INVESTIGATING THE FEASIBILITY OF IMPLEMENTING GEOTHERMAL COOLING SYSTEM IN TROPICAL CITIES

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechanical Engineering

Faculty of Engineering and Science
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September 2015

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATING THE FEASIBILITY OF IMPLEMENTING GEOTHERMAL COOLING SYSTEM IN TROPICAL CITIES"** was prepared by **WONG YUEN CHEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechanical Engineering at Universiti Tunku Abdul Rahman.

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ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Tan Yong Chai for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to two of my friends who had shared me their outcomes and offered me their helps throughout the project period. I would also like to thank my loving parent who had helped and given me encouragement.

INVESTIGATING THE FEASIBILITY OF IMPLEMENTING GEOTHERMAL COOLING SYSTEM IN TROPICAL CITIES

ABSTRACT

This project was carried out to determine the feasibility of the cooling system in tropical cities. The air conditioner usage at tropical cities is very high due to the tropical weather. Thus, an introduction of better cooling system is important to save the environment. In this report, the feasibility of geothermal cooling system was investigated based on energy efficiency and total cost. The geothermal cooling system will need higher initial cost compared to air conditioner but need lower operating cost. Thus, this project will determine the payback period for the geothermal cooling system.

Besides, this project also analysed the efficiency of the parallel loop and series loop piping system. It was found that the efficiency of parallel loop system greater than the series loop system. This project focused on the cooling system for the double storey terrace house. Several geothermal cooling systems were proposed and compared to get the best system. It was found that the 4 separated parallel loop geothermal cooling system had the optimised efficiency and cost. The power consumption for the geothermal cooling system was quarter of the power consumption of air conditional with COP of 3. This system needs a payback period of one and quarter years compared to air conditioners.

In conclusion, the geothermal cooling system was efficient, low operating cost and environmental friendly. However, it required high initial cost and large land space. The high initial cost could be compensated by the operating cost saved. Thus, it can be concluded that geothermal cooling system is feasible in Malaysia and other tropical cities if there is enough land space.

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LIST OF SYMBOLS / ABBREVIATIONS

A	pipe cross section area, m^2
c_p	specific heat capacity, J/(kg·K)
D	diameter, m
f	friction factor
g	gravitational acceleration, m/s^2
h	heat transfer coefficient of air, W/m^{2}K
h_a	pressure head required from pump, m
h_L	pressure head loss, m
k	thermal conductivity of pipe, W/mK
K_L	loss coefficient
ℓ	pipe length, m
$\dot{m}$	mass flow rate, kg/s
Nu_D	Nusselt number, dimensionless
p	pressure, Pa
P	pumping power required, W
Pr	Prandtl number, dimensionless
q	heat needed to be rejected, W
Q	volumetric flow rate, m^3/s
R_{tot}	thermal resistance for the heat transfer, K/W
r	radius of the pipe, m
Re_D	Reynolds number, dimensionless
T	temperature, K
V	fluid velocity, m^2/s
z	height, m

ρ	density, kg/m^3
μ	dynamic viscocity, kg/ms
η	pump efficiency

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CHAPTER 1

INTRODUCTION

1.1 Background

The word 'geothermal' consists of two components, 'geo' and 'thermal'. 'geo' means Earth while 'thermal' means heat. By combining the 2 components, geothermal means heat from ground (Jay and Brian, 2011).

Generally, geothermal is used to generate electricity. The heat from Earth's core, which is 4500 km from the surface has temperature up to 5000 ℃. Geothermal resources have the potential to provide up to 50,000 times more energy than all the oil and gas resources on Earth. There are several methods to extract geothermal energy. The easiest method is to drill into the geothermal reservoirs and bring the heat source to the surface. There are three main types of geothermal power plant, the dry steam, flash steam and binary power. Dry steam plant needs to be located near the steam reservoir to allow the steam tapped and piped directly to the plant's generator's turbines. Flash steam plant has 50 % lower efficiency than the dry steam plant because it used energy to convert hot water into steam. The advantage of flash steam plant is the condensed water can be reused. The binary power plant is used for cooler geothermal reservoirs. It uses lower boiling point liquid so that the liquid will vaporised in lower temperature and drive the turbine (Osman, 2010).

In this project, the main concern is not the geothermal energy from Earth's core, but geothermal from the surface. This type of geothermal called shallow geothermal. 'Shallow' in this case means less than 150 m below the Earth's surface (Jay and Brian, 2011).

1.2 Geothermal Cooling System

The shallow geothermal system is used as an air conditioning system. This system is called geothermal cooling system. This system has an advantage of higher efficiency. This is because the ground temperature is lower than the air temperature. The conventional air conditional releases heat into the air outside and due to the high temperature of the air, the air conditional needs to compress the fluid to release the heat effectively. While the geothermal cooling system does not need to compress the fluid because it releases the heat into the ground which is normally has lower temperature than the air above the ground (Jay and Brian, 2011).

The temperature of the ground is constant compared to surface. In four seasons countries, the temperature differences between ground and surface can reach between 5 and 14 ℃ in summer and up to 28 or more ℃ in the winter (Jay and Brian, 2011).

In Malaysia, due to the tropical weather, the temperature differences will be smaller compared to four seasons countries. The minimum temperature at 5 feet (1.5 m) below the surface is 27.6 ℃ (Tan, 2013). However, according to Soong (2013), the minimum temperature at 5 feet below the surface is 26 ℃.

The geothermal cooling system pumps the air from the room to the ground to release the heat. The geothermal cooling system basically uses two types of heat transfer, the conduction and convection. Convection occurs inside the air while conduction occurs when the heat dissipates out from air to soil (Jay and Brian, 2011).

In geothermal cooling system, the loop is the most important part to be considered. The efficiency of the geothermal cooling system depends on the heat transfer rate of the loop. In ground loops design, things to be considered are pipe diameter, pipe length, pipe material, depth and loop shape (Jay and Brian, 2011).

For the loop shape, there are closed loop and open loop system. A closed loop system means the fluid is circulated inside the loop while an open loop system pumps water from an aquifer, pond or lake. The closed loop system can be separated into two types, the horizontal loops and vertical loops (Jay and Brian, 2011).

Figure 1.1 shows a vertical loops system. In vertical loops system, the vertical two pipe or U-bend system is the most common. In this system, an U-bend shaped 20 mm diameter HDPE (high density polyethylene) is connected by heat fusion and inserted into a borehole. The borehole normally has a depth of 150 m or more. Depending on the soil, grout can be used to enhance the thermal conductivity of the pipe. The vertical loops system is commonly used because the soil at a depth of 8 m or more has good thermal stability. Besides, the vertical loops system requires less area compared to other loops. This will reduce the excavation needed to install the system (Jay and Brian, 2011).

Figure 1.1 Vertical Loops System (McQuay Air Conditioning, 2002)

Figure 1.2 shows a horizontal loops system. In horizontal loops system, the most common type is slinky-style loop. Figure 1.3 shows a slinky-style loop. This arrangement can fit 300 m length of 20 mm diameter pipe into a trench with size 240 m long and 1 m wide. This type of loop is one of the best horizontal loops system because it fully utilise the ground area (Jay and Brian, 2011).

Figure 1.2 Horizontal Loops System (McQuay Air Conditioning, 2002)

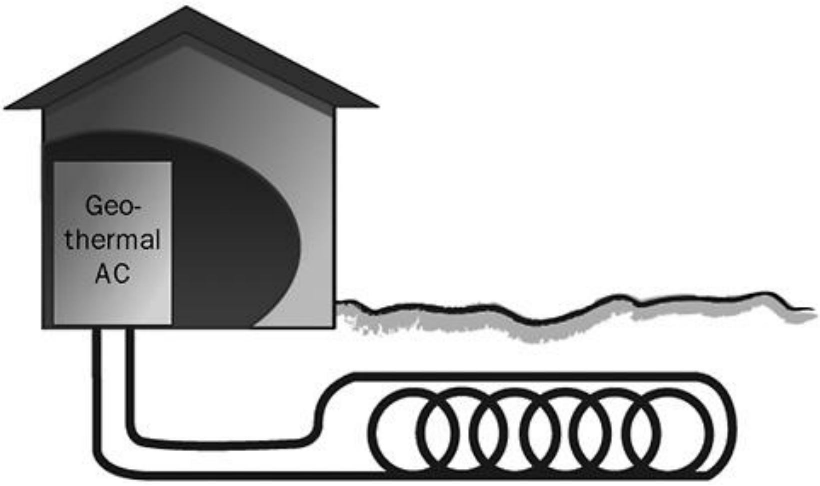


Figure 1.3 Slinky-Style Horizontal Loops System (Jay and Brian, 2011)

In open loops system, the water is pumped from outside such as pond or lake, then exchange the heat with the refrigerant inside the system. The water is then discharged. The water should be discharged back to the original source but in fact, most of the systems just discharge the water into adjacent pond or canal. This will lead to large amount of water waste. The advantage of open loops system is that the open loops system has higher efficiency than closed loops system. Figure 1.4 shows an open loop system. The water is pumped from left side then discharged to right side.

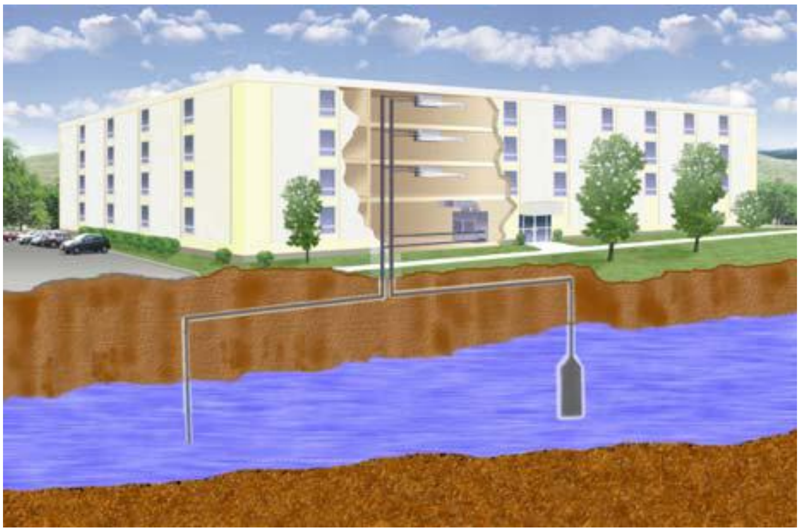


Figure 1.4 Open Loops System (McQuay Air Conditioning, 2002)

1.3 Tropical Cities

In this project, the main concern is to investigate the feasibility of implementing geothermal cooling system in tropical cities. Tropical is define as hot and humid weather. The tropical zone is located between 23.5 degrees north and 23.5 degrees south of the equator. Figure 1.5 shows various types of climate on Earth. The green colour is the tropical zone.

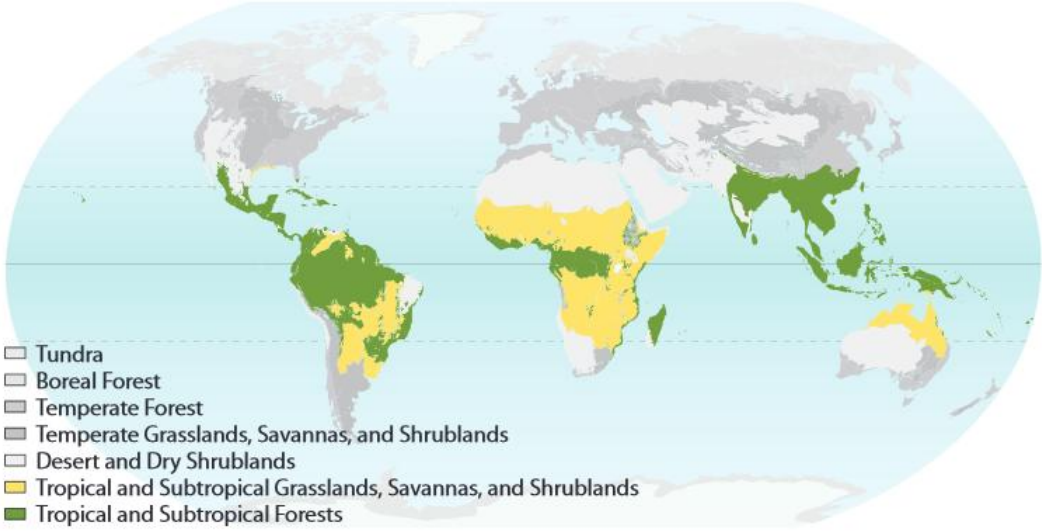


Figure 1.5 Earth Climate (Dong, et al., 2011)

1.4 Problem Statements

The feasibility of geothermal cooling system depends on the initial cost, operating cost, environmental impact and cooling capacity.

One of the main factors to implement geothermal cooling system is the cost. The contractor needed to be trained in order to construct the system. This will add initial cost to the geothermal cooling system Besides, the quality of the equipment used such as pipe also affect the initial cost (Jay and Brian, 2011).

The amount of operating cost saved depend on the coefficient of performance (COP) of the geothermal cooling system. A COP of 3 means that the system will have cooling power of 3 kWh for every 1 kWh of electricity input (SuperHomes, 2015).

According to Tenaga National Berhad (TNB), different amount of electricity usage has different rate. For example, for the first 200 kWh, the price is 21.8 sen per kWh. For 201-300 kWh, the rate become 33.4 sen per kWh. This means that the operating cost will increase almost exponentially. Thus, it is important to know the average electricity usage of the specific house type (double storey terrace in this project) when using the conventional cooling system (Tenaga Nasional Berhad, 2015).

Therefore, the first problem to be resolved in this project was to determine the initial cost and operating cost of geothermal cooling system and conventional cooling system for double storey terrace house.

In order to get the operating cost saved by geothermal cooling system, the COP of geothermal cooling system is needed. The COP is calculated based on the pumping power needed to pump the air into the loops to reduce the temperature of the room into desired value. In order to determine the pumping power, the suitable pipe length needed to be determined. Thus, the second problem statement to be resolved in this project was to determine the suitable pipe length for geothermal cooling system.

The arrangement of loops can affect the pumping power. The series loop should be avoided as it requires much more power. Parallel loop is preferred when the loop is long (Jay and Brian, 2011).

Thus, the third problem statement to be resolved in this project was to determine the pumping power for parallel loop and series loop piping system. The forth problem statement to be resolved in this project was to design and model the geothermal cooling system for a double storey terrace house using Computational Fluid Dynamics (CFD).

1.5 Aim and Objectives

Based on the problems stated in Chapter 1.4, the project was carried out with several objectives. The objectives for the project were:

1. To determine the suitable pipe length for geothermal cooling system in double storey terrace house.
2. To determine the pumping power for parallel and series loop piping system.
3. To determine suitable centrifugal pump size and power for geothermal cooling system for double storey terrace house.
4. To determine the initial cost and operating cost of geothermal cooling system and conventional cooling system for double storey terrace house.
5. To design and model the geothermal cooling system for a double storey house.

CHAPTER 2

LITERATURE REVIEW

2.1 Electricity Consumption In Malaysia

In Malaysia, the residential electricity consumption per capital is 681 kWh annually (Ahmad, 2010). This means that the electricity will be 567.5 kWh per month. Let say there are five persons in one house, the electricity consumption per household will be 284 kWh.

There was a survey to find out the average electricity consumption for residential in Malaysia. The survey separated the electricity consumption into three classes, the double storey house, single storey and apartment. The result states that the double storey house has highest consumption of 443.06kWh per month while the single storey house has electricity consumption of 404.64kWh per month and apartment has only 260.4kWh of electricity consumption per month (Asmarashid, Nur and Ariffudin, 2012).

The electricity consumption for air conditioner is about 44 % of total consumption. The electricity consumption for cooling is the largest portion among others (CETDEM, 2006).

2.2 Coefficient Of Performance (COP)

The coefficient of performance (COP) is used to measure the efficiency of the heat pumps, it is used when the heat pump is used for heating purpose. For cooling purpose, Energy Efficiency Ratio (EER) or Seasonal Efficiency Ratio (SEER) is used. The equations to calculate the COP and EER are as follows.

$$COP = \frac{NetCapacity\,(W)}{PowerInput(W)} \tag{2.1}$$

$$EER = \frac{NetCapacity\,(BTU\ /\ hr)}{PowerInput(kW)} \tag{2.2}$$

From equation 2.1, the net capacity is the amount of heat released by the heat pump while the power input is the electrical power consumed by the heat pump when release that amount of heat. For example, COP of 2 means the heat pump produce 2 times as much heat than the heat equivalent to the power input.

From equation 2.2, the EER is not dimensionless, thus, it is not representing the efficiency of the cooler. In order to get the efficiency value, the unit must be converted to eliminate both units in numerator and denominator. The EER efficiency equation will become as follows.

$$Efficiency(EER) = \frac{NetCapacity\,(Btu\,/\,h)}{PowerInput\ (W) \times 3.414(Btu\,/\,Wh)} \tag{2.3}$$

The 3.414 Btu/Wh in equation 2.3 is used to convert the power input unit into Btu/hr so that the EER becomes dimensionless. After the conversion, the EER value actually the same as the COP value (John, 2006).

The COP of the conventional air conditioner can be obtained from the manufacturer's official website. Table 2.1 shows the EER and COP of various models from different manufacturers.

Table 2.1: The EER And COP Of Various Models From Different Manufacturers

Brand-Model	EER (Btu/hW)	COP
Samsung-AR5000	13.32	3.9
LG-HS-091PM	14.98	4.4
Mitsubishi-MSY-GJ10VA	11.09	3.3
Panasonic-CS-S10RKH	12.6	3.7
Panasonic-CS-V9RKH	9.21	2.7

Note that all the model in Table 2.1 are inverter type air conditioner except the Panasonic CS-V9RKH which is a non inverter type air conditioner.

A comparative test was carried out on nine brands at India by Consumer Voice of Department of Consumer Affairs of India. The result shows that the conventional air conditioners have an average COP of 3.28 (Department of Consumer Affairs of India, 2014).

The EER for geothermal cooling system (the cooling system in this case is actually a geothermal heat pump) is 17 Btu/hW while the EER for conventional air conditioning system is 10.5 Btu/hW for outside temperature at 32.2 ℃, 9 Btu/hW for outside temperature at 37.7 ℃ and 8 Btu/hW for outside temperature at 43.3 ℃. This shows that the conventional air conditioner will have lower efficiency when the air temperature increases. By using equation 2.3, the COP of geothermal cooling system become 5 (Vibhute, Shaikh and Patil, 2013).

2.3 Human Thermal Comfort

It is important to know the human thermal comfort temperature so that the geothermal cooling system can be designed effectively. Thermal comfort is difficult to measure because it determined by human feeling. It is defined as the satisfaction of someone feeling towards the environment thermal condition. This feeling is defined using 'cold' or 'warm'. There are seven point thermal scale defined by ASHRAE. The scale has a value between -3 to +3 where -3 is cold while +3 is hot and 0 is neutral (Shan, 2001).

The indoor comfort temperature for human during summer is 23.9 ℃ to 25.6 ℃. In practice, a tolerance of ±1.1 to 1.7 ℃ is acceptable (Shan, 2001).

The thermal comfort envelope by ASHRAE is shown in Figure 2.1.

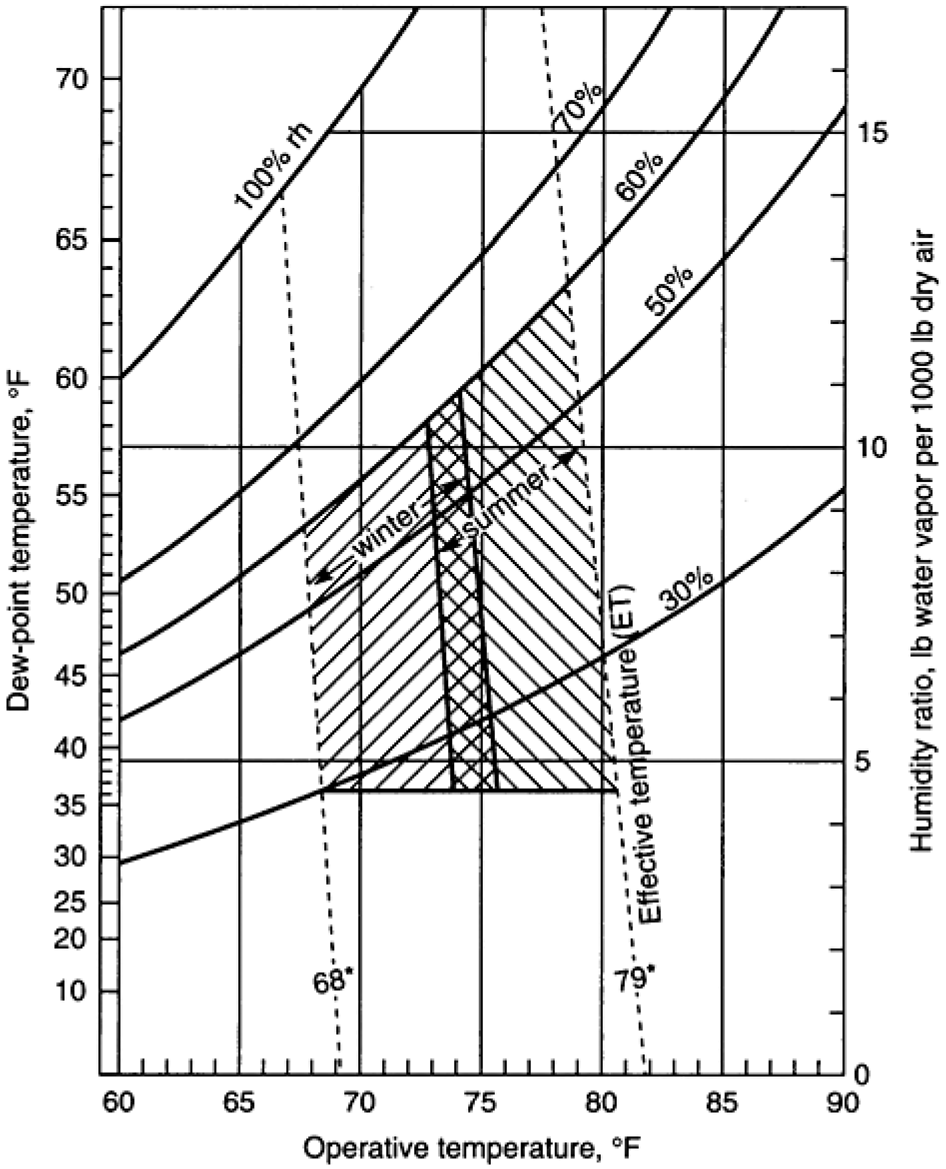


Figure 2.1 Comfort Chart (Eugene, Theodore and Ali, 2006)

From Figure 2.1, it shows that the human comfort temperature during summer is between 75 ℉ (24 ℃) and 80 ℉ (27 ℃).

2.4 Suitable Depth For Geothermal Heat Exchange Loop

It is important to know the suitable depth of the buried pipe before design the geothermal system. The pipe needs to be buried in the depth that the heat from Sun cannot reach. The ground can be separated into three zones, the surface, shallow and deep zone. Surface zone is at the depth of 1 m or less. This zone is very sensitive to short time temperature changes of weather. Shallow zone is at the depth of 1 to 8 m for dry light soils and up to 20 m for moist heavy sandy soils. This zone has stable temperature and can only be affected by seasonal weather changes. Deep zone is at the depth after the shallow zone. The temperature in this zone will increases when goes deeper due to the heat from Earth's core (Georgios and Soteris, 2004).

For geothermal cooling system, the heat exchange loop should be at shallow zone. The depth for the loop is 1 to 2 m from surface (Georgios and Soteris, 2004).

According to Vibhute, 2013, the suitable depth for geothermal horizontal loop is 4 feet to 6 feet, which is 1.2 m to 1.8 m. These show that the suitable depth for heat exchange loop is between 1 m and 2 m. This can be further clarified by Soong's project. The ground temperature at depth of 4 feet and more was constant (Soong, 2013).

2.5 Ground Temperature

The ground temperature is important when designing geothermal cooling system. The lower the ground temperature, the better the performance of the geothermal cooling system.

The ground temperature at 4 feet (1.2 m) depth was between 26℃ to 28℃. For the ground temperature at 5 feet (1.5 m) depth, the temperature profile remains same as ground temperature at 4 feet (Soong, 2013). This means that the temperature starts from 4 feet depth begins to constant. This shows that 4 feet is the optimum depth to install the geothermal heat exchange loop.

2.6 Piping Material

Pipe is one of the main component in geothermal cooling system. Thus, it is important to choose the right material for the pipe. The pipe used in geothermal heat pump is usually high-density polyethylene (HDPE) pipe or polybutylene pipe. By comparing the price of both material, polybutylene pipe is cheaper. However, it has poor dependability and high failure rate compared to HDPE pipe. Thus, HDPE pipe is commonly used in geothermal heat pump (Jay and Brian, 2011).

Besides HDPE, other materials also can be used. For example, PVC, CPVC (chlorinated polyvinyl chloride), galvanized steel and copper. However, these materials are more expensive than HDPE especially copper (Jay and Brian, 2011). Figure 2.2 shows the material life expectancy chart.

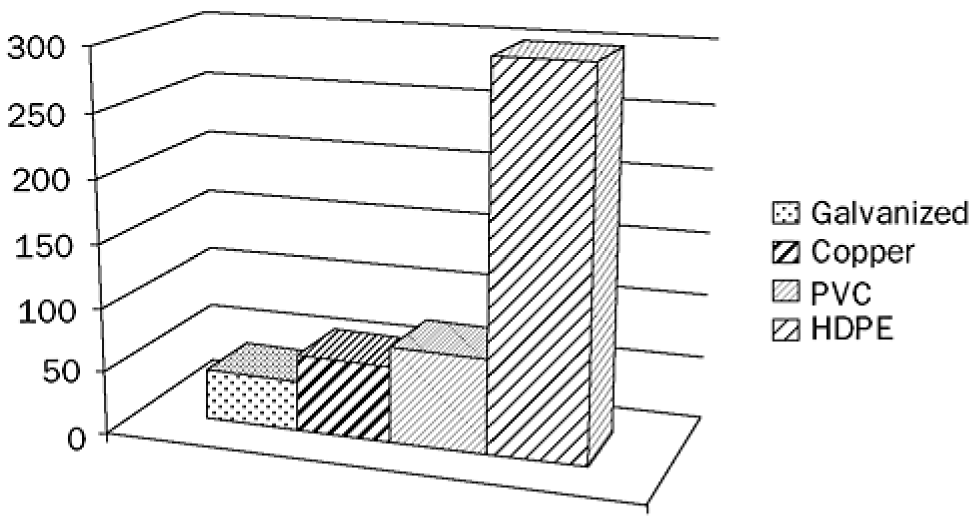


Figure 2.2 Material Life Expectancy Chart (Jay and Brian, 2011)

2.7 Loop Design

There are two types of loop system, the open loop system and closed loop system. The main concern in this project is horizontal closed loop system. This system is the most cost effective when enough yard space available (Georgios and Soteris, 2004).

The horizontal closed loop system can have three different piping connection. The three types of connection are series connection, parallel connection and trench collector (Georgios and Soteris, 2004). Figure 2.3 shows different types of connection for horizontal closed loop system.

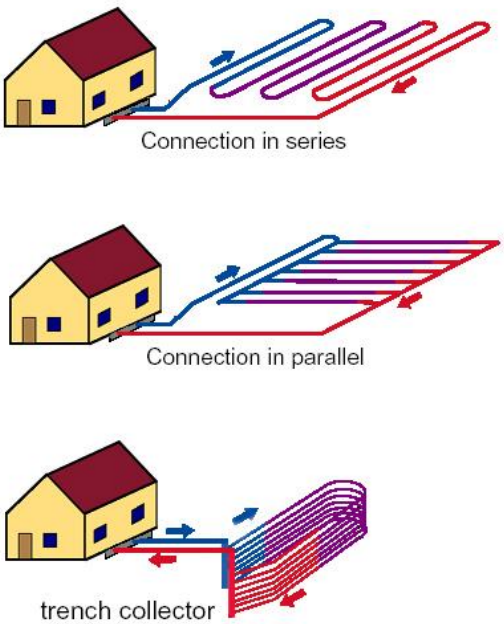


Figure 2.3 Different Piping Connection of Horizontal Closed Loop System
(Georgios and Soteris, 2004)

In practical applications, a parallel loops is preferred. The pipe length for each branch in parallel loop should be between 150 to 300 m length. Parallel loops is preferred because series loops require more pumping power (Jay and Brian, 2011).

In series pipe flow, the mass flow rate is same across the pipe and the head loss across the pipe is the total head loss within the pipe (Munson, et al., 2010). This means that the head loss increases as the pipe length increases. In parallel flow, the total mass flow rate is the sum of all the branch of parallel pipes. The head loss for all parallel pipes are same (Munson, et al., 2010). Based on this phenomenon, the parallel pipe will have smaller head loss due to the length of each parallel pipe is shorter compared to series pipe.

2.8 Cooling Load Calculation

When dealing with cooling system, it is important to know the heat absorbed by the house or building in order to design a suitable cooling system. When determine the cooling load needed, everything that contribute heat needs to be considered. This includes electrical appliances and even the colour of roof (Jay and Brian, 2011).

The cooling load analysis can be divided into two categories, the residential and non-residential cooling and heating load calculations. The cooling load needed depends on heat gain through structural components such as walls, through windows, caused by ventilation and occupancy. For the residential cooling load calculation, there are two main categories, the single family detached and multifamily buildings. The single family detached is like a bungalow where the external walls are exposed to sunlight while not all the walls in the multifamily buildings exposed to sunlight (ASHRAE, 2001).

When designing a geothermal cooling system, the peak load of the house or building must be considered (ASHRAE, 2001). This is because if the average load is considered instead of peak load, the cooling system will not be able to remove the load effectively during peak hour.

2.9 Computational Fluid Dynamics

The computational fluid dynamics (CFD) is a method to analyse and simulate the fluid flow. It solves the fluid flow solution by using the numerical approach and processing power of computer. The CFD can be considered as a numerical experiment. Unlike typical experiment which the fluid model is built when doing the experiment, the CFD uses governing equations and boundary conditions to find the solution (Munson, et al., 2010).

The accuracy of the CFD result depends on the governing equations and boundary conditions set and the mesh size. The governing equations and boundary conditions must be able to realise the actual situation. In CFD, the model is divided into many small parts when doing simulation. The small parts is known as mesh. The smaller the mesh size, the more number of mesh in the model. Thus, the accuracy of the result will be improved. However, large number of mesh means large processing load required. Thus, the best configuration is to mesh only the critical part of the model in small mesh size while the remaining non critical part will be meshed at larger mesh size (Munson, et al., 2010).

CHAPTER 3

METHODOLOGY

3.1 Measurement of Air Conditioner Consumption

In order to improve the accuracy of result for Chapter 3.2, an experiment was carried out to determine the air conditioner consumption in 24 hours. The testing site is located at Seri Kembangan and it is a double storey terrace house. However, in order to test the actual electricity consumption of one air conditioner, only one room is used as the testing site. Figure 3.1 shows the house for the experiment.

Figure 3.1 House For The Experiment

The room has a dimension of 2.8 m width x 3.5 m length x 2.8 m height. It has a window with dimension 1.17 m x 1.17 m facing southeast. Since it was a room in a terrace house, there is only one wall exposed to sunlight.

The air conditioner used in this test is Toshiba RAS-10UKPX4. It has a COP of 3.18 to 3.31. Figure 3.2 shows the specification plate of the air conditioner.

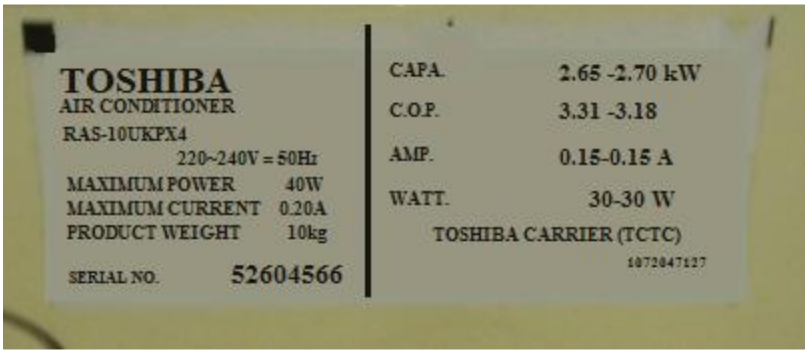


Figure 3.2 Specification Plate For Toshiba RAS-10UKPX4

The test was carried out twice to ensure the accuracy of the data collected. First test was carried out on 28 March 2015 while second test was on 30 March 2015. Both test was carried out in a period of 24 hours. Both test had the same result which is 13 kWh for 24 hours.

3.2 Feasibility of Geothermal Cooling System in Term of Cost

From the data collected in Chapter 2.1, the total electricity consumption for a double storey house is 443 kWh per month and the air conditioner has a percentage of 44 % from the total electricity consumption.

By using these data, the monthly air conditioner consumption can be obtained. After that, by referring the Tenaga Nasional Berhad tariff rate, the total cost for electricity consumption can be found. Table 3.1 shows the Tenaga Nasional Berhad tariff rate.

Table 3.1: Tenaga Nasional Berhad Tariff Rate (Tenaga Nasional Berhad, 2015)

Tariff Category	Rates
(1 - 200kWh) per month	21.8sen/kWh
(201 - 300kWh) per month	33.4sen/kWh
(301 - 600kWh) per month	51.6sen/kWh
(601 - 900kWh) per month	54.6sen/kWh

By referring Chapter 2.2, the coefficient of performance (COP) for geothermal cooling system and conventional air conditioner is 5 and 3.28 respectively. By comparing the COP of both system, the percentage of energy saved can be computed. The percentage equation is as follow.

$$\%Saved = \frac{COP_g - COP_a}{COP_g} \times 100\% \qquad (3.1)$$

where

%Saved = percentage of electricity saved

COP_g = COP of geothermal cooling system

COP_a = COP of conventional air conditioner

By using the percentage of electricity saved and the average air conditioner electricity consumption, the electricity consumption for geothermal cooling system can be estimated. Then, the cost for electricity consumption for geothermal cooling system also can be found. By comparing the electricity consumption cost for both system, the electricity cost saved per month can be obtained.

By using all the data above, the initial cost or installation cost of geothermal cooling system needed to make it feasible in term of cost can be found.

However, the data on electricity consumption of air conditioner obtained is based on average usage. This means that the actual electricity consumption for air conditioner to cool the whole double storey house will be greater than the average electricity consumption. From result obtained in Chapter 3.1, the air conditioner with has the electricity consumption of 13 kWh for 24 hours. The heat gain for the room in Seri Kembangan house can be calculated using residential cooling load calculation. By using the heat gain calculated and the electricity consumption data obtained in Chapter 3.1, the actual COP of the conventional air conditioner can be found. By using this data, the total electricity consumption per month can be found and by repeating the steps stated previously, the initial cost or installation cost of geothermal cooling system needed to make it feasible in term of cost can be found.

3.3 Cooling Load Analysis For Residential House

Due to this project was focused on double storey house, the residential cooling load analysis can be used. There are three categories of residences in residential cooling load analysis. First category is single-family detached. This type of house actually is a bungalow. The house has no sibling and all the walls are exposed to sunlight. Second category is multifamily buildings. Example of this category is terrace house. There are only one or two walls exposed to sunlight. Third category is other. For example the semi-detached house that has three walls exposed to sunlight (ASHRAE,2001).

When calculating cooling load, there are few heat gain sources needed to be considered. The heat gain through structural components, windows, infiltration, ventilation and occupancy (ASHRAE,2001).

3.3.1 Heat Gain Through Structural Components

Structural components of a house includes walls, floors, roof and ceiling. The heat gain for these components can be computed using cooling load temperature differences (CLTDs) and U-factors (ASHRAE,2001). Table 3.2 and 3.3 show the

CLTD values for single-family detached residences and multifamily residences respectively.

Table 3.2: CLTD Values For Single-Family Detached Residences (ASHRAE, 2001)

Daily Temperature Range[b]	Design Temperature, °C												
	29		**32**			**35**			**38**		**41**	**43**
	L	**M**	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**M**	**H**
All walls and doors												
North	4	2	7	4	2	10	7	4	10	7	10	13
NE and NW	8	5	11	8	5	13	11	8	13	11	13	16
East and West	10	7	13	10	7	16	13	10	16	13	16	18
SE and SW	9	6	12	9	6	14	12	9	14	12	14	17
South	6	3	9	6	3	12	9	6	12	9	12	14
Roofs and ceilings												
Attic or flat built-up	23	21	26	23	21	28	26	23	28	26	28	31
Floors and ceilings												
Under conditioned space, over unconditioned room, or over crawl space	5	2	7	5	2	8	7	5	8	7	8	11
Partitions												
Inside or shaded	5	2	7	5	2	8	7	5	8	7	8	11

[a]Cooling load temperature differences (CLTDs) for single-family detached houses, duplexes, or multifamily, with both east and west exposed walls or only north and south exposed walls, K.

[b]L denotes low daily range, less than 9 K; M denotes medium daily range, 9 to 14 K; and H denotes high daily range, greater than 14 K.

Table 3.3: CLTD Values For Multifamily Residences (ASHRAE, 2001)

Daily Temperature Range[b]		Design Temperature, °C 29		32			35			38		41	43
		L	M	L	M	H	L	M	H	M	H	M	H
Walls and doors[c]													
N	Low	8	6	11	9	7	13	12	9	14	12	15	18
	Medium	7	6	10	8	6	13	11	9	14	12	14	17
	High	5	3	8	6	4	11	9	7	12	9	12	15
NE	Low	13	9	16	12	9	18	15	12	18	14	17	20
	Medium	11	8	14	11	9	17	14	12	16	14	16	19
	High	9	7	12	9	7	14	12	10	14	12	14	17
E	Low	18	15	21	18	15	24	21	18	23	21	23	26
	Medium	17	13	19	16	13	22	19	16	22	18	22	24
	High	13	10	16	13	10	19	16	13	18	16	18	21
SE	Low	17	15	19	17	14	23	21	17	23	21	23	26
	Medium	16	12	18	15	12	21	18	15	21	18	21	24
	High	12	9	14	12	9	18	15	12	17	15	18	21
S	Low	14	12	16	14	12	19	17	14	20	18	21	24
	Medium	12	10	14	12	10	17	14	12	17	15	18	21
	High	9	6	11	9	7	14	12	9	14	12	15	18
SW	Low	22	20	24	22	19	28	26	22	28	26	29	32
	Medium	18	16	21	19	16	24	22	19	25	22	26	29
	High	13	10	16	13	11	20	17	14	19	17	20	23
W	Low	24	23	27	25	22	30	28	26	31	29	32	35
	Medium	21	18	23	21	18	26	23	21	27	24	27	31
	High	14	12	17	15	13	21	18	15	21	18	21	24
NW	Low	18	17	21	19	17	24	22	19	24	22	25	28
	Medium	16	14	18	16	13	21	18	16	22	19	22	25
	High	11	9	14	11	9	17	14	12	17	14	18	21
Roof and ceiling													
Attic or flat built-up	Light	32	29	36	33	31	39	36	33	39	36	40	43
Flat built-up	Medium or heavy	12	10	13	12	10	14	13	12	14	13	14	16
Floors and ceiling													
Under or over unconditioned space, crawl space		5	2	7	5	2	8	7	5	8	7	8	11
Partitions													
Inside or shaded		5	2	7	5	2	8	7	5	8	7	8	11

[a]Cooling load temperature differences (CLTDs) for multifamily low-rise or single-family detached if zoned with separate temperature control for each zone, K.

[b]L denotes low daily range, less than 9 K; M denotes medium daily range, 9 to 14 K; and H denotes high daily range, greater than 14 K.

[c]Low denotes low-density; medium denotes medium-density; and high denotes high-density construction.

From Table 3.2 and 3.3, design temperature is needed in order to obtain the CLTD value. The design temperature for Malaysia is shown in Table 3.4.

Table 3.4: Dry Bulb Temperature (ASHRAE, 2001)

	Cooling DB/MWB					
	0.4%		1%		2%	
Station	DB	MWB	DB	MWB	DB	MWB
1	2a	2b	2c	2d	2e	2f
LIBYA						
Banghazi	37.2	22.1	35.2	21.6	33.6	21.3
Tripoli	41.4	24.3	39.6	23.6	37.7	23.0
LIECHTENSTEIN						
Vaduz	28.3	19.2	26.8	18.3	25.3	17.7
LITHUANIA						
Kaunas	26.9	19.2	25.2	18.2	23.6	17.1
Klaipeda	24.9	18.6	23.0	17.5	21.2	16.9
Vilnius	27.1	18.1	25.3	17.7	23.8	16.7
MACEDONIA						
Skopje	35.2	20.2	33.3	19.8	31.8	19.4
MADEIRA ISLANDS						
Funchal	27.1	20.3	26.1	20.3	25.2	20.1
MALAYSIA						
George Town	32.9	26.0	32.2	25.8	32.0	25.8
Kota Baharu	32.9	26.2	32.4	26.1	32.0	26.0
Kuala Lumpur	34.2	25.4	33.8	25.5	33.2	25.5
Kuantan	33.5	26.0	33.0	25.9	32.5	25.9
Malacca	33.5	25.3	32.9	25.4	32.4	25.4
Sitiawan	33.3	26.2	32.9	26.1	32.5	26.1
Kuching	34.0	26.0	33.2	25.8	32.9	25.8
Miri	32.2	26.3	31.8	26.3	31.4	26.2

3.3.2 Heat Gain Through Windows

The heat gain through windows can be calculated using window glass load factors (GLFs) (ASHRAE, 2001). Table 3.5 and 3.6 show the GLF values for single-family detached residences and multifamily residences respectively.

Table 3.5: GLF Values For Single-Family Detached Residences (ASHRAE, 2001)

Design Temperature, °C	Regular Single Glass						Regular Double Glass						Heat-Absorbing Double Glass						Clear Triple Glass		
	29	32	35	38	41	43	29	32	35	38	41	43	29	32	35	38	41	43	29	32	35
No inside shading																					
North	107	114	129	148	151	158	95	95	107	117	120	129	63	63	73	79	82	88	85	85	95
NE and NW	199	205	221	237	243	262	173	177	186	196	199	208	114	117	123	132	139	139	158	158	167
East and West	278	284	300	315	322	337	243	246	255	265	268	278	161	161	170	177	186	186	221	221	230
SE and SW[b]	249	255	271	287	290	309	218	221	230	240	243	252	142	145	155	161	170	170	196	199	205
South[b]	167	173	189	205	211	227	145	148	158	167	170	180	98	98	107	114	123	123	132	132	142
Horizontal skylight	492	492	508	524	527	539	432	435	442	451	454	464	284	287	293	300	303	309	391	394	401
Draperies, venetian blinds, translucent roller shades, fully drawn																					
North	57	60	73	85	91	104	50	50	60	69	73	82	41	44	50	57	60	66	47	50	57
NE and NW	101	104	120	132	136	148	91	95	101	110	114	123	76	76	85	91	91	101	88	88	95
East and West	142	145	158	170	173	186	126	129	139	145	148	158	104	104	114	120	120	129	123	123	129
SE and SW[b]	126	129	145	155	161	173	114	117	123	132	136	145	91	95	101	107	110	117	110	114	120
South[b]	85	88	104	117	120	132	76	79	88	98	98	107	63	66	73	79	82	88	73	76	82
Horizontal skylight	246	249	262	271	274	284	224	224	233	240	243	249	183	186	192	199	199	205	218	218	224
Opaque roller shades, fully drawn																					
North	44	47	63	73	79	91	41	44	54	60	63	73	38	38	47	54	54	63	41	41	47
NE and NW	79	82	98	107	114	126	73	76	85	95	95	104	66	69	76	82	85	91	73	73	82
East and West	107	114	126	139	142	155	101	104	114	120	123	132	91	95	101	107	110	117	101	101	110
SE and SW[b]	98	101	114	126	132	145	91	95	104	110	114	123	82	85	91	98	101	107	91	91	98
South[b]	66	69	85	95	101	114	63	63	73	82	85	95	57	60	66	73	76	82	60	63	69
Horizontal skylight	189	192	202	214	218	227	180	180	189	196	199	205	164	164	173	180	180	186	177	180	186

[a]Glass load factors (GLFs) for single-family detached houses, duplexes, or multifamily residences, with both east and west exposed walls or only north and south exposed walls, W/m^2.

[b]Correct by +30% for latitude of 48° and by –30% for latitude of 32°. Use linear interpolation for latitude from 40 to 48 and from 40 to 32°.

To obtain GLF for other combinations of glass and/or inside shading: $GLF_a = (SC_a/SC_t)(GLF_t - U_tD_t) + U_aD_t$, where the subscripts a and t refer to the alternate and table values, respectively. SC_t and U_t are given in Table 5. $D_t = (t_a - 24)$, where $t_a = t_o - (DR/2)$; t_o is the outdoor design temperature and DR is the daily range.

Table 3.6: GLF Values For Multifamily Residences (ASHRAE, 2001)

Design Temperature, °C	Regular Single Glass						Regular Double Glass						Heat-Absorbing Double Glass						Clear Triple Glass		
	29	32	35	38	41	43	29	32	35	38	41	43	29	32	35	38	41	43	29	32	35
No inside shading																					
North	126	139	155	170	183	202	107	114	123	132	139	148	73	76	82	91	95	104	95	101	107
NE	278	281	287	300	306	315	246	249	252	262	265	268	164	164	167	173	173	180	224	224	230
East	429	432	438	448	454	464	378	382	385	394	397	401	249	249	255	262	262	265	344	344	350
SE	407	410	423	438	445	454	344	356	366	375	378	385	227	237	243	249	249	255	312	325	331
South[b]	278	287	303	319	331	347	240	246	255	265	271	281	158	164	170	177	183	189	214	221	227
SW	486	501	517	533	549	565	423	432	442	451	457	467	281	287	293	300	306	312	382	388	394
West	549	561	577	593	606	621	476	486	495	505	511	520	315	322	328	334	341	347	432	438	445
NW	388	401	416	432	445	464	337	344	353	363	369	382	224	227	237	243	249	255	303	309	315
Horizontal	785	795	807	823	833	845	688	694	703	713	719	725	454	460	467	473	479	486	624	631	637
Draperies, venetian blinds, translucent roller shades, fully drawn																					
North	66	79	91	104	114	126	57	66	73	82	88	98	47	54	60	66	73	79	54	60	66
NE	136	139	145	158	161	164	123	126	129	139	142	145	104	104	107	114	114	117	123	123	126
East	211	214	221	233	237	240	192	196	199	205	208	211	158	158	161	170	170	173	189	189	192
SE	202	205	218	230	233	243	183	186	192	199	202	208	151	151	158	164	164	170	180	180	186
South[b]	142	151	164	177	186	199	126	132	139	148	155	164	104	107	114	123	126	132	120	126	132
SW	249	262	274	287	296	309	221	227	237	246	252	262	180	186	196	202	208	214	214	218	224
West	281	290	303	315	325	337	249	255	265	271	278	287	205	208	218	224	227	237	240	246	252
NW	199	208	221	233	243	255	177	183	192	199	208	214	145	151	158	164	170	177	170	173	180
Horizontal	397	404	416	426	432	445	356	363	369	378	382	391	293	296	303	309	315	322	347	350	356
Opaque roller shades, fully drawn																					
North	54	66	79	91	101	114	47	54	63	73	79	88	44	47	57	63	69	76	47	50	57
NE	104	107	110	123	126	132	98	101	104	114	110	117	91	88	95	101	101	107	101	98	104
East	161	164	167	180	192	205	151	155	158	167	164	173	142	142	145	151	151	155	155	155	158
SE	155	158	167	180	183	192	145	148	155	164	164	173	132	136	142	148	148	155	145	145	151
South[b]	110	120	132	145	155	167	101	107	117	126	132	132	91	98	104	110	117	123	101	104	110
SW	192	205	218	230	243	255	180	186	196	205	211	221	164	170	177	183	189	196	177	183	189
West	214	224	237	252	262	274	202	208	214	224	230	240	183	189	196	202	208	214	199	202	208
NW	155	164	177	189	199	211	142	148	158	167	173	183	129	136	142	148	155	161	142	145	151
Horizontal	306	312	322	334	341	350	287	293	300	306	312	322	262	268	274	281	284	290	284	290	293

[a]Glass load factors (GLFs) for multifamily low-rise or single-family detached residences if zoned with separate temperature control for each zone, W/m^2.

[b]Correct by +30% for latitude of 48° and by –30% for latitude of 32°. Use linear interpolation for latitude from 40 to 48 and from 40 to 32°.

To obtain GLF for other combinations of glass and/or inside shading: $GLF_a = (SC_a/SC_t)(GLF_t - U_tD_t) + U_aD_t$, where the subscripts a and t refer to the alternate and table values, respectively. SC_t and U_t are given in Table 5. $D_t = (t_a - 24)$, where $t_a = t_o - (DR/2)$; t_o is the outdoor design temperature and DR is the daily range.

3.3.3 Infiltration and Ventilation

Infiltration is the heat transfer due to air leakage while ventilation is the heat transfer due to outside air introduced by air conditioning system. These heat exchange is negligible in this project because all the tests carried out all in sealed house.

3.3.4 Heat Gain From Occupancy

The heat gain per occupant is assume to be 67 W (ASHRAE, 2001). For the electrical appliances, the heat gain data for computers is shown in Table 3.7.

Table 3.7: Heat Gain From Computer (ASHRAE, 2001)

	Continuous, W	Energy Saver Mode, W
Computers[a]		
Average value	55	20
Conservative value	65	25
Highly conservative value	75	30
Monitors[b]		
Small monitor (330 to 380 mm)	55	0
Medium monitor (400 to 460 mm)	70	0
Large monitor (480 to 510 mm)	80	0

Sources: Hosni et al. (1999), Wilkins and McGaffin (1994).
[a]Based on 386, 486, and Pentium grade.
[b]Typical values for monitors displaying Windows environment.

For the lighting, we can neglect heat emission from lighting because most lighting used nowadays are light-emitting diode (LED) lamp which has a relatively small heat emission.

3.3.5 Load Calculation

The procedure for load calculation is shown in Table 3.7.

Table 3.8: Procedure For Residential Load Calculation (ASHRAE, 2001)

Load Source	Equation
Glass and window areas	$q = (\text{GLF})A$
Doors	$q = U_d A(\text{CLTD})$
Above-grade exterior walls	$q = U_w A(\text{CLTD})$
Partitions to unconditioned space	$q = U_p A \Delta t$
Ceilings and roofs	$q = U_r A(\text{CLTD})$
Exposed floors	$q = U_f A(\text{CLTD})$
Infiltration	$q = 1.2 Q \Delta t$ $Q = \text{ACH} \times (\text{room volume}) \times 1000/3600$
Internal loads— People, appliances, lights	Plan 67 W per person.
Total loads	Total cooling load = LF × (Sum of individual sensible cooling load components)

q = sensible cooling load, W
Δt = design temperature difference between outside and inside air, K
A = area of applicable surface, m^2
U = U-factors for appropriate construction, $W/(m^2 \cdot K)$
Q = volumetric airflow rate, L/s
ACH = air changes per hour, 1/h
GLF = glass load factor, W/m^2
CLTD = cooling load temperature difference, K
LF = latent load multiplier

From Table 3.8, the U-factor value for walls and roof is needed in order to compute the heat gain. Table 3.9, 3.10 and 3.11 show the U-factor for various types of wall, roof and door respectively.

Table 3.9: U-Factor For Wall (Spitler and Fisher, 1999)

	Layers (Inside to Outside)	Description	U (Btu/h·ft^2 °F)	U (W/m^2 K)
1	E0 A3 B1 B13 A3 A0	Steel siding with 4 in. (100 mm) insulation	0.066	0.375
2	E0 E1 B14 A1 A0	Frame wall with 5 in. (125 mm) insulation	0.055	0.312
3	E0 C3 B5 A6 A0	4 in. (100 mm) h.w. concrete block with 1 in. (25 mm) insulation	0.191	1.084
4	E0 E1 B6 C12 A0	2 in. (50 mm) insulation with 2 in. (50 mm) h.w. concrete	0.047	0.267
5	E0 A6 B21 C7 A0	1.36 in. (35 mm) insulation with 8 in. (200 mm) l.w. concrete block	0.129	0.732
6	E0 E1 B2 C5 A1 A0	1 in. (25 mm) insulation with 4 in. (100 mm) h.w. concrete	0.199	1.130
7	E0 A6 C5 B3 A3 A0	4 in. (100 mm) h.w. concrete with 2 in. (50 mm) insulation	0.122	0.693
8	E0 A2 C12 B5 A6 A0	Face brick and 2 in. (50 mm) h.w. concrete with 1 in. (25 mm) insul.	0.195	1.107
9	E0 A6 B15 B10 A0	6 in. (150 mm) insulation with 2 in. (50 mm) wood	0.042	0.238
10	E0 E1 C2 B5 A2 A0	4 in. (100 mm) l.w. conc. block with 1 in. (25 mm) insul. and face brick	0.155	0.880
11	E0 E1 C8 B6 A1 A0	8 in. (200 mm) h.w. concrete block with 2 in. (50 mm) insulation	0.109	0.619
12	E0 E1 B1 C10 A1 A0	8 in. (200 mm) h.w. concrete	0.339	1.925
13	E0 A2 C5 B19 A6 A0	Face brick and 4 in. (100 mm) h.w. concrete with 0.61 in. (16 mm) ins.	0.251	1.425
14	E0 A2 A2 B6 A6 A0	Face brick and face brick with 2 in. (50 mm) insulation	0.114	0.647
15	E0 A6 C17 B1 A7 A0	8 in. (200 mm) l.w. concrete block (filled) and face brick	0.092	0.522
16	E0 A6 C18 B1 A7 A0	8 in. (200 mm) h.w. concrete block (filled) and face brick	0.222	1.261
17	E0 A2 C2 B15 A0	Face brick and 4 in. (100 mm) l.w. conc. block with 6 in. (150 mm) ins.	0.043	0.244
18	E0 A6 B25 C9 A0	3.33 in. (85 mm) insulation with 8 in. (200 mm) common brick	0.072	0.409
19	E0 C9 B6 A6 A0	8 in. (200 mm) common brick with 2 in. (50 mm) insulation	0.106	0.602
20	E0 C11 B19 A6 A0	12 in. (300 mm) h.w. concrete with 0.61 in. (15 mm) insulation	0.237	1.346
21	E0 C11 B6 A1 A0	12 in. (300 mm) h.w. concrete with 2 in. (50 mm) insulation	0.112	0.636
22	E0 C14 B15 A2 A0	4 in. (100 mm) l.w. concrete with 6 in. (150 mm) insul. and face brick	0.040	0.227
23	E0 E1 B15 C7 A2 A0	6 in. (150 mm) insulation with 8 in. (200 mm) l.w. concrete block	0.042	0.238
24	E0 A6 C20 B1 A7 A0	12 in. (300 mm) h.w. concrete block (filled) and face brick	0.196	1.113
25	E0 A2 C15 B12 A6 A0	Face brick and 6 in. (150 mm) l.w. conc. blk. with 3 in. (75 mm) insul.	0.060	0.341
26	E0 A2 C6 B6 A6 A0	Face brick and 8 in. (200 mm) clay tile with 2 in. (50 mm) insulation	0.097	0.551
27	E0 E1 B14 C11 A1 A0	5 in. (125 mm) insulation with 12 in. (300 mm) h.w. concrete	0.052	0.295
28	E0 E1 C11 B13 A1 A0	12 in. (300 mm) h.w. concrete with 4 in. (100 mm) insulation	0.064	0.363
29	E0 A2 C11 B5 A6 A0	Face brick and 12 in. (300 mm) h.w. concrete with 1 in. (25 mm) insul.	0.168	0.954
30	E0 El B19 C19 A2 A0	0.61 in. (15 mm) ins. with 12 in. (300 mm) l.w. blk. (fld.) and face brick	0.062	0.352

Table 3.10: U-Factor For Roof (Spitler and Fisher, 1999)

	Layers (Inside to Outside)	Description	U (Btu/h·ft² °F)	U (W/m² K)
1	E0 A3 B25 E3 E2 A0	Steel deck with 3.33 in. (85 mm) insulation	0.080	0.454
2	E0 A3 BI4 E3 E2 A0	Steel deck with 5 in. (125 mm) insulation	0.055	0.312
3	E0 E5 E4 C12 E3 E2 A0	2 in. (50 mm) h.w. concrete deck with suspended ceiling	0.232	1.317
4	E0 E1 BI5 E4 B7 A0	Attic roof with 6 in. (150 mm) insulation	0.043	0.244
5	E0 BI4 C12 E3 E2 A0	5 in. (125 mm) insulation with 2 in. (50 mm) h.w. concrete deck	0.055	0.312
6	E0 C5 BI7 E3 E2 A0	4 in. (100 mm) h.w. concrete deck with 0.3 in. (8 mm) insulation	0.371	2.107
7	E0 B22 C12 E3 E2 C12 A0	1.67 in. (40 mm) insulation with 2 in. (50 mm) h.w. concrete RTS	0.138	0.784
8	E0 B16 C13 E3 E2 A0	0.15 in. (4 mm) insul. with 6 in. (150 mm) h.w. concrete deck	0.424	2.407
9	E0 E5 E4 B12 C14 E3 E2 A0	3 in. (75 mm) insul. with 4 in. (100 mm) l.w. conc. deck and susp. clg.	0.057	0.324
10	E0 E5 E4 C15 B16 E3 E2 A0	6 in. (150 mm) l.w. conc. dk with 0.15 in. (4 mm) ins. and susp. clg.	0.104	0.591
11	E0 C5 BI5 E3 E2 A0	4 in. (100 mm) h.w. concrete deck with 6 in. (150 mm) insulation	0.046	0.261
12	E0 C13 B16 E3 E2 CI2 A0	6 in. (150 mm) h.w. deck with 0.15 in. (4 mm) ins. and 2 in. (50 mm) h.w. RTS	0.396	2.248
13	E0 C13 B6 E3 E2 A0	6 in. (150 mm) h.w. concrete deck with 2 in. (50 mm) insulation	0.117	0.664
14	E0 E5 E4 C12 B13 E3 E2 A0	2 in. (50 mm) 1 w. conc. deck with 4 in. (100 mm) ins. and susp. clg.	0.057	0.324
15	E0 E5 E4 C5 B6 E3 E2 A0	1 in. (25 mm) insul. with 4 in. (100 mm) h.w. conc. deck and susp. clg.	0.090	0.511
16	E0 E5 E4 CI3 B2O E3 E2 A0	6 in. (150 mm) h.w. deck with 0.76 in. (20 mm) insul. and susp. clg.	0.140	0.795
17	E0 E5 E4 B15 C14 E3 E2 A0	6 in. (150 mm) insul. with 4 in. (100 mm) l.w. conc. deck and susp. clg.	0.036	0.204
18	E0 CI2 B15 E3 E2 C5 A0	2 in. (50 mm) h.w. conc. dk with 6 in. (150 mm) ins. and 2 in. (50 mm) h.w. RTS	0.046	0.261
19	E0 C5 B27 E3 E2 C12 A0	4 in. (100 mm) h.w. deck with 4.54 in. (115 mm) ins. and 2 in. (50 mm) h.w. RTS	0.059	0.335
20	E0 B21 C16 E3 E2 A0	1.36 in. (35 mm) insulation with 8 in. (200 mm) l.w. concrete deck	0.080	0.454
21	E0 CI3 B12 E3 E2 C12 A0	6 in. (150 mm) h.w. deck with 3 in. (75 mm) insul. and 2 in. (50 mm) h.w. RTS	0.083	0.471
22	E0 B22 C5 E3 E2 C13 A0	1.67 in. (40 mm) ins. with 4 in. (100 mm) h.w. deck and 6 in. (150 mm) h.w. RTS	0.129	0.732
23	E0 E5 E4 C12 B14 E3 E2 C12 A0	Susp. clg, 2 in. (50 mm) h.w. dk, 5 in. (125 mm) ins, 2 in. (50 mm) h.w. RTS	0.047	0.267
24	E0 E5 E4 C5 E3 E2 B6 B1 C12 A0	Susp. clg, 4 in. (100 mm) h.w. dk, 2 in. (50 mm) ins, 2 in. (50 mm) h.w. RTS	0.082	0.466
25	E0 E5 E4 C13 B13 E3 E2 A0	6 in. (150 mm) h.w. conc. deck with 4 in. (100 mm) ins. and susp. clg.	0.056	0.318
26	E0 E5 E4 B15 C15 E3 E2 A0	6 in. (150 mm) insul. with 6 in. (150 mm) l.w. conc. deck and susp. clg.	0.034	0.193
27	E0 C13 B15 E3 E2 C12 A0	6 in. (150 mm) h.w. deck with 6 in. (150 mm) ins. and 2 in. (50 mm) h.w. RTS	0.045	0.256
28	E0 B9 B14 E3 E2 A0	4 in. (100 mm) wood deck with 5 in. (125 mm) insulation	0.044	0.250
29	E0 E5 E4 C12 B13 E3 E2 C5 A0	Susp. clg, 2 in. (50 mm) h.w. dk, 4 in. (100 mm) ins, 4 in. (100 mm) h.w. RTS	0.056	0.318
30	E0 E5 E4 B9 B6 E3 E2 A0	4 in. (100 mm) wood deck with 2 in. (50 mm) insul. and susp. ceiling	0.064	0.363

Table 3.11: U-Factor For Door (ASHRAE, 2001)

Door Type	No Glazing	Single Glazing	Double Glazing with 12.7 mm Air Space	Double Glazing with $e = 0.10$, 12.7 mm Argon
SWINGING DOORS (Rough Opening—970 mm × 2080 mm)				
Slab Doors				
Wood slab in wood frame[a]	2.61			
6% glazing (560 × 200 lite)	—	2.73	2.61	2.50
25% glazing (560 × 910 lite)	—	3.29	2.61	2.38
45% glazing (560 × 1620 lite)	—	3.92	2.61	2.21
More than 50% glazing				
Insulated steel slab with wood edge in wood frame[a]	0.91			
6% glazing (560 × 200 lite)	—	1.19	1.08	1.02
25% glazing (560 × 910 lite)	—	2.21	1.48	1.31
45% glazing (560 × 1630 lite)	—	3.29	1.99	1.48
More than 50% glazing				
Foam insulated steel slab with metal edge in steel frame[b]	2.10			
6% glazing (560 × 200 lite)	—	2.50	2.33	2.21
25% glazing (560 × 910 lite)	—	3.12	2.73	2.50
45% glazing (560 × 1630 lite)	—	4.03	3.18	2.73
More than 50% glazing				
Cardboard honeycomb slab with metal edge in steel frame	3.46			
Stile- and -Rail Doors				
Sliding glass doors/ French doors				
Site-Assembled Stile- and -Rail Doors				
Aluminum in aluminum frame	—	7.49	5.28	4.49
Aluminum in aluminum frame with thermal break	—	6.42	4.20	3.58
REVOLVING DOORS (Rough Opening—2080 mm × 2130 mm)				
Aluminum in aluminum frame				
Open	—	7.49	—	—
Closed	—	3.69	—	—
SECTIONAL OVERHEAD DOORS (Nominal—3050 mm × 3050 mm)				
Uninsulated steel (nominal $U = 6.53$)	6.53	—	—	—
Insulated steel (nominal $U = 0.62$)	1.36	—	—	—
Insulated steel with thermal break (nominal $U = 0.45$)	0.74	—	—	—

Note: All dimensions are in millimetres.
[a] Thermally broken sill [add 0.17 W/($m^2 \cdot K$) for non-thermally broken sill]
[b] Non-thermally broken sill
[c] Nominal U-factors are through the center of the insulated panel before consideration of thermal bridges around the edges of the door sections and due to the frame.

With the U-factor value, the heat gain for each component can be calculated. The total cooling load is calculated by summing all the heat gain from the components. The equation to compute the total cooling load is shown in Table 3.8. The latent load (LF) in Table 3.8 is assumed to be 1 to simplify the calculation process.

3.4 Pumping Power Determination

When designing a geothermal cooling system, it is important to know the required pumping power for that suitable pump can be chosen. Equation 3.2 shows the formula to calculate the required pumping power.

$$P = \frac{\Delta p Q}{\eta} \tag{3.2}$$

where

P = pumping power required, W

Δp = pressure difference, Pa

Q = volumetric flow rate, m^3/s

η = pump efficiency

From equation 3.2, in order to calculate the pumping power, the pressure difference and volumetric flow rate are required. The volumetric flow rate is determined based on the heat needed to dispose out from the pipe. Different flow rate will have different heat transfer coefficient. In general, the greater the flow rate, the greater the heat transfer coefficient and hence, the required pipe length become shorter.

The pressure difference is as based on the pipe loop design. Equation 3.3 shows the governing equation to calculate the pressure difference. It is named as energy equation.

$$\frac{p_1}{\gamma}+\frac{V_1^{\ 2}}{2g}+z_1+h_a=\frac{p_2}{\gamma}+\frac{V_2^{\ 2}}{2g}+z_2+h_L \qquad (3.3)$$

where

p = pressure at inlet and outlet, Pa

γ = density of fluid, kg/m^3

V = fluid velocity, m^2/s

g = gravitational acceleration, m/s^2

z = height, m

h_a = pressure head required from pump, m

h_L = pressure head loss, m

In the geothermal cooling system, the inlet and outlet of the pipe are open air which means the inlet and outlet pressure are atmospheric pressure. Besides, the height of both inlet and outlet of the pipe are at the same level and the inlet velocity is zero because the overall air flow in the room is steady which is zero. As a result, $p_1 = p_2$, $z_1 = z_2$ and $V_1 = 0$. The equation becomes Equation 3.4

$$h_a = h_L + \frac{V_2^{\ 2}}{2g} \qquad (3.4)$$

where

h_a = pressure head required from pump, m

h_L = pressure head loss, m

V_2 = outlet velocity, m^2/s

g = gravitational acceleration, m/s^2

3.4.1 Determination of Head Loss

Basically there are two losses in head loss, the major losses and minor losses. Major losses are caused by viscous effects in straight pipes while minor losses are caused by various pipe components such as pipe elbow and tees. The equation for major head losses is shown in Equation 3.5

$$h_{L,major} = f\,\frac{\ell}{D}\frac{V^2}{2g} \tag{3.5}$$

where

$h_{L,major}$ = major loss, m

f = friction factor

ℓ = pipe length, m

D = pipe diameter, m

V = fluid velocity, m/s

g = gravitational acceleration, m/s^2

The friction factor can be obtained from Moody chart. The equation for minor head losses is shown in Equation 3.6

$$h_{L,\mathrm{min}or} = K_L\,\frac{V^2}{2g} \tag{3.6}$$

where

$h_{L,minor}$ = minor loss, m

K_L = loss coefficient

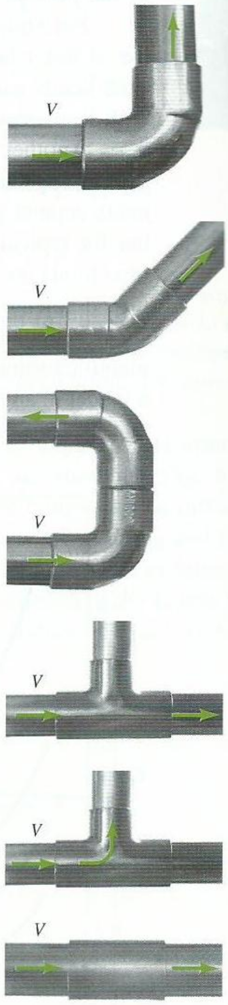
V = fluid velocity, m/s

g = gravitational acceleration, m/s^2

The loss coefficient is based on the pipe geometry. Table 3.12 shows the loss coefficient for various pipe components.

Table 3.12: Loss Coefficient for Various Pipe Components (Munson, 2010)

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210



3.4.2 Parallel Loop or Series Loop Piping System

When designing the piping loop for geothermal cooling system, there are two types of loop available, the parallel and the series loop. In general, parallel loop will need lower pumping power compared to series loop. In this section, two types of loop will be compared so that the best loop can be chosen.

In series loop, the volumetric flow rate is same throughout the system while in parallel loop, the volumetric flow rate is the sum of all the branch of parallel loop (Munson, 2010). For head losses, all the head losses at each branch are the same in parallel loop (Munson, 2010). This means that theoretically the head losses at parallel loop will be lower because when given a fix total pipe length, the pipe length for series loop equals to the fix pipe length while for parallel loop, the pipe length equals to the portion of fix pipe length. For example, given total pipe length required is 2m. In series loop, the head losses will be calculated using 2m length but in parallel loop with four branches, the head losses will be calculated using 0.5m length.

However, the analytical method to compute parallel loop piping system is not easy. For a two branches loop, the procedure to calculate the head losses is first evaluate head losses at each branch in term of velocity. Then equate the head losses for first branch to head losses for second branch. At this step, there will be two unknowns which are velocity at first branch and velocity at second branch. By introducing another equation which is the sum of both volumetric flow rates equals to the total flow rate, the velocity for both branches can be found and then the head losses also can be computed.

In order to compare the head loss in series and parallel loop piping system, two simple piping systems were designed. Figure 3.3 and Figure 3.4 show the pipe design for series and parallel loop respectively.

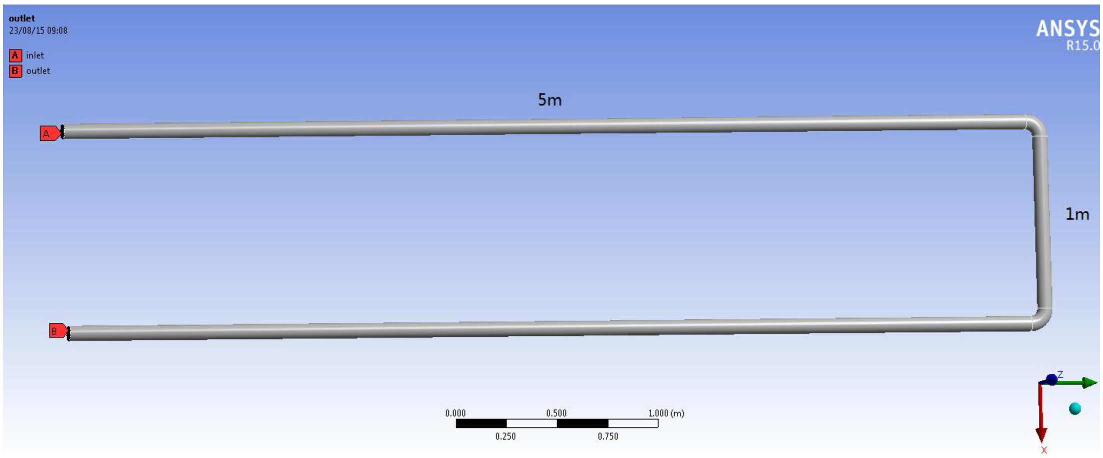


Figure 3.3 Series Loop Piping System Design

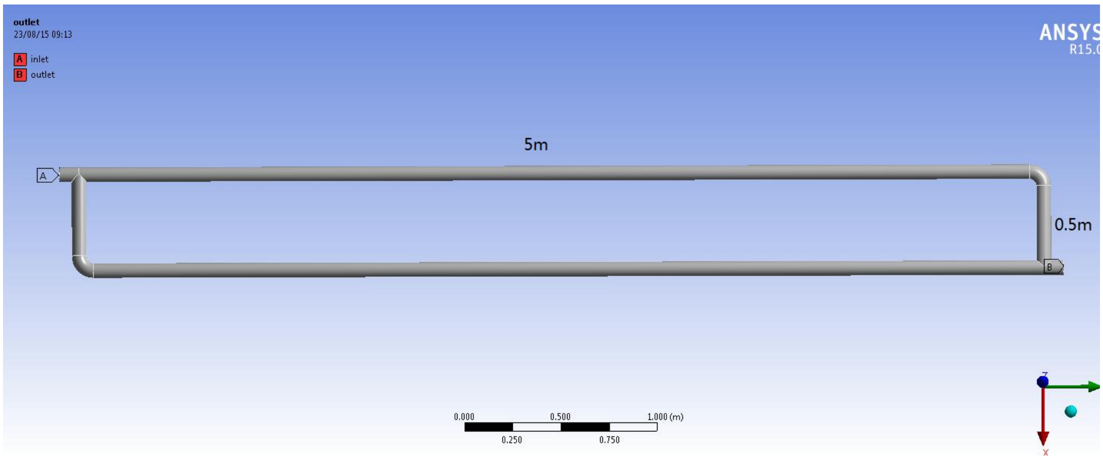


Figure 3.4 Parallel Loop Piping System Design

Both piping system had same total length which is 11 m and had two 90 ° elbows. The parallel loop piping system had two extra tee joints to separate the pipe into two branches. The mass flow rate for both systems was set to 1.049 kg/s and the pipe diameter was 75 mm for both systems.

Two methods were used to obtain the head loss for the systems. First is the analytical method and second is computational fluid dynamics method. The equations used for analytical method were shown in Chapter 3.4.1. The simulation software used for computational fluid dynamics method was Ansys 15.0. It is a simulation software used to solve fluid dynamics problem.

3.5 Distance between Pipes

When design the pipe loop, it is important to know the minimum distance between the pipes. This is to ensure the heat released from pipe does not interfere with other pipe. In this report, the author used computational fluid dynamics method to find out the minimum distance between pipes. The simulation method is simple, only two dimensional simulation required to solve this problem. Figure 3.5 shows the model for simulation.

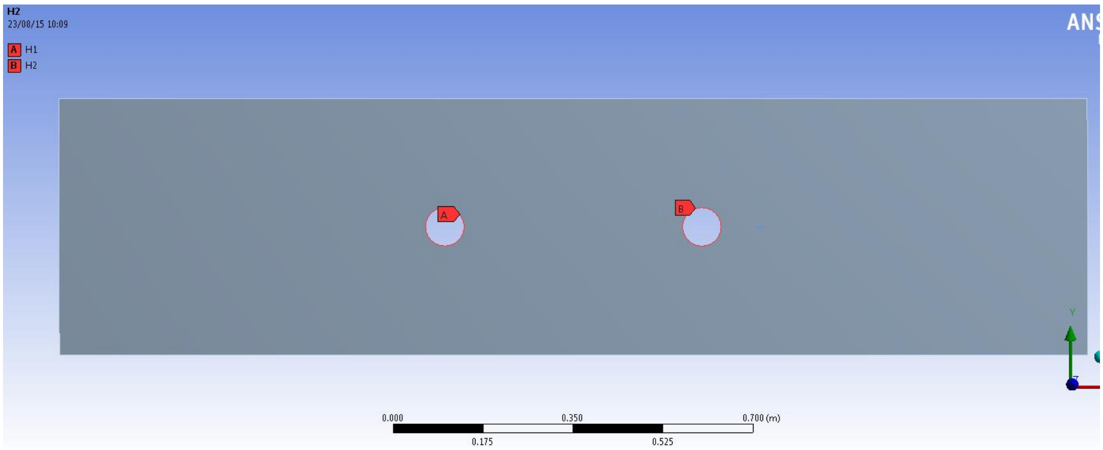


Figure 3.5 Pipe Distance Simulation Model

The model showed in Figure 3.5 is a plate with two holes. H1 and H2 are the pipe surface which has a diameter of 75 mm and the distance between the holes are 500 mm. The plate is to simulate the soil so that the temperature distribution can be simulated. As a result, the minimum pipe distance can be obtained.

3.6 Room Temperature

In order to design the geothermal cooling system, one of the important data needed is the room temperature. The room temperature was taken in two sites. First is the room temperature for the Seri Kembangan room stated at Chapter 3.1 and second is the room temperature at the house at Equine Park. Both houses are landed house and the house at Equine Park is a semi detached double storey house. The temperature were taken at upper floor because the temperature at upper floor are higher compared to ground floor.

The temperature was taken on 8 August 2015 for Seri Kembangan house and 22 August 2015 for Equine Park house. The temperature was taken for 24 hours and started at 3.30 pm. The temperature was taken in two sites so that the average temperature for landed house can be obtained. The temperature was taken using data logger with thermosensors.

3.6.1 Data Logger

The data logger is used to record the temperature over a long period of time. It is useful because it eliminates the need for human monitoring. The data logger consists of three components, the thermosensor, Arduino board and a laptop.

The thermosensor used is LM35DZ. It has advantages of low self heat generation and high accuracy. Figure 3.6 shows a LM35DZ sensor. Red colour wire is the input voltage, yellow colour is output voltage and blue wire is ground. Table 3.13 shows the specification of LM35DZ. The electrical characteristics of the sensor was shown in Appendix A.

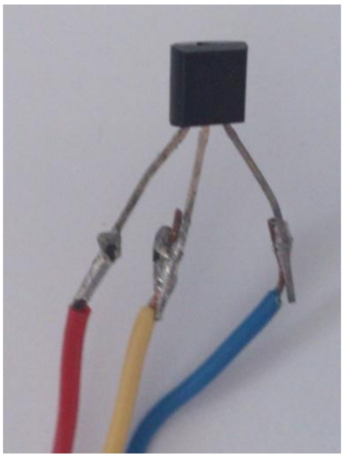


Figure 3.6 LM35DZ Sensor

Table 3.13: LM35DZ Specification

Description	**Specification**
Supply voltage range	4 to 20 V
Temperature range	0 to 100 ℃
Scale factor	10 mV/℃
Accuracy	1 ℃
Self heating	0.08 ℃
Current drain	60 μA max

According to the data sheet of LM35DZ sensor, the sensor can be connected to the Arduino board directly; however, there will be noise if the connecting wire too long. Besides, the radiated interference other electrical noise also will cause the fluctuation of the signal. Thus, a RC damper is used to filter the noise. Figure 3.7 shows the filter circuit for the sensor while Figure 3.8 shows the actual circuit for the sensor.

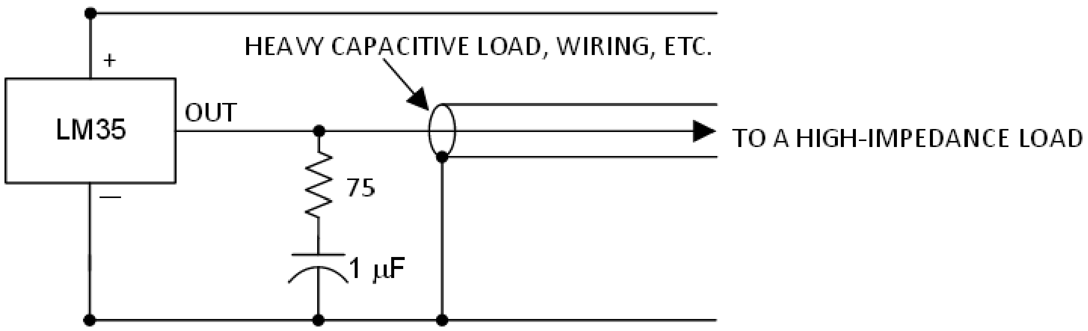


Figure 3.7 RC Damper Ciruit (Texas, 2015)

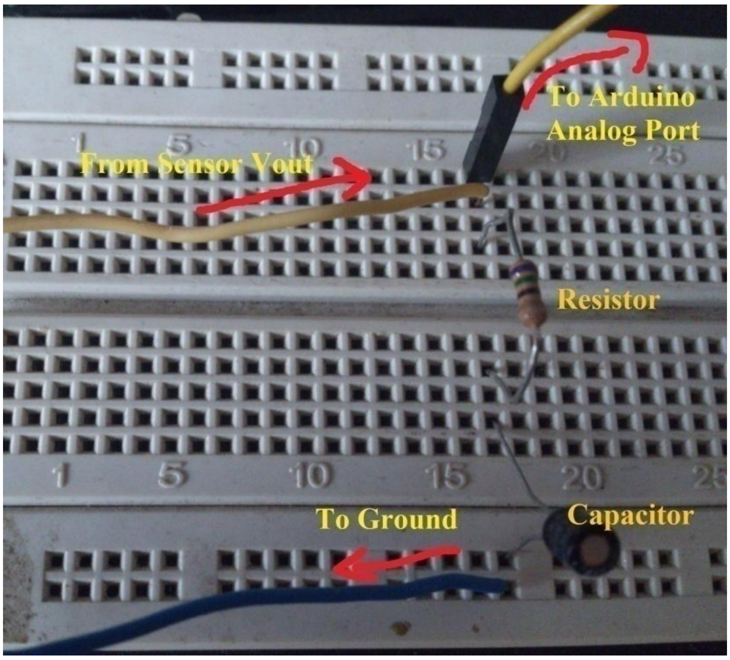


Figure 3.8 Actual RC Circuit

Arduino board is a microcontroller. The board used was Arduino Mega. It can record up to 16 sensors simultaneously. Figure 3.9 and Table 3.14 shows the Arduino board and specification respectively. The full specification of Arduino Mega board was shown in Appendix B. The primary use for the board is to convert the analog signal which is the output voltage of the sensor to digital signal which is the only signal the laptop recognises. Since it is a microcontroller, programming is needed. Figure 3.10 shows the programming code for the Arduino board.

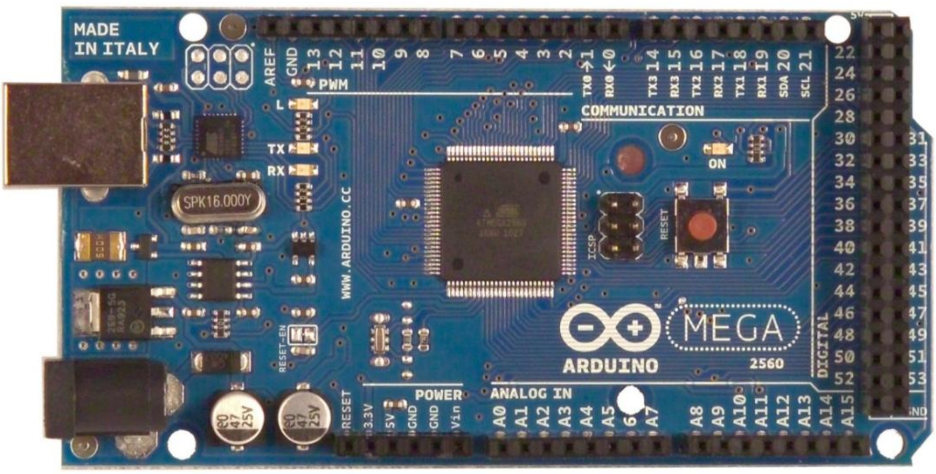


Figure 3.9 Arduino Mega

Table 3.14: Arduino Mega Specification

Description	**Specification**
Supply voltage range (recommended)	7 to 12 V
Operating voltage	5 V
Analog input pin	16
Flash memory	128 KB


```
//declare variables
int T = 0; //define time
float tempC; //define temperature
int temp = 0; //define port number

void setup()
{
Serial.begin(9600); //opens serial port, sets data rate to 9600 bps
}

void loop()
{
  for (temp = 0; temp < 2; temp++){ //loop the process with increase port number
    tempC = 0; //set temperature to zero
    for (int i = 0; i < 5; i++){ //loop the process 5 times
      tempC = tempC + analogRead(temp); //read the analog port and add to the previous temperature
    }
    tempC = (5 * tempC * 100.0)/(1024.0 * 5);  //convert the digital value to decimal value
    Serial.print(tempC,1);  //show the temperature in computer with one decimal place
    Serial.print(",");  //separate each temperature by comma
  }
  Serial.print(T); //show time, for record purpose
  T = T + 10;
  Serial.println(); //jump to next line
  delay(1800000);    //wait 30mins and loop the process
}
```

Figure 3.10 Programming Code for Arduino Board

The programming for the board is simple. First, define the variables for the time, port number and temperature. The 'void loop' means the codes inside will keep looping unless the board power supply is cut off. Two 'for' functions were used. The first 'for' function was used to repeat the analog port reading process so that the board will read the voltage from one sensor to another sensor. It only repeat for twice because there were only two sensors used. The second 'for' function was used to get the average temperature for each sensor so that the noise can be minimised further. 'Serial.print' is the code to show the result on computer. Since the time interval for temperature recording is 30 mins, 'delay' was used and 1800000 is in millisecond which is equivalent to 30 mins.

Figure 3.8 shown is for one sensor only, thus, in order to utilize all 16 ports of the Arduino board, 16 circuits needed to filter all the noise. Figure 3.11 shows how the complete circuit look like. The circuit shown in the figure had not connected to the sensors. Hence, there will be more messy after connected to the sensors.

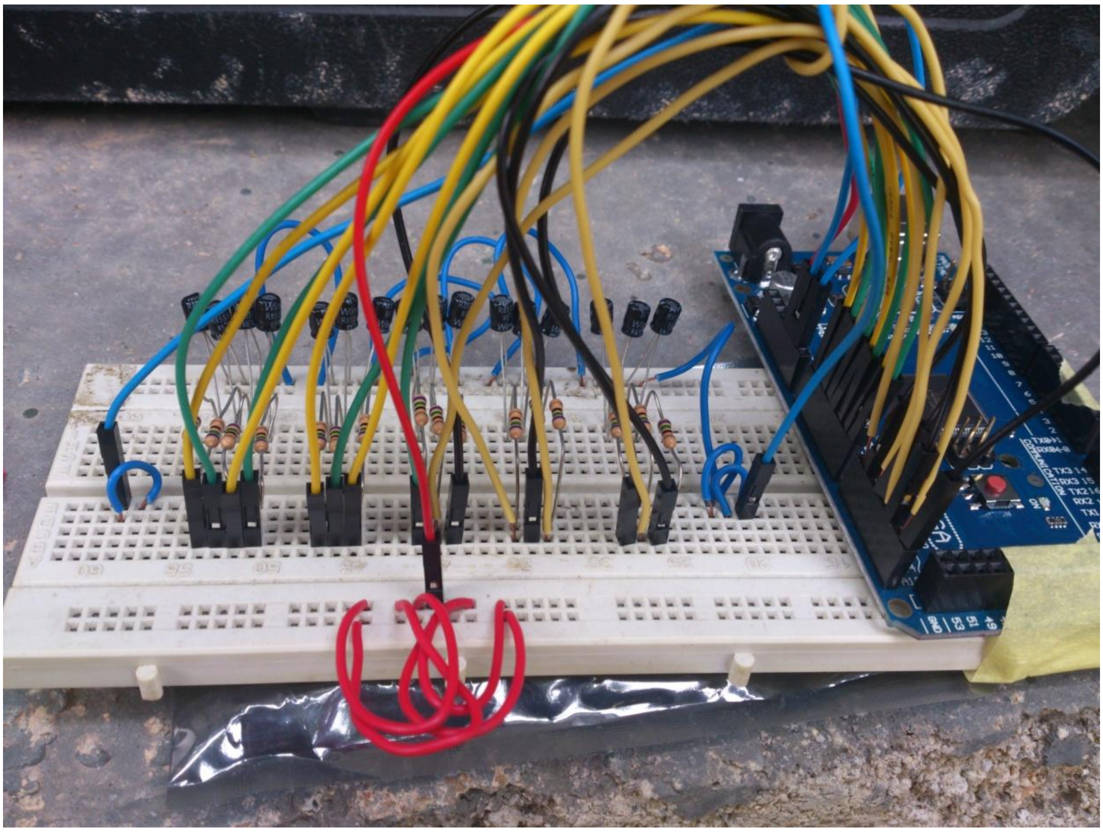


Figure 3.11 Complete Damper Circuit

As mentioned earlier, each sensor has three legs and red wire connected to input voltage, blue wire to ground and yellow to output voltage. All the red wire from sensors will connect to the ports around the red wires in the board and blue wire from sensors will connect to the port below the blue wires in the board. The blue wires are putting at both sides so that the wire from sensors can connect to nearest port. Lastly, the yellow wire from sensor will be connected to the row below all the yellow/green/black wire on the board. There are 16 wires in total for 16 sensors. Figure 3.12 illustrates the location for the sensors wire.

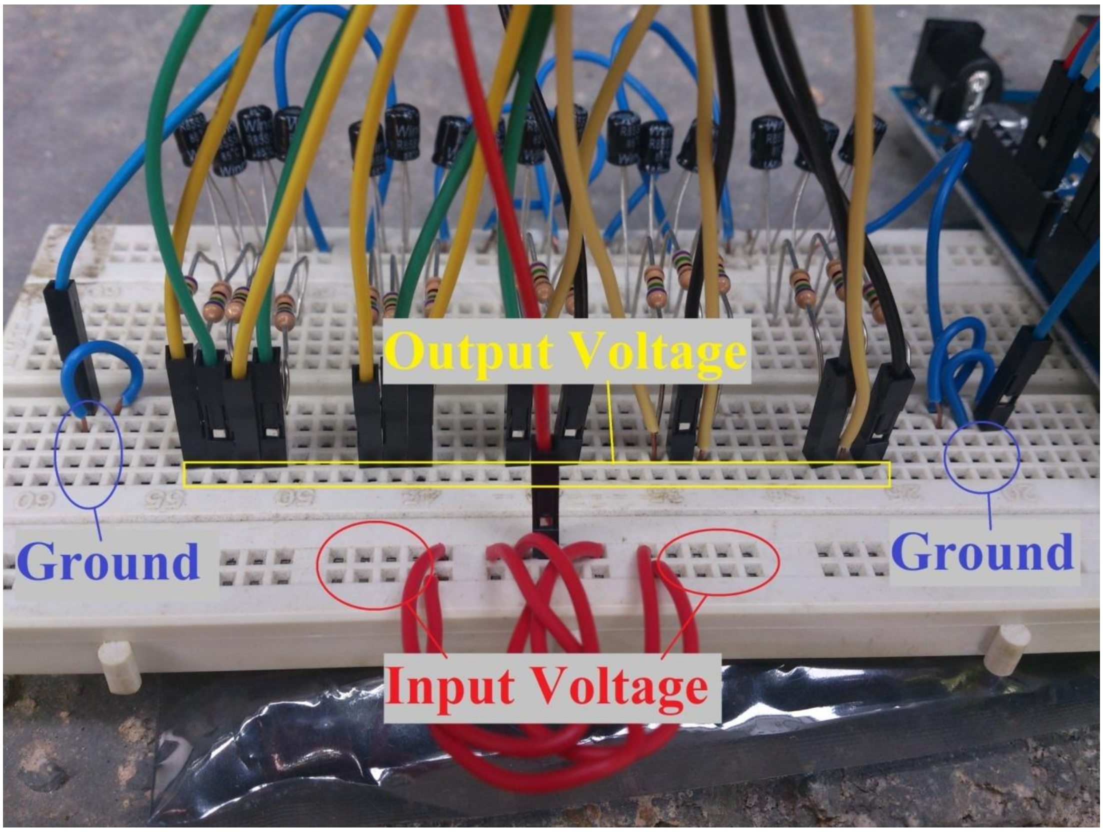


Figure 3.12 Illustration of The Sensor Wire Location

When connecting the sensors wire, there are some precautions needed to be considered. First is when connect the output voltage to the board, all the wire must be ensured to be separated from each other. This is important because the wires used in the sensors were multi coil wire and there may be some coil touches the other wire. This will affect the voltage measured by Arduino. Second is when not all the ports are used, the yellow/green/black wire of unused port should be taken out because it will cause the ground voltage become unstable and as a result, the measurement value will be offset.

Besides the method shown in Figure 3.12, the red wires (input voltage) and blue wires (ground) can be combined using a wire terminal block. All the copper coils of the wire end of the same colour wire (red or blue) are first twisted together, then plug into one side of the terminal block. The other side will be connected to the voltage supply or ground of the Arduino board. This alternative method will make the circuit board cleaner because the circuit board will only have all the yellow wires which are the signal from the sensors. Figure 3.13 shows a wire terminal block.

Figure 3.13 Wire Terminal Block

3.7 Double Storey Terrace House Design

Since one of the objectives of the project was to design a geothermal cooling system for a double storey house, a house model was needed in order to design the geothermal cooling system for it. Figure 3.14 and Figure 3.15 shows the layout plan for the house model. Note that the layout is for two side by side terrace houses.

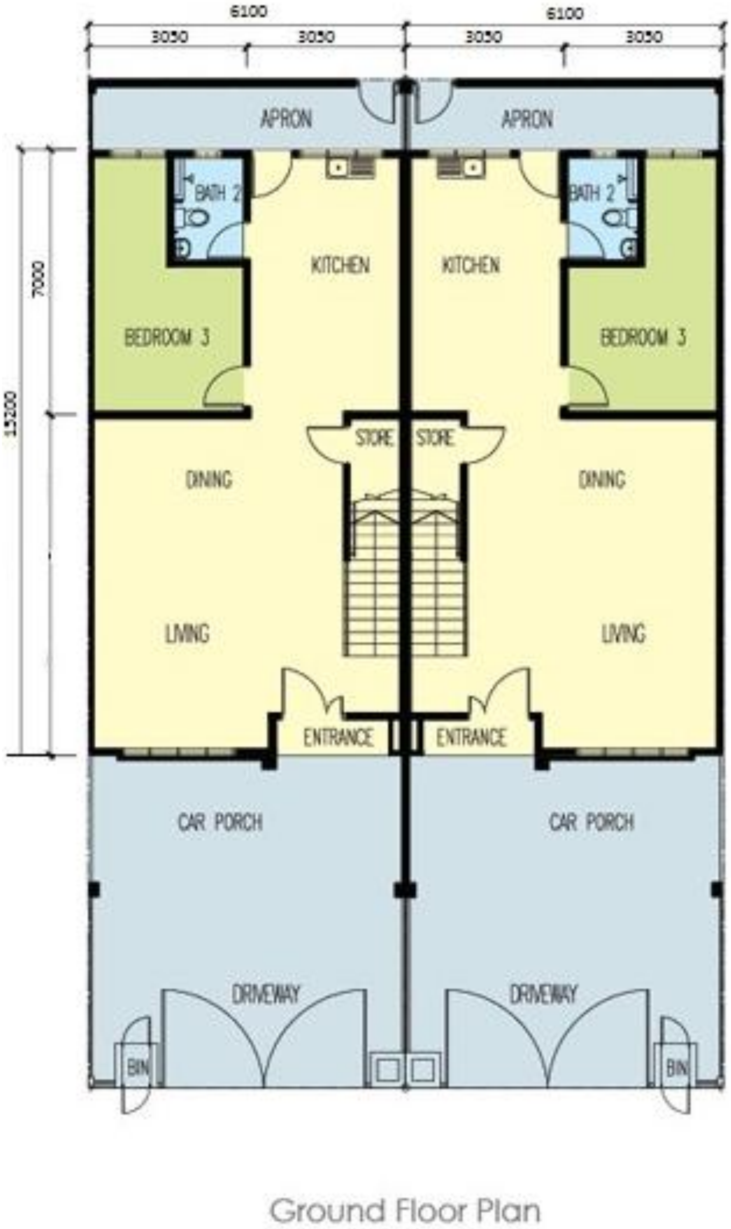


Figure 3.14 House Layout Plan (Gound Floor)

Figure 3.15 House Layout Plan (First Floor)

The terrace house is facing South, with build up dimension 6.1 m width x 15.2 m length. The height for each floor is 3 m. Each window has dimension of 1.2 m width x 1.15 m height and each floor assume to have 4 windows (2 at front wall and 2 at back wall). The door dimension is 0.82 m width x 2.03 m height.

It consists of 3 rooms at the first floor. Bedroom 1 and 2 have the same dimension which is 3.05 m width x 6 m length whereas the master bedroom is 6.1 m width x 5 m length. The bathroom and the small dented area in balcony were ignored to simplify the geometry of the house.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Temperature Profile of The Room

The first section of Chapter 4 would be the temperature profile. The temperature profile is important and it is the first thing needed to know in order to proceed to other steps. There were two testing sites for the temperature profile measurement. The first site was a room located at Seri Kembangan house which mentioned in Chapter 3.1 while the second site was located at a house at Equine park. Both houses are double storey house.

A data logger which was mentioned in Chapter 3.6.1 was used to measured the temperature of the room. Two thermosensors were used, one located near the window of the room while the other one located at the centre of the room. The temperature was recorded for a period of 24 hours with the interval 30 mins. The temperature test was carried out on 8 August 2015 and 22 August 2015 for Seri Kembangan house and Equine Park house respectively. The temperature results for both sites were shown in Table 4.1 and Table 4.2.

Table 4.1: Temperature of The Seri Kembangan Room

Time	Temperature (°C)	
	Room Centre	Window
1530	33.2	33.3
1600	33.3	33.4
1630	33.7	33.4
1700	33.7	33.6
1730	33.3	33.2
1800	33.7	32.7
1830	33.3	33.2
1900	33.2	32.7
1930	32.8	32.4
2000	32.7	32
2030	32.6	31.7
2100	32.2	31.7
2130	32.2	31.5
2200	32.1	31.3
2230	31.9	31.2
2300	31.8	31.2
2330	31.7	31.1
0000	31.5	30.8
0030	31.2	30.8
0100	31.2	30.7
0130	31.2	30.5
0200	31.2	30.3
0230	30.8	30.3
0300	30.8	30.1
0330	30.8	29.8
0400	30.6	29.7
0430	30.3	29.3
0500	30.3	29.3
0530	30.3	29.3
0600	30.2	29.3
0630	30.3	28.9
0700	30	28.9
0730	29.9	28.8
0800	29.9	29.1
0930	29.9	29.3
1000	30.3	30.3
1030	30.3	30.3
1100	30.5	30.6
1130	30.8	30.9
1200	31	31.1
1230	31.2	31.2
1300	31.5	31.8
1330	31.9	32.1
1400	32.3	32.5
1430	32.7	32.8
1500	33.1	33.1
1530	33.1	33.2
Average	31.62765957	31.1638
Maximum	33.7	33.6

Table 4.2: Temperature of The Equine Park Room

Time	Temperature (°C)	
	Room Centre	Window
1530	33	33.2
1600	33	33.2
1630	33.2	33.4
1700	33.4	33.3
1730	33.1	33
1800	33.1	32.7
1830	33	32.5
1900	33.2	32.3
1930	32.8	32.4
2000	32.6	32
2030	32.5	31.7
2100	32.2	31.5
2130	32.1	31.5
2200	31.9	31.3
2230	32	31.3
2300	31.9	31.2
2330	31.7	31
0000	31.4	30.8
0030	31.1	30.8
0100	31.2	30.7
0130	31	30.4
0200	31	30.3
0230	30.6	30.1
0300	30.6	30
0330	30.5	29.7

Time	Temperature (°C)	
	Room Centre	Window
0400	30.5	29.5
0430	30.5	29.3
0500	30.2	29.3
0530	30.2	29.1
0600	30.2	29
0630	30	28.8
0700	30	28.7
0730	29.8	28.7
0800	29.8	29.1
0930	29.7	29.2
1000	30	29.8
1030	30.2	30.1
1100	30.5	30.7
1130	30.6	31
1200	30.8	31.2
1230	31.2	31.6
1300	31.5	31.8
1330	31.7	32.4
1400	32.3	32.6
1430	32.6	33
1500	32.8	33.2
1530	32.8	33.2
Average	31.4893617	31.0979
Maximum	33.4	33.4

From the results shown in Table 4.1, the maximum temperature for both room centre and near window were 33.7 °C and 33.6 °C respectively. For Table 4.2, the maximum temperature for both room centre and near window were 33.4 °C. Both results showed that the temperature increased to maximum after 4 pm. For better visualisation, the results obtained were plotted in graphs shown in Figure 4.1 and 4.2.

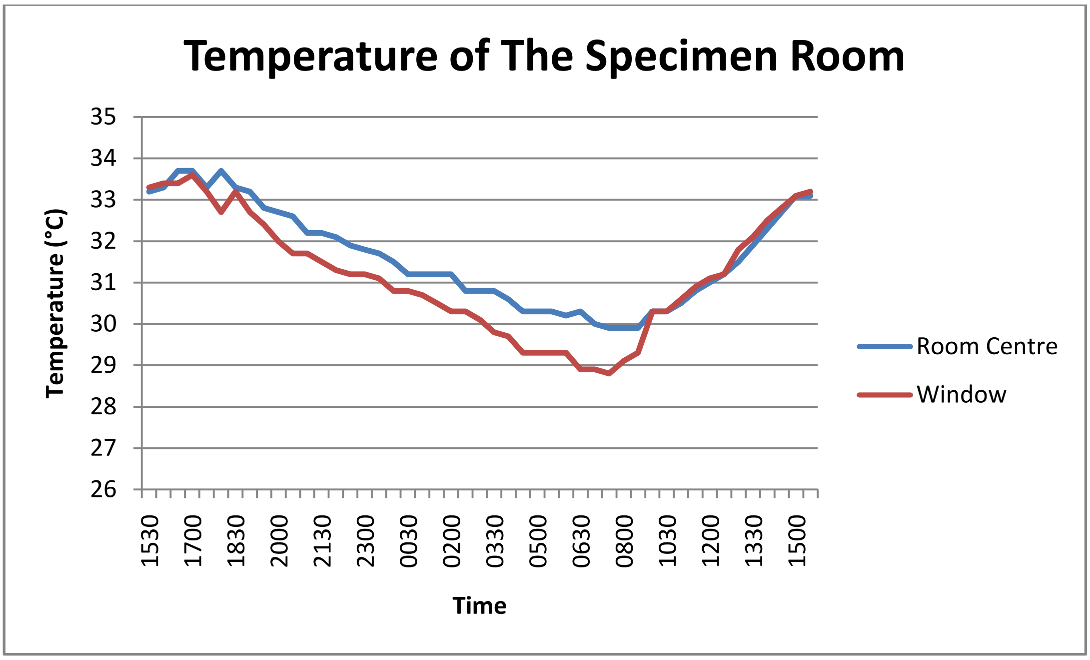


Figure 4.1 Temperature of The Seri Kembangan Room

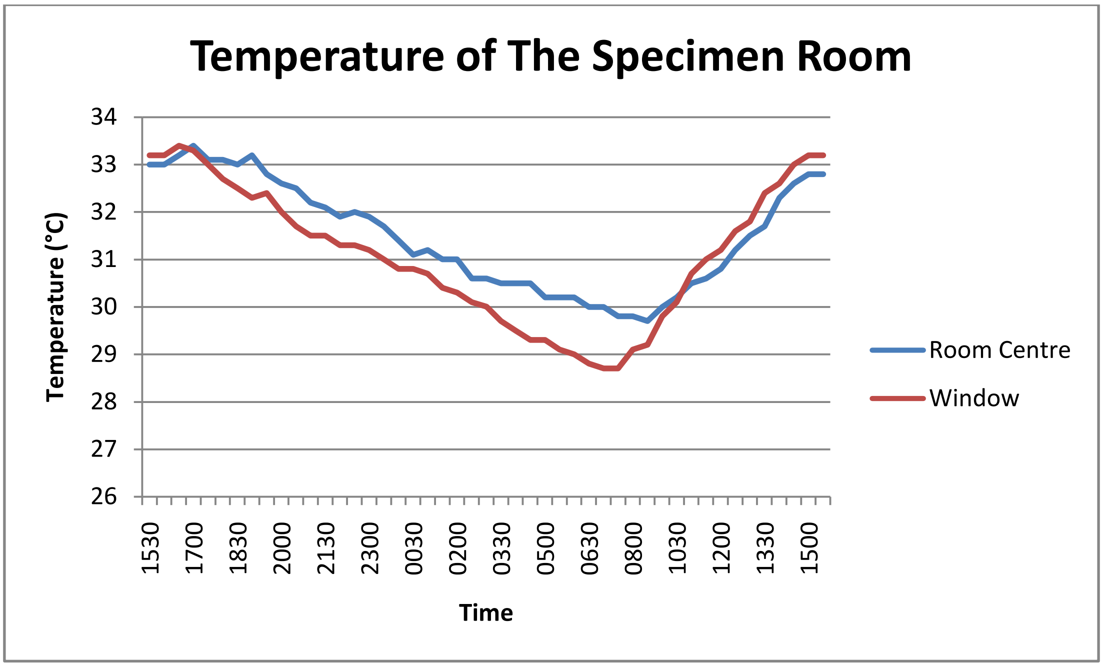


Figure 4.2 Temperature of The Equine Park Room

From both Figure 4.1 and 4.2, it was clearly show that the temperature at window drop faster than that of the room centre. This is because the room is actually a thermal insulator which will hold the heat from enter or release from the room.

This will cause the temperature at room centre lags behind the temperature at window. Another reason to cause the lagging of temperature is the heat transfer rate from outside the room to inside the room. Since the window was closed during the measurement process, the heat transfer become slower and as a result, the lagging phenomenon occurs. The third reason will be the zero air flow inside the room due to the window was closed. When there is no air flow, the convection heat transfer will be minimal and as a result, the lagging phenomenon occurs.

From the results obtained, the maximum temperature for both rooms were 33.7 ℃ and 33.4 ℃. Thus, the geothermal cooling system designed will have to consider these temperature. For calculation simplification, the temperature will be set to 33 ℃ when designing the cooling system.

4.2 Minimum Pipes Distance

Besides temperature, another important parameter needed to know when designing the geothermal cooling system is the distance between pipes. Distance between pipes means the width of the gap between two parallel pipes. The distance should be large enough to prevent the heat from one pipe transfer to the other pipe. When the heat from one pipe reaches the other pipe, the cooling rate for the other pipe will be reduced. Thus, in order to prevent this, minimum pipe distance was found and implemented into pipe loop design. The method to find the minimum pipe distance was mentioned in Chapter 3.5.

As mentioned in Chapter 3.5, the distance was found using computational fluid dynamics (CFD). The temperature of the pipes were set to 33 ℃ as determined in Chapter 4.1 whereas for the temperature of the soil, it was set to 26 ℃ by referring to Chapter 2.5. The pipes distance was set to 500 mm by default. The simulation result was shown in Figure 4.3. The two circular holes were the pipe cross section while the solid rectangular plate is the soil.

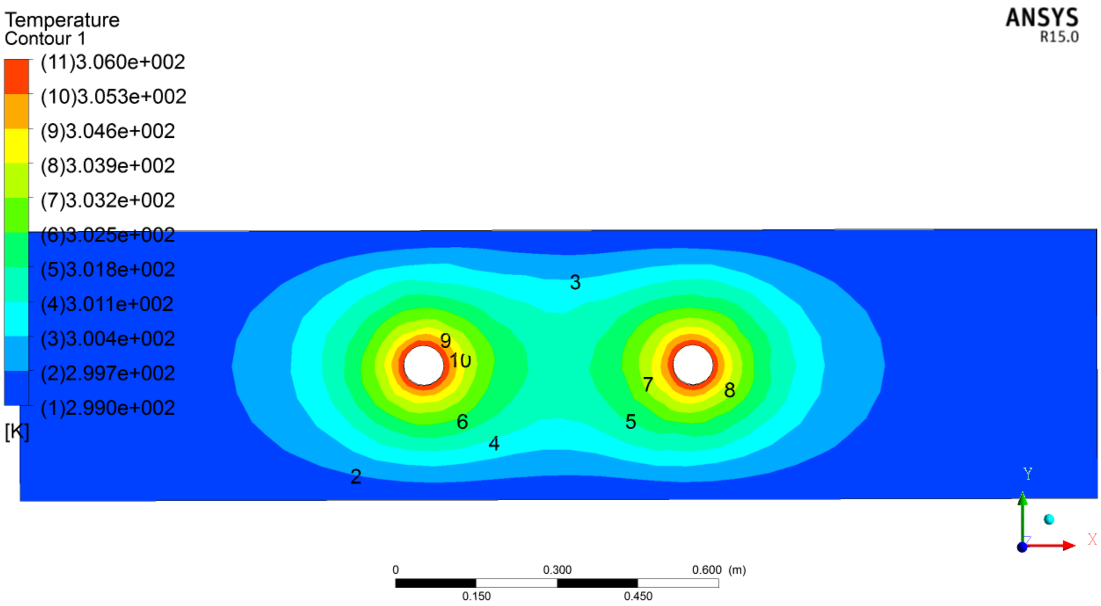


Figure 4.3 Temperature Contour of The Soil

Figure 4.3 shows the temperature of the soil at different location. The temperature shown in the left side label is in Kelvin. Red colour indicates highest temperature while blue colour indicates lowest temperature. Thus, based on Figure 4.3, the highest temperature located near the pipes and the temperature was decreasing as it goes far from the pipe. The minimum distance of the pipes can be determined by measuring the distance between the pipe centre and the blue contour. Figure 4.4 shows the distance between blue contour and the pipe more clearly.

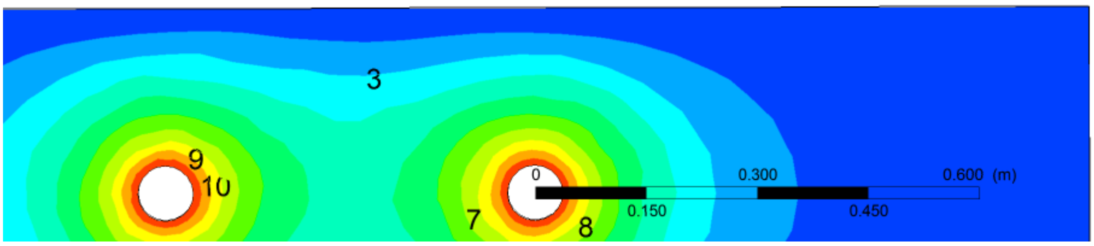


Figure 4.4 Distance Between Pipe and Blue Contour

According to Figure 4.4, the distance between pipe and blue contour was around 0.35 m. Hence, 350 mm will be taken as the minimum distance between pipes when designing the geothermal cooling system. However, this distance was not enough to eliminate the effect of heat from one pipe to the other. This is because even though the temperature at 350 mm away from the pipe is constant with the soil temperature, the temperature at less than 350 mm away from the pipe will affect the other pipe if the pipe is too close. This will slow down the cooling rate because the temperature of the soil at the middle of the pipes will be higher. However, it is not significant because there is no direct heat transfer from one pipe to the other but only the increases the temperature of the soil. In conclusion, 350 mm is still an acceptable minimum distance between pipes.

4.3 Testing Site at Seri Kembangan House

As mentioned in Chapter 3.1, a electricity consumption test was carried out at a room of a double storey terrace house at Seri Kembangan. The result for the electricity consumption for a 1 hp air conditioner for the room was 13 kWh for one day. This section will show the results obtained for the specimen room. By using these results, the coefficient of performance, COP of the air conditioner can be calculated so that the operating cost can be obtained by referring to the method in Chapter 3.2.

4.3.1 Cooling Load of The Specimen

The aim to carry out this test was to compare the efficiency of the conventional air conditioner and the geothermal cooling system. Thus, It is important to know the cooling load or heat gain of the specimen so that the efficiency of the air conditioner can be found and the suitable geothermal cooling system can be designed.

Before calculating the cooling load, several parameters or specifications have to be known. The room dimensions were stated in Chapter 3.1. Figure 4.5 shows the layout of the room.

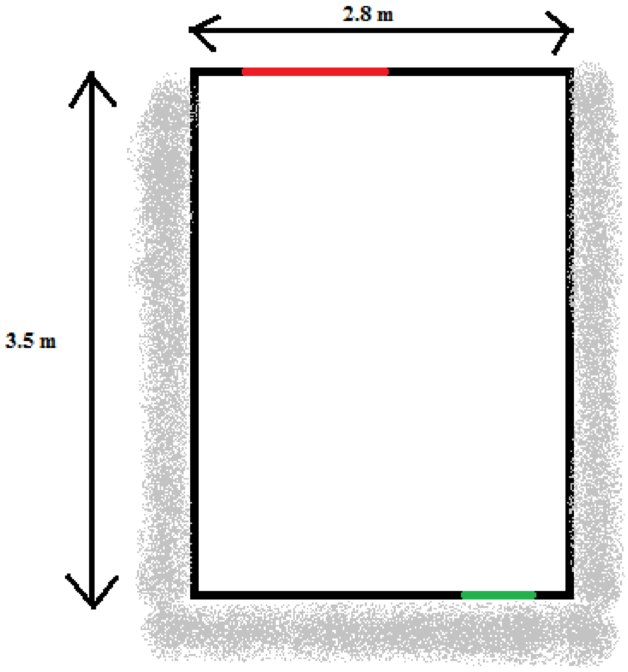


Figure 4.5 Specimen Room Layout

The room has only one wall expose to sunlight and the wall is facing Southeast. The remaining three walls which are shaded with grey colour in Figure 4.5 are inner wall of the house which are the shaded wall. The red colour label in Figure 4.5 is the window while the green colour is the door. The window has the area of 1.17 m x 1.17 m. The door is negligible and treated as shaded wall because it is not expose to sunlight. The height of the room is 2.8 m.

The first step for cooling load calculation is to calculate the cooling load temperature differences (CLTD) for walls and roof. By referring to Table 3.3, there are few parameters needed in order to get the CLTD value. The parameters are design temperature and daily temperature range. The design temperature can be obtained in Table 3.4 which shows that the temperature for Kuala Lumpur is 34.2 ℃. The daily temperature range will be 'L' which denotes low daily range because from the results in Chapter 4.1.1, the temperature range is around 5 ℃ which is less than 9 ℃.

By using the parameters above and Table 3.3, the CLTD value for the walls and roof can be calculated. There are four walls in the room, one facing Southeast while the other three are shaded walls. The calculations for CLTD value for walls and roof were as follow.

For Southeast wall,

$$CLTD_{wall\,,SE} = \left(\frac{34.2-32}{35-32}(21-18)\right) + 18 = 20.2$$

For shaded walls,

$$CLTD_{wall\,,shaded} = \left(\frac{34.2-32}{35-32}(14-13)\right) + 13 = 13.73$$

For roof,

$$CLTD_{roof} = \left(\frac{34.2-32}{35-32}(8-7)\right) + 7 = 7.73$$

The second step was to calculate the glass load factor (GLF) of window. Besides the parameters stated above, Table 3.6 also needs some extra information in order to obtain the GLF value. The specification of the window needed to be determined. The window of the specimen room is a regular single glass window and the window has draperies. Thus, the calculation for GLF value for window was as follow.

$$GLF = \left(\frac{34.2-32}{35-32}(218-205)\right) + 205 = 214.53$$

The third step was to determine the U-factor of the walls and roof. The U-factor for wall and roof can be obtained in Table 3.9 and Table 3.10 respectively. For convenience, The table will be regenerated and put in Table 4.3 and Table 4.4.

Table 4.3: U-Factor for Wall

5	E0 A6 B21 C7 A0	1.36 in. (35 mm) insulation with 8 in. (200 mm) l.w. concrete block	0.129	0.732
6	E0 E1 B2 C5 A1 A0	1 in. (25 mm) insulation with 4 in. (100 mm) h.w. concrete	0.199	1.130
7	E0 A6 C5 B3 A3 A0	4 in. (100 mm) h.w. concrete with 2 in. (50 mm) insulation	0.122	0.693
8	E0 A2 C12 B5 A6 A0	Face brick and 2 in. (50 mm) h.w. concrete with 1 in. (25 mm) insul.	0.195	1.107
9	E0 A6 B15 B10 A0	6 in. (150 mm) insulation with 2 in. (50 mm) wood	0.042	0.238
10	E0 E1 C2 B5 A2 A0	4 in. (100 mm) l.w. conc. block with 1 in. (25 mm) insul. and face brick	0.155	0.880
11	E0 E1 C8 B6 A1 A0	8 in. (200 mm) h.w. concrete block with 2 in. (50 mm) insulation	0.109	0.619
12	E0 E1 B1 C10 A1 A0	8 in. (200 mm) h.w. concrete	0.339	1.925
13	E0 A2 C5 B19 A6 A0	Face brick and 4 in. (100 mm) h.w. concrete with 0.61 in. (16 mm) ins.	0.251	1.425

Table 4.4: U-Factor for Roof

	Layers (Inside to Outside)	Description	U (Btu/h·ft² °F)	U (W/m² K)
1	E0 A3 B25 E3 E2 A0	Steel deck with 3.33 in. (85 mm) insulation	0.080	0.454
2	E0 A3 BI4 E3 E2 A0	Steel deck with 5 in. (125 mm) insulation	0.055	0.312
3	E0 E5 E4 C12 E3 E2 A0	2 in. (50 mm) h.w. concrete deck with suspended ceiling	0.232	1.317
4	E0 E1 BI5 E4 B7 A0	Attic roof with 6 in. (150 mm) insulation	0.043	0.244
5	E0 BI4 C12 E3 E2 A0	5 in. (125 mm) insulation with 2 in. (50 mm) h.w. concrete deck	0.055	0.312
6	E0 C5 BI7 E3 E2 A0	4 in. (100 mm) h.w. concrete deck with 0.3 in. (8 mm) insulation	0.371	2.107

The highlighted row in both Table 4.3 and 4.4 are the materials for walls and roof respectively. The u-factor for wall is 0.88 W/m^{2}K and roof is 0.244 W/m^{2}K. The next step was to calculate the area of the walls, roof and window. The calculation for area was as follow.

$$Area_{window} = 1.17 \times 1.17 = 1.37\ m^2$$

$$Area_{wall\ ,SE} = (2.8 \times 2.8) - Area_{window}$$

$$= 7.84 - 1.37 = 6.47\ m^2$$

$$Area_{roof} = 3.5 \times 2.8 = 9.8\ m^2$$

$$Area_{wall\ ,shaded} = 2(3.5 \times 2.8) + (2.8 \times 2.8) = 27.44\ m^2$$

The last step would be the cooling load calculation. The formula for the cooling load calculation can be obtained in Table 3.8. The cooling load calculation was as follow.

$$q_{wall\ ,SE} = U_{wall} \times Area_{wall\ ,SE} \times CLTD_{wall\ ,SE}$$

$$= 0.88 \times 6.47 \times 20.2$$

$$= 115.01\ W$$

$$q_{window} = GLF \times Area_{window}$$
$$= 214.53 \times 1.37$$
$$= 293.91\ W$$

$$q_{roof} = U_{roof} \times Area_{roof} \times CLTD_{roof}$$
$$= 0.244 \times 9.8 \times 13.73$$
$$= 32.83\ W$$

$$q_{wall\ ,shaded} = U_{wall} \times Area_{wall\ ,shaded} \times CLTD_{wall\ ,shaded}$$
$$= 0.88 \times 9.8 \times 13.73$$
$$= 186.66\ W$$

After all the cooling loads were calculated, the total cooling load could be found. There are several assumptions were made during the load calculation, first was the room was empty and second was the window was closed during the test. Thus, the total cooling load would be as follow.

$$q_{total} = q_{wall\ ,SE} + q_{window} + q_{roof} + q_{wall\ ,shaded}$$
$$= 115.01 + 293.91 + 32.83 + 186.66$$
$$= 628.51\ W$$

The cooling load calculated was the maximum load for one hour, thus, the total load for one day would be approximate 15.08 kW. By using this value, the actual COP of the air conditional could be found. The actual COP of the air conditional would be as follow.

$$COP_{AC,actual} = \frac{cooling\ load}{air\ cond\ electricity\ consumption}$$
$$= \frac{15.08\ kW}{13\ kW} = 1.16$$

By comparing the actual COP with the COP stated in the air conditional specification which was around 3.25, the author found that the actual COP was much lower maybe due to the age of the air conditional and also the ideal COP is the maximum COP to achieve.

4.3.2 Geothermal Cooling System for The Specimen

With the cooling load and the room temperature data, the suitable geothermal cooling system could be determined. There are few parameters needed to be determined in geothermal cooling system design. The parameters are pipe length required, mass flow rate of the air in the system, pumping power required and the pipe loop design.

4.3.2.1 Pipe Length Calculation

One of the parameter for geothermal cooling system design was pipe length required. The minimum pipe length required was calculated so that the heat gain of the room could be fully transferred into the ground. The calculation for pipe length was long but standard. The first thing to be determined is the mass flow rate of the air. It could be calculated using steady flow energy equation shown in Equation 4.1.

$$q = \dot{m} c_p dT \tag{4.1}$$

where

q = heat needed to be rejected, W

$\dot{m}$ = mass flow rate, kg/s

c_p = specific heat capacity, kJ/kgK

dT = temperature difference for inlet and outlet, K

From Chapter 4.3.1, the cooling load was 628.51 kW. The specific heat capacity for air at temperature 300 K is 1.007 kJ/kgK while the temperature difference was 7 K because the inlet temperature was same as the room temperature which is 33 ℃ based on Chapter 4.1 whereas the outlet temperature will be 26 ℃ based on Chapter 2.3 because it satisfies the human comfort temperature. Thus, the calculation for the mass flow rate was as follow.

$$q = \dot{m} c_p dT$$

$$\dot{m} = \frac{q}{c_p dT} = \frac{628.51}{1.007k \times 7}$$

$$= 0.089\ kg/s$$

Then, the required pipe length would be calculated by using heat transfer equation shown in Equation 4.2.

$$q = \frac{dT}{R_{tot}} \tag{4.2}$$

where

q = heat needed to be rejected, W

dT = temperature difference between soil and air flow, K

R_{tot} = thermal resistance for the heat transfer, K/W

The R_{tot} is the total thermal resistance to resist the heat from the air in the pipe to release into the soil. Equation 4.3 shows the equation to calculate R_{tot} in this case.

$$R_{tot} = \frac{1}{2\pi r_1 hL} + \frac{\ln(\frac{r_2}{r_1})}{2\pi kL} \tag{4.3}$$

where

R_{tot} = thermal resistance for the heat transfer, K/W

r_1 = inner radius of the pipe, m

r_2 = outer radius of the pipe, m

h = heat transfer coefficient of air, W/m^{2}K

k = thermal conductivity of pipe, W/mK

L = pipe length required, m

Most of the parameters in Equation 4.3 are constant except the heat transfer coefficient of the air which is vary with the mass flow rate. The heat transfer coefficient coul be calculated by using Equation 4.4.

$$h = Nu_D \frac{k}{D} \tag{4.4}$$

where

h = heat transfer coefficient of air, W/m^{2}K

Nu_D = Nusselt number, dimensionless

k = thermal conductivity of air, W/mK

D = inner diameter of the pipe, m

The Nusselt number could be obtained by using Equation 4.5.

$$Nu_D = \frac{\frac{f}{8}(\mathrm{Re}_D - 1000)\,\mathrm{Pr}}{1 + 12.7(\frac{f}{8})^{\frac{1}{2}}(\mathrm{Pr}^{\frac{2}{3}} - 1)} \tag{4.5}$$

where

Nu_D = Nusselt number, dimensionless

f = friction factor

Re_D = Reynolds number, dimensionless

Pr = Prandtl number, dimensionless

The Prandtl number is constant which is 0.707 at 300 K for air. Equation 4.6 and 4.7 shows the equations for Reynolds number and fraction factor.

$$\mathrm{Re}_D = \frac{4\dot{m}}{\pi \mu D} \tag{4.6}$$

where

Re_D = Reynolds number, dimensionless

$\dot{m}$ = mass flow rate, kg/s

μ = dynamic viscocity, kg/ms

D = pipe outer diameter, m

$$f = (0.79 \ln \mathrm{Re}_D - 1.64)^{-2} \tag{4.7}$$

where

f = friction factor

Re_D = Reynolds number, dimensionless

Equation 4.7 is only applicable for smooth surface such as PVC surface. With all the equations above, the pipe length could be found. The calculation was as follow.

$$Re_D = \frac{4\dot{m}}{\pi \mu D} = \frac{4 \times 0.089}{\pi \times 184.6 \times 10^{-7} \times 0.075} = 8.2 \times 10^4$$

$$\begin{aligned} f &= (0.79 ln Re_D - 1.64)^{-2} \\ &= (0.79 \ln(8.2 \times 10^4) - 1.64)^{-2} = 0.0188 \end{aligned}$$

$$\begin{aligned} Nu_D &= \frac{\frac{f}{8}(Re_D - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}} - 1\right)} \\ &= \frac{\frac{0.0188}{8}\left((8.2 \times 10^4) - 1000\right)(0.707)}{1 + 12.7\left(\frac{0.0188}{8}\right)^{\frac{1}{2}}\left(0.707^{\frac{2}{3}} - 1\right)} \\ &= 153.93 \end{aligned}$$

$$h = Nu_D \frac{k}{D} = 153.93 \times \frac{0.025}{0.075} = 51.31 \ W/m^2K$$

$$q = \frac{dT}{R_{tot}}$$

$$R_{tot} = \frac{dT}{q} = \frac{33-26}{628.51} = 0.01114 \ K/W$$

$$R_{tot} = \frac{1}{2\pi r_1 hL} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi kL}$$

$$L = \frac{1}{2\pi r_1 h R_{tot}} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi k R_{tot}}$$

$$= \frac{1}{2\pi\left(\frac{0.075}{2}\right) \times 51.31 \times 0.01114} + \frac{\ln\left(\frac{0.0889}{0.075}\right)}{2\pi \times 0.5 \times 0.01114}$$

$$= 12.29 \ m$$

From the above calculations, the minimum pipe length required was 12.29 m. This means that the pipe should exceed 12.29 m in order to completely remove all the heat gained in the room.

4.3.2.2 Pipe Loop Design

After the required pipe length is calculated, the pipe loop design could be determined. From Chapter 4.2, the minimum pipes distance was 350 mm. Thus, the distance between the pipes should be more than 350 mm so that the cooling system able to cool the room. Figure 4.6 shows the proposed pipe loop design for the room.

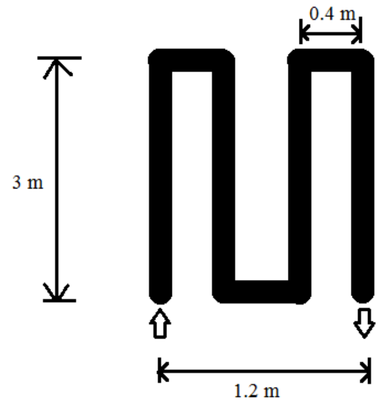


Figure 4.6 Proposed Pipe Loop Design for The Specimen

The pipe in Figure 4.6 would have a total length of 13.2 m. It is okay to have longer pipe length because the longer the pipe, the greater the heat released. However, the pipe length cannot be too long because this will increase the material cost and also the pumping power required. The distance between pipes was 0.4 m which was above the minimum distance required (0.35 m). The design consisted of 6 elbows. It is important to know the number of elbow because it can affect the pumping power required. The greater the number of elbow, the greater the pumping power required. Thus, the elbow amount should be kept low in order to reduce the pumping power required which means to improve the coefficient of performance (COP) of the geothermal cooling system.

However, to reduce the number of elbow means the pipe loop should be straight and less turns. This will cause the pipe loop occupies large area of land. This is impossible because the land is limited especially for a terrace house, the land is only the garage of the house.

4.3.2.3 Pumping Power Required

This section would cover the method to calculate the pumping power required. The method was mentioned briefly in Chapter 3.4. There were few parameters need to be determined before calculating the pumping power. There were mass flow rate of the air in pipe, total pipe length and the pipe components such as elbow, tee joint and valve.

According to previous section, the mass flow rate of air was 0.089 kg/s. For the total pipe length, it not only the pipe length buried in the ground but also includes the pipe length from ground to the room. The length from the geothermal pipe loop to ground surface was assumed to be 1.5 m and the length from ground to the upper floor room was assumed to be 3 m. Thus, the extra length will be 4.5 m each for inlet and outlet. Total pipe length will be 22.2 m.

For the pipe components, the geothermal pipe loop itself consisted of 6 elbows. For the pipe from the loop to the room, the number of elbow was assumed to be 4 pieces. Hence, the total number of elbow will be 10. The number of elbow will contribute to the head loss of the pipe. The loss coefficient for the pipe components was shown in Table 3.12. The elbow for this pipe deign was assumed to be regular 90 °, flanged which has a loss coefficient of 0.3.

In order to calculate the pumping power required, the head loss of the pipe must be calculated. The equations to calculate the head loss were listed in Chapter 3.4.1. There are two head losses, the major head loss and minor head loss. Major head loss is caused by the pipe and it proportional to the pipe length. Minor loss is caused by the pipe components such as elbow and tee joint. The head losses can be calculated by using Equation 3.5 and Equation 3.6 stated in Chapter 3.4.1. The calculation for the losses is shown as follow.

$$
\begin{aligned}
h_{L,major} &= f\frac{L}{D}\frac{V^2}{2g} \\
&= 0.0188 \times \frac{22.2 \times 17.32^2}{0.075 \times 2 \times 9.81} \\
&= 85.34\ m
\end{aligned}
$$

$$h_{L,minor} = K_L\frac{V^2}{2g}$$

$$= (10 \times 0.3)\frac{17.32^2}{2 \times 9.81}$$

$$= 45.89\ m$$

The friction factor f was same with the friction factor determined when calculating the pipe length previously. The velocity V was converted from the mass flow rate which is 0.089 kg/s. Equation 4.8 shows how to convert mass flow rate to velocity.

$$V = \frac{Q}{A} = \frac{\dot{m}}{\rho A} \tag{4.8}$$

where

V = velocity, m/s

Q = volumetric flow rate, m^3/s

A = pipe cross section area, m^2

$\dot{m}$ = mass flow rate, kg/s

ρ = density of air, kg/m^3

The density of air at 300 K is 1.165 kg/m^3. The calculation for velocity was as follow.

$$V = \frac{\dot{m}}{\rho A} = \frac{0.089}{1.165 \times \frac{\pi \times 0.075^2}{4}} = 17.32\ m/s$$

The total head loss will be the sum of major loss and minor loss. The total head loss would be 131.23 m. According to Equation 3.3 in Chapter 3.4, the pressure head required from the pump is the sum of the total head loss and the head from the velocity. The calculation for the pump pressure head was as follow.

$$h_a = h_L + \frac{V^2}{2g}$$

$$= 131.23 + \frac{17.32^2}{2 \times 9.81}$$

$$= 146.53\ m$$

Finally, the pumping power could be calculated by using Equation 3.2 shown in Chapter 3.4. The efficiency of the pump was assumed to be 0.8 and the volumetric flow rate could be calculated using Equation 4.8. The calculation was as follow.

$$P = \frac{\Delta p Q}{\eta} = \frac{h_a \rho g Q}{\eta} = \frac{146.53 \times 1.165 \times 9.81 \times 0.077}{0.8}$$
$$= 160.21\ W$$

So, the pumping power required would be 160.21 W. The COP of the geothermal cooling system was then can be calculated by using the pumping power and the cooling load calculated previously.

$$COP_g = \frac{cooling\ load}{pumping\ power} = \frac{628.51}{160.21} = 3.92$$

The COP of the geothermal cooling system was 3.92. By comparing to the COP of the air conditioner which was 1.16, it clearly show that the geothermal cooling system had much higher efficiency that the air conditioner. The percentage of energy saved could be computed using Equation 3.1 mentioned in Chapter 3.2.

$$\%Saved = \frac{COP_g - COP_a}{COP_g} \times 100\%$$
$$= \frac{3.92 - 1.16}{3.92} \times 100\%$$
$$= 70.4\%$$

This shows that the geothermal cooling system can save a lot of electricity. It can save up to 70 % from the air conditional electricity consumption. This means that the geothermal cooling system uses only about one-third of the air conditional electricity consumption. The electricity consumption is the operating cost, in order to make the geothermal cooling system feasible, the initial cost should be low enough so that the saving in the operating cost can compensate the extra initial cost as soon as possible. The initial cost of the geothermal cooling system and the air conditional will be mentioned in later chapter.

4.4 Parallel Loop and Series Loop Piping System

One of the objectives of the project was to compare parallel loop and series loop piping system. It is important to know the effect of the loop design so that the optimised geothermal cooling system can be designed. In order to compare the effect of the loop pattern, both pattern should have some equal parameters. Since the project is about feasibility of the geothermal system, the main concern is on the pumping power which will affect the efficiency of the system directly. Thus, the constant parameters will be the cooling load, pipe total length, pipe diameter, piping material and the flow rate.

The design of the parallel pipe and series pipe was mentioned in Chapter 3.4.2. Both pipe loops had a total length of 11 m and the mass flow rate were 1.049 kg/s. All the remaining parameters of the pipe loop were shown in Table 4.5.

Table 4.5: Pipe Loop Parameters

Specifications	**Value**
Pipe diameter	75 mm
Number of elbow	2
Type of elbow	Regular 90 °, flanged
Loss coefficient for elbow, K_L	0.3

The parameters shown in Table 4.5 were applicable for both parallel and series pipe loop. The friction factor for parallel loop was 0.0132 while the friction factor for series loop was 0.0117. The friction factor was calculated using the formulas shown in Chapter 4.3.2.1. The equations used were equation 4.6 and 4.7. The friction factor were different in series and parallel pipe because the flow rate in each branch of parallel loop is smaller than that of in the series loop. The flow rate for each branch was assumed to be half of the flow rate of the system because the parallel loop consisted of 2 branches. This assumption was proved in later calculation.

Besides the parameters stated in Table 4.5, the parallel loop pipe also consisted of 2 tee joints. The tee joints were used to split the pipe into 2 parallel loops and the joints had the total loss coefficient of 1.2. According to Table 3.12 shown in Chapter 3.4.1, the loss coefficient of tee joint in line flow is different with that of in branch flow. In this parallel loop pipe, each branch will have one line flow and one branch flow. Thus, the loss coefficient of the tee joint for each branch will be 0.2 + 1 = 1.2.

According to Chapter 3.4.2, in parallel pipe loop, the flow rate of the system is the sum of the flow rate of each branch of the parallel pipe loop while in series loop, the system flow rate will be equal to the flow rate of the pipe loop. Besides, the friction head loss for parallel pipe loop are same for each branch while in series pipe loop, the head loss is the sum of the head loss throughout the pipe loop.

The calculation for the total head loss for both pipe loop were shown below.

For parallel pipe, every branch has the same head loss, thus, the head loss can be obtained by just calculate the head loss of one branch.

$$
\begin{aligned}
h_L = h_{L1} = h_{L2} = h_{L1,major} + h_{L1,minor} \\
&= f\frac{\ell}{D}\frac{{V_1}^2}{2g} + K_L\frac{{V_1}^2}{2g} \\
&= 0.0132\frac{5.5}{0.075}\frac{{V_1}^2}{2\times 9.81} + (0.3+0.2+1)\frac{{V_1}^2}{2\times 9.81} \\
&= 0.1258{V_1}^2
\end{aligned}
$$

Since the pipe pattern of each branch of the parallel loop are same, h_{L2} will be equalled to $0.1258V_2^2$. Hence,

$$h_{L1} = h_{L2}$$

$$0.1258{V_1}^2 = 0.1258{V_2}^2$$

$$V_1 = V_2$$

As mentioned earlier, the total flow rate equals to the sum of the flow rate of each branch, thus,

$$Q = Q_1 + Q_2$$
$$= AV_1 + AV_2$$
$$Q = 2AV_1$$

The velocity for each branch will be

$$V_1 = V_2 = \frac{Q}{2A} = \frac{0.9}{2 \times \frac{0.075^2 \times \pi}{4}} = 101.86\ m/s$$

The volumetric flow rate was converted from mass flow rate using Equation 4.9 and the density was set to 1.165 kg/m^3.

$$Q = \frac{\dot{m}}{\rho} \tag{4.9}$$

where
Q = volumetric flow rate, m^3/s
$\dot{m}$ = mass flow rate, kg/s
ρ = density of air, kg/m^3

Then, the total head loss can be calculated as follow,

$$h_L = 0.1258V^2 = 0.1258 \times 101.86^2 = 1305.23\, m$$

For series pipe loop, the calculation is similar to the calculation in Chapter 4.3.2.3. First, calculate the velocity using Equation 4.9, then use the velocity calculated to calculate the head loss. The velocity obtained for series pipe loop was 203.72 m/s. The calculation for head loss was shown below.

$$h_L = h_{L,major} + h_{L,min\,or}$$
$$= f\frac{\ell}{D}\frac{V^2}{2g} + K_L\frac{V^2}{2g}$$
$$= 0.0117\frac{11}{0.075}\frac{203.72^2}{2\times 9.81} + (2\times 0.3)\frac{203.72^2}{2\times 9.81}$$
$$= 4898.99\,m$$

The friction head loss for parallel pipe and series pipe were 1305.23 m and 4898.99 m respectively. By comparing the head loss of both systems, it clearly showed that parallel loop had much lower head loss than that of series loop. This means that the efficiency of the geothermal cooling system will increase if using parallel pipe loop design.

The reduction of head loss is due to several factors. The first factor is the reduction of the flow rate in the pipe loop. When the flow rate is high, the friction will increase significantly. This can be verified from the head loss equation where the equation shows that the head loss is proportional to the square of the velocity. In parallel pipe, the flow rate will be separated because the pipe is divided into branches. Thus, parallel pipe will have lower velocity and head loss compared to series loop pipe.

Second factor is the reduction of the pipe length. The major head loss is proportional to the pipe length. The greater the pipe length, the greater the major head loss. In parallel loop pipe, the head loss in each branch are same and the head loss of the whole system is not equalled to the sum of all the head loss of each branch but also equals to the head loss of each branch. When the pipes are divided into branches, the pipe length will be divided as well, as a result, the pipe length will be reduced. This will cause the major head loss decreased because of the reduction of the pipe length.

The third factor is the reduction of the number of pipe fitting such as elbow. The minor head loss is proportional to the friction coefficient of the pipe fitting. When there is less pipe fitting, the minor head loss will be reduced. In parallel pipe, the number of fitting will be divided by the number of branches and hence, the minor loss will be reduced. However, this factor is not applicable in the pipe loop design in this chapter because the number of elbow is not significant and the parallel loop pipe had extra fittings which were the tee joints. In actual case, the pipe loop should have a lot of elbow in order to reduce the land space required. In that case, the parallel loop pipe will have significant effect on the reduction of the minor head loss.

Besides the analytical approach, the head loss of both parallel loop and series loop also obtained using simulation method. The simulation software used was Ansys 15.0. All the parameters for the simulation were same as the parameters used in analytical approach. Figure 4.7 and Figure 4.8 show the pressure contour of both parallel pipe and series pipe respectively.

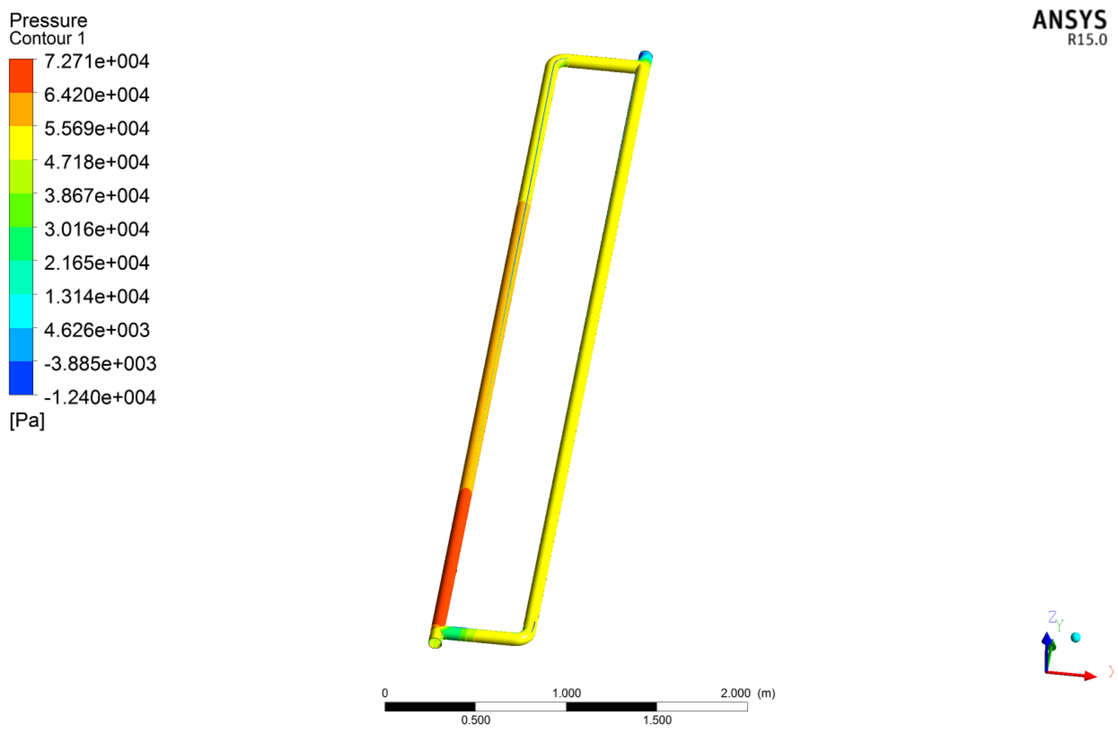


Figure 4.7 Parallel Pipe Pressure Contour

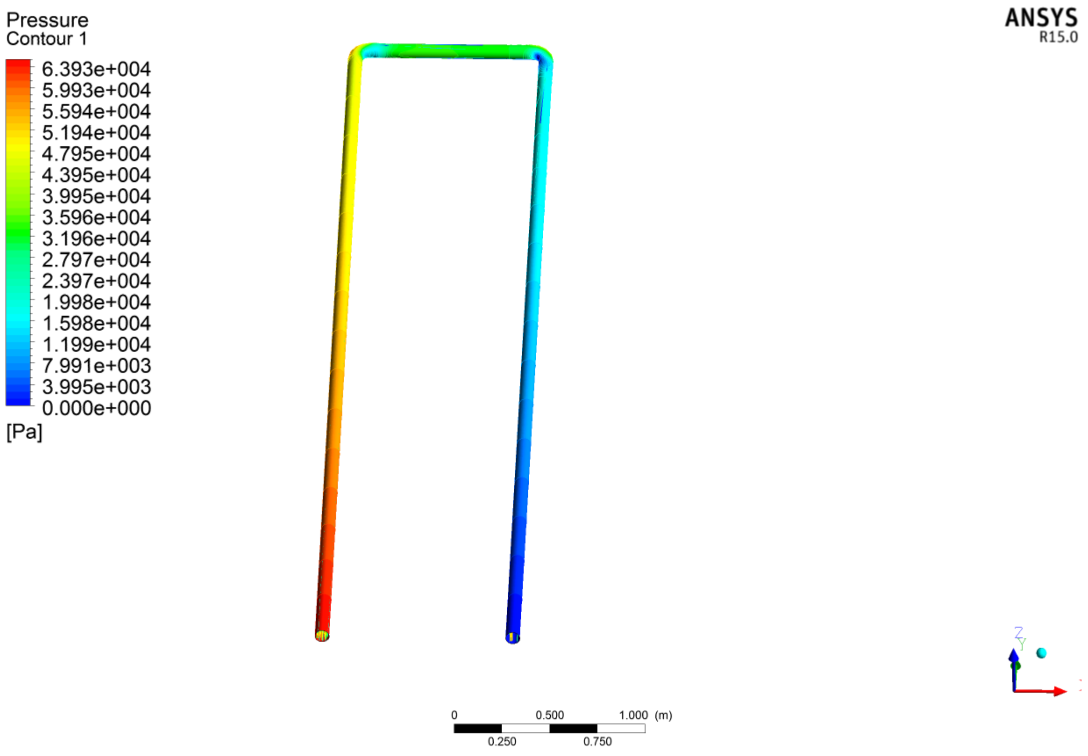


Figure 4.8 Series Pipe Pressure Contour

The inlet for both pipe loop were located on the left bottom side in the figures. It was clearly seen that the pressure at inlet for both parallel loop and series loop were highest (red colour) and decreased as it went farer. The minimum pressure located at outlet. The pressure loss for both parallel loop and series loop was shown in Figure 4.9 and Figure 4.10 respectively.

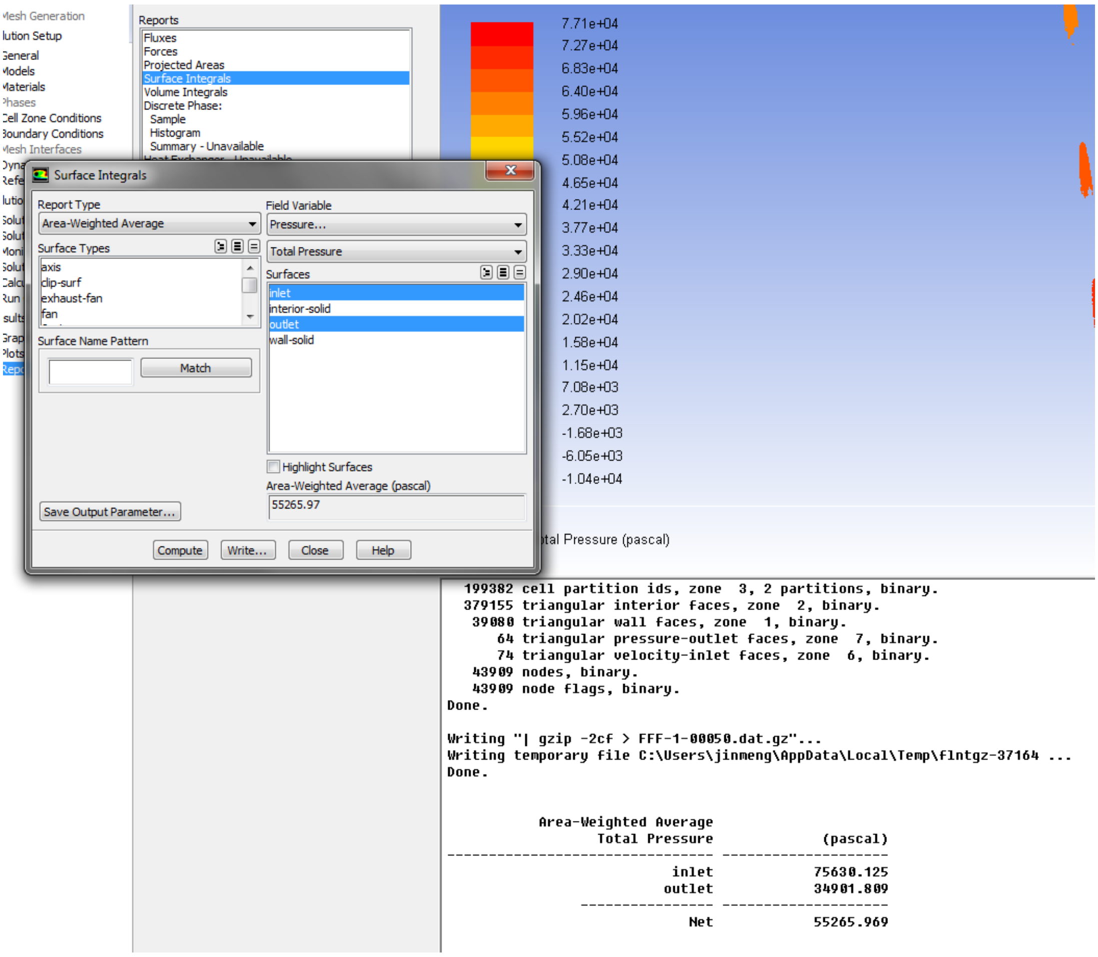


Figure 4.9 Parallel Pipe Pressure Loss

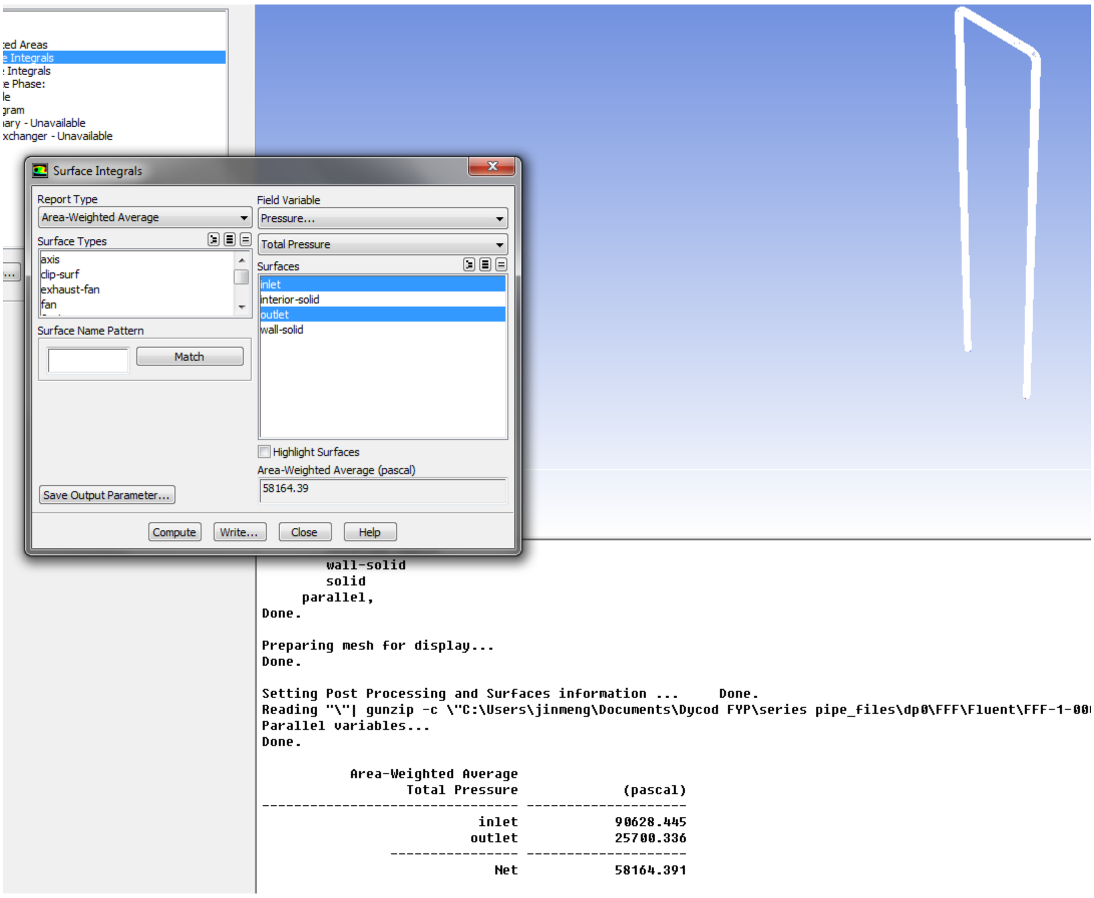


Figure 4.10 Series Pipe Pressure Loss

The pressure at inlet and outlet for both parallel and series pipe were shown in Figure 4.9 and Figure 4.10. The inlet and outlet pressure for parallel pipe were 75630.125 Pa and 34901.809 Pa respectively whereas the inlet and outlet pressure for series pipe were 90628.445 Pa and 25700.336 Pa respectively. Thus, the pressure loss will be the pressure difference between the inlet and outlet. The pressure loss for parallel pipe and series pipe were 40728.316 Pa and 64928.109 Pa respectively. The pressure loss can be converted into head loss by using the Pascal Law equation shown in Equation 4.10.

$$P = h\rho g \tag{4.10}$$

where

P = Pressure loss, Pa

h = head loss, m

ρ = density of air, kg/m^3

g = gravitational acceleration, m^2/s

The density of air is 1.165 kg/m^3. By applying the Equation 4.10, the head loss for both parallel and series loop can be found. The head loss for parallel and series loop were 3563.7 m and 5681.17 m respectively.

By comparing the head loss of both pipe loop, the parallel loop had lower head loss than the series loop. However, the difference is not significant as shown in the analytical results. This is probably caused by the pipe fitting used. Besides, the head loss calculated and head loss simulated were different. The head loss obtained from simulation was higher because the head loss included the velocity head loss. The velocity head loss for both parallel and series pipe were same because the inlet and outlet velocity for both pipe loop were same.

There are few things to discuss on the difference of both results. First is about the head loss difference between parallel pipe and series pipe. It clearly showed that the head loss difference obtained from calculation was greater than the result obtained from simulation. There are two possible reasons, first is the series pipe head loss from calculation higher than the series head loss from simulation, second is the parallel pipe head loss from simulation is higher than the parallel head loss from calculation.

One of the factor will be the tee joint loss coefficient. The tee joint in the simulation was created by merging two perpendicular pipes. As a result, the geometry of the tee joint will not as smooth as the actual tee joint which is specially designed. This will cause the head loss increased.

Second thing is about the greater head loss result from simulation compared to calculation. As mentioned earlier, this was probably due to the absence of velocity head loss in calculation. By using Equation 3.4 in Chapter 3.4, the velocity head for both parallel and series pipe was around 2000 m. Based on this value, it clearly showed that the parallel pipe results were similar in both calculation and simulation. However, for series pipe, the result obtained from calculation after considered the velocity loss was greater than that of simulation. The factor to cause the difference is the loss coefficient of the elbow because the elbow in the simulation was created using fillet while the elbow used in calculation was threaded type.

Based on the results obtained, the parallel loop pipe has lower head loss than that of the series loop pipe. This means that the parallel loop pipe can save more power that series loop pipe. As a result, parallel pipe will have greater efficiency than that of the series pipe. In conclusion, parallel pipe should be preferred if the main concern is on the efficiency. The effect of parallel pipe besides efficiency will be shown in next section.

4.5 Relationship Between Cooling Load and Coefficient of Performance

The cooling load is different for every house or room or building. Generally, the greater the volume of the room, the greater the heat gain or cooling load. However, the cooling load also depends on the direction of the room, location of the room, wall, window, roof and door material and internal heat gain such as heat gain from human and electrical appliances.

Coefficient of Performance (COP) is the efficiency measurement for cooling devices such as air conditioner. The greater the COP, the better the efficiency. In this, section, the author will compare the effect of cooling load on the COP. Ideally, the efficiency of the air conditional is constant regardless of the cooling load. However, for geothermal cooling system, the cooling load will affect the COP of the system.

The analysis would be divided into three parts. The first part was on the series loop pipe while the second part was on the parallel loop pipe. The third part was to determine the overall analysis on the relationship.

4.5.1 Series Pipe Loop

This section will show the relationship between the cooling load and the COP of the geothermal cooling system that uses series pipe loop design. The equations used for calculating the COP or the geothermal system can be obtained in Chapter 4.3.2. The calculation steps were same as the steps shown in Chapter 4.3.2. In order to calculate the COP of the system, first thing is to calculate the required mass flow rate of the air, then calculate the required pipe length. After that, calculate the head loss and pumping power required. Finally, compare the pumping power required with the cooling load to get the COP of the geothermal cooling system.

In order to plot the relationship graph, the calculation needs to be repeated many times. Thus, a spreadsheet was created to simplify the calculation works. The spreadsheet was divided into two parts. The first part was to calculate the required pipe length while the second part was to calculate the pumping power and COP. Figure 4.11 and Figure 4.12 show the pipe length and COP part respectively.

	A	B	C	D	E
1					
2		Cooling load q	1500		
3		Cp	1007		
4		Tout	26		
5		Tin	33		
6		m dot	0.212796141		
7					
8		Pr	0.707		
9		pi	3.1415		
10		viscosity	1.85E-05		
11		diameter ID	0.075	OD	0.0889
12		Re	1.96E+05		
13		f	0.015681275		
14		Nu	305.2446712		
15		k air	0.025		
16		h	101.7482237		
17					
18		Tsoil	26	k soil	2
19		Rtot	0.004666667	soil OD	0.35
20		k pipe	0.5		
21		L	20.53612567		

Figure 4.11 Spreadsheet for Pipe Length (Series)

	A	B	C	D	E	F
1						
2		length	12.28642	10	extra length	
3		volume flow rate	0.076535			
4		velocity	17.32444			
5		g	9.81			
6		density	1.165			
7		no of elbow	6			
8		KL	1.8			
9						
10		h major	85.33726			
11		h minor	27.53543			
12		h total	112.8727			
13						
14						
15		z2-z1	0			
16		pressure head	128.1702			
17		pump efficiency	0.8			
18		pumping power	140.1363			
19						
20		COP	4.484991			

Figure 4.12 Spreadsheet for COP (Series)

The spreadsheets consisted of 3 types of boxes, the yellow, white and grey boxes. The yellow boxes were the variables that needed to be keyed in. The white boxes were constant parameters while the grey boxes were the calculation results. However, since the purpose of this section was to determine the relationship of the cooling load and the COP, the only variable will be the cooling load. The inlet and outlet temperature were set to 33 ℃ and 26 ℃ respectively. The inlet temperature will be the room temperature obtained in Chapter 4.1 whereas the outlet temperature will be the minimum temperature the geothermal cooling system could achieve. For the pipe diameter, it was fixed at 75 mm which were same throughout the report.

The 'extra length' shown in Figure 4.12 was the pipe length from underground to the room. It was assumed to be 10 m because the pipe was buried 1.5 m from ground surface and the room height was assumed to be 3.5 m, so the total extra length for each pipe will be 5 m and the cooling system had 2 pipes (one inflow and one outflow). For the number of elbow, the number was set to 6 which is the minimum number of elbow. The result was shown in Figure 4.13.

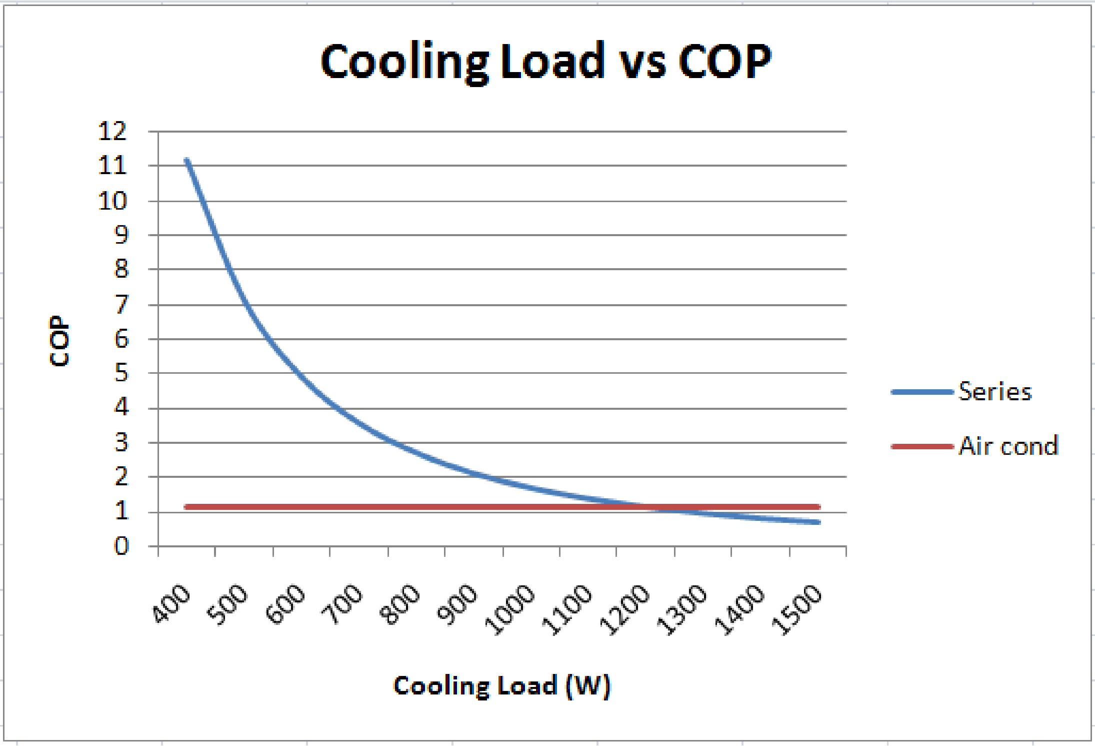


Figure 4.13 Cooling Load vs COP for Series Pipe

Based on Figure 4.13, the COP decreased exponentially as the cooling load increased. This is because the COP depends on the pumping power and the pumping power depends on the head loss which depends largely on flow rate and pipe length. When the cooling load increased, the flow rate would increase and the head loss is proportional to the square of the velocity. As a result, the head loss will increase exponentially. This will cause the pumping power and COP decreased when cooling load increased.

Thus, when designing the geothermal cooling system, it is important to know the whether the system able to support the cooling load or not. The red line in the graph shown in Figure 4.13 was the COP of the air conditioner used in the test (Chapter 3.1). Based on the graph, the COP of the geothermal cooling system will drop below the COP of the air conditioner when the cooling load is above 1250 W. For actual application, the COP should be higher than 3 in order to compete with air conditioner. The COP of the geothermal cooling system higher than 3 when the cooling load is below 800 W. This means that geothermal cooling system is only suitable for medium size room which normally has a cooling load of 600 W to 800

W. In conclusion, a simple series loop geothermal cooling system is suitable only when the room size is not very large.

4.5.2 Parallel Pipe Loop

This section will show the relationship between the cooling load and the COP of the geothermal cooling system that uses parallel pipe loop design. The calculation steps were similar to the calculation for series loop in Chapter 4.5.1 if some modification. First is the number of parallel pipe loop. When the number of branch of the pipe more than one, the flow rate of each branch will divided by the number of branch. As a result, the air heat transfer coefficient will be reduced and the pipe length will be increased. Besides, since the flow rate reduced, the head loss will be reduced. This will reduce the overall pumping power and thus, COP increased.

Same as the series loop pipe in Chapter 4.5.1, the calculation needs to be repeated many times in order to plot the relationship graph. Thus, a spreadsheet was created to simplify the calculation works. The spreadsheet was divided into two parts like the series loop pipe. The first part was to calculate the required pipe length while the second part was to calculate the pumping power and COP. Figure 4.14 and Figure 4.15 show the pipe length and COP part respectively.

	A	B	C	D	E
1					
2		Cooling load q	4227.1		
3		Cp	1007		
4		Tout	26		
5		Tin	33		
6		m dot	0.599673713		
7		no of pipe	10		
8		Pr	0.707		
9		pi	3.1415		
10		viscosity	1.85E-05		
11		diameter ID	0.075	OD	0.0889
12		Re	5.51E+04		
13		f	0.020495495		
14		Nu	113.0833206		
15		k air	0.025		
16		h	37.69444021		
17					
18		Tsoil	26	k soil	2
19		Rtot	0.001655982	soil OD	0.35
20		k pipe	0.5		
21		L	100.6764129		

Figure 4.14 Spreadsheet for Pipe Length (Parallel)

	A	B	C	D	E	F
1						
2		length	10.06764	10	extra length	
3		volume flow rate	0.514741			
4		velocity	11.65171	total V	116.5171	
5		g	9.81			
6		density	1.165			
7		no of elbow	6			
8		KL	12.6			
9						
10		h major	37.94665			
11		h minor	87.18676			
12		h total	125.1334			
13						
14						
15		z2-z1	0			
16		pressure head	817.0918			
17		pump efficiency	0.8			
18		pumping power	6008.484			
19						
20		COP	0.703522			

Figure 4.15 Spreadsheet for COP (Parallel)

All the parameters were same as the spreadsheet in series loop pipe except the number of branch and loss coefficient. The loss coefficient for parallel pipe was different because it consisted of extra tee joint. However, The loss coefficient is constant throughout this section. The flow rate will be different also but the flow rate was calculated not input variable. Thus, the parameters needed to be cared were the number of branch only.

The branch number will be set to 2, 3, 4 and 5 respectively. This is to compare the effect of the branch number on the COP of the geothermal cooling system. The results were shown in Figure 4.16.

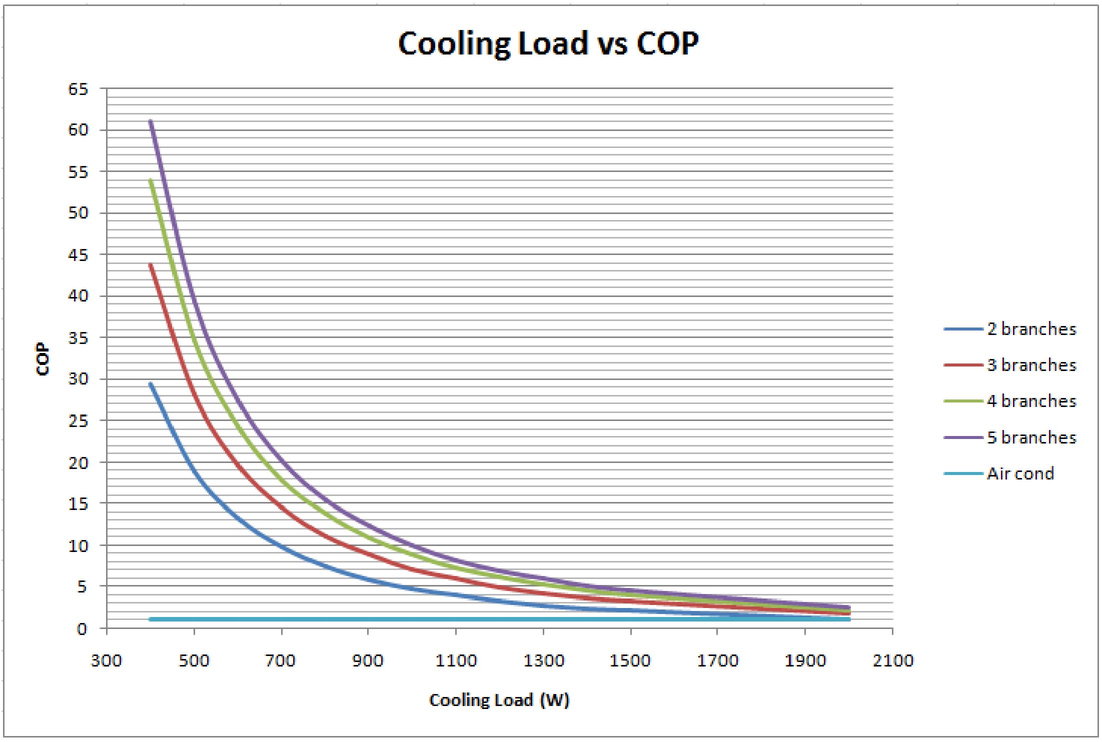


Figure 4.16 Cooling Load vs COP for Parallel Pipe

From Figure 4.16, the COP of parallel pipe could reach up to 60. The curve pattern were same with the series loop pipe which had a exponential decrease. The results showed that even the cooling load reached 2000 W, the COP of the geothermal cooling system still greater than the COP of the air conditioner tested. Figure 4.17 shows the closer look of the graph near 2000 W cooling load.

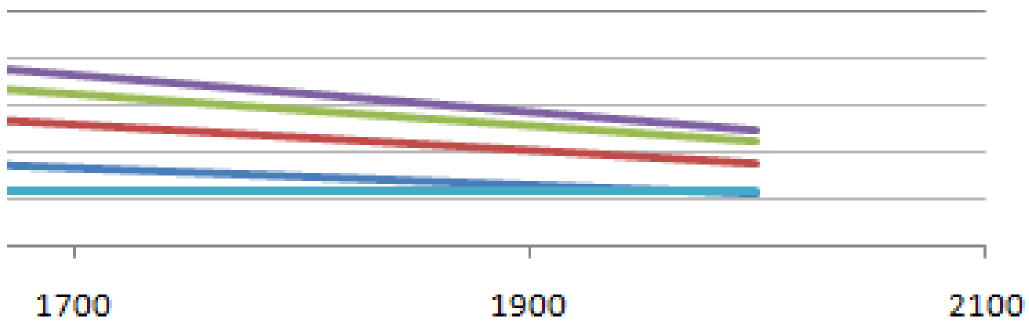


Figure 4.17 Closer Look of The Graph

Figure 4.17 shows that the COP of the geothermal cooling system at 2000 W cooling load were more than 2 for 4 and 5 branches, more than 1 for 2 and 3 branches. This showed that the parallel loop pipe had significant improvement compared to series loop pipe. However, in order to achieve COP of 3, the cooling load should be controlled at below 1900 W for 5 branches parallel loop pipe. A cooling load of 1900 W is only enough for 2 to 3 medium rooms. This means that even the parallel cooling system also cannot support a double storey house. It can only support one storey of the house.

For a large cooling load house that has cooling load more than 1900 W, one of the method to solve the problem is by further increase the branch number. However, the result will not be significant. Based on the graph in Figure 4.17, the curves were going to merge each other as the cooling load increased. This means that the branch number has limited effect on the COP when the cooling load is high. This is mainly due to the change of the ratio of the head loss components. The increase of branch number reduces the friction head loss. However, the total head loss consists of other head loss as well such as velocity head loss. The velocity head loss is constant regardless of the number of branches. This means that there will be a minimum head loss for each cooling load.

In conclusion, the parallel pipe loop system has better COP that series pipe loop system. However, the piping cost for parallel loop will be higher than that of the series loop because the pipe length required for parallel loop is higher. This is because the heat transfer coefficient of air is lower when the flow rate decreased.

Besides, the parallel loop also uses extra pipe fitting such as tee joint in order to split the pipe into branches. Thus, series pipe loop is preferable when the cooling load is small while parallel loop is preferable when the cooling load is great.

4.5.3 Overall Analysis on The Cooling Load - COP Relationship

This section will focus on the effect of number of branches on the COP. This is important because the limit of the geothermal cooling system can be obtained. According to Chapter 4.5.2, the COP improved as the branch number increased. This section will determine the maximum improvement caused by the increase number of branch.

The calculations used in this section were same as previous two sections. The spreadsheet used also could be reused in this section. The difference was that the manipulating variable is branch number instead of cooling load. Figure 4.18 shows the branch number against head loss graph.

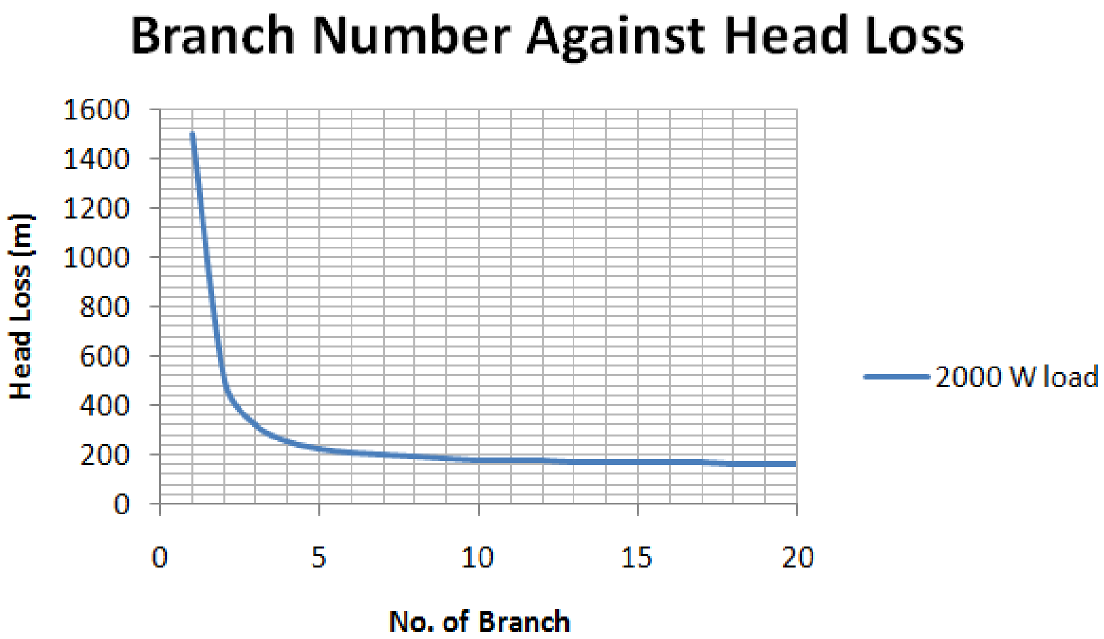


Figure 4.18 Branch Number Against Head Loss Graph

The curve shown in Figure 4.18 was an exponential curve. The cooling load for the curve was set to 2000 W. Based on Figure 4.18, the head loss reduced as the pipe number increased. However, the reduction became not significant when the number of branch above 5. The curve became almost horizontal when the branch number more than 15. This means that the effect of the branch number on the head loss became smaller and smaller as the branch number increased. Based on Figure 4.18, the minimum head loss the system could achieve was around 160 m.

The reduction effect on the head loss was probably due to the velocity head loss which was independent with the branch number. This means that there would be a minimum head loss for each cooling load. As the COP decreased when cooling load increased as shown in Figure 4.13 and 4.16, the minimum head loss should be increased as the cooling increased. This means that the parallel loop method may not satisfy large cooling load application.

Since there is a minimum head loss, there must be a maximum COP the geothermal cooling system can achieve for different cooling load. In order to clarify this, a graph on the relationship between branch number and COP was plotted. Figure 4.19 shows the branch number against COP graph.

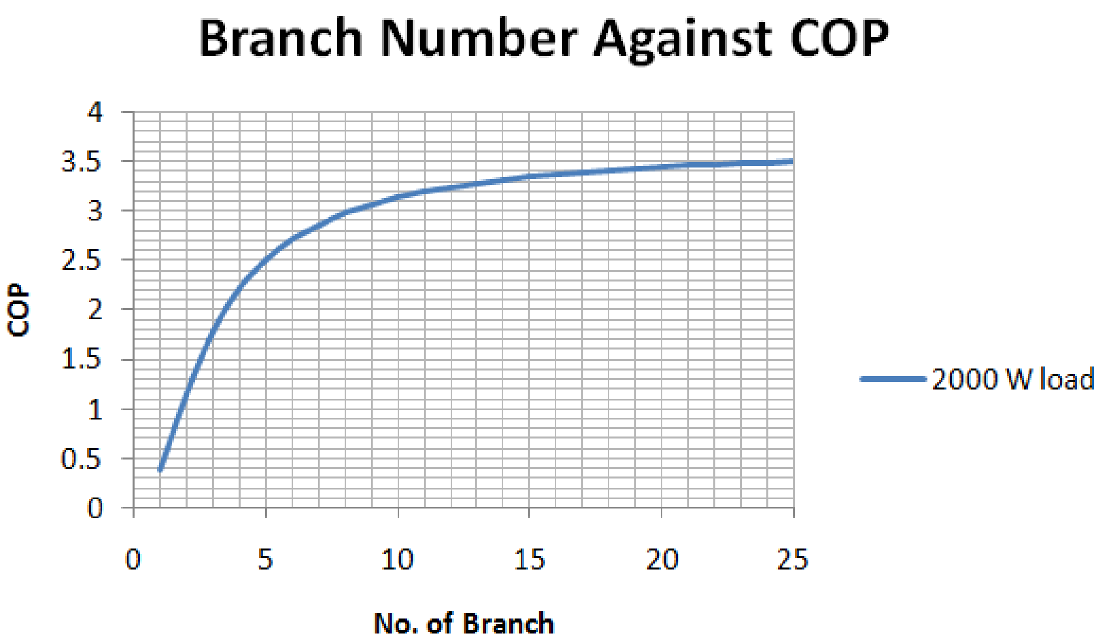


Figure 4.19 Branch Number Against COP Graph

The curve in Figure 4.19 was a logarithmic growth curve. The cooling load was fixed to 2000 W. The curve in Figure 4.19 showed that the COP increased as the branch number increase. However, the increment became not significant when the number of branch above 10. The curve became almost horizontal when the branch number more than 20. This means that the effect of the branch number on the COP became smaller and smaller as the branch number increased.

According to Figure 4.19, the maximum COP was around 3.5. This means that for 2000 W cooling load, the geothermal cooling system could only achieve a COP of 3.5. Besides, as the cooling load increased, the COP decreased. This means the maximum COP that the geothermal cooling system can achieve will decrease as the cooling load increases. In conclusion, a single parallel pipe geothermal cooling system may not suitable for high cooling load application.

A graph that consisted of several cooling load was plotted in order to obtain some maximum COP of each cooling load. Figure 4.20 shows the branch number against COP graph for several cooling load.

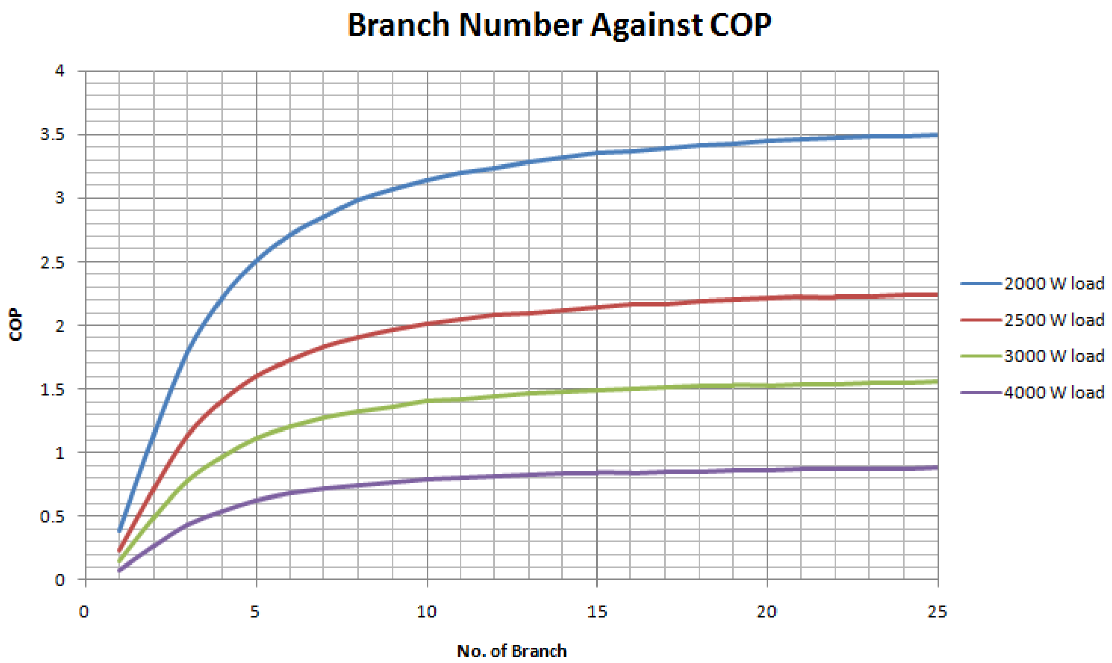


Figure 4.20 Branch Number Against COP Graph for Several Cooling Load

There were 4 curves in Figure 4.20 and each curve represented different cooling load. The represented cooling load were 2000 W, 2500 W, 3000 W and 4000 W. All 4 curves were plotted until the branch number equalled to 25. All the four curves became horizontal when the branch number more than 20. This means that the maximum COP of the geothermal cooling system for different cooling load were found in Figure 4.20.

Based on Figure 4.20, the maximum COP for the 4 different cooling load could be found. The maximum COP for 2000 W, 2500 W, 3000 W and 4000 W were 3.5, 2.2, 1.55 and 0.9 respectively. If compared to the COP of the air conditioner tested which was 1.16, the geothermal cooling system for 4000 W cooling load was worse than the air conditioner. This means that the maximum cooling load that the geothermal cooling system can support is around 3000 W.

However, if compared to ideal COP of air conditioner, only the 2000 W cooling load geothermal cooling system could be used. As mentioned earlier, a 2000 W cooling load was only satisfied 2 to 3 medium size rooms. This means that a geothermal cooling system could only support single storey house or one storey of a double storey house.

In conclusion, the parallel loop piping system is essential for COP improvement. However, it has a maximum constraint. The COP of a parallel loop piping system will not improve anymore when the branch number reaches certain amount.

4.6 Geothermal Cooling System for Double Storey House

This section will design a suitable geothermal cooling system for a double storey terrace house. The house layout was shown in Chapter 3.7. It consisted of 2 floors and the house was facing South. Each floor had 4 windows (2 windows at front while 2 windows at back). Since the house was a terrace house, the walls at both left and right side were not exposed to Sunlight. The plan layout was shown in Figure

3.14 and 3.15 in Chapter 3.7. Figure 4.21 and 4.22 show the plan layout again for easy viewing.

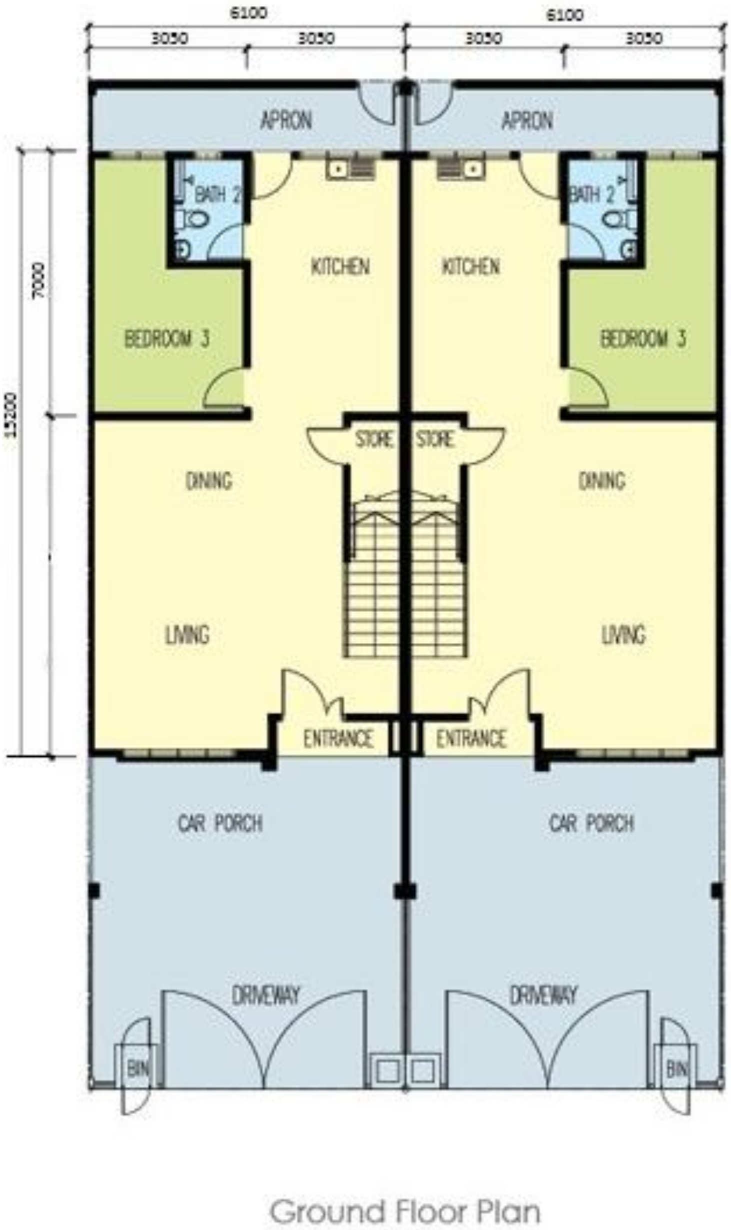


Figure 4.21 House Layout Plan (Gound Floor)

Figure 4.22 House Layout Plan (First Floor)

4.6.1 Cooling Load Calculation

For simplicity, all the materials were same as the testing room at Seri Kembangan house in Chapter 4.3. This means the windows, walls and roof specifications were same with the room in Chapter 4.3. The design temperature would be equalled also which was 34.2 ℃.

The calculations steps were similar to the calculations shown in Chapter 4.3.1. First was to calculate the CLTD value of walls, door, roof and shaded wall. The calculation method was same as Chapter 4.3.1 except the wall direction. The walls that exposed to Sunlight were front wall and back wall. The front wall was facing

South while the back wall was facing North. Table 4.6 shows the CATD value of the walls, door, roof and shaded wall of the house.

Table 4.6: CLTD Value for House Structure

Structure	CLTD Value [K]
North wall	12.2
South wall	18.2
Door	18.2
Roof	13.73
Shaded wall	7.73

The second step was to calculate the GLF value for windows. Table 4.7 shows the GLF value for windows of the house.

Table 4.7: GLF Value for Windows

Window Direction	GLF Value [W/m^2]
North	87.8
South	160.53

The third step was to determine the U-factor of the wall, roof and door. Since the specifications of the wall and roof were same with the test room in Chapter 4.3, the U-factors for wall and roof would be same as the U-factors in Chapter 4.3. For door, the door was a wood slab door with no glazing. The U-factor for door could be found in Table 3.11. Table 4.8 shows the U-factors for the wall, roof and door of the house.

Table 4.8: U-Factor for Wall, Roof and Door

Structure	U-factor [W/m^{2}K]
Wall	0.88
Roof	0.244
Door	2.61

The forth step was to calculate the area for every components. The calculations were shown below.

For North window,

$A_{win,N} = 1.2 \times 1.15 \times 4 = 5.52\ m^2$

For South window,

$A_{win,S} = 1.2 \times 1.15 \times 4 = 5.52\ m^2$

The area was multiplied by 4 because each side of wall consisted of 2 windows for each floor. Thus, there were 4 windows for each wall.

For door,

$A_{door} = 0.82 \times 2.03 = 1.66\ m^2$

For North wall,

$A_{wall,N} = (2 \times 3 \times 6.1) - A_{win,N}$

$= 36.6 - 5.52 = 31.08\ m^2$

For South wall,

$A_{wall,S} = (2 \times 3 \times 6.1) - A_{win,S} - A_{door}$

$= 36.6 - 5.52 - 1.66 = 29.42\ m^2$

For shaded wall,

$A_{wall,shaded} = 2 \times 2 \times 3 \times 15.2 = 182.4\ m^2$

For roof,

$A_{roof} = 15.2 \times 6.1 = 92.72\ m^2$

By referring to Chapter 4.3.1 and Table 3.8, the cooling load for every components could be found. Table 4.9 shows the cooking load for all components and total cooling load.

Table 4.9: Cooling Load for All Components

Component	Cooling Load [W]
North windows	484.66
South windows	886.13
Door	78.75
North wall	333.67
South wall	419.41
Shaded wall	1240.76
Roof	310.62
People x 4	268
Computer	55
TV, large	80
TV, medium	70
Total	**4227.1**

The total cooling load for the double storey terrace house was 4227.1 W. This amount of cooling load will make the geothermal cooling system design become difficult because the result in Chapter 4.5 shows that a single geothermal cooling system can only be efficient when the cooling load less than 2000 W. Thus, multi geothermal cooling system will be used to improve the COP. One of the method is to separate the cooling system based on the room number. This means for upper floor, there will be 3 cooling system for each room. The concept is similar to conventional air conditioner which will be installed for every room.

In order to design a suitable geothermal cooling system for each room, the cooling load for each room must be calculated. The calculation method used were same as the calculations shown in Chapter 4.3.1. Thus, the calculation will not be shown again in this part. The cooling load for all the rooms were calculated and tabulated in Table 4.10.

Table 4.10: Cooling Load for Each Room

Description	Cooling Load [W]
Bedroom 1	640.02
Bedroom 2	640.02
Master Bedroom	961.59
Whole ground floor	1998

Based on the results in Table 4.10, the cooling load at upper floor was higher than ground floor. This was because the upper floor gained extra heat from roof. The proposed geothermal cooling system for the double storey house will be discuss in next section.

4.6.2 Proposed Geothermal Cooling System

Since the cooling load of the house was high, a single geothermal cooling system might not sufficient. There were 6 proposed geothermal cooling systems for comparison. The 6 proposed geothermal cooling systems were:

1. One series loop system
2. One parallel loop system
3. Six series loop systems
4. Two parallel loop systems
5. Six parallel loop systems
6. Four parallel loop systems

The COP of all the 6 proposed systems will be calculated and compared. The pipe diameter, inlet temperature and outlet temperature in all 6 systems were equalled so clearer comparison. Besides, the maximum length for one straight pipe was set to 5 m. This means that when a pipe reached 5 m, it must be bent using an elbow. For example, a 10 m length pipe must have 2 elbows to make the pipe become 5 m each. . There will be 4 extra elbows to connect from the system to the house. The formula to calculate the elbow number is simple. First, divide the total length by 5, then round up to become integer. After that, multiply the value by 2 and finally plus 2. The value obtained will be the elbow number inclusive of the 4 extra elbow mentioned earlier

4.6.2.1 Single Series Loop System

The first proposed system was single series loop geothermal cooling system. This means that the whole house was cooled using one cooling system. In order to determine whether this proposed system workable or not, the COP of this system was calculated. The COP of this system could be obtained using the spreadsheet shown in Chapter 4.5.1. By using the spreadsheet, the pipe length required was 43.64 m. By using the method mentioned above, the elbow number was 20. The COP calculated was 0.057. The result showed that the single series loop system was totally failed in double storey house cooling application. In conclusion, a single series loop geothermal cooling system is only suitable for small room application.

4.6.2.2 Single Parallel Loop System

The second proposed system was single parallel loop geothermal cooling system. This system was similar to the first proposed system. The only difference was the pipe loop was parallel instead of series. The COP of this system could be obtained using the spreadsheet shown in Chapter 4.5.2. A graph of branch number against COP was plotted and shown in Figure 4.23.

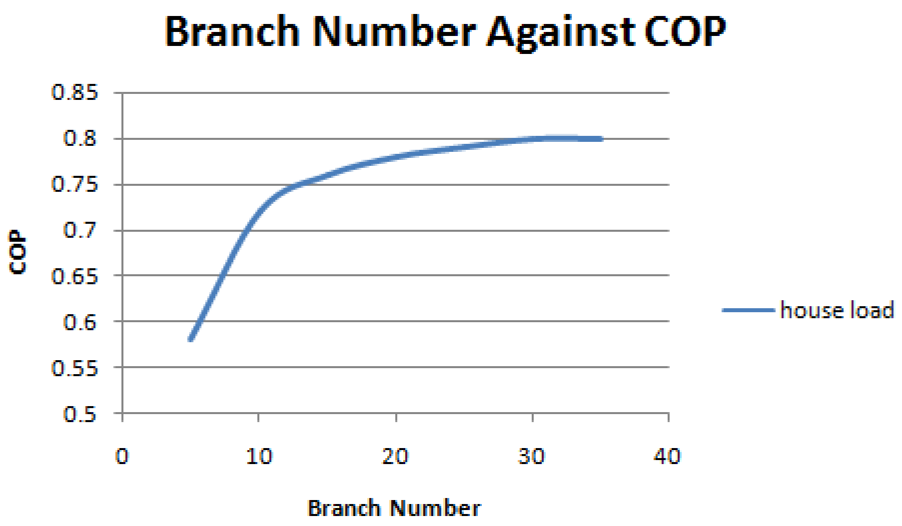


Figure 4.23 COP Curve for Single Parallel System

Based on Figure 4.23, the maximum COP was 0.8. The COP of this system was a lot better than the first proposed system. However, the COP of this system was considered very low as well. In conclusion, the single parallel loop geothermal cooling system did not satisfy the double storey house cooling application.

4.6.2.3 Six Separated Series Loop System

The design proposed in this section was a system that consisted of 6 separated series loop system. This means that each cooling system will operate independently. Each system will be used to cool each room at upper floor of the house. For ground floor, there will be 3 separate system to cool the whole ground floor. The cooling load for each rooms was calculated in Chapter 4.6.1. For the ground floor, the cooling load would be divided into 3 because the cooling load was assumed to be shared by 3 separated geothermal cooling system. The pumping power and COP for all the 6 systems were calculated and tabulated in Table 4.11.

Table 4.11: Pumping Power and COP for Six Systems

Description	Pumping Power [W]	COP
Bedroom 1	114.68	5.58
Bedroom 2	114.68	5.58
Master bedroom	417.12	2.31
Ground floor no. 1	130	5.12
Ground floor no. 2	130	5.12
Ground floor no. 3	130	5.12
Total	1036.48	

The overall COP could be found by divide the total cooling load by the total required pumping power. The total cooling load was 4227.1 W while the total pumping power was 1036.48 W. The overall COP would be 4227.1/1036.48 = 4.08. The COP of the proposed cooling system showed that it was suitable for the double storey house cooling application. In conclusion, the 6 separated series loop geothermal cooling system was one of the suitable system for double storey house cooling application.

4.6.2.4 Two Separated Parallel Loop System

The forth proposed design was the 2 separated parallel loop system. Each parallel loop system would be installed for each floor. The cooling load for upper floor was 2241.63 W while the cooling load for ground floor was 1998 W. Similar to the parallel loop system in Chapter 4.6.2.2, a graph of branch number against COP was plotted to find the maximum COP that the system could achieve. The graph was shown in Figure 4.24. In order to find overall COP of the system, the pumping power for both systems was plotted in Figure 4.25.

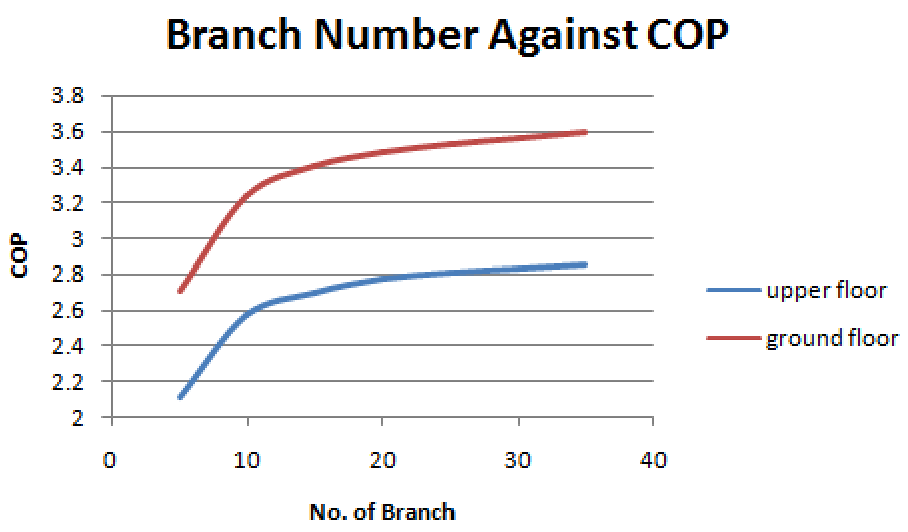


Figure 4.24 COP Curve for Two Separated Parallel System

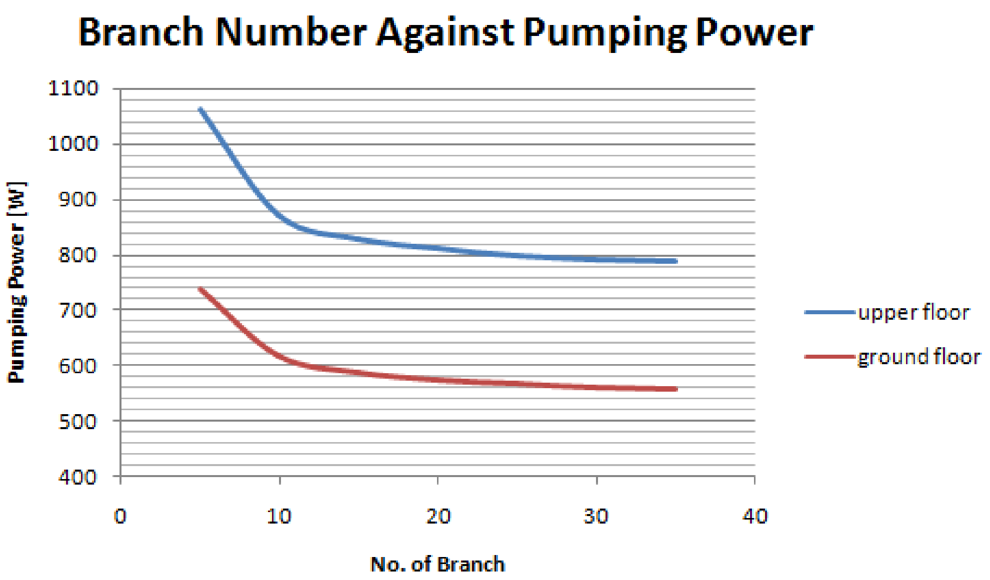


Figure 4.25 Pumping Power Curve for Two Separated Parallel System

Based on Figure 4.24, the minimum pumping power for upper floor and ground floor was 780 W and 560 W respectively. The total pumping power = 780 + 560 = 1340 W. The overall COP = 4227.1/1340 = 3.15. Although the COP of this system was lower than the COP of the third proposed system which had a COP of 4.08, this system had an advantage of simplicity. This is because there are only 2 separate systems required. In conclusion, the 2 separated parallel loop geothermal cooling system was one of the considerable proposed system for the double storey house cooling application.

4.6.2.5 Six Separated Parallel Loop System

The fifth proposed design was the 6 separated parallel loop geothermal cooling system. Ideally, this design will have an excellent COP compared to other proposed design. Similar to 6 separated series loop system, the 6 separated parallel loop system had 6 independent cooling system. One parallel system was installed for Each room at upper floor and 3 systems were installed at ground floor. The only difference between the two systems was that this system used parallel pipe loop instead of series. A graph of branch number against COP for all the 6 systems was shown in Figure 4.26 and a graph of branch number against pumping power required for all the 6 systems was shown in Figure 4.27

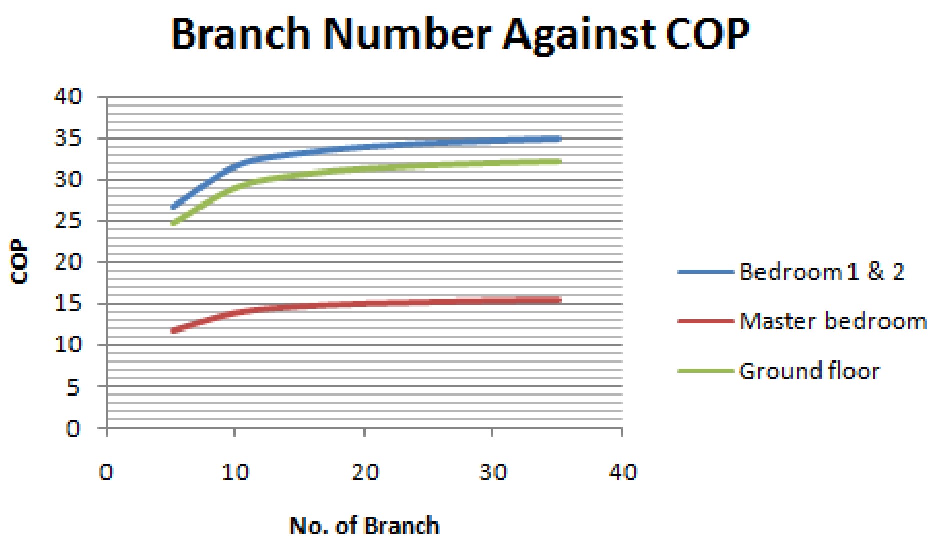


Figure 4.26 COP Curve for Six Separated Parallel System

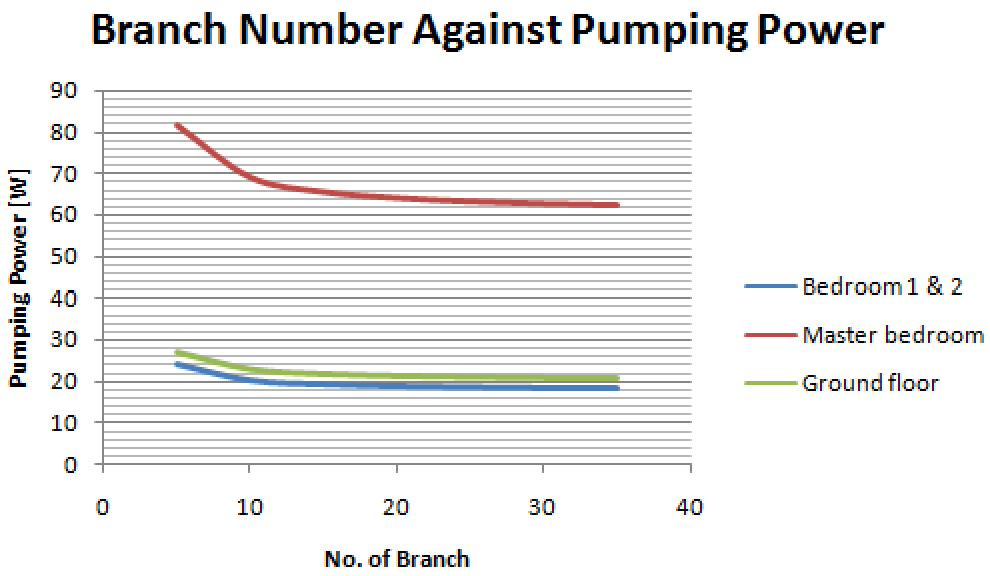


Figure 4.27 Pumping Power Curve for Six Separated Parallel System

Based on Figure 4.26, the COP of the parallel loop system could reach up to 35. This means that this system was very efficient compared to all the previous proposed systems. In order to calculate the overall COP of the system, a graph of pumping power was plotted and shown in Figure 4.27. From the figure, the minimum pumping power for bedroom 1 & 2, master bedroom and each system in ground floor was 18 W, 62 W and 21 W respectively. The overall COP of the system could be calculated by dividing the cooling load by the total pumping power required. The total pumping power required = $2 \times 18 + 62 + 3 \times 21 = 161\ W$. The overall COP would be 26.26.

The COP of this proposed system was very high compared to previous proposed systems. In conclusion, the 6 separated parallel loop geothermal cooling system was the most preferable choice for double storey house cooling application if the main concern was the efficiency.

4.6.2.6 Four Separated Parallel Loop System

The last proposed system was the 4 separated parallel loop geothermal cooling system. This system consisted of 4 separated systems. There would be 2 systems install in each floor. For upper floor, one system would be installed at master bedroom while the other one would be install for both bedroom 1 & 2. Similar to Chapter 4.6.2.5, a graph of branch number against COP for all the 4 systems was shown in Figure 4.28 and a graph of branch number against pumping power required for all the 4 systems was shown in Figure 4.29.

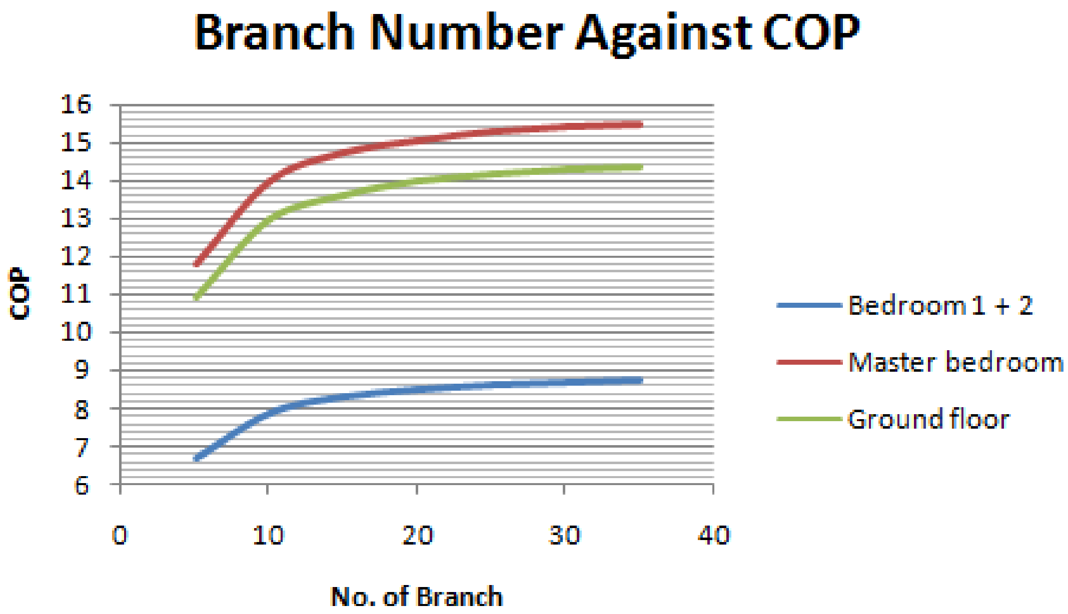


Figure 4.28 COP Curve for Four Separated Parallel System

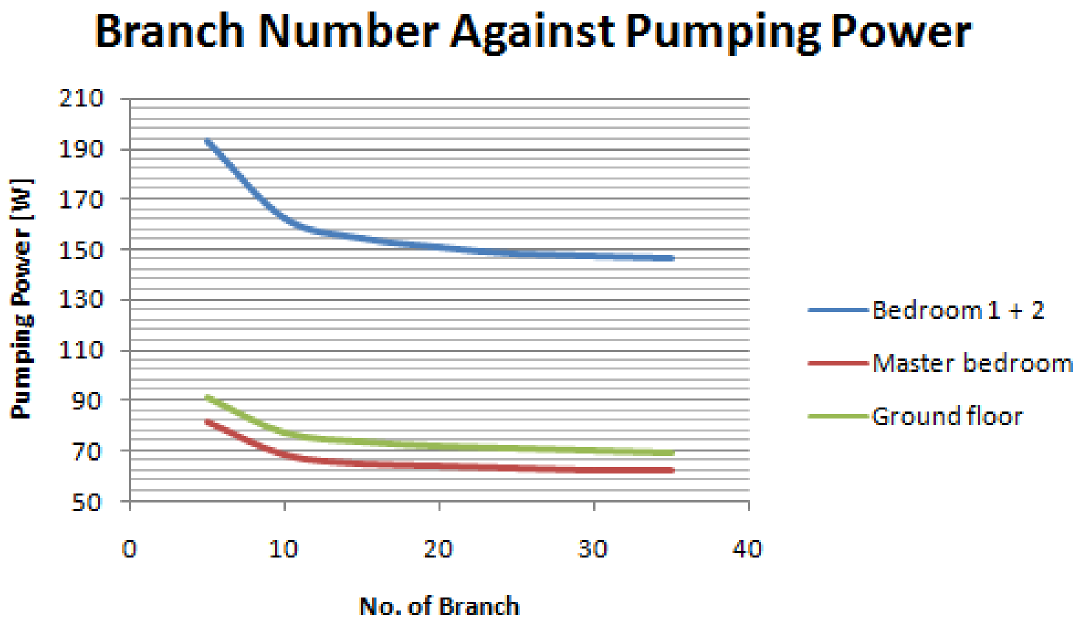


Figure 4.29 Pumping Power Curve for Four Separated Parallel System

Based on Figure 4.28, the COP of the parallel loop system could reach up to 15.4. This means that the COP of this system was less efficient compared to 6 separated parallel loop system. In order to calculate the overall COP of the system, a graph of pumping power was plotted and shown in Figure 4.29. From the figure, the minimum pumping power for bedroom 1 + 2, master bedroom and each system in ground floor was 146 W, 62 W and 68 W respectively. The overall COP of the system could be calculated by dividing the cooling load by the total pumping power required. The total pumping power required = $146 + 62 + 2 \times 68 = 344\ W$. The overall COP would be 12.29.

Although the COP of this system was only half of the 6 separated parallel loop system, the initial cost of this system would be lower because there were only 4 pumps required instead of 6. Besides, a COP of 12.29 was much more higher than conventional air conditioner, thus, this system was suitable for double storey house cooling application.

After the analysis on all the six proposed system, the best proposed system that suit the application would be the 4 separated parallel loop geothermal cooling system. It fulfilled the efficiency required and also had the least cost of installation because it had less separate system compared to the 6 separated system. Besides, it was also noted that the parallel loop system was always more efficient than the series loop system. Thus, a parallel loop system should be used unless there were some constraint such as the land size limitation because parallel loop system would have longer pipe length compared to series loop system.

4.7 Cost Analysis

This section would compare the initial cost and operating cost between conventional air conditioner and geothermal cooling system for both test room at Seri Kembangan and double storey terrace house model. The initial cost was roughly calculated because it was difficult to estimate the profit margin of the contractor. The profit margin used in this report was set to 30 % of the total cost. For the air pump, after viewing some of the online shopping website such as amazon.co.uk, aliexpress.com and made-in-china.com, the price for an air pump with around 160 W power was 50 - 100 USD. In order to make the initial cost calculation simple, the average air pump cost which would be 75 USD or RM 300 was used. The price for the pipe would be RM6 per meter and for the fittings, the elbow was priced at RM8 and the tee joint was priced at RM10.

For the operating cost, the saving in operating cost could be found by comparing the COP between both air conditional and geothermal cooling system. According to Chapter 2.1, the average electricity consumption for a double storey house was 443 kWh per month and 44 % of it was came from air conditional. So the average electricity consumption without air conditional would be 248 kWh. The electricity tariff was show in Table 3.1 in Chapter 3.2. Thus, the saving in operating cost could be obtained by comparing the total electricity cost of the house for both systems. After the costs were computed, the feasibility of the geothermal cooling system could be determined by analysing the initial cost and operating cost.

4.7.1 Testing Site at Seri Kembangan House

Based on Chapter 4.3.2.3, the pipe length, number of elbow, pumping power and COP of the geothermal cooling system were 22.2 m, 10 pcs, 160.21 W and 3.92 respectively. The system consisted of 1 pump and the labour cost was estimated at RM 400. The installation was assumed to be carried out by 2 workers with RM 100 each per day and 1 supervisor with salary RM 200 per day. The initial cost calculation was shown below.

$$
\begin{aligned}
Cost_{initial} &= [(pipe\ length \times 6) + (elbow\ no. \times 8) + pump + 420 + labour] \\
&\quad \times profit\ margin \\
&= [(22.2 \times 6) + (10 \times 8) + 300 + 420 + 400] \times 1.3 \\
&= RM\ 1733.16
\end{aligned}
$$

The '420' shown in the calculation above was the price for backhoe loader rental for one day. For the initial cost of the air conditional, the total cost includes installation would be RM 1200 for 1 hp air conditional. For operating cost, the cost would be calculated for monthly basis. The total electricity consumption inclusive of cooling system for one double storey house was

$$Electricity_{geo} = 248000 + (160.21 \times 24 \times 30) = 363.35\ kWh\ per\ month$$

$$Elecricity_{ac} = 248000 + (13000 \times 30) = 638\ kWh\ per\ month$$

The total electricity consumption for geothermal cooling system and air conditional was 363.35 kWh and 638 kWh per month respectively. After that, the difference in operating cost could be calculated by referring to the tariff rate shown in Table 3.1.

$$
\begin{aligned}
Cost_{geo} &= [(200 \times 0.218) + (100 \times 0.334) + (63.35 \times 0.516)] \\
&= RM\ 109.69 \\
Cost_{ac} &= (200 \times 0.218) + (100 \times 0.334) + (300 \times 0.516) + (38 \times 0.546) \\
&= RM\ 252.55
\end{aligned}
$$

The initial cost difference was 1733.16-1200 = RM 533.16 while the operating cost difference was 252.55-109.69 = RM 71.43 per month. By dividing the initial cost with the operating cost, the payback period was found and the value was around 8 months. In conclusion, for a single room cooling application, the geothermal cooling system was feasible in term of cost and efficiency. However, an enough land space was required for the system.

4.7.2 Double Storey Terrace House

The geothermal cooling system used in the terrace house was the 4 separated parallel loop geothermal cooling system. Based on Chapter 4.6.2.6, pumping power and COP of the geothermal cooling system were 344 W and 12.29 respectively. The required pipe length for 35 branches parallel loop for bedroom 1+2, master room and ground was 156 m, 152 m and 152 m respectively. There would be an extra length of 20 m for each system to connect the ground loop to the room. Thus, the total pipe length became $(156 + 20) + (152 + 20) + 2 \times (152 + 20) = 692\ m$. The third component was doubled because there were 2 systems in the ground floor. The number of elbow for bedroom 1+2, master room and ground was 8 each system. The pipe loop itself had 4 elbows and the another 4 elbows were used to connect the pipe loop to the room. Hence, the total number of elbow would be $8 \times 4 = 32$. Since there were 35 branches in each system, the tee joint number for each system would be $34 \times 2 = 68$ and the total tee joint number would be $68 \times 4 = 272$.

The pipe loop design for the parallel loop system was shown in Figure 4.30. It had a total width of 11.9 m due to the pipes distance was 350 mm. The air would flow from bottom centre to the top centre. The vertical length depends on the pipe length required for each system. It normally around 4 m.

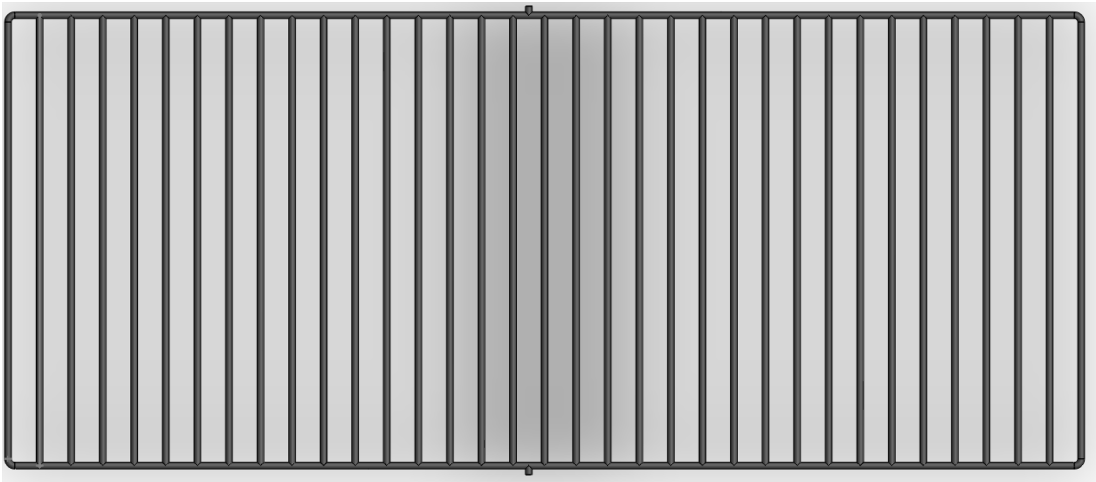


Figure 4.30 Pipe Loop Design for Parallel Loop System

Since there were 4 separated systems in this geothermal cooling system, 4 air pumps required. The labour cost was estimated at RM 1400 for 2 days. The installation was assumed to be carried out by 5 workers with RM 100 each per day and 1 supervisor with salary RM 200 per day. The initial cost calculation was shown below.

$$\begin{aligned} Cost_{initial} &= [(pipe\ length \times 6) + (elbow\ no. \times 8) + (tee\ joint\ no. \times 10) \\ &\quad + (pump\ no. \times 300) + 840 + labour] \times profit\ margin \\ &= [(692 \times 6) + (32 \times 8) + (272 \times 10) + (4 \times 300) + 840 + 1400] \\ &\quad \times 1.3 \\ &= RM\ 13738.40 \end{aligned}$$

The '840' shown in the calculation above was the price for backhoe loader rental for two days. For the initial cost of the air conditional, the total cost includes installation would be RM 1200 for 1 hp air conditional. For a double storey house, it was normal to have 6 air conditional in order to cool the whole house. Thus, the initial cost for air conditionals would be RM 7200. For operating cost, the cost would be calculated for monthly basis. The total electricity consumption inclusive of cooling system for one double storey house was

$$Electricity_{geo} = 248000 + (344 \times 24 \times 30) = 495.68\ kWh\ per\ month$$

$$Elecricity_{ac} = 248000 + (13000 \times 30 \times 6) = 2588\ kWh\ per\ month$$

The electricity consumption above was for the air conditional tested which had only a COP of 1.16. For normal air conditional, the COP should be around 3. The COP of the tested air conditional was low because the air conditional was old and lack of maintenance. For a air conditional with COP of 3, the power consumption would be $= 4227.1 \times 24 \div 3 = 33816.8\,W$ per day. So, the total electricity consumption inclusive of air conditionals for one double storey house was

$$Elecricity_{ac} = 248000 + (33816.8 \times 30) = 1262.5\,kWh\,per\,month$$

The total electricity consumption for geothermal cooling system and air conditional was 495.68 kWh and 1262.5 kWh per month respectively. After that, the difference in operating cost could be calculated by referring to the tariff rate shown in Table 3.1.

$$\begin{aligned} Cost_{geo} &= [(200 \times 0.218) + (100 \times 0.334) + (195.68 \times 0.516)] \\ &= RM\ 177.97 \\ Cost_{ac} &= (200 \times 0.218) + (100 \times 0.334) + (300 \times 0.516) + (300 \times 0.546) \\ &\qquad + (362.5 \times 0.571) \\ &= RM\ 602.59 \end{aligned}$$

The initial cost difference was 13738.40-7200 = RM 6538.40 while the operating cost difference was 602.59-177.97 = RM 424.62 per month. By dividing the initial cost with the operating cost, the payback period was found and the value was around 15 months or one and quarter years. The payback time for geothermal cooling system in one house was twice the payback time for a single room because the geothermal cooling system used for the house was parallel loop system. A parallel loop system was higher cost because it needed more pipe fittings and longer total pipe length.

The land space for the system could be estimated by multiplying the loop pipe length with the distance between pipe which was 0.35 m. The total land size required would be $(152 + 152 + 156 + 152) \times 0.35 = 214.2\,m^2$. This amount of land size was very big compared to the house car park land size which was normally around 40 m^2 for a terrace house.

In conclusion, for a double storey terrace house cooling application, the geothermal cooling system was feasible in term of cost and efficiency. Although it more than 1 year to cover the installation cost, it would save a lot of money in long run. However, an enough land space was required for the system.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The project was about the feasibility study of the geothermal cooling system in tropical cities. It was about the efficiency and estimated cost for the cooling system. Before the analysis on the feasibility of the geothermal cooling system, it was important to do some preliminary works. The preliminary works were important because it would affect the result directly.

The first thing needed to obtained was the temperature profile of the house. It was important because cooling system was all about heat and temperature. The house temperature was measured at two different locations by using temperature sensor. Both houses were double storey house because the objective of the project was focused on double storey house. The temperature sensors used were LM35DZ and a data logger was used to record the temperature data 24 hours. LM35DZ was used because it had high accuracy and low self heat generation. The data logger used was an Arduino board which consisted of microprocessor and I/O pins.

Besides, the distance between pipes also important because it could affect the space needed for the geothermal pipe loop. Generally, Larger distance was preferable because the heat from one pipe would not transfer to the other pipe. However, large distance means large land size. Thus, a minimum distance was determined to get an optimised pipe loop design. The result was found using simulation and the result showed that the minimum distance required was 350 mm. The simulation result was for 75 mm diameter HDPE pipe. For larger diameter pipe, the distance would be increased.

In order to study the feasibility of the geothermal cooling system, a test was carried out to determine the electricity consumption of the air conditioner. The test was carried out twice for accuracy. The result showed that the electricity consumption for air conditioner in one day was 13 kWh. The result was then compared to the cooling load calculated to get the coefficient of performance (COP) of the air conditioner. The COP obtained was 1.16 which was much lower than the COP stated in the air conditioner specification.

Besides, this project also concerned in the type of pipe loop used. There were two types of pipe loop, the series and parallel pipe loop. The series pipe loop had simpler design while the parallel pipe loop required a lot of pipe fittings. The result showed that parallel loop had much higher efficiency than the series loop. However, the material cost and land space required for parallel loop was also much more higher than the series loop. This was because the parallel loop needed longer pipe length and more pipe fittings. Thus, the available land size must be considered when choosing a suitable pipe loop.

In order to determine the most suitable pipe loop design for geothermal cooling system used in double storey house, six designs were proposed. In general, the parallel loop system had better efficiency than the series loop. Besides, it was found that the cooling load for one double storey house was too high for a single geothermal cooling system. The COP of the geothermal cooling system was very low when the cooling load was too high. Thus, the geothermal cooling system should be separated into few independent systems so that it could cool the house efficiently. The low COP of the geothermal cooling system was probably due to the high velocity of the air flow.

After the most suitable design was determined, the proposed geothermal cooling system was compared with the air conditioner. It was found that the initial cost of the geothermal cooling system for a double storey house was much higher than the air conditioner. This was because the installation works for a geothermal cooling system was labour intensive. However, the operating cost for a geothermal cooling system for a double storey house was lower than the air conditioner. This was because the geothermal cooling system was more efficient than the air conditioner. According to the result, the payback period for the geothermal cooling system compared to air conditioner was 1.25 years. This was considered good because it not only save money in long run but also save the Earth. However, land space was also an issue because the pipe loops needed around 200 m^2 of land space while the car park space for normal terrace house was around 40 m^2. In a nutshell, the geothermal cooling system was feasible in Malaysia provided there was enough land space.

5.2 Recommendations

Due to the time constraint, the ground temperature was not measured but only referred to other reference. The ground temperature should be measured because different place might have different temperature. Besides, there should be more air conditioner specimen to test the electricity consumption. Different air conditioner might have different efficiency. An new air conditioner should be used to test instead of aged air conditioner because an old air conditioner should have lower efficiency due to wear and tear.

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APPENDICES

APPENDIX A: Electrical Characteristics: LM35, LM35C, LM35D Limits

PARAMETER	TEST CONDITIONS	LM35 TYP	LM35 TESTED LIMIT[1]	LM35 DESIGN LIMIT[2]	LM35C, LM35D TYP	LM35C, LM35D TESTED LIMIT[1]	LM35C, LM35D DESIGN LIMIT[2]	UNIT
Accuracy, LM35, LM35C[3]	$T_A = 25°C$	±0.4	±1		±0.4	±1		°C
	$T_A = –10°C$	±0.5			±0.5		±1.5	
	$T_A = T_{MAX}$	±0.8	±1.5		±0.8		±1.5	
	$T_A = T_{MIN}$	±0.8		±1.5	±0.8		±2	
Accuracy, LM35D[3]	$T_A = 25°C$				±0.6	±1.5		°C
	$T_A = T_{MAX}$				±0.9		±2	
	$T_A = T_{MIN}$				±0.9		±2	
Nonlinearity[4]	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$	±0.3		±0.5	±0.2		±0.5	°C
Sensor gain (average slope)	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$	10	9.8		10		9.8	mV/°C
		10	10.2		10		10.2	
Load regulation[5] $0 \le I_L \le 1$ mA	$T_A = 25°C$	±0.4	±2		±0.4	±2		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$	±0.5		±5	±0.5		±5	
Line regulation[5]	$T_A = 25°C$	±0.01	±0.1		±0.01	±0.1		mV/V
	$4 V \le V_S \le 30 V$, $–40°C \le T_J \le 125°C$	±0.02		±0.2	±0.02		±0.2	
Quiescent current[6]	$V_S = 5 V$, 25°C	56	80		56	80		µA
	$V_S = 5 V$, $–40°C \le T_J \le 125°C$	105		158	91		138	
	$V_S = 30 V$, 25°C	56.2	82		56.2	82		
	$V_S = 30 V$, $–40°C \le T_J \le 125°C$	105.5		161	91.5		141	
Change of quiescent current[5]	$4 V \le V_S \le 30 V$, 25°C	0.2	2		0.2	2		µA
	$4 V \le V_S \le 30 V$, $–40°C \le T_J \le 125°C$	0.5		3	0.5		3	
Temperature coefficient of quiescent current	$–40°C \le T_J \le 125°C$	0.39		0.7	0.39		0.7	µA/°C
Minimum temperature for rate accuracy	In circuit of Figure 14, $I_L = 0$	1.5		2	1.5		2	°C
Long term stability	$T_J = T_{MAX}$, for 1000 hours	±0.08			±0.08			°C

APPENDIX B: Specification of Arduino Mega Board

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

the board