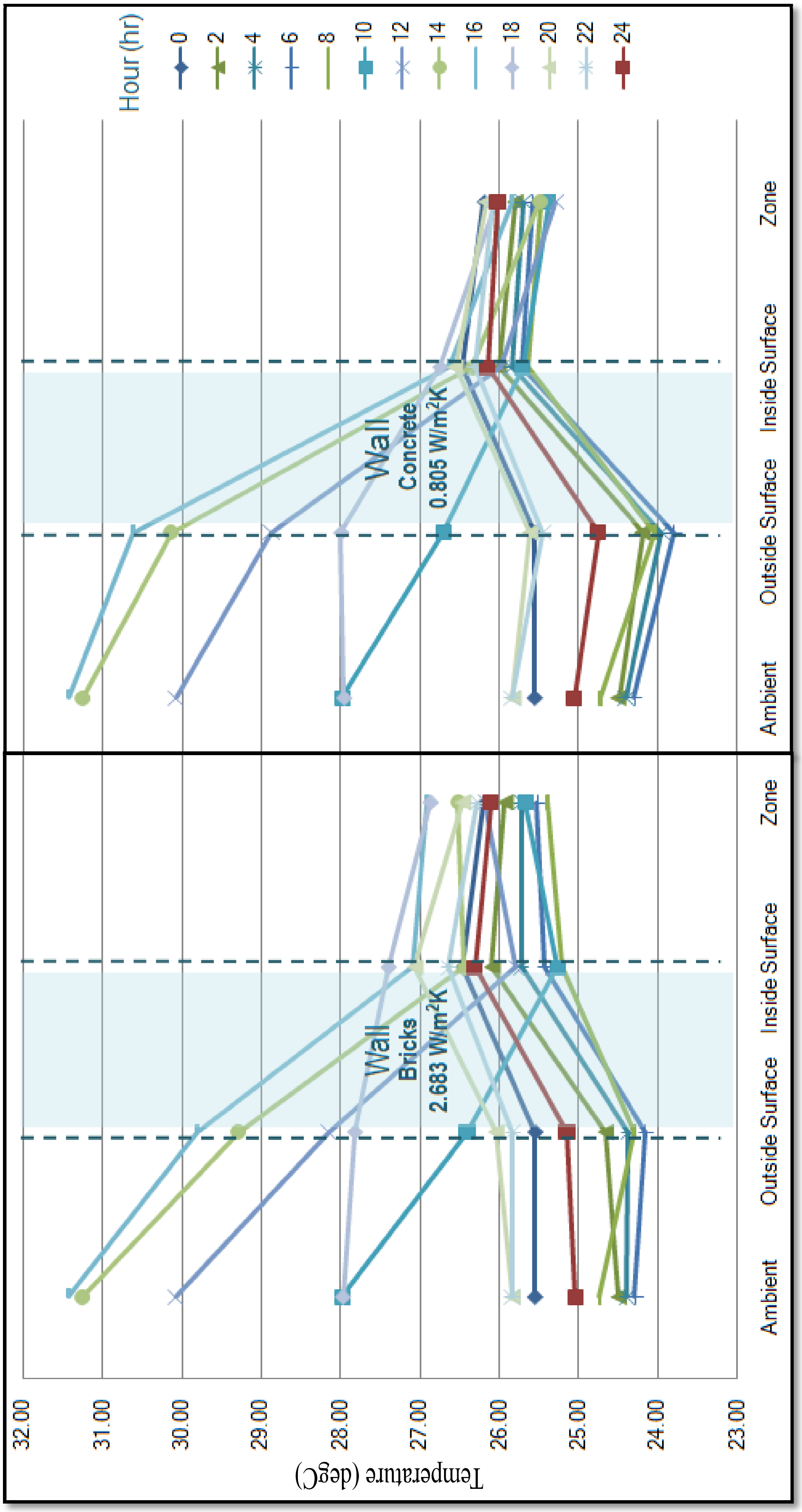
```
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* I n p u t s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------

*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* S c h e d u l e s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* W a l l s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
WALL WALL
 LAYERS   = PLASTER_CE BRICKS PLASTER_CE
 THICKNESS= 0.02       0.115  0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 11 : HBACK= 64
WALL FLOOR
 LAYERS   = CONCSLAB TILE
 THICKNESS= 0.08     0.01
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 11
WALL ROOF
 LAYERS   = PLASTERBRD AIRSPACE CLAY_TILES
 THICKNESS= 0.025      0        0.025
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 11 : HBACK= 64
WALL INNER_WALL
 LAYERS   = PLASTER_CE BRICKS PLASTER_CE
 THICKNESS= 0.02       0.115  0.02
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 11 : HBACK= 11
WALL AIRSPACE
 LAYERS   = AIRWALL
 THICKNESS= 0.155
 ABS-FRONT= 0.6   : ABS-BACK= 0.6
 HFRONT   = 0 : HBACK= 0
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* W i n d o w s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
WINDOW SINGLE
 WINID=1001 : HINSIDE=11 : HOUTSIDE=64 : SLOPE=90 : SPACID=0 : WWID=0 : WHEIG=0 : FFRAME=0.15 :
UFRAME=8.17 : ABSFRAME=0.6 : RISHADE=0 : RESHADE=0 : REFLISHADE=0.5 : REFLOSHADE=0.1 :
CCISHADE=0.5
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONES LIVING_S DINING_M KITCHEN_N ROOM1_S ROOM2_M ROOM3_N BATH1_M BATH2_N
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* O r i e n t a t i o n s
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ORIENTATIONS NORTH SOUTH EAST WEST HORIZONTAL
*
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++
BUILDING
*++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++
*
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e LIVING_S / A i r n o d e LIVING_S
*------------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
```

```
ZONE LIVING_S
AIRNODE LIVING_S
WALL  =WALL       : SURF=  1 : AREA=     2.47 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=SINGLE     : SURF=  2 : AREA=     7.41 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =INNER_WALL : SURF=  3 : AREA=    16.87 : BOUNDARY=IDENTICAL
WALL  =INNER_WALL : SURF=  4 : AREA=     9.88 : ADJACENT=ROOM2_M : FRONT
WALL  =AIRSPACE   : SURF=  6 : AREA=     2.06 : ADJACENT=DINING_M : FRONT
WALL  =INNER_WALL : SURF=  8 : AREA=    14.81 : ADJACENT=ROOM1_S : FRONT
WALL  =ROOF       : SURF= 10 : AREA=    22.85 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 11 : AREA=    22.85 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 74.04   : VOLUME= 61.7    : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  DINING_M  /  A i r n o d e  DINING_M
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE DINING_M
AIRNODE DINING_M
WALL  =AIRSPACE   : SURF=  7 : AREA=     2.06 : ADJACENT=LIVING_S : BACK
WALL  =INNER_WALL : SURF= 12 : AREA=     6.17 : ADJACENT=ROOM2_M : FRONT
WALL  =AIRSPACE   : SURF= 14 : AREA=     2.06 : ADJACENT=KITCHEN_N : FRONT
WALL  =INNER_WALL : SURF= 16 : AREA=     8.23 : ADJACENT=ROOM3_N : FRONT
WALL  =INNER_WALL : SURF= 18 : AREA=     5.76 : BOUNDARY=IDENTICAL
WALL  =INNER_WALL : SURF= 19 : AREA=     4.11 : ADJACENT=BATH1_M : FRONT
WALL  =INNER_WALL : SURF= 21 : AREA=     4.53 : ADJACENT=BATH1_M : FRONT
WALL  =INNER_WALL : SURF= 23 : AREA=     4.12 : ADJACENT=ROOM1_S : FRONT
WALL  =ROOF       : SURF= 25 : AREA=     9.06 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 26 : AREA=     9.06 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 29.35   : VOLUME= 24.46   : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  KITCHEN_N  /  A i r n o d e  KITCHEN_N
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE KITCHEN_N
AIRNODE KITCHEN_N
WALL  =AIRSPACE   : SURF= 15 : AREA=     2.06 : ADJACENT=DINING_M : BACK
WALL  =INNER_WALL : SURF= 27 : AREA=     8.23 : ADJACENT=ROOM3_N : FRONT
WALL  =WALL       : SURF= 29 : AREA=     3.95 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=SINGLE     : SURF= 61 : AREA=     2.22 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =INNER_WALL : SURF= 30 : AREA=     2.88 : ADJACENT=BATH2_N : FRONT
WALL  =INNER_WALL : SURF= 32 : AREA=      3.7 : ADJACENT=BATH2_N : FRONT
WALL  =INNER_WALL : SURF= 34 : AREA=     7.41 : BOUNDARY=IDENTICAL
WALL  =INNER_WALL : SURF= 35 : AREA=     9.88 : ADJACENT=ROOM2_M : FRONT
WALL  =ROOF       : SURF= 37 : AREA=    12.47 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 38 : AREA=    12.47 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 40.4    : VOLUME= 33.67   : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  ROOM1_S  /  A i r n o d e  ROOM1_S
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE ROOM1_S
AIRNODE ROOM1_S
WALL  =INNER_WALL : SURF=  9 : AREA=    14.81 : ADJACENT=LIVING_S : BACK
WALL  =INNER_WALL : SURF= 24 : AREA=     4.12 : ADJACENT=DINING_M : BACK
WALL  =INNER_WALL : SURF= 39 : AREA=     4.11 : ADJACENT=BATH1_M : FRONT
WALL  =INNER_WALL : SURF= 41 : AREA=    14.81 : BOUNDARY=IDENTICAL
WALL  =WALL       : SURF= 42 : AREA=     6.01 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WINDOW=SINGLE     : SURF= 62 : AREA=     2.22 : EXTERNAL : ORI=SOUTH : FSKY=0.5
WALL  =ROOF       : SURF= 43 : AREA=    16.72 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 44 : AREA=    16.72 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 54.17   : VOLUME= 45.14   : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  ROOM2_M  /  A i r n o d e  ROOM2_M
*------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE ROOM2_M
AIRNODE ROOM2_M
WALL  =INNER_WALL : SURF=  5 : AREA=     9.88 : ADJACENT=LIVING_S : BACK
WALL  =INNER_WALL : SURF= 13 : AREA=     6.17 : ADJACENT=DINING_M : BACK
```

```
WALL  =INNER_WALL : SURF= 36 : AREA=      9.88 : ADJACENT=KITCHEN_N : BACK
WALL  =INNER_WALL : SURF= 45 : AREA=      6.17 : BOUNDARY=IDENTICAL
WALL  =ROOF       : SURF= 46 : AREA=      8.36 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 47 : AREA=      8.36 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 27.08   : VOLUME= 22.57   : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  ROOM3_N  /  A i r n o d e  ROOM3_N
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE ROOM3_N
AIRNODE ROOM3_N
WALL  =INNER_WALL : SURF= 17 : AREA=      8.23 : ADJACENT=DINING_M : BACK
WALL  =INNER_WALL : SURF= 28 : AREA=      8.23 : ADJACENT=KITCHEN_N : BACK
WALL  =WALL       : SURF= 48 : AREA=      2.88 : EXTERNAL : ORI=EAST : FSKY=0.5
WALL  =WALL       : SURF= 49 : AREA=      6.01 : EXTERNAL : ORI=NORTH : FSKY=0.5
WINDOW=SINGLE     : SURF= 63 : AREA=      2.22 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =INNER_WALL : SURF= 50 : AREA=     11.11 : BOUNDARY=IDENTICAL
WALL  =ROOF       : SURF= 51 : AREA=     12.54 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 52 : AREA=     12.54 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 40.63   : VOLUME= 33.86   : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  BATH1_M  /  A i r n o d e  BATH1_M
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE BATH1_M
AIRNODE BATH1_M
WALL  =INNER_WALL : SURF= 20 : AREA=      4.11 : ADJACENT=DINING_M : BACK
WALL  =INNER_WALL : SURF= 22 : AREA=      4.53 : ADJACENT=DINING_M : BACK
WALL  =INNER_WALL : SURF= 40 : AREA=      4.11 : ADJACENT=ROOM1_S : BACK
WALL  =INNER_WALL : SURF= 53 : AREA=      4.53 : BOUNDARY=IDENTICAL
WALL  =ROOF       : SURF= 54 : AREA=      2.55 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 55 : AREA=      2.55 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 8.27    : VOLUME= 6.89    : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* Z o n e  BATH2_N  /  A i r n o d e  BATH2_N
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
ZONE BATH2_N
AIRNODE BATH2_N
WALL  =INNER_WALL : SURF= 31 : AREA=      2.88 : ADJACENT=KITCHEN_N : BACK
WALL  =INNER_WALL : SURF= 33 : AREA=       3.7 : ADJACENT=KITCHEN_N : BACK
WALL  =WALL       : SURF= 56 : AREA=      2.88 : EXTERNAL : ORI=WEST : FSKY=0.5
WALL  =WALL       : SURF= 57 : AREA=       3.7 : EXTERNAL : ORI=NORTH : FSKY=0.5
WALL  =INNER_WALL : SURF= 58 : AREA=      5.76 : BOUNDARY=IDENTICAL
WALL  =ROOF       : SURF= 59 : AREA=      2.93 : EXTERNAL : ORI=HORIZONTAL : FSKY=1
WALL  =FLOOR      : SURF= 60 : AREA=      2.93 : BOUNDARY=IDENTICAL
 REGIME
 CAPACITANCE = 9.49    : VOLUME= 7.91    : TINITIAL= 25      : PHINITIAL= 90      : WCAPR= 1
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* O u t p u t s
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
OUTPUTS
 TRANSFER : TIMEBASE=1.000
 DEFAULT
 AIRNODES = LIVING_S DINING_M KITCHEN_N ROOM1_S ROOM2_M ROOM3_N BATH1_M BATH2_N
 NTYPES =   1 : TAIR - air temperature of zone
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
* E n d
*--------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------
END
```

Temperature across the wall for two different types of materials



Screenshot of Simulation Studio - Result