Study of Ground Exchange Air Conditioning (GEAC) System Design for A Small House

By

Marco Jones John
13863

Dissertation submitted in partial fulfillment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

MAY 2014

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Approved by:

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(MOHD SYAIFUDDIN MOHD)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH PERAK
MAY 2014

CERTIFICATION OF ORIGINALITY

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

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(MARCO JONES JOHN)

ABSTRACT

Ground-source or geothermal exchange air conditioning are a highly efficient, renewable energy technology for space cooling. This technology relies on the fact that, at depth, the earth has a relatively constant temperature. Although this technology is widely applied in the seasonal countries such as America and Europe, but it is not so well known in a hot and humid country like Malaysia. The yearlong hot climate does not requires us to have extra heating but is really in need of a more efficient way of cooling our homes.

Based on countless research done on ground exchange heat pump, it is in theory that with the application of Ground Exchange Air Conditioning (GEAC), we are able to have the same amount of cooling but with smaller energy consumption than those air conditioner without it. Therefore in this project, the author will embark on a journey to design and a GEAC system that is optimized to be used in a hot and humid country like Malaysia. This report will utilized the steps in engineering design as well as system engineering design in order to achieve the objectives of this project.

ACKNOWLEDGEMENT

The author wishes to take the opportunity to express his utmost gratitude to the individual that have taken the time and effort to assist the author in completing the project. Without the cooperation of these individual, no doubt the author would have faced some major and minor complications throughout the course.

First and foremost, the author would like to convey his uttermost appreciation to God for His blessing especially on the perseverance and determination to complete the project.

Secondly, the author's utmost gratitude goes to the author's supervisor, Mohd Syaifuddin Bin Mohd and Mr Mui'nuddin Maharun as the internal examiner. Without their guidance and patience, the author would not be succeeded to complete the project.

To both the Final Year Project Coordinator, Dr. Masdi Bin Muhammad and Dr. Azmi Bin Abdul Wahab for providing all the initial information required to begin the project. Without their excellent management and coordination for FYP I and II, this project will not complete as per said in the timeline.

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CHAPTER 1: INTRODUCTION

1.1 PROJECT BACKGROUND

The background of this project is to do a detail design and optimization on the Ground Exchange Air Conditioning (GEAC) system, to work in conjunction with the conventional air conditioning system available today for application in domestic housing in Malaysia. Cooling of an indoor compound is necessity in the hot and humid climate of country like Malaysia. With the energy crisis facing by the world nowadays, and the uncertainty price of fossil fuel and gas, the cost of cooling a building or an indoor compound had become high [1]. Therefore it is a necessary to find a reliable ways to reduce to the energy usage for cooling applications. In addition, by using less energy, this will indirectly reduce the greenhouse gas emissions as the demand for electricity is also reduced [2].

1.2 PROBLEM STATEMENT

Home air conditioning unit was once a luxurious item, is now becoming a necessity, or an affordable convenience to the middle income population. As technology advances, and air condition unit becomes more affordable and energy efficient, it is still taking a large sum of a household electricity consumption due to its high power rating, which is 581W on average and long usage time [3]. Reducing the cost of household electricity consumption has always been a dream for every air-conditioned house owner and one of the method to do so is with the installation of GEAC system.

GEAC system works by rejecting heat into the underground earth/soil at specific depth via a set of piping system. The temperature of soil is about constant throughout the year and relatively lower than ambient air at day [4]. The relatively lower temperature of soil will greatly affect the efficiency of the cooling system and thus decreases the work load on the compressor, as well as the cost of operation of the air conditioning system.

The proposed research project will look into the detail design of a GEAC system as well as simulation for application in Malaysia. Theoretically, it is possible to achieve an energy saving of 30% [2], [4] because heat from the condenser loop will be rejected to a lower temperature medium compared with ambient air.

1.3 OBJECTIVES

The main objective of the project is to study and design a Ground Exchange Air Conditioning (GEAC) System for a small house. Under this main objective, there are 3 sub-objectives that is necessary to be accomplish in order to achieve the main objective at the end of this project. Those sub-objectives are:

1. To study the design characteristic of GAEC, based on Open-Loop system
2. To develop an initial design of GAEC system design configuration, which includes the specification of the design and material used
3. To utilise computer aided engineering tools to simulate and configure the proposed design to obtain a final detail design.

The computer aided engineering tools used are ANSYS Workbench 14.5, ANSYS Mechanical APDL 14.5, and CATIA V5. For designing and detail calculation the geo-exchanged cooling configuration, calculation using the fundamental of thermodynamic, fluid and heat transfer and air conditioning is needed.

CHAPTER 2: LITERATURE REVIEW

2.1 AIR CONDITIONER

Air conditioning, which may be described as the control of the atmosphere so that a desired temperature, humidity, distribution and air movement is achieved, is a rapidly expanding activity throughout the world. As the technology progresses, more and more efficient air conditioner are being designed and produced. It is like a race between the different manufacturers to come out with the most efficient way of removing heat from confined spaces that will consume the least electrical energy, and thus reducing the cost of power consumption in a household electricity bill.

2.1.1 COMPONENTS OF AN AIR CONDITIONER

Air conditioner requires four major components for the refrigerant cycle which consists of an evaporator, a compressor, a condenser and a thermal expansion valve [25], the figure 1 below shows the refrigeration cycle.

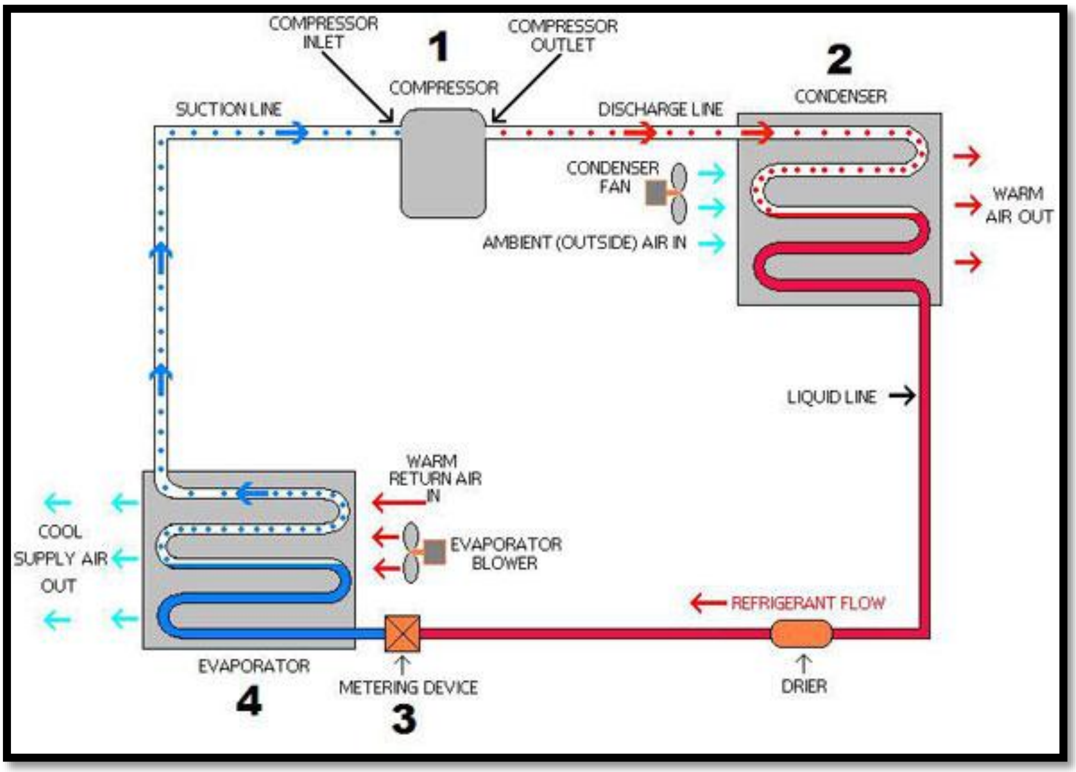


Figure 1: Refrigeration cycle [26]

2.2 CONDENSER COOLING METHOD

As mention in the previous page, the condenser can either be air-cooled or water cooled. Both of these cooling methods has their own pros and cons, and the selection between these cooling methods will depends on the required situation of the application.

2.2.1 AIR-COOLED

An air-cooled system uses air to transfers heat taken from the cooled space to the ambient air by means of a heat exchanger. This heated air is then released or expelled when the colder ambient air are blown through it. The equipment must be located outside the room to be cooled. If the cooling unit is located inside the space, as in a portable air conditioner, the hot air must be driven by a fan through a duct to somewhere outside the space. The cooling unit located outside the space, the hot air can just be released into the air surrounding the unit or again, driven elsewhere.

2.2.2 WATER-COOLED

A water-cooled system uses water as a medium to transfers the heat from the space to the ambient air by means of cooling tower or dumped underground. Water may also be supplied from and returned to a chilled water system in a commercial or industrial setting. The water cooled unit is used more for cooling enclosed spaces or spaces in sealed buildings where the existing building system cannot handle additional heat being dumped on it. There must be a dependable supply of water to run the unit.

2.3 GROUND EXCHANGE UNIT

Ground exchange unit for this project serve as an extension to the condenser that will extend to the underground, as illustrated in figure 3. The heat form the condenser are dissipated underground through a set of pipes or wells (acting as a heat sink) and in theory, are more efficient that dissipating the heat to the ambient air. This is due to the properties of soil underground, which has lower bulk temperature and better thermal conductivity compared to air.

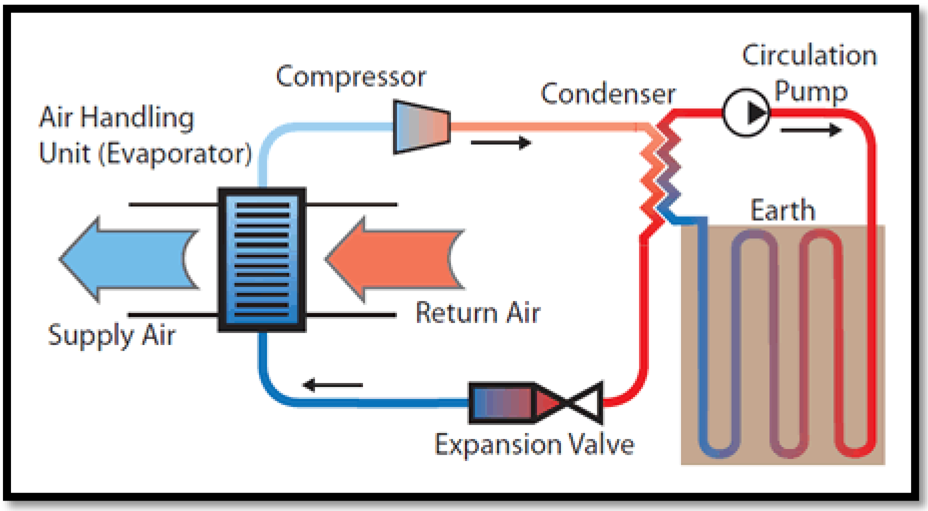


Figure 2: HVAC and GEAC system [23]

2.4 PROPERTIES OF SOIL AS A HEAT SINK

Extensive studies and researches has been done on the thermal conductivity of soil and how it can be utilize as a renewable energy [5], [6], [7]. A study on ground heat exchangers by Florides, G. and Kalogirau, S. (2007) states that at a certain depth underground, the temperature remains relatively constant throughout the year. Florides, G. and Kalogirau, S. (2007) explain that "this is due to the fact that the temperature fluctuations at the surface of the ground are diminished as the depth of the ground increases because of the high thermal inertia of the soil. Also, there is a time lag between the temperature fluctuations at the surface and in the ground. Therefore, at a sufficient depth, the ground temperature is always higher than that of the outside air in winter and is lower in summer" [8]. Florides, G. and Kalogirau, S. (2007) conducted a test to determine the temperature variation of the ground at various depths in summer (August) and winter (January) as shown in Fig. 1. The graph shows actual ground temperatures as measured in a borehole drilled for this purpose in Nicosia, Cyprus. As can be seen, the temperature is nearly constant below a depth of 5 m for the year round [8].

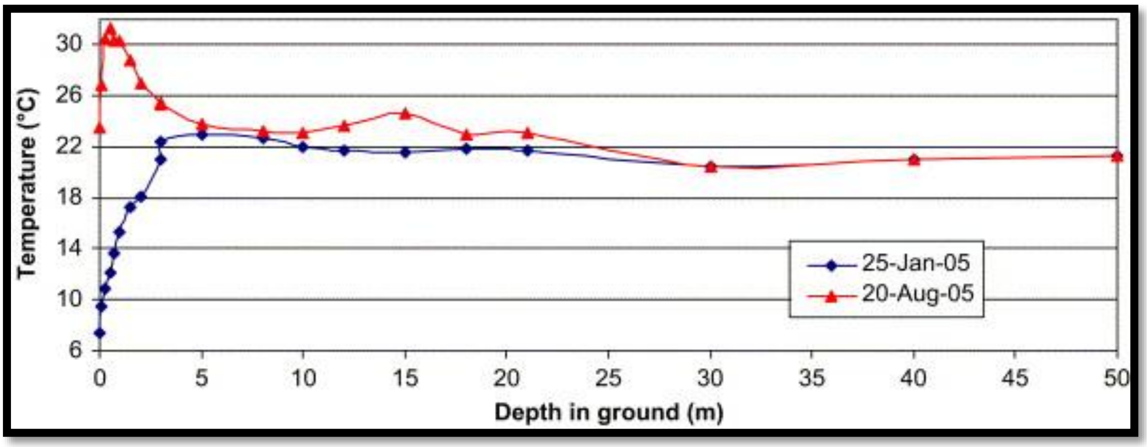


Figure 3: The temperature variation of the ground at various depths in summer (August) and winter (January) [7]

2.5 TYPES OF GEAC SYSTEM

The type that is referred to is the loop system type of the GEAC system, there are two types that is available in literature. The two types in question are open loop system and closed loop system [9], and each loop system has their own different configuration type which is shown in Appendix A [8]. In this project we will be focusing on the Open Loop system.

2.6 OPEN LOOP GEAC SYSTEM OPERATING PRINCIPLE

The open loop system utilizes the ground water as medium to dissipate heat into the underground, through a set of wells, the wells are called production well and injection well. The groundwater is pumped up the production well using a submersible pump [10] and will flow through the series of pipe before being injected back into the ground in the injection well. There can be more than one injection well in the system [10]. Below show the schematic diagram of open loop geothermal well system from a study done by Boyce *et al* (n.d.) [10]:

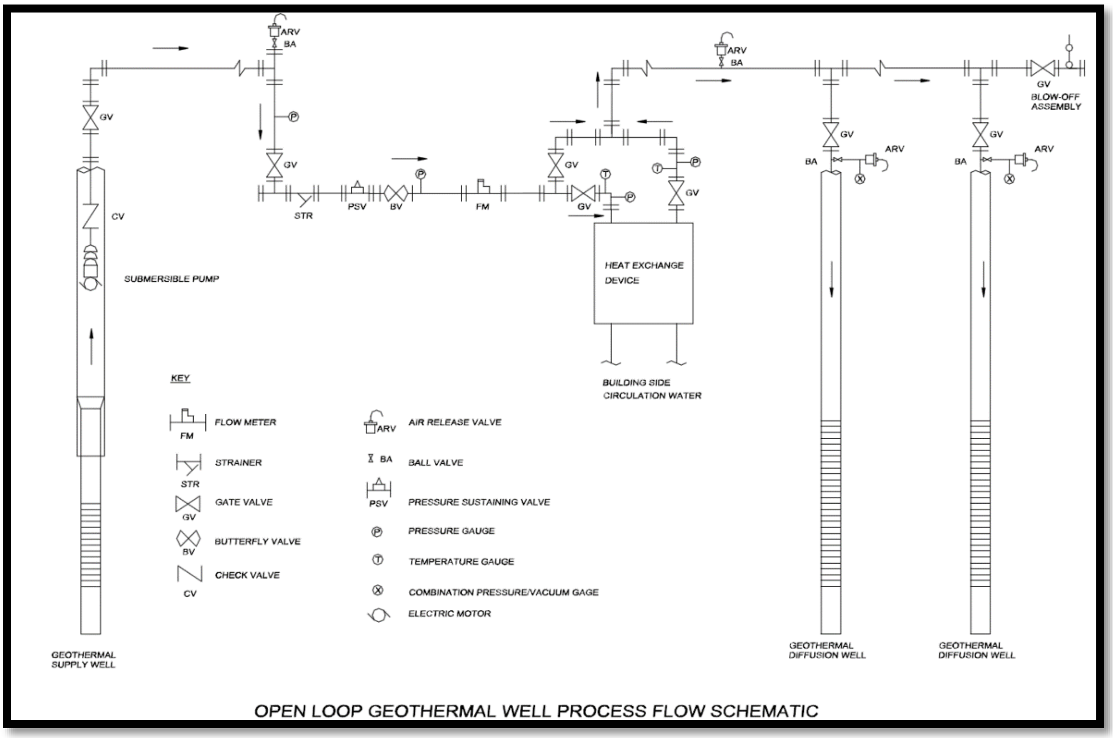


Figure 4: Open loop geothermal well system schematic diagram [10]

Several variations on the open loop system are in use, the most common of these are Open loop – direct, standing column system and open loop-indirect [8].

2.6.1 OPEN LOOP – DIRECT

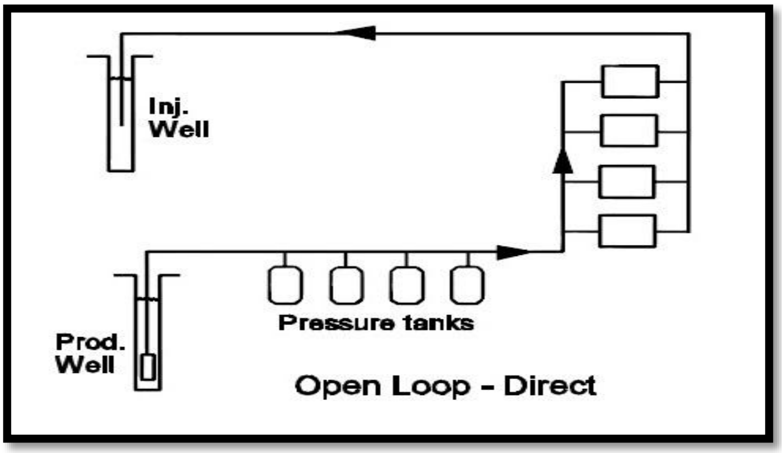


Figure 5: Open Loop – Direct [8]

The direct use of the groundwater in the heat pump units is largely an extension of residential design and is sometimes used in very small commercial applications [4]. It is very susceptible to water quality induced problems, the most common of which is scaling of the refrigerant-to-water heat exchangers. This design is recommended in only the smallest applications in which practicality or economics precludes the use of an isolation heat exchanger and/or groundwater quality is excellent [11].

2.6.2 STANDING COLUMN SYSTEM

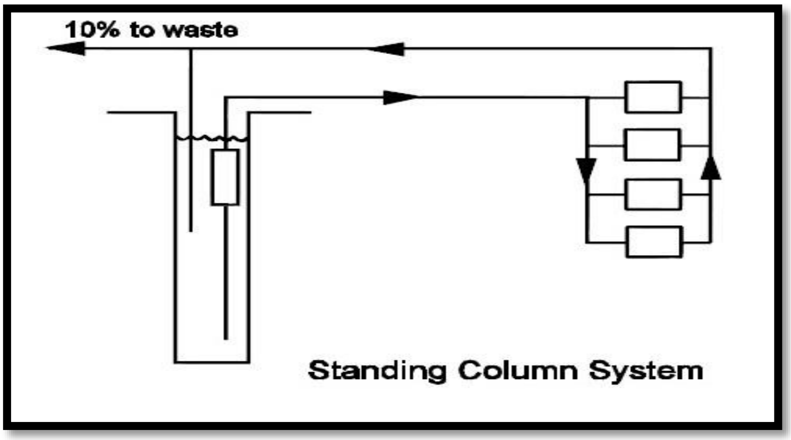


Figure 6: Standing Column System [8]

Like the direct groundwater system, it too is subject to water quality induced problems. In general, water quality in the area where most of the installations have been made is extremely good with low pH and hardness [12]. Standing column systems are used in locations underlain by hard rock geology; where, wells do not produce sufficient water for conventional open loop systems and where water quality is excellent. Well depths are often in the 1000 to 1500 ft range and the systems operate at temperatures between those of open and closed loop systems [12].

2.6.3 OPEN LOOP-INDIRECT

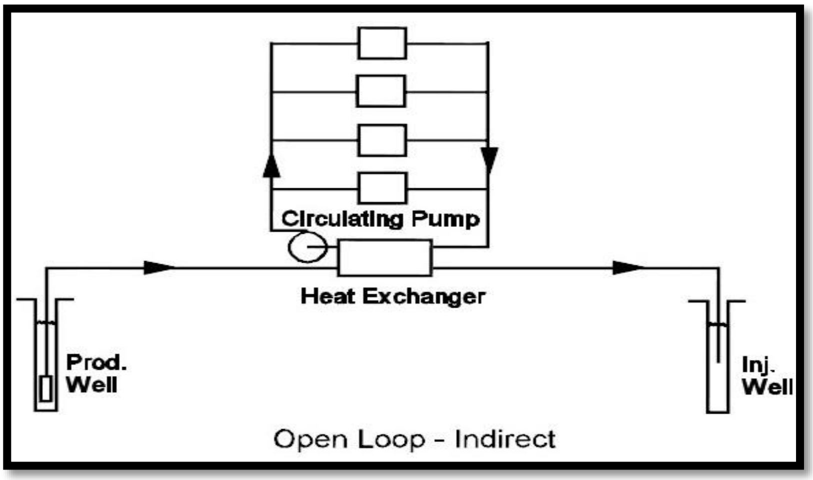


Figure 7: Open Loop – Indirect [8]

Indirect open loop systems employ a heat exchanger between the building loop and the ground water. This eliminates exposure of any building components to the ground water and allows the building loop and ground water loops to be operated at different flows for optimum system performance [4]. Water can be disposed of in an injection well or to a surface body if one is available. These systems offer energy efficiency comparable to closed loop systems at substantially reduced capital cost [13]. Due to the elimination of water quality and geology limitations this system type is the most widely applicable of the three.

2.7 HYBRID GEAC SYSTEM SOLUTION

Hybrid means the combination of two or more system or mechanism that is able to operate individually, to form a new system or mechanism that receives the benefits of the combined individual system or mechanism. For example, a hybrid car is a combination of batteries and electric motors coupled with an internal combustion engine (ICE). The resulting product has the efficiency of the electric motor and the long driving range on an internal combustion engine.

Hybrid GEAC system solution according to the authors understanding are the combination of open-looped and closed looped system. Providing the efficiency of an open-looped system with the cheaper and simpler installation of a closed loop system. In one way or the other, by combining these two system, a lot of problem that are faced when operating the systems individually are solved.

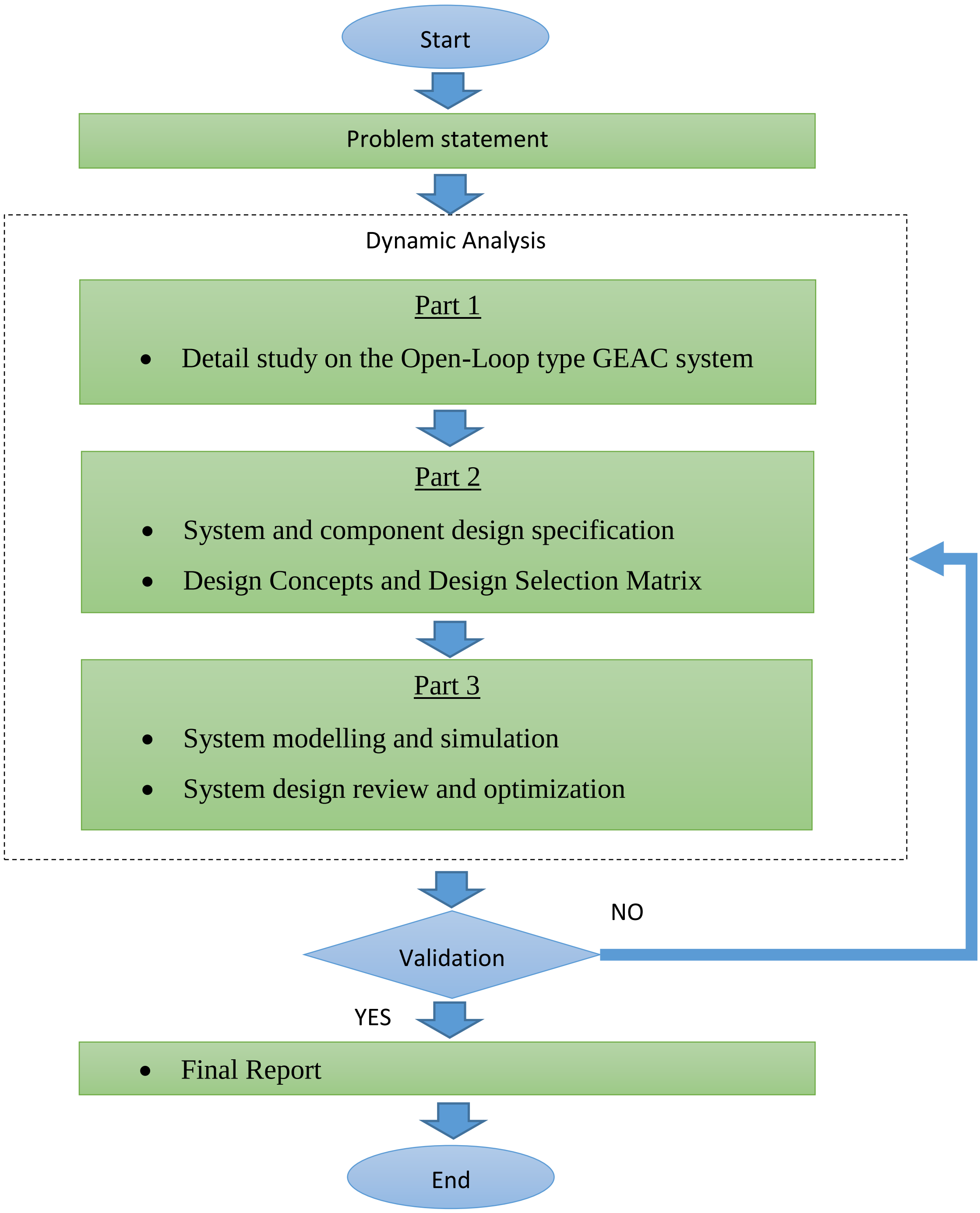
Table 1: List of references

Year of Published	Author	Title	Summary	Approach/Description
n.d.	G. Phetteplace	A Guide for Best Practices for Ground-Source (Geothermal) Heat Pumps	A guide to describe the practices and approaches for sucsessful and efficient procurement, design, construction and operation of ground –source heat pump systems	Explaining what is and the application of geothermal heat pumps (GHP) Propose and explain the steps in building GHP
n.d.	Boyce *et al*	Open Loop Geothermal Well Systems On Long Island	A overview on the background of geothermal well system in long island	
2006	G. Florides & S. Kalogirou	Ground heat exchangers – A review of the systems, models and application	Describing the various type of ground heat exchangers and its application	Explain the types of heat exchangers and what is the suitable application of the system
2005	K. Nagano *et al*	Development of a design and performance prediction tool for the ground source heat pump system	Introduces a novel design and performance prediction tool for the ground source heat pump (GSHP) system	Showing the design step and calculation to create a user friendly interface for data input and graphical output
2006	A. M. Omer	Ground-source heat pumps systems and applications	A crash course on the study of earth-energy system, heat transfer mechanism, heat pump, and heat pump types and application	
2011	L. I. Lubis *et al*	Thermodynamic analysis of a hybrid geothermal heat pump system	The thermodynamic analysis of a hybrid GHP system are carried out using energy analyses	

CHAPTER 3: METHODOLOGY

3.1 PROJECT METHODOLOGY

Systematic and progressive approach needs to be carried out to ensure that this project will finish within the desired time frame and is in line with the proposed Gantt chart. The figure below shows the flowchart of this project.



The flowchart shows the planned flow/methods/processes in proceeding with this project. Proper management of steps and procedure are key in completing this project within the proposed schedule as indicated in the Gantt chart.

The project is divided into two part as to fulfil the objectives: the first part are the analysis phase of the project, while the second part are the fabrication and assembly phase. The first part which is called the dynamic analysis phase are further divided into three parts. Based on the proposed schedule, the dynamic analysis phase will consume most of the work and time that will be put into this project.

The first part of the dynamic analysis are completed in the first part of this final year project (FYP 1), which includes the early stages of this project such as, introduction, problem statement, the objectives, literature review and project methodology. During this period, the author are required to submit the proposal for the topic and do a proposal defence.

The second and third part requires a lot of analytical and research work, therefore it will consume more than 1/3 of work and time specified for the whole project (FYP 1 and FYP 2). The second part will consist of the datum referencing, decomposition chart, morphology chart and concept design evaluation, which includes design criteria and weighted evaluation matrix. Basically, part 2 is to develop the concept design for the GEAC system.

Part 3 is where the developed concept design will obtain its dimensions through the derivation of governing equations based on the expected result. For example, the amount of cooling load, the work input to the pump and etc. This dynamic analysis are expected to be completed before the submission of progress report during FYP 2.The completion of the analysis phase will mark the start of the finalization of the final report

3.2 SYSTEM DESIGNING APPROACHES

The overall design approach consist of six stages: (1) define the purpose of the design, (2) develop a conceptual design of the system, (3) develop or define the mathematical model of the system, (4) implement the solution method, (5) validate the design, and (6) apply the design. Each of these are described in the following paragraphs.

The first stage of the design approach are to clearly define the purpose and objectives of the design. This helps to determine the level of detail and accuracy desired by the design and helps in making decisions regarding the resources needed.

The second stage in the design approach is to develop a conceptual design of the system. American Society for Testing and Materials (ASTM) defines a conceptual design as "an interpretation or working description of the characteristics and dynamics of the physical system". The purpose of the conceptual design are to describe the system by a set of assumptions and concepts that can be evaluated mathematically.

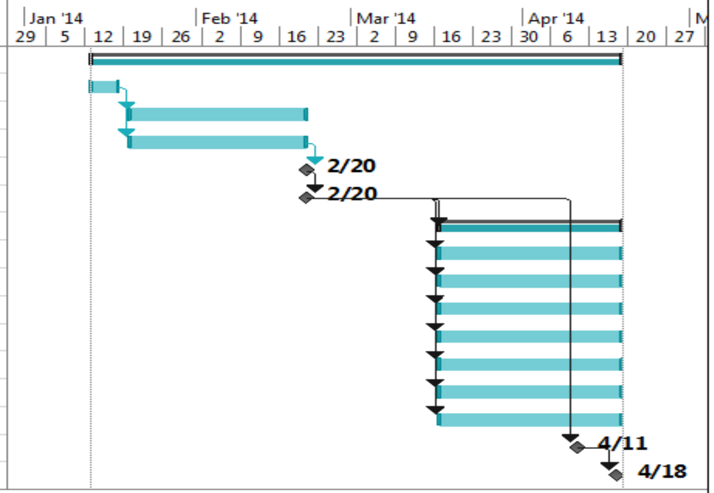
The third stage in the design approach is to develop a mathematical model of the system. In this stage, the conceptual design are translated into mathematical equations that can be solved for the desired unknowns. The solution method and limiting assumptions or simplifications are also identified.

The fourth stage in the design approach is to implement the solution method to solve the mathematical equations. With respect to this report, this stage involves using the computer calculations method with the aid of commercially-available software developed for this type of study.

The fifth stage in the design approach is to validate the model. With respect to this project, this stage involves comparing model results, where applicable, to an analytical solution or to experimental data. The sixth stage in the design approach is to finally use the model to analyse the performance and behaviour of the actual thermal design.

3.3 GANTT CHART AND MILESTONES

ID		Task Mode	Task Name	Duration	Start
1			**Final year Project 1 (FYP1)**	**70 days**	**Mon 1/13/14**
2			**Selection of project topic**	**5 days**	**Mon 1/13/14**
3			**Literature Review**	**24 days**	**Mon 1/20/14**
4			**Preliminary Research Work**	**24 days**	**Mon 1/20/14**
5			**Submission of Extended Proposal**	**0 days**	**Thu 2/20/14**
6			**Proposal Defense**	**0 days**	**Thu 2/20/14**
7			**Project Work continues**	**25 days**	**Mon 3/17/14**
8			System Target Specifications	25 days	Mon 3/17/14
9			System and components requirements calculations	25 days	Mon 3/17/14
10			Design Concepts and Design Selection Matrix	25 days	Mon 3/17/14
11			Component Sizing and Selection	25 days	Mon 3/17/14
12			Preliminary Design	25 days	Mon 3/17/14
13			System Modeling & Simulation	25 days	Mon 3/17/14
14			Critical Design Review	25 days	Mon 3/17/14
15			**Submission of Interim Draft report**	**0 days**	**Fri 4/11/14**
16			**Submission of Interim Report**	**0 days**	**Fri 4/18/14**



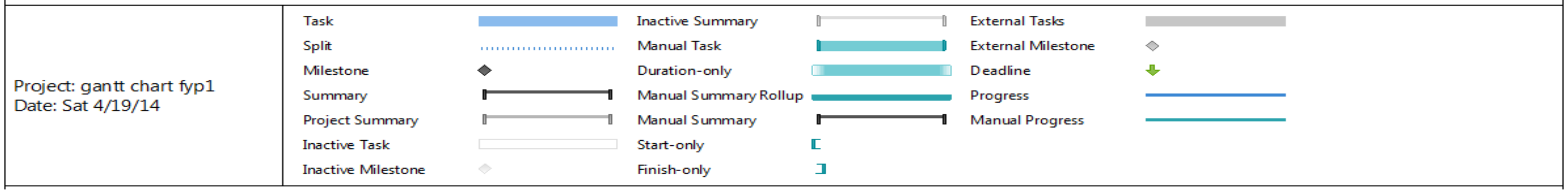


Figure 8: Gantt chart for FYP 1

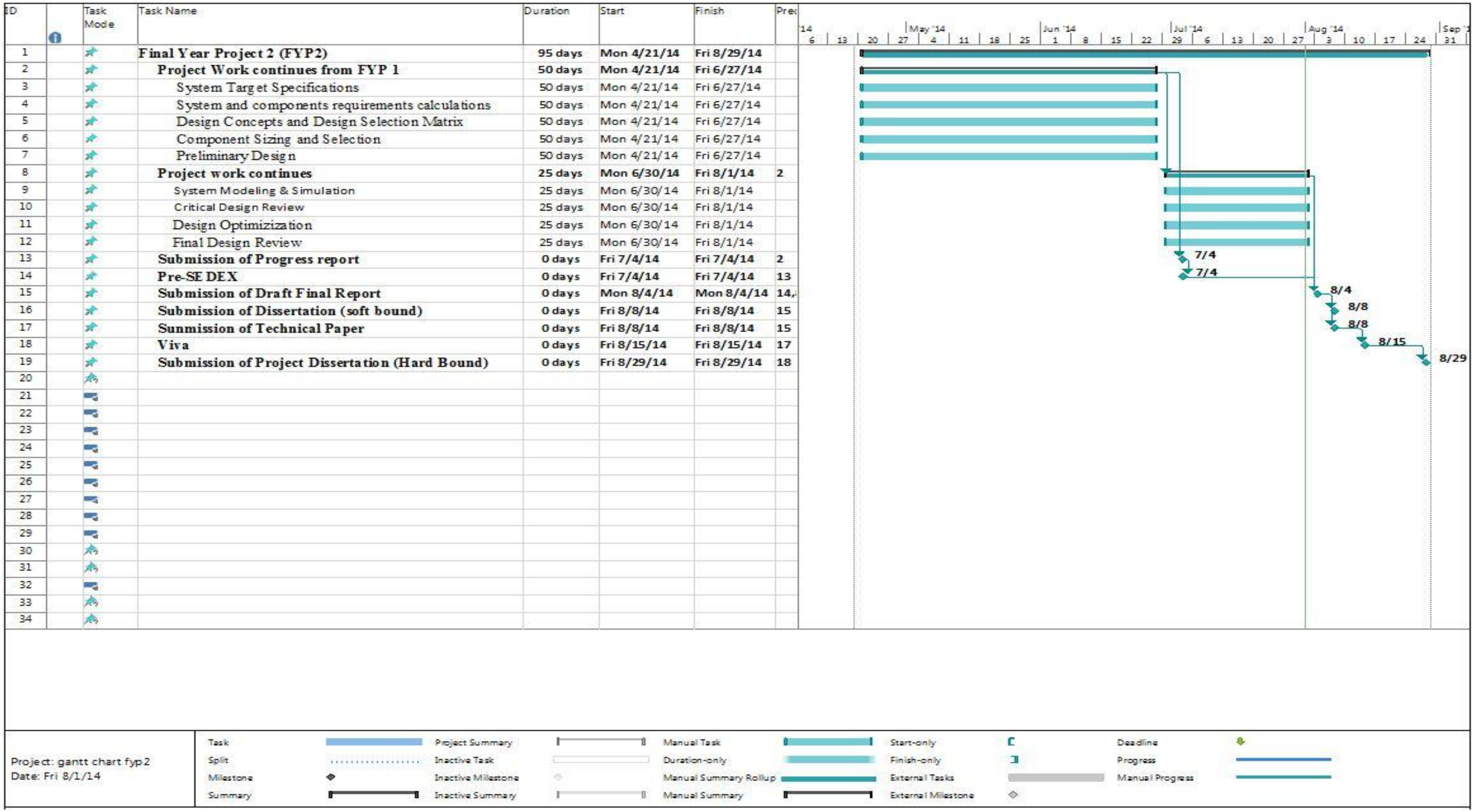


Figure 9: Gantt chart for FYP2

CHAPTER 4: CONCEPT GENERATION

4.1 DATUM REFERENCING

In a designing project, a datum is chosen to be used as a reference and also acts as guidance during the project concept generation. A datum will consist of all the essential components and mechanisms in which it will be taken as the basic requirements before beginning the design phase.

Figure 10 [23] below shows the general layout of conventional air conditioning unit working with a GEAC unit as the datum that has been chosen. The figure also shows the process flow of the refrigerant in the air conditioning unit as well as in the GEAC unit. The liquid in the GEAC unit can either be refrigerant or water.

For the sake of this project, the system will be divided into two unit, the air conditioning unit and the GEAC unit. The author will only be focussing on the GEAC unit as the air conditioning unit will be assume to already be available as a unit at the homes of future customers.

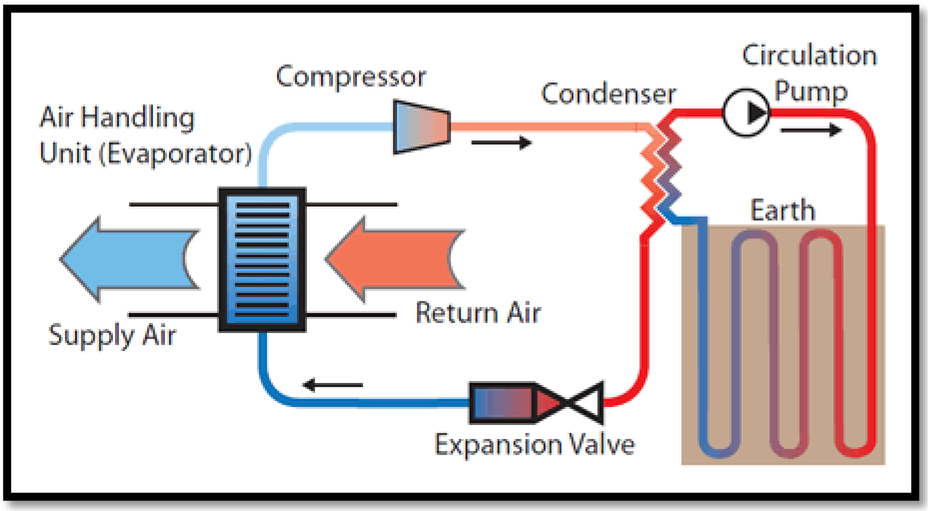


Figure 10: HVAC and GEAC system [23]

As discussed in the literature review, there are two types of GEAC system configuration that can be considered, which is Open-looped and Closed-looped. Both of this configuration has their own pros and cons. The author decided to design a hybrid GEAC system which combines the flexibility of the closed-looped system with the effectiveness of an open-looped system.

Figure 11 below shows the datum for this project's GEAC unit. This is the GeoColumn™ Hybrid Geothermal Heating, Ventilation and Air Conditioning (HVAC) system [24].

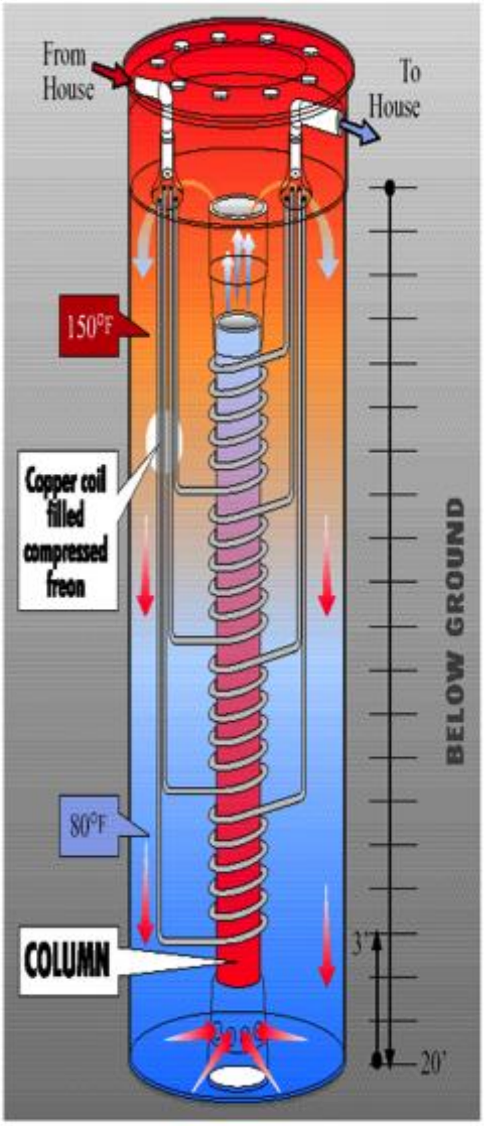


Figure 11: Datum for GEAC unit [24]

The GeoColumn™ system is revolutionary. It is a hybrid GSHP heat exchanger system. To transfer heat it uses both the copper pipe direct exchange method *and* the water-to-ground heat exchange method in one GeoColumn™ unit.

The GeoColumn™ system is regulated by integrated microprocessors that coordinate the heat pump, air handler, air exchanger and thermostat. The air handler uses one direct expansion coil for both heating and cooling instead of one for each.

The GeoColumn™ unit itself is a factory sealed and tested 20-foot long drum of water that surrounds a vertical column (containing the heat exchange equipment) and seamless copper pipes (containing refrigerant) that coil around it. It is buried about three feet underground, below the frost level.

4.2 DECOMPOSITION CHART

In concept generation, there are three major steps which are the decomposition process of the complex system, generation of morphology chart and finally the conceptual designs sketching based on the morphology chart.

4.2.1 PHYSICAL DECOMPOSITION CHART

The decomposition process is aimed to simplify the project flow by breaking down complex system into smaller units that are easier to manage and understand. For that reason, decomposition must result in unit that meaningfully represent the original entity and appear obvious to the decomposer for better understanding the design task and allocating resources to it [22].

Based on the datum, a physical decomposition is conducted as a top-down approach to understand the physical nature of the Ground Exchange Air Conditioning (GEAC) system. The system is first break down into subsystems, which will then further separated into their respective subsidiary subassemblies and components. Detailed and accurate description of the interaction between each subsystems is necessary to produce a complete and well-organized system.

The physical decomposition of the GEAC system is represented by the tree diagram in figure 12 below.

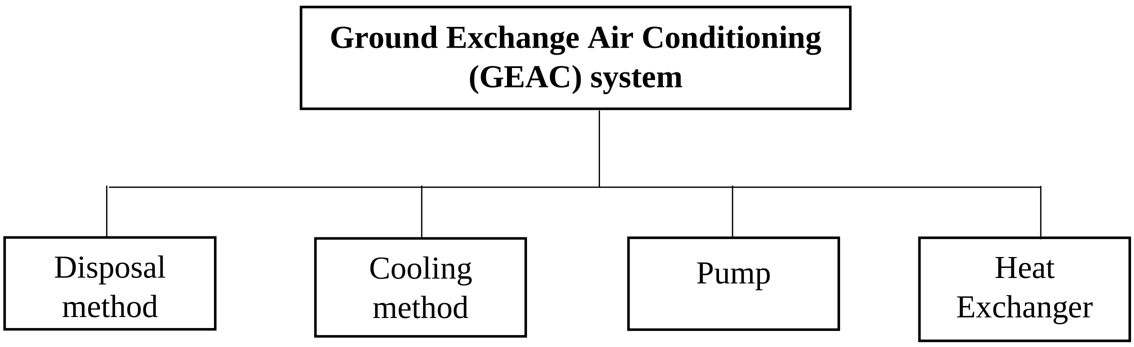


Figure 12: Physical decomposition of a GEAC system

4.2.2 FUNCTION STRUCTURE

The physical decomposition process is transformed into functional decomposition, in other to widen the alternatives to solve the problem addressed in the problem statement. Function structure can be easily constructed by identifying the inputs and outputs for each physical component.

Functional decomposition is being make use in the schematic design, representing the mechanical components abstractly by a labelled function block and its interacting flow lines [6]. Usually, function blocks are being utilized to represent the system transformation by changing the inputs into the desired outputs. The function structure is an essential element during the generation of functional decomposition tree diagram.

The function structure for the GEAC system is shown in figure 13 below.

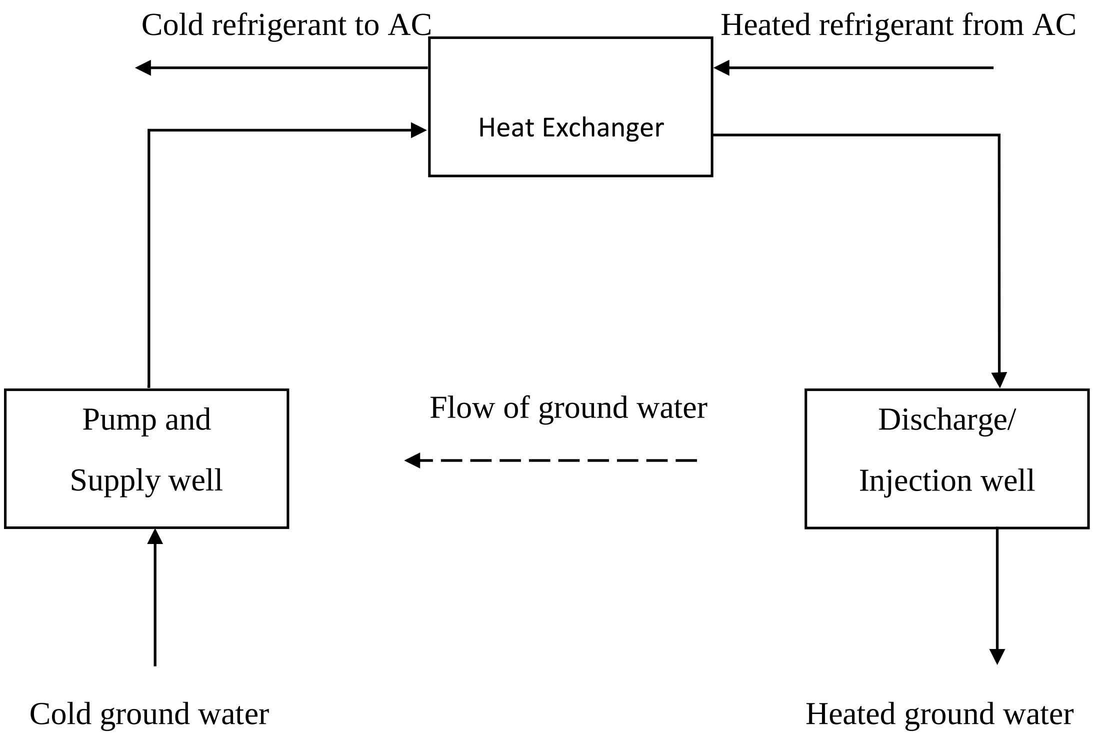


Figure 13: Functional structure of GEAC system

4.2.3 FUNCTIONAL DECOMPOSITION CHART

By referring to the function structure of the system, each function block representing a subsystem of the GEAC system. All the subsystems are defined in the functional decomposition diagram tree as shown in Figure 14.

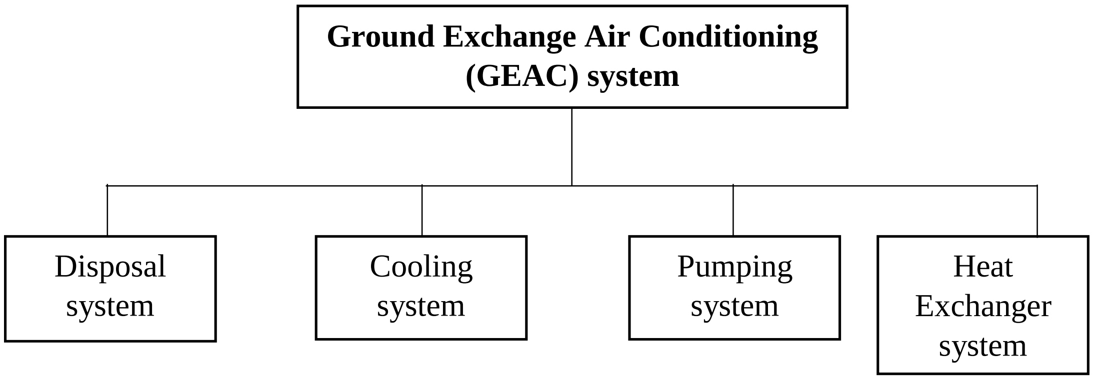


Figure 14: Functional decomposition for GEAC system

4.3 MORPHOLOGY CHART

Table 2: Morphology Chart

Subsystem	Alternatives			
	1	2	3	4
Disposal system	Two wells	Single column well	One supply well, open water disposal	Open water supply and disposal
Cooling system	Direct	Indirect		
Pumping system	Pedestal sump pump	Submersible sump pump		
Heat Exchanger system	Shell and tube heat exchanger	Plate heat exchanger	Coil heat exchanger	

4.4 MORPHOLOGY CHART (GENERATED CONCEPT)

Table 3: Morphology Chart (Generated Concept)

Subsystem	Alternatives			
	1	2	3	4
Disposal system	Two wells	Single column well	One supply well, open water disposal	Open water supply and disposal
Cooling system	Direct	Indirect		
Pumping system	Pedestal sump pump	Submersible sump pump		
Heat Exchanger system	Shell and tube heat exchanger	Plate heat exchanger	Coil heat exchanger	

4.5 GENERATED CONCEPT - JUSTIFICATION

Table 4: Generated Concept - Justification

System	Selection	Justification
Disposal system	Single column well	Based on the datum selected, by using only one well, it is possible to save on the cost of drilling a hole into the ground. It also does not require a large area of land compared to other configuration such as two wells type
Cooling system	Direct	There is only one loop, which is the refrigerant loop. The refrigerant will flow directly following the loop to the well. This provides better arrangements without the use of many heat exchangers.
	Indirect	The indirect cooling ensures that there is no contamination to the system. The ground water are kept isolated from the system but are indirectly involve in the cooling mechanism of the system
Pumping system	Submersible sump pump	Submersible sump pump are designed to work while completely under water, thus is suitable for this kind of application. Submersible sump pump is also smaller and requires no special rigging to be installed compare to pedestal sump pump. (*further studies indicates that it can be excluded from the final design)
Heat exchanger system	Coil heat exchanger	The coil heat exchanger are very suitable for the datum's design since it can be shaped to fit in a single column well. Thus it is more space efficient than those large and fixed shape heat exchanger.

4.6 PRELIMINARY CONCEPTUAL DESIGN

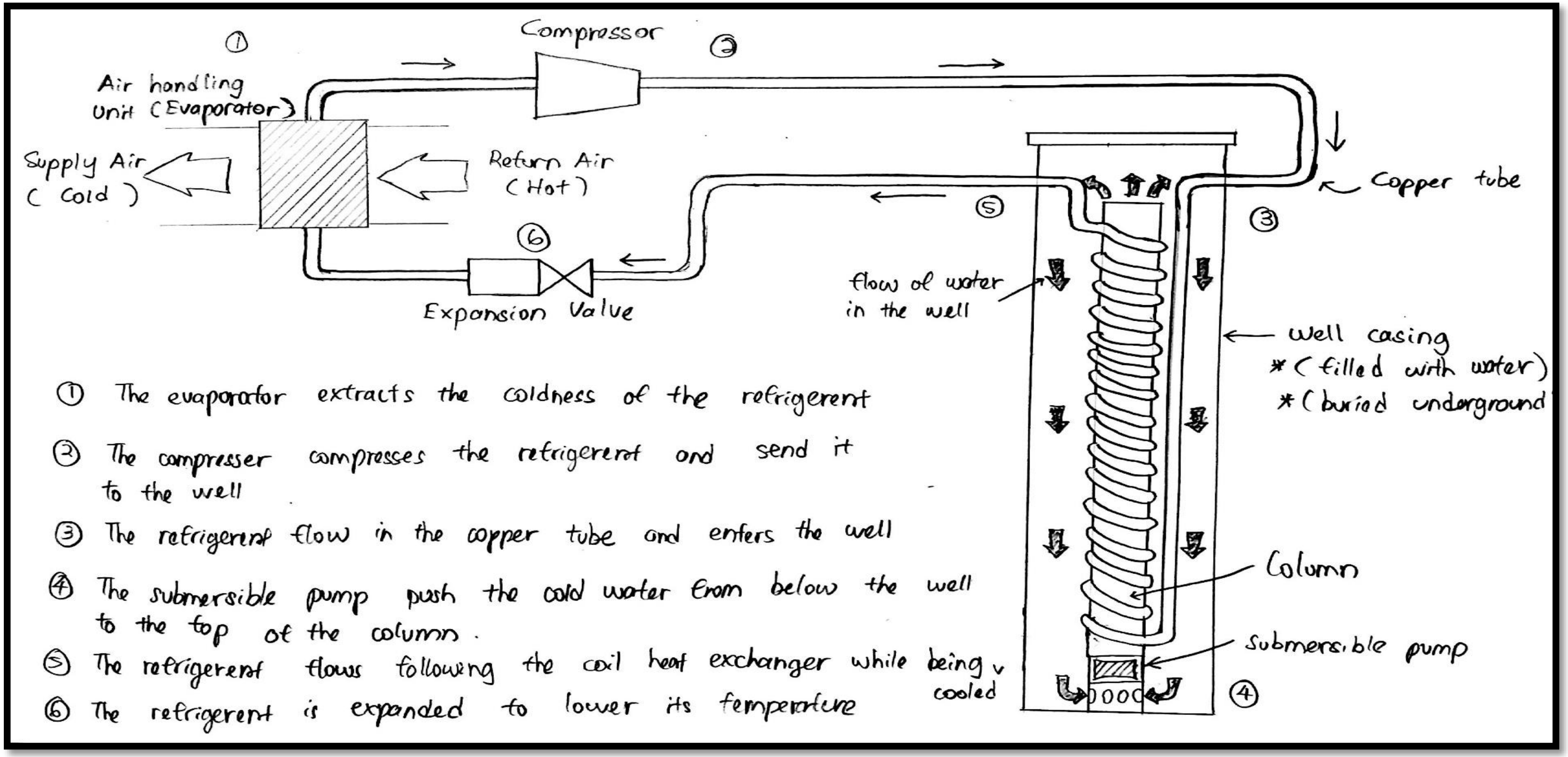


Figure 15: Preliminary conceptual design

CHAPTER 5: GOVERNING EQUATION

5.1 DESIGN SPECIFICATION

5.1.1 DEMAND IDENTIFICATION

The system is to provide cooling for a small house. The definition of small house varies between people's opinions, and can change depending on few factors such as the number of people living in that space. For this project, the small house will have an area layout of less than 1000 ft^2 will take taken into consideration. Figure 16 below shows an example of a small house area layout with 1000 ft^2 of space [28].

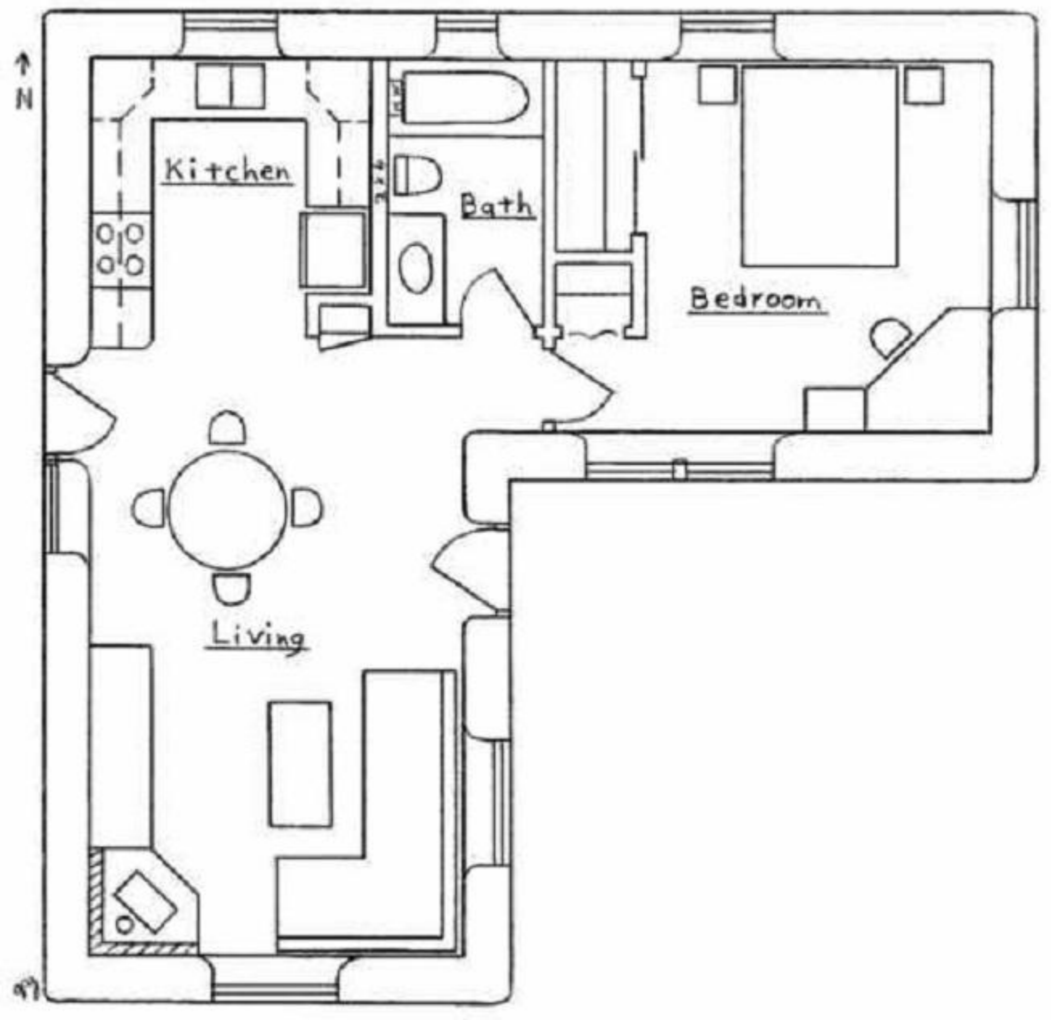


Figure 16: Plan layout of small house with 1000 ft2 area [28]

The arrangement in figure 16 are a typical layout for a small house with an area of less than 1000 ft^2. It usually consist of 1 to 2 bedrooms (sometimes even 3), 1 to 2 or 3 bathrooms (depending on the number of bedrooms), 1 kitchen and 1 living room.

5.1.2 COOLING LOAD DEMAND

Since the objective of this project to design a GEAC system that can be installed and use with the existing Air-split conditioner, no detail cooling load required will be done. Therefore, the cooling load for the system will be taken directly from the installed and available unit.

Taking the figure 16 small house layout as a reference, we can isolate the bedroom and living room as the space that require cooling. Assuming that the bedroom installed a 1 horsepower (HP) air conditioner and a 2 HP air conditioner in the living room, then we have a 3 HP cooling load.

Taking the conversion unit for HP to kW;

$$1\ hp = 0.746\ kilowatts = 2545\ Btu/hr = 0.212\ refrigerent\ ton$$

The above equation shows that 1 HP is equal to 0.746 kW of power, but bear in mind that the power rating of 1HP or 0.746 kW represent only the mechanical power of the compressor motor and not the cooling capacity of the air conditioner. Usually a 1 HP equipment is able to remove 9000 BTU/hr. of heat and reaching up to 10000 BTU/hr. of heat with a more efficient machine of the same capacity [29].

Assuming that the installed air conditioning unit is enough to cool the respective spaces, the design of this GEAC unit will be based on the minimum 9000 BTU/hr. cooling capacity for the bedroom, while the living room will have a GEAC unit a with a cooling capacity of 18000 BTU/hr. Therefore the total cooling load for this small house is approximately 27000 BTU/hr which is equivalent to 2.249 refrigerant ton.

5.2 AIR COOLED VS. WATER COOLED

A simple comparison of the effectiveness of air cooled and water cooled condenser is through the calculation of the overall heat transfer coefficient, or U-value, refers to how well heat is conducted over a series of mediums.

5.2.1 OVERALL HEAT TRANSFER COEFFICIENT

The overall heat transfer coefficient is influenced by the thickness and thermal conductivity of the mediums through which heat is transferred. The larger the coefficient, the easier heat is transferred from the source to the cooling medium. In a heat exchanger, the relationship between the overall heat transfer coefficient (U) and the heat transfer rate (Q) can be demonstrated by the following equation:

$$\boldsymbol{Q = UA\Delta T_{LM}}$$

Where,

Q = heat transfer rate, W=J/s

A = heat transfer surface area, m^2

U = overall heat transfer coefficient, W/(m^2°C)

ΔT_{LM} = logarithmic mean temperature difference, °C

From this equation we can see that the U value is directly proportional to Q, the heat transfer rate. Assuming the heat transfer surface and temperature difference remain unchanged, the greater the U value, the greater the heat transfer rate. In other words, this means that for the same heat exchanger, a higher U value could lead to faster cooling times.

Several equations can be used to determine the U value, one of which is:

$$\boldsymbol{\frac{1}{U} = \frac{1}{h_1} + \frac{L}{\lambda} + \frac{1}{h_2}}$$

Where,

h = convective heat transfer coefficient, W/(m^2°C)

L = thickness of the wall, m

λ = thermal conductivity, W/(m°C)

5.2.2 HEAT TRANSFER THROUGH A METAL WALL

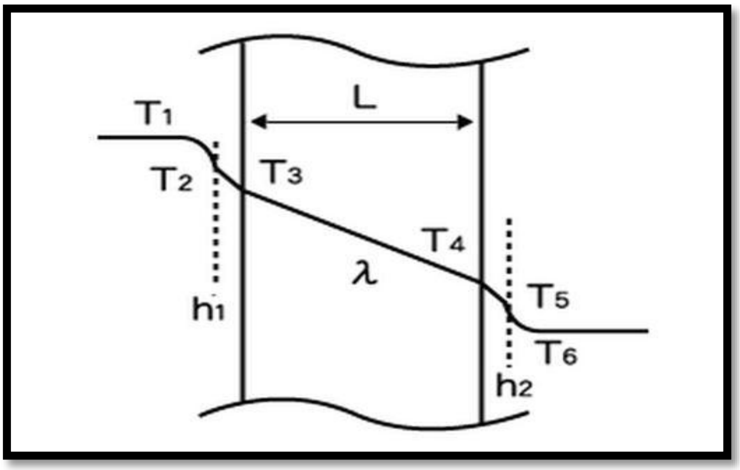


Figure 17: Illustration of heat transfer through a wall [31]

The convective heat transfer coefficient (h), sometimes referred to as the film coefficient, is often used when calculating heat transfer between a fluid and a solid. In the case of a heat exchanger, heat transfer basically occurs from fluid 1 (source of heat) to solid (metal wall) to fluid 2 (cooling medium). For this project the metal wall will be copper, while the source of heat (fluid 1) will be the refrigerant R-134a. The cooling medium (fluid 2) will be either air for air cooled condenser and water for water cooled condenser.

To simplify the calculation, the following values will be used as a reference:

Table 5: Estimation of some convective heat transfer coefficient

Fluid/Gas	Convective heat transfer coefficient (h)
Refrigerant R-134a	2500 W/m2.K
Water	25 W/m2.K (free), 200 W/m2.K (forced)
Air	100 W/m2.K (free), 10000 W/m2.K (forced)

Table 6: Properties of copper

Material	Thermal conductivity	Thickness
Copper	400 W/m.K	0.125 mm

The overall heat transfer coefficient for free convection:

Air:

$$\frac{1}{U} = \frac{1}{2500} + \frac{0.000125}{400} + \frac{1}{25}$$

$$U = 24.75\ W/m2.K$$

Water:

$$\frac{1}{U} = \frac{1}{2500} + \frac{0.000125}{400} + \frac{1}{100}$$

$$U = 96.2\ W/m2.K$$

The overall heat transfer coefficient for forced convection:

Air:

$$\frac{1}{U} = \frac{1}{2500} + \frac{0.000125}{400} + \frac{1}{200}$$

$$U = 185.2\ W/m2.K$$

Water:

$$\frac{1}{U} = \frac{1}{2500} + \frac{0.000125}{400} + \frac{1}{10000}$$

$$U = 1998.75\ W/m2.K$$

From the calculation above, it is clear that water cooled condenser are better when compared to air cooled counterpart. The overall heat transfer coefficient for both (free and forced) are higher and thus able to transfer more heat at the same amount of time or able to transfer the required amount of heat in a shorter time period.

5.3 AIR CONDITIONER WORKING CONDITION

The temperature inside the house will need to be kept constant at 20°C, the T-S diagram in figure shows the working condition of this refrigeration cycle. The temperature of the evaporator will usually be 10°C to 15°C lower than the set temperature [26], while the condenser temperature are 20°C higher than the soil temperature for water cooled condenser such as in this GEAC unit. Air cooled condenser will be 25°C to 30°C higher than the ambient temperature [26].

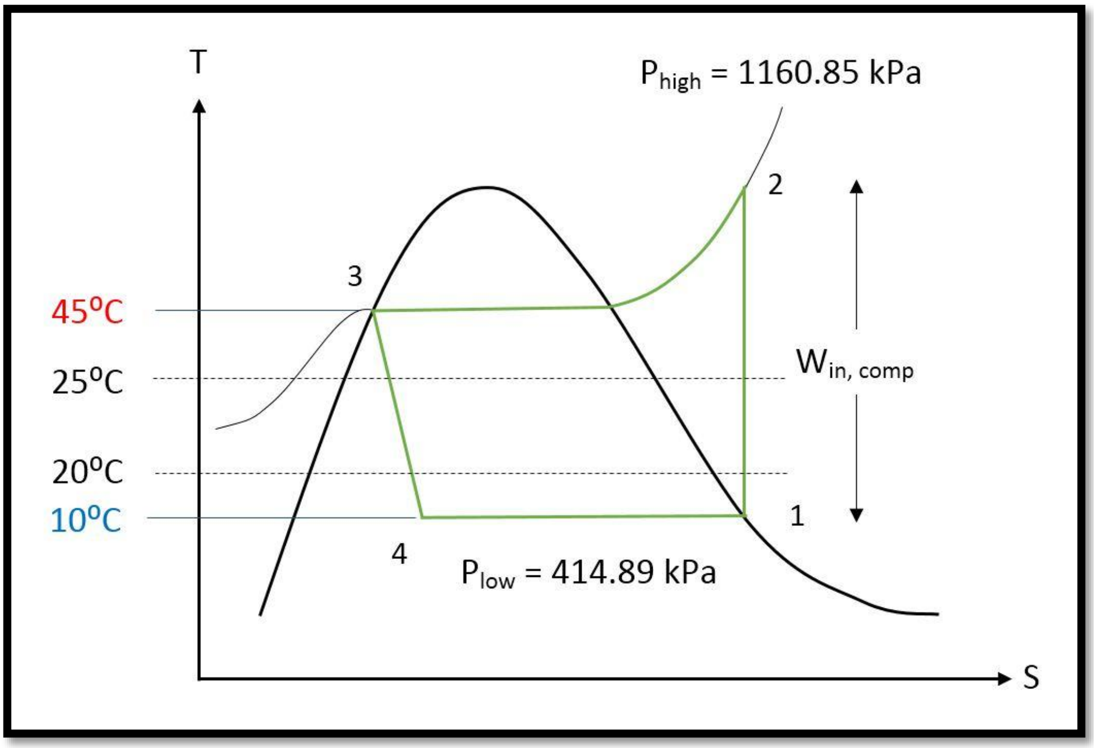


Figure 18: Water cooled condenser T-S diagram

From the diagram above, the pressure of the condenser will be 1160.85 kPa at 45°C when the ground temperature is at 25°C while the pressure at the evaporator is 414.89 kPa at 10°C.

Where:

- Point 1 to Point 2: Compressor work input
- Point 2 to Point 3: Condenser heat rejection
- Point 3 to Point 4: Throttling device
- Point 4 to Point 1: Evaporator heat absorption

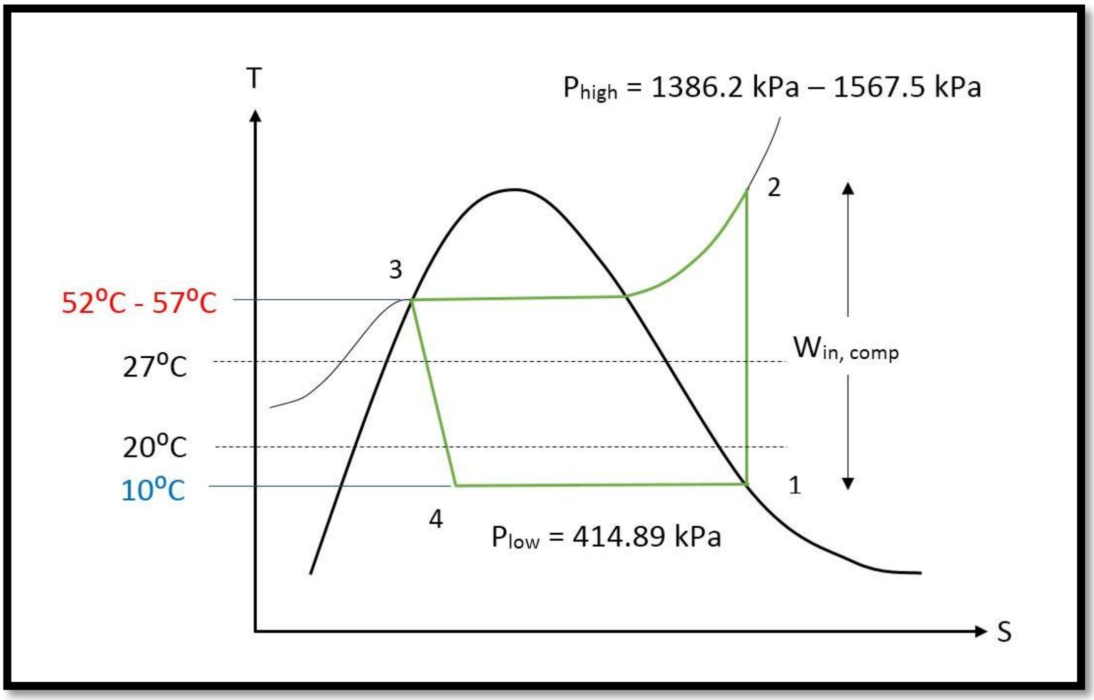


Figure 19: Air cooled condenser T-S diagram

From the diagram above, the pressure of the condenser will be in the range of 1386.2 kPa to 1567.5 kPa depending on the temperature of the condenser when the ambient temperature is at 27°C. The ambient temperature fluctuate throughout the day and this further affect the working condition of the air cooled condenser. The pressure at the evaporator is also 414.89 kPa at 10°C.

From the comparison of these two figures, it can be conclude that the compressor with an air cooled condenser will have to draw more power to compress the refrigerant to a higher pressure. It also shows that the fluctuation in the temperature difference also affect the performance of the system.

5.4 UNDERGROUND TEMPERATURE PROFILE

Soil temperature fluctuates annually and daily affected mainly by variations in air temperature and solar radiation. The annual variation of daily average soil temperature at different depths can be estimated using a sinusoidal function as mention by Hillel (1982) [35], Marshall & Holmes (1988) [36] and Wu & Nofziger (1999) [37]. This program estimates daily soil temperature and display these values as functions of time or depth for user defined input parameters. The annual variation of daily average soil temperature at different depth is described with the following function [35].

$$T(z,t) = T_a + A_e e^{-z/d} \sin[\frac{2\pi(t - t_0)}{365} - \frac{z}{d} - \frac{\pi}{2}]$$

Where:

- $T(z,t)$ = the soil temperature at time t and depth z
- Ta = the average soil temperature
- Ao = annual amplitude of the surface soil temperature
- d = damping depth of annual fluctuation
- to = the time lag from an arbitrary starting date to the occurrence of the minimum temperature in a year

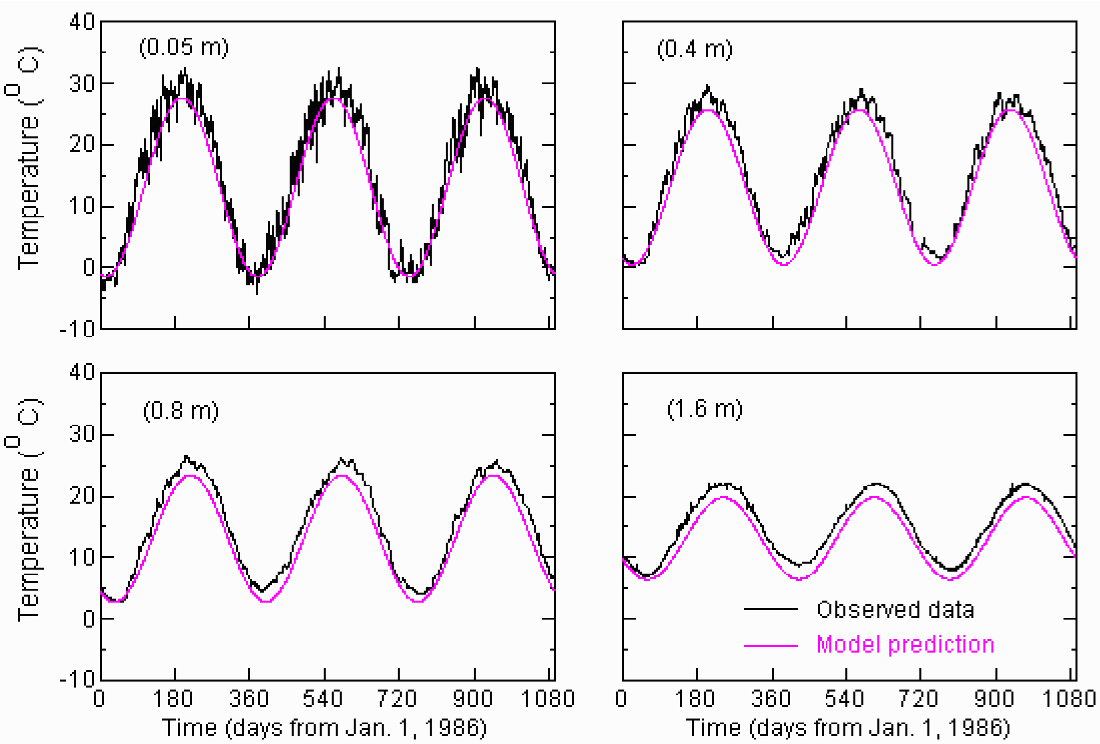


Figure 20: Comparison of of measured and predicted soil temperatures at four depths based upon air temperatures at site [37]

There are other factors that affects the soil temperature distribution such as the present of wetness in the soil or water table. Difference in soil density and types of soil makes it hard to do a prediction on the soil temperature distribution without performing an experiment on the actual soil. Figure 21 is based on research cited by de Vries (1963, 1975) [38], [39], and Farouki (1986) [40], shows the impact of water content upon estimated soil temperature.

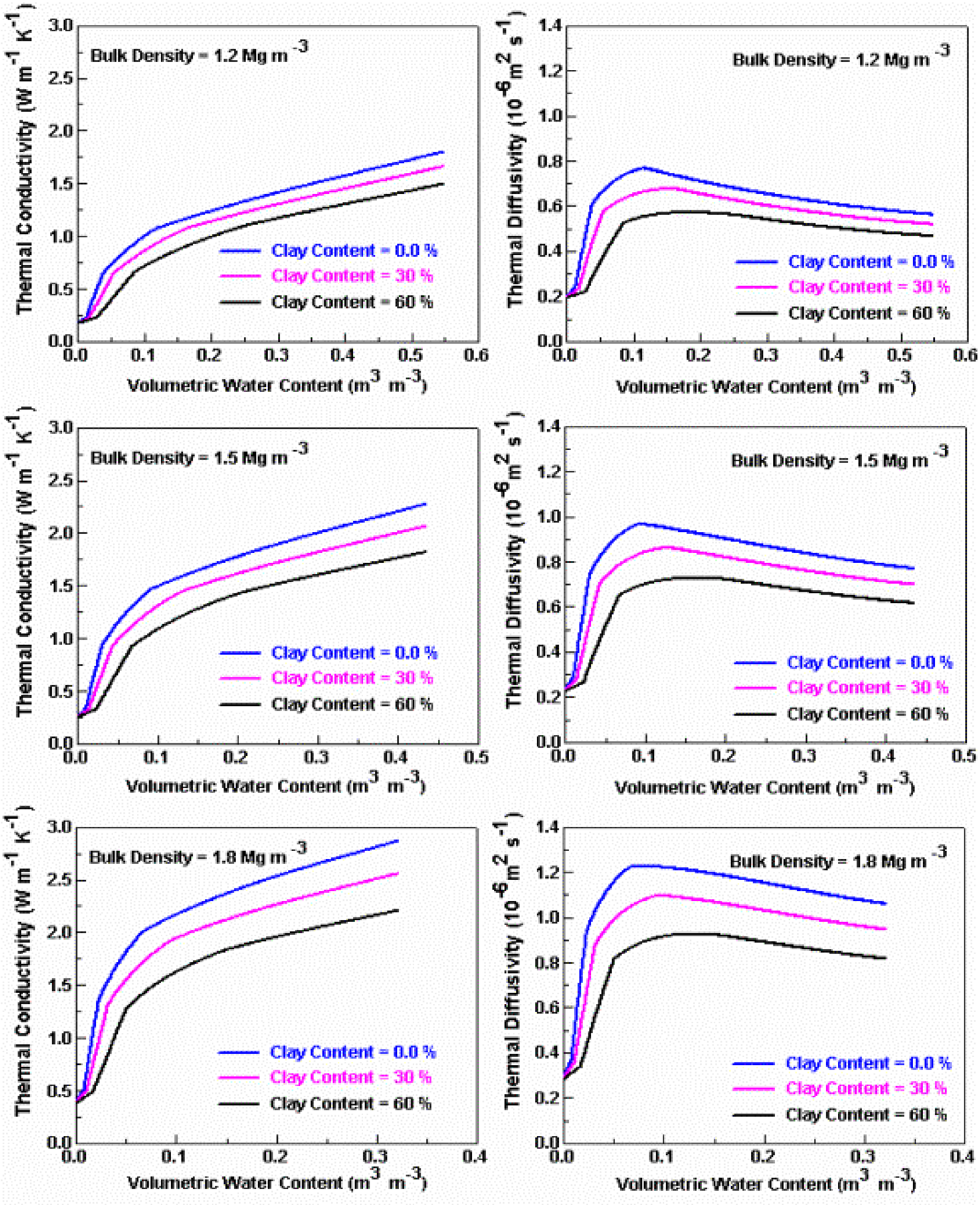


Figure 21: The thermal conductivity and diffusivity of three different density of soil affected by the present of water [38][39][40]

CHAPTER 6: SIMULATION AND MODELLING

6.1 SIMULATION AND MODELLING

6.1.1 ASSUMPTIONS

Few assumption are made to ease the designing process as well as the calculation process:

- The system is known as closed and steady state system (mass balance achieved)
- The losses from internal friction of the pipe are small and negligible
- No gas/pressure leakage on piping and equipment

Few conditions are also set:

- Heat exchanger are will be made from copper metal
- Pipe diameter, D = 0.02 m
- Pipe thickness, t = 0.000125 m
- GEAC unit casing are made out of aluminium metal

6.1.2 VAPOUR COMPRESSION CYCLE SIMULATION

To understand better the working of an air conditioning system, the author did an experiment on vapour compression cycle which are widely used in today's air conditioning system. The equipment used is Hilton 812 Water Chiller Unit located at block 18, refrigeration lab.

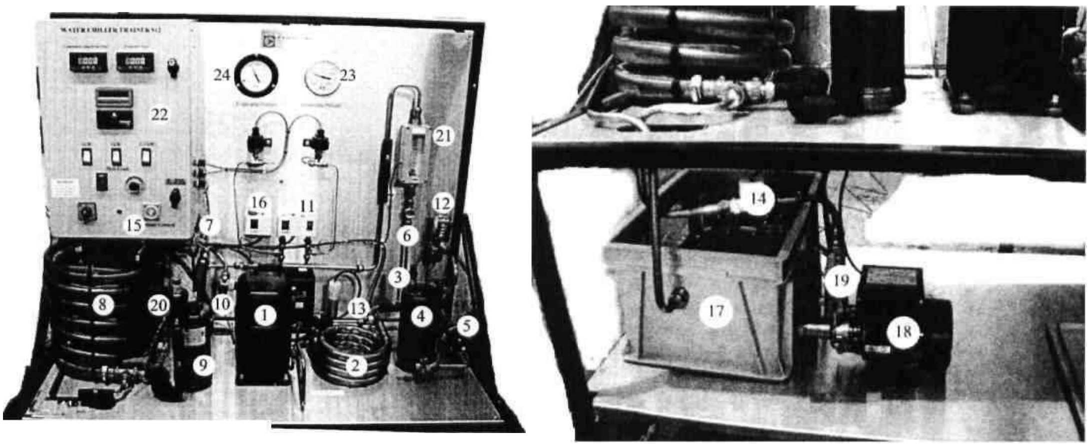


Figure 22: Hilton 812 Water chiller Unit (taken from Lab manual)

The purpose of the simulation is to study the temperature and pressure of the refrigerant through the system. Though it is not used for space conditioning but the overall system function is similar to that of an air conditioner. This equipment is chosen because it has a water cooled condenser, and the result obtain will be used as a reference for designing the ground exchange unit.

The equipment are used to study the effect system performance while varying heat load are applied, in term of kW, to the system. The heat load available started from a minimum of 0.5kW to the maximum 2.5 kW. Temperature sensor are placed at various point along the refrigeration line, as shown in figure below, to measure the temperature of the refrigerant at real time. Other than the temperature, pressure and flow rate are also measured.

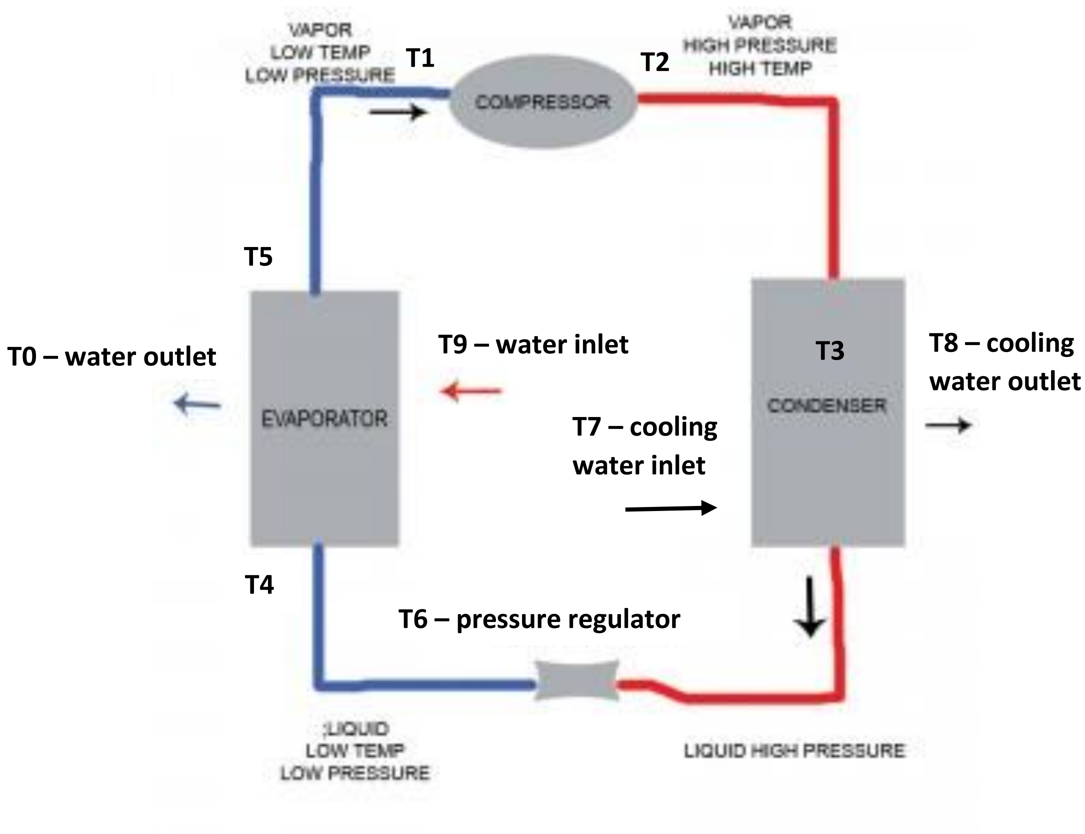


Figure 23: Temperature sensor along the refrigeration line

Procedure:

1. The system are started up.
2. Load are applied, system run for 5 minute
3. Temperature and pressure measurement are noted down

Result:

Table 7: Result for Vapor Compression Cycle simulation

Parameters	Unit	Sample Data	Data1	Data2	Data3
T1 Compresor suction temperature	°C	19.5	4.2	4.5	6.1
T2 Compressor discharge temperature	°C	100.2	103.3	105.9	108.2
T3 Condensed liquid temperature	°C	60.7	56.5	56.9	57.2
T4 Evaporator inlet (refrigerant)	°C	10.6	-9.4	-8.8	-6.7
T5 Evaporator outlet (refrigerant)	°C	19.5	-1.4	-0.1	2.6
T6 Evaporator pressure regulator outlet	°C	20.4	0.2	1.4	3.8
T7 Condenser cooling water inlet	°C	14.7	28.0	27.9	27.7
T8 Condenser cooling water outlet	°C	70.3	66.0	66.0	65.7
T9 Evaporator water inlet	°C	21.0	-1.5	0.2	3.3
*T10/0 Evaporator water outlet	°C	18.0	-2.4	-1.4	1.3
Condenser Pressure	kN/m2	1620.0	1625.0	1650.0	1680.0
Evaporator Pressure	kN/m2	250.0	100.0	110.0	125.0
Refrigerant flow rate	R/s	16.6	6.1	6.5	7.5
Heating Load Applied	kW	2.5	0.5	1.0	1.5
Condenser water flow	g/s	14.0	35.0	37.0	43.0
Evaporator water flow	g/s	214.0	185.0	186.0	187.0

Based on the result above:

- Temperature increase inside the compressor is:

$$\Delta T_{comp} = 100.2\ ℃ - 19.5\ ℃$$

$$= 80.7\ ℃$$

- Temperature decrease in the condenser:

$$\Delta T_{cond} = 100.2\ ℃ - 60.7\ ℃$$

$$= 39.5\ ℃$$

Discussion:

The temperature of compressor outlet is not correct since it is too high (more than 100℃), taking a look into the condenser pressure reading shows a more reasonable measurement. Pressure at the condenser is around the 1620 kPa to 1680 kPa which translate to a temperature of 57℃ to 62℃. This is not to be expected from a water cooled condenser, but maybe due to old age of the equipment it is not as efficient. Other than that, the result is a decent benchmark in designing this GEAC system.

The heat gain from the compressor shows an increase of 1℃ to 2℃ for every 0.5 kW increase of heat load. The compressor pressure also increases at an average of 30 kN/m2 for every 0.5 kW increase in heat load. To compensate for the increase in heat load, the refrigerant flow rate also increases at an average of 0.5 g/s to 1 g/s.

6.1.3 DESIGNING THE HEAT EXCHANGER

Following the vapour compression cycle simulation, it is assume that the higher the heat load the higher the refrigerant temperature at the compressor inlet and thus higher compressor outlet temperature.

As specified, the cooling capacity of a 1 HP compressor is equivalent to 9000 btu/hr or 2.64 kW of heat load and 2 HP compressor produces around 18000 Btu/hr (5.3 kW). Some of the value for the required parameter to design this heat exchanger will be calculated based on the result obtain from the vapour compression cycle simulation.

Required parameter:

- Heat load = cooling capacity = 2.64 kW & 5.3 kW
- Thermal conductivity of copper, k = 400 W/m.K
- Heat transfer coefficient of refrigerant R-134a, h_1 = 2500 W/m2.K
- Heat transfer coefficient of water (free convection), h_2 = 25 W/m2.K
- External diameter, $r_1 = 0.01\ m$, internal diameter, $r_2 = 0.009875\ m$
- Assuming temperature refrigerant (inside), T_1 = 57°C, Temperature water (outside), T_2 = 25°C

Calculating heat transfer through a copper tube:

Using the formula, $\dot{Q} = \frac{T_1 - T_2}{R_{total}}$

$$R_{total} = \frac{1}{(2\pi r_1 L)h_1} + \frac{\ln\frac{r_1}{r_2}}{2\pi Lk} + \frac{1}{(2\pi r_2 L)h_2}\ , \quad L = 1\,m$$

$$= \frac{1}{(2\pi 0.01)2500} + \frac{\ln\frac{0.01}{0.009875}}{2\pi 400} + \frac{1}{(2\pi 0.009875)25}$$

$$= 0.65$$

$$\dot{Q} = \frac{T_1 - T_2}{R_{total}} = \frac{57 - 25}{0.65} = 49.23\ W$$

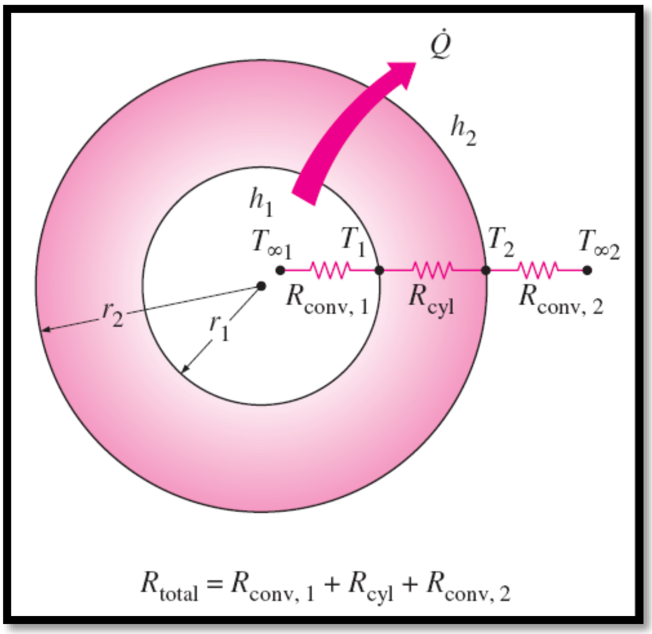


Figure 24: The thermal resistance network for a cylindrical shell subjected to convection from both the inner and the outer sides

From the calculation, 1 meter of cylindrical copper tube will reject 49.23 W of heat from the refrigerant, to remove 2.68 kW of heat, the length of the copper tube must be;

$$lenght\ of\ copper\ tube\ (2.68\ kW), l = \frac{2680\ W}{49.23\ W_{/m}} = 54.438\ m\ \approx 55\ m$$

$$lenght\ of\ copper\ tube\ (5.3\ kW), l = \frac{5300\ W}{49.23\ W_{/m}} = 107.65\ m\ \approx 108\ m$$

Therefore the total length of copper tube needed is 55 meters in order to remove 2.68 kW of heat energy, whereas to remove 5.3 kW of heat energy, 108 meter of coil is needed.

The design of this heat exchanger will take on the design of a helical coil heat exchanger due to its limited space and offers advantage compare to other type of heat exchanger due to its small footprint. Using a helical coil calculator [26], the specification of the helical coil based on the given condition is:

2.68 kW heat exchanger:

Coil diameter, D = 0.2 m, Coil height, H = 2.4 m, the total number of turns is 80 with a turn spacing of 0.01 m.

5.3 kW heat exchanger:

Coil diameter, D = 0.2 m, Coil height, H = 5.16 m, the total number of turns is 171 with a turn spacing of 0.01 m

Figure 25: Copper coil [33]

ANSYS workbench Transient Thermal Analysis:

The figure below shows the transient thermal analysis done on the copper pipe with 1 meter length. The resulting simulation show that the maximum total heat flux generated is equal to 46.738 W/m^2 which is almost to the value found from the manual calculation done previously. The time taken for the time to reach equilibrium is approximate 18.324 seconds.

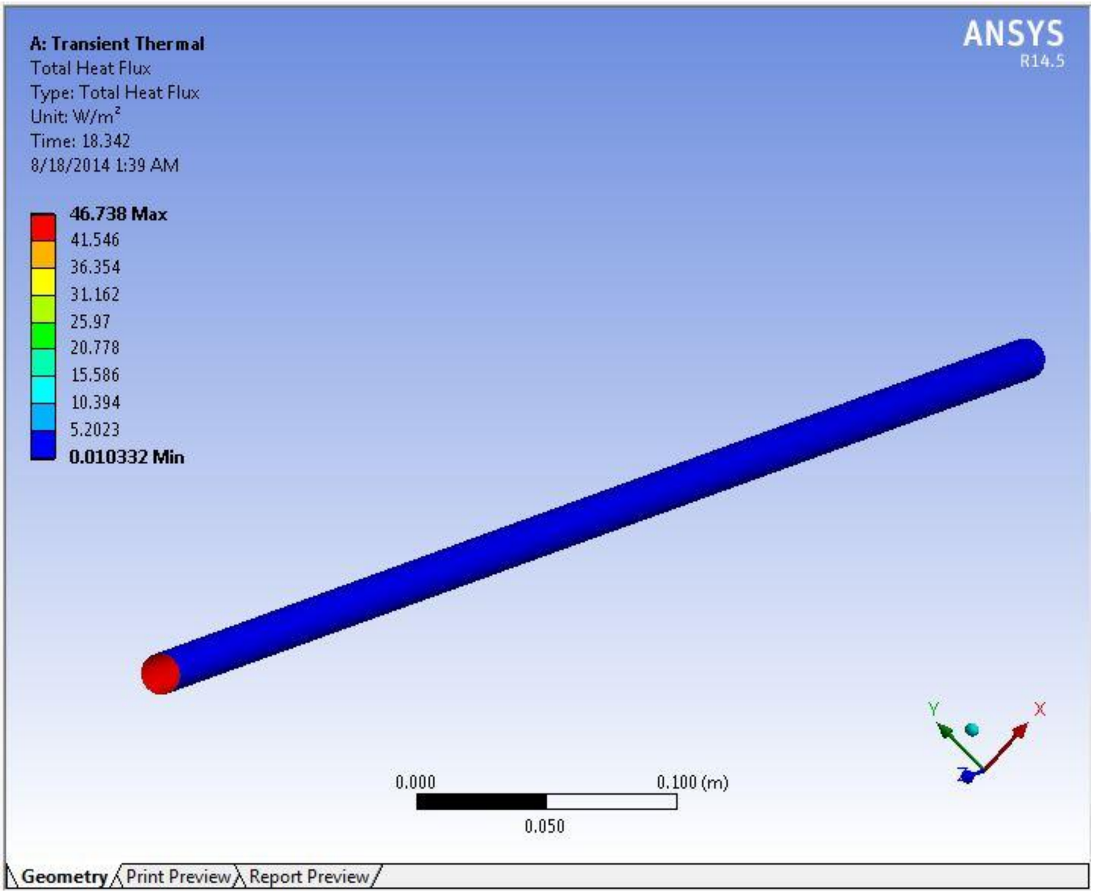


Figure 26: ANSYS transient thermal analysis on copper tube

6.1.4 DESIGNING THE CASING

The material of the casing needs to have high thermal conductivity to be able to reject heat from the water to the surrounding soil as fast as possible. The chosen material for the casing is aluminium due to its high thermal conductivity among other reason. Table below shows the properties of aluminium metal as compared to other candidate materials for the casing.

Table 8: Comparison table [24]

Materials	Thermal conductivity K (W/m.K)	Specific heat capacity C_p (J/g.K)	Density *P* (kg/m3)
Aluminium	205	900	2712
Copper	400	386	8940
Stainless steel	16	502	8027.2

Aluminium are also favourable due to its smaller density other than its high thermal conductivity. Copper has the highest thermal conductivity, but due to its high density, the casing will be very heavy compared to an aluminium casing. Rust will be an important factor when burying things underground, therefore choosing the right material will ensure a long service life. Stainless steel is very good at repelling rust, but due to its poor thermal conductivity and high density, it is not favourable.

Deciding on the size of the casing:

Since the diameter of the casing has been fix, the length of the body will determine the overall volume of the casing.

Using the formula:

$$Q = mC_p \Delta T$$

Where:

- Q = heat transferred
- C_p = heat capacity of water = 4186 J/kg.K
- Delta T = temperature difference between initial and final condition
- M = mass of water required

Assuming that the air conditioner will be used for 12 hours of operation, therefore the total amount of heat generated is;

$$12\ hour \times \frac{3600\ seconds}{1\ hour} = 43200\ seconds$$

$$2680\frac{J}{s} \times 43200\ s = 115776000\ J\ or\ 115.776\ MJ$$

$$5300\frac{J}{s} \times 43200\ s = 228960000\ J\ or\ 228.96\ MJ$$

The amount of heat generated during that period of time is 115.776 MJ and 228.96 MJ.

To ensure that the amount of temperature drop in the condenser is satisfied, the temperature rise of the water in the casing must not be more than $20°C$, when the initial temperature of the water is $25°C$. This can be achieved by having a large amount of water in the casing, and the size of the can range from 2 m to 6 m but the casing must be longer than the helical coil height (2.4 m). Using the heat transfer formula to find the mass of water required in the casing.

The mass of water required at 1 HP,

$$Q = mC_p\Delta T$$

Where:

- Q = heat transferred = 115.776 MJ
- C_p = heat capacity of water = 4186 J/kg.K
- Delta T = 20°C
- M = mass of water required

$$m = \frac{Q}{\Delta T C_p} = \frac{115776000}{(20)(4186)} = 1382.9\ Kg$$

The mass of water required at 2 HP,

$$Q = mC_p\Delta T$$

Where:

- Q = heat transferred = 228.96 MJ
- C_p = heat capacity of water = 4186 J/kg.K
- Delta T = 20°C
- M = mass of water required

$$m = \frac{Q}{\Delta T C_p} = \frac{228960000}{(20)(4186)} = 2734.83\ Kg$$

Assuming the diameter and thickness of the casing is equal to 0.635 m and 0.005 m (standard oil barrel size) respectively, the length of the casing can be determined based on the mass of water required.

Casing length for 1 HP A/C:

Casing outside diameter = 0.635 m, thickness = 0.005m, internal diameter = 0.625 m, total volume of helical coil = 0.0157 m^3

Unit of conversion, 1 kg of water = 0.001 m^3 of water

$$1382.9\ kg = 1.3829\ m^3 \approx 1.4\ m^3$$

The total volume, V_{total},

$$V_{total} = Area \times lenght$$

$$1.4\ m^3 + 0.0157\ m^3 = \pi \times \left(\frac{0.625}{2}\right)^2 \times lenght$$

$$lenght = 4.614\ m$$

Casing length for 2 HP A/C:

Casing outside diameter = 0.635 m, thickness = 0.005m, internal diameter = 0.625 m, total volume of helical coil = 0.034 m^3

Unit of conversion, 1 kg of water = 0.001 m^3 of water

$$2734.83\ kg = 2.735\ m^3$$

The total volume, V_{total},

$$V_{total} = Area \times lenght$$

$$2.735\ m^3 + 0.034\ m^3 = \pi \times \left(\frac{0.625}{2}\right)^2 \times lenght$$

$$lenght = 9.03\ m$$

ANSYS Transient Thermal Analysis on casing:

The figure below shows the transient thermal analysis on the casing using ANSYS Mechanical 14.5. The simulation is run for 100 seconds to simulate the heat transfer between the casing and the soil, longer simulation times tends to get stuck and stop as the application crashes. The load applied to the inside of the casing with a convection heat transfer to simulate the water inside the casing at $45°C$. Based on the result of this short simulation, the casing is able to conduct heat away from the water as predicted.

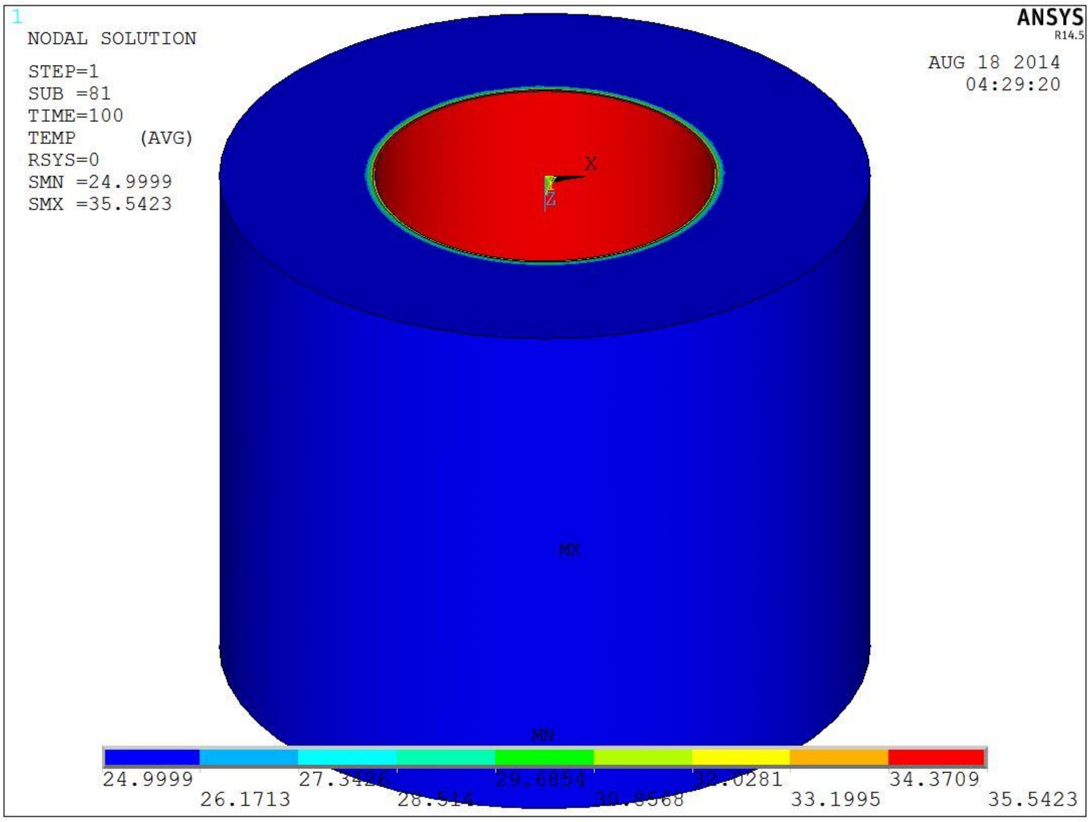


Figure 27: Transient thermal analysis on casing result

6.1.5 DETAIL DESIGN

Specification of the Heat Exchanger:

- 1 HP (2.68 kW heat load)
  - Height, H = 2.4 m
  - Coil diameter, D_c = 0.2 m, Copper tube diameter, D_t = 0.2 m
  - Coil Turn spacing, S = 0.01 m

- 2 HP (5.3 kW heat load)
  - Height, H = 5.16 m
  - Coil diameter, D_c = 0.2 m, Copper tube diameter, D_t = 0.2 m
  - Coil Turn spacing, S = 0.01 m

Specification of Casing:

- 1 HP (2.68 kW heat load)
  - Height, H = 4.2 m
  - Casing outer diameter, D_o = 0.635 m, Internal diameter, D_i = 0.625 m

- 2 HP (5.3 kW heat load)
  - Height, H = 9.1 m
  - Casing outer diameter, D_o = 0.635 m, Internal diameter, D_i = 0.625 m

Comparing the final design and the preliminary conceptual design, all the listed parts are included except for the submersible pump. As stated, the submersible pump are used to create the water movement in the casing, but the natural convection flow of the water due to the heat transfer from the heat exchanger are enough to create the same water movement. This does not only reduce the number of equipment needed but also eliminates the only equipment with a moving part for this ground exchange unit. Thus making this ground exchange unit independent of any kind of electrical power supply.

6.1.6 PARAMETRIC STUDY

The purpose of this study is to know the available dimension of the casing and how it affect its performance, also to determine which parameter is more critical, either length or diameter of the casing.

The specification for the casing and heat exchanger can be altered to suit the needs of the customer or developer, for example some customer or developer have some limitation on the amount of area that can be used for air conditioning purposes or the depth of the hole must not be more than a specified limit due to any reason. However the minimum dimension of the casing must not be smaller than the dimension of the heat exchanger. This is to prevent the size of the casing from disrupting the function of the heat exchanger.

Taking the total surface area outside of the casing as a measure of the effectiveness of the casing performance, since larger surface area of contact between the casing and the soil produces more heat transfer. Using the formula for calculating surface area of a cylinder:

$$surface\ area\ of\ casing, A_c = \pi d\ \times l$$

Where:

d = diameter of the casing

l = length of the casing

the equation shows that the surface area of the total surface area of the casing is directly proportional to the diameter and length of the casing. Therefore, by increasing either one of the parameter above while fixing the other will result in the increase of the surface area of the casing.

Taking the 1 HP ground exchange unit as a benchmark, the surface area of the casing with the specified dimension is $8.38m^2$. Utilizing excel spreadsheet, the author increases the value of one or the two parameters by 0.01m for each point, while keeping the other constant. The steps are repeated to get a total of 40 points or an increase of 0.4m for both parameters. The result of this parametric study is shown in figure 28.

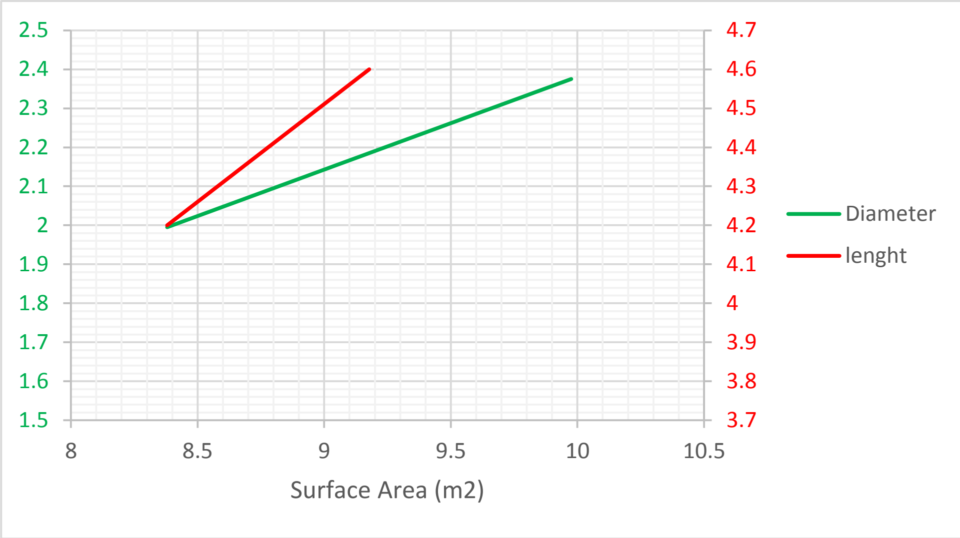


Figure 28: Parametric study result

The plot shows the increase of surface area of the casing to $9.18m^2$ when the length of the casing is increased. But when the diameter of the casing is increased, the surface area rose to $10.06m^2$.

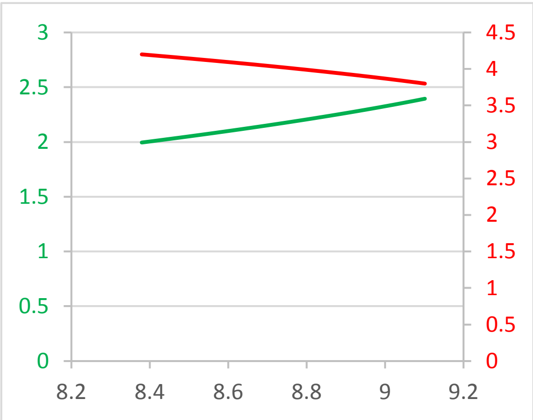


Figure 29: Plot 1

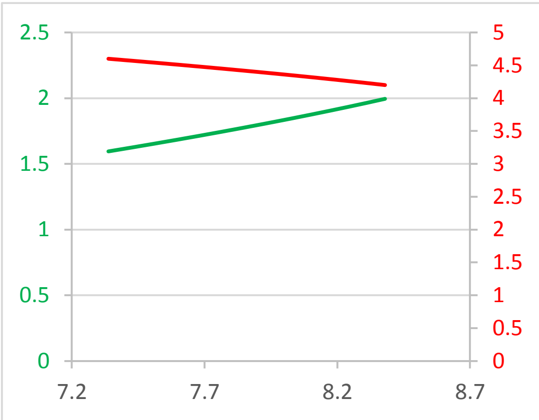


Figure 30: Plot 2

Another study done is by decreasing the value of one parameter while increasing the other. Figure 29 shows the result of increasing the diameter and decreasing the length of the casing, the surface area rose to $9.1m^2$. Whereas figure 30 shows the result when the condition is reversed, length is increased while diameter is decreased, the surface area drops to $7.34m^2$.

This study shows that the diameter of the casing is the more critical parameter in designing this casing, as more surface area are being made available for heat transfer compared to increasing the length of the casing. But due to the profile of the soil and design of the heat exchanger, it is preferable for the casing to be longer than having a larger diameter, as long as the volume of water required is maintained.

Figure below shows the CATIA modelling representation of the detail design: (Page 50 & 51 for the Engineering drawing)

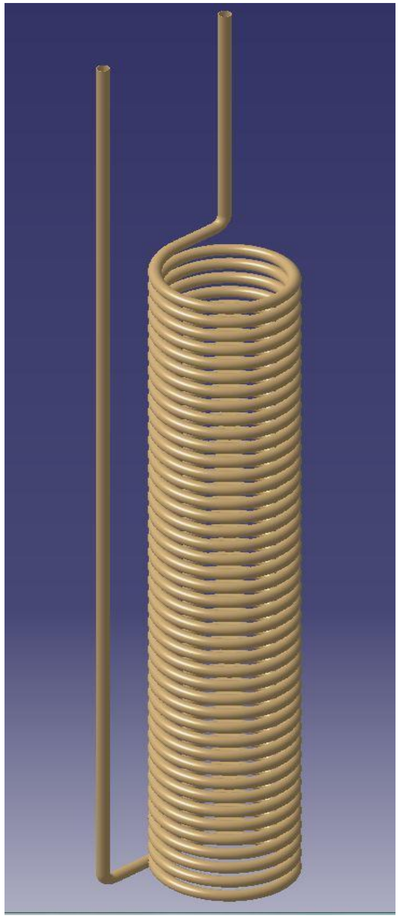


Figure 33: Coil

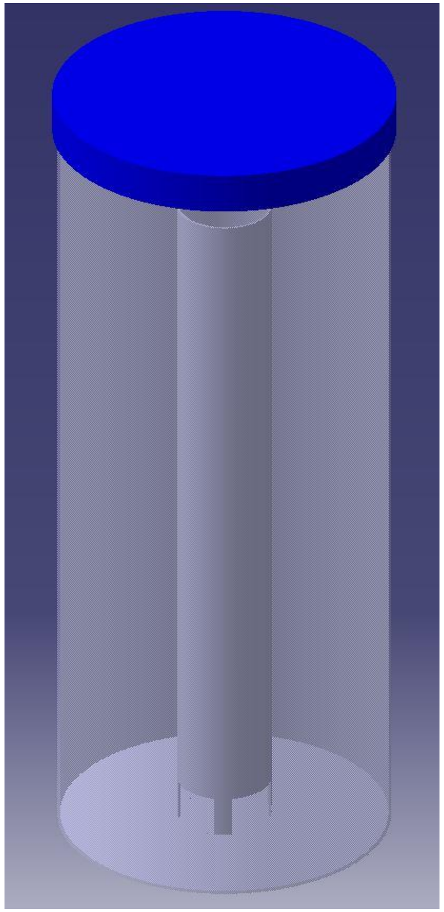


Figure 32: Casing

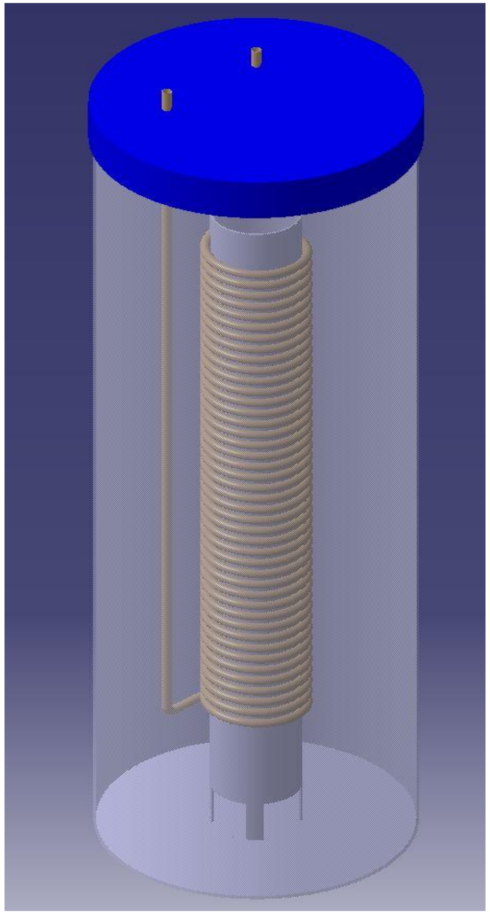


Figure 31: Full assembly

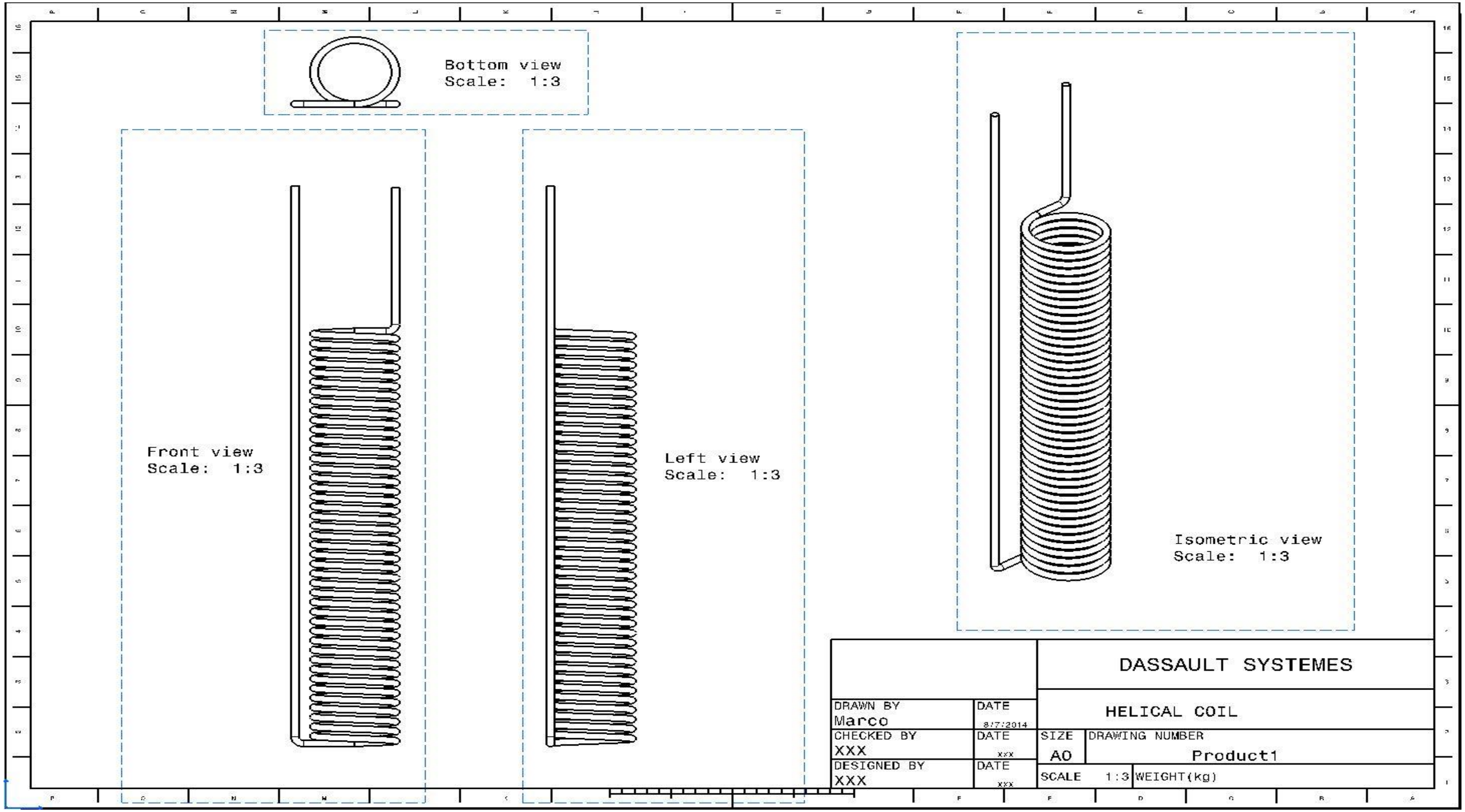


Figure 34: Engineering Drawing of hcoil heat exchanger

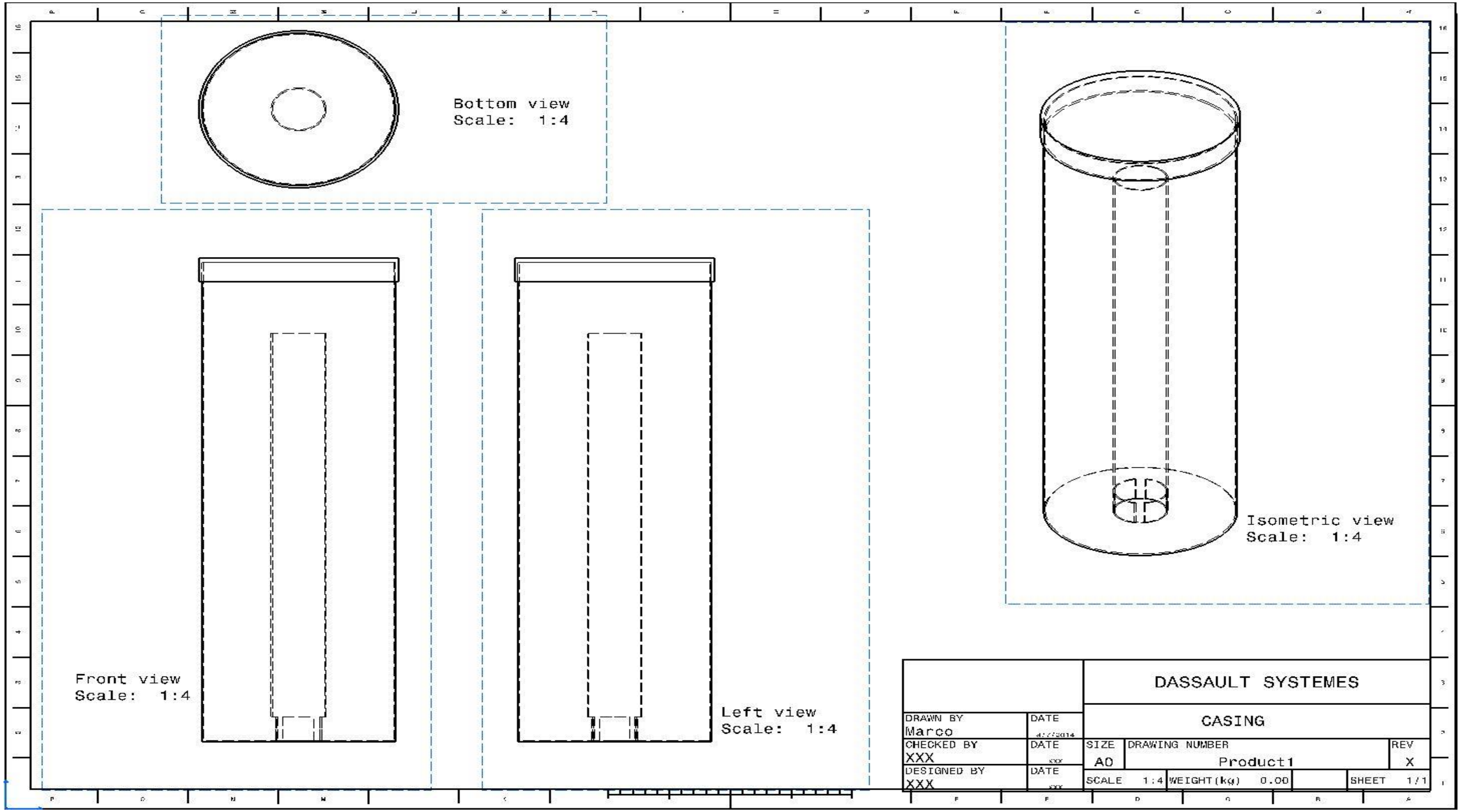


Figure 35: Engineering Drawing of casing

CHAPTER 7: CONCLUSION

7.1 CONCLUSION

Going back to the objectives of this project, there are three sub-objectives that leads to the main objectives which is, to study and design a small GEAC system for a small house. The first sub-objectives, which is the literature review, saw the author did extensive research on air conditioning and its components, as well as on the ground exchange unit, which is based on the open-loop configuration.

The author compares an air cooled condenser to a water cooled condenser, and shows why water cooled condenser are better at removing heat. This opens an opportunity to create a more efficient system that can save on electricity bill cost. The ground shows to be a reliable heat sink due to its constant temperature, but can only be fully utilized with the use of ground exchange unit.

The design of this ground exchange unit are based on open-loop configuration which uses underground water source as a cooling medium. But using untreated water source can cause problems to the equipment due to its unguaranteed quality. That is why the second sub-objectives are performed, to find alternatives and solution to be incorporated in the new GEAC system design. The initial proposed design shows the use of a hybrid solution, which combines the open-loop and closed-loop configurations. This eliminates the use of untreated water source as well as simplifies the system configuration.

In theory, this GEAC system should work but to be sure, the third sub-objective are carried out. Assumption and detail calculation based on simulation work are done to obtain the exact dimension of the unit. Based on the result gathered, the final detail design can finally be drafted and with that achieved the objectives of this project.

7.2 RECOMMENDATION

The author would recommend to anyone who will continue or do any research similar to this project, to use the information gathered in this project to further refine and improve the result obtain. A lot of assumption are made to simplified the calculation, therefore eliminates the real world working situation as it is assume to be in an ideal condition. Losses are not included in the calculation, which may influence the result in the real working conditions. The author also recommends to utilized more simulation software as it greatly increases the validity of a project.

7.3 SUGGESTION

The author suggest that the result to be improve by building a detail and elaborate MATLAB Simulink model to simulate the refrigeration cycle with an air cooled condenser or a water cooled condenser and many more other working conditions. The author also suggest to building a prototype based on the result of this project, so that test and experiment can be done. Real working observation on the GEAC unit will increase our understanding on the system, so that improvement can be made.

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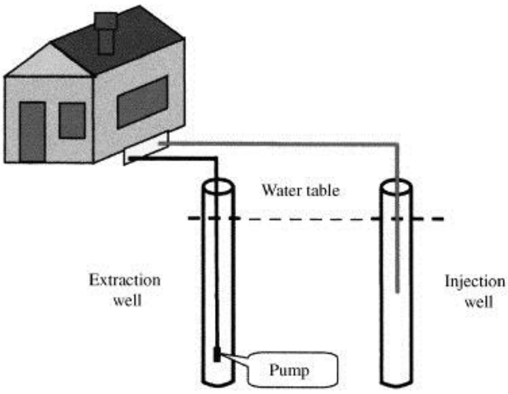
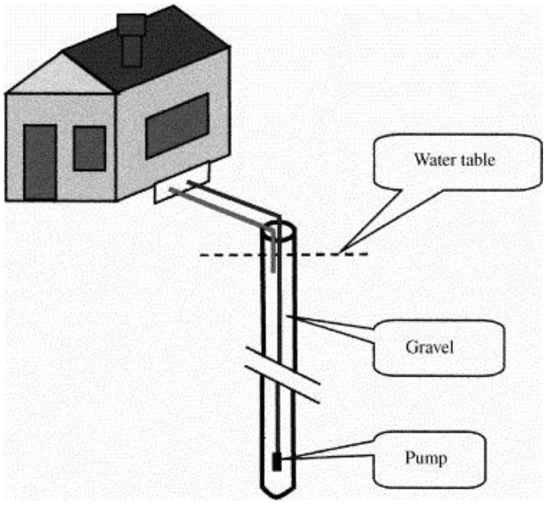
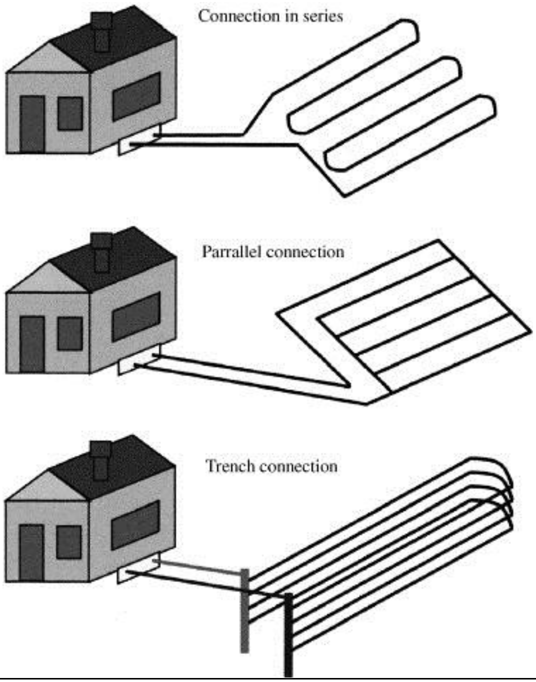
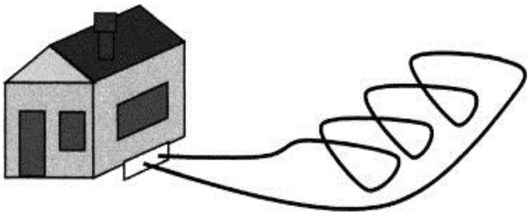
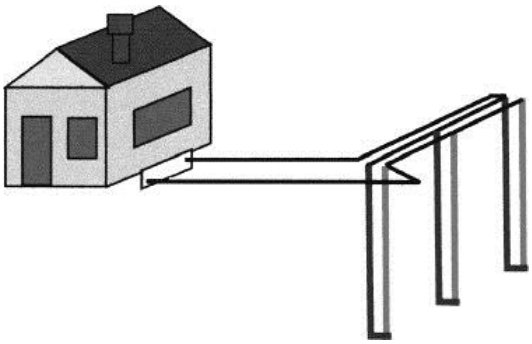
APPENDICES

APPENDIX A

A. 1 OPEN LOOP SYSTEM TYPES

Name	Image
Two well type (with extraction well and injection well)	
Standing column well (can also be considered as closed loop system)	

A. 2 CLOSED LOOP SYSTEM TYPES

Name	Image
Horizontal-type closed loop system	
"Slinky"-type closed loop system	
Vertical – type closed loop system	

A. 3 WATER WELL TERMINOLOGY