AIR AND TEMPERATURE FLOW DISTRIBUTION INSIDE TERRACE HOUSE

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DECLARATION

I hereby, declared this report Air and Temperature flow distribution inside terrace house is the results of my own research except as cited in references.

Signature: ……………………………………….

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APPROVAL

This report is submitted to the Faculty of Mechanical Engineering of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Honours. The member of the supervisory is as follow:

Signature: ……………………………………………….

Supervisor: Dr. Ernie Binti Mat Tokit

Date:

DEDICATION

To my beloved parents

(Mutussin Bin Junaidil and Setih Harija Binti Abd Hamid)

My beloved family,

(Muhammad Fakhruz Razi Bin Mutussin, Siti Nur Farahdiyana Binti Mutussin, Muhammad Fakhrul Haiyin Bin Mutussin, Siti Nur Farhain Binti Mutussin, Muhammad Fakhrul Iman Bin Mutussin and Muhammad Fakhrul Naim Bin Mutussin)

My Supervisor,

(Dr. Ernie Binti Mat Tokit)

My lectures,

And all my beloved friends

(Azrin Ahmadin, Mohamad Ikhwan Bin Mohamed Razak, Syafiq Firdaus, Mad Haniff bin Mad Rasi, Rais Adham, Azamuddin Nasir, Muthana Jumadil, Ahmad Afiq Amsyar dan Mohd Zairunshah Bin Bernados)

ABSTRACT

Thermal comfort can be a problem for the occupants of many residential buildings, especially for terrace house, in hot and humid climates. This paper therefore presents the results of ongoing research to investigate the distribution of air and temperature flow within the terrace house. The purpose is to achieve thermal comfort level in Malaysia's naturally ventilated residential house using computational fluid dynamics (CFD) method. CFD simulations on the house model allow us to visualize the house's temperature distribution and air flow pattern and velocity. The house's thermal comfort was found to be well beyond the limits set by ASHRAE standards. Simulations were used to investigate the effects of changing the terrace house's wall height. However, there is almost no significant change in the house's temperature distribution and air flow velocity. Result also shows that the use of two air conditioners installed on the front and back walls has significant effects on temperature distribution where the average temperature is 26.3ºC but still higher air velocity which is 3.1m/s than that specified by ASHRAE. Thus, the thermal comfort level in the house is not achieved.

ABSTRAK

Dalam iklim panas dan lembap, keselesaan haba boleh menjadi masalah kepada kediaman yang mempunyai banyak penduduk terutamanya bagi rumah teres. Oleh itu, kerja ini membentangkan hasil karya penyelidikan yang berterusan untuk menganalisis pengedaran aliran udara dan suhu di dalam rumah teres. Ini bertujuan untuk mencapai tahap keselesaan haba di dalam rumah yang menggunakan pengudaraan secara semula jadi di Malaysia dengan menggunakan kaedah dinamik bendalir berkomputer (CFD). Simulasi CFD terhadap model rumah teres itu membolehkan kita menggambarkan taburan suhu dan corak pengaliran udara dan halaju udara di dalam rumah. Didapati keselesaan haba di dalam rumah melebihi batas yang ditetapkan oleh piawaian ASHRAE. Simulasi digunakan untuk mengkaji kesan perubahan pada ketinggian dinding rumah teres. Walau bagaimanpun, hampir tidak menunjukkan perubahan yang ketara pada taburan suhu dan halaju aliran udara di dalam rumah. Keputusan juga menunjukkan bahawa penggunaan dua penghawa dingin yang di pasang pada bahagian depan dan belakang dinding mempunyai kesan yang besar ke atas taburan suhu dimana purata suhu ialah 26.3ºC tetapi mempunyai halaju udara yang lebih tinggi iaitu 3.1m/s daripada yang ditetapkan oleh ASHRAE. Oleh itu, ia tidak mencapai tahap keselesaan haba di dalam rumah teres.

ACKNOWLEDGEMENTS

Alhamdulillah, by the will of Allah, I am able to complete my Final Year Project within the required time. The writing of this project has been a fascinating process and personal experience in the recent past. Many people contributed to this process and without their support, it would have been impossible to complete this project. Therefore, I want to take this opportunity to express my gratitude in this section.

First and foremost, I offer my sincerest gratitude to my supervisor, Dr. Ernie Binti Mat Tokit, who has supported me throughout my Final Year Project with her motivation, enthusiasm, and immense knowledge. Her guidance helped me in all time of analysis work and writing the report by commenting on my views and helping me understand and improve my ideas. Without her understanding, support, encouragement, and continuous optimism this project would hardly have been completed. One simply could not wish for a better or friendlier supervisor.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamic
MRT	Mean Radiant Temperature
M	Metabolic Rate
TE	Thermal Environment
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
CIDB	Construction Industry Development Board

CHAPTER 1

INTRODUCTION

1.1 Background Study

In the last 40 years, accelerated urbanization has led to the percentage of urban population in Malaysia, from 27 % in 1970 to 71 % in 2010 (Razali, 2016). In order to satisfy housing settlements due to the growing national population, more land will be created for urbanisation. Terraced houses in Malaysia are the most common types of residential buildings. The Malaysia terraced house is originated from the townhouses of Malacca dating back to the 17th century and the Chinese shops of the 19th century (Saji, 2012). They are also known as row houses in some areas. Terrace houses are the most living areas in urban areas in mass housing schemes. The house in Malaysia is reasonably modest and basic accommodation is an optional. In the tropical climate area, terrace houses generally encountered the hotter indoor condition caused by higher vitality contribution from sun powered.

In warm and humid climates, thermal comfort is necessary in residential and commercial buildings. The majority of residential buildings do not have air conditioning systems. They mainly rely on natural ventilation and passive cooling to achieve certain thermal comfort levels. In order for occupants to be thermally comfortable in an interior space, four environmental parameters are generally accepted to be present in adequate proportions (Halipah, 2004). Environmental parameters for thermal comfort are air temperature (Ta), mean radiant temperature (MRT), pressure (Pa) and relative air speed (Vt) and personal parameters: clothing or thermal resistance and activity or metabolic rate (M) (Fanger, 1972) . It is reasonable to consider, however, that all variables in design are interdependent. This paper used the simulation to determine the temperature flow and comfort zone within a terraced house in Malaysia. As the main variables for determining the thermal environment, the air temperature and the relative air velocity were selected. Computational Fluid Dynamic (CFD) simulations were carried out to account for indoor thermal environment (TE) and thermal comfort.

In Malaysian climate, a reasonable temperature of thermal comfort in a house ranges from 25.5°C to 28.5°C (Jones, 1993). Earlier researchers recommended similar values, such as 28.7°C (Humphrey, 1994), 26.3°C and 28.5°C (Gail, 1998). The effect of air speed in the room is well known and critical in promoting thermal comfort. For convenience, indoor air speeds between 0.15 and 1.5 m/s are recommended (Olgyay, 1963). In a warm climate, indoor air speeds of 1.0 m/s are very pleasant and up to 1.5 m/s is acceptable (Szokolay S. , 1980). Rajeh (Rajeh, 1994) suggested that air movement of 1.0 m/s would generally provide a satisfactory condition in Malaysia's terrace housing. The data published is reasonably consistent and most researchers agree that the temperature range for thermal comfort in tropical climates should not exceed 28°C and that the air velocities are in between 0.15 and 1.5 m/s.

1.2 Problem Statement

Nowadays, the hot and humid tropical climate in Malaysia is a problem for residents of many residential buildings who do not have air conditioning systems. Poor passive design of the terrace house causes heat to be trapped, which influences the indoor temperature increment and makes the occupant uncomfortable. Passive cooling in a tropical climate is difficult to achieve in terms of the design of mass housing. A good design of the house keeps the indoor environment pleasant and comfortable for most of the year without any mechanical devices. Terraced houses are typical examples with a problem of low comfort that must be taken into account. Low air velocity and high air temperature are observed during the day and the wind effect, especially in single-sided ventilation, is not well captured. The use of natural ventilation as an energy-efficient means of providing thermal comfort and a healthy indoor environment has been increasingly investigated.

1.3 Objective

The aim of this work is to analyse the air and temperature flow inside a terrace house. This general objective can be broken down into a specific objective as follow:

i. To investigate the effect of terrace house wall height on the air flow and temperature distribution, and
ii. To predict the effect of air conditioner in the terrace house in order to achieve thermal comfort

1.4 Scope of Project

The scope of the project is the limitation that must be put to ensure the project meet the objectives. The several scope of this project is:

i. The design of the terrace house based on the past study
ii. Mean velocity of air flow is around (0.3m/s –0.8m/s).
iii. Temperature mean 29°C -32°C.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter reviews the analysis on the flow and temperature distribution inside terrace house.

2.1 Terrace House

The Malaysia terraced house or originated from the townhouses of Malacca dating back to the 17th century and the Chinese shops of the 19th century (Saji, 2012). In some areas they are also known as link-houses or row-houses. Terrace houses are the most living areas in urban areas in mass housing schemes. It is also the most common typology of housing in Malaysia and has been constructed linearly in rows, sharing common walls and can be in the form of a single or multiple story as shown in Figure 2.1. According to the fire department regulation, the length of each row cannot exceed 96 meters, so that a maximum of 16 houses can be built in a row. The unit width is over 6 meters for high-cost housing and 4.3 meters for low-cost housing. The built-up area of each unit is normally 130~170 square meters. The minimum built-up is 50 square meters for low cost house (Omar, 1990).

The finishing unit plot size is larger than the intermediate units in the middle of a row. The design and planning of a unit is almost repeated due to the restriction of space and the monetary dimension. In the ground floor there is usually a combination of living and dining area and a kitchen. On the second floor, there is the front main bedroom and two back bedrooms if the built terrace house has two floors. This limited planning often resulted in the owner extending the buildings to the space to increase the living space. One local expert explained that this phenomenon was considered the freedom of self-transformation of a resident and also demonstrated one of the reasons for the general preference for a terrace house.

Figure 2.1 Terrace House (PropertyGuru, 2016).

2.2 Thermal Comfort

Thermal comfort is defined as 'the state of mind,' which expresses thermal environment satisfaction by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE, 2004). It also define as “a state in which there are no driving impulses to correct the environment by the behaviour” (Hensen, 1990) where thermal comfort is the absence of heat or cold irritation and discomfort, and the state of pleasure. Alternatively, the person is not fully aware of the thermal condition of the environment and does not consider whether the space in which he or she stays is too hot or too cold.

Personal differences, such as mood, culture and other individuals, organization and social factors, influence thermal comfort. Environmental parameters for thermal comfort are air temperature (Ta), mean radiant temperature (MRT), pressure (Pa) and relative air speed (Vt) and personal parameters: clothing or thermal resistance and activity or metabolic rate (M) (Fanger, 1972). The purpose of this paper is to simulate the indoor thermal environment and the comfort of a terrace house. As the main variables for determining the thermal environment, the air temperature and the relative air velocity were selected. It is therefore reasonable to consider that all variables of the design are interdependent.

2.2.1 Comfort Zone

The comfort zone can be defined as "a thermal condition in which the occupants make little or no effort to adapt their bodies to the surrounding environmental conditions". The greater a person's efforts, the less comfortable the climate is. Usually, maximum comfort cannot be achieved. However, it is the designer's job to build homes that offer an indoor climate close to an optimum within a certain range of thermal comfort. It also depends on the clothing worn, the physical activity, health condition and age. It also depends on the wear of clothes, physical activity, health and age. Although the ethnic difference is not so important, the geographical location plays a role due to the habit and the capacity of individuals to acclimatize. In addition to psychological and physiological factors, the comfort zone is determined by four main factors:

- Air temperature
- Temperature of surrounding surfaces (radiant heat)
- Relative humidity

- Air velocity

For comfort zone a number of scales have been developed, some of which are shown in Table 2.1.

Table 2.1 Scales of thermal sensation (ASHRAE, 2004)

	ASHRAE	Fanger	Rohles & Nevins	Gagge's DISC	SET* (°C)
Painful			+5	+5	
Very hot			+4	+4	37.5-
Hot	7	+3	+3	+3	34.5 – 37.5
Warm	6	+2	+2	+2	30.0 – 34.5
Slightly warm	5	+1	+1	+1	25.6 – 30.0
Neutral	4	0	0	0.5	22.2 – 25.6
Slightly cool	3	-1	-1	-1	17.5 – 22.2
Cool	2	-2	-2	-2	14.5 – 17.5
Cold	1	-3	-3	-3	10.0 – 14.5
Very cold			-4	-4	

*SET: Standard Effective Temperature

2.2.2 Air Temperature (Ta)

Malaysia in the equatorial region with warm and humid weather all year round. The climate has been characterized by high temperature and moisture. Malaysia is situated between 1 and 7 degrees North latitude and extends from 100 to 119 degrees East longitude. It has a minimum diurnal temperature range of 23 to 27°C and a maximum temperature of 30 to 34°C. Figure 2.2 shows changes in the average ambient air temperature in the different sections of the terrace house, when the house is naturally ventilated. In all sections, the air temperature decreases from about 29°C at 12AM to about 27°C at 6AM. Thereafter, the air temperature increases and reaching the highest value of about 31°C at 6PM. The air temperature limits for acceptable thermal comfort as specified in the ASHRAE standard are also shown in Figure 2.2 (ASHRAE, 2004). It can be seen that the average ambient air temperature inside the house is well beyond the limits of acceptable thermal comfort at any given time.

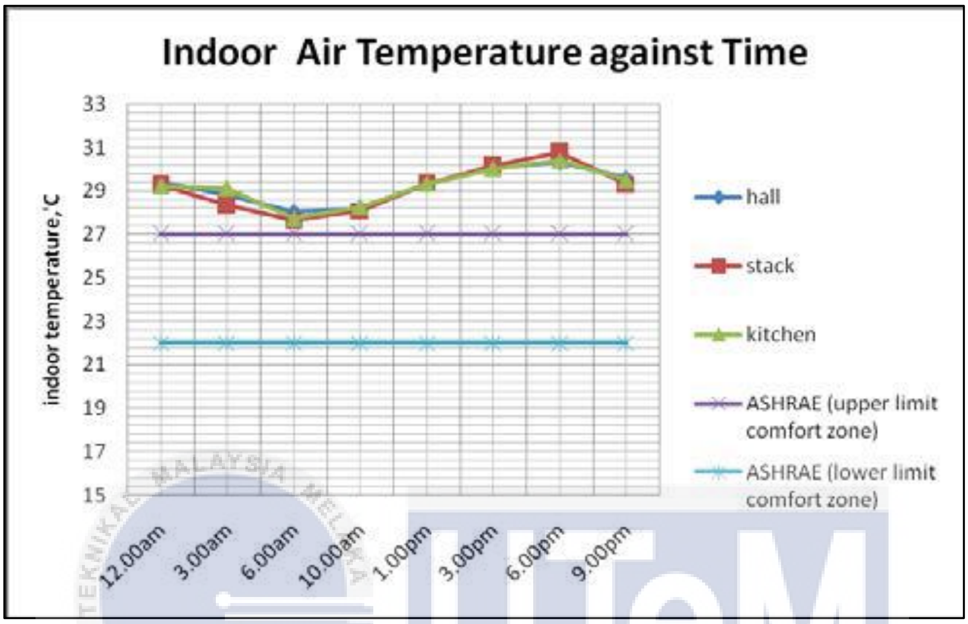

Figure 2.2 Average air temperature variation inside the terrace house (Haslinda Mohamed Kamar, 2011)

2.2.3 The Relative Air Velocity

Malaysia is experiencing seasonal, monsoon-dominated climate change. The seasonal pattern of wind and rainfall in this region is a predominant climate characteristic. Winds of monsoon occur twice a year, i.e. Monsoon northeast and southwest. The Southwest Monsoon comes from Australia and blows from May to September over Sumatra Island and the Straits of Malacca. The North - East Monsoon originates from the Central Asian continent and blows from November to March through the South China Sea through Malaysia to Australia. Inter-monsoon winds occur during the months of April and October.

However, the average air velocity is not based on the wind season of the monsoon because the air velocity of the monsoon is not constant throughout the year. So, the variation of average air velocity were taken from experiment in various sections of the terrace house. Figure 2.3 shows average air velocity in various section of terrace house. The limits of air velocity for acceptable thermal comfort as specified by the ASHRAE standard (ASHRAE, 2004) are also shown in this figure. The air velocity in the hall and stack sections can be seen to be relatively constant at approximately 0.1 m/s from 1PM to 6PM. The air velocity seems to vary from 0.1 m/s to 0.2 m/s in the kitchen area. The average air speed inside the house is below the acceptable thermal comfort level specified in the ASHRAE standard at any given time (ASHRAE, 2004).

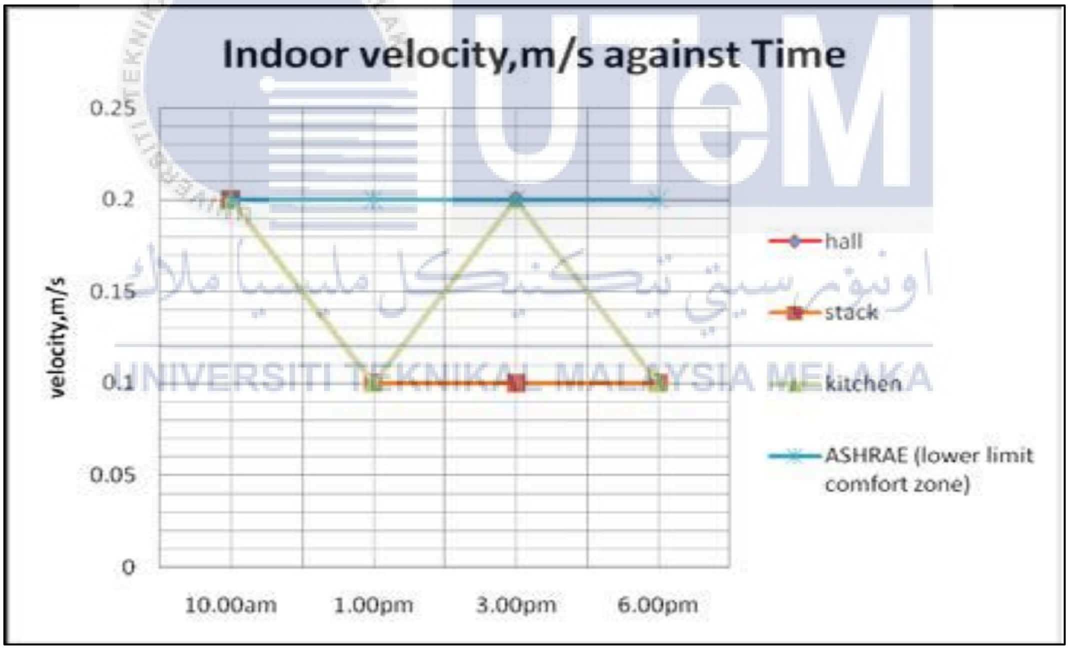

Figure 2.3 Variation in terrace house average air velocity (Haslinda Mohamed Kamar, 2011)

2.3 Theory of Natural Ventilation

Natural ventilation is the process of air supply and air removal without the use of mechanical systems from an indoor space. It refers to the flow of external air into an indoor area caused by natural forces due to differences in pressure. Buoyancy is a major force behind natural ventilation. Buoyancy is controlled by a difference in temperature between indoor and outdoor density. When buoyancy is the dominant force, the flows will have an upward flow, as hot air moves upward and cold air replaces it underneath. When the temperature difference is smaller, leading to a reduced buoyancy force, the flow is downward, as air moves from top to bottom (Heiselberg, 2004). Once there is a negligible temperature difference, the stack pressure is reduced to near zero and buoyancy effects are less pronounced.

Buoyancy effects are determined by the ratio of buoyancy forces to viscous forces, known as the Grashof (Gr) number:

$$Gr = \frac{g\beta\Delta T l^3}{v^2}$$

Where g is gravity, β is the thermal expansion coefficient, ΔT is a temperature difference, L is a length scale, and ν is the kinematic viscosity. Transition to turbulent flow approximately occurs when the Rayleigh (Ra) number is Ra = 109 (DeWitt, 2007):

$$Ra = GrPr$$

Where Pr is the Prandtl (Pr) number:

$$\mathrm{Pr} = \frac{v}{a}$$

And α is the thermal diffusivity.

Wind-driven flow is due to a pressure difference between the openings. In cross-ventilation, the pressure difference is often created by wind on the windward side. The flow creates a higher pressure on the windward side of the building and a lower pressure on the leeward side, driving flow from windward to leeward (Linden, 1999). Other driving forces in wind-driven flow are turbulence effects and the opening size. The effect of wind-driven flow is measured using the Reynolds (Re) number:

$$Re = \frac{\rho V l}{\mu}$$

Where ρ is the density, V is a velocity, and μ is the fluid dynamic viscosity.

Most flows have a combination of buoyant forces and wind driven forces. The relationship Gr/Re2 is used to determine the dominant effect. If Gr/Re2 << 1 buoyancy effects are negligible, Gr/Re2 >>1 are dominant, and Gr/Re2 ~ 1, the effects can be determined as mixed conditions.

2.3.1 Natural Convection

Natural convection is a mechanism that the fluid movement is not generated by external forces or sources but only by the difference in the fluid density caused by the temperature gradient. This mechanism occurs only when a cold air exposed hot object as shown in Figure 2.4. Due to the heat transfer, the temperature outside the object is lower and the presence of the hot object increases the temperature of the object adjacent. The object is therefore surrounded by a thin layer of warmer air and heat is transferred to the outer layer of air from the thin layer. The temperature increases adjacent to the object and reduces its density. As a consequence, the heated air rises. This movement is called the natural convention current.

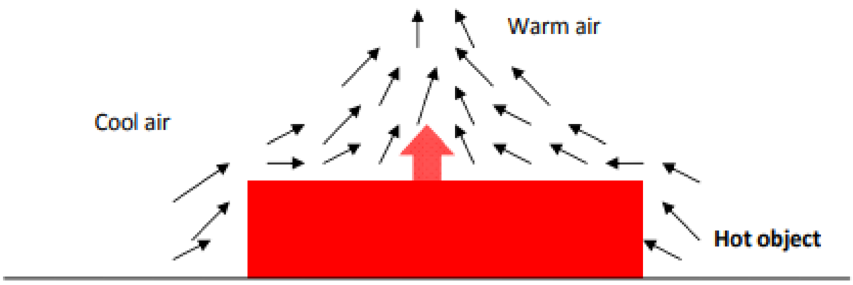

Figure 2.4 Natural heat transfer convection from a warm body (Bahrami, 2009)

The movement of the air and temperature in the natural convection of a building. Air movement is the key requirement in the overall ventilation process for the integration and design of façade, shape, openings and orientation of the building (Almeida, 2005). Moreover, a study by Chen (Chen, 2009) shows that temperature, humidity, air flow patterns and air velocity are key factors to be considered in the collection, measurement and evaluation of indoor and indoor air flow quality data. In addition, indoor air movements and temperature can also be affected by outdoor air due to differences in air pressure through the construction of façades due to the appropriate location of openings and passive design strategies (Ghiaus, 2005). The air flow movement can be classified into single-sided ventilation, double or cross ventilation and ventilation of stacks.

2.3.1.1 Single-Sided Ventilation

Single-sided ventilation is defined as a condition in which there is only one or more openings in a closed room building. Ventilation on one side is practically where wind speeds move in and out through the same window on the same side of a building as shown in Figure 2.5.

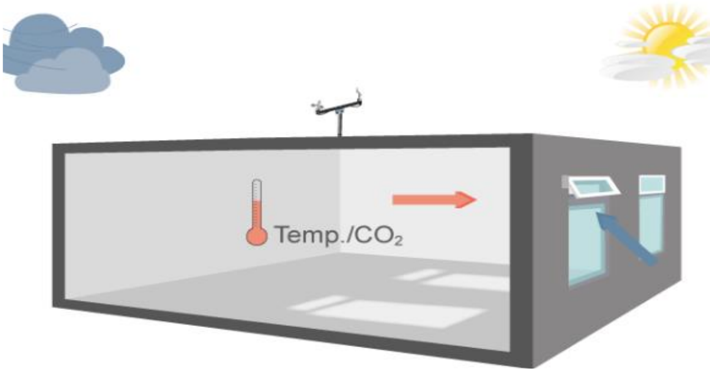

Figure 2.5 Single-sided ventilation (WINDOW MASTER)

2.3.1.2 Cross or Double-Side Ventilation

Cross ventilation, on the other hand, works efficiently when wind speeds move in and out through different windows or doors on different façades. Some scholars such as Szokolay (Szokolay S. V., 1986) and Givoni [17] used this basic rule in their studies to increase the air velocity in buildings in order to create a more comfortable indoor environment. In general, natural ventilation in buildings can be classified as air pressure ventilation, known as wind power, and ventilation with stack effect or thermal force (Ghiaus, 2005). As explained by Szokolay (Szokolay S. V., 1986), air pressure ventilation occurs when a wind flow is blocked by the surfaces of a building. The speed of the wind creates lower pressure on the leeward side of the building while the pressure is much higher on the wind side. The differences in air pressure from both sides of the building can stimulate the flow of air into the indoor environment and thus reduce the air temperature in the building. Like Figure 2.6 below shows that the different air pressures outside and inside the building lead to cool air flowing into the rooms horizontally through the apertures.

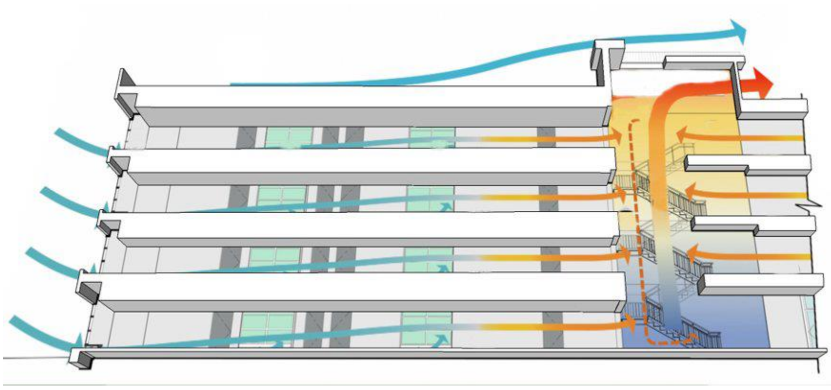

Figure 2.6 Natural ventilation in a building caused by wind forces and buoyancy effect (Ardalan Aflaki, 2015)

Building corridors are an example of an architectural element by acting as connectors between outdoor environments and indoor isolated spaces that create cross ventilation in buildings. Corridors can also play an important role in the channelling and flow of air into parts of a building. A Mohamed microclimate study (Mohamed, 2008) found that well-designed and integrated corridors within a building provide sufficient local air flow. Their study shows that corridors transfer air outdoors by providing an air pressure zone that directs air into the building. The increase in air pressure and the need for air change can be further improved through the integration of these corridors with other passive design strategies (Ghiaus, 2005; Zhou, 2008).

2.3.1.3 Stack Ventilation

Stack ventilation or thermal force can occur through vertical air movement, where cool air is heated by human activity or the operation of machinery in a building. The warm air increases vertically and is released by architectural elements from the building, as shown in Figure 2.7. Thermal force occurs because of the density difference between cool and warm air. The differences between outdoor and indoor temperatures can also create thermal strength (Evans, 1980). In the study of Ismail and Abdul Rahman (Ismail, 2010), the difference in temperature between indoor and outdoor environments and the difference in height between indoor and outdoor opening are both important factors in the application of proper stack ventilation in buildings. Many studies have shown that air wells are an appropriate technique for stack ventilation in buildings. This design strategy produces air flow vertically in the building through the process shown in Figure 2.7, replacing hot air with fresh, cool air. This passive element is used in warm and arid climates for a long time, known as a wind catcher. The wind catcher's function is to cause wind movement that takes fresh air through the façade of the building and discharges warm air through a vertical duct in the building (Ghiaus, 2005). During this process, contaminated indoor air can be efficiently disposed of and replaced by cool air, creating comfortable indoor conditions (Allocca, 2003; Jafarian, 2010). Chimneys and stack air ducts can be used in smaller buildings to achieve this, while larger air wells or atria can generate sufficient wind flow to achieve thermal comfort in larger structures.

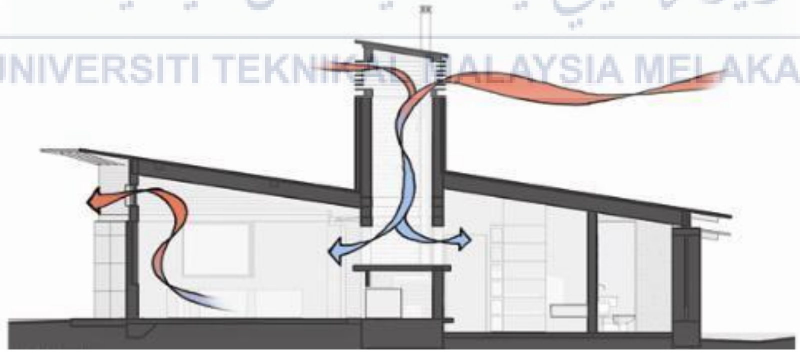

Figure 2.7 Simple wind catcher functions in buildings (Ardalan Aflaki, 2015)

Stack ventilation and cross ventilation are two ventilation systems commonly used in traditional architectural buildings for occupants, in order to cool the indoor environment and provide optimum thermal comfort. A study conducted by Siew (Siew, 2011) shows that different types of natural ventilation are used in tropical vernacular architecture to reduce high temperatures and humidity. However, previous research has agreed that cross ventilation is a more efficient approach than stack ventilation in tropical regions where temperature differences between indoor and outdoor environments are generally not substantial. (Ghiaus, 2005; Givoni, 1994). In general, the effective functioning of natural ventilation depends on the use of various architectural elements and techniques to induce air movement in buildings.

2.4 Related Research

2.4.1 Title: Evaluation of Thermal Comfort in a Residential Terrace House with Natural Ventilation

This paper presents a study on thermal comfort assessment in a naturally ventilated residential terrace house in Malaysia using the Computational Fluid Dynamics (CFD) method. They perform actual measurements in different parts of the house to achieve the average air temperature, relative humidity and air flow pattern. The aim of the paper is to perform CFD simulation on a simplified house model to predict and visualize the house's temperature distribution and air flow pattern and speed. Measurement of thermal comfort parameters over a period between 12 AM and 9 PM. They also compare the measurement results to the acceptable thermal comfort limits described in the ASHRAE standard. (ASHRAE, 2004). Due to their research, the air velocity vector (m/s) contour of the ambient air was obtained inside the house. They observed that the air flow distribution within the house is not uniform with natural convection and that the speed is generally higher than 0.2 m/s.

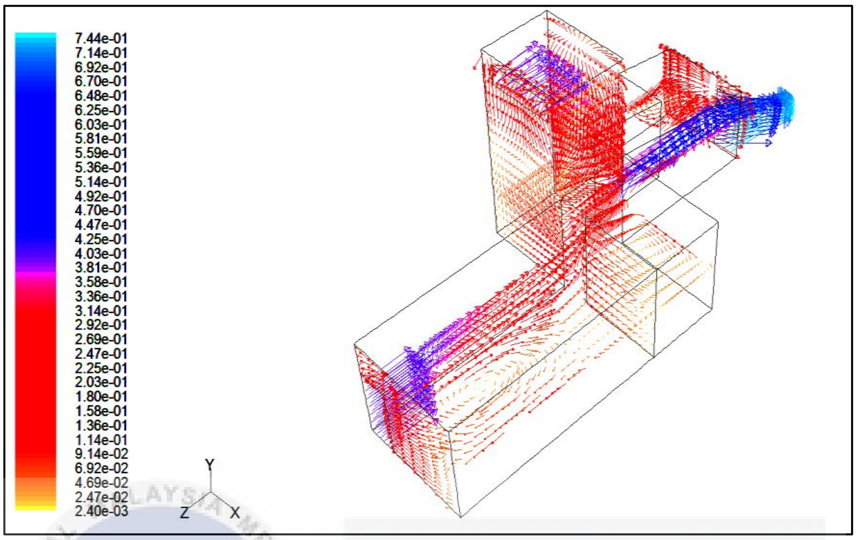

Figure 2.8 Result of flow of air inside the terrace house (Haslinda Mohamed Kamar, 2011)

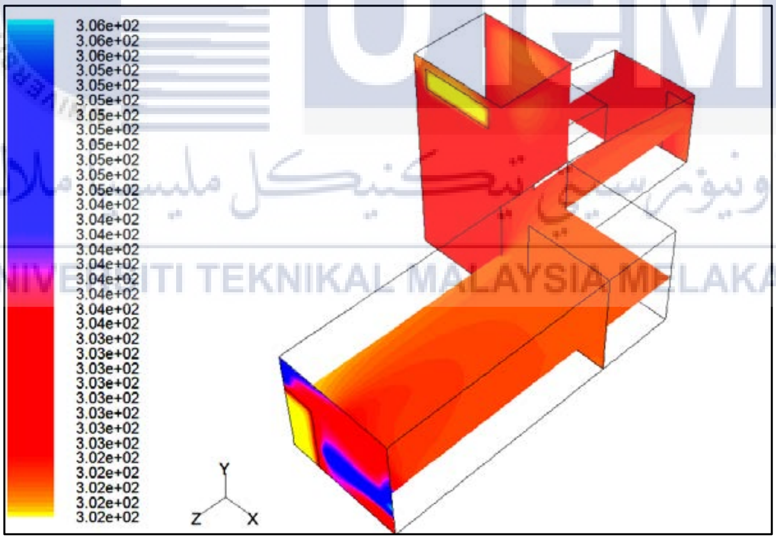

Figure 2.9 Result of temperature distribution of air inside the terrace house. (Haslinda Mohamed Kamar, 2011)

2.4.2 Title: Simulation of Air Movement in Terrace House Using Convection Ventilator

This paper was written by Minah Ayol, Adnan Husain, Abdul Mutalib Leman and Mohd Zainal Mohd Yusof (2005) to verify the effectiveness of using convection ventilator in reducing indoor air temperature and improving air movement temperature in naturally ventilated building to find a comfort environment. The simulation were performed inside the terrace house which involving occupants with two types of turbulence model before and after installing the ventilator via FLOVENT. The parameters that were used in this simulation were measured in six major areas in the house after installing the ventilator turbine and the result obtained were compare with the ASHRAE standard (ASHRAE, 2004). As a result, the actual measurements result were compared to CFD simulation. The overall average error percentage was less than 50% and the results showed small difference between simulation and actual measurement.

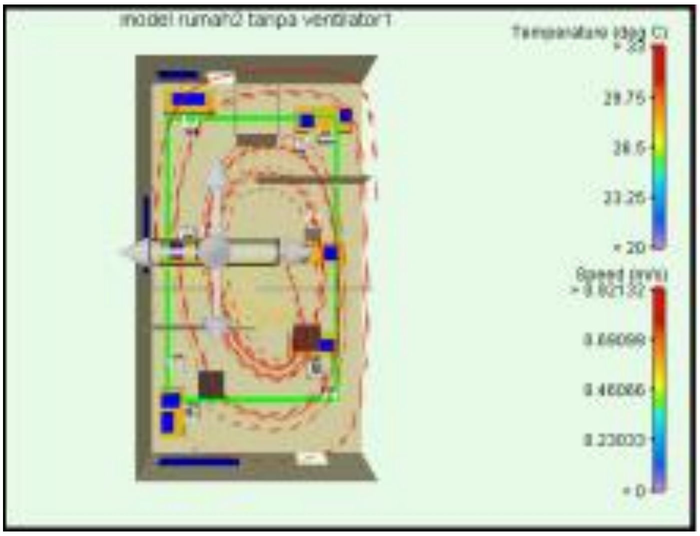

Figure 2.10 Air movement before installing the Ventilator

Figure 2.11 Air movement after installing the Ventilator

CHAPTER 3

METHODOLOGY

3.0 Introduction

In this chapter, the work flow of the development of this project from the beginning of the project until the end of the project is presented. It includes the detailed process and step which are deemed necessary in the simulation task. Besides, the method of software design and development is explained in this chapter too.

3.1 Project Overview

Before proceeding on simulating the project, a flow chart is necessary to ensure a good project documentation and make the flow of the project more efficient. A flow chart diagram shows the workflow or process in a sequences in present of text and symbol as shown in Figure 3.1.

Literature studies were carried out to understand the simulation about a houses. Related information about the modelling method for terrace house module using the CFD software and that to measure the parameters were acquired through online articles, online journals and research papers. In this section, software implementation process using the CFD software will be discussed in details.

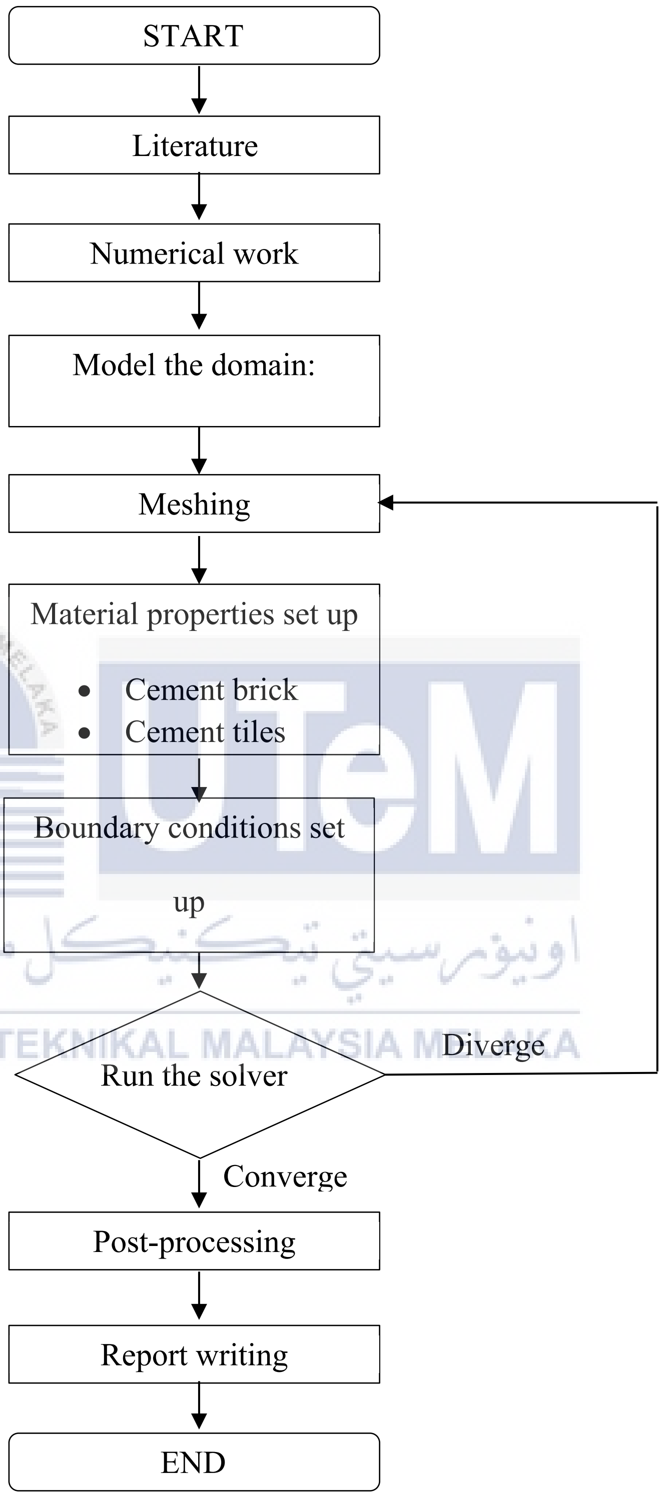

Figure 3.1 Flow chart

3.2 Numerical Work

Computational fluid dynamic (CFD) software uses numerical analysis and algorithms to analyse problem involving fluid flow. Usually, the boundary condition of the external environment was set so that it is ready to calculate and simulate the interaction of the fluid by using computer. Moreover, the external environment of the module such as the air flow, humidity, and temperature can be set to analysis the heat dissipation of the module through conduction, convection and radiation (Poppe, 2008).

In the thermal processing, the Navier Stokes equation is fundamental mathematical formula for the fluid motion in CFD software. Besides, the heat transfer equation is used to solve the energy equation involving the heat transfer in a fluid system. The CFD software also provides a lot of models such as Turbulence Model, Eddy Viscosity Model, Reynolds Stress Model, Radiation Model and many others (Norton, 2013). The simulated physical interface provided by the CFD Models allows user to model the most aspects of fluid flow single phase flow, non-isothermal flow and compressible flow. With the models provided, the heat and air flow inside the terrace house module can be simulated accurately.

There are various CFD software such as OPENFOAM, OPENFLOWER, FLASH ANSYS, ANSYS FLUENT and many others. All these software work best in different kind of application. Thus, appropriate software must be used in order to get an accurate result. In this project, the CFD simulation software used is FLUENT. FLUENT is a CFD software created by John A. Swanson. This software is suitable to use in predict air flow, temperature and heat transfer in a system. FLUENT has a user friendly operation interface that allows users to design their module easily. It also has localized grid feature that support integrally matched, nested non-conformal grid interface between different parts of the solution domain. An accurate simulation result on the terrace house module can be produced by using FLUENT. The module created can attached with different type of material, heat dissipated, specific heat capacity, thermal conductivity and many other parameters. With these features, a simulated module that is very close to real module can be developed in a short time.

3.3 Model the Domain using ANSYS

In order to study the thermal behaviour of the terrace house, a terrace house was modelled using software named ANSYS. The chosen of terrace house because terrace house is commonly house for occupant that has low income.

The first step to design the terrace house using ANSYS is to scope out the project and define the data required. In this step, geometry and physical properties of the terrace house were based on Malaysian Construction Industry Development Board (CIDB) as shown in Table 3.1.

Table 3.1 Dimension of terrace houses by the Malaysian Construction Industry (Rukiah, 2015)

Elements	Terrace house CIDB
Floor space	60 m^2
Bedroom Min. number	3
Min. area of habitable room:	
i. First room	11.7 m^2
ii. Second room	9.9 m^2
iii. Third room	7.2 m^2
Min. Kitchen area	5.4 m^2
Living and dining rooms	Provided as one combined space

Bathroom/toilet	Min. area 1.8m²

Next, the structure of the terrace house was design by using ANSYS software. When building the terrace house, the objects inside the terrace house such as refrigerator, chair, table and others were not considered. Only the wall within two different room was considered. After that, the wall parts were attached with material and thermal power loss required. The model of the terrace house with different dimension was built as shown in figure 3.2. In addition, another terrace house with different height was developed also using ANSYS and terrace house with two air conditioner system as shown in Figure 3.3 and 3.4.

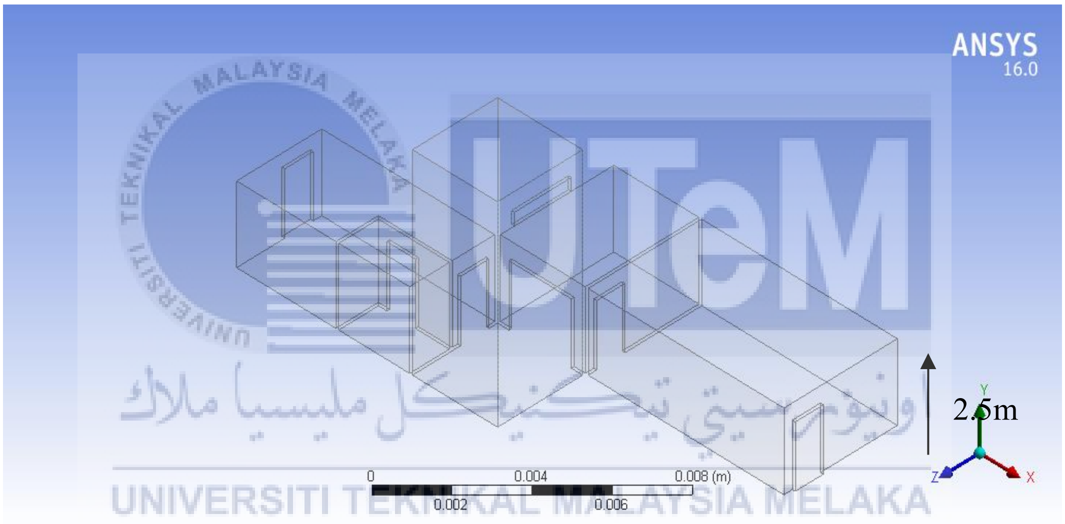

Figure 3.2 Geometry of terrace house

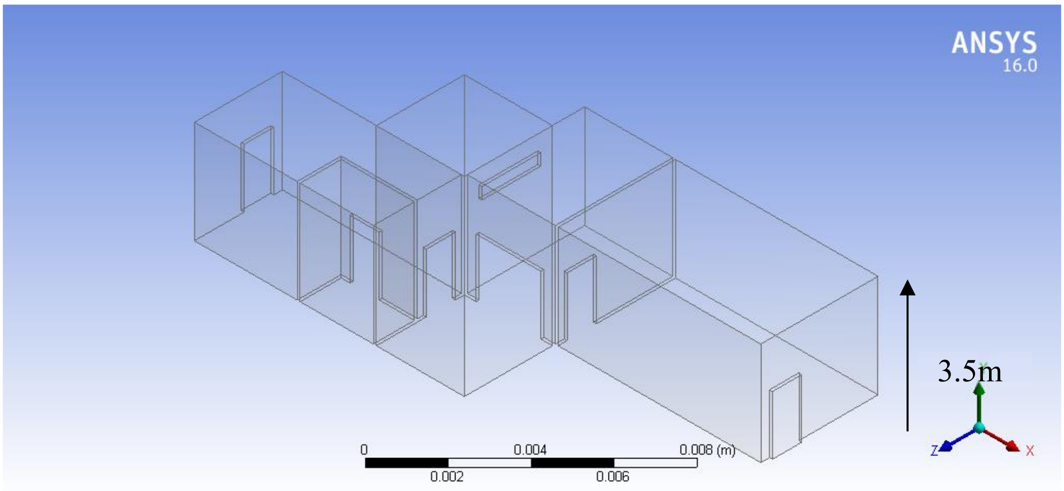

Figure 3.3 Geometry of new house wall height

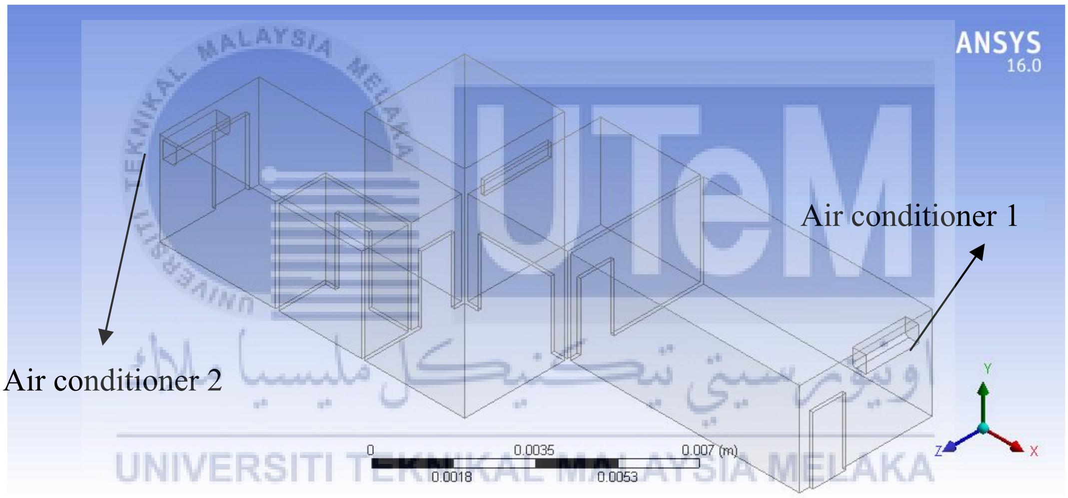

Figure 3.4 Geometry of terrace house with two air conditioner

3.4 Meshing

After the model of the terrace house was developed, the designed were then mesh also using ANSYS software. Meshing is a discreet geometry for fluid flow analysis. In this situation, the flow domain used for the terrace house was hexahedra and tetrahedral for 3D wall. The classification of grids for the terrace house was unstructured grids as shown in Figure 3.3 where the grid shows irregular connectivity.

The mesh of the grid were based on the law of skewness. The skewedness of a grid is an appropriate indicator of the quality and appropriateness of the mesh. According to the skewness definition, a value of 1 indicates the worst cell and a value of 0 indicates the best equilateral cell. The following equation applies to the equilateral volume deviation method. Where the best cell size is the equilateral cell size with the same circumradius.

$$Skewness = \frac{optimal\ cell\ size - cell\ size}{optimal\ cell\ size}$$

Figure 3.3 shows result of meshing the terrace house. Once the meshing was developed, the name selection was set for air inlet (front door), air inlet 2 (stack), air outlet (back door), and front wall, stack wall and back wall. The meshing work continued for the house with new height and house with two air conditioner system. Figure 3.7 and 3.9 shows meshing results and statistic of meshing for both cases.

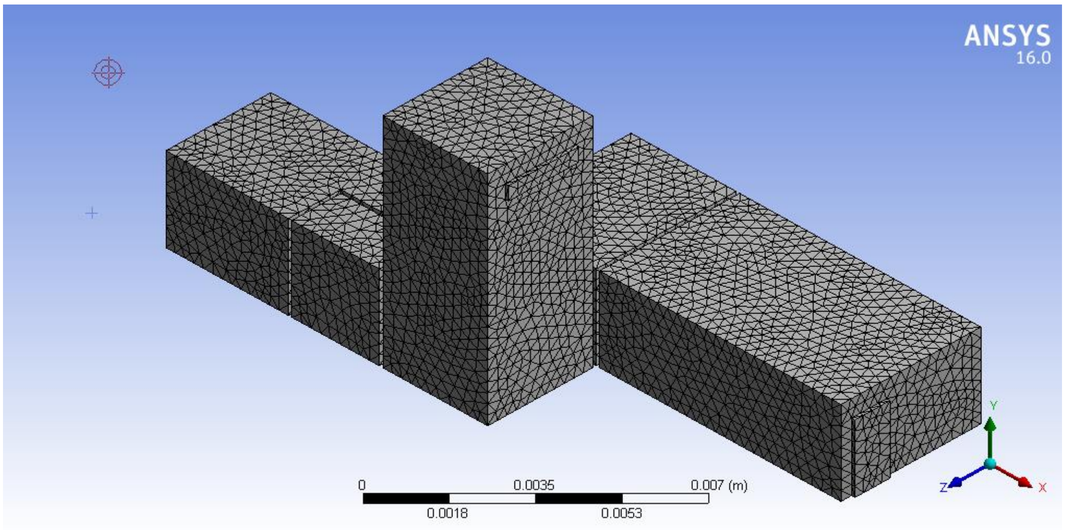

Figure 3.5 meshing the terrace house

Statistics	
Nodes	12478
Elements	59143
Mesh Metric	Skewness
Min	1.2245e-003
Max	0.79685
Average	0.23417
Standard Devi...	0.12426

Figure 3.6 Statistics of the meshing

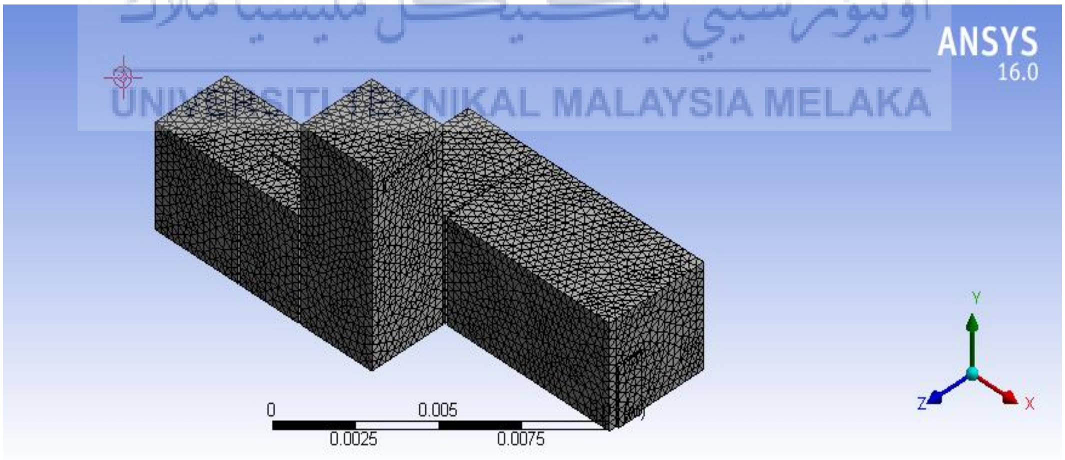

Figure 3.7 Meshing of new house height

Statistics	
Nodes	26111
Elements	133193
Mesh Metric	Skewness
Min	7.2146e-004
Max	0.79888
Average	0.23557
Standard Devi...	0.1239

Figure 3.8 Statistic meshing for house with new height

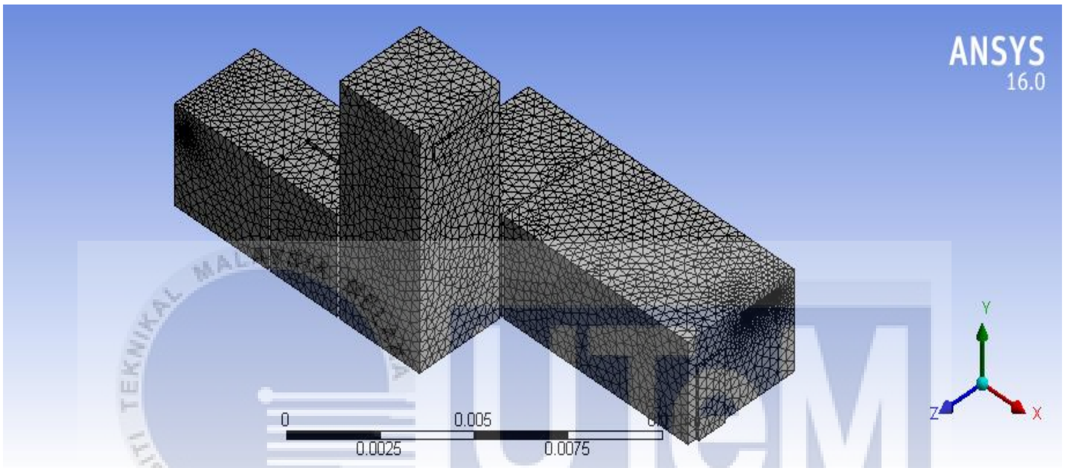

Figure 3.9 Meshing house with two air conditioner

Statistics	
Nodes	15459
Elements	74079
Mesh Metric	Skewness
Min	1.1418e-004
Max	0.79946
Average	0.23434
Standard Deviation	0.12374

Figure 3.10 Statistic meshing of house with two air conditioner

3.5 Material properties

The material used for the wall of the terrace house is bricks. Brick is one of the most typically used materials in the construction and housing industry. Brick is a popular material for housing because of the strength, non-inflammable, and cheap. In humid and climate region, lower thermal conductivity is needed for the wall of houses since it has lower heat transfer rate which is slow for the material to become hotter. Table 3.2 shows the difference of the density and thermal conductivity for four type of materials. Based on the table below, Brick show less thermal conductivity among four material.

Table 3.2 Density and thermal conductivity for building materials. [37]

Material	Density ρ,(kg/m 3)	Thermal conductivity k (W/mK)
Red Brick	1595.12	0.61-0.74
Tepetate	1023.47	1.047-0.93
Adobe	1306.66	0.93-0.582
Concrete	2161.29	1.3-2.6

3.6 Boundary Condition

After meshing the terrace house, the boundary conditions that represent the natural ventilation on the model were set. The boundary conditions including inlet air velocity, outlet air pressure and the wall thermal conditions. All these type of boundary condition were based on past paper as shown in Table 3.3.

Table 3.3 Boundary condition for the terrace houses [15]

Boundary Condition	Area	Parameters
Inlet Air Velocity	Front door	Temperature = 29.6ºC Velocity = 0.4 m/s
	Stack	Temperature = 29.8ºC Velocity = 0.4 m/s
Outlet Air pressure	Back door	Temperature = 29.3ºC Pressure = 101 kPa
Wall Thermal Conditions	Stack	Heat gain = 10 W/m² Temperature = 30ºC
	Stack	Heat gain = 29.8 W/m² Temperature = 29.3ºC
	Front wall	Heat gain = 19.8 W/m² Temperature = 29.4ºC
Air Conditioner	Front wall	Temperature = 20 Velocity = 0.25 m/s
	Back wall	Temperature = 20 Velocity = 0.25 m/s

3.7 Run Solver

Once the model of the terrace house was developed, the solution domain is set. The solution domain is the air inside the terrace house in order to numerically study air flow such as temperature distribution, air velocity flow and pressure. Figure 3.11 shows the working environment of FLUENT.

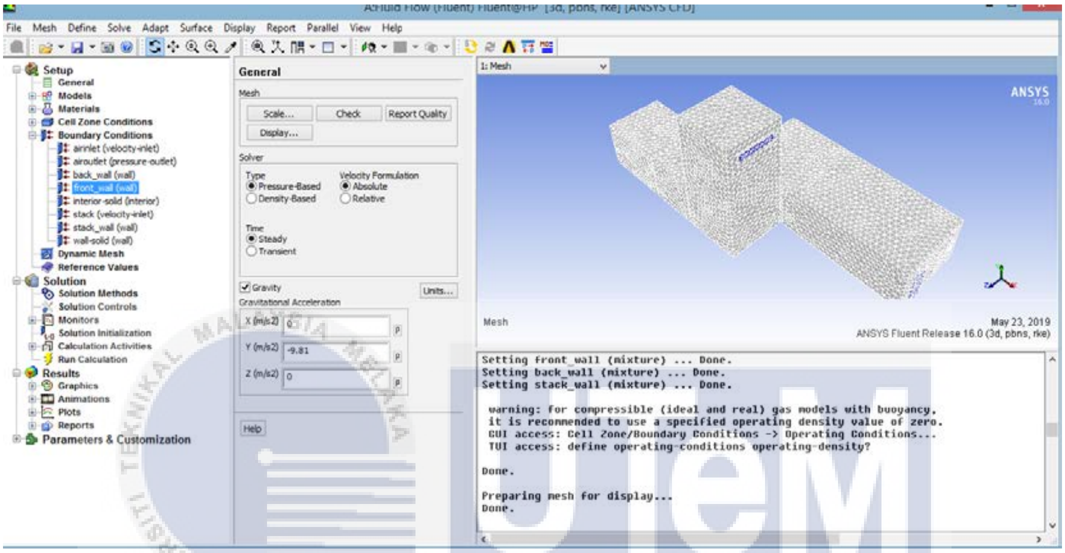

Figure 3.11 Working environment of FLUENT

Once the solution domain developed the solver was set to run. The profile window showed the scaled residuals. Figure 3.12 shows the result on the profile window. If all the variables in the residual table does not reach zero at the end of the simulation, steady solution is not converged. The result can be viewed in result section in the FLUENT to study in graphical or tabular format. Figure 3.13 shows the contour of the terrace house. After the solution was done, the air and temperature flow distribution of the terrace house can be viewed in the result section.

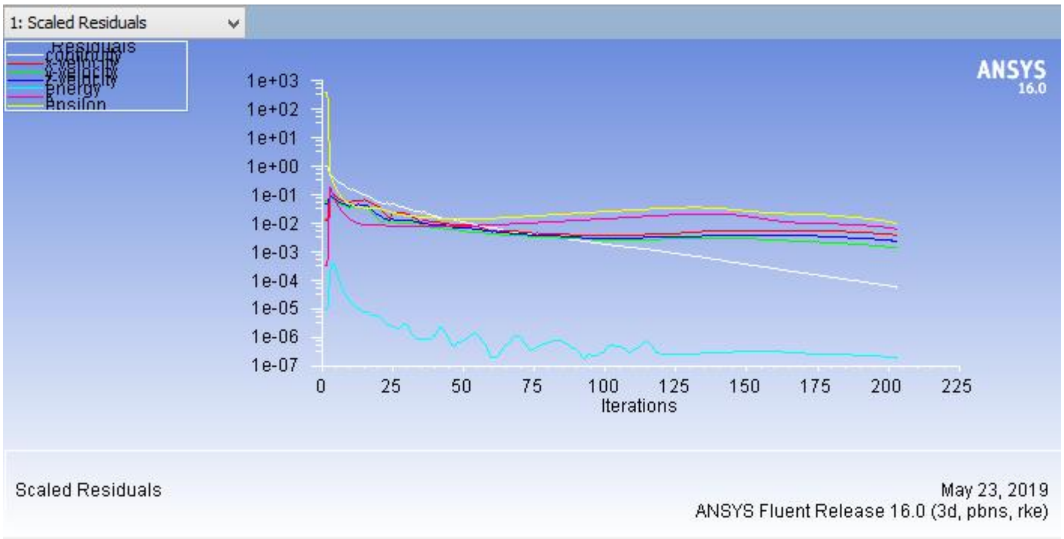

Figure 3.12 Profile window

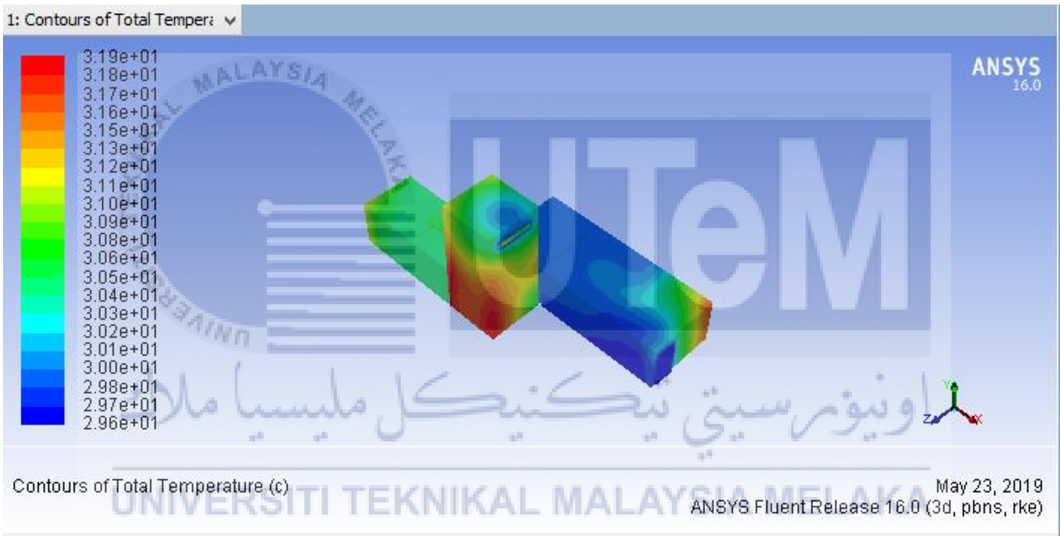

Figure 3.13 Temperature contour of the terrace house

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

All information acquired from the simulation were provided and addressed in detail in this section. To accomplish the goal of this study, three distinct houses instances are evaluated to forecast the terrace house's thermal comfort. The terrace building created in this research has the same layout as the terrace house of previous article with only distinct geometric significance. The first design is the building with natural ventilation. The second model represents the 3.5 m height of the building from the ground level. The third version represents the front and back wall building with air conditioning installation.

The air velocity and temperature flow distribution are acquired and evaluated through the simulation. The simulation outcome was displayed in distinct plane and perspective in contour, vector and streamline. Besides that, the houses ' thermal comfort is also discussed. The simulation results of three different cases are also compared and discussed.

4.1 Analysis

4.1.1 Validation

This chapter describe the process of comparing the outcomes of this simulation and previous research to guarantee that the simulation continuously generates the expected results. Figures 4.1 and 4.2 demonstrate the validation of the house's previous results and present simulation.

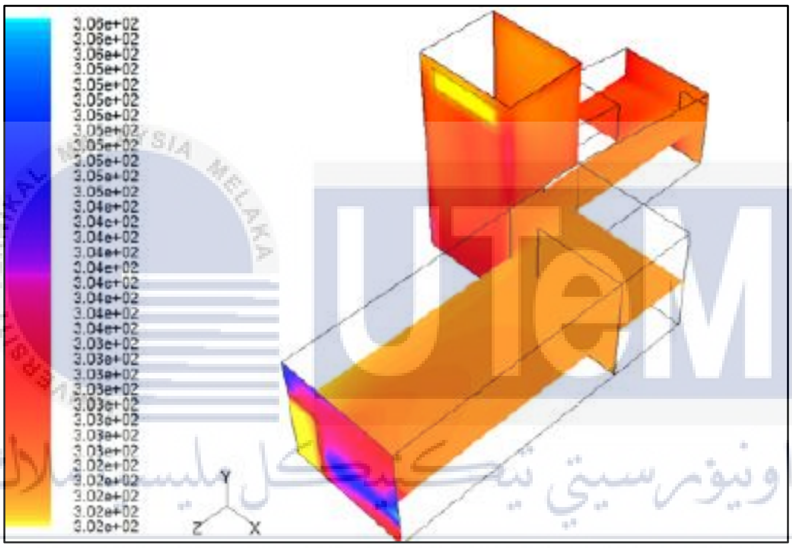

Figure 4.1 Temperature distribution of past paper

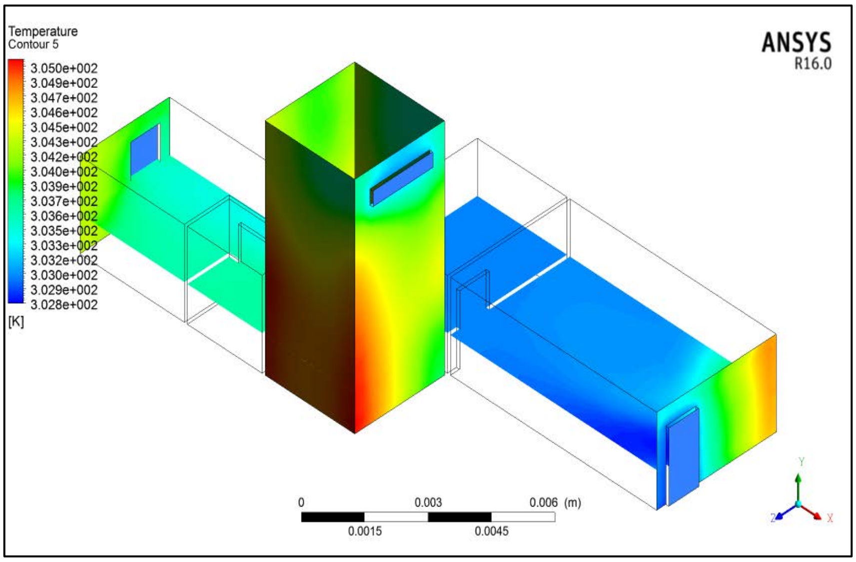

Figure 4.2 Temperature distribution of the terrace house

Based on the Figure 4.1 and 4.2, the temperature distribution range for the terrace house is almost the same (305K to 302K). It can be seen that the temperature from the hall section is consistently uniform towards the back door for both cases. Different dimension used for the current design of the terrace house. Table 4.1 shows the results of the validation and the percentage of error.

$$Error\ (\%) = \frac{|approx - exact|}{exact} \times 100$$

Table 4.1 Results of validation and percentage of error

	Front wall		Stack wall	
	1	2	1	2
Temperature (K)	305K	304K	303K	304.3K
Percentage of error (%)	0.327%		0.429%	

4.1.2 Air velocity and temperature flow distribution

Simulation of a terrace house with naturally ventilated is presented in this section. Figure 4.3 demonstrates the air speed distribution acquired from the CFD simulation. Based on the simulation outcomes, air is seen flowing from the front door on the centre room wall in a streamline situation with reducing velocity. It demonstrates that air circulation also happens in the centre of the room, but there is almost no air flow close the wall far from air inlet. The air also moves in a streamline situation and with growing speed from the centre door to the back door. In the stack section and in the kitchen where the region near the back door, uneven stream situation is seen.

The air velocity, pressure and temperature inside the terrace house is presented by XZ plane which 1.35m from floor level as shown in Figure 4.4 and 4.5. The air velocity circulation that occurs in the section of the hall is due to the wall that acts as an obstacle. When the air flows through an oblique body, the force of viscosity causes the swirl or recirculation that causes the solution to reverse flow. The air velocity drops near the middle wall, which then increases the temperature and pressure.

Figure 4.5 shows the temperature distribution contour on the walls and the air inside the house. The air temperature distribution is taken at a height of 1 m above the level of the floor. It can be seen that the air temperature in the hall almost uniform at about 302K (29°C). However, the air temperature slightly higher close to the front wall and stack wall. The kitchen air temperature is also quite uniform at about 303 K (30°C). There is a significant temperature variation on the surface of the stack wall with the highest temperature being about 305.1 K (32.1°C). This is due to a heat gain through the wall. The front wall of the house stack and back wall is about 303.8 K (30.8°C) at a fairly uniform temperature.

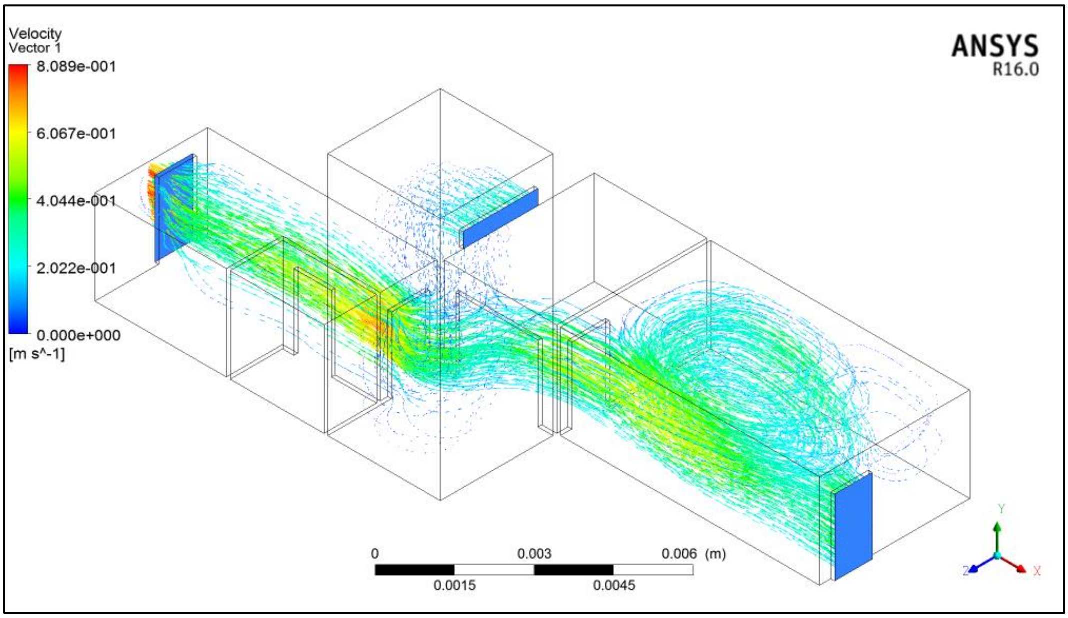

Figure 4.3 Velocity vector inside the terrace house

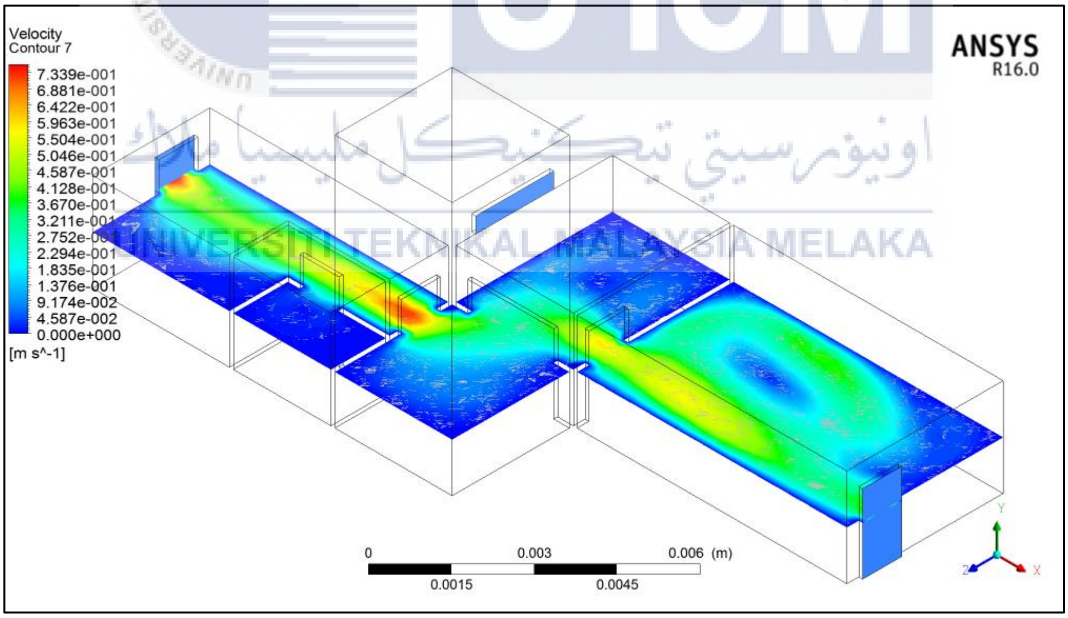

Figure 4.4 Air velocity contour on XZ plane

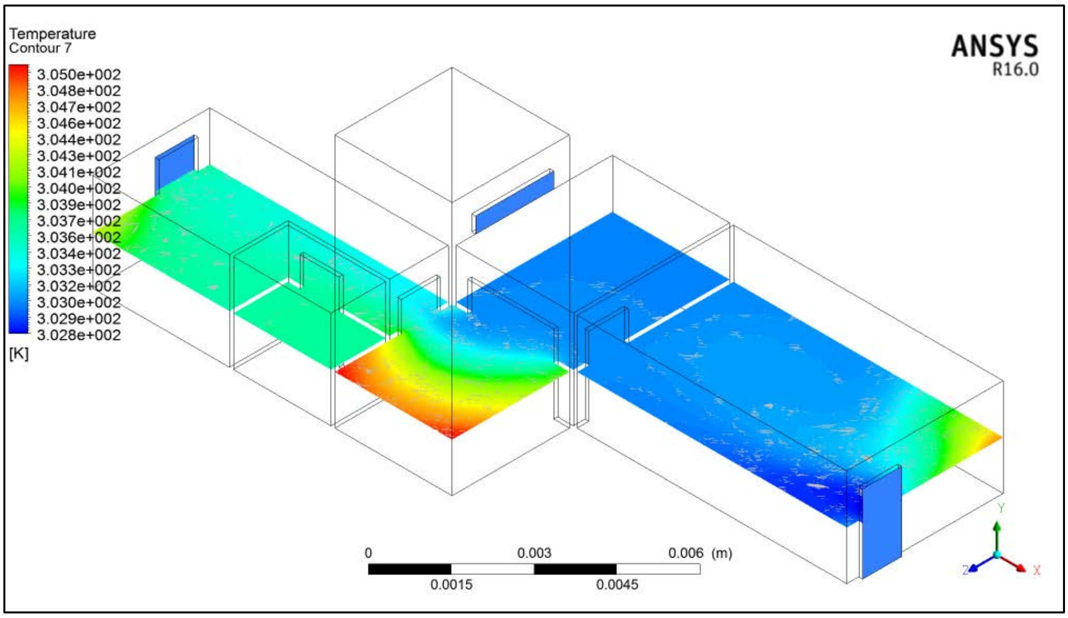

Figure 4.5 Temperature contour on XZ plane

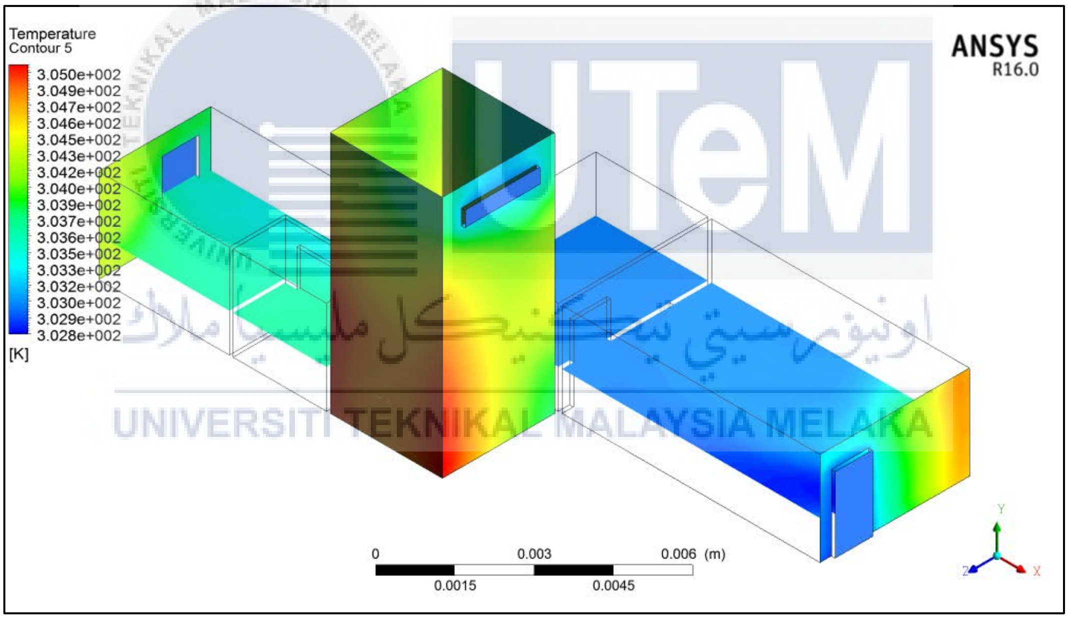

Figure 4.6 Temperature contour of the terrace house

4.1.3 Effect of wall height in air and temperature flow

The simulation result of the house's second model with 3.5 m wall height is analysed in this section. The terrace house that represents the naturally ventilated with the difference in the height of the wall. The objective is to investigate the effects of wall height on the distribution of air velocity and temperature flow. The boundary conditions prescribed on this model are similar to the first cases.

Figure 4.7 showed the result of the air velocity flow for the 3.5 m wall height. Based on the figure, it can be seen that the height of the wall caused less circulation in the section of the hall. The air velocity flow through the hall slightly decreased. The drop in air velocity is due to the hall's increasing volume. The air velocity is about to become zero in the middle of the hall as shown in Figure 4.8. The decrease in velocity causes the air to not force enough through the middle wall, which then produces no viscosity force for circulation.

The observation below shows that different wall height temperature distribution for the terrace house. The house's air velocity decreases as the height of the wall increases the house volume and thus increases the temperature. The front wall surface has a difference temperature variation with the highest temperature of 305.3 K (32.3°C) compared to the normal wall height of 303.8 K (30.8°C). This is due to the wider front wall area, which increases the height of the wall and the heat gain from the environment. The wall height, however, does not make a big difference in temperature distribution and air velocity flow.

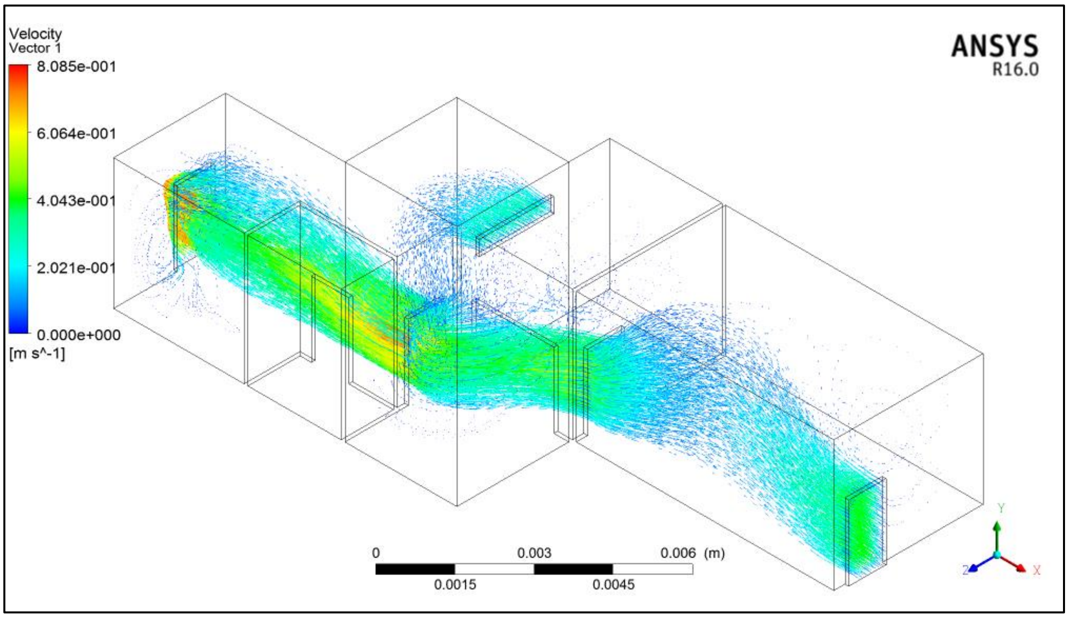

Figure 4.7 Air velocity flow distribution

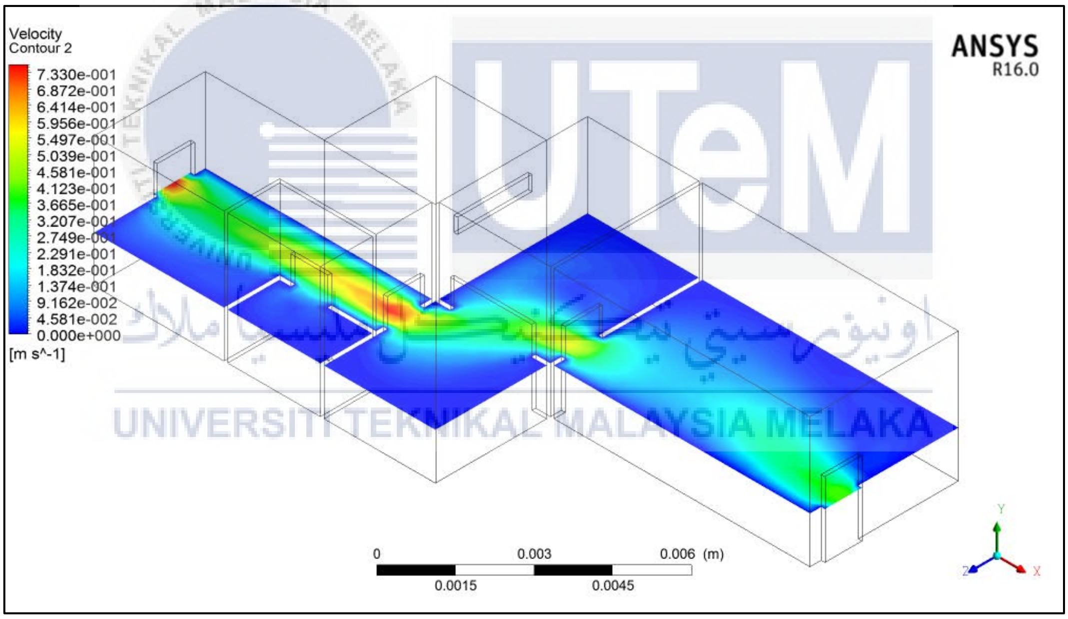

Figure 4.8 Velocity contour on XZ plane

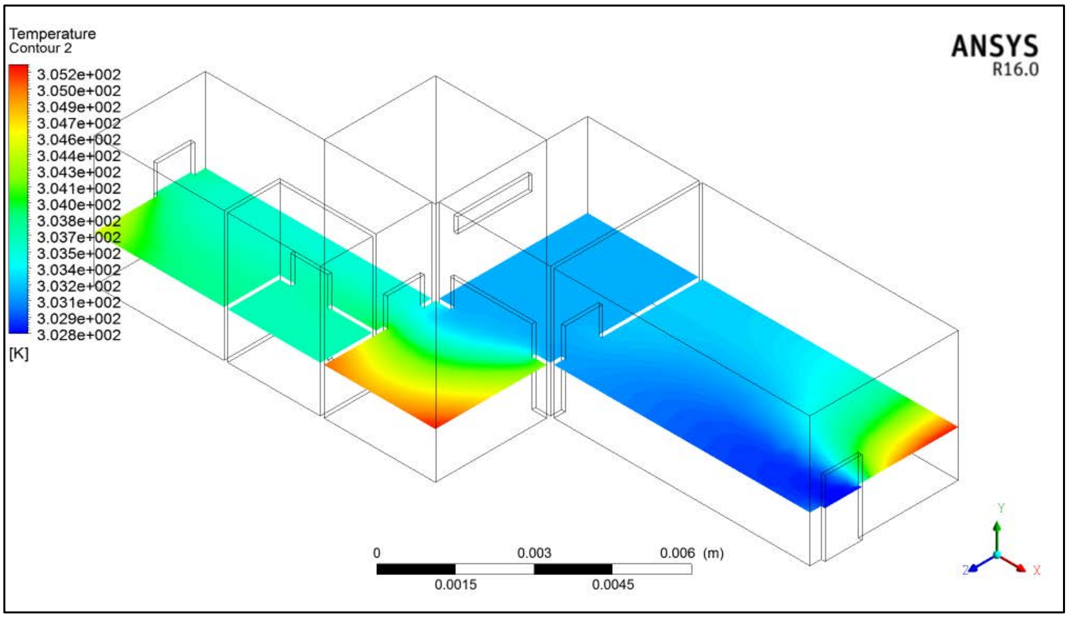

Figure 4.9 Temperature contour on XZ plane

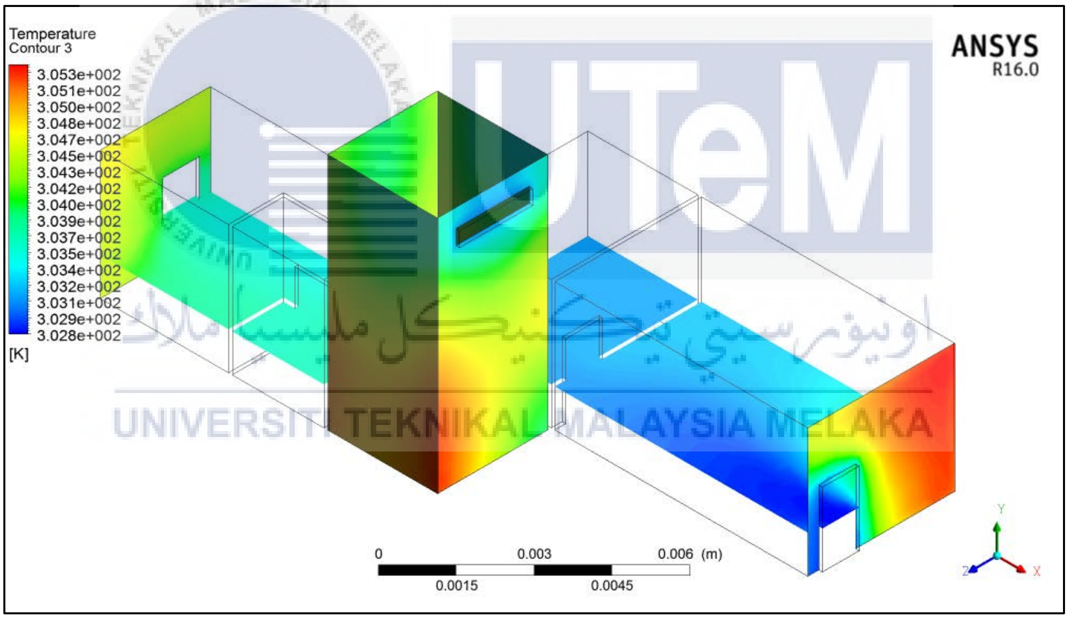

Figure 4.10 Temperature distribution

The significant difference of air flow and temperature distribution happen in the hall section. Figure 4.11 and 4.12 show the comparison of air velocity and temperature distribution on YZ plane in the hall section. The air velocity is seen to be slower on the 4th plane of the new house height compare to normal house height. The region for high temperature is larger for new house height since there is no circulation in the hall section to cool the front wall due to heat flux from environment.

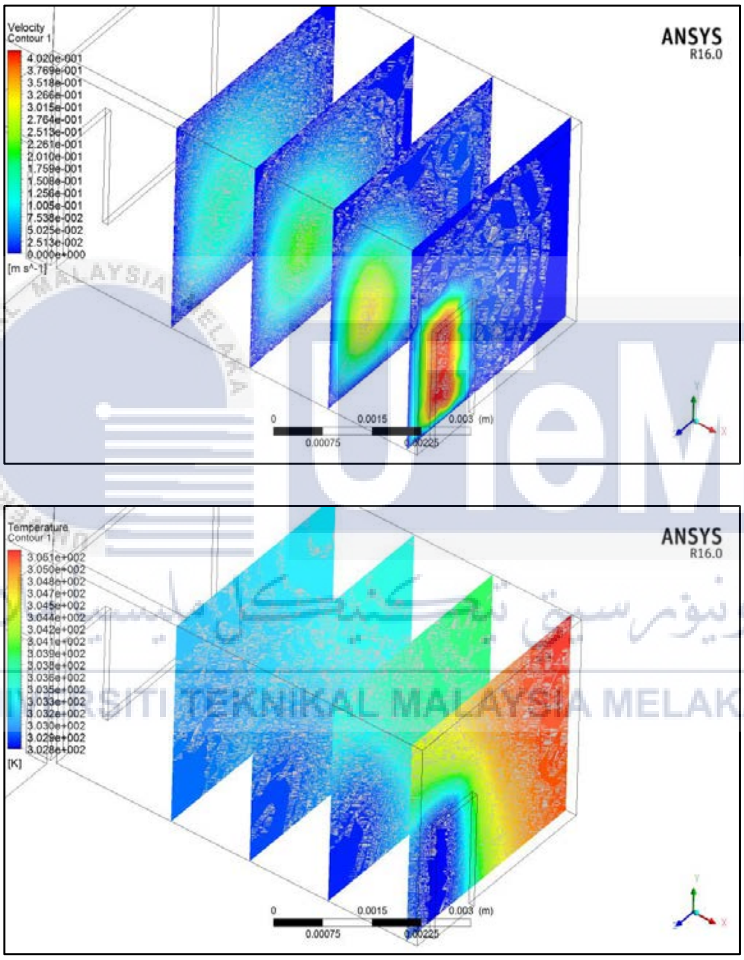

Figure 4.11 Air velocity and temperature distribution on YZ plane for house with new height

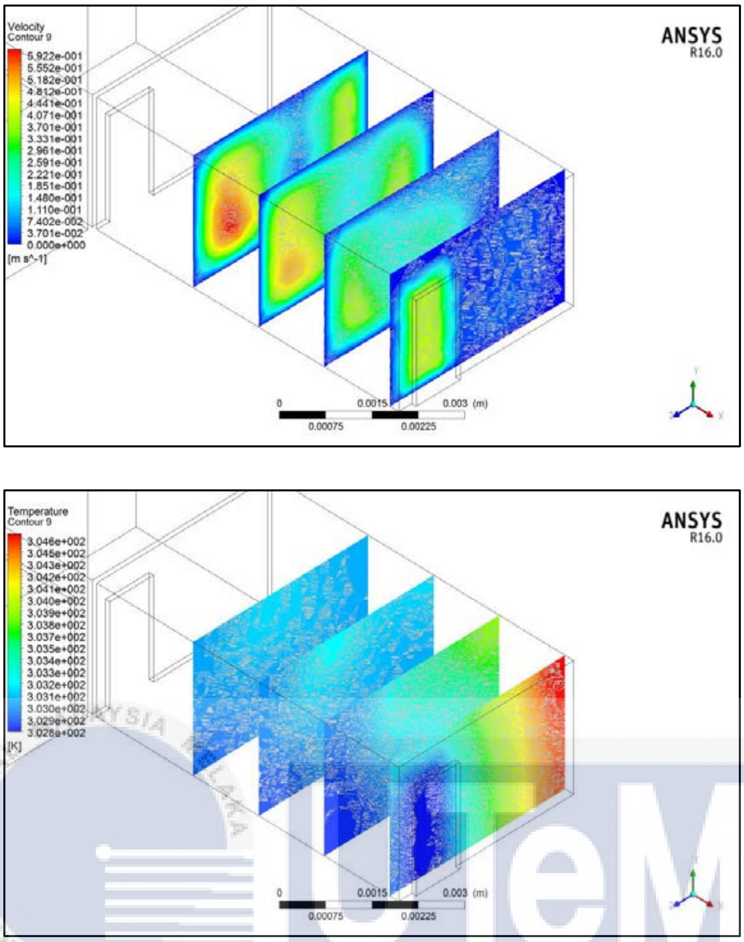

Figure 4.12 Air velocity and temperature distribution on YZ plane for house with normal height

The above observation shows that the effect of changing the height of the wall has almost negligible effects on the temperature distribution inside the terrace house. The flow condition and air velocity inside the house are also unaffected by changing wall height. Furthermore, both parameters are still outside the range of thermal comfort level specified by the ASHRAE standard.

4.1.4 Effect of air conditioner in air and temperature flow

The simulation on the house's third model is conducted to study the effect of the air conditioner system on the air and temperature flow inside the terrace house. The model represents the naturally ventilated house furnished with two air conditioners that are installed on the front and back walls near the top of the wall. The air conditioner is predicted to improve the air flow and circulation conditions inside the house, thus improving the temperature distribution. The boundary condition for the natural ventilation was prescribed the same as the first and second models. In addition, the air conditioner has the boundary condition which temperature at 20°C and air flow at a speed of 0.25 m/s.

Figure 4.11 shows the air velocity distribution inside the terrace house when the air conditioner is turned on. It can be observed that the air conditioner installed in the hall and kitchen section caused swirling air flow. The swirling flow intensity appears to be the highest in the area closed to the front and back walls. The air flow rate increases compared to the natural ventilation condition, where the highest air velocity is about 3.2 m/s near the front wall. Swirling air flow condition can also be seen in the area that is closed to the middle partition wall and the kitchen. The air flows from the door on the partition wall to the back door with a uniform velocity in a streamline condition. In the stack section, lower air velocity with uniform pattern occurs.

Figure 4.12 shows the distribution of air temperature inside the house when the air condition is turned on. It can be seen that the temperature inside the hall and kitchen section drops to 298.6 K (25°C) and appears to be affected by the front and back wall air conditioner. The air conditioner cools down the temperature that appears on the front and back wall with a high temperature in natural ventilated house. However, high temperature can be seen at the top section of the stack. Due to the surrounding heat gain, the stack wall shows higher temperature than the air inside the house.

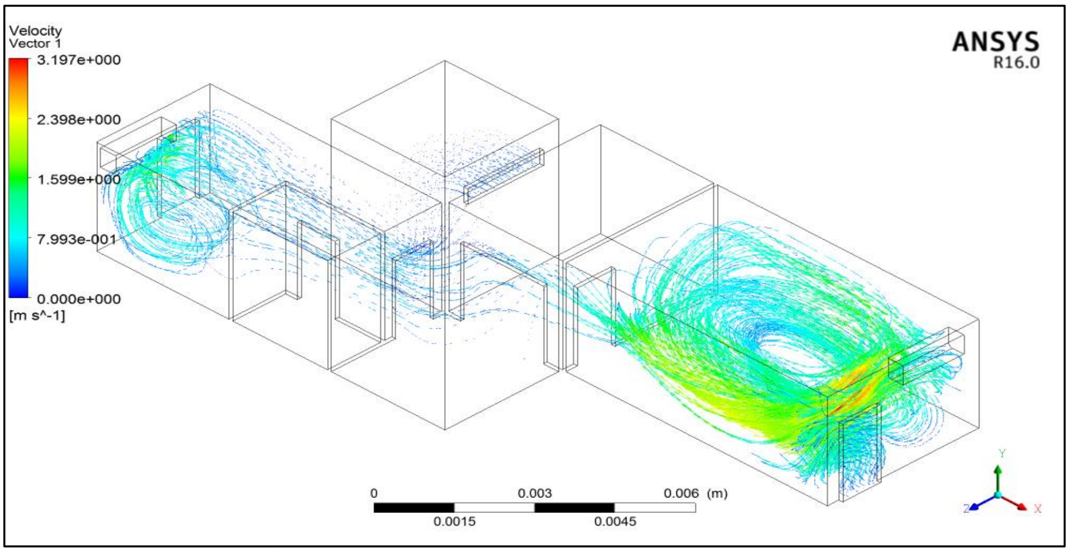

Figure 4.13 Air velocity flow distribution

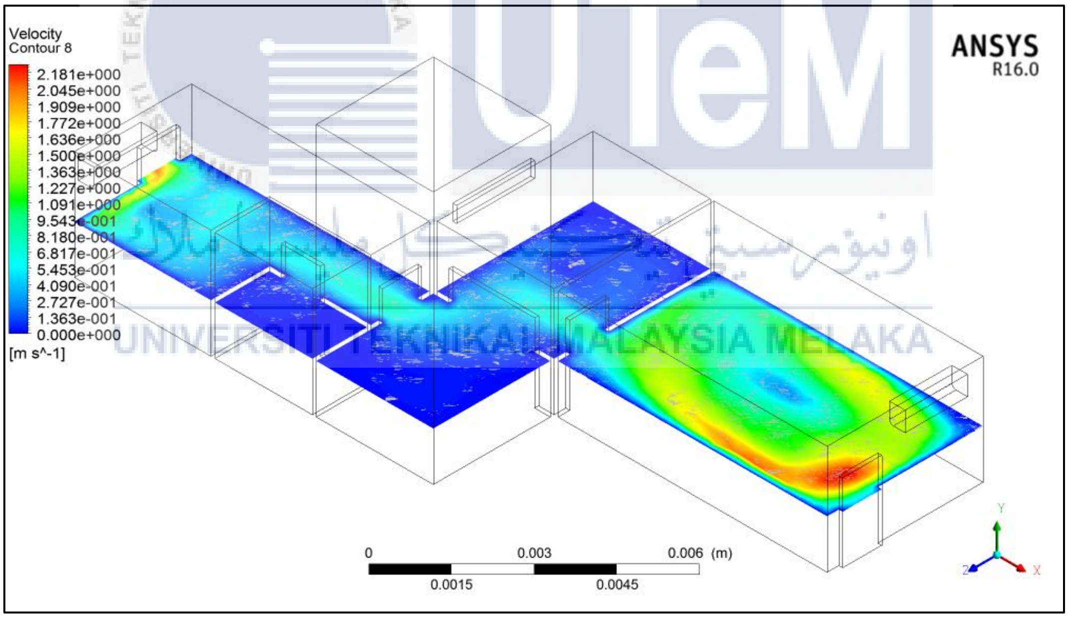

Figure 4.14 Velocity contour on XZ plane

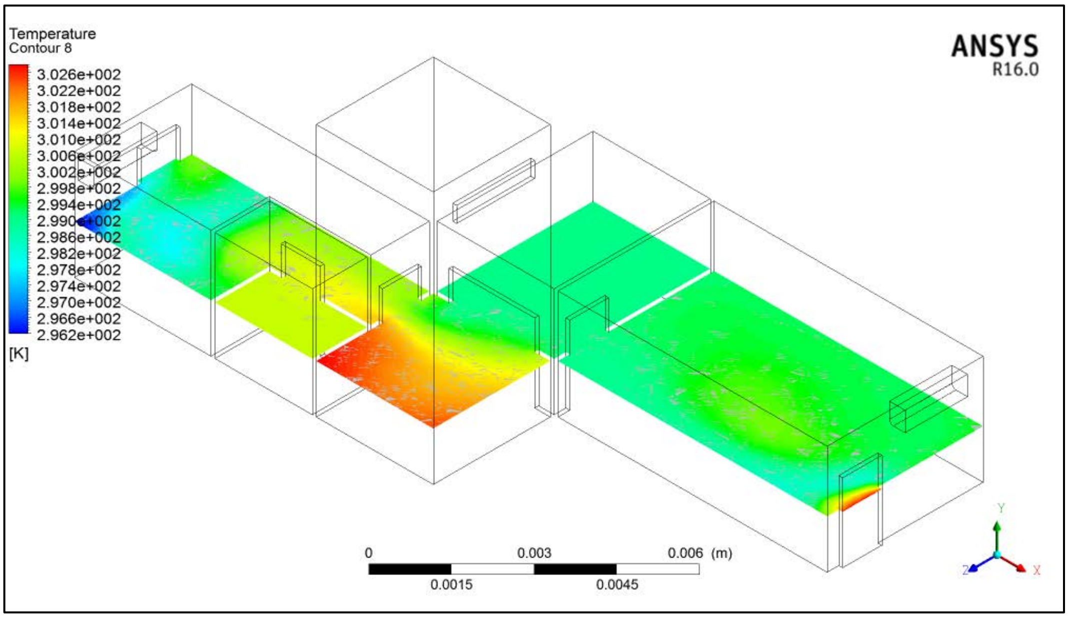

Figure 4.15 Temperature contour on XZ plane

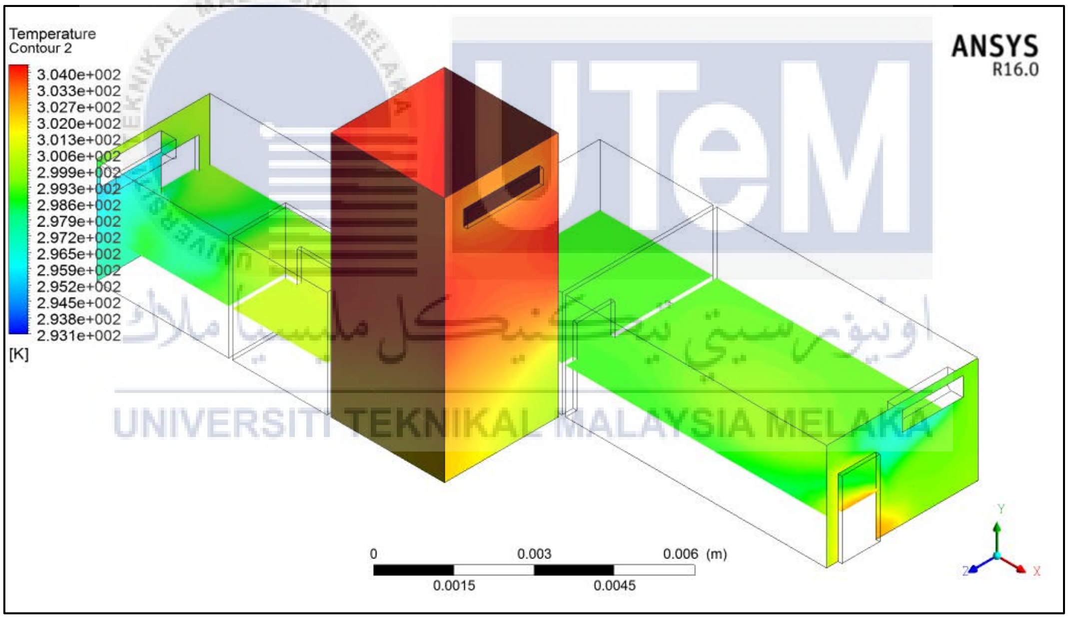

Figure 4.16 Temperature distribution

The stack section comparison is shown in Figure 4.15 and 4.16. The air velocity with air conditioner in the stack is high on the bottom plane where the air is attracted to the air flow from the front door and front air conditioner. Thus, the air mixed and flowed out to the back door. While the air velocity without air conditioner is high on top plane due to no high air flow velocity that affected the air from the stack. The temperature increased with the decrease in velocity on the stack section for house with air conditioner system.

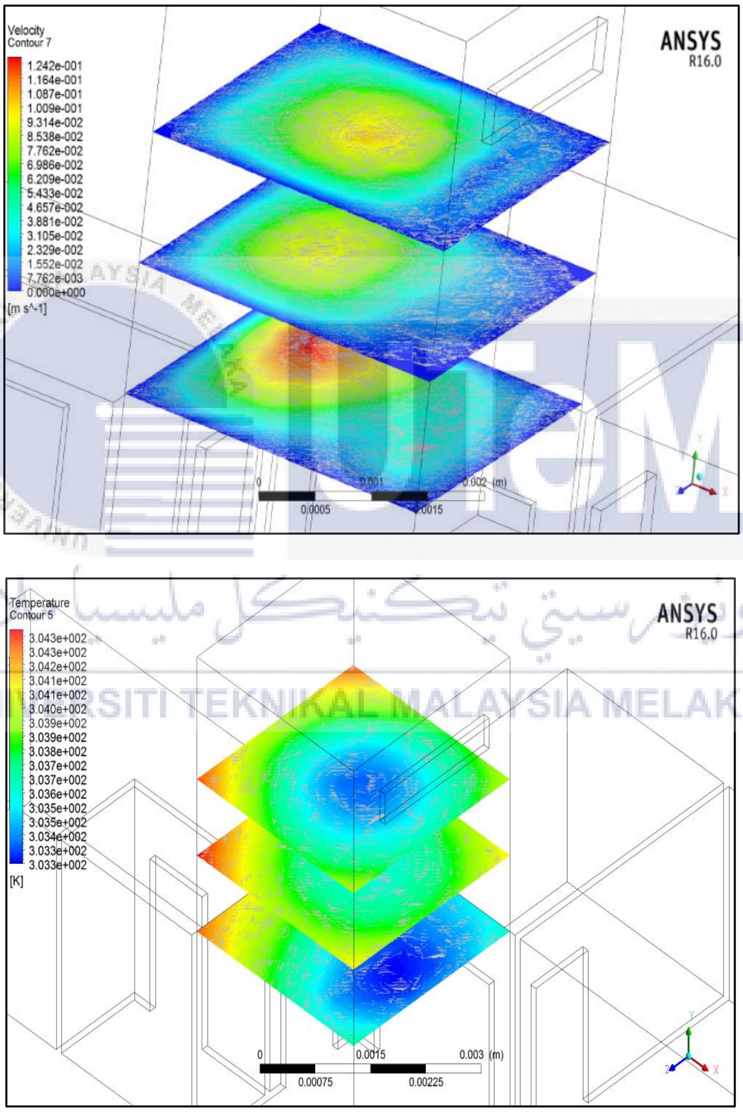

Figure 4.17 Temperature and velocity contour on XZ plane with air conditioner

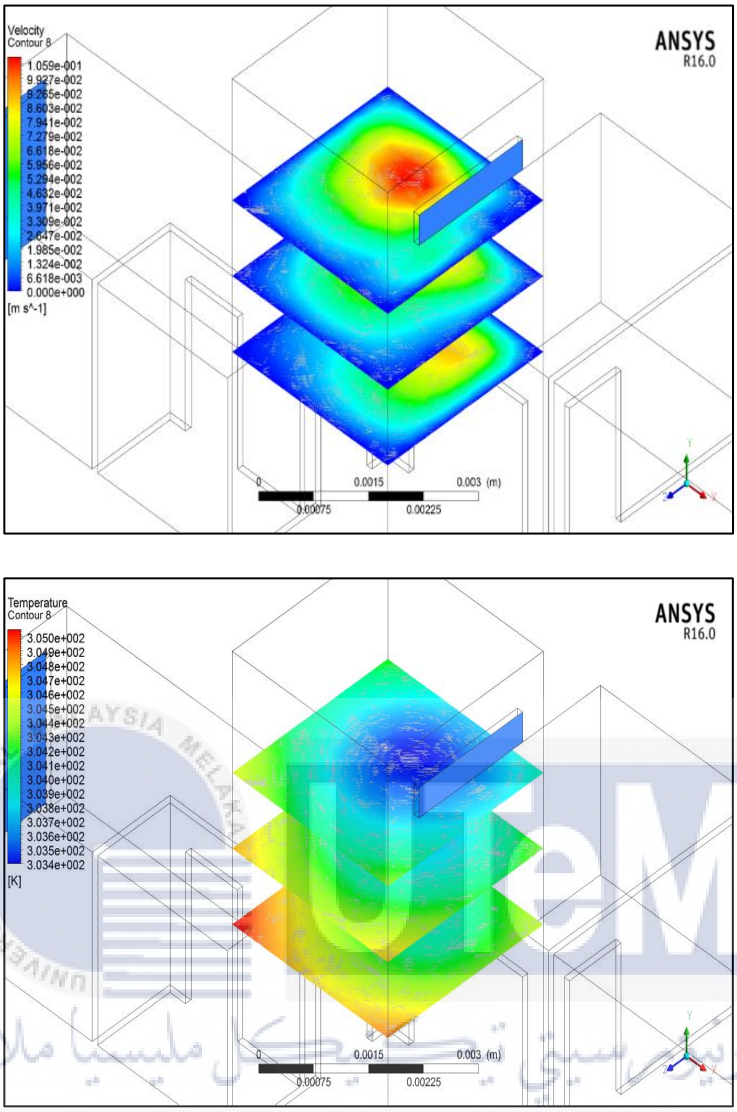

Figure 4.18 Temperature and velocity contour on XZ plane without air conditioner

The above findings show that the use of air conditioning system will create vortex and swirling air flow condition. The air conditioner also increases the air flow velocity inside the terrace house anywhere else. Where the air velocity is about 3.2 m/s higher. The air velocity is much higher than the level specified by the ASHRAE standard, which could cause the occupants discomfort. In order to achieve thermal comfort, the temperature must be between 25-27°C, the air velocity must be 0.2-0.8 m/s and the relative humidity must be between 30% and 60%. However, the air conditioner system helps to make the temperature distribution in the house colder and more uniform, especially in the hall and kitchen section.

CHAPTER 5

CONCLUSION

5.0 Introduction

This chapter will be discussing on the conclusion and recommendation for the future work to further improvement of this system concept. This project is divided into two parts, which is hardware description and software implementation. This chapter also will conclude overall procedure and finding of the project.

5.1 Conclusion

A study was presented on the distribution of air and temperature flow within a terrace house to achieve thermal comfort. The simulation's boundary condition was based on past study. The CFD simulation was conducted on the house's representative models. Based on the simulation, when it was naturally ventilated, air velocity (0-0.8m/s) and temperature (305K to 302K) flow were observed inside the terrace house. The use of air conditioner installed in the hall and kitchen wall section produces a swirling air flow and decreases both section temperature about 26.3ºC. Almost everywhere inside the house, the air temperature distribution becomes more uniform. However, since the air velocity is high, the level of thermal comfort in the house remains outside the recommended level. The results of the CFD analysis also show the change in the house's wall height where it shows almost negligible effect on the air flow as well as temperature distribution inside the terrace house.

5.2 Recommendation

This project has an enormous potential to be improved in a few ways. The house's optimized model has been successfully developed, but many additional features can be added to improve the distribution of air and temperature flow to achieve thermal comfort. The additional features will be discussed in this section.

The main weakness of the optimized model is the terrace house design. The design of the terrace house is lack of ventilation to allow air to flow in and out. Ventilation is good for the house's air flow and temperature distribution. By adding a window to the front wall next to the front door for another air inlet to cool the section of the hall. The ventilation can also be placed at the high temperature area so that the temperature decreases as the air flow exits the ventilation.

Another way to improve the air flow and temperature distribution inside the house is by changing the air conditioner position. The air conditioner is good for lowering the temperature distribution, but it increases the air flow outside the level specified by ASHRAE. By changing the air conditioner position, the air produced can flow to all areas of the house. Furthermore, the air velocity produced from the air conditioner must be lower than 0.25 m/s as the thermal comfort is not achieved due to higher air velocity.

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