An-Najah National University
Faculty of Graduate Studies

Theoretical and Experimental Analysis of Combined Thermal Solar Collector and Horizontal loop Ground Source Heat Pump

By

Ibrahim Mohammad Ibrahim Khoswan

Supervisor

Dr. Abdelrahim Abusafa

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This Thesis was defended successfully on 16/8/2012 and approved by

Defense Committee Members	**Signature**
1. Dr. Abdul Rahim Abo Safa / Supervisor	…………………
2. Dr. Afif Hasan / External Examiner	…………………
3. Dr.Imad Brik / Internal Examiner	…………………

Dedication

I want to dedicate this work to the sole of my dad who always encouraged me for higher education but hadn't the opportunity to share me this moment.

To my mother, wife, sisters, brothers, to my little children Mohammad and Khalid.

Acknowledgment

I would like to thank Dr. Abdul Rahim Abu Safa for his continuously support and encouragement; I would like to thank all my instructors without missing any one of them for their unlimited support especially Dr. Imad Brik, for their support for the scientific research.

الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

Theoretical and Experimental Analysis of Combined Thermal Solar Collector and Horizontal loop Ground Source Heat Pump

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء مـــا تمـــت الإشارة إليه حيثما ورد، وأن هذه الرسالة كاملة، أو أي جزء منها لم يُقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

Abbreviations

ΔT	Temperature difference
r	Density
α	Thermal diffusivity
K	Thermal conductivity
Q	Heat transfer
COP	Coefficient of performance
W	Work
Cp	Specific heat at constant pressure
D	Diameter
S	Pipe Wall thickness
Lc	Loop length
Twet	Water entering temperature
P	Pressure
Tav	Average Temperature
A	Area
T g	Ground Temperature
SPBP	Simple payback period
VOCs	Volatile organic compounds
CFC	Clorofloro carbons
HCFC	Hydro chlorofluorocarbons
GWP	Global worming potential
GHP	Ground Source heat pump
LPG	Light petroleum gas

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Theoretical and Experimental Analysis of Combined Thermal Solar Collector and Horizontal loop Ground Source Heat Pump

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Abstract

Conventional energy resources are environmentally harmful unlike renewable energy resources. At the end of the last century the world came together to address the problems of climate change; which led to the thinking of ways to conserve energy and reduce the emissions. The Geothermal energy is one of the most important ways to conserve energy. The main objectives of this research study are: To design and built Horizontal loop Ground Source Heat pump, to obtain a comparison between ordinary heat pump and geothermal heat pump, to find the effect of the heat sink temperature on the performance of the heat pump, and to find the effect of adding a solar water heater to the system in the heating mode on the performance of the system. For this purpose a full design was conducted for the ground horizontal loop heat pump, the system was build and tested for heating and cooling modes before and after the heat pump was connected to the ground. The same test was held after connection to a solar water heater. The COP found to be around 5 to 6 for cooling, for heating the COP was found to be between 3.5 and 4. And for solar water heater it was 7 for a temperature difference of 5°C and more.

The payback period for the economical feasibility study of the geothermal heat pump compared to conventional systems was 2 months if

the comparison was between installing GSHP not a Diesel Boiler system, 6 months if the comparison was between installing GSHP or LPG boiler system, 15 months if the comparison was between installing GSHP or conventional heat pump. And the reduction in the emissions as calculated for a home load of 35 kW if heated with diesel and if heated with GSHP was 307 tons of CO_2 though the 25 years life cycle which would need 12320 trees more.

Chapter One

Introduction

Chapter One
Introduction

Conventional energy sources based on oil, coal, and natural gas are harmful to environment, to economical progress, and to human life. These traditional fossil fuel-based energy sources are facing an increasing pressure on a host of environmental fronts, with the most serious challenge confronting the future use of coal being the Kyoto Protocol greenhouse gas reduction targets. Renewable energy sources currently supply around 15% of world's total energy demand in 2008 [1]. The supply is dominated by traditional biomass, mostly fuel wood used for cooking and heating, especially in developing countries. New renewable energy sources (solar energy, wind energy, modern bio-energy, geothermal energy, and small hydropower) are currently contributing in energy production in the world. A number of scenario studies have investigated the potential contribution of renewable Energy resources to global energy supplies, indicating that in the second half of the 21st. century their contribution might reach 20% with the right policies in place [1].

The potential of renewable energy resources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as small hydropower, wind, solar, biomass, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources [2]. It is time for transition to renewable-based energy systems, taking into consideration the costs of solar and wind power systems which have dropped substantially in the past

30 years, and continue to decline, unlike the prices of oil and gas which continue to fluctuate, in fact each moving in opposite directions [2].

It is becoming very clear that the future growth of the energy sector is primarily in the new renewable resources regime, and not in conventional sources. In fact the financial markets starts to awake to the future growth of renewable and other new energy technologies,

The renewable energy systems can have dramatically reduced, and widely dispersed environmental impacts, rather than larger, more centralized impacts of conventional systems that in some cases are serious contributors to ambient air pollution, acid rain, and global climate change, keeping in mind, the social, economical and environmental effects of renewable energy system which will be an extra. And Geothermal Energy is one of the renewable energy resources which is a clean low cost energy based on the idea of using the ground as a heat source/sink (which is defined as the Medium where heat is absorbed/rejected without changing its temperature) to reduce the cost of heating or cooling or for getting high temperature from the earth below the crust for producing steam and thus generate electricity.

Geothermal energy in both cases is a sustainable renewable energy resource because it reduces the energy consumed, and thus reduces the emissions and the use of the resources, this way it is a sustainable energy resource and sustainable way of using resources keeping in mind meeting our needs without compromising the needs of the future generations. So it has an economical dimension (reducing costs), ecological dimension (maintaining the environment, maintaining the resources, and reduce the emissions), Social dimension (human being health, human prosperity, and human development) with the fact those future generations was taken into consideration by acting this way, and that is the basis of the sustainable economies that are modeled now days in Sweden, Canada, and many countries in the world [3]. In fact that was the basis of the Rio summit 1992, Kyoto protocol 1997, Johannesburg Summit 2002**,** Millennium Summit 2005, which all was to address the problem of global warming and change of climate.

Geothermal energy that uses the ground as a heat sink makes use of the refrigeration cycle in which the refrigerant is pumped from the evaporator heat exchanger forcing the refrigerant to evaporate by reducing the pressure inside the evaporator we can bring the refrigerant vaporize at temperatures lower than ambient temperature, and the heat that is absorbed in the lower temperature medium is rejected into the condenser unit at high temperature which is another heat exchanger and the refrigerant is then condensed at the high temperature medium because it is on the high pressure side. To bring the refrigerant to vaporize again an expansion valve is used to reach to the lower pressure state again. If the cycle is reversed by means of a 4-way valve the low temperature side becomes the high temperature side and vise versa, and the refrigeration cycle is a heat pump. Heat pumps are the most efficient known way that can be used for heating and cooling as it has the best coefficient of performance (which is defined as the energy output divided by the energy input as will be shown later), Figure (1.1) shows the components of a refrigeration cycle and the high and low pressure sides of the cycle. The power consumed for operating the cycle is always lower than the amount of useful power because we use the power for producing pressure difference not to produce heat this power is used to make the cycle moves opposite to the conventional way i.e. from the lower temperature side to the higher temperature side for this it is called heat pump. Of course it has negative impacts on the environment but it is much less than any source for the conservation of energy that can be achieved [4].

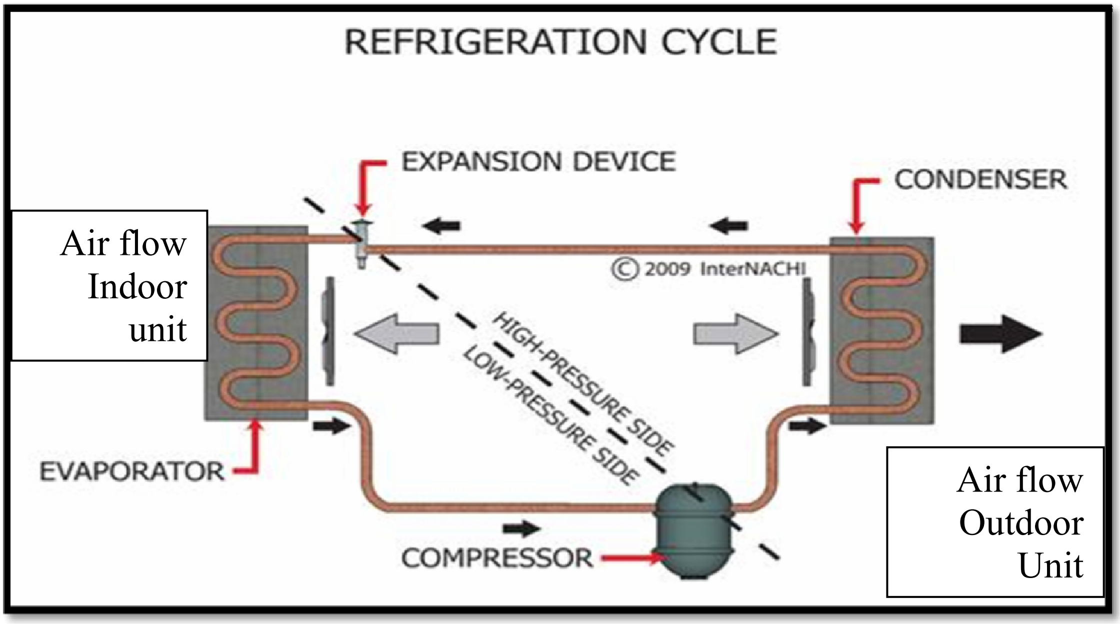

Figure (1.1) Refrigeration cycle [4]

Heat pumps are normally used for decreasing or increasing the temperature of the desired space for example from 35ºC to 23ºC in summer and from 10ºC to 23ºC in winter as per ASHRAE standards. Then the high temperature will surely depend on the reference temperature which will be the cold medium temperature, the higher the temperature of the cold medium the higher will be the temperature of the worm medium, which means better performance of the heat pump at the same power input, and this is the principle of the geothermal heat pump to enhance the environment of the evaporator (ground temperature is higher than ambient temperature in winter the ground is heat source) to achieve better performance, and lower temperature for the condenser (ground temperature is less than ambient temperature in summer then ground is heat sink) as shown in figure (1.2) below.

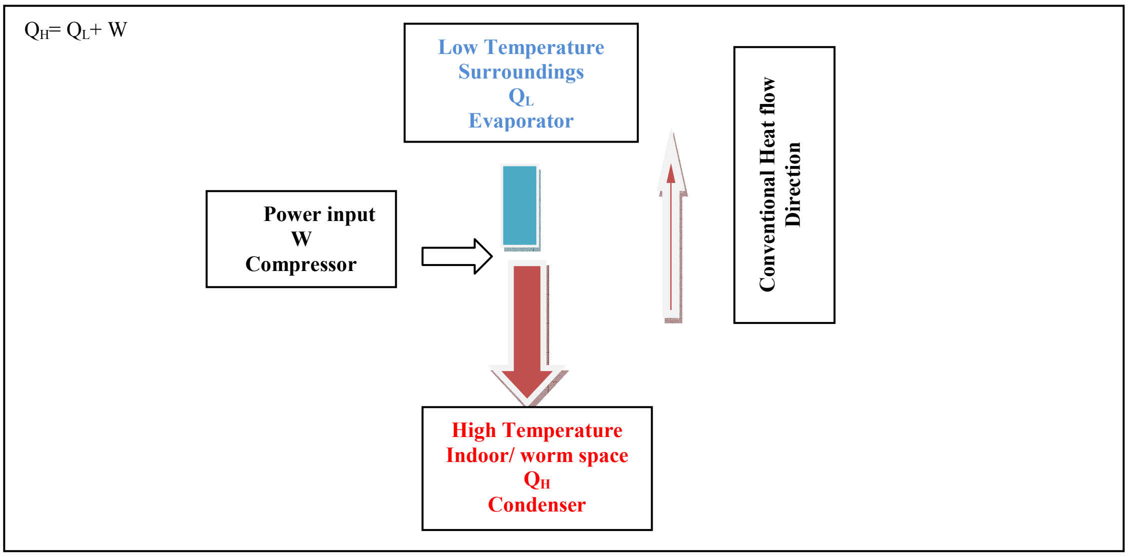

Figure (1.2) Heat flow and the second law of thermodynamics for heat pump

That will increase the overall performance, reduce costs, and reduce emissions [6]. Geothermal heat pumps are modern technology, it has been known for several years, but since 2005 it has spread all over the world. Figure (1.3) presents the geothermal heat pump use worldwide and for different periods of time which take us back to the 1995 when geothermal energy was only 14617 TJ/year but in 2005 the consumption was more than 87503 TJ/year which is 6.2 times more. Sweden is the most leading country in geothermal energy, the very low temperature of the weather there makes it difficult to use conventional heat pumps but the earth has a constant temperature no matter what the ambient temperature is and that why the use geothermal in melting ice in tunnels, streets and as high quality energy for heating. USA is the second leading country in this field. Many other countries are also using this technology now days but it is still new.

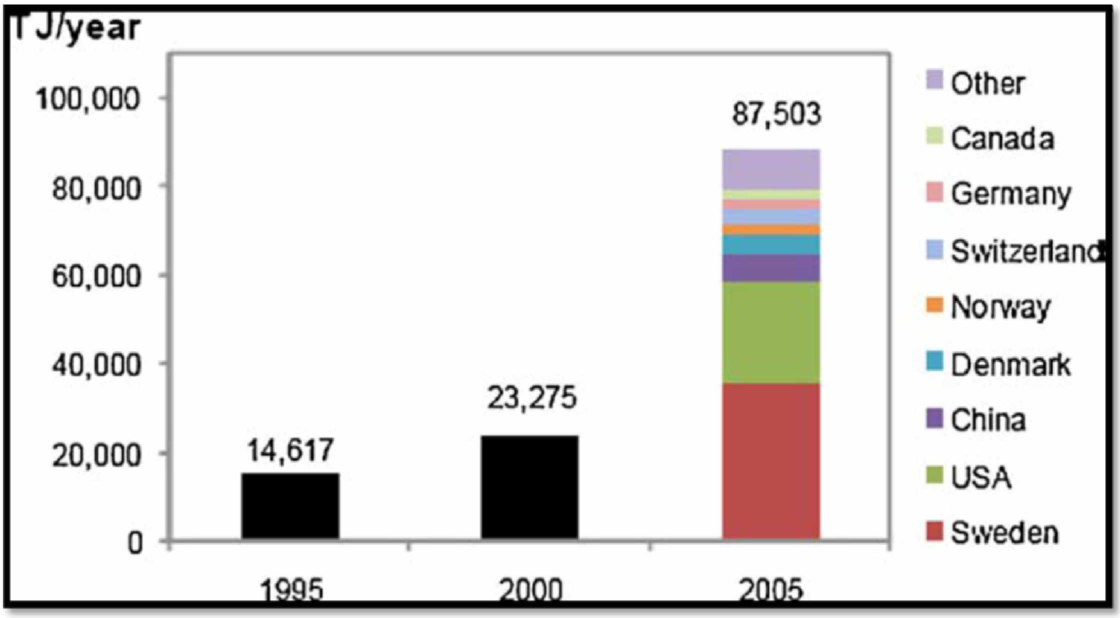

Figure (1.3) Geothermal heat pumps spread worldwide [6]

Types of Geothermal Heat Pumps:

Geothermal heat pumps use embedded heat exchangers to exchange heat from or into the ground, and because it has no outdoor unit to exchange heat with the ambient air is known as ground source heat pumps.

The geothermal heat pumps are divided into several types depending on the loop design, loop orientation. Open loops and closed loops. In the open loops systems, water is drawn from underground or lakes and used directly in heating or cooling the building. Closed loops use a dedicated fluid loops that is circulated in ground or lakes to geo-exchange the energy and this can be divided into three parts. The vertical loops the horizontal loops and the water surface loops. In the vertical loops which are commonly used, loops are run perpendicular to the ground surface and the holes can be several hundreds of meters below. As shown in figure (1.4) below.

Figure (1.4) Vertical loop geothermal heat pumps [7]

Horizontal loops run parallel to the surface and close to the surface see figure (1.5) below. Surface water loops uses the body of water as a heat source or sink.

Figure (1.5) Horizontal Geothermal heat pumps [7]

In this study, a combined geothermal heat pump with solar water heater was built and tested in the new campus of An-Najah National University; the location is north of the open court behind the college of physical education. The selection of this site was because of the ease of access for excavation, loading and unloading of materials, availability of water, and electricity. The idea of the geothermal heat pump started in the mid of the previous century. Combining solar water heater to such system creates better environment for the evaporator which improves the performance of the heat pump in sunny winter days. Energy utilization in the environment is an increasing concern, and geothermal heat pump systems also known as ground source heat pump or geo-exchange systems are now relatively well established as means of significantly reducing energy consumption in space conditioning of buildings. This improvement in efficiency, however, generally comes at higher first cost, which must be offset by lower operating and maintenance cost as will be shown later. The main objectives of this research study are: To design and build Horizontal loop Ground Source Heat pump, to obtain a comparison between conventional heat pump and geo-thermal heat pump to find the effect of the heat sink temperature on the performance of the heat pump, and to find the effect of adding a solar water heater to the system in the heating mode on the performance of the system. To perform an economical analysis based on the life cycle cost analysis for diesel boiler, Gas boiler, conventional heat pump, and geothermal heat pump. And finally to perform an environmental impact analysis for the gas, diesel, conventional heat pump, and geothermal heat pump.

Chapter Two

Literature Review

Chapter Two
Literature Review

Technology is used to control the world, because technology is a system to make our lives better, and knowledge of using tools and machines to do tasks efficiently. The environment in which we live always needs improvements for better life and better living conditions. From the start of the life on this planet human beings tried to improve quality of their lives. Human beings worked on air conditioning long time ago. For example the Roman circulated water through the walls to cool them down**.** Other techniques involve the use of wind towers to cool buildings during hot season were in Persia, and in Egypt the fan was invented and used in the middle age. In the second century Ding Huane [8](a Chinese inventor) invented rotary fan of air conditioning manually powered, before that in the first century, Emperor Xuanzong cooled the cool Hall built in the imperial palace [8].

In 1758 Benjamin Franklin and John Hadley conducted an experiment to explore the principle of evaporation as means to rapidly cool an object. In 1820 Michael Faraday discovered that compressing and liquefying ammonia could chill air when the liquefied ammonia was allowed to evaporate. In 1842 John Gorrie used compressor technology to create ice. In 1902 the first modern electric air conditioning unit was invented by Willis Haviland Carrier .Thomas Midgley, Jr. created the first chlorofluorocarbon gas, Freon, in 1928 [9]. Earlier in 1912 Heinrich Zoelly invented the first ground coupled heat pump. Donald Kroeker designed the first commercial geothermal heat pump to heat the Common wealth building (Portland, Oregon) and demonstrated it in 1946 [10] , but Professor Carl Nielsen of Ohio State University built the first residential open loop version in his home in 1948. After World War II several projects were installed and researches were on going. But horizontal loops researches decreases because the leaks happened underground, system under sizing, and drying problems around pipes. The technology became popular in Sweden as a result of the 1973 oil crisis, and has been growing slowly in worldwide acceptance since then, and after solving problems that appears in 1940s[10].

The development of Polyethylene pipe in 1979 greatly augmented the heat pump’s economic viability [11]. As of 2004, there are over a million geothermal heat pumps installed worldwide providing 12 GW of thermal capacity [12] . Each year, about 80,000 units are installed in the USA and 27,000 in Sweden [13].

The first concept of determining the thermal response of the ground was presented by Mogensen [14]. He suggested a chilled heat carrier fluid system. After that the first test rigs for thermal response tests were developed independently at Lulea Technical University, Sweden [15] and at Oklahoma State University, USA. They were both based on Mogensen’s concept but they used heated carrier fluid. Demir et al. performed the experimental verification of the heat transfer in a horizontal (parallel pipe) ground source heat exchanger [16]. Ozgener et al. conducted an experimental evaluation of a vertical solar assisted ground coupled heat pump system where the solar collector was directly installed into the ground coupled loop, [17]. Hepbasli studied the exergetic aspects of a ground solar heat pump system integrated with a solar domestic hot water tank, [18]. Trillat et al. designed and built a family house in region of Savoie, France, they evaluated these kinds of systems, [19], and a similar study was done by Han et al. in another family house in the countryside of Tianjin, China, [20]. Wang et al. presented a new management strategy to improve the efficiency of these systems [21]. A model and an experiment of a solar assisted ground coupled heat pump system with a vertical double-spiral ground heat exchanger were done by Bi et al [22]. Allen [23] wrote in using low enthalpy ground water for enhancing heat pumps. Piechowski [24] solves heat and moisture transport equations for horizontal pipes embedded in soil. He states that the soil temperature around a pipe drops by 30–40% within a few centimeters, indicating the influence of precise near field models.

Berdal [25] discussed the design of a process consisting of combining the solar water collector with the vertical geothermal heat pump. He studied the temperature decrease in ground in the long term for small systems and made simulation beside the theoretical proof for that decrease in ground temperature of geothermal heat pump vertical bore hole U tube systems. Eugster and Rybach [26] conducted a series of measurements on a 105 meter deep bore hole heat pump.

In this study, horizontal loops were buried under ground they were used as a heat sink\source in order to reduce the cost of digging. To enhance the coefficient of performance in winter a solar plate collector was used.

Solar radiation is relatively high in Palestine, the annual average daily solar radiation intensity is about (5.4) kWh/m^2-day [27], which is mostly equal to the USA annual daily solar radiation intensity [28].

The sun shines over (2800) hours all over the year in Palestine, and this makes our ambient relatively wormer than other areas in Europe and North America where the ambient temperature is extremely low.

In areas with shallow ground is too cold to provide comfort directly, but it is still warmer than the winter air. The thermal inertia of the shallow ground retains solar energy accumulated in the summertime, and seasonal variations in ground temperature disappear completely below 10m of depth. That heat can be extracted with a geothermal heat pump more efficiently than it can be generated by conventional furnaces. Heat pumps are very efficient because they utilize the electrical power to absorb heat from cold ambient to indoor. But geothermal heat pumps are more efficient and economically feasible ecologically. In high temperature regions geothermal resources, a geothermal heat pump can still provide space air conditioning and heating. Like an air conditioner or refrigerator. A ground-source heat pump uses the shallow ground or ground water (typically starting at 10°C –12 °C depending on the location and several factors) as a source of heat, thus taking advantage of its seasonally moderate temperatures. In contrast, an air-source heat pump draws heat from the air (colder outside air) and thus requires more energy and vise versa in summer and the same system can be used to circulate the cooled water through the house for cooling in the summer months. The heat is exhausted to the relatively cooler ground (or groundwater) rather than delivering it to the hot outside air as an air conditioner does. As a result, the heat is pumped across a larger temperature difference and this leads to higher efficiency and lower energy use [29]. This technology makes geothermal heating economically visible in any geographical location. In 2004, an estimated million ground source heat pumps with a total capacity of 15 GW extracted 88 pJ of geothermal energy for space heating. It is estimated that the global geothermal heat pump capacity will grow by 10% annually [30].

Chapter Three

Air Conditioning and Basic Thermodynamics

Chapter Three
Air Conditioning and Basic Thermodynamics

Thermodynamics is the science that relates the heat with the power [31], Although this Thesis is mainly focusing on Ground Source Heat Pumps (GSHP’s) the underlying theory and components of heat pump systems are the same regardless of the heat source utilized.

3.1 Thermodynamics Basics

First law of thermodynamics is the law of conservation of energy and the second law of thermodynamics is the law asserts that energy has quality as well as quantity, and actual processes occur in the direction of decreasing quality of energy.

This chapter will outline the fundamental principles behind heat pump technology. Clausius stated that it is impossible to operate a cyclic device in which the only effect is the transfer of heat from a cooler body (T_c) to a hotter body (T_h) ([The second law of thermodynamics) [32]. This still holds true but it has been found that the addition of an energy input can produce a net heat transfer from T_c to T_h.

The first mention of exploiting this was William Thomson [33]. Then in 1852 Lord Kelvin as part of his theory of the dissipation of energy outlined and designed a ‘heat multiplier’ to heat a room to a higher temperature than its surroundings using less fuel than if burned in a furnace [34]. He had figured out the basic concept of a heat pump; a device which transfers heat from the surroundings to a warm space in order to maintain that space at a higher temperature than its surroundings. The great majority of heat pump systems work on a vapor compression cycle [35]. Although there are several different thermodynamic cycles which can feasibly perform heat pumping, but normally heat transfer usually occurs from a hotter body to a cooler body (until they reach equilibrium). On the contrary it can be seen that a heat pump is moving heat in a direction it would not normally travel. In this case it is helpful to remember that temperature is simply a term for heat energy. The heat energy of a body cannot be raised exempt for adding energy to it. A heat pump achieves this in the form of work for compression. This is in correlation with the first law of thermodynamics which states that it is always possible to convert any given quantity of mechanical energy into its equivalent heat energy [36].

3.2 Difference between Heat and work

Energy can transfer in a closed system in two forms heat and work. And heat is the energy transferred between two systems because of temperature difference. If there is no temperature difference there is no heat transfer [37]. Thus if there is energy transfer through a system and it is not heat it is work. The only two forms of energy interacts with a fixed mass are heat and work. And heat transferred to a system increases the energy of the molecules of the material and thus the internal energy of the system. But the work is the energy interaction which is not caused by the temperature difference between the system and its surroundings as mentioned. It can be a piston work, electric work shaft work. Figure (3.1) below shows the actual vapor compression Refrigeration cycle on a Temperature-Entropy (T-S) diagram and equipment required to create it.

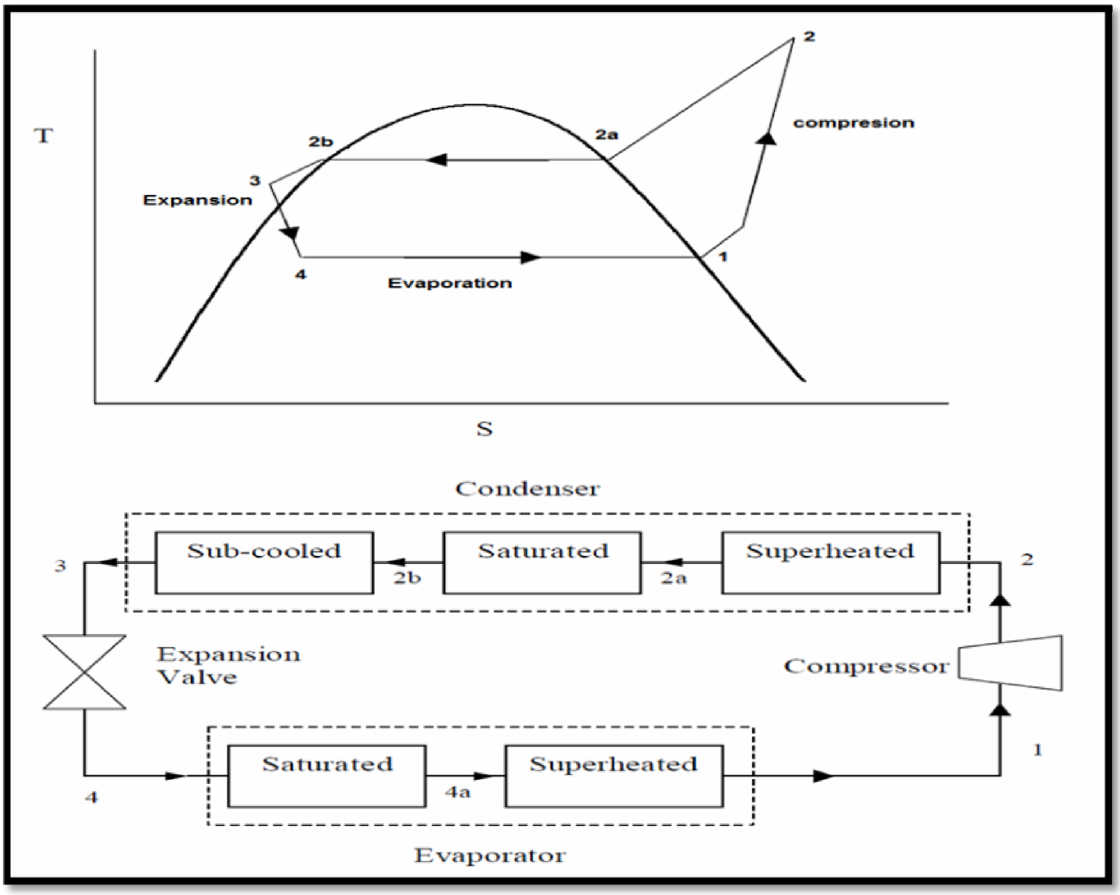

Figure (3.1): Typical Refrigeration cycle with T S Diagram [37]

This is a useful starting point for understanding the Vapor Compression Cycle tracking the movement of a ‘working fluid’, which in this case is a refrigerant (in liquid, vapor form), form 4-1 and 2a-2b ‘isothermal’ i.e. constant temperature) processes are taking place. These represent stages where heat is either extracted from a source (air, water, ground etc) or deposited in a sink (for a heat pump this could be a building). From 1-2 and 3-4 are ‘Adiabatic’ processes where no heat is gained or lost although there is a temperature change. All stages in this process are assumed to be reversible. In reality however this is not possible to achieve this ideal reversible cycle. Firstly difficulties are presented by trying to compress a two phase liquid and therefore evaporation will continue to the saturated vapor line. Secondly during the compression stage heat will be lost due to frictional losses. Furthermore the work output from the expander is relatively small compared to the work input during compression (due to a smaller specific volume) and therefore it is usually replaced by a simple throttle valve.

3.3 Efficiency and coefficient of performance

Efficiency is a main term in thermodynamics it indicates how well is the energy is converted or transferred. Efficiency is defined as the desired output divided by required output. And the same for coefficient of performance which is used for heat pumps and refrigerators. The coefficient of performance of any refrigerator is given by:

$$COP_R = \frac{Q_c}{w}, \frac{\text{Cooling load}}{\text{compresor work}} \qquad \text{3.1}$$

Where COP_r is the refrigerator coefficient of performance and Q_C is the cooling capacity, W is the net work consumed. Carnot cycle is the most efficient cycle ever found and the maximum theoretical performance is given by:

$$COP_{rc} = \frac{1}{\frac{T_h}{T_c} - 1} \qquad \text{3.2}$$

Where COP_{rc} is Carnot refrigeration coefficient of performances, T_c is the absolute cold Medium temperature, T_h is the absolute hot medium temperature, and for the heat pump

$$COP_{hp} = \frac{Q_h}{w}, \frac{\text{Heating Load}}{\text{Compresor Work}} \quad \text{...3.3}$$

And the maximum is theoretical performance which is for Carnot cycle is given by

$$COP_{hpc} = \frac{1}{1-\frac{T_c}{T_h}} \quad \text{...3.4}$$

or

$$COP_{hpc} = COP_{cr} + 1 = \frac{1}{\frac{T_h}{T_c}-1} + 1 = \frac{1+\frac{T_h}{T_c}-1}{\frac{T_h-T_c}{T_c}} = \frac{T_h}{T_h-T_c} = \frac{1}{1-\frac{T_c}{T_h}} = Cop_{hpc}$$

The heat pump itself is not ‘creating’ this extra heat but simply transporting it from a large low temperature ambient source, adding the heat produced from compression work and delivering a final amount to the desired hotter body. The same principle can be utilized to cooling instead of heating, and it is the basis for refrigeration and air-conditioning systems. For cooling the refrigerant flow is reversed, i.e. the condenser acts as the evaporator and vice versa, heat is absorbed inside the building and deposited outside.

3.4 Changes of State

In order to understand this movement of heat a review of what happens during a phase change (change of state) occurs is important. A phase change is defined as a sudden change in one or more thermodynamic properties, i.e. specific heat capacity, and a small change in thermodynamic variables such as temperature. Change from liquid on to vapor is known as first order phase changes. When this occurs, energy appears in the form of heat absorbed or released depending on the direction of the phase change. These processes are termed endothermic if energy is absorbed and exothermic if energy is released. This amount of energy is fixed and typically significant [34].In the cycle shown the heat is moved by the refrigerant between 4 and 1. In heating mode energy is absorbed into the system within the evaporator coil (4-1), the refrigerant is changed from a low temperature/pressure liquid and vapor mix to a low temperature/ pressure vapor through the addition of heat from the ambient source this will occur at the saturation line, This is called isothermal heat absorption from the outdoor in heating mode, and because of the vacuum that is resulted before the compressor the refrigerant is forced to vaporize at low temperature. In some cases the saturated vapor become superheated, this will cause flow control devices to admit the correct volume of refrigerant to the coil by means of thermostatic expansion valve on after the condenser point 3-4. If no superheating is involved this process is complete at the saturated vapor line (1). The vapor then flows to the compressor where it is transformed into a high temperature, pressure vapor and discharged to the indoor coil (condenser in heating mode). During condensation the heat picked up during evaporation and added during compression is deposited to the indoor heating distribution system (water, air), which is initially at a lower temperature, and reject heat as a result of condensation from the refrigerant (2-3) as a matter of fact this is not possible without the forced heat exchange that is caused by the fan that convicts the heat from the condenser unit to the surroundings and from the evaporator unit to the surroundings. Warm high pressure liquid leaves the indoor coil (3) and undergoes a temperature/pressure drop by passing through the throttle valve (3-4) it drops below the temperature of ambient heat supplied and this drives the heat transfer during evaporation and hence the cycle repeats itself. Heat exchangers are used to facilitate heat transfer to the evaporator and from the Condenser and are designed depending on the load and the temperature of the medium. The coil is usually copper with aluminum fins. The length of the tube is a function of the heat transferred which is calculated as a surface area. The number of fins is also determined according to the load. The number of rows of the tubes and the fan is also a determinant factor to the size of the heat exchanger. The medium that the exchangers are placed in, also an important factor, because this will increase or decrease the heat capacity of the medium.

3.5 Heat Generation by Compression

In the section above it has already been mentioned that heat is given off during compression. The first law of thermodynamics relates to the fact energy cannot be created or destroyed, but simply transferred from one form to another. This is what happens in our case when the energy input in the form of work (electricity) for compression is simply converted to heat energy. Because the compressor compresses the vapor molecules together that results friction resulting heat. This is then added to the energy picked up from the surroundings. Utilizing a liquid as the working fluid instead of air is preferable since it is "closer to the isothermal conditions of taking in and giving out heat of the ideal Carnot cycle" [33]. Air is a 'bulky' working medium and has higher power demands associated with larger frictional losses. Furthermore liquids have a greater "latent heat of vaporization" [33] than air and therefore heat pump units can be more compact. These are some of the main reasons behind the adoption of the vapor compression cycle for heat pumps as opposed to a reversed Joule cycle using air as the working fluid.

3.6 Low Temperature Heat Sources

Any heat source for a heat pump must have properties that are necessary to qualify for an ideal heat source these properties are:

1. High and stable during the heating season.
2. Abundant.
3. Not corrosive or polluted.
4. Have favorable thermo-physical properties.
5. Require low investment to exploit.
6. Have a high specific heat per unit volume (so there is only a small temperature drop during extraction). [35]

Variety different sources are available in nature from which a heat pump can draw heat during the evaporation process in the outer heat exchanger. The option selected will depend on local circumstances, the location of the building and its heat demand. The most popular heat sources are air, water (i.e. lake, pond, and ground water) or the ground (soil, rock). Systems have been designed to make use of all types of different heat sources however such as exhaust air, sea water, waste water and effluent water. There is a popular conception that 0°C, the temperature at which water freezes, this is the limit of 'coldness' and therefore no heat can be extracted at this temperature or below whether it be from the earth, water or air. It is possible that we are conditioned to think in this way since human body temperature needs to be maintained at 37°C and as we move away from this value we sense discomfort and 'coldness'. However it is only at -273°C (absolute zero on the Kelvin temperature scale) that a substance is devoid of all temperature and energy. Therefore the environment can be seen to be a "surrounding cushion of useful heat that makes the operation of a heat pump possible" [34]. So even at 0°C there are still 273 units of useful energy in the environment. This energy stored in the environment is low grade energy; unlike electricity for example which is high grade energy, and for this reason we need to go through the heat pump process because it can serve a useful purpose which is heating. Water is a good option for a heat source if it is deep enough to prevent temperature equalization between top and bottom of the abstraction source. However it is clear that this will only be an option if a suitable water source is nearby. In addition groundwater systems can be utilized which have an 'open loop' configuration as described above if suitable aquifers are present for extraction and re-injection. In all these sources the main thermal recharge for horizontal loop systems is provided for mainly by solar radiation to the earth's surface as described earlier [35]. except when heat pumps utilize exhaust building air, waste water such as effluent or cooling water or waste heat , this will not have recharge.

Chapter Four

Thermal Load Calculations

Chapter Four
Thermal Load Calculations

4.1 Introduction

The heating and cooling load calculation are the first steps of a stronger HVAC design procedure; a full HVAC design involves more than just the load estimate calculation. It involves correct sizing the HVAC system, selecting HVAC equipment and designing the air distribution system to meet the calculated loads. It begins with an accurate understanding of the heating and cooling loads on a space [36]. Historically, energy codes did not address stringent levels of energy efficiency, but rules of thumb were developed for HVAC sizing that worked based on the construction of buildings at that time. As energy codes have become more stringent since 2000 building enclosures have become more energy efficient; however, these rules of thumb have not changed. Full credit should be taken for improvements such as better windows, enhanced air tightness strategies, and additional insulation [37]. It is detrimental to energy use to oversize the HVAC system, comfort, indoor air quality, and building and equipment durability. All of these impacts derive from the fact that the system will be “short cycling” in both heating and cooling modes, and to reach the peak operational efficiency and effectiveness, the HVAC system should run for as long as possible to meet the loads. An oversized HVAC system will have both a higher initial cost and a higher operation cost. The frequent starting and stopping of short cycling can lead to premature failure of the equipment, limits the total amount of air circulating through the room, and inadequate duration of airflow. In the cooling season in humid climates, calm cold conditions can occur due to reduced dehumidification which caused by the short cycling of the equipment. Because the system has to run long enough for the coil to reach the temperature for condensation to occur and an oversized system that short cycles may not run long enough to condense moisture from the air sufficiently. In fact excess humidity in the conditioned air delivered to a space may lead to mold growth in the space [37].

According to ACCA (Air conditioning Contractors of America) the critical inputs to load calculations and their associated risks are:

- Indoor and outdoor design conditions which includes Location, Latitude, Elevation, and Orientation, Internal conditions (Indoor temperature and relative humidity).

- Building Enclosure which includes Insulation levels of walls, ceilings, and floors Window specification, Thermal conductivity , Solar Heat Gain Coefficient (SHGC), Infiltration and ventilation levels, Interior and exterior shading.

- Internal loads which includes, Number of occupants, Electronics, lighting and appliances.

4.2 Load Components

Heating and cooling load calculations are dependent on the building location, indoor design conditions, orientation, and building construction. The use of commercial software to calculate the heating and cooling loads greatly simplifies the process.

4.2.1 Peak Heating and Cooling Load

The peak heating load represents the rate of heat energy lost to the surrounding environment at design outdoor and indoor conditions, which must be produced by the HVAC system to maintain occupants comfort. The total estimated heat loss is a combination of the sensible heat loss through conduction, infiltration, and ventilation loads. No credit is taken for solar gains or internal loads in calculating the heating load because the peak heat loss occurs at night during periods of occupant inactivity. The peak cooling load represent the rate of heat energy gained by the house from the surrounding environment at design conditions, which must be removed by the HVAC system to maintain occupant comfort. The cooling load is a combination of the sensible and latent heat gains.

4.2.2 Location – Design Conditions

The building location is described by its latitude and elevation. And it describes the values for the outdoor design conditions such as the elevation of the location, latitude, winter heating dry bulb temperatures, summer cooling dry bulb temperatures and relative humidity (RH) information. Indoor design conditions for the cooling season design conditions of 24°C (75 °F) 50% RH and heating season design conditions of 21°C (70 °F) 30% RH as per ASHRAE Comfort Zone Chart. These conditions represent the regions of the ASHRAE comfort zone where on average, people feel most comfortable.

The ambient design conditions described by the ASHRAE tables represent the average temperatures for a long period that will not be exceeded more than a few hours per season, and they do not represent the worst weather conditions ever experienced in a given location.

A right-sized system will run almost all of the time at the outdoor design condition and proportionally less at temperatures closer to the inside design temperatures. Designing a system using peak heating and cooling loads based on extreme weather conditions that occur for only a few hours per season, will result in an oversized system.

4.2.3 Building Orientation

The orientation of the building must be considered in the cooling load calculation because of the change in solar heat gains at various times of the day East, Southeast, South, Southwest, West, North, Northeast Northwest are typically the orientations used for undertaking load calculations, although the exact cardinal orientation can be used for houses. House orientation can greatly affect the sensible heat gain on the house depending on the ratio of windows to opaque walls and the degree of shading from the sun. The peak cooling load for the worst case orientation is acceptable most often.

4.2.4 Building Components

Building construction, materials, and proper details are critical components of the heating and cooling load calculations. The R-value (thermal resistance) of the building foundation construction components, wall, and roof, can be accurately calculated using the insulation levels specified combined with the remainder of the components that make up the construction assembly (i.e. sheathing, drywall, exterior siding materials, roofing materials, structural framing system, etc.). The window performance, described by the U-value (transfer coefficient) and SHGC (solar heat gain coefficient), must be known and accurately represented by the data input.

4.2.5 Ventilation And Infiltration

Infiltration and ventilation brings outside air into the conditioned space, impacting the heating and cooling load. The target ventilation and infiltration rate must be accurately represented in the data input of the load calculation.

4.3 Refrigeration cycle

Heating ventilation and air conditioning systems always affected by the refrigeration cycle in the control and performance. And any form of cooling should use one of the following systems (vapor compression cycle, absorption, and thermo electric) but most cycles depend of the vapor compression cycle especially in HVAC systems and industrial systems. Figure [3.1] above shows a vapor compression cycle TS diagram. The superheated vapor from evaporator (indoor unit in cooling) enters the compressor which raises the pressure due to compression. This vapor enters the condenser (outdoor unit) at high pressure and high temperature where it rejects the heat to the surroundings. The condenser is a finned tube made of copper to force heat rejection by means of a fan to the surroundings. The same is for the evaporator which forces the air into the copper tubes to heat the refrigerant making the indoor temperature decreases as heat is absorbed from the cooled space.

In the normal air conditioner the saturated liquid vapor mixture is heated up by absorption of heat resulted from the vacuum in the evaporator connected to the compressor and enters the compressor as a superheated vapor. The vapor is superheated vapor at high pressure and ready to lose the temperature to become to equilibrium. The condenser makes this operation easy by forced cooling of the finned tubes to allow the vapor loses heat to a high temperature medium. This operation cools the vapor down to saturated vapor liquid mixture then to sub cooled liquid. And the pressure is still high to bring the pressure down an expansion valve reduces the pressure and prepare the liquid for vaporization by spraying the liquid into a mixture of vapor and liquid.

Although heat pumps are very useful but it has advantages and disadvantages the advantages of the heat pumps are:

1. Low running cost because the heat produced as a result of the refrigeration effect is always higher than the power consumed.

2. The first cost is very low compared to the conventional heating systems.

3. The carbon emissions are very low compared to the conventional systems.

4. Instantaneous heating no warm up.

Disadvantages of heat pumps are:

1. The indoor temperature depends on the surrounding temperature the lower the surroundings temperature the lower the performance.

2. Still have carbon emissions.

3. The heating has low humidity because no water vapor is resulted in this operation.

4. No heat is available without electricity.

For cooling and refrigerators there is no comparison because the only way to cool is using refrigerators that is why we used heat pumps to compare them with conventional heating systems.

To have better cooling performance in summer and in very hot weather cooling towers are installed and this is to increase the capacity of the condensers to reject heat into the surrounding by means of evaporative cooling. This can be explained as the condenser has high temperature water is sprayed above the condenser making it vaporizes and air is blown to increase the evaporative capacity of water. This will reduce the temperature of condenser as water will absorb heat from condenser to vaporize reducing the condenser temperature, but in winter when the performance is low particularly in cold weathers; auxiliary systems are used for compensation extra electric heaters are placed into the evaporator, heating coils are also used for heating as an auxiliary system. Here comes the idea for geothermal heat pump, which was used in cold countries without limitations in severe weather for better performance and higher temperatures no matter of the weather coldness. In the following section geothermal or ground source heat pumps are explained as an introduction to the experimental work that has been conducted in this thesis.

4.4 Geothermal source theoretical back ground

Geothermal heat pump or ground source heat pump consists of the same components of ordinary heat pump with the only difference is the outdoor unit (condenser in cooling, and evaporator in heating), instead of exchanging heat with the air by means of a fan and a finned tube heat exchanger, it exchanges heat with water by means of a Heat exchanger and a circulation pump that exchanges heat with earth or water in lake. This can be accomplished by placing the heat exchanger in a tank that is filled with fluid and insulated from ambient conditions. The fluid can be water or a mixture of water and antifreeze or alcohol. Water is a very good working fluid because it has high heat capacity. The larger the heat capacity of the fluid, the higher the heat exchanges between the heat pump and the geothermal heat exchanger, and the larger the performance of the heat pump. The specific heat of water is 4.19 kJ/kg°C but for air the heat capacity is 1 kJ/kg °C. This means that for each kilogram of air heat can be added as many as one kilojoule. But for each kilogram of water the maximum heat that can be added is 4.19kJ which is four times, but adding salt or antifreeze or anything to the water will decrease the heat capacity. Water is excellent for applications that are above freezing point and below boiling point. But in cold weathers fluids will have to withstand a temperature below freezing point of water, in this case adding antifreeze will be the solution and the performance will drop a little bit but the system will not be damaged because of freezing the water in the heat exchanger, which means that water will expand when ice is formed and damage the heat exchanger by deformation of the cylinder of tank.

The lakes or rivers will have a temperature that is higher than freezing point of water so in countries where temperature drops below the freezing point water in rivers and lakes is still at above 5°C which means better environment for the outdoor unit. If the heat exchanger is placed in the ground the temperature is higher and it is between 10-15°C or a little more depending on the location, the solar radiation, the conductivity of the ground the emissivity, and the wind speed that is adjacent to the ground. This is a constant temperature around the year.

This explains the idea of the heat sink which means that heat will not be accumulated to raise the temperature of the ground.

It is well known that half of the solar radiation received by the earth is absorbed at its surface and based on that reason the ground temperature will have seasonal variations down to a depth of around 15m. There is more variation in the first two meters. Beyond this level however the temperature is fairly constant and will roughly equate to the mean annual air temperature of the region as in figure (4.1), this is due to the fact the earth has a high thermal inertia of soil and is able to store the heat absorbed.

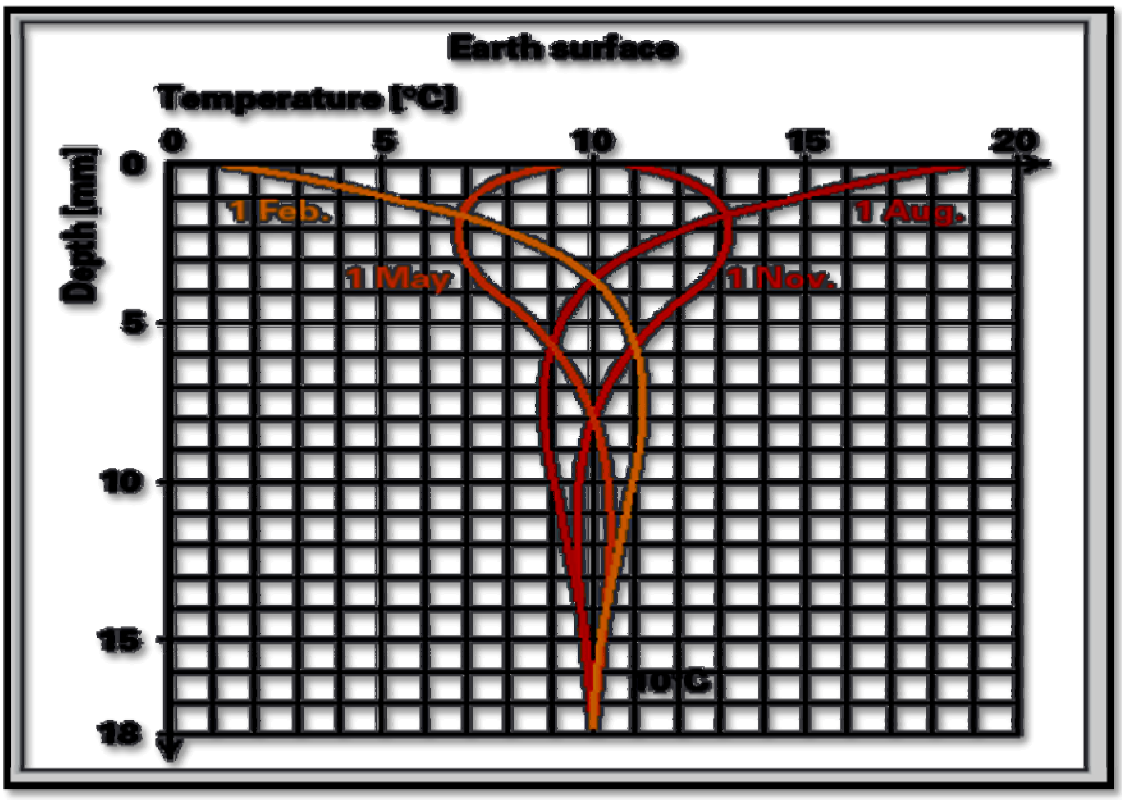

Figure (4.1) Seasonal Temperature variations reference UK [39]

After heat is extracted it is regenerated by solar irradiation, precipitation and on a smaller scale thermal gradient in the ground.

"Energy flowing from deeper layers upwards represents only (0.063-0.1 W/m²) and can be disregarded" however [39]. As depth increases further there is a slow but steady increase in temperature of 2.6ºC per 100m, the mean temperature at 100m is usually between 7-15ºC [40]. This is of course subject to variation dependant on the local geology, soil conditions and therefore two identical heat pumps may differ in performance according to location.

The ability of the ground to dissipate the heat rejected into it depends on three components: The Heat transferred through the earth's crust in the form of substance transfer, the heat conducted to earth through rocks, and the heat stored in rocks and fluids of the earth [41].

4.5 Ground Characteristics

The definition of geothermal energy is subject to variation, in some cases it is considered to be heat below 15-20m in the ground while in others simply all energy stored as heat beneath the earth's surface. Regardless of definition this relatively constant store can be utilized by a heat pump for heating and cooling applications since in winter the ground temperature will be above the average air temperature while in the summer it is likely to be below it see figure (4.2).

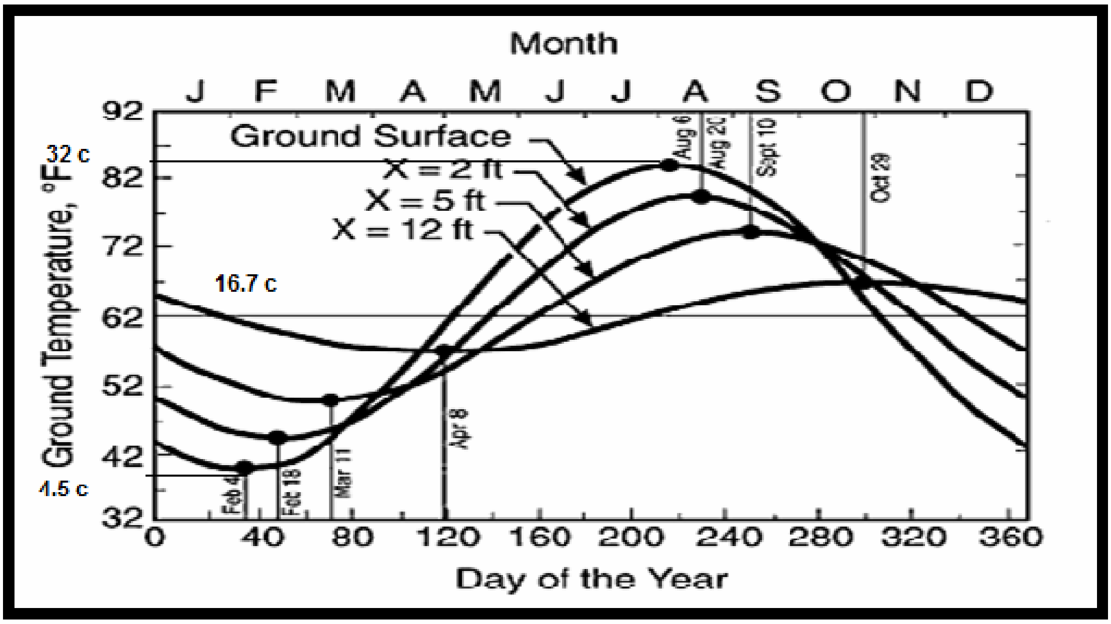

Figure (4.2) Typical Ground Temperature change around the year [42]

The capacity of the GSHP for heating and cooling will depend on not just the size of the system but also the thermal properties of the ground system performance is significantly affected by the material in which the ground heat exchanger (loop) is laid. Factors which will determine performance are [43]:

1. Subsurface temperature.
2. Thickness and nature of superficial deposits i.e. soil.
3. Rock properties i.e. stratigraphy (formation) and lithology (type). These will determine strength and conductivity.
4. Hydrological issues, depth to groundwater, seasonal variations in

Groundwater temperature, flow direction etc for vertical type geothermal heat pumps "In general groundwater flow improves heat exchange" [42], when significant flow is present, at 4-10°C heat exchange occurs through a dual mechanism of conduction in the aquifer material and convection in the groundwater itself. Ground source heat pumps which are located on a site of low permeability rock, and hence low water flow, will not benefit from convective heat transfer. Thermal conductivity and diffusivity are two parameters which need to be clarified in order to estimate the likely subsurface temperatures and heat transfer characteristics. The heat transfer to the ground collector (loop) will not only be determined by the area for exchange but also these two factors thermal conductivity and thermal diffusivity.

Based on the classical heat conduction equation developed by Fourier in 1822 which considers the soil to be a homogeneous and isotropic conducting medium the thermal diffusivity can be expressed in the following equation:

$$\alpha \nabla^2 T = \frac{\partial T}{\partial t} \quad \text{(4.1)}$$

Where T is the temperature (°K), t is time (s), and α is the thermal diffusivity (m^2/s) of the conducting medium and defined by

$$\alpha = \frac{k}{\rho\, c_p} \quad \text{(4.2)}$$

Where k is the thermal conductivity (W/(m °K), ρ is the density (kg/m^3)

And c_p is the mass specific heat capacity (J/(kg °K).The higher the value of α, the faster the propagation of heat within the medium [44].

4.5.1 Thermal conductivity (K)

Thermal conductivity is the quantity of rate of heat transmitted per unit area, per unit temperature gradient under steady state conditions. By Multiplying this factor by the thermal gradient will give the heat flow within the ground. When considering thermal conductivity in rocks factors such as porosity, composition and the nature of any saturating liquids will determine its value. Generally, the larger the extent of porosity the lower the thermal conductivity will be; unless the rock is saturated. Thermal conductivity can vary by a factor of two for rocks most commonly found near the surface and even more significantly for the range of sediments found in this area. Generally rocks have higher K values than soils. Variability in the latter is explained due to mixing of mineral and organic particles and their associated thermal characteristics [45]. Furthermore in dry soils air is trapped, and since this has a low K value, saturation will raise the conductivity of soils; “Low conductivity soil may require as much as 50% more collector loop than highly conductive soil” as in table 4.1 [43].

Table (4.1): Thermal Conductivity of Typical Rocks and Sediments [43]

Rock Material	Thermal conductivity W/ m2 °K
Low porosity sedimentary rocks (<30%) i.e.shale, sandstone, siltstone	2.2-2.6
Quartz sandstone (5% & 30% porosity)	6.5, 2.25
Igneous plutonic rocks i.e. granite, gabbro	3.0
Schist, Serpentine	2.9
Quartzite	5.5
Sand (gravel), saturated sand	0.77, 2.5
Silt	1.67
Clay, saturated	1.11, 1.67
Loam	0.91
For Comparison: Water	0.6
Air	0.0252

4.5.2 Thermal Diffusivity

Thermal diffusivity is the ground thermal conduction in relation to thermal capacity. This links thermal conductivity, specific heat (C_p) and density (**r**). Density is multiplied by specific heat is termed volumetric heat capacity. The relationship is shown in the equation 4.2.

A high thermal diffusivity value is desirable since this means the material will quickly adjust temperature to that of the surrounding environment since heat is conducted rapidly relative to thermal mass. Specific heat capacity (C) describes the quantity of heat required to change unit mass of the material by unit temperature or quantity of energy that can be dissipated or absorbed before a change in temperature. Water has a high specific heat capacity (4190 J/kg°C) which explains how saturation will increase the overall value for the rock soil.

4.5.3Thermal Recharge

In ground source coupled heat pumps GSHP the hydrologic cycle circulates water and therefore heat via pressure difference [45]. This heat can be attributed to the atmosphere and geothermal heat flow in proportions relative to the depth of the aquifer. For this reason there is generally a stable temperature present in the aquifer which does not exhibit major seasonal changes, “any deficit created by heat fluid extraction is replenished by the (lateral) groundwater flow” [46]. As mentioned above for all horizontal systems in heating only mode, the main thermal recharge is provided by solar radiation falling on the earth’s surface. Therefore it is vital to ensure the surface above the ground heat exchanger is not covered by trees or grass. An alternative to natural recharge is to utilize forced recharge like a solar Collectors and a GSHP, during conditions where excess heat is present which is not required for water heating it can be injected into the heat exchanger and thermally replenish the surrounding ground**.**

4.6 Design of the Ground Source Heat Pump

4.6.1 Formulas and Concept

For estimation of the excavation size and according to ASHREA each ton refrigeration will need 2500 ft^2 [232 m^2] of land area to absorb the heat rejected into the ground but this is of course depends on several things of which, the location, the depth and size of the excavation, the time of the year, the soil diffusivity of heat, the heat pump design conditions, the fluid, the pipes type and thermal properties, the flow type and velocity which is relevant to the pump selection of flow and head, the ground water, the percentage of water content in soil, and many other factors. All the calculations were conducted using computer software.

For the purpose of test a ¾ tones of refrigeration, (10000 Btu/hr) type Electra was used with a coefficient of performance (COP of 3). All approvals were taken for the excavation and search and the excavation was done in an area of 15 m long, 2.5 m width and 2 m deep. To design the loop underground several factors were taken into consideration of which:

A. The fluid used was water because it has high heat capacity as explained before. From tables of properties of refrigerant R410a which is used in the heat pump, it can be seen that the condenser unit rejects the heat at 75 ° C in summer and absorbers heat in the vicinity of the evaporator at 2-4 ° C because the outdoor design temperature is 35 ° C for cooling in summer and 0 ° C for heating in winter. The outdoor temperature should be less than 35° C in summer and more than 0 ° C in winter to achieve better performance. Antifreeze should be added to the water in case of lower temperature which is not our case. Table 4.2 below shows several types of solutions that can be added to water to prevent freezing. Using the formula:

$$Q[kW] = \dot{m}\left[\frac{L}{s}\right] * Cp\left[\frac{kJ}{kg}\,℃\right] * \rho\left[\frac{kg}{L}\right] * \Delta T[\,℃] \qquad (4.3)$$

Table (4.2): Densities and Specific Heats for Various Solutions [47]

	% by Weight	**Mean Temp** (°C)	**Freezing Point** (°C)	**Density** (kg/m^3)	**Specific Heat** (kJ/°K*kg)
Pure Water	100	25	0	999.6	4.184
Methanol Solution	13.6	25	-9.4	980.2	4.232
	10.0	30	-6.7	904.2	4.274
	6.3	35	-3.9	989.0	4.296
	2.0	40	-1.1	989.4	4.275
Ethylene Glycol Solution	20.0	25	-9.4	1034.4	3.848
	14.6	30	-6.7	1024.4	3.975
	8.8	35	-3.9	1017.3	4.100
	2.5	40	-1.1	1002.9	4.190
Propylene Glycol Solution	23.5	25	-9.4	1024.5	4.023
	18.3	30	-6.7	1017.3	4.065
	12.9	35	-3.9	1012.5	4.107
	5.9	40	-1.1	1005.3	4.149
Sodium Chloride Solution	13.3	25	-9.4	1103.6	3.627
	10.1	30	-6.7	1077.2	3.688
	6.4	35	-3.9	1048.4	3.847
Calcium Chloride Solution	14.3	25	-9.4	1134.7	3.332
	11.3	30	-6.7	1103.6	3.499
GS4 Diluted antifreeze Solution	100	-23.3	-59.4	1295.0	2.795
	80	-15.0	-40.0	1262.5	3.089
	60	-6.67	-21.1	1175.0	3.382
	40	-2.22	-11.7	1120.0	3.709
	20	-1.11	-5.6	1050.0	3.989

B. Pipe Type: Pipes are either steel for vertical design, or High density polyethylene for horizontal design, for leakage problems steel pipes are not used. HDPE pipes are defined by their pressure ratings which can be measured by the Standard Dimension Ratio – SDR.

It is common to use the SDR as method of rating pressure piping as seen in the figure (4.3) where S is the thickness of the pipe and D is the outer diameter of the pipe. Then SDR is

$$SDR = \frac{D}{S}, \frac{Diameter}{SThickness} \qquad (4.4)$$

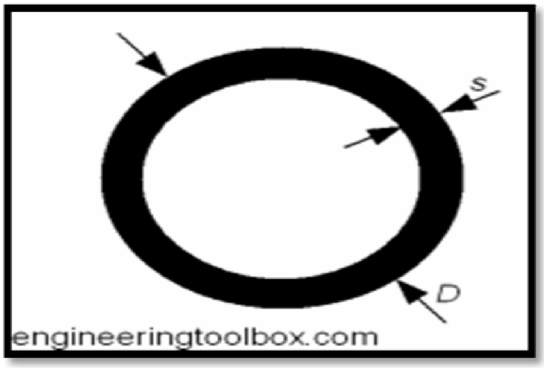

Figure (4.3) Standard Dimension Ratio descriptions [48]

The higher the SDR the lower the thickness compared to the diameter and the lower the pressure the pipe can withstand. This property is not very common in the market which makes things difficult so SDR for local pipes must be calculated and matched to the design SDR used, so the pipe properties has been searched for this property in the local market and compared to the universal standards. The pipes are available in the local market. All properties for the pipe are now known such as thickness, material, is known the thermal resistance is known Appendix (1) so the heat conducted through pipes is now known as in tables (4.3) and table (4.4) below.

Table (4.3): Pipe and Tube Dimensions [49][50]

Nominal Diameter (in.)	SDR 9 OD/ID (mm)	SDR 11 OD/ID (mm)	SDR 13.5 OD/ID (mm)	SDR 17 OD/ID (mm)	Schedule 40 OD/ID (mm)	Schedule 80 OD/ID (mm)	Copper (L) OD/ID (mm)
3/4 (20 mm)	26.7 / 20.8	26.7 / 21.8		26.7 / 23.6	26.7 / 20.9	26.7 / 18.8	22.2 / 19.9
1 (25 mm)	33.4 / 26.0	33.4 / 27.4	28.6/ 24.3	33.4 / 29.5	33.4 / 26.6	33.4 / 24.3	28.6 / 26.0
1 1/4 (32 mm)	42.2 / 32.8	42.2 / 34.5	34.9/ 29.7	42.2 / 37.1	42.2 / 35.0	42.2 / 32.5	34.9 / 32.1
1 1/2 (37.5 mm)	48.2 / 37.5	48.2 / 39.4	41.3/ 35.2	48.2 / 42.7	48.2 / 40.9	48.2 / 38.1	41.3 / 38.2
2 (50 mm)	60.3 / 46.9	60.3 / 49.3	54.0/ 46.0	60.3 / 53.3	60.3 / 52.5	60.3 / 49.3	54.0 / 50.42
3 (75 mm)	88.9 / 69.1	88.9 / 72.6		88.9 / 78.5	88.9 / 77.9	88.9 / 73.7	79.4 / 74.8
4 (100 mm)	114.3 / 88.9	114.3 / 93.5		114.3 / 101	114.3 / 102	114.3 / 97.2	104.8 / 99.2
6 (150 mm)	168.2 / 130.8	168.2 / 138		168.2 / 148	168.2 / 154	168.2 / 146	
8 (200 mm)	219.1 / 170.4	219.1 / 179		219.1 / 193	219.1 / 203	219.1 / 194	
10 (250 mm)	273.1 / 212.4	273.1 / 224		273.1 / 241	273.1 / 254	273.1 / 243	
12 (300 mm)	323.9 / 251.9	323.9 / 265		323.9 / 285.8	323.9 / 303	323.9 / 289	

"Evaluation of Methods for Calculating Soil Thermal Conductivity, "(http://www.gaiageo.com/

Table (4.4): Minimum Required Flow Rate (L/min) for Non laminar Flow Re>3000 [49]

Fluid (% by weight)	T = -1 ° C Nominal Diameter SDR 11 Pipe				T = 10 ° C Nominal Diameter SDR 11 Pipe			
	3/4 in. (20 mm)	1 in. (25 mm)	1 1/4 in. (32 mm)	1 1/2 in. (37.5 mm)	3/4 in. (20 mm)	1 in. (25 mm)	1 1/4 in. (32 mm)	1 1/2 in. (37.5 mm)
20% Ethanol	14.3	18.2	22.7	26.1	9.8	12.1	15.1	17.4
20% Ethylene Glycol	9.5	11.7	14.8	17.0	6.8	8.4	10.6	11.7
20% Methanol	11.0	13.6	17.0	19.7	7.6	9.5	11.7	13.2
20% Propylene Glycol	12.9	15.9	20.4	23.1	8.7	10.6	13.6	15.5
20% Calcium Chloride	8.6	11.0	13.6	15.5	5.3	7.6	8.4	9.7
Water	--	--	--	--	4.2	5.3	6.5	7.6

C. Soil: Ground temperature is changing according to the geographical location, the time of the year, time after being disturbed, type and the depth in the ground. The type of soil is a determinant factor because different soils have different thermal conductivities and different thermal diffusivity. Moisture content affects the diffusivity and conductivity all this is shown in table (4.5) and table (4.6)

If the heat pump capacity is known the pump flow rate can be calculated; the recommended velocities are known for the pipes at a known diameter and flow and thus can be adjusted for better friction values. After sizing the pipes length and fittings needed, everything can be summed out to find the total dynamic head lost in pipes. And the pump is approximated to the standard available in the market.

Table (4.5): Thermal Conductivity and Diffusivity of Sand and Clay Soils [49]

Soil Type	Dry Density (kg/m^3)	5% Moist		10% Moist		15% Moist		20% Moist	
		k (W/m K)	α (m^2/day)	k (W/m K)	α (m^2/day)	k (W/m K)	α (m^2/day	k (W/m K)	α (m^2/day)
Coarse 100% Sand	1900	2.1-3.3	0.089-0.14	2.4-3.5	0.086-0.12	2.8-3.8	0.085-0.11	-	-
	1600	1.4-2.4	0.072-0.12	2.1-2.6	0.089-0.11	2.3-2.8	0.083-0.10	2.4-2.9	0.078-0.093
	1300	0.9-1.9	0.056-0.12	1.0-1.9	0.056-0.10	1.0-2.1	0.047-0.093	1.2-2.1	0.048-0.083
Fine Grain 100% Clay	1900	1.0-1.4	0.045-0.060	1.0-1.4	0.037-0.049	1.4-1.9	0.043-0.059	-	-
	1600	0.9-1.0	0.045-0.054	0.9-1.0	0.037-0.045	1.0-1.2	0.034-0.045	1.0-1.4	0.038-0.051
	1300	0.5-0.9	0.033-0.056	0.6-0.9	0.033-0.047	0.7-0.95	0.032-0.044	0.7-1.0	0.028-0.042

***Values indicate ranges predicted by five independent methods. k = Thermal Conductivity, α= Thermal Diffusivity, Coarse Grain= 0.075 to 5mm - Fine Grain less than 0.075mm (0.075mm = #200 U.S. Standard Sieve)**

Table (4.6): Thermal Properties of Rocks at 25°C [49]

Rock Type	**% Occurrence in Earth's Crust***	**k - All**** ***Thermal Conductivity*** **(W/mK)**	**k - 80%***** ***Thermal Conductivity*** **(W/mK)**	**c p** ***Specific Heat*** **(J/kgK)**	***ρ*** ***Density*** (kg/m^3)	**α** ($k/\rho c_p$) ***Thermal Diffusivity*** (m^2/day)
Dense Rock	--	3.46	--	840	3200	0.111
Average Rock	--	2.42	--	840	2800	0.089
Dense Concrete	--	1.73	--	840	2400	0.073
Heavy Soil, Saturated	--	2.42	--	840	3200	0.078
Solid masonry	--	1.3	--	880	2290	0.056
Heavy Soil, Damp	--	1.3	--	960	2100	0.056
Heavy Soil, Dry	--	0.87	--	840	2000	0.045
Light Soil, Damp	--	0.87	--	1050	1600	0.045
Light Soil, Dry	--	0.35	--	840	1440	0.024
Igneous Rocks						
Granite (10% Quartz)	10.4	1.9-5.1	2.3-3.3	879	2640	0.084-0.12
Granite (25% Quartz)			2.6-3.6			0.093-0.13
Amphibolite	42.8	1.9-4.7	2.6-3.8		2800-3120	

Rock Type	% Occurrence in Earth's Crust*	k - All** *Thermal Conductivity* (W/mK)	k - 80%*** *Thermal Conductivity* (W/mK)	c p *Specific Heat* (J/kgK)	ρ *Density* (kg/m^3)	α ($k/\rho c_p$) *Thermal Diffusivity* (m^2/day)
Andesite		1.4-4.8	1.6-2.4	502	2560	0.10-0.16
Basalt		2.1-2.4		712-879	2880	0.065-0.084
Gabbro (US Cen. Plains)		1.6-2.8		753	2960	0.060-0.107
Gabbro (US Rocky Mtns)		2.1-3.6				0.079-0.14
Diorites	11.2	2.1-3.3	2.1-2.9	920	2880	0.065-0.093
Grandiorites		2.1-3.5		879	2720	0.074-0.12
Seditmentary Rocks						
Claystone		1.9-2.9				
Dolomite		1.6-6.2	2.8-6.2	879	2720-2800	0.10-0.21
Limestone		1.4-6.2	2.4-3.8	920	2400-2800	0.093-0.13
Rock Salt		6.4		837	2080-2160	
Sandstone	1.7	2.1-3.5		1005	2560-2720	0.065-0.11
Siltstone		1.4-2.4				
Wet Shale (25% Quartz)	4.2	1.0-4.0	1.7-3.1	879	2080-2640	0.084-0.11
Wet Shale (No Quartz)			1.0-1.6			0.047-0.056
Dry Shale (25% Quartz)			1.4-2.4			0.065-0.093
Dry Shale (No Quartz)			0.9-1.4			0.042-0.051
Metamorphic Rocks						
Gneiss	21.4	1.7-5.7	2.3-3.5	920	2650-2800	0.084-0.11
Marble	0.9	2.1-5.5	2.1-3.3	920	2720	0.074-0.11
Quartzite		5.2-6.9		837	2560	0.20-0.28
Schist	5.1	2.1-4.5	2.4-3.8		2720-3200	
Slate		1.6-2.6		920	2720-2800	0.056-0.084

*** Percentage of sedimentary rocks is higher near the surface.**

**** "All" represents the conductivity range of all samples tested.**

***** "80%" represents the mid-range for samples of rock.**

4.6.2 Geothermal Design using Computer software

In the design stage calculations were done manually and using GAIA software figure (4.4), to determine the loop length and the best orientation of the pipes and to find out what is the effect of increasing the depth and the width of the trench. This simplifies changing the parameters to reduce the loop length because for a given load we can tune the pipe properties, the fluid properties, the orientation, the trench features, and the land type. Other factors that affect the design but cannot be tuned for a given location are face velocity of wind, the water flow rate, the location, the thermal conductivity, diffusivity of soil, coldest and hottest day of the year, pipe resistance, dimension, and type, the separation distance between loops and the layers being used see figure (4.5), figure (4.6).

Figure (4.4) Ground loop design software menu [50]

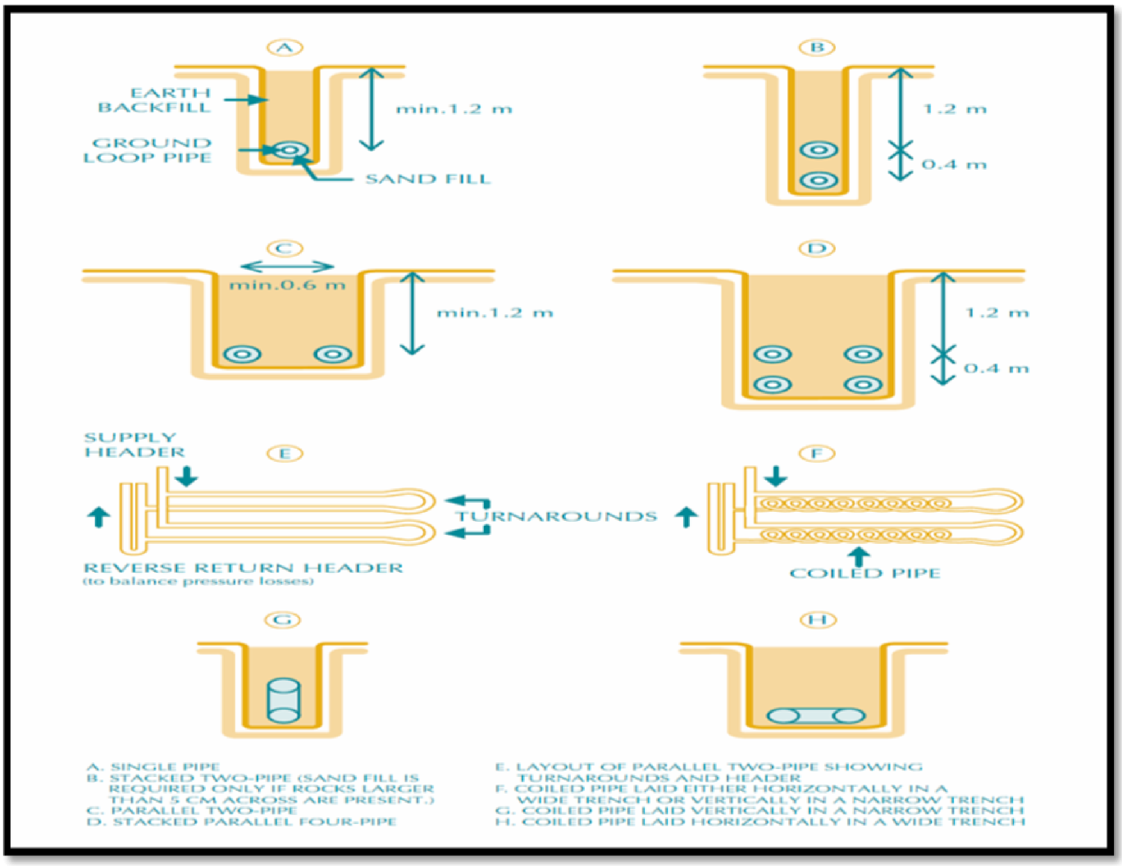

Figure (4.5) loop orientation for horizontal and vertical geothermal heat pumps [51]

To achieve maximum contact to the ground and reduce the length and depth the silky orientation was selected, also two loops was used at a depth of 2 m this can be changed for different orientations as per design literature. As in figure (4.7).Pipe diameter was selected based on the Reynolds number and the flow which was selected to be non laminar because Reynolds number was above 3000 and for the temperature above 10 °c as per table (4-4) above and for water applications the required water flow is 4.2 L/min for SDR 11 tube 3/4" diameter. This can be validated as follows.

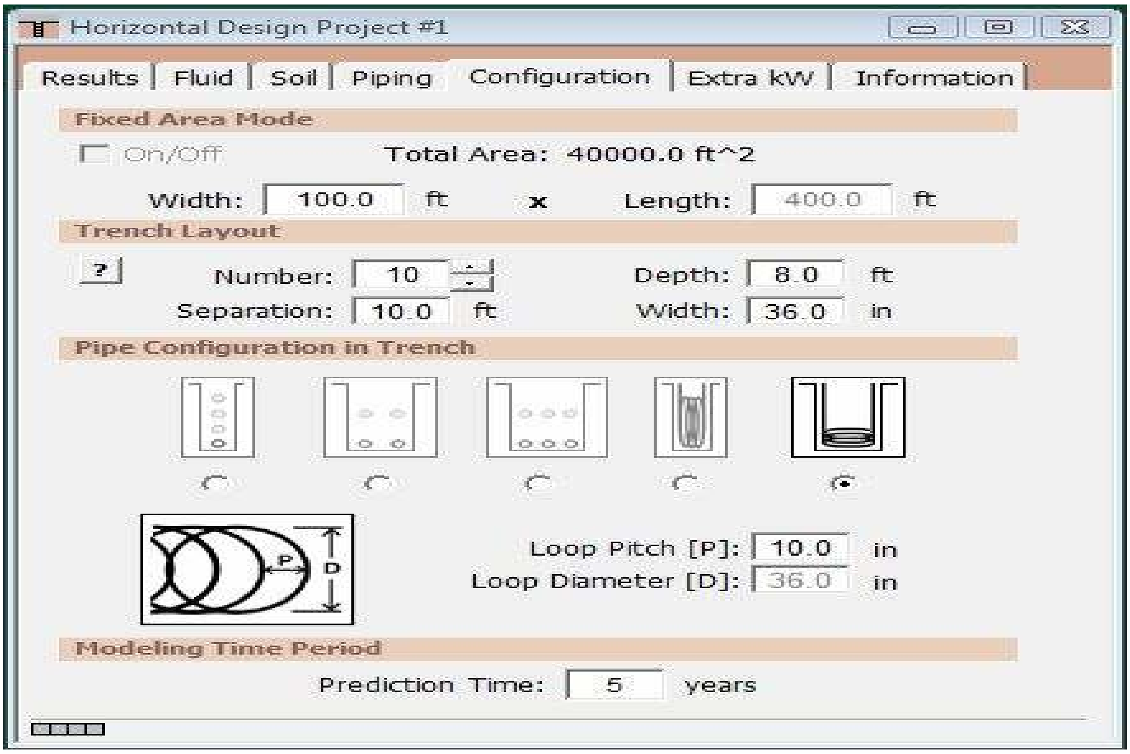

Figure (4.6) Loops orientation in software [50]

The heat pump is 10000 Btu/hr which is equal to 2.91 kW then to circulate water that can hold this amount of heat we use equation (4.3)

$$Q_{nominal}[kw] = m\left[\frac{L}{s}\right] * Cp\left[\frac{kJ}{kg}\ ℃\right] * \Delta\left[\frac{kg}{L}\right] * \Delta T[\ ℃] \quad \text{.................. (4.3)}$$

2.91 kW =m *4.19*1*10

Then

M = 0.0696 L/s which is equal to 4.19 L/min so the selection is correct.

Using equation (4.4)

$$\mathrm{SDR} = \frac{\mathrm{D}}{\mathrm{S}} \quad \text{.. (4.4)}$$

20 mm pipe OD =26.7mm, ID = 21.8mm

Then

$$S = \frac{(OD - ID)}{2}$$

As shown in figure (4.3)

S= (26.7-21.8)/2 =2.45 mm.

SDR=26.7/2.45 =10.89 then SDR for our pipe is SDR 11.

The pipes were selected based on the above calculations and as per catalogue of GOLANI pex pipes Appendix (1) and Appendix (2) the pipe diameter was 25 mm the pipe thickness is 2.3 mm

Then

SDR = 25/2.3 =10.86 or SDR 11

So pipe SDR 11, 3/4" was selected as in figure (4.8) and the flow is turbulent then from Hazen William's formula Appendix (5) for friction loss calculation equation below

$$H_L = 0.2083X\frac{100^{1.852}}{C^{1.852}}X\frac{Q^{1.852}}{d^{4.8655}} \quad \text{.......................................} \quad (4.5)$$

See appendix 5 and 6 Where H_L is the friction loss in feet per 100 feet of pipe

Q is the volumetric flow rate in GPM

C is Hazen Williams flow factor for thermo plastic pipes c =150 d is the internal diameter of pipe in inches

Then HL = 0.1278 inch for each 100 feet or 1 meter per 100 meter of pipe

For the friction in valves and fittings table (4.7) below was used. Then the total friction is shown in table 4.8 below:

Table (4.7) Equivalent length of straight pipes for valves and fittings in meter obtained from [48]

Equivalent Length of Straight Pipe for Valves and Fittings (m)												
Screwed Fittings		Pipe Size										
		1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
Elbows	Regular 90 deg	0.7	0.9	1.1	1.3	1.6	2.0	2.3	2.6	2.8	3.4	4.0
	Long radius 90 deg	0.5	0.6	0.7	0.7	0.8	1.0	1.0	1.1	1.1	1.2	1.4
	Regular 45 deg	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2	1.7
Tees	Line flow	0.2	0.4	0.5	0.7	1.0	1.4	1.7	2.3	2.8	3.7	5.2
	Branch flow	0.7	1.1	1.3	1.6	2.0	2.7	3.0	3.7	4.0	5.2	6.4
Return Bends	Regular 180 deg	0.7	0.9	1.1	1.3	1.6	2.0	2.3	2.6	2.8	3.4	4.0
Valves	Globe	6.4	6.7	6.7	7.3	8.8	11.3	12.8	16.5	18.9	24.1	33.6
	Gate	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.8
	Angle	3.9	4.6	4.6	4.6	5.2	5.5	5.5	5.5	5.5	5.5	5.5
	Swing Check	2.2	2.2	2.4	2.7	3.4	4.0	4.6	5.8	6.7	8.2	11.6
Strainer			1.4	1.5	2.0	2.3	5.5	6.1	8.2	8.8	10.4	12.8

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Table (4.8): Calculated minor losses in pipes

Fitting	Quantity	Equivelant length (m)	Total length (m)	Total friction (m)
pipe	1	100	100	1
elbow 90	63	5	315	3.15
steel elbow	1	1.6	1.6	0.016
Steel Tee	3	2	6	0.06
Brass coupling	4	8.8	35.2	0.352
Check valve	1	4.4	4.4	0.044
Ball valve	3	8.8	26.4	0.264
Strainer	1	2.3	2.3	0.023
flow meter	1	10	10	0.1
Total loses m				5.009

This was calculated using software as in figure (4.7) below. The pump was selected to have 8 meters head and the corresponding pump flow will be larger than needed because these types of pumps are used for heating and cooling which normally has this characteristics. The effect on the results will be discussed later in the conclusion.

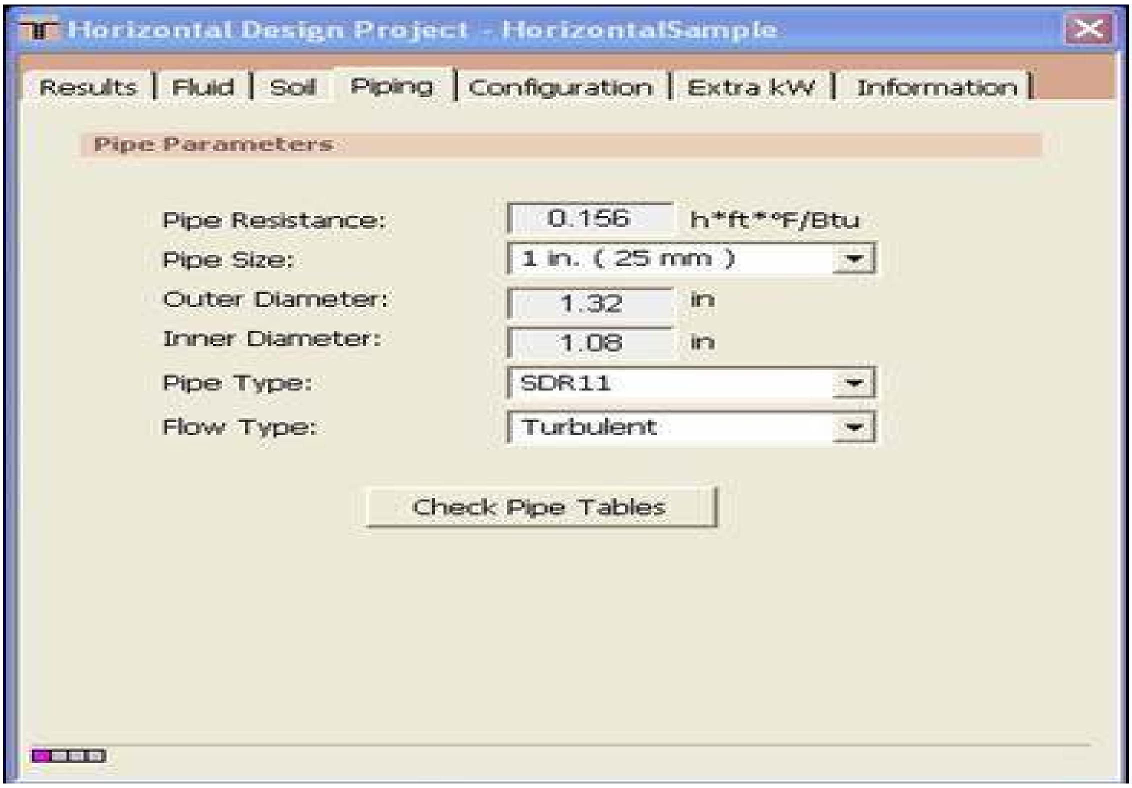


Figure (4.7) Pipes parameter menu GIGA GEO software

As for the loop it was designed to dissipate heat by means of a 4 loops in parallel of 100 m long each slinky tube. They were connected in parallel through a manifold to a circulation pump which is used to circulate water into the underground loops. The working fluid can be selected as shown in figure (4.9) the working heating and cooling temperature is set and this will calibrate the density and the specific heat automatically from the library, the flow rate is set automatically which is 11.4 L/min as per recommendation for each ton of heating or cooling. Our flow was calculated to be 4.2 L/min but the selected pump was 66 L/min so there is no problem in the flow.

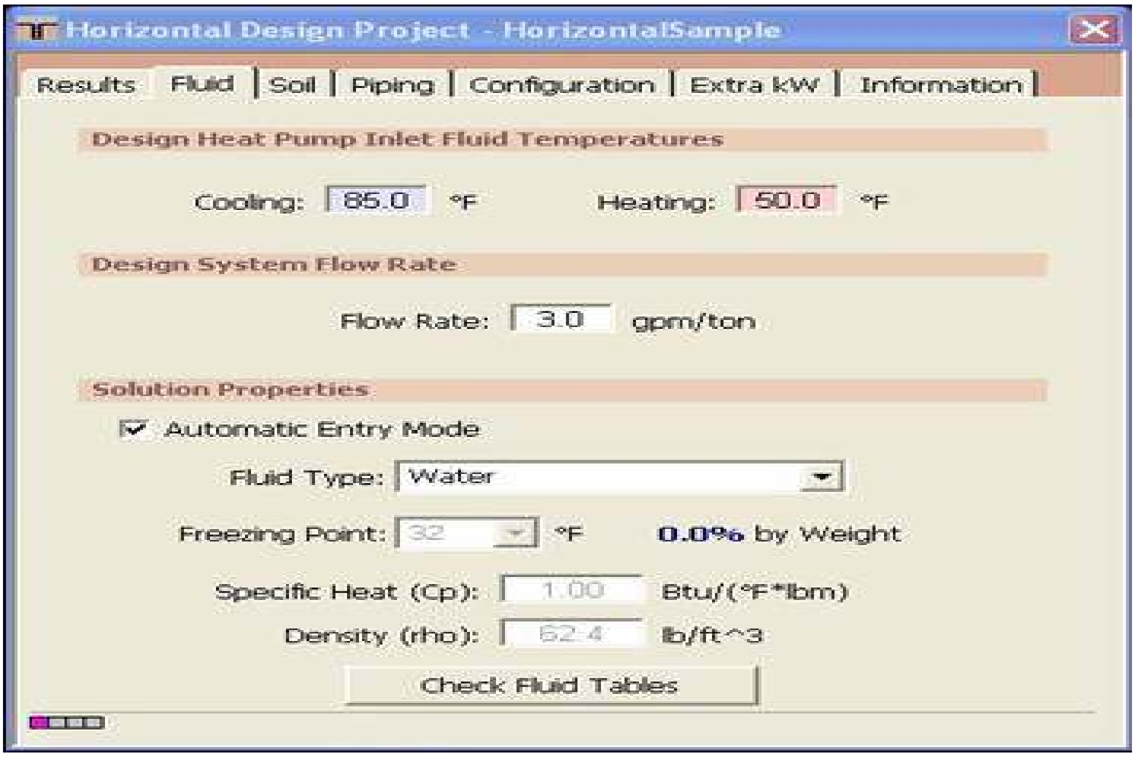


Figure (4.8) Fluid parameters menu, Appendix (3) fluid properties

Soil is another parameter that affects our design from tables in appendix 2 the temperature of the ground for local area must be selected prior to design. The soil type, the location, the sun factor that has something to do with the recharge, the regional swing air temperature and the coldest and warmest day in the year all these factors must be known to adjust the thermal conductivity and thermal diffusivity of the soil as per the classical heat Conduction or equation 4.1. Using those formulas, all necessary parameters are calculated using the software as described in figure (4.9).

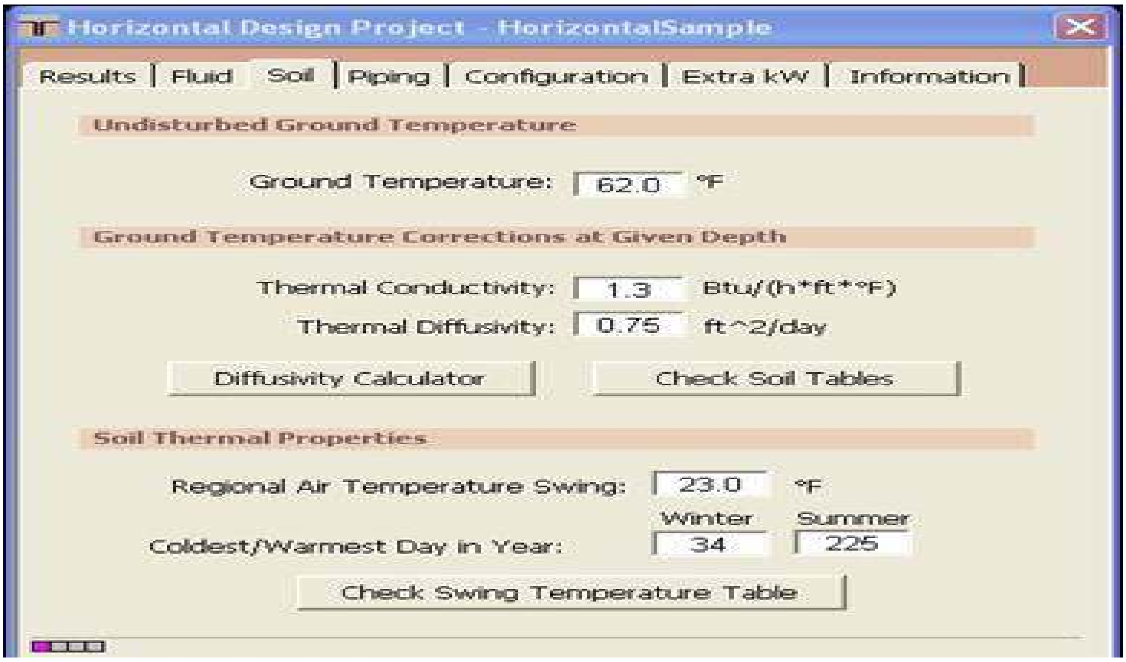


Figure (4.9) soil parameters calculations

4.6.3 Earth Connection

Closed-Loop Ground Heat Exchangers (GHEX)

This section is based on ASHRAE methods of calculation of heat exchanger size and performance of geothermal heat pump horizontal and vertical loops and also the pond heat exchangers.

4.6.4 Ground heat exchanger (GHEX) sizing

Ground heat exchanger or loops sizing is concerned mainly with the determination of pipes Length of the heat exchanger to be laid underground. The method used in the GSHP is adapted from IGSHPA (International Ground-source Heat Pump Association 1988). The required loop length based on heating requirements is denoted by L_h, can be defined by this equation as per ASHREA:

$$Lh = qd,heat\left[\frac{\frac{(coph-1)}{coph}(Rp+RsFh)}{Tg,min-Tewt,min}\right] \quad (4.6)$$

where COP_h is the design heating coefficient of performance of the heat pump system, R_p is the pipe thermal resistance, R_s is the soil/field thermal resistance, F_h is the GHEX part load factor for heating, $T_{g,min}$ is the minimum undisturbed ground temperature, and $T_{ewt,min}$ is the minimum design entering water temperature (Tewt) at the heat pump. A similar equation can be used to calculate the required GHEX length L_c based on cooling requirements:

$$Lc = qd,cool\left[\frac{\frac{(copc-1)}{copc}(Rp+RsFc)}{Tewt,max-Tg,max}\right] \quad (4.7)$$

where COPc is the design cooling coefficient of performance of the heat pump system, F_C is the part load factor for cooling, $T_{g,max}$ is the maximum undisturbed ground temperature (see equation 4.3, 4.4), and $T_{ewt,max}$ is the maximum design entering water temperature at the heat pump.

These two equations represent a simplification of the ones developed by Ingersoll and presented in Kavanaugh and Rafferty [52]. Equations (4.3) and (4.4) do not take into consideration long-term thermal imbalances that could alter the soil temperature field over a period of many years. These thermal imbalances are generally attributable to significant differences between the annual heat extracted from the ground and the heat that is rejected to the ground during the cooling season. However, this simplification could be considered acceptable at the preliminary feasibility evaluation stage.

There are a large number of possible configurations for horizontal systems.

Equations (4.3) and (4.4) require the determination of pipe thermal resistance R_P and soil field thermal resistance R_S. These are determined from geometrical and physical considerations, as shown in IGSHPA [52]. For horizontal GHEX, the method takes into account surface effects that have a significant influence on horizontal soil/field resistance values. Soil resistance values are tabulated as a function of radial distance for different kinds of soil (e.g. light soil or heavy soil, damp or dry, rock, etc.). Thermal resistances for permafrost were extrapolated from those for regular soil, based on soil conductivity properties.

As shown by equations (4.3) and (4.4), there are two possible heat exchanger lengths that can be used for designing a closed-loop system. The choice between using the cooling or heating length is left to the user in the Energy Model as per ASHREA. This design decision has an impact on both cost and performance of the GSHP system.

Selecting a GHX length that will not be sufficient for heating will require an auxiliary heating system. Using a GHX length insufficient for cooling will require a supplemental heat rejecter. The GSHP Project Model takes into account these two possibilities when designing the geo loops.

4.6.5Design entering water temperature (T_{ewt})

The design of a GHX is in many ways similar to that of a conventional heat exchanger. For a conventional heat exchanger, the inlet and outlet temperatures are usually provided for sizing the heat exchanger. This also applies for a GHX: the final size of the GHX is in great part determined by the user's requirements for the minimum or maximum temperatures allowed at the GHX's outlet during the course of the year. However, the values for the maximum and minimum GHX outlet temperatures have a fairly limited range of acceptable values. Practical constraints, mainly from the heat pumps, tend to make this design decision more straightforward.

For example, extended range heat pumps will usually have a 20°F (-6.7°C) recommended minimum design entering water temperature ($T_{ewt,max}$) and 110°F (43.3°C) recommended maximum design entering water temperature ($T_{ewt,max}$). Specific designs may go below and above these temperatures but are not common. From a literature review [52], the following design entering water temperature estimates were used in the GSHP:

Minimum design entering water temperature:

$$Tewt, min = Tg, \min - 15°F \qquad (4.8)$$

Maximum design entering water temperature:

$$Tewt, max = \min\,(Tg, max + 20\,℉, 110\,℉) \qquad (4.9)$$

Part load factor (F)

Determining the GHX length using equations (4.3) and (4.4) requires the evaluation of the GHX part load factor. The part load factor (F) represents the fraction of equivalent full load hours during the design month to the total number of hours in that month, as seen by the GHX [52]. It can be evaluated as:

$$F=\frac{qav}{qmax} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.10)$$

Where; q_{av} and q_{max} are the average load and peak load for the month respectively. The part load factor F is evaluated for the design cooling month and the design heating month, typically July and January in the Northern Hemisphere, leading to the values F_C and F_h used in equations 4.6 and 4.7.

4.6.6 Heat Pump System

This section presents the modeling elements associated with the heat pump system. The calculation of these elements is necessary to finalize the earth connection sizing of either closed-loop ground heat exchangers GHXs. The heat pump coefficient of performance COP, and their related capacity $Q_{c/h}$ are evaluated first, followed by the determination of the heat pump entering water temperature for both types of earth connection.

4.6.7 Coefficient of performance COP and capacity Q_h

The coefficient of performance (COP) of a heat pump system is a function of the entering water temperature. Tarnawski approach (1990)

[52] correlates the COP of any heat pump to the entering water temperature. The ground heat exchanger load and heat pump useful capacity are linked through:

For cooling:

$$Qc = Qh, c = \frac{COPc}{COPc+1} \quad \text{...... (4.11)}$$

For heating:

$$Q_h = Q_{he,h} \frac{COPh}{COPh-1} \quad \text{...... (4.12)}$$

where Q_c is the heat pump cooling capacity at the evaporator, $Q_{he,c}$ is the heat rejected to the GHX at the heat pump condenser in cooling mode, Q_h is the heat pump heating capacity at the condenser, and $Q_{he,h}$ is the heat extracted from the GHX at the heat pump evaporator in heating mode.

Chapter Five
Experimental Work

Chapter Five
Experimental Work

A model for a typical horizontal geothermal heat pump for a small room of about 15 m^2 was designed and built. The area where the unit was installed was selected to be easy to dig in and near electricity and water sources. The room was close to the open Court that has an open view to receive the sun light most of the day. The built air-conditioner was 10000 Btu/hr Type Electra Model 10 with the condensing unit placed into a 175 liter tank of 1 mm thick made of galvanized steel and welded locally with a dimension of 50x50x70 cm. Apparatus was equipped with circulating pump of 150 liter/min and a head of 8 m type Wilo PH123-E single phase. Valves, check valves, pipes and fittings are type Teami Italy. Pex pipes are type Golani pex.

The ground loop was 400 meter of PE pipes of 20 mm diameter. The trench excavated was 12meter long 2.5 meter wide and 2 meter depth inside the Court which was backfilled before several years figure (5.1). Pipes were laid in two rows and two layers with 100 cm space between centers. The slinky loops design with a distance of 15 cm space was used as shown in figure (5.2).

All pipes were collected to a manifold of different ends to sure smooth circulation of the water. The heat pump consists of an indoor unit with the fan and the coil and the control module was mounted on a wooden board fixed on a steel cart, the compressor was mounted on the cart on a shelf, and the condenser unit was placed in the tank. The unit is already tested in factory for a cop of 3 as per energy label. Temperature of the air, supply water, temperature of refrigerant at inlet and exit of evaporator and condenser, Ground temperature (T_g), influent (T_3) and effluent (T_4) of refrigerant, temperatures of the evaporator and Compressor discharge temperature (T_c) were measured by means J type thermo couple with data logger. Pressure before and after condenser measured by means of refrigerant pressure Burdon gages. and the kilowatts consumed were measured using clamp multimeter. The heat pump was connected to the ground loop, the temperature for influent (T1) and effluent (T2) and flow rate of water ($F^{\cdot}$) in the tank were measured using Multi Data S1 Zinner Heat meter as described here in after.

Figure (5.1) Locations of the underground loops before excavation

Figure (5.2) Pipe laying in the trench.

5.1 Installation of Geothermal Heat Pump:

Pipes were assembled, laid, and tied together to form a slinky loop, and connected to the heat pump which was ready on the cart to be installed as in figure (5.3).

Figure (5.3) Trench after finalizing the pipes and backfilling

The heat pump was disassembled and reassembled with the geo thermal loops with the following parts:

1. Evaporator of 10000 Btu/hr cooling/heating capacity (Model Electra 10 2010) as in figure (5.4) and Appendix (14).

Figure (5.4) Evaporator 10000 btu/hour type (Electra)

2. Condenser of the same size type (Electra 10).

3. Compressor of 0.45 kW type (Copland) figure (5.5).

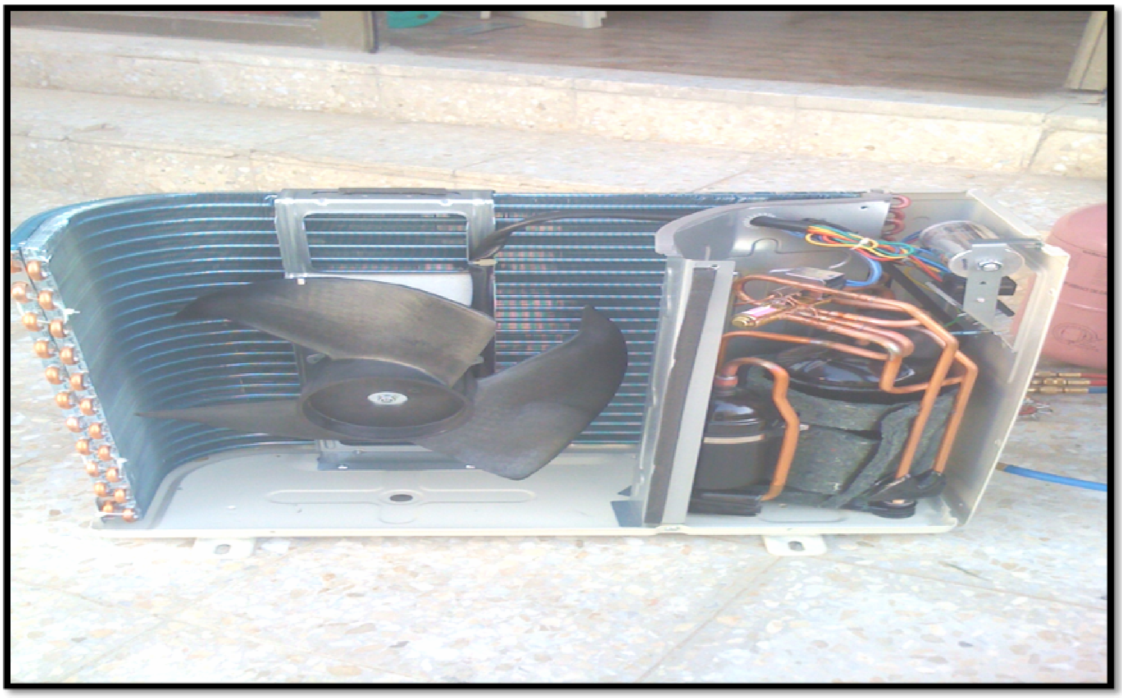


Figure (5.5) Condenser and compressor of Heat pump before installation

4. Copper piping and capillary tube.

5. Flow meter as in figure (5.6) below.

Figure (5.6) flow meter type RV pulse electromagnetic connected to the multi Data S1.

6. Multi data calculator type Zinner S1 Appendix (9) as in figure (5.7).

Figure (5.7) Multidata S1 logger heat meter type Zinner

7. Thermocouples Type J with data logger type TM 940 see figure (5.8)

Figure (5.8) Thermocouple reader and Data logger TM 940.

8. Circulating pump 125 watt 60L/min@5 m head Wilo figure (5.9). and Appendix (10)

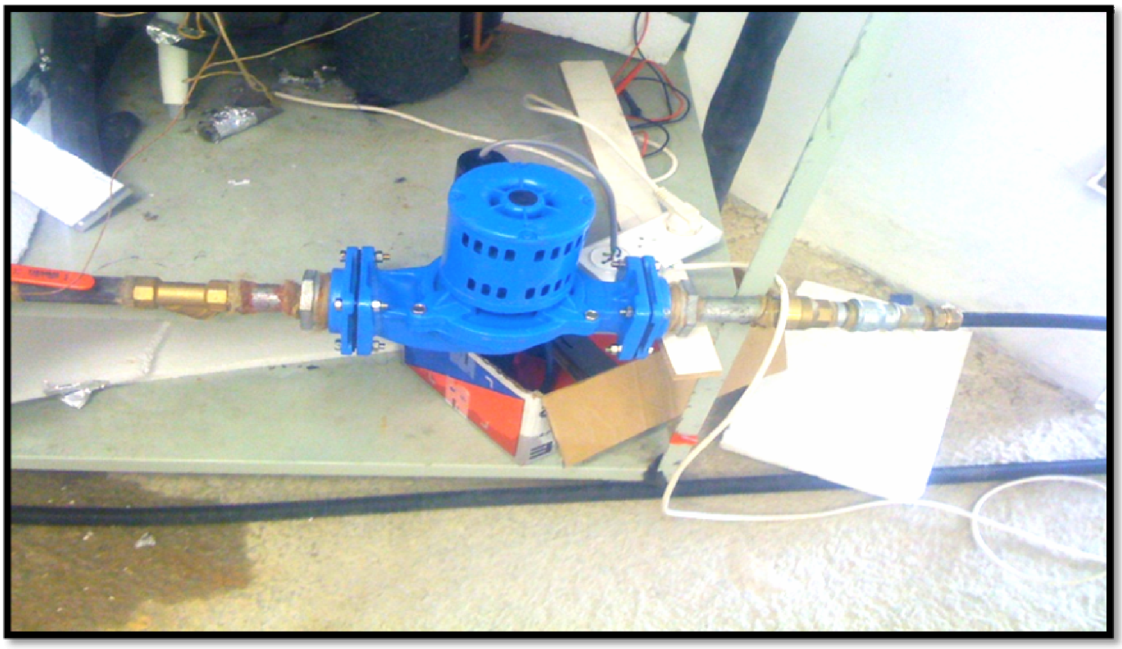


Figure (5.9) Wilo circulation pump

9. Pipes 20 mm of 450 meter Golani pex figure (5.1). Appendix (1)

10. Collectors, valves strainer check valve and plumbing staff Tiamee Italy.

11. Galvanized steel tank 70x50x50 cm as in Figure (5.10)

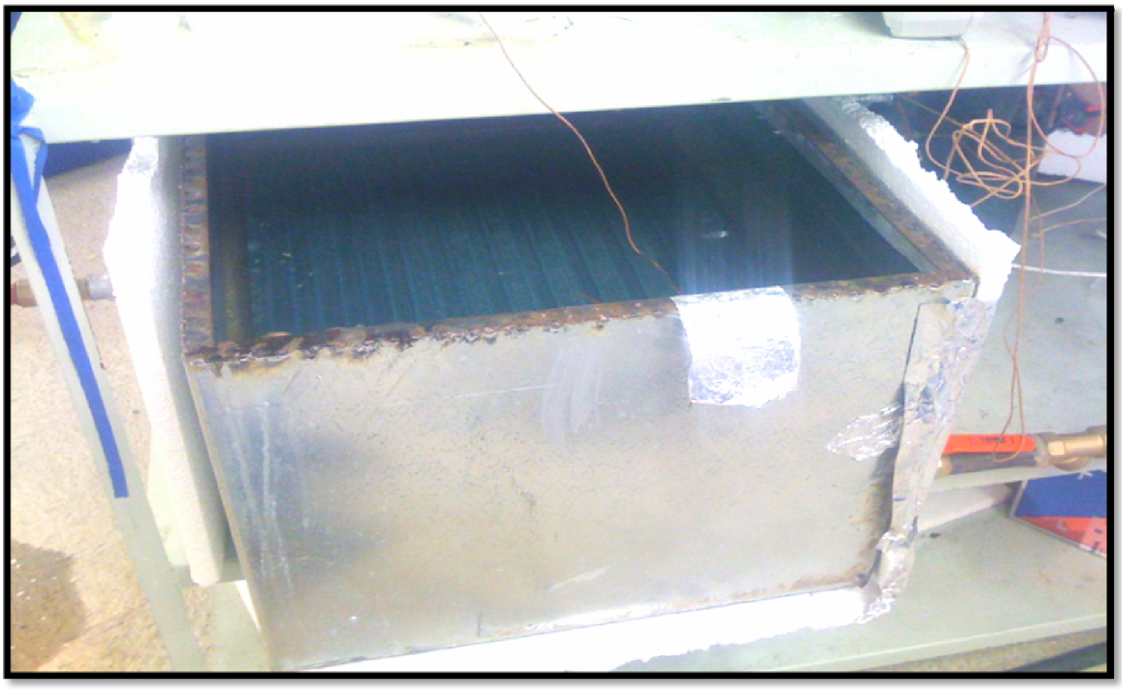


Figure (5.10) Galvanized steel tank 70x50x50 cm.

12. Solar plate collector local 190x90 cm, figure (5.11)

Figure (5.11) Local Solar water Heater 190x90 cm.

5.2 Experiments

Preliminary Experiment

Experiments were carried out on cooling mode for a period of one month; this includes calibration of the system, including the calibration of the coefficient of performance, and testing system performance using water as condensing agent rather than air. Data were taken for the evaporator influent and effluent temperature, ampere, Voltage, pressure of refrigerant, temperature of the compressor discharge and the ambient temperature. The evaporator was the indoor unit which has the low temperature; the condenser was the heat exchanger immersed in water and it has the high temperature. The water is used to cool down the condenser which replaced the air in the outdoor units for conventional air conditioners as in figure (5.12). On heating mode the system is reversed via the four way reversing valve that is installed between the compressor, the condenser, and the evaporator. The function of this valve is to use the evaporator as a condenser and the condenser as an evaporator without the need for moving them. In our case the system reversed for winter operation and the evaporator was the heat exchanger that is immersed in water, and the condenser (high temperature side) was the indoor unit. The system was started but could not maintain working due to compressor overload resulted from the high ambient temperature during summer. On heating mode the indoor unit is the condenser unit which was placed in the room at 30°C. When the heat pump is on the condenser is over heated because of the smaller size of the indoor unit and the smaller fan that rejects heat and this overloads the compressor and the compressor shut down so the system did not operate on heating during summer.

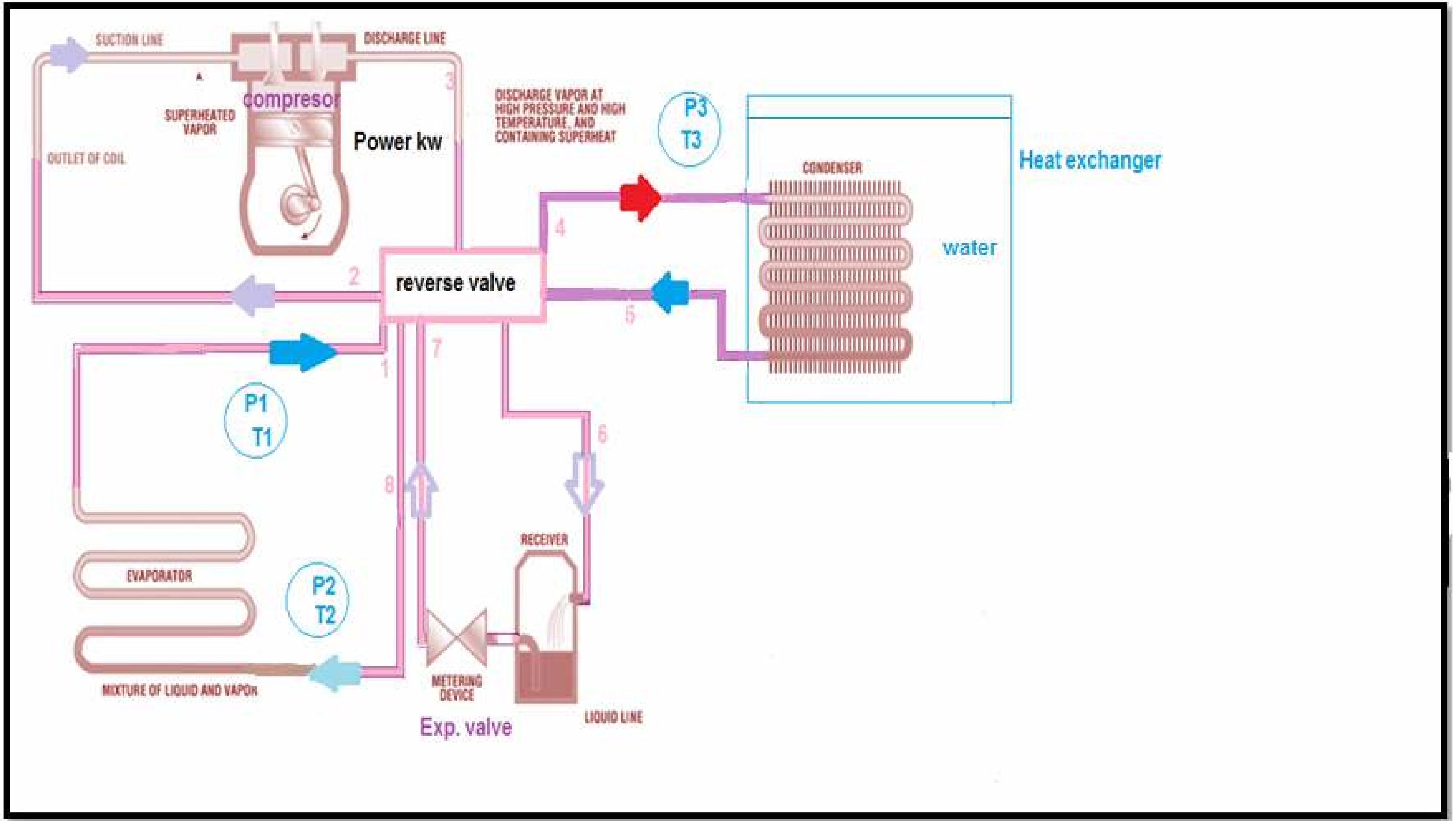


Figure (5.12): Preliminary experiments before connection to ground with evaporator is the indoor unit and the condenser is the water tank heat exchanger

5.3 Experiments of Ground loop connected system

After doing tests the system was connected to the ground loop or the underground heat exchanger. The same data were taken again for cooling mode because it was summer. The evaporator is the indoor unit which has the low temperature and the condenser that is immersed in water has a high temperature that heats up the water in the tank while the system was connected to the ground loop as in the above case when the condenser was not connected to the ground loop. But because of the exchange of heat between the condenser and the ground loop the variation in temperature is expected to be lower. Data was recorded between July and September.

Between December and January the heat pump was switched to heating mode where again the same data was recorded. The evaporator is the ground coupled heat exchanger in this case and the condenser is the indoor unit. Refrigerant is getting superheated inside the evaporator absorbing heat from the surrounding which is the getting out of the evaporator as a result of evaporation then pumped to the condenser with the extra friction heat through the compressor. The resulted heat is rejected inside of the room by means of the condenser and the fan

5.3.1 Cooling Mode using the ground loops

In this stage the apparatus was connected to the underground loops and installed in the designated room. Data was recorded for summer season in the cooling mode with the ground loops are filled with water and connected to the heat pump. The influent and effluent temperatures of water in the ground loops, the evaporator influent and effluent temperature, the pressure of refrigerant as well, the ambient temperature, the flow, the voltage and amperage of the compressor, and pump were all recorded and analyzed.

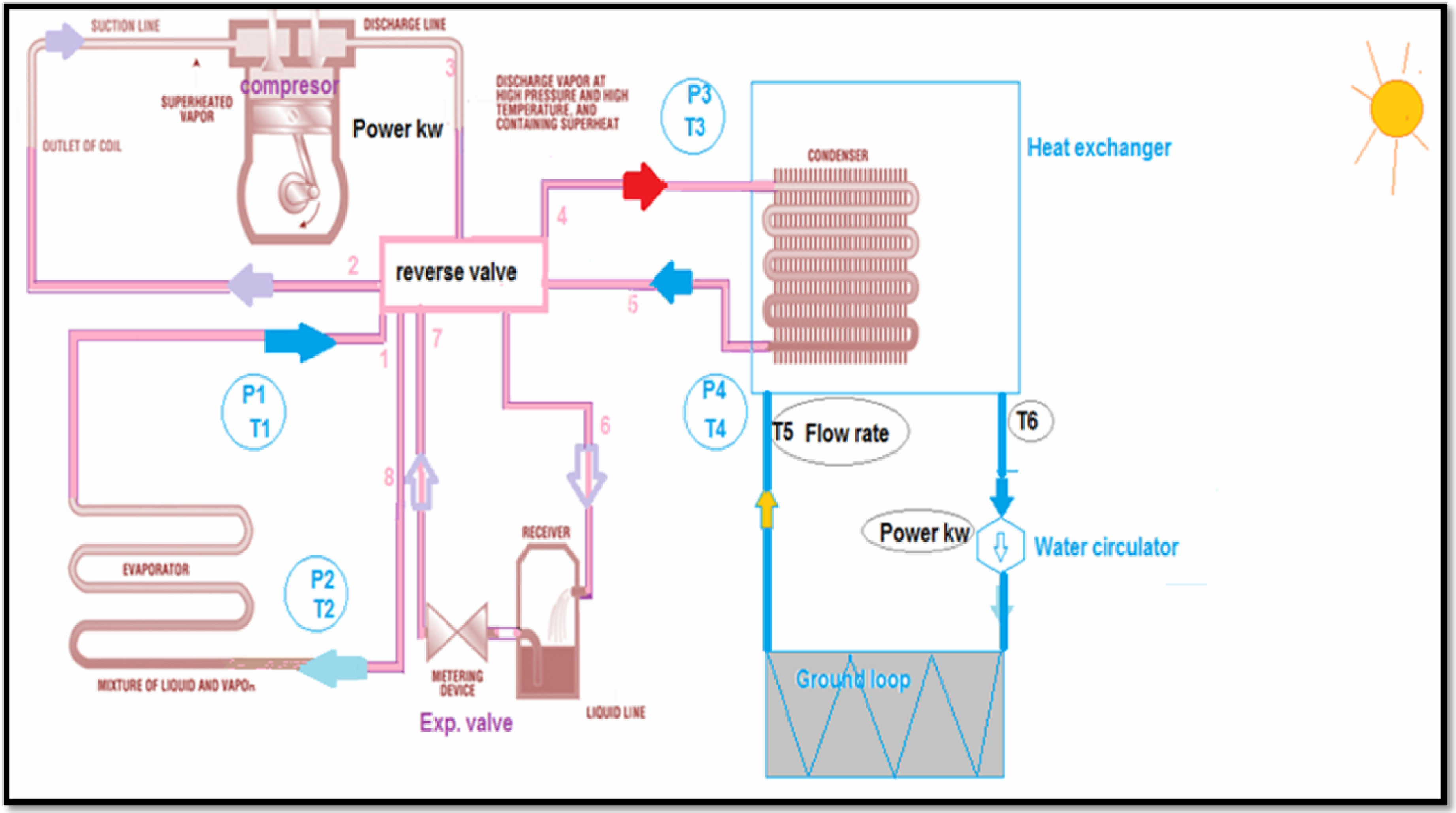


Figure (5.13): Cooling Mode heat pump after connection to ground with evaporator is the indoor unit and the condenser is the water tank heat exchanger

5.3.2 Heating mode using the ground loops

In this stage the heat pump was switched to heating mode using the same pipe arrangement. In this mode the evaporator is the heat exchanger coupled to ground loop, and the condenser is the indoor unit. The same data was recorded for the winter season. In the same arrangement and in the sunny winter days the solar water heater was installed and coupled to the heat exchanger instead of the ground source as in figure (5.14). The same data was recorded.

After taking all data the calculations were rechecked and charts were prepared and all the behaviors for the four modes were compared to the conventional heat pump a/c units and the results are presented in chapter 6.

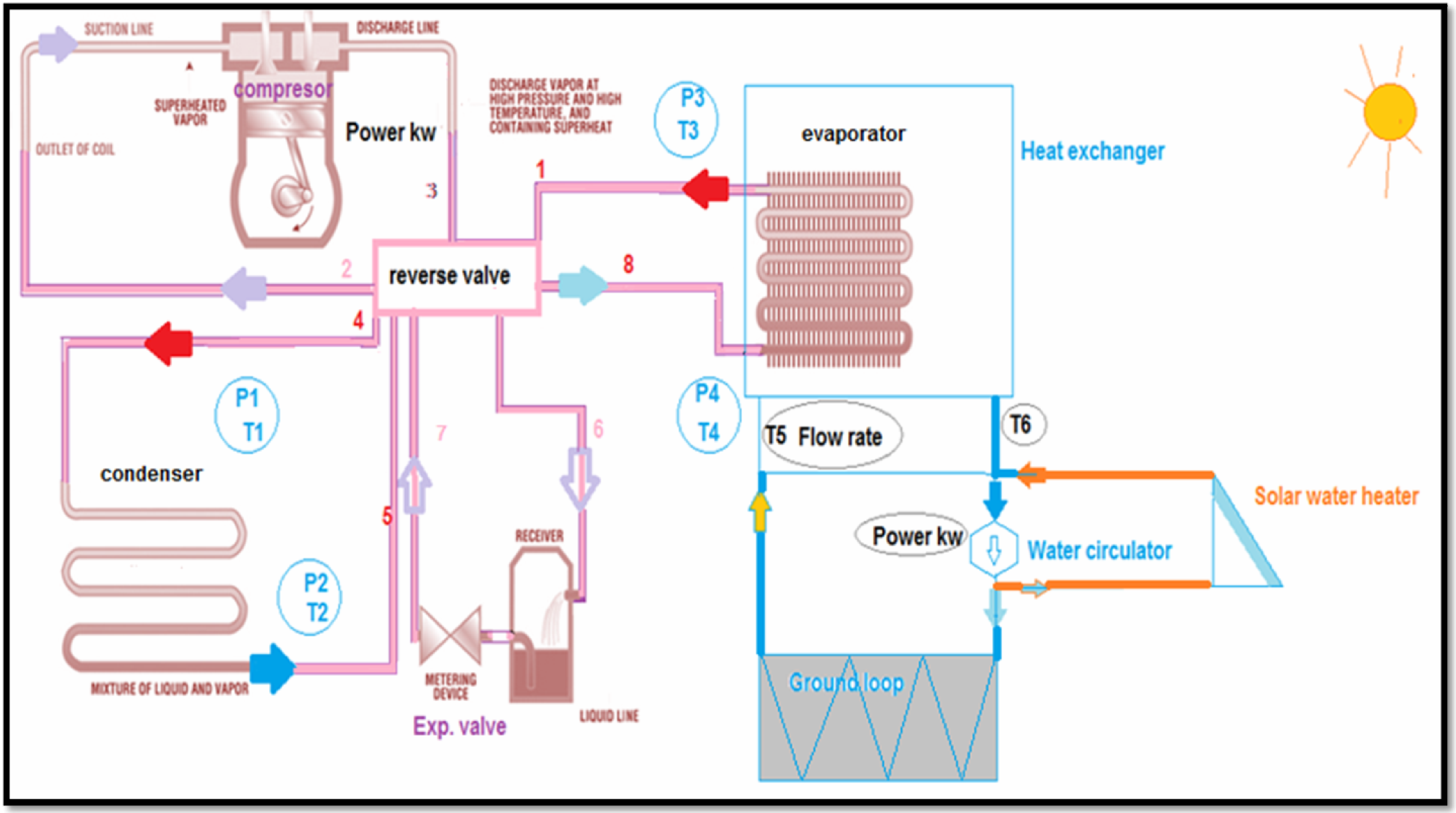


Figure (5.14) Combined Ground source- Solar heat pump connected to ground with condenser is the indoor unit and the evaporator is the water tank heat exchanger connected to the ground loop (Heating mode)

Chapter Six

Results and discussion

Chapter Six
Results and discussion

6.1 Preliminary Experiment

In this test the condenser unit which is the outdoor unit was installed inside the prefabricated tank with the dimensions 70x50x50 cm made of Galvanized steel as described before. The tank was insulated and the piping was welded and arranged from the compressor to the condenser and from the evaporator to the compressor to the four ways reversing valve and the condenser and the expansion capillary tube. The tank was filled with water. For the ground loop tests at later stage the system final connection was connected to ground and solar collector as shown in figure (6.1). The pressures and temperatures of the refrigerant were recorded for the evaporator (P_1, T_1, P_2, T_2) and for condenser, (P_3 , T_3, P_4,T_4), water flow rate at the heat exchanger to ground loop, temperature at inlet and outlet of the heat exchanger (T_5,T_6) and the power consumption for both the compressor and pump. All this readings were recorded with respect to time.

In preliminary test the unit was operated at cooling mode i.e.; the evaporator unit is the indoor unit. The temperature of water in the tank (T_5) and the temperature of evaporator inlet (T_3), and outlet (T_4) were plotted against time as in figure (6.2). As the unit operates the discharge line which is the condenser inlet gets hot as a result of the heat absorbed from the evaporator and the friction between the molecules of the refrigerant vapor this makes the refrigerant heated up to 75 °C. The refrigerant used is

R410a which has exactly 75 °C discharge temperature when compressed at 364 psig or nearly 25 bars as shown in table 6.1 below, the pressure measured P_3 of the refrigerant out of the compressor at the inlet of the evaporator was also in line with the table (6.1) below.

Table (6.1): Theoretical Air Conditioner Performance Comparison for different refrigerants [53]

Assuming 110F(43c) Condenser, 45F(7.2) Evaporator, 5F (-15c) Subcooling, 15F(-9.4 c) Superheat			
	R-22	R-407C	R-410A
Compression Ratio	2.66	2.83	2.62
Compressor Discharge Temperature	171F	167F	166F(75 c)
Compressor Discharge Pressure	226 psig	241 psig	364 psig (25 bar)
Temperature Glide	0F	9F	0F (-17.7c)

When the unit was started up the temperature of the evaporator was cooled down to -5°C then the temperature started to reach equilibrium around zero Celsius. The evaporator outlet temperature started to cool down from around ambient down to reach around 12°C which is the cooling coil temperature that should be achieved to cool down the space to 23°C, which was 12°C less than the outdoor dry bulb temperature. The water temperature increased from 26°C to steady state temperature at 30°C. The water temperature did not exceed 37°C because the load is higher than the installed unit capacity which is 3/4" Ton refrigeration or 10000 btu/hr or in SI units 2.6 kW, for the ground loop the load is the heat rejected in the condenser which is the heat absorbed from the evaporator added to the compressor work, this is equal to the heat capacity of water mass available in the tank less the heat losses through the tank to the surrounding which is negligible as the tank was insulated and can be assumed to be adiabatic system at this point the load is equal to the capacity which is defined as the energy produced by the heat pump to raise the temperature of the load which is water. The energy that has to be dissipated in the ground loop can be calculated by multiplying the water mass in the tank by the specific heat of water by the temperature difference of water between the initial state and the final state which was 5°C divided by the time period between the initial and final state which was 2.6kW, and this was exactly the capacity of the heat pump 2.6kW. Appendix 4 shows the P-h diagram for R 410 a refrigerant and the temperatures and pressures for the cycle knowing the amount of the refrigerant flow and subtracting the enthalpy of the condenser outlet from the inlet the heat rejected can be calculated, This was the plan but as the refrigerant flow meter was not available the heat rejected was assumed to be the same between the condenser and water and the tank was insulated.

The condenser inlet maximum temperature was 75°C. Evaporator air supplied temperature was 12°C out Applying Carnot COP formula then maximum COP refrigeration

$cop_{rcr} = \frac{T_l}{T_h - T_l}$, COP_{rcr} = (273+12)/ (75-12) = 4.5, But the calculated COP from the data taken was

$COP_{hp} = \frac{Q_h}{W} = \frac{mcp\Delta T}{W} = \frac{175*4190*5}{220\ volt*1.63Ampre*.85*3600s}$=3.34 but the rated cop from appendix 14 was 3.22 at cooling which means the water cooled case has better COP. The same test was done for several days as plotted in the figure (6.1), figure (6.2) figure (6.3), figure (6.4), and figure (6.5) for different days. The compressor work is the work done by the compressor and this was calculated by multiplying the voltage and the current and the power factor and this was also plotted against time as in figure (6.6), and figure (6.7). the work stated at 0.28 kW and grows up till 0.375 kW and continue at the same level for an hour then starts to increase again to reach 0.465 kW and stops increasing at this value and this can be explained as the temperature of the water around the condenser reaches a value of 30°C and the driving force for heat transfer becomes very small the condenser cannot add heat to the water and this will over load the compressor to compensate the difficulty of rejecting heat to the water. Power is almost 24% higher to compensate the difficulty in heat rejection. The same jump in work of the compressor happened in 13-6-2011 when at 11:20 but lower temperature and hour earlier for the same reason the compressor is over loaded by the condenser higher temperature because the condenser is not loosing heat to the surrounding and the temperature builds up making things difficult for the compressor that requires more work.

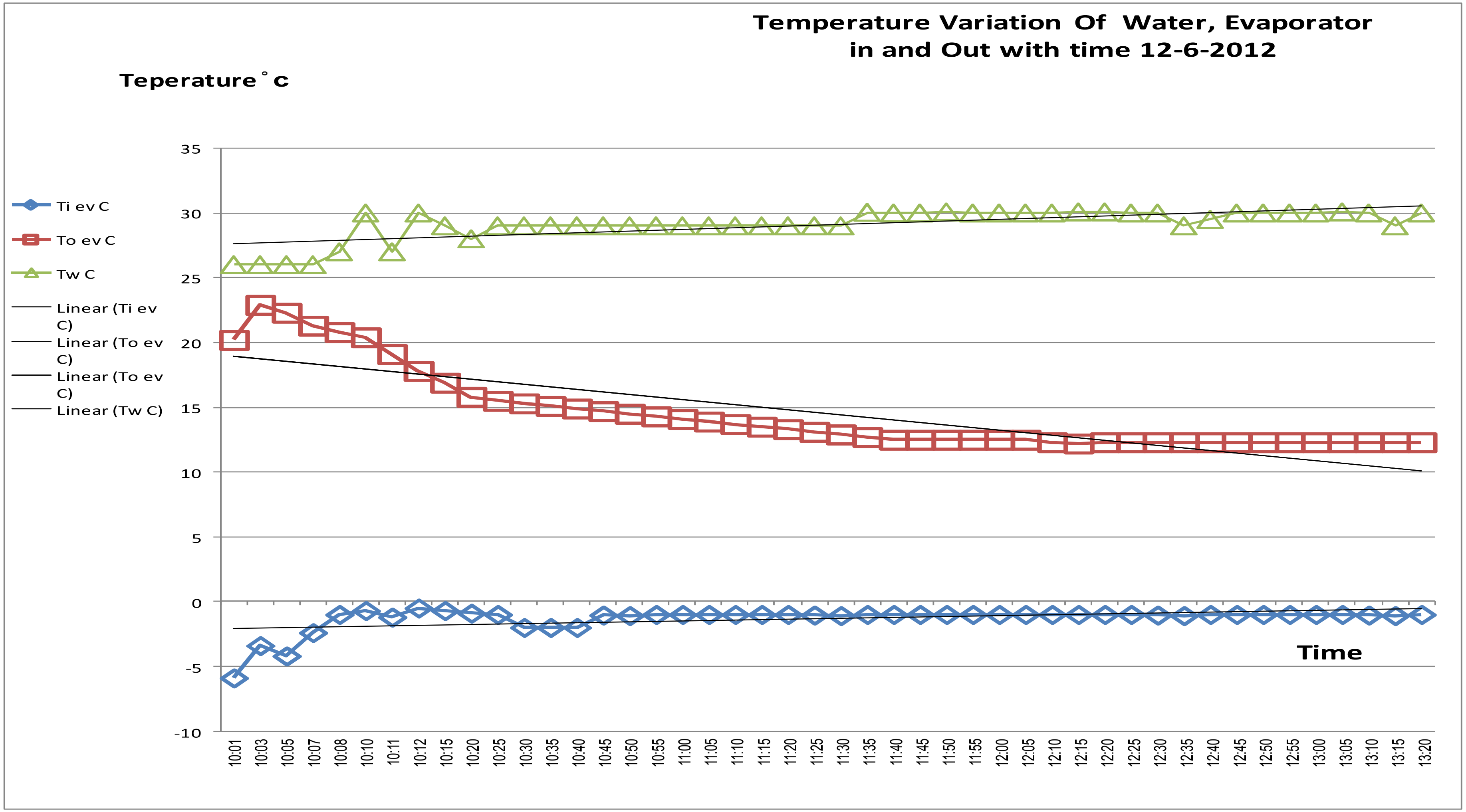


Figure (6.1) Water temperature variation in the condenser tank, Evaporator influent and effluent Temperature of heat pump on cooling Mode dated 12-6-2011 preliminary tests

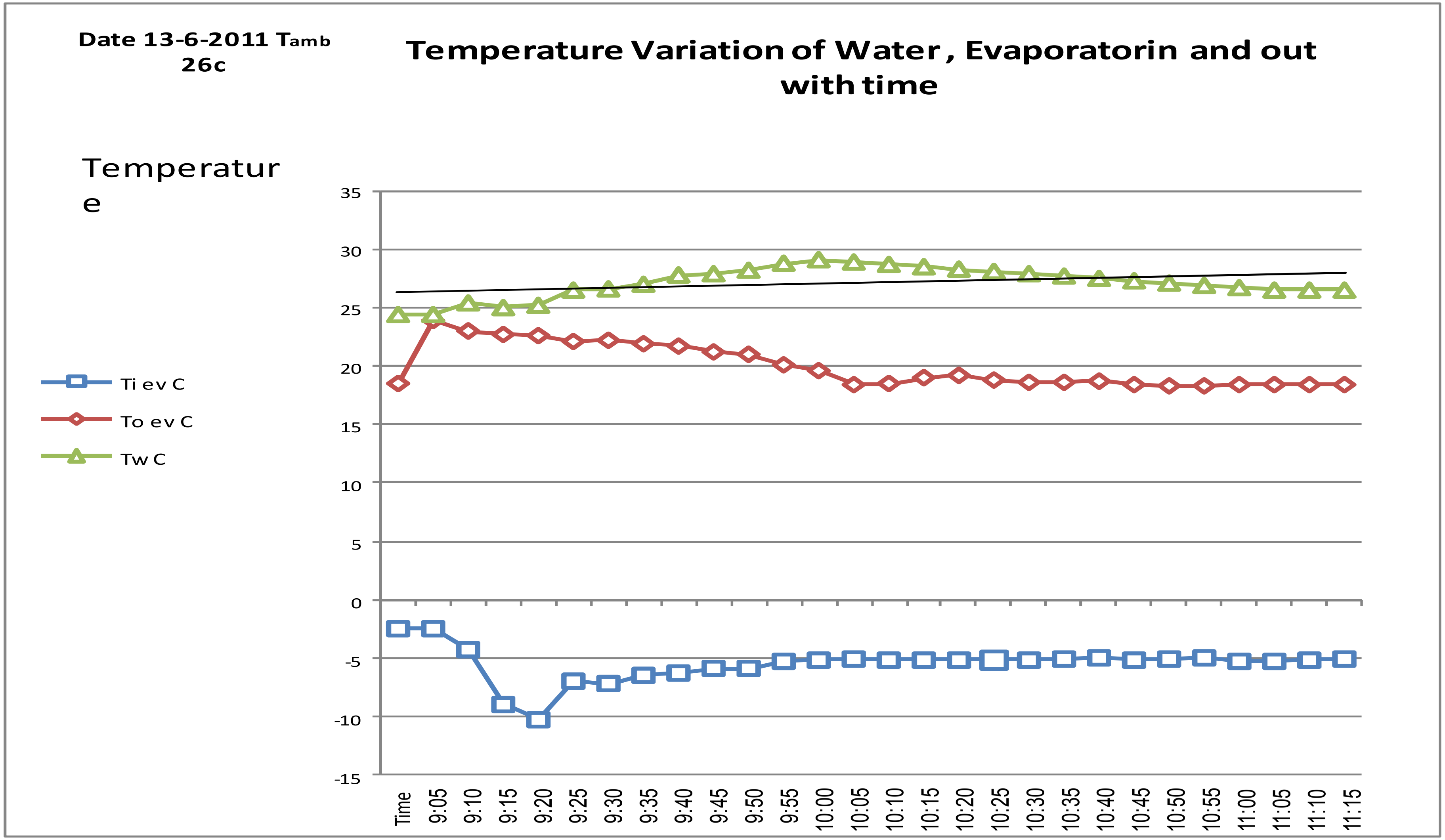


Figure (6.2) Water temperature variation, Evaporator influent and effluent Temperature of heat pump on testing dated 13-6-2011

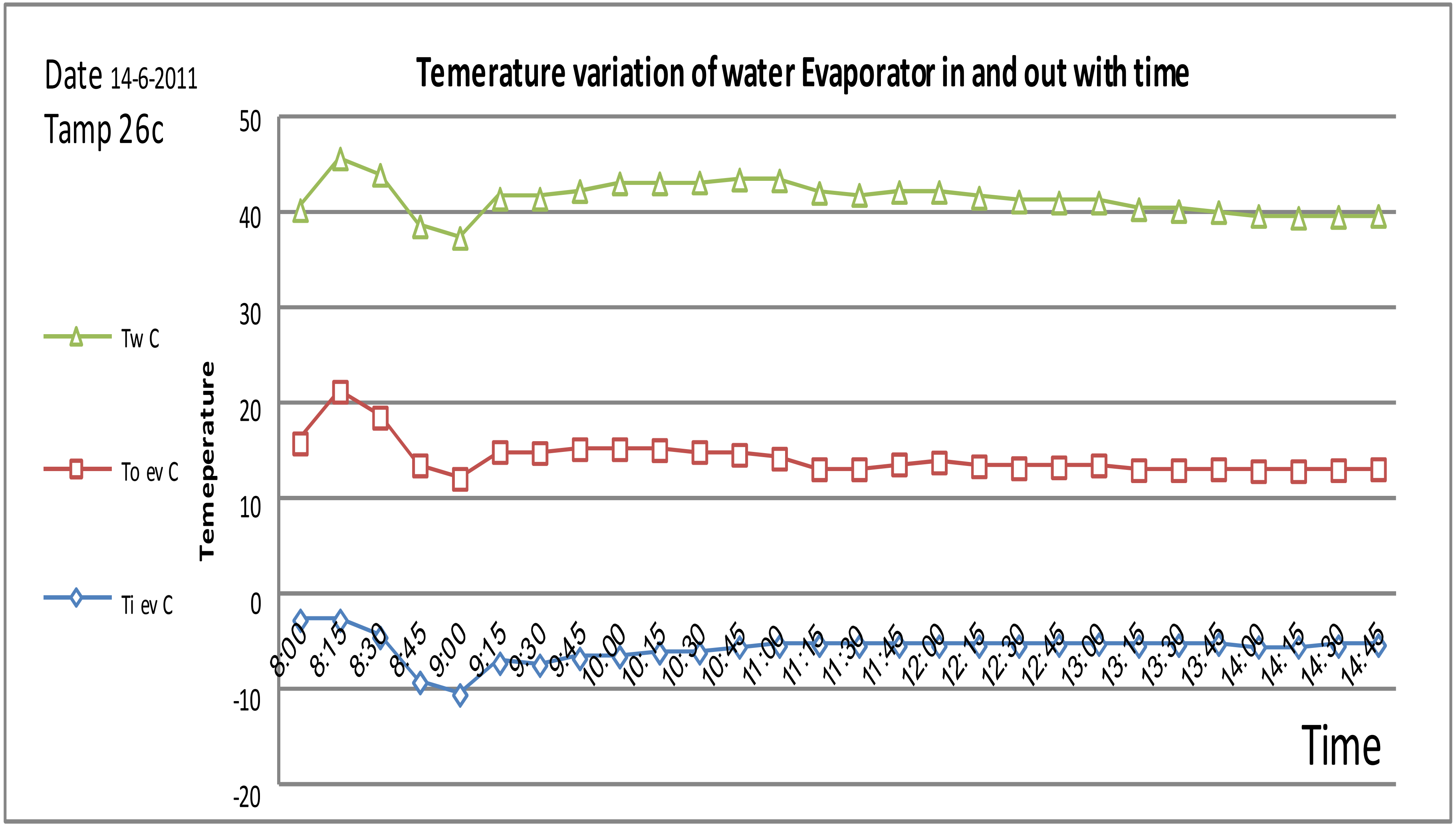


Figure (6.3) Water temperature variation, Evaporator influent and effluent Temperature of heat pump on testing dated 14-6-2011

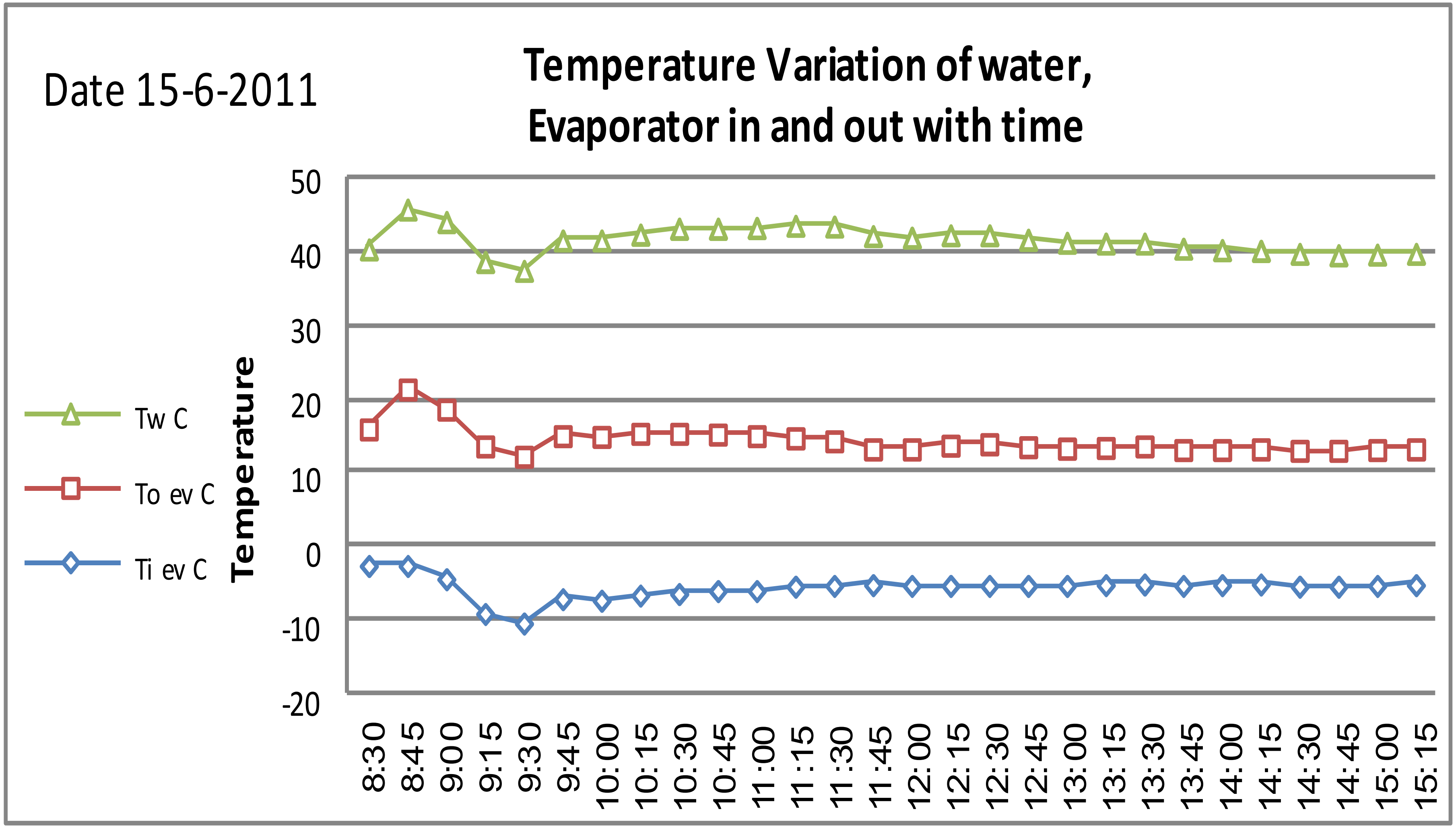


Figure (6.4) Temperature variation of water, evaporator influent and effluent of heat pump on testing dated 15-6-2011

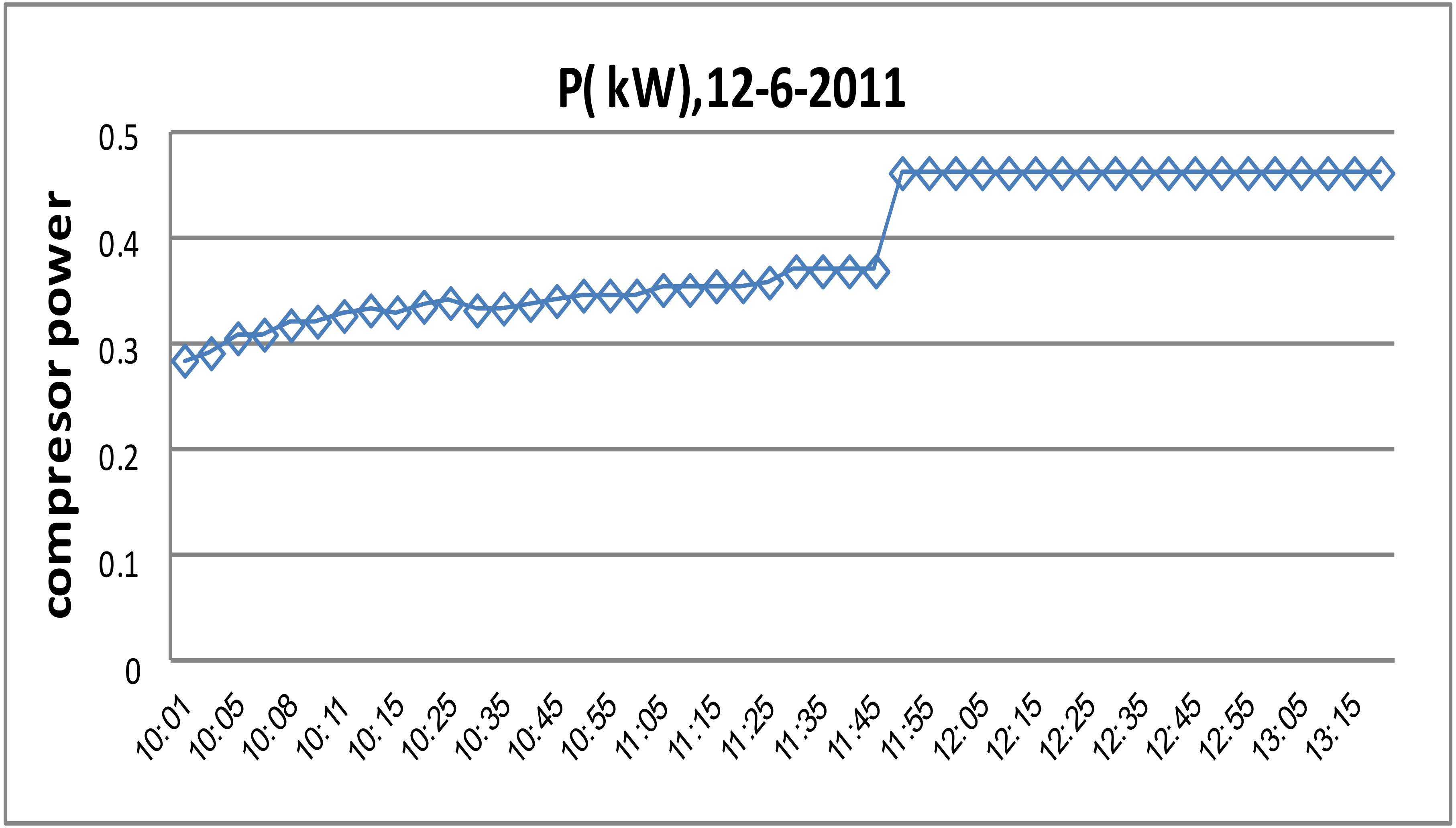


Figure (6.5) Compressor power consumption with time.(12.6.2011)

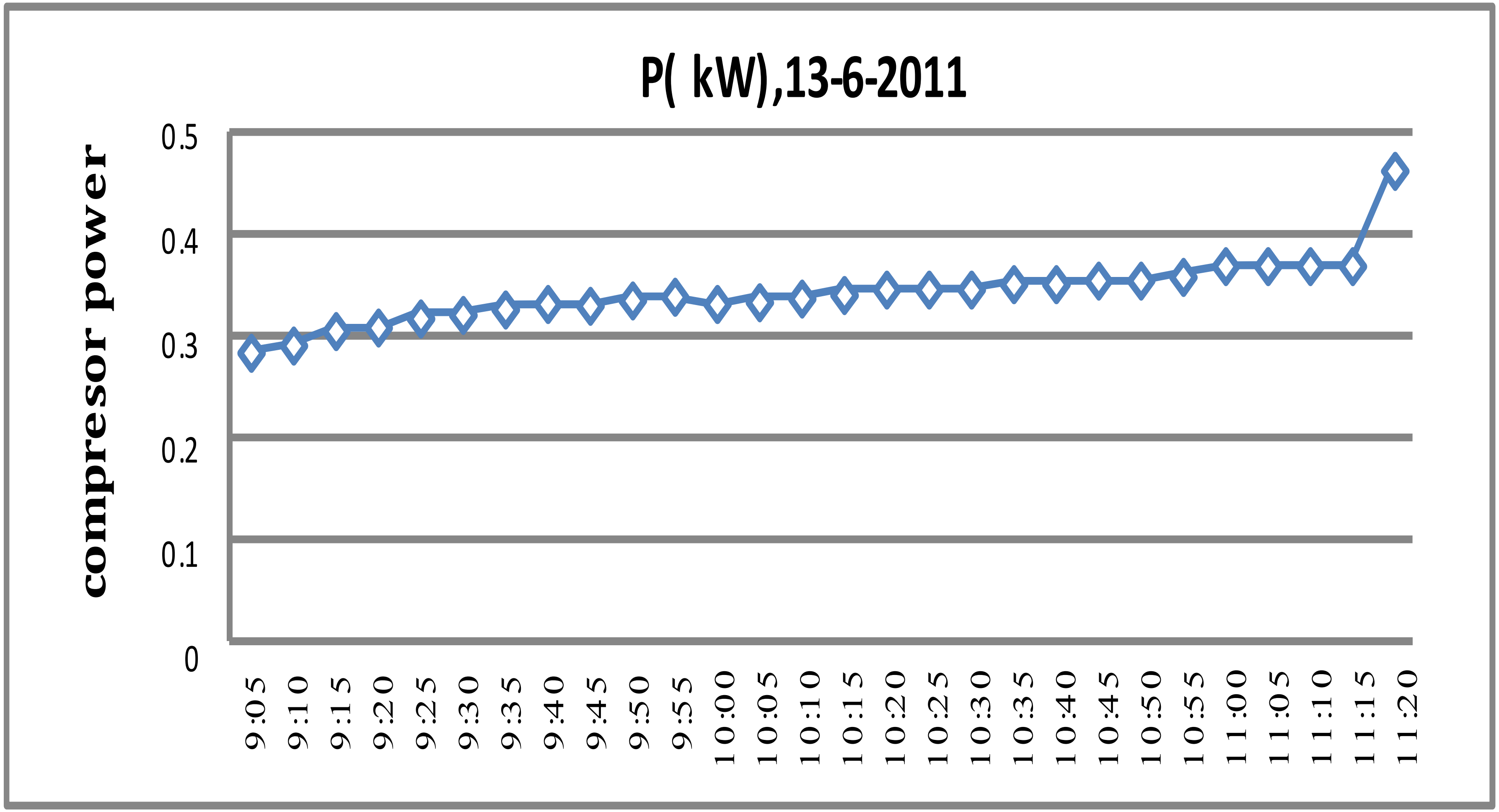


Figure (6.6) Compressor power consumption vs. time (13.6.2011)

The heat which is added to the water in the tank can be calculated using the following formula

$Qc = m\,Cp\,\Delta T$, where m is the mass of water, cp is the water specific heat at constant pressure of pump; ΔT is the temperature rise for water in the tank.

Multiplying power consumed by time period between the start and the end of the experiment to convert the average power into energy which is the area under the power time curve, and dividing the heat by that result the COP is determined.

$COP_r = \frac{Qc}{W}$, Q_h-Q_c= W

But Q_h was 3666250 Joules, w = 1098000 joule

Then Q_c = 2568250 Joules $COP_r = \frac{2568250}{1098000} = 2.34$ or COPh= COPr+1

COP_{hp} is known as calculated in page 91

Cop_h =3.34

Cop_h = 2.34+1 = 3.34

It is very clear that the heat pump performs better in the water medium than it performs in the air medium in heating mode because water has higher heat capacity and higher heat transfer coefficient. By definition the heat transferred through a medium is:

$Q = \text{UA}\Delta\text{T}$, where q is the heat transferred in kW, A is the area of the medium in m^2, and ΔT is the temperature difference between the inside and the outside of this medium.

Then the heat transfer coefficient in terms of area is

$$\frac{Q}{\Delta T} = UA$$

For water cooled condenser ΔT =(Tout-Tin)= 5 °C between tank inlet and outlet, and Q= 2.6 kW the capacity of the unit then,

UA= $\frac{0.26}{5} = UA = \ 0.52\ kW/°C$

For air cooled condenser the same equation was applied taking into consideration the difference between the average temperature of inlet and outlet of the condenser and the ambient temperature

The condenser inlet is 75°C and the outlet is 35°C, and the air temperature 30°C then Using the log mean

$$LMTD\,\frac{\Delta Ta - \Delta Tb}{\ln \frac{\Delta Ta}{\Delta Tb}}$$

ΔT_a= 75-30=45, ΔT_b= 35-30=5

LMTD =$LMTD = \frac{40}{2.19} = 18.29\ °C$

Then, $UA = \frac{2.6\ kW}{(18.29\ °C)}$= 0.142 kW/°C

Which is less than that for water cooled condenser which means less heat is transferred in air than in water cooled condenser and that is the reason for better performance especially in severe conditions where the ambient temperature is very high or very low, so that the heat exchangers are unable to exchange heat to or from the ambient. From figure (6.1) it can be noticed that the heat is accumulating and this is because there is no circulation for the water. And thus the condenser unit face difficulties to reject heat into water after several hours causing the power consumed by the compressor to be higher in this case.

The temperature of the discharge line out of the compressor and before entering the condenser is given by T discharge in figure (6.7) below the water temperature is also shown in the blue plot T_w the difference between the temperature of water and compressor discharge is the same for all the time as shown in figure (6.7) below.

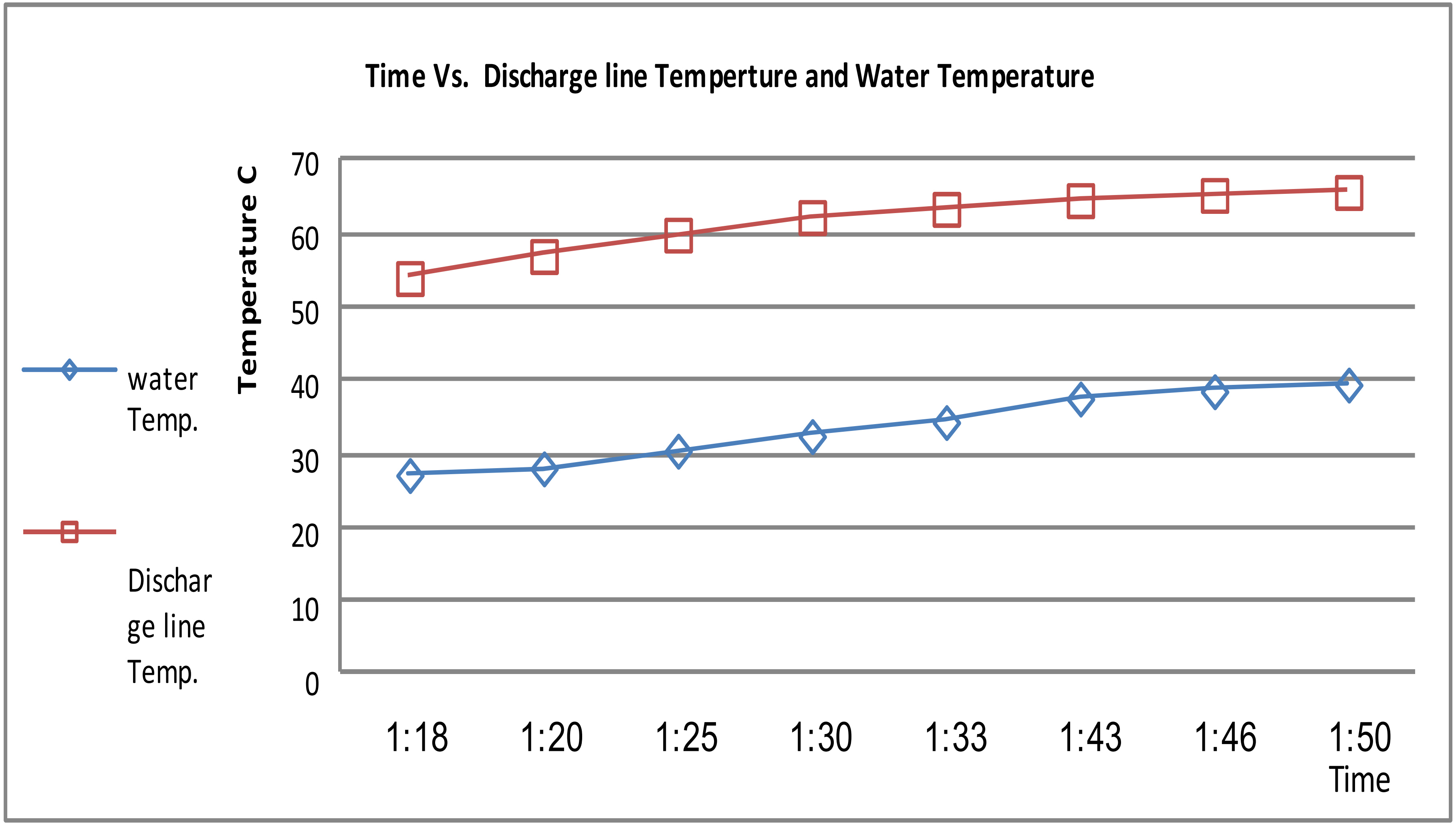


Figure (6.7) Water temperature and compressor discharge temperature as a function to time

The maximum condenser inlet temperature during this test was 65 °C. The minimum temperature for evaporator inlet was -5°C. Compared to the data obtained from table (6.1). The testing data was acceptable based on the fact that the room temperature was 26°C while the condenser temperature is expected to be less and also the evaporator temperature is also lower than the table because of the same reason.

The pressure of the refrigerant which is R410a is 364 psi which is the same values we got in our tests. A test is shown in Appendix 15.

6.2 Cooling Mode GSHP

In cooling mode the System was connected to the ground loop which was prepared before four months to neglect the effect of excavation and installation and reach equilibrium. The recorded data was taken as shown in appendix 8. Data was taken for several days in August and September. The room temperature was almost 26°C. The temperatures of water entering and leaving the ground source heat exchanger were recorded as a function of time. The temperatures of the refrigerant entering and leaving the evaporator were also recorded. The ground temperature was in average 17 °C, the water flow through the ground heat exchanger was recorded.

Figure (6.8) shows the temperature difference between inlet and outlet of ground loop versus time in a sample data for cooling mode.

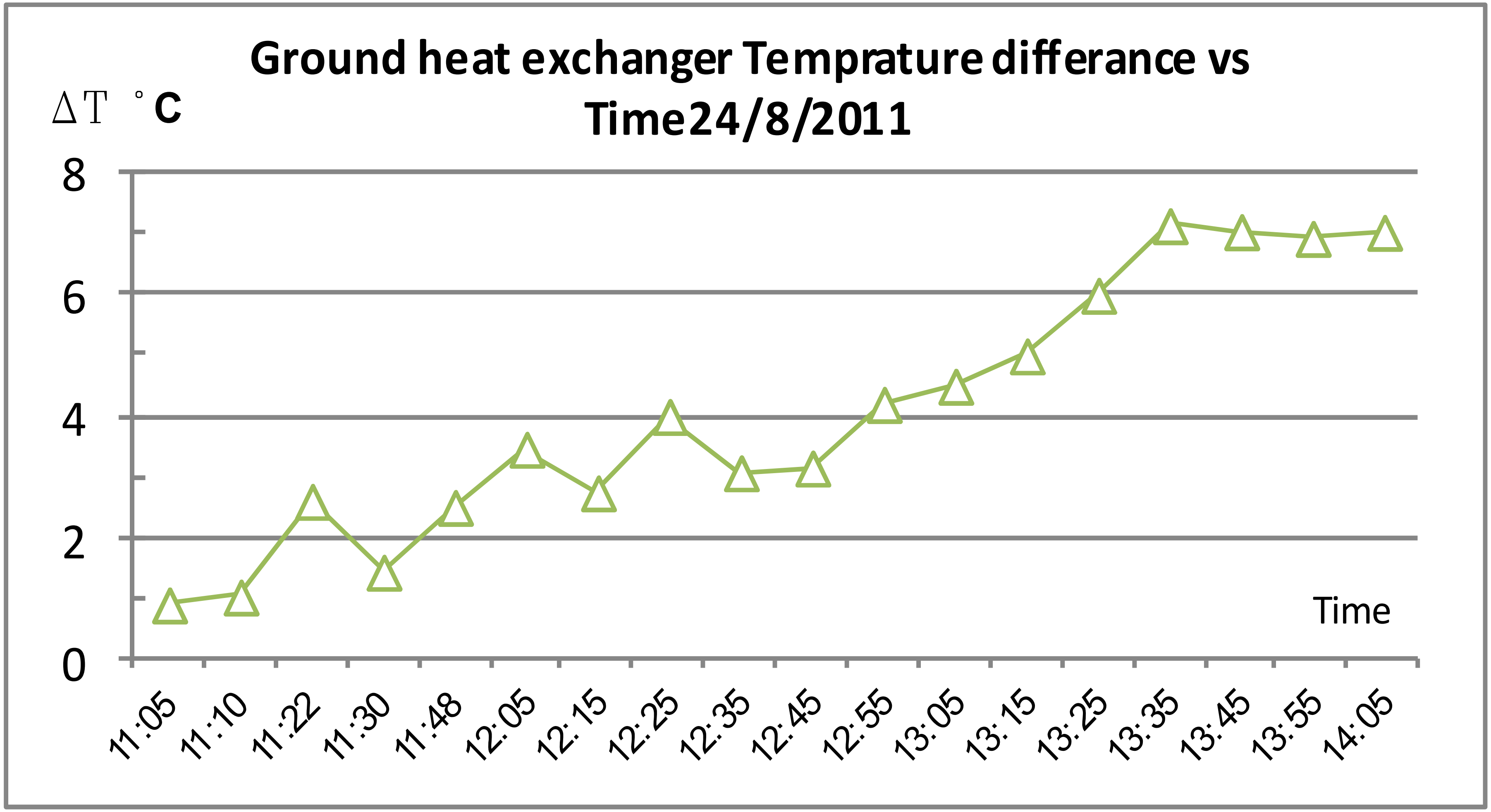


Figure (6.8) Ground heat exchanger temperature difference between inlet and outlet of the ground loop vs. time for cooling mode in 24-8-2011

The temperature difference was very small and almost zero between ground heat exchanger inlet and outlet at the beginning of the operation and it starts to increase slowly. The difference was 7°C and was obtained after 2 hours and it is constant. This is the steady state when the load is balanced by the work done by the system and the system is capable to remove the heat from the surroundings at a constant rate. Same data were plotted in figures (6.9), (6.10), (6.11) for different dates.

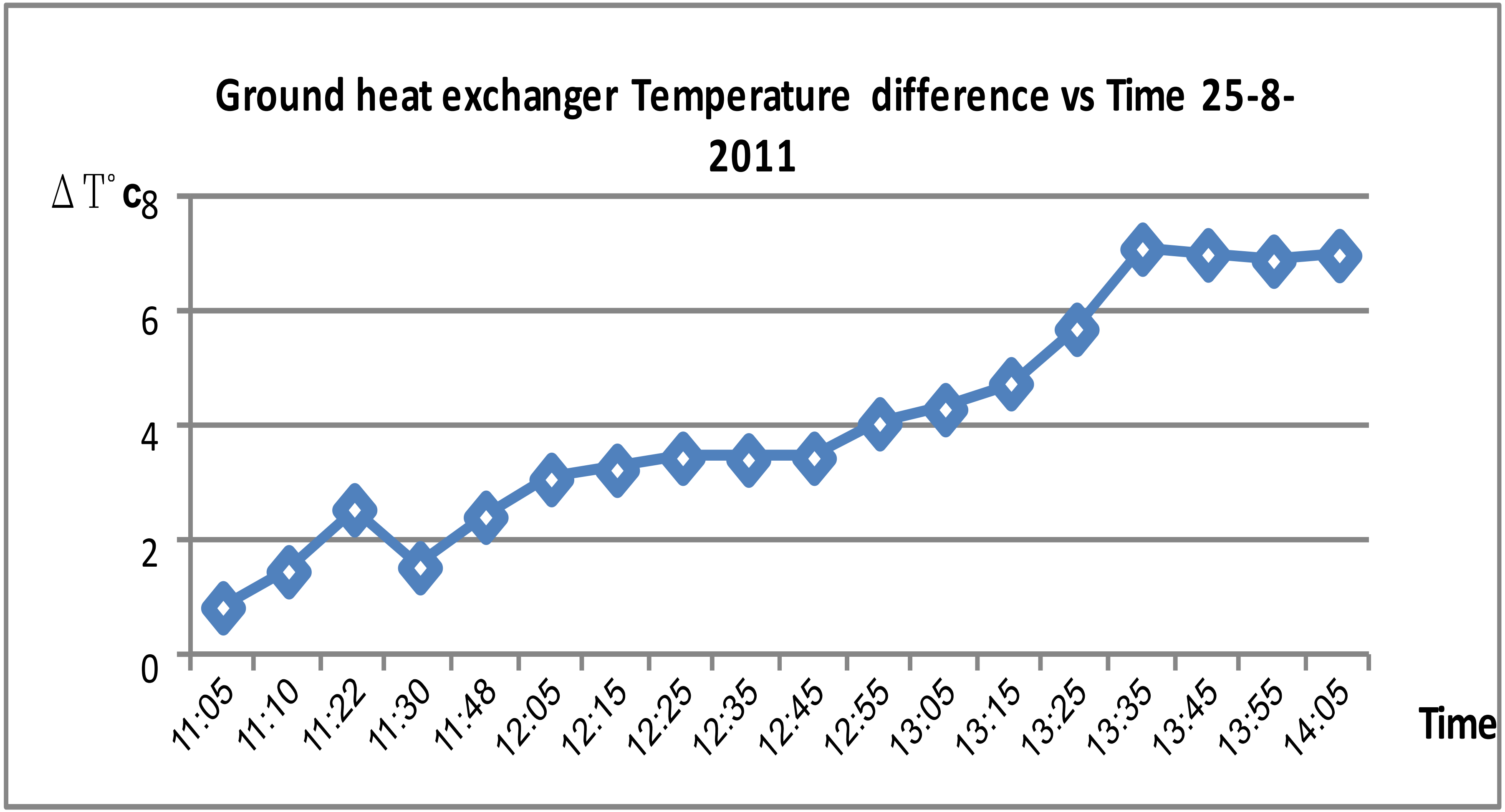


Figure (6.9) Ground heat exchanger Temperature difference vs. Time in 25-8-2012

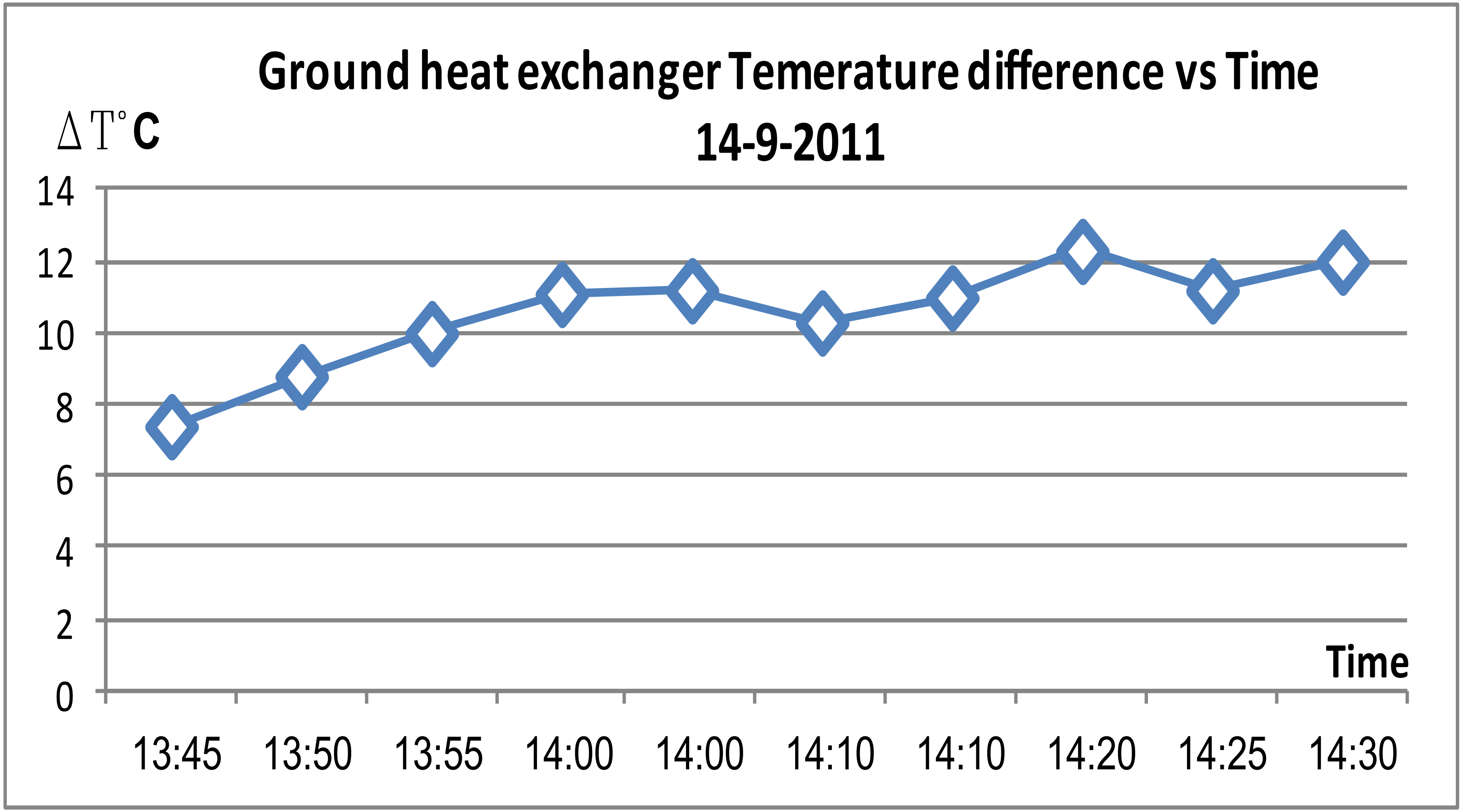


Figure (6.10) Ground heat exchanger Temperature difference between inlet and outlet vs. time 14-9-2011

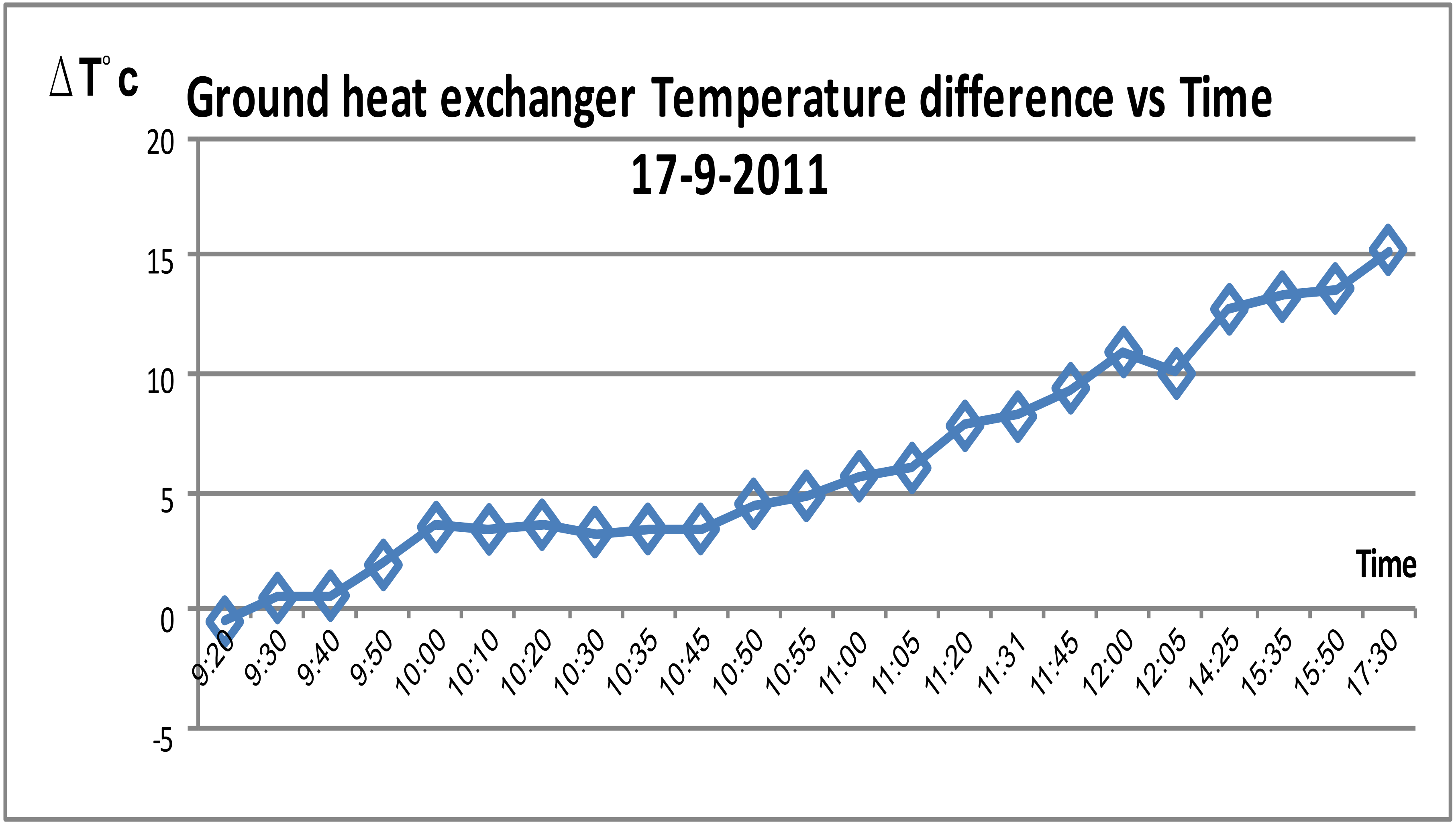


Figure (6.11) Ground heat exchanger Temperature difference between inlet and outlet vs. time in 14-9-2011

Figure (6.12) below shows the behavior of the coefficient of performance of the heat pump neglecting the work of the circulating pump and calculating the work of the circulating pump the COP increases gradually for around two hours then stops at the highest value of 3.3 and remain constant at a steady state, because the COP is defined as the useful power divided by the consumed power, the consumed power by the compressor starts at a value of around 300 watt, the pump work is constant at 125 watt, The energy transferred per unit time from the evaporator to the condenser increases gradually first of all because the refrigerant needs a cretin time to complete the cycle, another reason is that the energy transferred by the heat pump is a function of time as the time passes the temperature of water surrounding the condenser increases and the energy accumulates and builds up. This means the heat absorbed in the evaporator which is a function of the time divided by the work consumed will most likely behave the same. To be more precise the heat from evaporator was not measured for technical reasons it was calculated from the main equation that defines the

$COPr = \frac{Q_c}{W} = \frac{Q_c}{Q_{h-Q_c}}$, therefore the heat rejected in the condenser is the summation of the heat absorbed in the evaporator and the work done by the compressor. Add to that the work done by the pump then the geothermal can be found as per the following curve. See appendices 15.

The same data for different days were plotted in figure (6.13), figure (6.14), and figure (6.15).

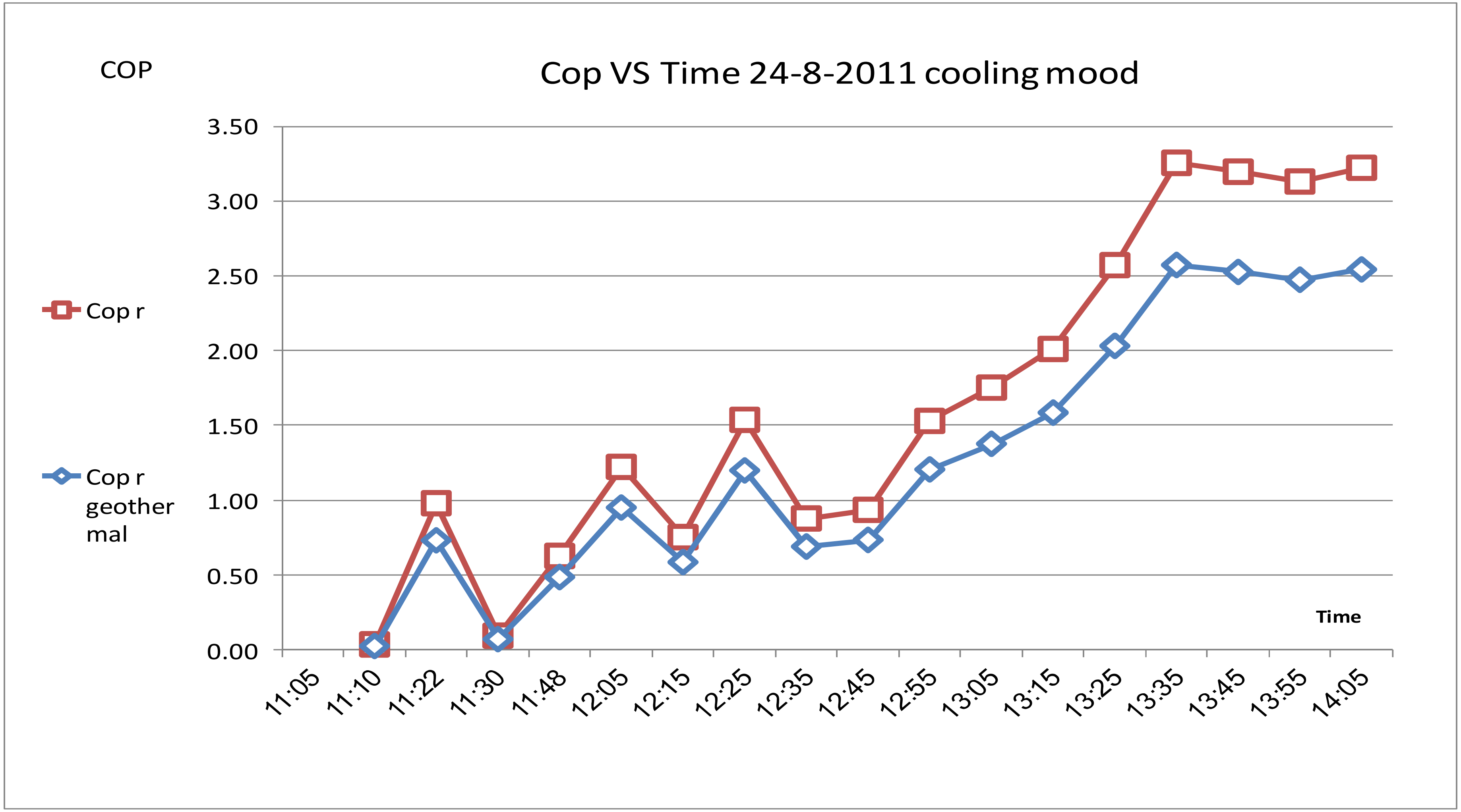


Figure (6.12), Cop of geothermal Heat pump with and without adding the power consumed by the circulating pump 24-8-2011 on cooling mode.

The geothermal COP is defined as the useful output divided by the total input including the pump and the compressor as shown below:

$COPr,geo = \frac{Qc}{W\ comp+Wpump}$, $COPh,geo = \frac{Qh}{W\ comp+Wpump}$ An average cop of 5 for geothermal heat pump was obtained and 6.5 can be considered when the power consumed by the pump was neglected, this drop in performance is due to power consumed by the pump which is close to 25% of the power consumed by the heat pump. The used pump is a standard pump which is usually used for circulating high flow rates of water and the smallest available one in the market, in other words the pump is oversized. If a well designed pump is used with a flow 0.167 l/s flow and with the same head, the needed power could be 110 watt less which is negligible compared to compressor power it presents 3% of the power, which means the COP of the geothermal heat pump will be around 6. Compared to the COP tested, which means efficient to use the geothermal heat pump and that was for the following reasons:

1- Water has a large specific heat which is four times that for air thus the heat capacity is larger and this can improve the rejected heat so improves the heat absorbed for the same power input, and this improves the performance.

2- The ground temperature which is at least 15°C degrees less than the ambient temperature improves the heat rejection rate the geothermal heat pump into the ground thus higher Q_h and higher Q_c for same power input.

3- As the ambient temperature increases more investment is needed in the heat pump for better heat transfer this means that larger units should be used for the same room in different outdoor conditions. Which is not the case for geothermal heat pump as ground temperature is almost the same for different areas unlike the weather. For instance Jericho has an ambient temperature for design of 46 °C but Nablus, and other west bank cities have 35°C which is 10°C degrees that is greater investment is needed and more consumption for the same output.

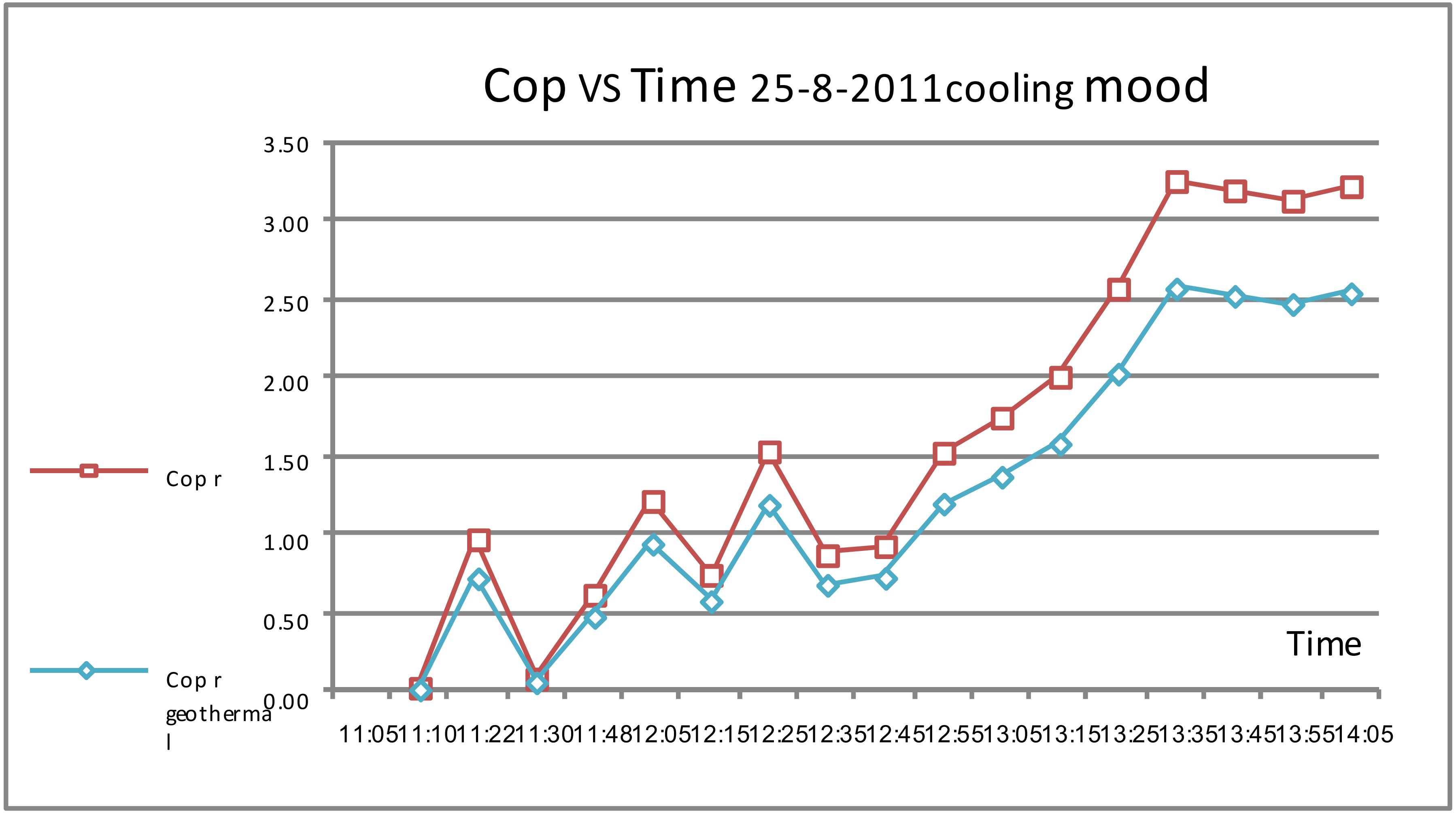


Figure (6.13) Cop of geothermal Heat pump with and without adding the power consumed by the circulating pump on cooling mode 25-8-2011

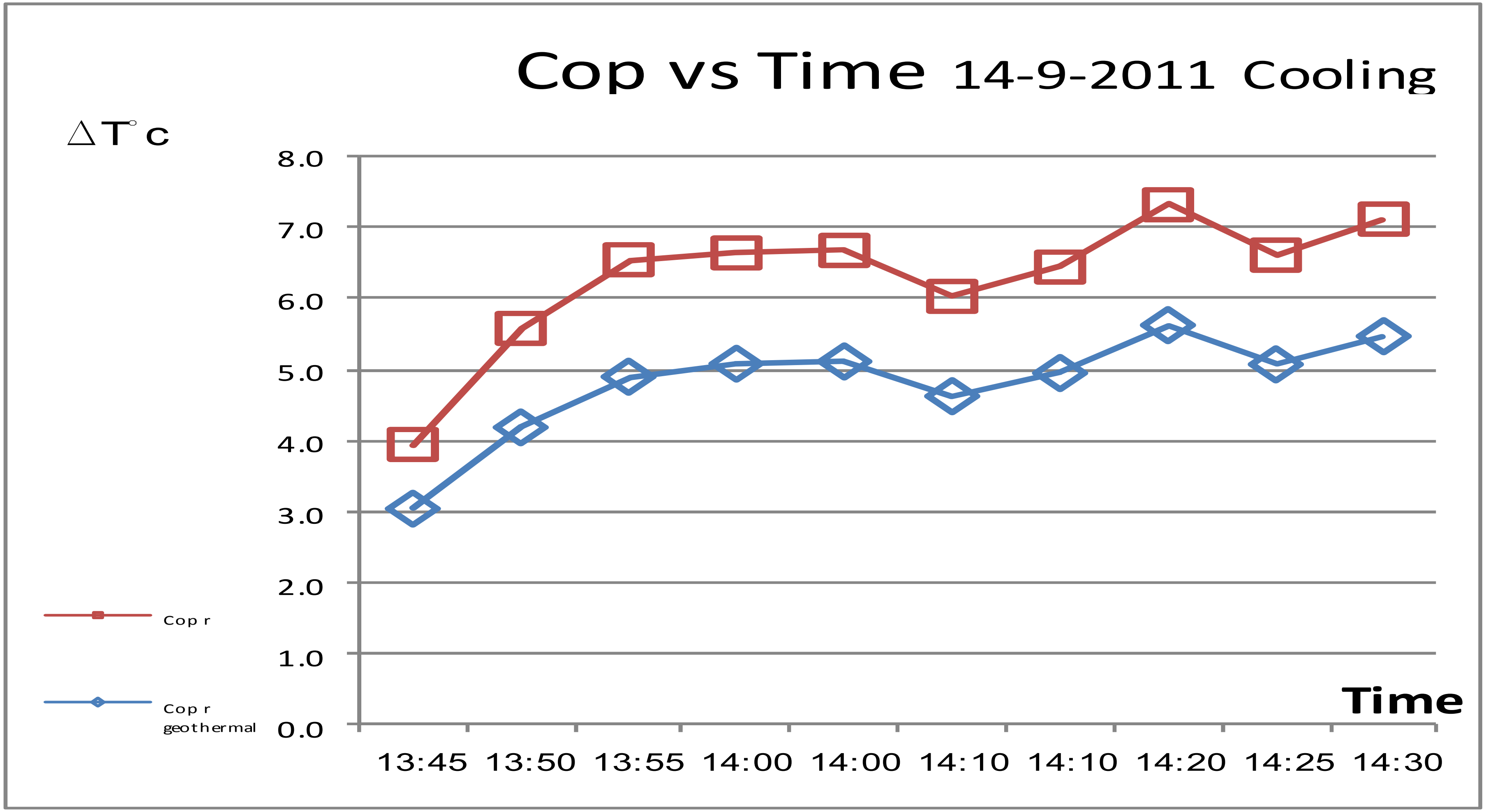


Figure (6.14) Cop of geothermal Heat pump with and without adding the power consumed by the circulating pump on cooling mode 14-9-2011

Figure (6.15) shows the plot of heat absorbed, heat rejected, and total power consumed by the compressor and the pump with time, using the cooling mode with geothermal loop. It is obvious that as the system starts both heat absorbed and rejected are the same. This was because the compressor work against the refrigerant molecules did not heat them up at the beginning yet after an hour of operation, the heat difference increases due to friction losses. The work increases then after half an hour it reaches to equilibrium and it is the same. The difference between the power consumed and the power gained through this process is very large and worth the investigation as there is no such equipment that can produce more power than consumed and any process should involve losses.

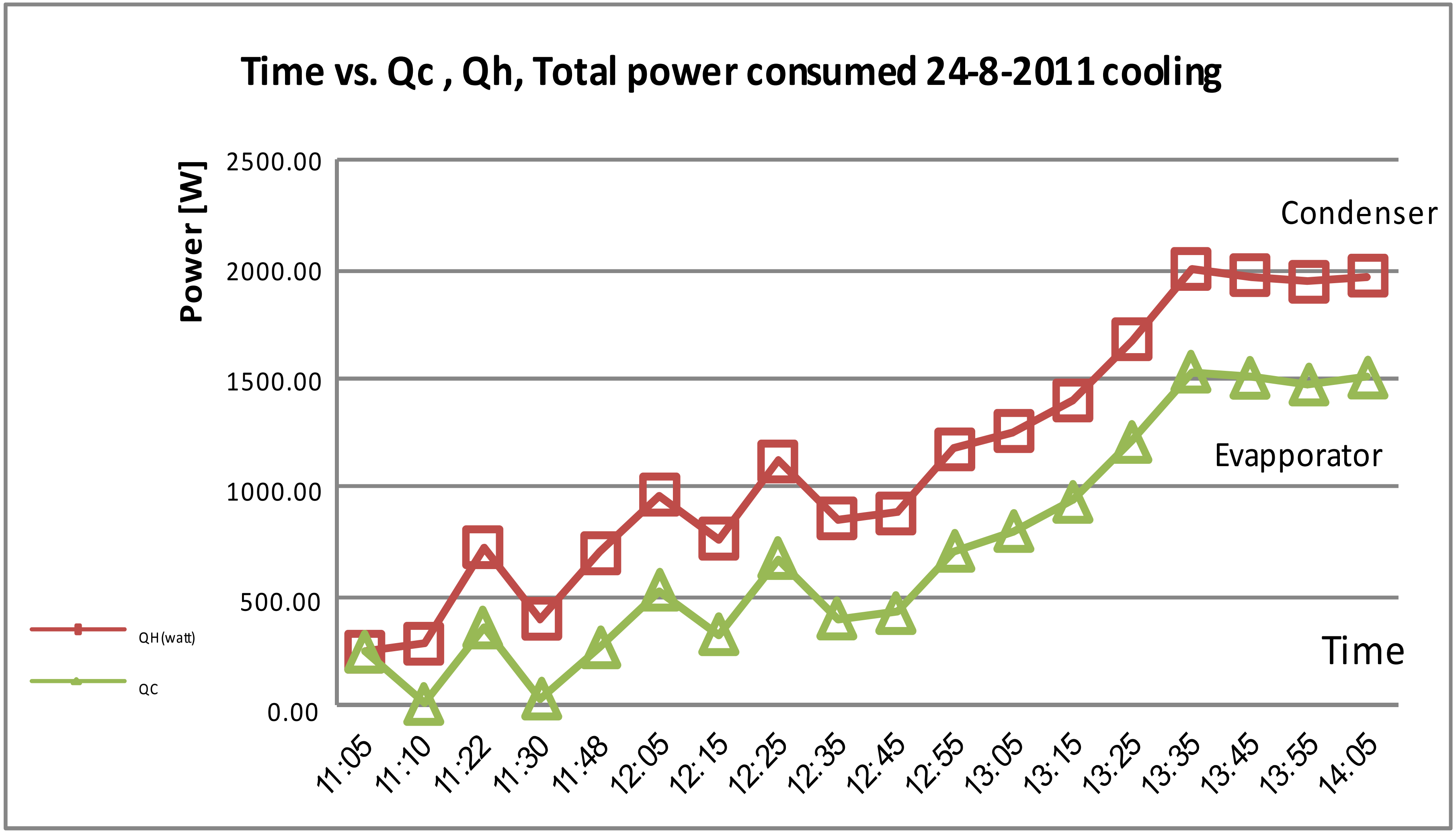


Figure (6.15) heat absorbed, heat rejected, power consumed vs. time geothermal Heat pump 24-8-2011

Again calculating the heat transfer coefficient for the cooling mode but for the ground loop, the average temperature between the inlet and the outlet of the ground loop on 24-8-2011 at the steady state was

$$LMTD = \frac{\Delta Ta - \Delta Tb}{ln\frac{\Delta Ta}{\Delta Tb}} =$$

$$\Delta Ta = 33.5°C - 17°C = 16.5°C$$

$$\Delta Tb = 26°C - 17°C = 9°C$$

$LMTD = \frac{16.5-9}{ln\frac{16.5}{9}}$=12.5°C

Then, $UA = \frac{2.6\ kW}{(12.5\ °C)}$= 0.2 kW/ °C

Which is higher than that for air, but less than that for water, and this makes sense as liquid has the best contact with heat exchanger than air and solids. But buried pipes have larger surface area (32.7 m^2, 400 m of 26 mm diameter) pipes than the area for immersed condenser in the preliminary experiments and this resulted high performance.

6.3 Heating Mode

Heating mode experiment was conducted between December and January. The heating was performed using the reversed cycle where the evaporator was used as a condenser and the condenser as an evaporator using a revering valve. Tests were conducted at an ambient temperature of around 10 °C the results are tabulated in Appendix 15**.**

The room temperature was 22 °C in average during the experiments. The temperatures of water entering and leaving the ground source heat exchanger were recorded with time. The temperature of the refrigerant entering and leaving the condenser was also recorded the temperature of the ground was in average 17 °C the flow rate of water through the ground heat exchanger was recorded. The power consumed was also recorded.

Figure (6.16) shows the temperature difference versus the time in a sample data for heating mode.

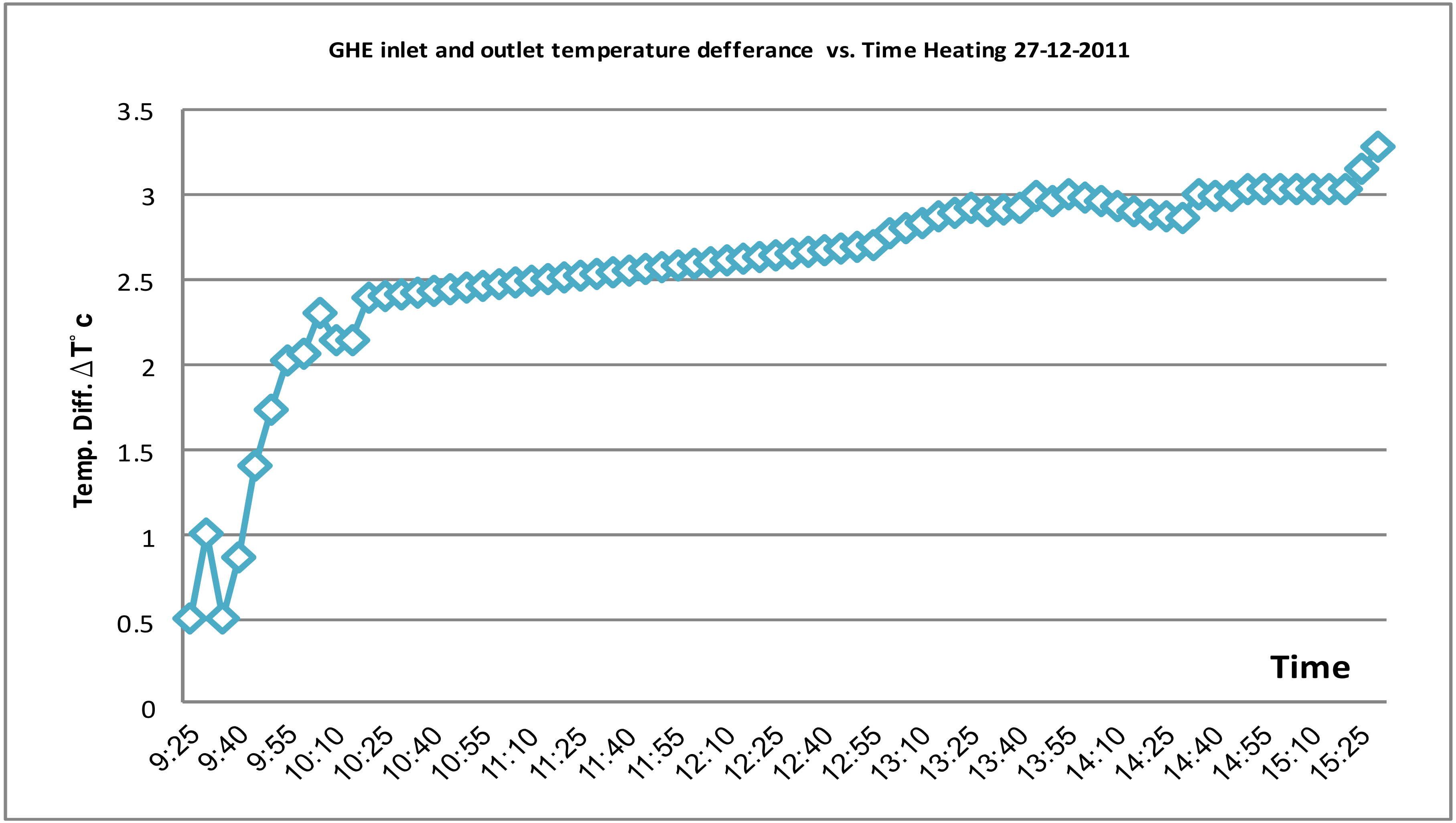


Figure (6.16) Temperature difference between inlet and outlet of geothermal heat pump at heating mode vs. time 27-12-2011

The temperature difference between the ground source heat exchanger inlet and outlet was 0.5 °C at start then it starts to increase for half an hour sharply to reach 2.5 °C, and then the increase was 0.5 °C for a period of four hours. The increase stops after that point and the difference is fixed due to balance in the system and the quantity of heat absorbed is constantly rejected to ground. The reason that the temperature difference is small is that the flow rate of the circulation pump is high the less the flow the better the geo-exchange is. The steady state value of temperature difference was 3°C. Similar results are\shown in figure (6.17) and figure (6.18) below.

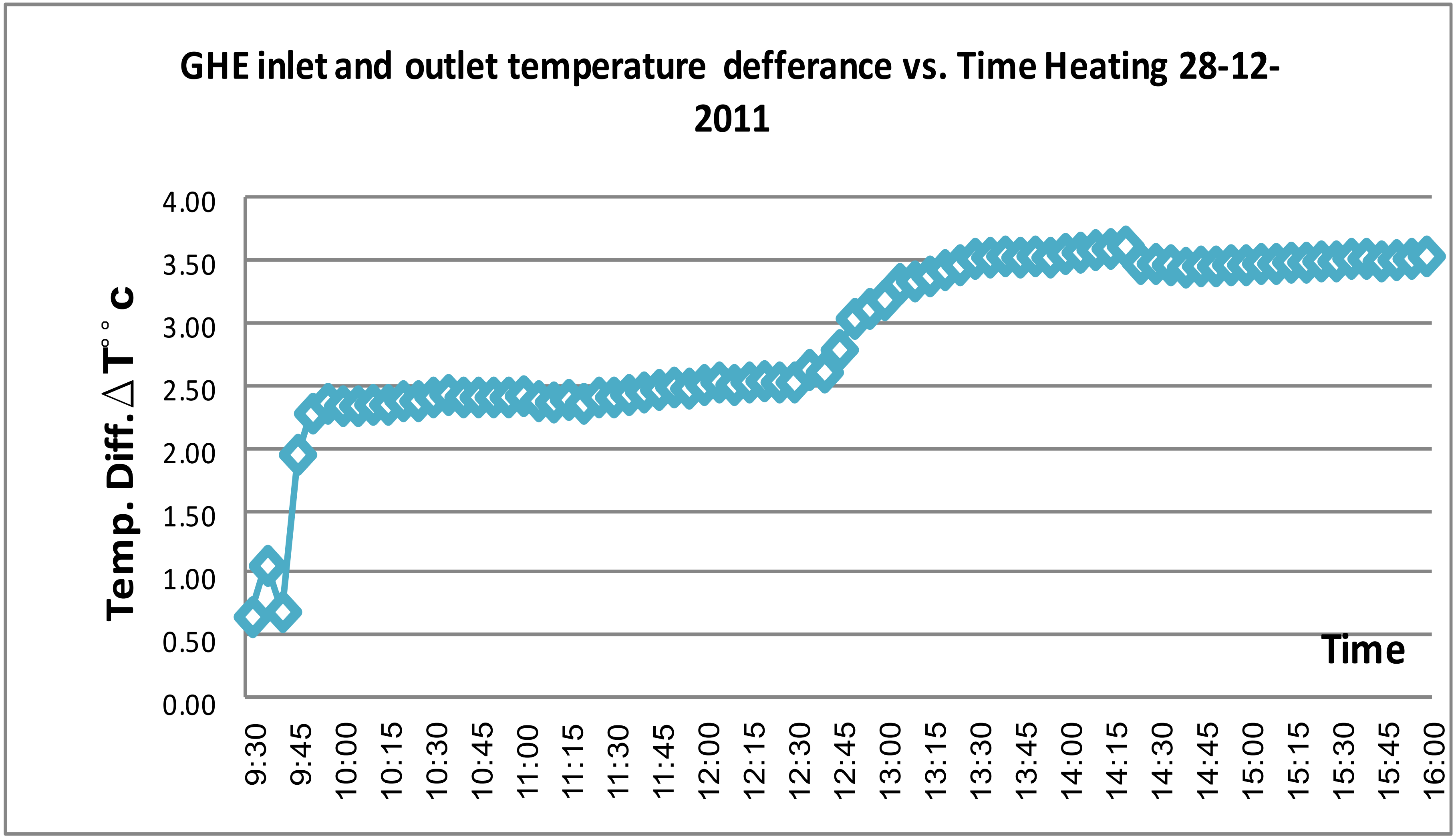


Figure (6.17) Temperature difference between inlet and outlet of geothermal heat pump at heating mode vs. time 28-12-2011

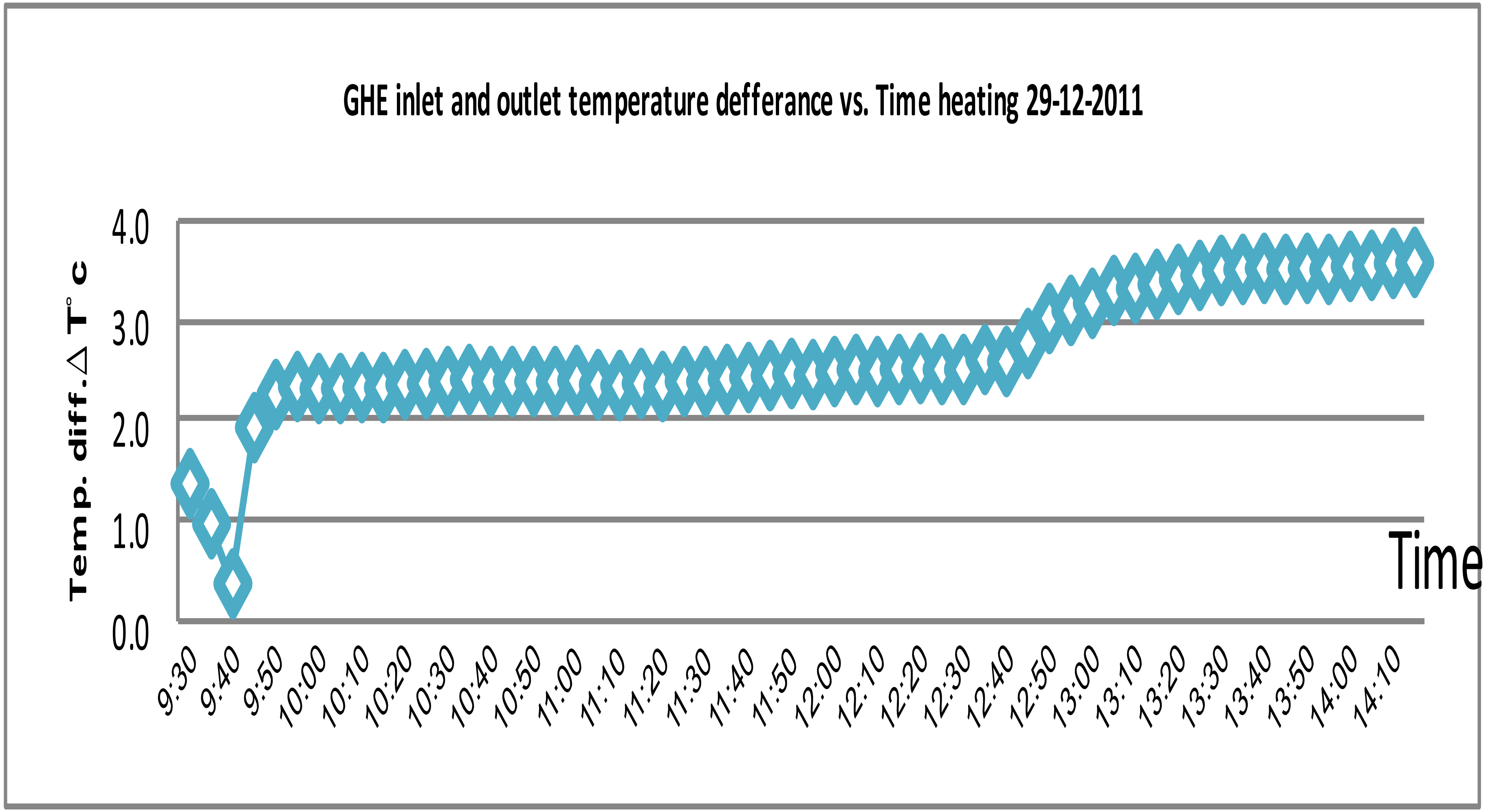


Figure (6.18) Temperature difference between inlet and outlet of geothermal heat pump at heating mode vs. time 29-12-2011

Figure (6.19) below shows the relation between the heat pump coefficient of performance and time, the coefficient of performance increases with time due to temperature difference Increases which increases the heat absorbed and improves the performance. The transient state was one hour and in this hour the performance increased from zero to six. The performance increases slightly in its steady state to reach a maximum of eight after six hours of operation. Similar results were tabulated in appendices 15 heating mode and shown in figure (6.20), and figure (6.21).

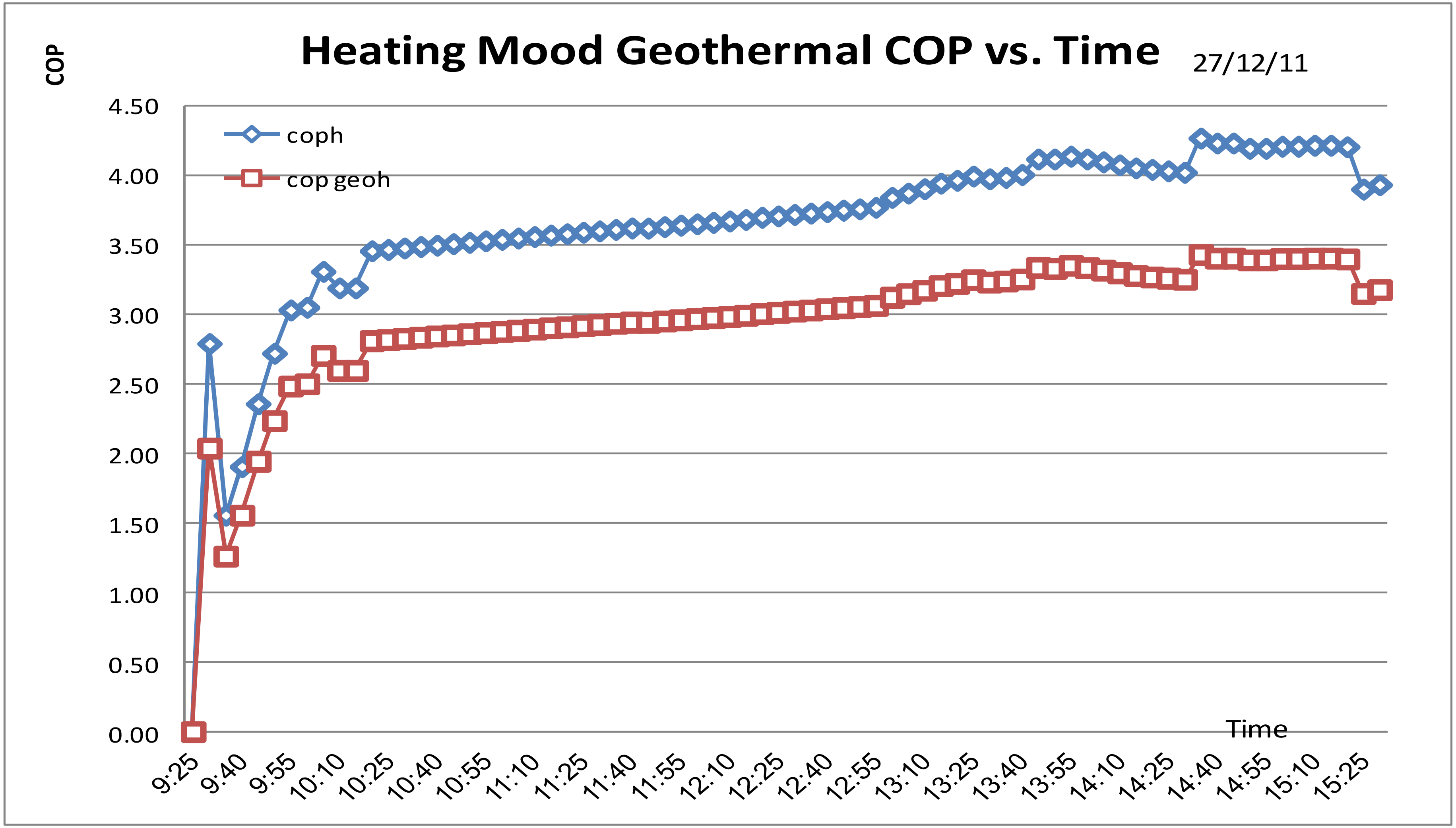


Figure (6.19) Relation between COP and time for heating mode geothermal heat pump in 27-12-2011

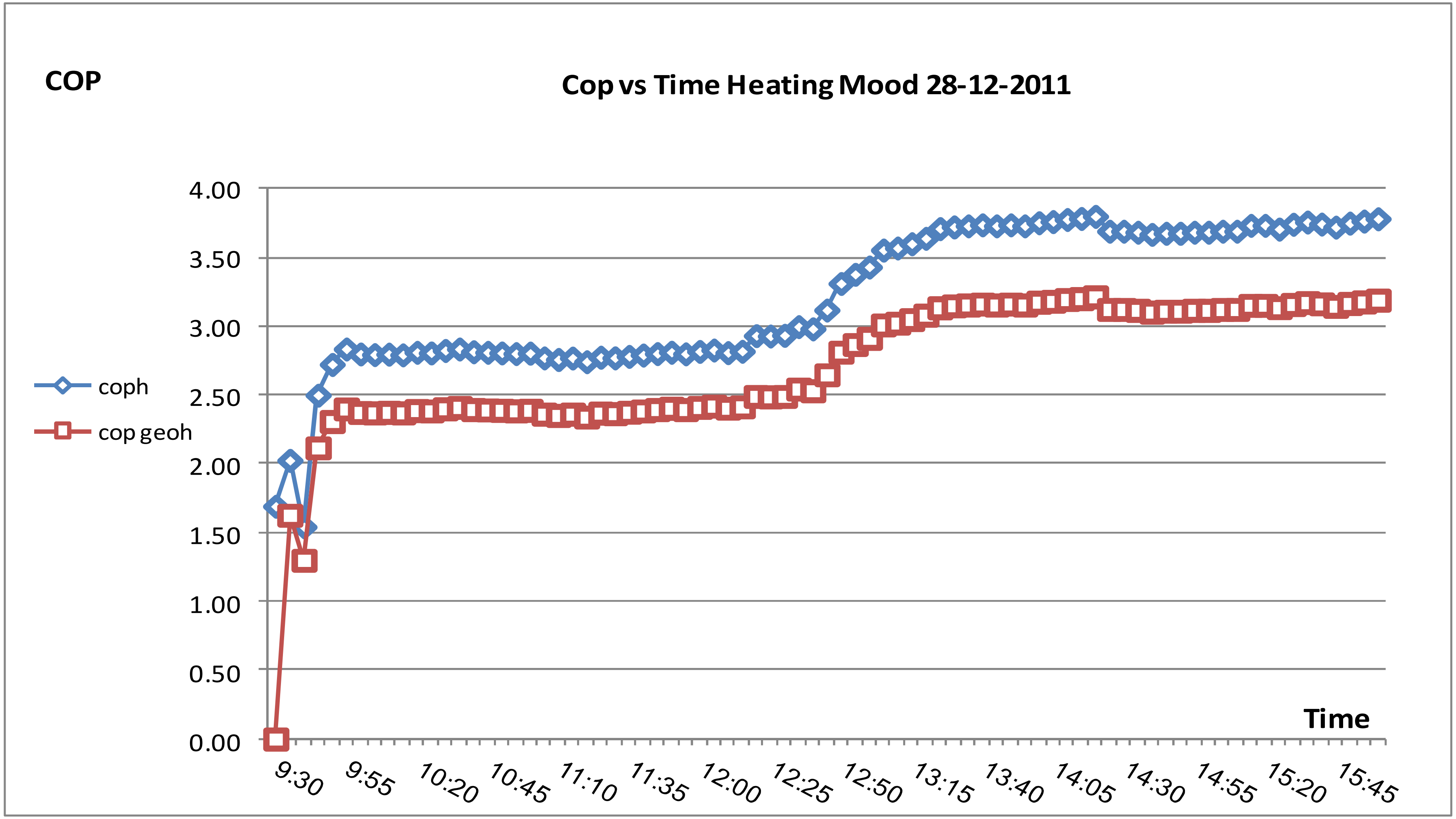


Figure (6.20) Relation between COP and time for a heating mode geothermal heat pump in 28-12-2011

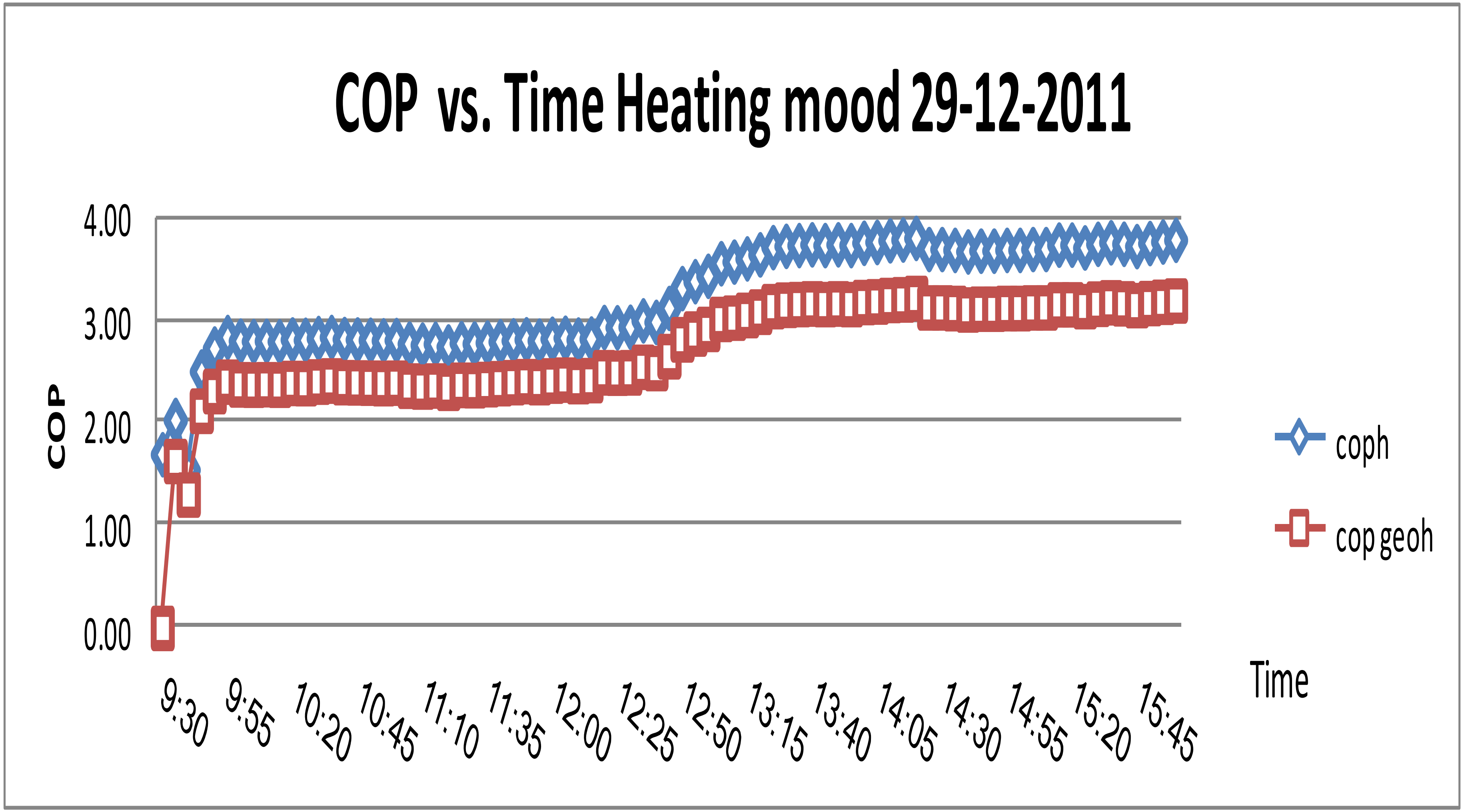


Figure (6.21) Relation between COP and time for a heating mode geothermal heat pump in 29-12-2011

The work of the heat pump is the same as the work of the cooling mode, but the useful energy which is heat in this experiment is larger because of the energy added by the compressor is vital and added to the energy absorbed and they are summed and delivered to the space. A plot of the energy consumed by compressor and the useful energy and the absorbed energy are shown in figure (6.22) below. The pump consumed power is again constant and 125 watt which was included in the COP calculations and is negligible in the plot because the useful power is thirty tow times the pump power.

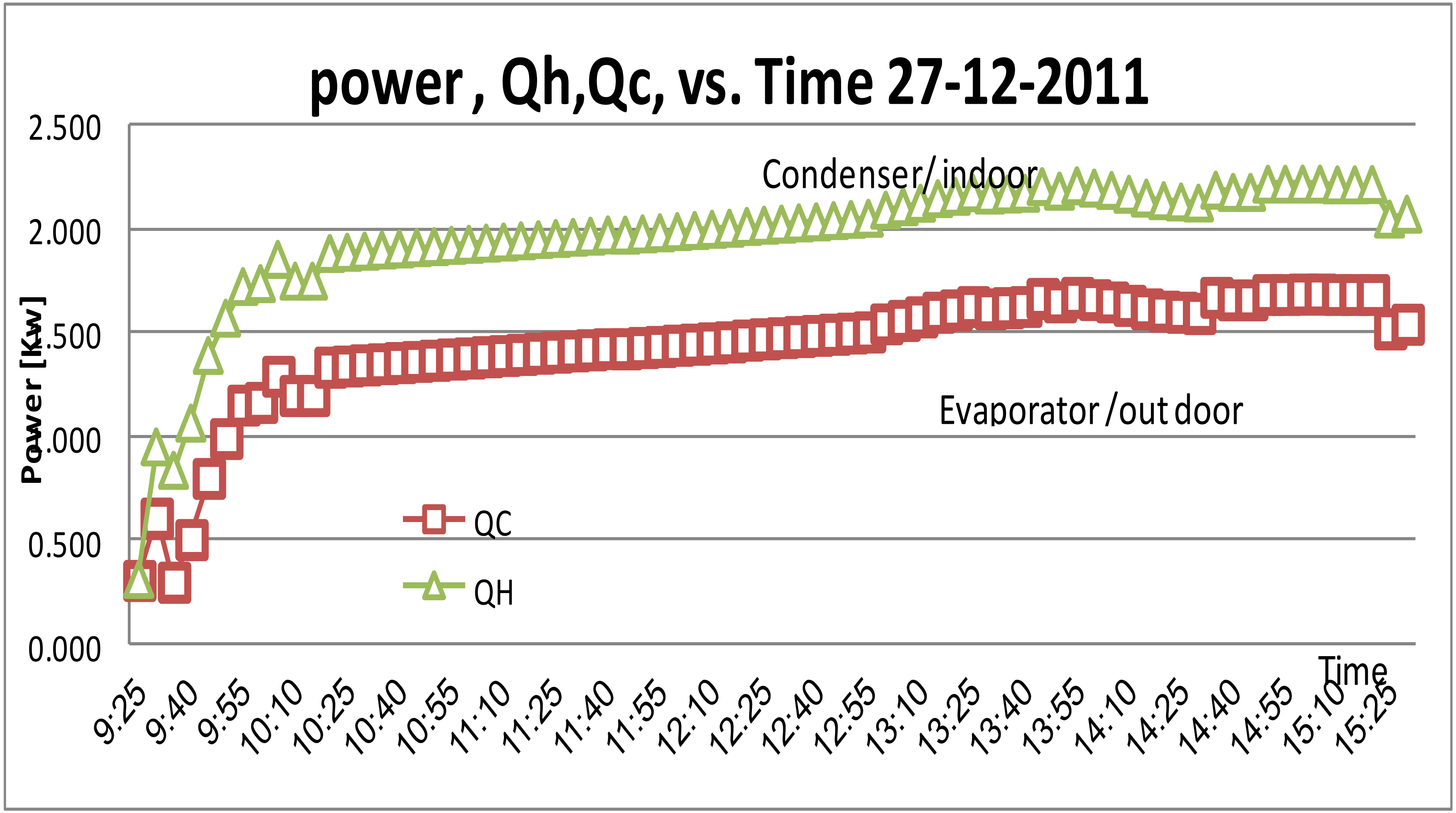


Figure (6.22) compressor power consumed, heat absorbed QC, and heat rejected Qh, relation with time. Time 27-12-2011.

Calculating the heat transfer coefficient will be the same for heating mode, the average temperature between the inlet and the outlet of the ground loop on 24-8-2011 at the steady state was

$$LMTD = \frac{\Delta Ta - \Delta Tb}{ln\frac{\Delta Ta}{\Delta Tb}} =$$

$$\Delta Tb = 14°C - 12.39°C = 1.61°C$$

$$\Delta Ta = 16.25°C - 14°C = 2.25°C$$

$$LMTD = \frac{2.25 - 1.61}{ln\frac{2.25}{1.61}} = 1.92°C$$

Then, $UA = \frac{2.6\ kW}{(1.92\ °C)} = 1.35\ kW/\ °C$

Which is the highest for all tests, and this makes sense as the ground loop has water as a working fluid and the refrigerant is in liquid state in the condenser so the heat transfer coefficient was higher has high, another reason is that in the condensation state of the refrigerant the heat transfer coefficient is higher.

6.4 Combined flat plate solar collector and heat pump experiment

Finally a flat solar water collector was connected to the heat pump as described in figure (5.14) and the same data were recorded. The test was performed during February. The system was disconnected from the ground and connected to solar water collector with a standard dimensions 190x90 cm and 9 steel columns with polyurethane insulation. The temperature difference, COP versus time was plotted as shown in figure (results were shown in figure (6.23).

Calculating the heat transfer coefficient will be the same for heating mode, the average temperature between the inlet and the outlet of the ground loop on 24-8-2011 at the steady state was

$$LMTD = \frac{\Delta Ta - \Delta Tb}{ln\frac{\Delta Ta}{\Delta Tb}} =$$

$$\Delta Tb = 14°C - 12.39°C = 1.61°C$$

$$\Delta Ta = 16.25°C - 14°C = 2.25°C$$

$$LMTD = \frac{2.25-1.61}{ln\frac{2.25}{1.61}} = 1.92°C$$

Then, $UA = \frac{2.6\ kW}{(1.92\ °C)} = 1.35$ kW/ °C

Which is the highest for all tests, and this makes sense as the ground loop has water as a working fluid and the refrigerant is in liquid state in the condenser so the heat transfer coefficient was higher has high, another reason is that in the condensation state of the refrigerant the heat transfer coefficient is higher.

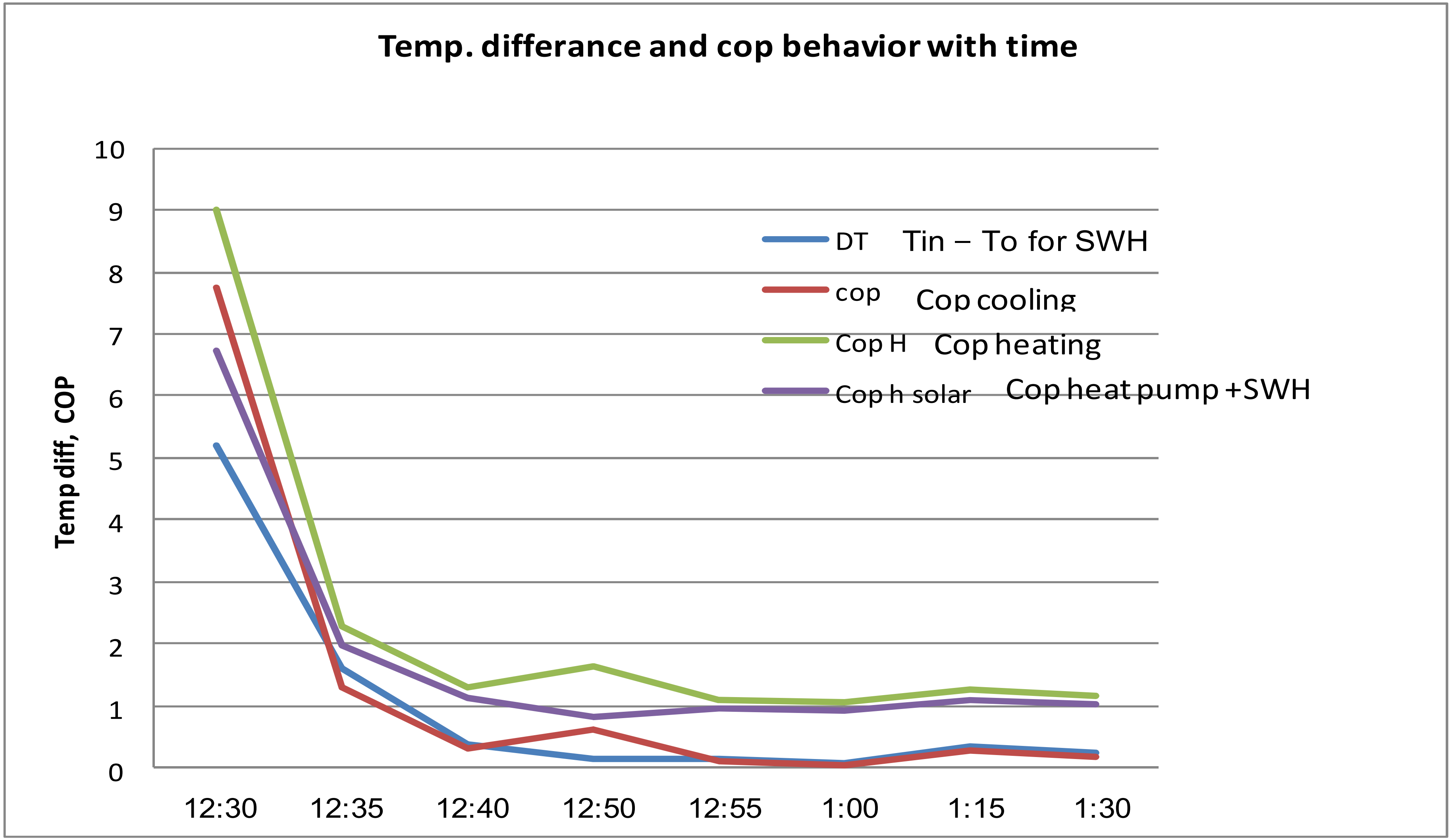


Figure (6.23) Relation between temperature difference of inlet and outlet of solar collector, COP of Heat pump and time

From the figure (6.23) the temperature difference was 5 °C between inlet and of the solar collector which was due to high flow rate, and drops with time which will drop the COP due to less heat absorbed and lower quality of heat available. This means the solar heater is not capable of heating up the evaporator faster which will drop the performance. To calculate the needed area of SWH:

Q= V $*C_p*\Delta T$, m· = volume flow rate of the installed pump, r is the density of water, C_p =4190 W/kg°C, ΔT is the temperature difference needed for maximum COP.

At 5 °C temperature difference the performance was 9, the lower temperature difference means lower Q_h and thus lower performance, and the opposite is quite right the higher the temperature difference the higher the performance achieved.

Q= 1 l/s x 1 kg/l x 4190 x 5= 21 kW

In winter the Solar intensity drops to 3 kWhr/m^2 day and assuming the Sun shines for 2 hours per day, then

21 kW= (3 kWhr/m^2 day) x(1/2hours / day)x Area(m^2)

A=21/1.5= 14 m^2, Each SWH is 1.9 mx 0.9 m = 1.71 m^2

Then the total SWh needed are 14/1.71 = 8 numbers

In fact the limited budget prevents adding more collectors to achieve higher temperature difference. A storage tank can be added with a circulating pump or a four way valve with a sensor and a controller. When the water temperature inside the storage tank becomes higher than the temperature of the ground the controller actuates the valve to close at the ground loop and opens at the solar system and the heat pump becomes more efficient and more economical. When there is no sun the temperature of the water inside the tank becomes lower and when it is lower than ground temperature it reverse the system to the ground loop.

Chapter Seven

Economical Analysis of Geothermal Heat Pump

Chapter Seven
Economical Analysis of Geothermal Heat Pump

Geothermal energy is a renewable energy resource that encourages conservation of natural resources. According to the United States Environmental Protection Agency, geo-exchange systems save energy in 30-70 percent in heating costs, and 20-50 percent in cooling costs, compared to conventional systems [53]. Geo-exchange systems require much less maintenance than conventional systems thus save money. In addition to being highly reliable they are built to last for decades.

7.1 Benefits of using geothermal (ground source) heat pump

Ground source heat pumps add numerous benefits to energy conservation, by increasing the energy efficiency of heating and cooling systems by 2-3 times, and as a result decreasing the costs to heat houses in the winter and cool it in the summer by the same two to three times. An example can be taken as a home with a geothermal heating system say the temperature outside is near zero degrees Celsius, which is the freezing point for water, temperature below earth's freeze-depth is constant, at about 12-13°C, and a house has to be heated up to about 22°C. Therefore the temperature of outside air needs to be rise by 22°C. If the geothermal energy is add up into the mixture, the "starting temperature" will be 13°C. So now we need to increase the air temperature by only 8°C, instead of 22°C. That is actually over 60% increase of efficiency. Geothermal heat pump has no condenser fan and no defrost cycle is needed, no need to reverse the cycle to melt the accumulated ice on the outdoor coil in heating mode. So this consumed power for fan and defrost is reserved [54]. According to the *InterNACHI Residential Standards of Practice* [53], for a small heat pump of the model built the estimated defrosts per day is 2 minutes out of an hour of operation is needed. For an operation of 12 hours we need an extra 24 minutes for defrost which is 3.5% of the consumption. This is a significant reservation for an around a year operation because there is no need for a defrost cycle which will never be reached. In the first cost the outdoor coil can be designed for less material and thus reduce in the cost of fins and pipes and fan together with the sensors and controls which will be replaced by the cost of the pump and the heat exchanger coupled to the ground. The only extra cost is the cost of pipes buried and the excavation and back filling which is any way part of the excavation costs for building a new home. While doing the excavation for the new home, extra depth should be reach for baring the pipes. Then the foundation is done. After finishing the building the pipes are connected to the geothermal heat pump.

7.2 Cost of geothermal heat pump

Although they are efficient and cost effective geothermal heating and cooling systems are not so “popular”, because of the high first cost of geothermal heating systems. From manufacturers of US geothermal heat pump systems the average vertical geothermal heating and cooling system for an average home will end up of about $30,000 [55]. And heat pump, while not the most expensive item on the total price list for a geothermal heating system, excavation certainly costs a lot, and adds significant chunk to the geothermal price tag. The most costly item in the system is the excavation and the loops used. But horizontal heat exchangers are less expensive and very useful for houses but not for buildings because of the land use. Horizontal heat exchangers are less expensive because the deepness that must be achieved is very low compared to the hundreds of meters that must be achieved in the vertical loop design. Special tools that are so expensive must be used in this case. Special tools for pipe installations, and special pipes and fittings that are costly should be used; unlike the horizontal loop design the excavation is achievable in normal excavators and not more than few meters below the finish level. The pipes used are the same pipes that are used in normal sanitary and heating system which are polyethylene pipes. The pipes are cheap and available and have a very high life time. This makes things less expensive for the horizontal loops. The estimated cost for a horizontal geothermal heat pump local assembled will be around 8500 US$ based on the cost of material as per the installed unit.

To evaluate the geothermal heat pump an economical analysis must be conducted between each of the systems available for this reason a load of 35 kW which is a normal home load to be a basis. The power consumption for each kW of electricity is 0.55 New Israeli Shekels. For diesel 6.75 NIS per liter which is equivalent to 8.375 NIS per kilogram as per the average diesel cost for 2012 [55]. Each kilogram of gas has a cost of 5 NIS pumped by the company at the whole sale price.

The normal heat pump as per manufacturer has a performance of 3 but a performance of 3.5 has been assumed for more conservative results. The consumption is 10 kW. Table 7.1 below shows a comparison for each of the conventional systems using diesel and LPG , and the conventional heat pump system compared to the GHP.

Table (7.1) Economical simple pay pack period for some conventional systems and heat pumps compared to geothermal heat pump system.

<table>
<tr><th>Method</th><th>Conv. H.P</th><th>GSHP</th><th>Diesel heating</th><th>LPG heating system</th></tr>
<tr><td>Rating</td><td>35 kW</td><td>35 kW</td><td>35 kW</td><td>35 kW</td></tr>
<tr><td>Consumption</td><td>10</td><td>5.8</td><td>5</td><td>3.35</td></tr>
<tr><td>Unit</td><td>kWh</td><td>kWh</td><td>kg</td><td>kg</td></tr>
<tr><td>Annual Operating hours</td><td>450 h</td><td>450 h</td><td>450 h</td><td>450 h</td></tr>
<tr><td>running cost rate*(NIS)</td><td>0.55</td><td>0.55</td><td>8.375**</td><td>5</td></tr>
<tr><td>Initial cost (NIS)</td><td>20000</td><td>33000</td><td>30000</td><td>30000</td></tr>
<tr><td>annual running cost</td><td>2475 Nis</td><td>1435.5 Nis</td><td>19687.5 NIS</td><td>7537.5 Nis</td></tr>
<tr><td>Annual saving of using each system vs GSHP</td><td colspan="2">1040 NIS</td><td>18252 NIS</td><td>6102</td></tr>
<tr><td>Extra Invest. in GSHP or HP ,diesel, LPG .</td><td colspan="2">13,000 NIS</td><td>3,000 NIs</td><td>3,000NIS</td></tr>
<tr><td>SPBP years (Invest)/Saving</td><td colspan="2">1.3 year(15 Months)</td><td>0.165(2 Months)</td><td>0.49(6 Months)</td></tr>
</table>

***The rate of electricity was 0.55 Nis as per the electricity bill ,** Diesel cost per liter is converted to cost per kilogram [56]**

Appendix (10), Appendix (11), Appendix (12), Appendix (13), Appendix (14) for data of each system

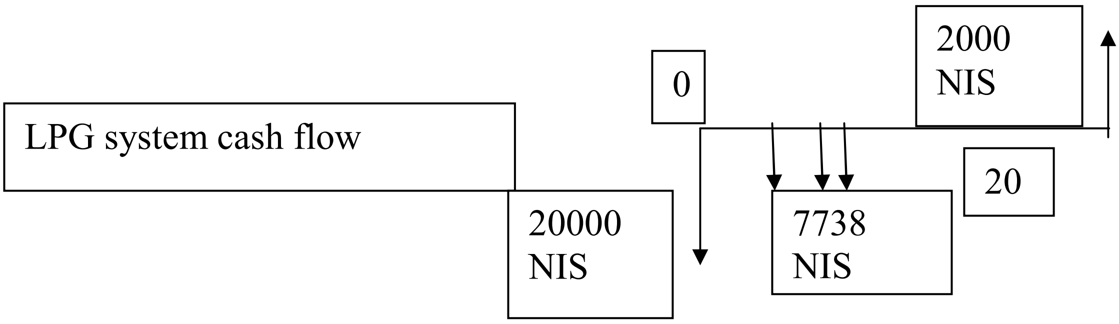
7.3 Engineering economy for geothermal heat pumps

"Engineering economy is defined as: determining the economic factors and the economic criteria utilized when one or more alternatives are considered for selection" [55]. Now it is known that money makes money and this brings to our attention the term the time value of money which means that the money that are borrowed today has a different value tomorrow and this has something to do with the cost of opportunity or opportunity cost which means that the cost of any investment measured in terms of the value of the next best alternative that is not chosen. Or it is the sacrifice related to the second best choice available to someone, or group, which has picked among several choices [57]. Then when choosing among any alternative we should choose the best profit or the less loss, and that what was done in this study a comparison of some alternatives to heat a house using different systems and calculating the best alternative using the present worth method.

To understand this comparison a rate of return of 10% was assumed. In finance, rate of return (ROR) is the ratio of money gained or lost for an investment compared to the amount of money invested. The (ROR) is usually expressed as a percentage. Investments usually generate cash flow to the investors to overcome the investor for the time value of money.

Except for rare periods of significant deflation where the opposite may be true, The rate of return idea came from that money in cash is worth less today than it was yesterday, and worth more today than it will be worth tomorrow. The main factors that determine the rate of return at which they are willing to invest money include estimates of future inflation rates, estimates regarding the risk related to investment, whether the money is wanted to be available or not [58].

To find the feasibility of the systems the present worth method was used using a rate of return 10% and a life time of 15 years for all systems which is the average life time of any mechanical system, and assuming a selvage value of 2000 Nis each. Table 8.2 shows the present worth for each system, as a comparison basis for all systems. The less the negative value the best the alternative as shown in the cash flow for all system below.



$PW_{LPG} = -20{,}000 - 7738*(P/A,_{i10\%,\,n\,15}) + 2000(P/F,_{i10\%,\,n\,15})$

$= -20000 - 7738*7.6061 + 2000*0.2394 = -78377.$

$PW_{Diesel} = -33000 - 19888*(P/A,_{i10\%,\,n\,15}) + 2000(P/F,_{i10\%,\,n\,15})$

$= -33000 - 151270 + 479 = -183791$

$PW_{geo} = -30000 - 1636*(P/A,_{i10\%,\,n\,15}) + 2000(P/F,_{i10\%,\,n\,15}) = -44965$

$PW_{conv\ hp} = -30000 - 3675*(P/A,_{i10\%,\,n\,15}) + 2000(P/F,_{i10\%,\,n\,15}) = -57473$

Table (7.2) Economical study for systems available in market and the feasibility of each system compared to ground source heat pumps for heating season and using 35 kW system as per table 7.1

Heating Method	**LPG heating**	**Diesel heating**	**GHP**	**Conventional H.P**
First cost (Nis)	20000	33000	30000	30000
Annual running cost (Nis)	7538	19688	1436	2475
Maintenance cost(Nis)	200	200	1000	1000
Salvage value (Nis)	2000	2000	2000	2000
Interest rate (Nis)	10%	10%	10%	10%
Life time(years)	10	10	10	10
P. W *(Nis)15 years	-78377	-183791	-44965	-57473

***P.W is the present worth value for the system.**

As the least negative value is -44965 for geothermal heat pump then it is the best alternative to be used for heating.

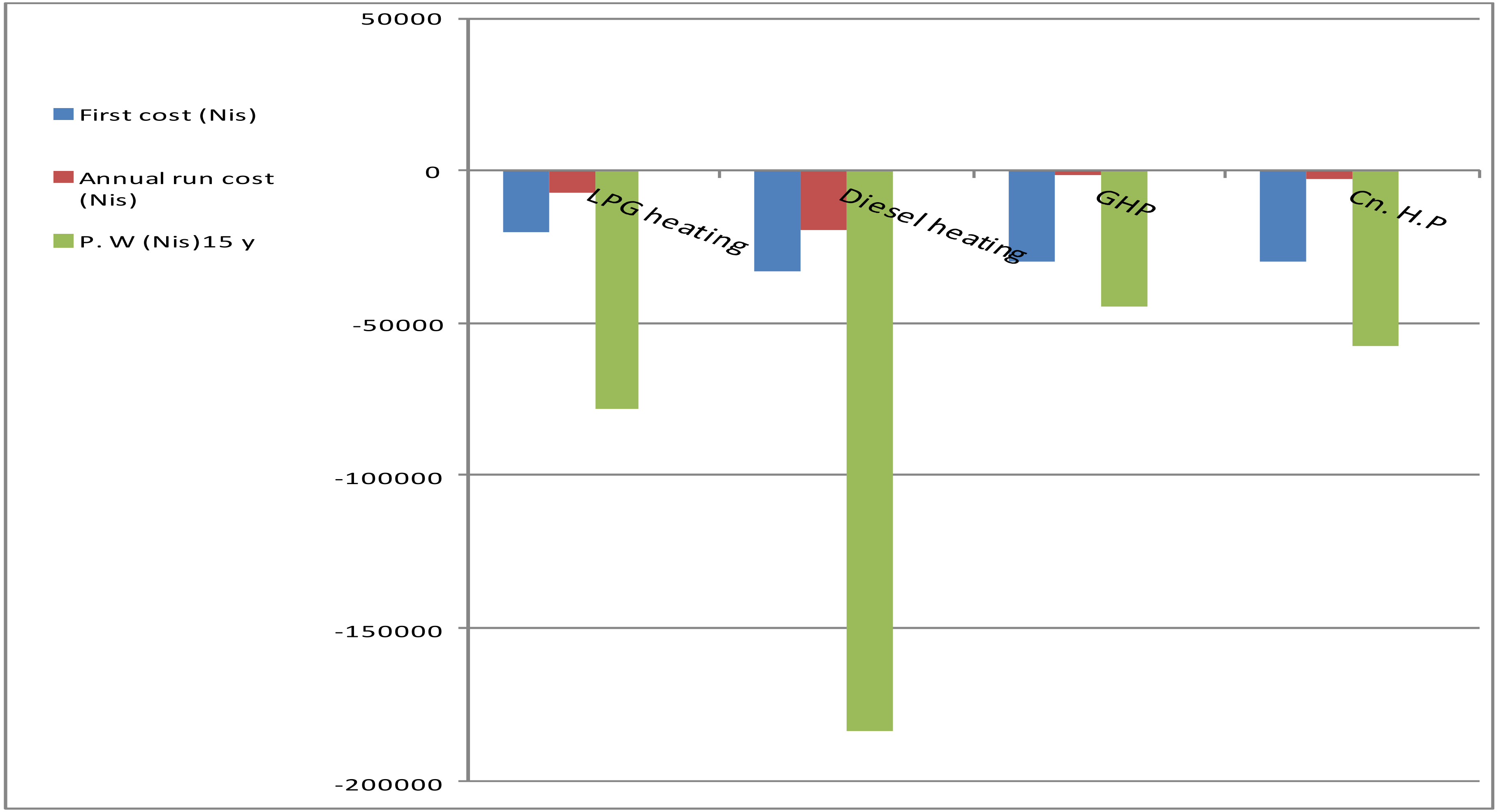


Figure (7.1) Economical present worth evaluation for diesel heating system, LPG heating system, Conventional heat pump and ground source heat pump

7.4 How to Make Heat Pumps Even Better

7.4.1Variable Flow

Heat pumps move energy rejected to the ambient through water with a pump. In the most basic control arrangement, the circulating pumps operate all the time and can quickly add significant consumption of energy. For this reason, ASHRAE Standard 90.1-2001, Energy Standard for Buildings except Low-rise Residential Buildings, requires that any heat pump system with more than a 10 horsepower pump be variable flow, and that each heat pump have a two position isolating valve that closes when the compressor is not operating. It is estimated that switching to variable flow compressors reduces the annual pump work by 72%. Heat pumps are normally on off controlled when the temperature inside the room reaches above the set point it stops and a delay timer is actuated to prevent starting of compressor before the refrigerant is completely at equilibrium, when the temperature drops below the set point by 1 degree and the timer permits, the compressor starts pumping the refrigerant from the evaporator to the condenser. This can be enhanced to reduce the consumption of the compressor depending on the load and preventing failure of pump due to frequent starts and stops by using a variable speed controller. This means modifying the speed of the compressor depending on the load. The controller is a modulating type. And it varies the frequency of the current according to a formula and this modifies the speed and thus reduces the power consumed as electrical power is proportional to mechanical power.

The lower the speed the lower the mechanical power which is the torque times the speed. When the heat pump is large, several compressors are used and they are summed as modules. The main module is the modulating compressor which is quarter of the load. The remainder starts after the first compressor reaches the maximum capacity. When reached the second quarter starts and the variable compressor slows down to minimum. When load increases the variable compressor increases capacity to meet the load until it reaches the maximum again another quarter starts and the variable is back to minimum. This improves the performance of the geothermal heat pump but for sure has higher first cost.

The pump also can be controlled to reduce the power. It can be connected to a control panel that switches the pump on when the water temperature is high in summer or low in winter, ie. When there is a demand for circulation. When there is no demand for circulation the control panel stops the pump. In our case, and for heating mode connected to the solar heater. If solar radiation is available a sensor placed inside the solar heater feels the water temperature if the temperature is higher than the ground temperature the control then opens a valve installed on the solar system and shuts the ground source loop. Water with temperature that easily reaches 30 °C can pass to the system and thus the performance is boosted to the maximum. The heat pump will start at a higher temperature rather than the geothermal loop (12°C to 15°C) or the ambient (normally around zero).

7.4.2 Ventilation System Enhancements

When clean air is a matter, the cool air in summer or hot air in winter has to be thrown away and replaced by fresh air, and then the ventilation load is a significant part of the load. By using energy recovery (such as enthalpy wheels or plate heat exchangers), the ventilation operating cost can be dramatically reduced. This will depend on the quantity of air replaced and the outdoor and indoor conditions. As per ASHREA the payback is usually around 2 years.

Chapter Eight
Environmental Impact Analysis

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Environmental Impact Analysis

8.1 Energy and Environment

The conversion of energy from one form to another will for sure affect environment, and the air we breathe, and thus the study of energy is not complete without considering its impact on the environment. Fossil fuels such as coal, oil, and natural gas have been powering the industrial development and the amenities of modern life that the world enjoys since the 1700s, but this has not been without any undesirable side effects.

From the soil we farm and the water we drink to the air we breathe, the environment has been paying a heavy toll for it. Pollutants emitted during the combustion of fossil fuels are responsible for smog, acid rain, global warming and climate change. The environmental pollution has reached such high levels that it became a serious threat to vegetation, wild life, and human health. Air pollution has been the cause of numerous health problems including asthma and cancer [59].

Hydrocarbons (HC), nitrogen oxides (NO_x), and carbon Monoxide (CO) are large components of volatile organic compounds' (VOCs) emissions, and the two terms are generally used interchangeably for motor vehicle emissions. A significant portion of the VOC or HC emissions are caused by the evaporation of fuels during refueling or spillage during spit back or by evaporation from gas tanks with faulty caps that do not close tightly. The solvents, propellants, and household cleaning products that contain benzene, butane, or other HC products are also significant sources of HC emissions.

The increase of environmental pollution at alarming rates and the rising awareness of its dangers made it necessary to control it by legislation and international treaties [60]. Children are most susceptible to the damages caused by air pollutants since their organs are still developing. They are also exposed to more pollution since they are more active, and thus they breathe faster. People with heart and lung problems, especially those with asthma, are most affected by air pollutants. This becomes apparent when the air pollution levels in their neighborhoods rise to high levels [60].

8.2 Ozone and Smog

The dark yellow or brown haze that builds up in a large stagnant air mass, and hangs over populated areas on calm hot summer days. Smog is made up mostly of ground-level ozone (O_3), but it also contains numerous other chemicals, including carbon monoxide (CO), particulate matter such as soot and dust, volatile organic compounds (VOCs) such as benzene, butane, and other hydrocarbons. The harmful ground-level ozone should not be confused with the useful ozone layer high in the stratosphere that protects the earth from the sun's harmful ultraviolet rays. Ozone at ground level is a pollutant with several adverse health effects as in figure (8.1).

Figure (8.1) Smog and pollution [61] Climate Change 2001: Impacts

The primary source of both nitrogen oxides and hydrocarbons is the Motor vehicles. Hydrocarbons and nitrogen oxides react in the presence of sunlight on hot calm days to form ground-level ozone, which is the primary component of smog. The smog formation usually peaks in late afternoons when the temperatures are highest and there is plenty of sunlight.

Although ground-level smog and ozone form in urban areas with heavy traffic or industry, the prevailing winds can transport them several hundred miles to other cities. This shows that pollution knows of no boundaries, and it is a global problem.

Ozone irritates eyes and damages the air sacs in the lungs where oxygen and carbon dioxide are exchanged, causing eventual hardening of this soft and spongy tissue. It also causes shortness of breath, wheezing, fatigue, Headaches, and nausea, and aggravates respiratory problems such as asthma [62].

Every exposure to ozone does a little damage to the lungs, just like cigarette smoke, eventually reducing the individual's lung capacity. Staying indoors and minimizing physical activity during heavy smog minimizes damage.

Ozone also harms vegetation by damaging leaf tissues. To improve the air quality in areas with the worst ozone problems, reformulated gasoline (RFG) that contains at least 2 percent oxygen was introduced [62]. The use of RFG has resulted in significant reduction in the emission of ozone and other pollutants, and its use is mandatory in many smog-prone areas.

The other serious pollutant in smog is carbon monoxide, which is a colorless, odorless, poisonous gas. It is mostly emitted by motor vehicles, and it can build to dangerous levels in areas with heavy congested traffic. It deprives the body's organs from getting enough oxygen by binding with the red blood cells that would otherwise carry oxygen. At low levels, carbon monoxide decreases the amount of oxygen supplied to the brain and other organs and muscles, slows body reactions and reflexes, and impairs judgment [60].

It poses a serious threat to people with heart disease because of the Fragile condition of the circulatory system and to fetuses because of the oxygen needs of the developing brain. At high levels, it can be fatal, as evidenced by numerous deaths caused by cars that are warmed up in closed garages or by exhaust gases leaking into the cars.

Smog also contains suspended particulate matter such as dust and soot emitted by vehicles and industrial facilities. Such particles irritate the eyes and the lungs since they may carry compounds such as acids and metals.

8.3 Acid Rain

Fossil fuels are mixtures of various chemicals, including small amounts of sulfur. The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2), which is an air pollutant. The main source of SO_2 is the electric power plants that burn high-sulfur coal.

The sulfur oxides and nitric oxides react with water vapor and other Chemicals high in the atmosphere in the presence of sunlight to form sulfuric and nitric acids see figure (8.2). The acids formed usually dissolve in the suspended water droplets in clouds or fog. These acid-laden droplets, which can be as acidic as lemon juice, are washed from the air on to the soil by rain or snow. This is known as acid rain. The soil is capable of neutralizing a certain amount of acid, but the amounts produced by the power plants using inexpensive high-sulfur coal has exceeded this capability, and as a result many lakes and rivers in industrial areas will be affected. Forests in those areas also experience a slow death due to absorbing the acids through their leaves, needles, and roots. Even marble structures deteriorate due to acid rain. The magnitude of the problem was not recognized until the early 1970s, and serious measures have been taken since then to reduce the sulfur dioxide emissions drastically by installing scrubbers in plants and by de-sulfurizing coal before combustion.

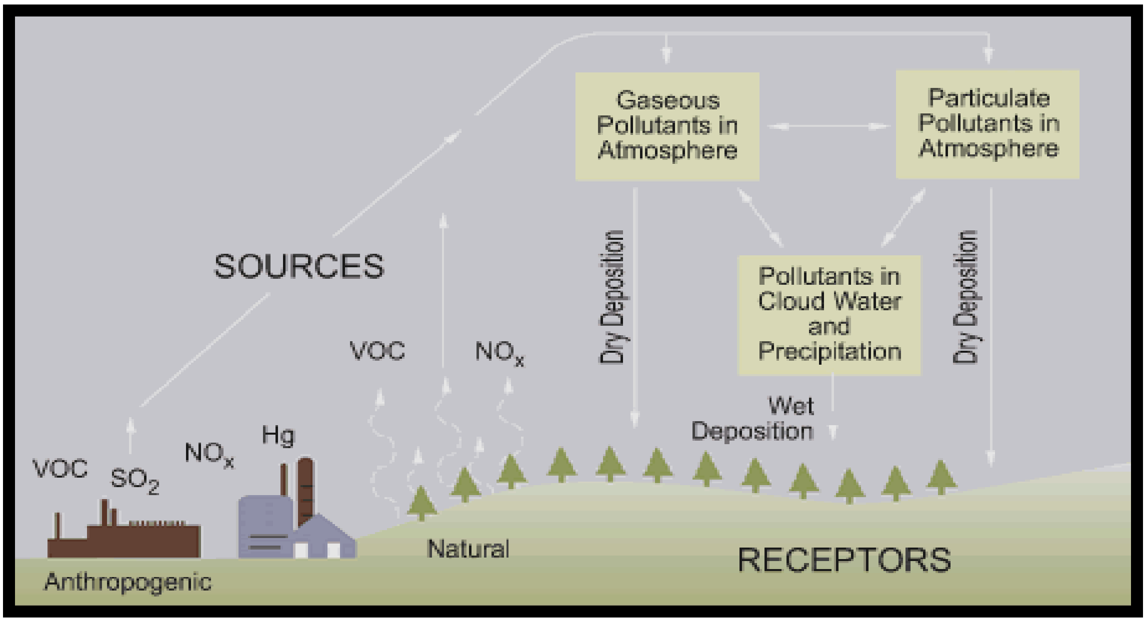

Figure (8.2) Acid Rain Phenomena [63]

8.4 The Greenhouse Effect

Global Warming and Climate Change the greenhouse effect experienced on earth. When the surface of the earth, which warms up during the day as a result of the absorption of solar energy, cools down at night by radiating part of its energy into deep space as infrared radiation. Carbon dioxide (CO_2), water vapor, and trace amounts of some other gases such as methane and nitrogen

Oxides act like a blanket and keep the earth warm at night by blocking the heat radiated from the earth. Therefore, they are called "greenhouse gases," with CO_2 being the primary component. Water vapor is usually taken out of this list since it comes down as rain or snow as part of the water cycle and human activities in producing water (such as the burning of Fossil fuels) do not make much difference on its concentration in the atmosphere (which is mostly due to evaporation from rivers, lakes, oceans, etc.). CO_2 is different, however, in that people's activities do make a difference in CO_2 concentration in the atmosphere figure (9.3).

The greenhouse effect makes life on earth possible by keeping the earth warm (about 30°C warmer). However, excessive amounts of these gases disturb the delicate balance by trapping too much energy, which causes the average temperature of the earth to rise and the climate at some localities to change. These undesirable consequences of the greenhouse effect are referred to as global warming or global climate change.

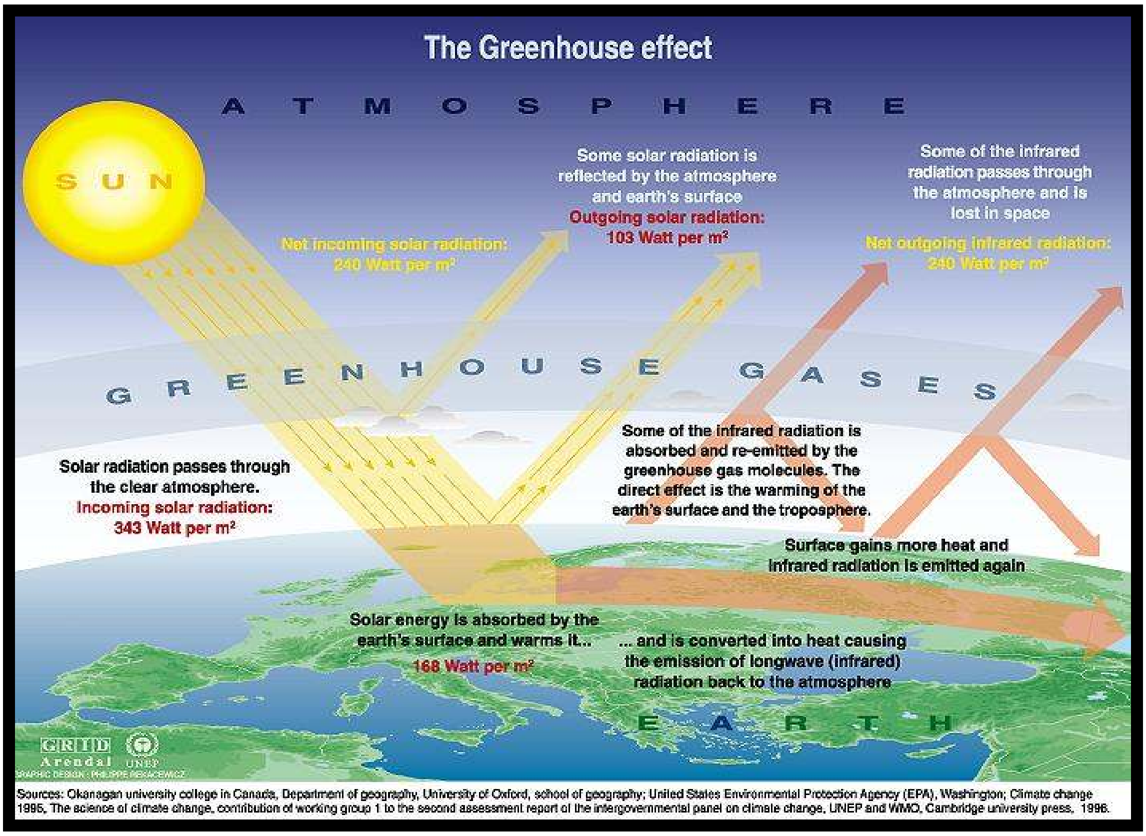

Figure (8.3) Green house phenomena [64]

The global change in climate is due to the excessive use of fossil fuels in electric power generation, buildings, transportation, and manufacturing, and it has been an important concern in recent decades.

The absorption of solar energy during the day heats the earth up; when it is night earth cools down by radiating part of its energy into deep space as infrared radiation. When we have green house gases they act as glass layer. The infra red radiation cannot cross the glass layer or the green house gases because it has a low frequency; this keeps the earth wormer during day and night. If there is no green house gases the earth will radiate the absorbed energy back to the space keeping it cold. The energy will not accumulate [65]. The earth effective temperature which is defined as the temperature of a blackbody that would emit the same amount of radiation taking 30% of the received radiation as reflection radiation then the temperature of the earth after radiating the absorbed temperature will be about −18°C without the atmosphere which is about 33°C below the actual surface temperature of about 14°C [67] ,[68], but if the percentage of the green house gases is higher than the natural and allowed amount the temperature will rise and this is defined as the global warming. The current concentration of CO_2 in the atmospheres is about 360 ppm (0.36 percent). This is 20 percent higher than the level a century ago, and it is projected to increase to over 700 ppm by the year 2100 [66]. Under normal conditions, vegetation consumes CO_2 and releases O_2 during the photosynthesis process, and thus keeps the CO_2 concentration in the atmosphere in check. A mature, growing tree consumes about 12 kg of CO_2 a year and exhales enough oxygen to support a family of four. However, deforestation and the huge increase in the CO_2 production in recent decades disturbed this balance.

In a 1995 report, the world's leading climate scientists concluded that the earth has already warmed about 0.5°C during the last century, and they estimate that the earth's temperature will rise another 2°C by the year 2100 [69]. A rise of this magnitude is feared to cause severe changes in weather patterns with storms and heavy rains and flooding at some parts and drought in others, major floods due to the melting of ice at the poles, loss of wetlands and coastal areas due to rising sea levels, variations in water supply, changes in the ecosystem due to the inability of some animal and plant species to adjust to the changes, increases in epidemic diseases due to the warmer temperatures, and adverse side effects on human health and socioeconomic conditions in some areas.

The seriousness of these threats has moved the United Nations to establish a committee on climate change. A world summit in 1992 in Rio de Janeiro, Brazil, attracted world attention to the problem [69]. The agreement prepared by the committee in 1992 to control greenhouse gas emissions was signed by 162 nations. In the 1997 meeting in Kyoto (Japan), the world's industrialized countries adopted the Kyoto protocol and committed to reduce their CO_2 and other greenhouse gas emissions by 5 percent below the 1990 levels by 2008 to 2012. This can be done by increasing conservation efforts and improving conversion efficiencies, while meeting new energy demands by the use of renewable energy (such as hydroelectric, solar, wind, and geothermal energy) rather than by fossil fuels.

8.5 Energy use facts and figures

It is not a secret that world demand of energy has raised from 10% to 111% per capita between the years 1990 to 2008. The Middle East is a part of the world and a part of this growth. 79% was the growth in the energy demand per capita in Middle East in the same period and 170% growth in use as per IEA (International Energy Association). These facts are because of the fast urbanization in the last few 20 years in the rural areas. As seen in Europe and the United States the percentage is reasonable because of increase in population. But the demand is higher than the population growth in the developing countries because of the fact that people is now affected by globalization and open market so people are improving their quality of life and seeks more energy. Table (8.1) below shows the behavior of the world towards energy use, and the relation between energy consumption and population growth.

Table (8.1)Regional energy use (kWh/capita & TWh) and growth between 1990–2008 (%) [70] and [71]

	kWh/capita			**Population (million)**			**Energy use (1,000 TWh)**		
	1990	**2008**	**Growth**	**1990**	**2008**	**Growth**	**1990**	**2008**	**Growth**
USA	89,021	87,216	– 2 %	250	305	22 %	22.3	26.6	20 %
EU-27	40,240	40,821	1 %	473	499	5 %	19.0	20.4	7 %
Middle East	19,422	34,774	79 %	132	199	51 %	2.6	6.9	170 %
China	8,839	18,608	111 %	1,141	1,333	17 %	10.1	24.8	146 %
Latin America	11,281	14,421	28 %	355	462	30 %	4.0	6.7	66 %
Africa	7,094	7,792	10 %	634	984	55 %	4.5	7.7	70 %
India	4,419	6,280	42 %	850	1,140	34 %	3.8	7.2	91 %
Others*	25,217	23,871	nd	1,430	1,766	23 %	36.1	42.2	17 %
The World	19,422	21,283	10 %	5,265	6,688	27 %	102.3	142.3	39 %

Source: IEA/OECD, Population OECD/World Bank
Energy use = kWh/capita* Mrd. capita (population) = 1000 TWh
Others: Mathematically calculated, includes e.g. countries in Asia and Australia. The use of energy varies between the ”other countries”: E.g. in Australia, Japan or Canada energy is used more per capita than in Bangladesh or Burma.

According to IEA (International Energy Association) heating and cooling counts 31% of the total energy consumption in the United States as in figure (8.4) and this is one third of the total household consumption. This is always the same for most of the developed and growing countries now days except for poor countries, which means one third of emissions are due to the heating and cooling in house hold applications, adding industry and commerce this value will increase to 42%.

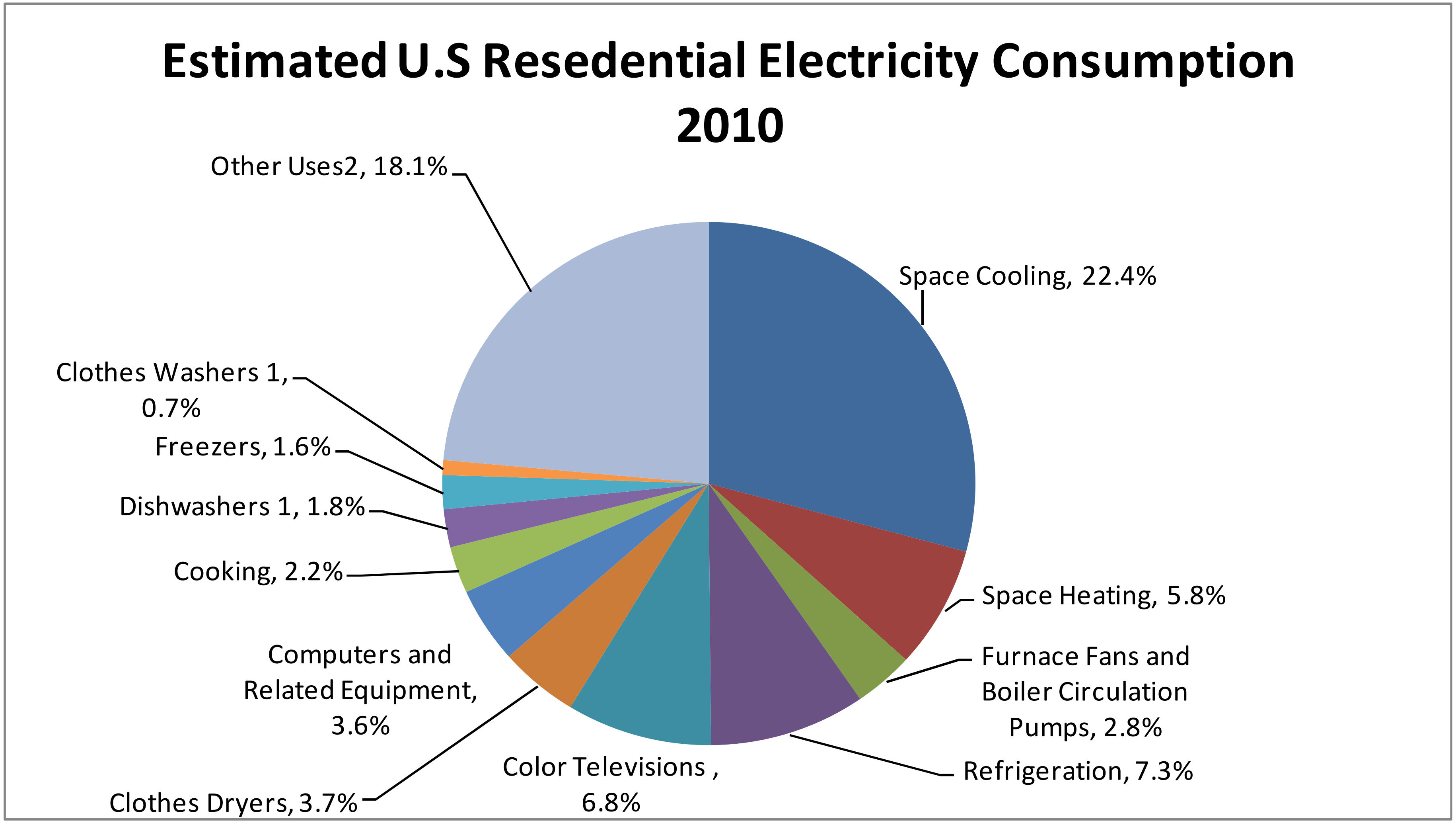

Figure (8.4) House hold consumption [72]

It is estimated that each person in USA generates 2.3 tones of CO_2 per capita per year while a healthy tree will absorb 25 kilogram of CO_2 per year [73].

For Heating and cooling in USA they will probably need 9.4 Million trees, and for each person in the USA a 92 tree is needed. If we take the regional consumption in Middle East 34,774 kWh this will produce 1.39 tons of CO_2 per capita per year based on the consumption of 2008, and this will need 55 trees per capita, which is almost 60% of the trees needed for an American citizen.

If geothermal heat pumps are utilized the consumption will be reduced by at least 30% which will reduce the CO_2 by the same 30% of 0.417 tone reduction. Then the trees needed per capita in Middle East are 39 trees compared to 92 trees per capita in USA.

8.6 Carbon footprint Life cycle assessment

A carbon footprint is defined as "the total set of greenhouse gases (GHG) emissions caused by an organization, event, product or person [74] However, calculating a carbon footprint which conforms to this definition is often impracticable due to the large amount of data required, which is often time consuming to obtain. A more practicable definition has been suggested, which is gaining acceptance within the field:

"A measure of the total amount of Carbone dioxide(CO_2) and Methane(CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO_{2e}) using the relevant 100-year Global worming potential (GWP100)."[75]

Greenhouse gases can be emitted through transport, land clearance, and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings, and services. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide, or its equivalent of other GHGs, emitted. The name of the carbon footprint originates from ecological footprint, which was developed by Wackernagel and Rees at the end of the last century. The carbon footprint is a subset of the ecological footprint and of the more comprehensive Life Cycle Assessment (LCA) [76].

An individual's, nations, or organizations carbon footprint can be measured by undertaking a GHG emissions assessment. Once the size of a carbon footprint is known, a strategy can be devised to reduce it, e.g. by technological developments, better process and product management, changed Green Public or Private Procurement (GPP), carbon capture, consumption strategies, and others [77]. Table 8.2 below shows the carbon foot print for each of the energy sources as will be used for calculations for foot print of each system compared in the examples used in our study.

Table (8.2) Carbon footprint for different energy sources [78]

Conversion to CO_{2e} (gross CV basis)		
Energy source*	**Units**	**Kg CO_{2e} per unit**
Grid electricity	kWh	0.5246
Natural gas	kWh	0.1836
LPG	kWh	0.2147
	liters	1.4918
Gas oil	kWh	0.26744
	liters	3.0595
Fuel oil	kWh	0.2674
	tones	3228
Burning oil	kWh	0.2468
	tones	3165
Diesel	kWh	0.2517
	liters	2.6676
Petrol	kWh	0.2407
	liters	2.3117
Industrial coal	kWh	0.3325
	tones	2383
Wood pellets	kWh	0.039
	tones	183.9

Then for each kWh we spend we have 0.5246 kg CO_2 and for each diesel liter we burn we have 0.2517 kg CO_2 using the above table for a comparison of conventional heat pump, geothermal heat pump, diesel heating system, and LPG heating system as in table (8.3) below

Table (8.3) Calculation of Several heating systems and their emissions and corresponding number of trees needed for reduction of the emissions

Method	Conv H.P*	GHP	Diesel heating* system	LPG heating system*
Rating	35 kW	35 kW	35 kW	35 kW
Consumption	10	5.8	5	3.35
Unit	kWh	kWhr	kg	kg
CO_2 emission rate per unit generated	0.53	0.52	3.33	0.75
Total tone CO_2 emission per 900 hr operation/ year	5.48	2.71	14.99	2.26
Average efficiency as per appendex11	300%	700%	60%	80%
Life time (years)	25	25	15(25)	15(25)
Life time CO_2 (tone)	136.89	67.86	224.78(375)	33.92(56.5)
number of pine trees needed for the life cycle for each system	5,476	2,714	15,000	2,260

Figure (8.5) shows the efficiency of different systems used and the resulted energy conservation due to the increase of the efficiency which will reduce the running cost and the emissions as seen in figure (8.6), figure (8.7).

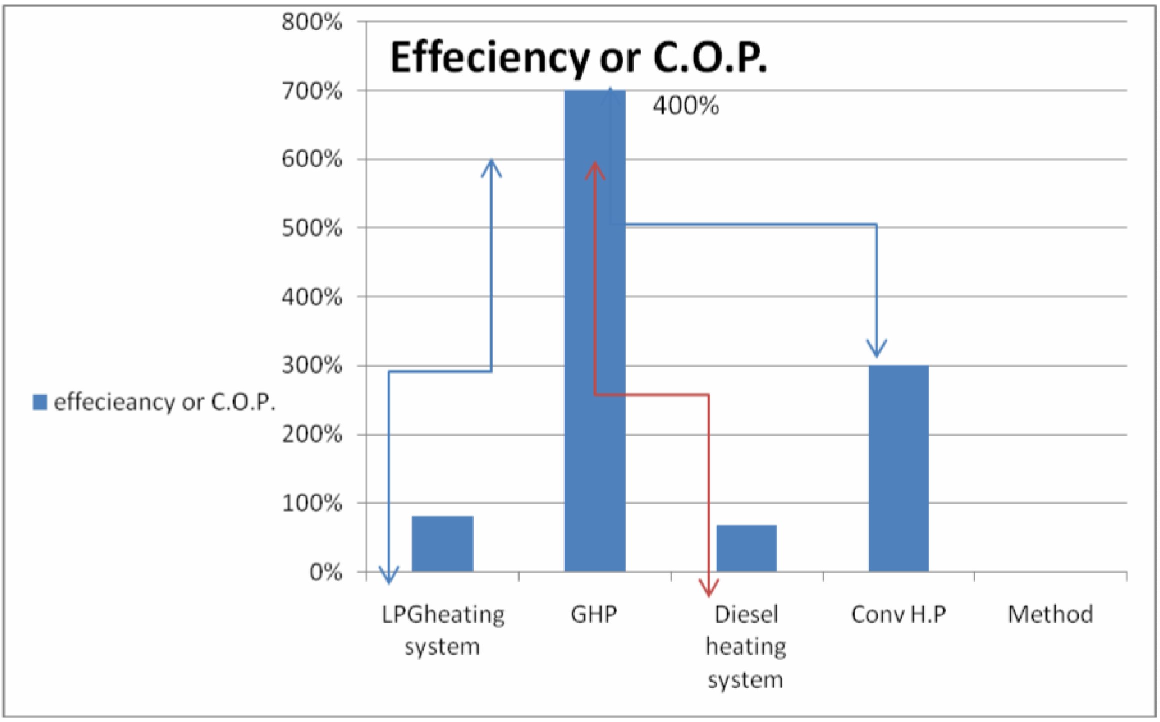

Figure (8.5) Efficiency of several heating systems

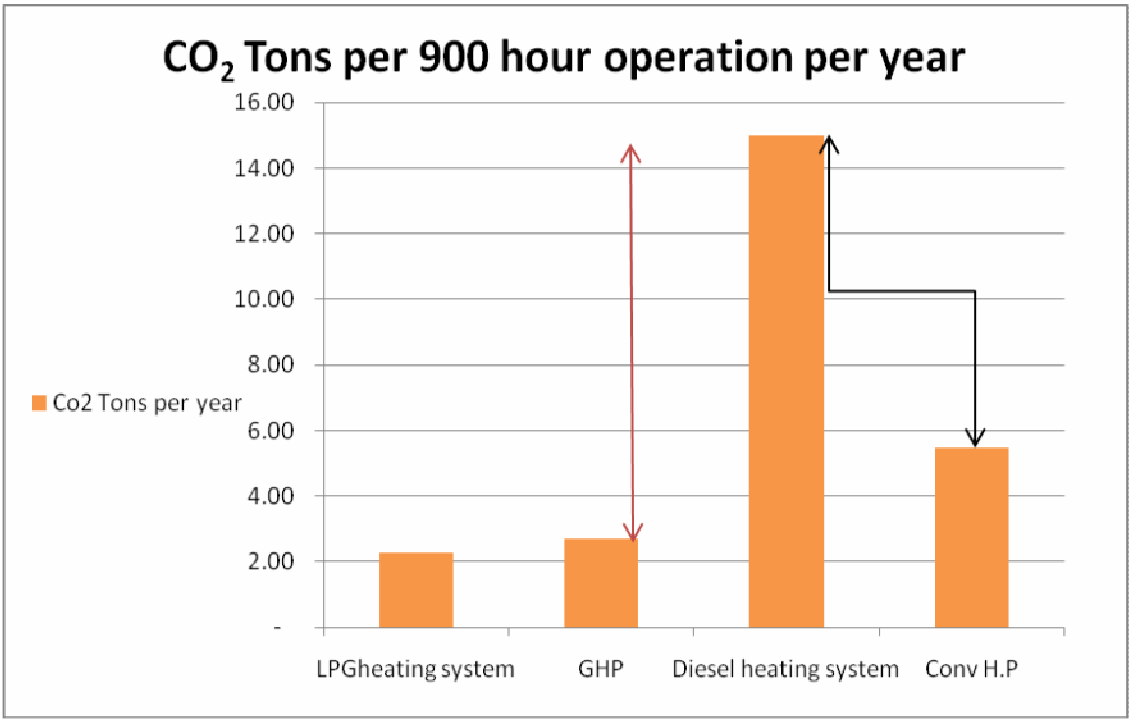

Figure (8.6) CO2 Production for various heating systems including GSHP system.

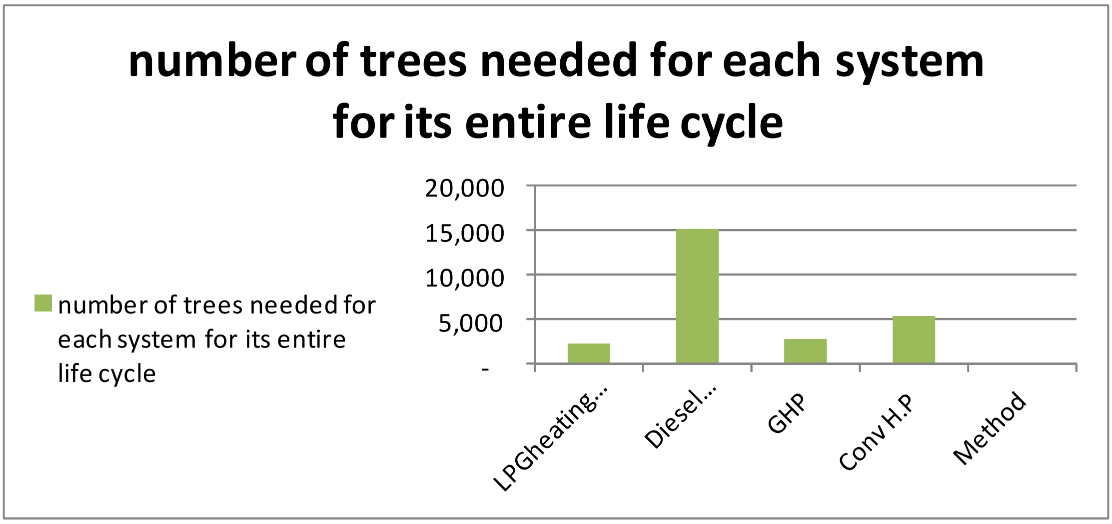

Figure (8.7) Quantity of Pine trees needed for treatment of polluted air to reach normal levels

Chapter Nine

Conclusion and Recommendations

Chapter Nine
Conclusion and Recommendations

Conclusion

The main objectives of this research were to design and built Horizontal loop Ground Source Heat pump, to obtain a comparison between ordinary heat pump and geothermal heat pump, to find the effect of the heat sink temperature on the performance of the heat pump, and to find the effect of adding a solar water heater to the system in the heating mode on the performance of the system. As a first step a thorough study was done to the system that was studied and tested during the development and building of the geothermal heat pumps. The history of the geothermal heat pumps, their types, advantages, and uses of each type were studied. A manual calculation was conducted. The GIGA software (trial version) was used to check the design and manual calculations. The system was built and tested. The tests including operating the system on cooling, heating, and finally assisting the heat pump by using the solar plate collector.

The results show that during the preliminary experiments and using water cooled condenser rather than air cooled condenser, the coefficient of performance improves by 0.34, while the maximum COP achieved by factory for the same unit before building the system was 3.2 this means an improve of 3.7 % in the performance has been achieved. The Heat transfer coefficient for a unit area was 0.52 kW/°C, for water cooled condenser and 0.142 kW/°C, for air cooled condenser in the preliminary experiments this means better heat transfer of the water cooled condenser.

On cooling mode using the geothermal loops the performance improves by 2 to be 5 using the pump and the compressor power consumed in the calculated COP, and neglecting the pump power, the COP of the heat pump will reach 6.5-7 in most cases. This is almost double the performance of the same air conditioner using air cooled condenser. The COP drops using the pump, because the pump was overdue as described before and that was a result of the fact that the required flow was lower than available flow. The designed flow was not a standard flow, because the flow is something that is determined by the capacity of the heating system and the normal heating load will be around 30 kW which needs 4.3 m^3/hour for cooling, and 1.4 m^3/hr for heating. This was a test has a small load 2.6 kW which needs a special pump that is 10% of the available circulating pumps, which was not available. In larger application the same pump can be used and this will distribute the consumed power of the pump on larger load. Larger heat transferred for same power of the pump which will result higher COP. The heat transfer coefficient was 0.2 kW/°C for cooling using ground heat exchanger. Which is higher than that for air, but less than that for water, and this makes sense as liquid has the best contact with heat exchanger than air and solids.

In heating mode the COP achieved for heat pump was 4-4.5 and for geothermal was around 3.2-3.5, which was the same for the normal heat pump as per factory test, using lower power pump higher performance can be achieved. The advantage of the geothermal heat pump on the ordinary heat pump is that ordinary heat pump actually cannot work on the conditions that are around zero unlike geothermal heat pump which will provide the same performance. For better performance a solar plate collector was installed to achieve higher temperatures and thus reduce the power consumed. The higher COP was 23 and the lower COP was 6 which were very high. The high value of COP was due to the flow of heat from high temperature region which is the solar water heater to lower temperature region which is the evaporator. And this will add the high temperature from SWH to the temperature achieved by the compression of the refrigerant. Water is heated to reach 30-35°C and passed to the evaporator at which the water temperature is around 12°C. The medium is better for boiling the refrigerant faster and has less work done by the compressor to achieve the supply conditioned air to the surroundings. A total number of 8 SWH are needed for constant performance of the Solar heat pump plus storage tank and another pump and control system. This extra investment is too high and unnecessary because the heat can be extracted from ground for less investment. The efficiency is better for water than for air because the heat capacity is higher for the same mass of water than of air, and the ground has higher temperature than that of air at cold regions and lower temperature than air for hot regions. In other words air is available everywhere, ground is not always available but it has better efficiency for heat exchange, water is less available but it has the best efficiency for heat exchange of both ground and air. And this can be illustrated in figure (9.1).

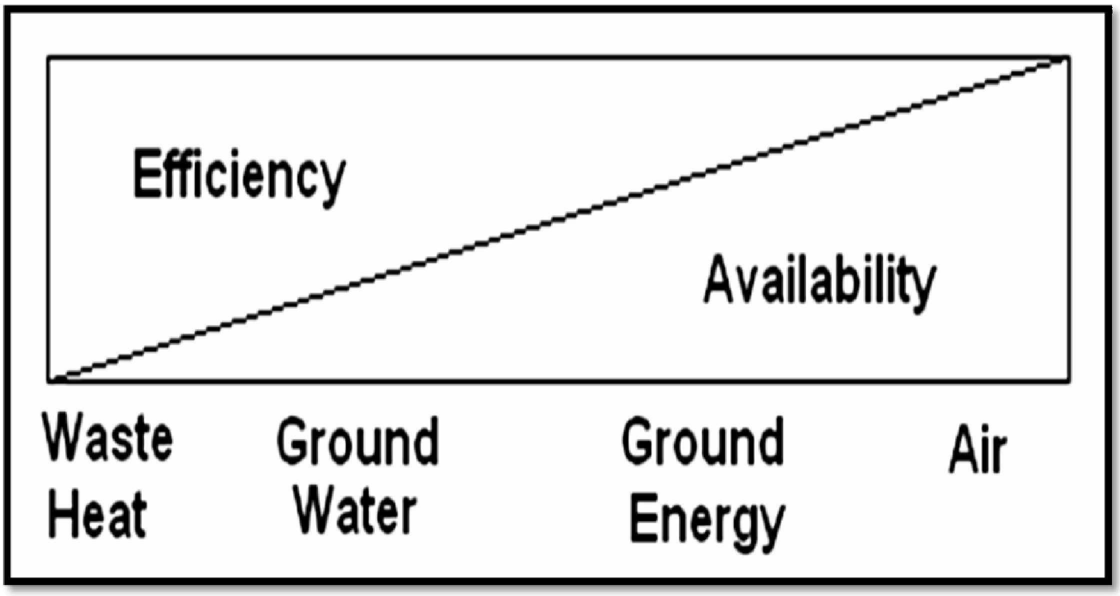

Figure (9.1): Efficiency and Availability of heat sinks

So air is the most available but less efficient and lower cost, ground is more efficient but less available especially for high rise building, water is the most efficient way for heat exchange but it is the least available.

Ground source heat pumps have a lot of benefits that can be summarized by:

- Very high coefficient of performance.
- Very low power consumption 0.55 Nis per kW.
- Instant heating and cooling.
- No fuel is needed.
- No direct emissions.
- Low noise.
- Small space is needed.

- No explosions or flames or other risks.
- No toxic materials.
- Ozone friendly.
- Very low pay back period.
- Low emissions for electricity because some of it is produced by fossil fuels. But if connected to wind turbines or hydro power it has negligible CO_2 emissions.
- Long life cycle 15-20 years.
- Low maintainace cost.
- No chimney, no fuel tank no boilers room no large piping network.
- No defrost cycle.

Geothermal heat pumps reduces the cost of cooling by 20-50% and for heating 30-70% adding solar water heater will increase the performance more and thus reduce the costs. Because has no defrost cycle 3.5% reduction in power consumption can be considered. A horizontal ground source heat pump is estimated to cost around 8500 US$ for 35 kW systems which is a little higher than the conventional systems, the running cost is estimated to be 382$ per year for 10 hours operation in winter only and double the value in booth seasons. The payback period for installing the system is 11 years but taking the extra investment installing the Geothermal heat pump instead of conventional systems will be 1.6 years payback period for shifting from conventional heat pumps to geothermal, 2 months for shifting from diesel boiler system to geothermal heat pump and 6 months for shifting from gas boiler systems to geothermal heat pump on winter operation alone. By comparing all above mentioned systems using the present worth method at a rate of return of 10% and for equal life of 20 years the investment will gain 9562 $ using geothermal and gaining 712 $ for conventional heat pump but it is losing for diesel and LPG systems. Geothermal heat pump can be improved by variable speed compressors and variable speed fans. It can be provided with electricity that is clean and has no emissions if produced from renewable energy resources. As per ASHRAE for units with 10 HP or more variable speed control should be installed and this will save 72% of energy consumed, also heat recovery from exhaust air before entry of fresh air to system will reduce a good amount of energy needed to cool fresh air. For heating systems solar collectors can be installed to enhance the medium and boost the performance and can be coupled to the ground or directly to the heat exchanger.

From economical point of view GSHP has 2 years of payback period or less as per ASHRAE. In USA 32% of the residential electricity is used for heating and cooling, 7.3% for refrigeration. This value will need 9.4 million trees of pine per year to absorb CO_2 In USA and 92 trees of pine per capita per year, In Middle East 55 trees per capita per year will be needed based on 2008 statistics. A comparison of the amount of CO_2 reduction between using diesel boiler system and GSHP was 157 tons of CO_2 which would need 6277 trees of pine to reduce the emissions.

Recommendations

In this chapter and after targeting the objectives assigned earlier, some items can be suggested as ideas for future researches and that were not possible to accomplish during the period of one year of work and experiments, the insufficient funds available to do more experiments and buy more measuring devices that are modern and quite expensive, and that can produce more accurate results and more clear picture about this modern renewable and clean source\ sink of heat that can save large amounts of money. And the fact that our closed market which makes things difficult to find equipment like refrigerant flow meter device, Superheat and sub cooling measuring device… etc, Difficulty to have access to the testing area at night and after duty period. Some of the tests that are recommended to be held in the future by other scholars are:

- Measuring the flow rate of the refrigerant and calculating the actual heat absorbed and rejected at the evaporator and condenser from the enthalpy difference at both inlet and outlet of the evaporator and condenser. As the pressure and temperature was measured at those points. This flow meter was not available in the local market and quite expensive.

- Testing the performance of the system at night by installing a data logger for measuring all data in different periods of time and for longer watching of COP during the season.

- Testing the performance of the system by adding more solar water heaters and a storage tank and finding out the maximum performance using control circuit that opens and closes the heat pump upon the need for heat and the availability of hot water from solar energy.

- Testing different soils and the conductivity and diffusivity of those soils and enhancing the performance by mixing different soils.

- Modeling the system on a Mathematical model and finding the effects of different changes in working fluid, soil, solar recharge of earth.

- Combining Cooling tours for cooling together with solar heaters in winter.

- Combining absorption cycle with the GSHP to achieve peter performance and less electricity consumption during cooling.

These were some ideas for future researches and to improves the model that was built to share in the improvement of the clean energy and conservation of energy systems used in Palestine and makes the society more sustainable and self established economically by reducing the needs for the conventional heat resources and the dependency on fossil fuel, to have better availability of heating resources for every citizen in a clean cheap way, to keep our limited resources as long as possible taking into considerations the needs of the future generations of having the opportunity to meet their needs.

Horizontal Ground source heat pumps are less expensive than vertical ground source heat pumps, they have high performance and lower pay back periods because they have lower first costs as there is no special tools no deep excavations are needed. They are good for our areas because of the rock type of our area and the fact that our buildings are not high so the loops can be integrated below the foundation. HGSHP has low emissions low running cost. So it is the best choice for shifting from conventional system to clean systems.

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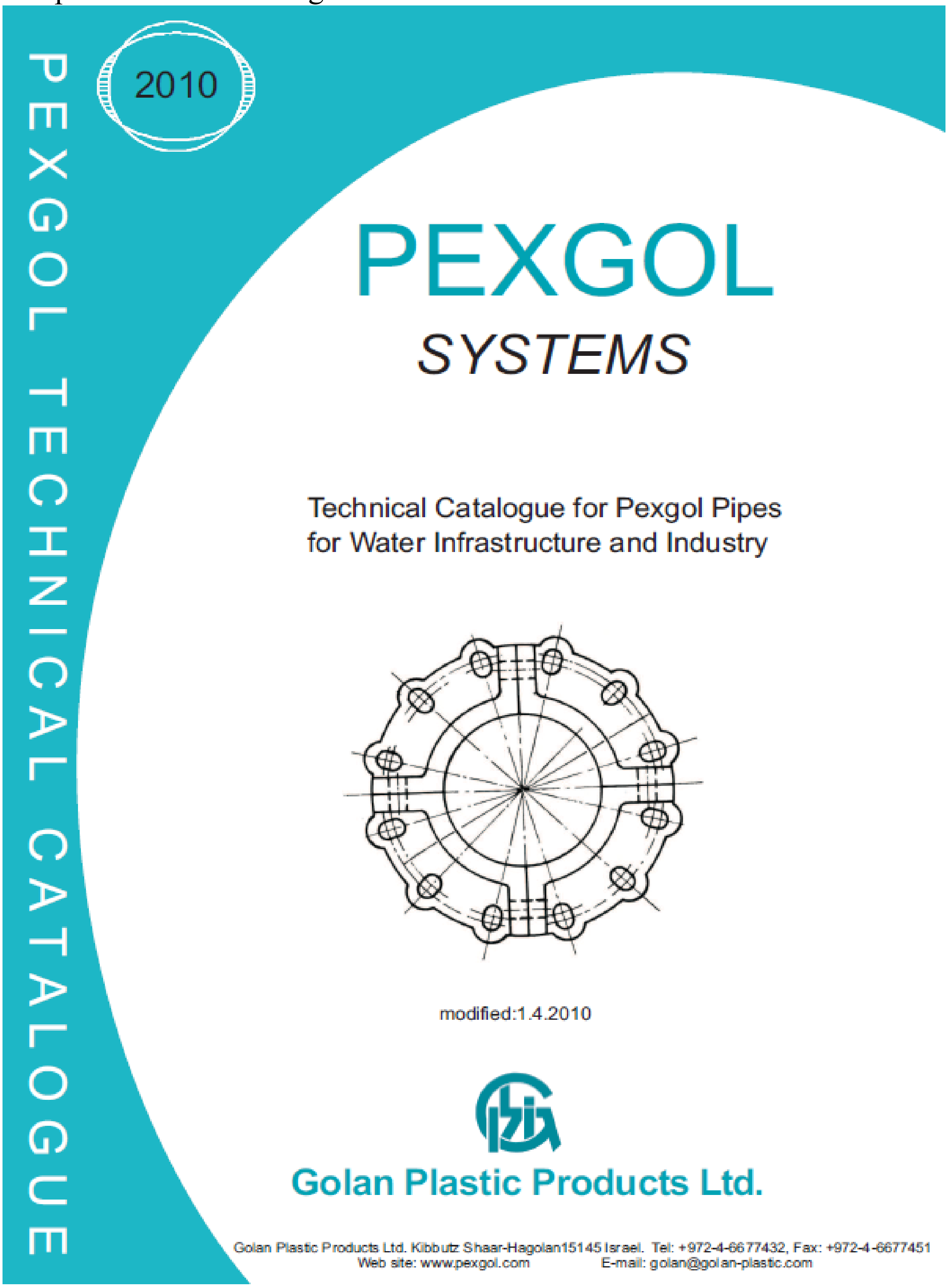
Appendices

Appendix (1)

Pex Pipes Characteristics

Adapted from www.Pexgol.com


PEXGOL TECHNICAL CATALOGUE

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PEXGOL

SYSTEMS

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Golan Plastic Products Ltd. Kibbutz Shaar-Hagolan15145 Israel. Tel: +972-4-6677432, Fax: +972-4-6677451
Web site: www.pexgol.com E-mail: golan@golan-plastic.com

PEXGOL

Introduction

PEXGOL pipes are produced by Golan Plastic Products, an industrial enterprise owned by Kibbutz Shaar Hagolan. Golan Plastic Products, started in 1960 as an extrusion plant and today it is one of the biggest plastic products producers in the building sector in Israel. In 1975 Golan Plastic Products started manufacturing hot water pipes made of polyethylene crosslinked by the Peroxide high pressure process. These pipes, sold under the name of PEXGOL, are now well-known for their quality and reliability in Israel as well as on the international market.
In 1991 Golan started manufacturing PEX-c pipes crosslinked by irradiation (electron beam).
In 1997 Golan started manufacturing a new multilayer pipe, sold under the name of MULTYGOL. This pipe is a Pex pipe reinforced by aluminum.

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yosibar@golan-plastic.com

MRS. SARIT CHOHEN
CUSTOMER SUPPORT
+ 972 - 46677604
+ 972 - 523864024
sarit@golan-plastic.com

Whereas the products shown in this catalogue illustrate and describe the current state of their development, Golan reserves the right at all times to make such technical alterations as it shall see fit to its products. Although every care has been taken in the preparation of the information, specifications and other data included in this catalogue, we cannot rule outinadvertent errors or omissions. Purchasers should take into account possible deviations or variations which will not substantially diminish the functionality or performance of the products and in many cases designed to improve the same.

GOLAN PLASTIC PRODUCTS Ltd.

Kibbutz Shaar-Hagolan15145 Israel. Tel: +972-4-6677432, Fax: +972-4-6677451
Web site: www.pexgol.com E-mail: golan@golan-plastic.com

PEXGOL CROSSLINKED P.E.

The unique Pexgol Pex-a pipes are produced from special HMW-HDPE RESINS. The crosslinking is performed during the production process, resulting in irreversible chemical links between adjacent P.E. chains. The crosslinked P.E. is a thermo-elastic material with a 3-D molecular structure, having very high dimensional stability at high temperatures. The crosslinking process renders the pipe improved mechanical properties such as:

1. Resistance to corrosion and pressure at high temperatures.
2. Exceptional high abrasion resistance.
3. Superb chemical resistance.
4. Excellent longevity at high temperatures.

CROSSLINKING METHOD

Peroxide (Chemical) crosslinking Pex-a

Mechanical Properties	Value	Unit	Standard to which tested
Density	938	kg/m³	
Tensile strength (at 20!C)	20-26	N/mm²	DIN 53455
(at 100!C)	9-13	N/mm²	
Elongation at break (at 20!C)	350-550	%	DIN 53455
(at 100!C)	500-700	%	
Impact strength (at 20!C)	No failure	KJ/m²	DIN 53453
(at -100!C)	No failure	KJ/m²	
Moisture absorption (at 22!C)	0.01	mg/4d	
Coefficient of friction on steel	0.08 - 0.1	-	
Surface energy	$34x10^{-3}$	N/m	
Oxygen permeability (at 40!C) for pipe with oxygen barrier coating	< 0.1	gm/m³ x day	DIN 4725
Resistance to ultraviolet light rays (UV). There are two types: A. White pipe: non-resistant to sunlight (UV) B. Black pipe: resistant to sunlight (UV)			

Thermal Properties	Value	Unit	
Service temperature range	-140+110	!C	
Coefficient of linear expansion (at 20!C)	$1.4x10^{-4}$	m/m!C	
Coefficient of linear expansion (at 100!C)	$2.05x10^{-4}$	m/m!C	
Softening temperature	+133	!C	
Specific heat	2.3	KJ/kg!C	
Coefficient of thermal conductivity	0.35	w/m!C	DIN 4725

Electrical Properties	Value	Unit	
Specific internal resistance (at 20!C)	10^{15}	Ω.m	
Dielectric constant (at 20!C)	2.3	-	
Dielectric loss factor (at 20!C/50Hz)	$1x10^{-3}$	-	
Rupture voltage (at 20!C)	60-90	KV/mm	

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PEXGOL CROSSLINKED P.E.

The unique Pexgo Pex-c-C pipes are produced from special HMW-HDPE RESINS.
The crosslinking is performed in a state of the art E-beam accelerator after the production process, resulting in irreversible cross- links between adjacent P.E. chains.
The crosslinked P.E. is a thermo-elastic material with a 3-D molecular structure, having very high dimensional stability at high temperatures.
The crosslinking process renders the pipe improved mechanical properties such as:

1. Resistance to corrosion and pressure at high temperatures.
2. Exceptional high abrasion resistance.
3. Superb chemical resistance.
4. Excellent longevity at high temperatures.

CROSSLINKING METHOD
E-beam crosslinking Pex-c.

Mechanical Properties	Value	Unit	Standard to which tested
Density	945	kg/m³	DIN 53429
Tensile strength (at 20!C)	23-26	N/mm²	DIN 53455
(at 100!C)	9-13	N/mm²	
Elongation at break (at 20!C)	350-550	%	DIN 53455
(at 100!C)	500-700	%	
Impact strength (at 20!C)	No failure	KJ/m²	DIN 53453
(at -100!C)	No failure	KJ/m²	
Moisture absorption (at 22!C)	0.01	mg/4d	
Coefficient of friction on steel	0.08-0.1	-	
Surface energy	$34x10^{-3}$	N/m	
Oxygen permeability (at 40!C) for pipe with oxygen barrier coating	<0.1	gm/m³.day	DIN 4726
Resistance to ultraviolet light rays (UV). There are two types: A. White pipe: non-resistant to sunlight (UV) B. Black pipe: resistant to sunlight (UV)			

Thermal Properties	Value	Unit	
Service temperature range	-140+110	!C	
Coefficient of linear expansion (at 20!C)	$1.4x10^{-4}$	m/m/!C	
Coefficient of linear expansion (at 100!C)	$2.05x10^{-4}$	m/m/!C	
Softening temperature	+133	!C	
Specific heat	2.3	KJ/kg!C	
Coefficient of thermal conductivity	0.35	w/m!C	DIN 4725

Electrical Properties	Value	Unit	
Specific internal resistance (at 20!C)	10^{15}	Ωm	
Dielectric constant (at 20!C)	2.3	-	
Dielectric loss factor (at 20!C/50Hz)	$1x10^{-3}$	-	
Rupture voltage (at 20!C)	60-90	KV/mm	

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2.

PEXGOL

Worldwide Approvals

Spanish Standard Institute Approval	Suddeutsches Kunststoff-Zentrum Amtlich anerkannte Prufanstalt fur Kunststoffe GERMANY
French Standard Institute for Building Approvals (incl. drinking water approval)	Deutscher Verein des Gas-und Wasserfaches e.V (incl. drinking water approval)
Portugese Standard Institute Approvals (incl. drinking water approval)	Technischer Uberwachungs-Verein Bayern Oxygen Permeability Approval
Danish Technical Institute for Building Purposes Approval (incl. drinking water approval)	Canadian Standard Approval
Finnish Standard Institute Approvals (incl. drinking water approval)	Uruguay Standard Institute Approvals
Norway Standard Institute Approvals (incl. drinking water approval)	Venezuelan Standard Institute Approval
Holland Standard Institute Approval	Russian Standard Institute Approval
Poland Standard Institute Approval	America Standard Food Approval For Drinking Water
China Standard Institute Approval	American National Standard Institute Approval
Israeli Standard Institute Standard Mark Approval (according to Israeli Std 1519 Part 1)	American National Standard Institute Approval
International ISO 9001 Approval	Ireland Standard Institute Approval
International certificatin network	Dutch Standard Institute Approval

Worldwide Approvals

Comparison with Other Plastic Pipes

PEXGOL pipes are produced from a special type of polyethylene. This is a high density polyethylene (HDPE) with a very high molecular weight.
During production the raw material is pressed under high pressures and temperatures and in the presence of a special catalyst. While the pipes are being extruded the material crosslinks, resulting in an unbreakable (chemical) cross-connection between the adjacent long molecules of the polyethylene. As a result of the crosslinking, a 3-dimensional network is formed and the pipe can be considered as one enormously big molecule.

The combination of a special raw material of a very high molecular weight and the crosslinking process itself, result in a special pipe having several important qualities:

* Corrosion resistance
* Excellent mechanical resistance
* Unique chemical resistance
* Very low friction coefficient
  (C=155 in Hazen-Williams Formula)
* Excellent abrasion resistance
* Very good resistance to heat
* Excellent longevity
* No longitudinal crack formation or other stress cracks
* Low creep
* No stone sediments due to pipe smoothness

These properties provide many advantages compared to normal pipes (which are not crosslinked):

1. High working pressures.
2. High working temperature (up to 110!C and above).
3. Excellent durability in harsh corrosive surrounding conditions:
   - industrial
   - sewage
   - sea water
   - corrosive ground
4. Immunity against improper pipe laying procedures.
5. Low head losses enabling considerable saving.

Regular polyethylene pipes are limited to a working temerature of up to 40!C (according to ISO Standard 4427). They are also very sensitive to scratches resulting from careless handling during transportation and laying of the pipes. In non-crosslinked pipes (such as PE, PP or PB), cracks may appear after a few years. These stress cracks occur as a result of the internal pressure or external stresses such as pipe bending or stone impregnations (as a result of poor sand bedding). This phenomena is also known as S.C.G.: Slow Crack Growth. The sensitivity to stress cracking is a material property, common for non-crosslinked pipe materials. S.C.G. does not appear with crosslinked PE pipes due to the 3-dimensional crosslinked structure of PEXGOL pipes, which totally blocks the growth of these cracks. The excellent resistance of PEXGOL pipes to Slow Crack Growth makes it an ideal choice for industrial piping, gas transportation, chemical and regular sewage transportation. For that reason it is possible to lay PEXGOL pipes in trenches without sand bedding!

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Domestic water supply lines

Pexgol pipes are the perfect plastic piping system for central heating systems and sanitary pipes (hot and cold water pipes). The Pexgol pipes are often used in the "Pipe-in-pipe" configuration.

Swift and Elegant Installation

The simplicity of the system - a pipe within a pipe - means quick, easy installation in less than half the time needed to install any other system.

The quality of Installation

Pexgol is an excellent system for hot and cold water. It is completely impervious to internal and external corrosion and prevents the buildup of stone sediments.

"Without Breaking Wall Tiles"

Domestic pipelines run through the most expensive areas of the apartment: the kitchen, bathroom and toilets. The Pexgol system prevents the need to break tiles, walls and flooring. Repairing the system is performed simply by pulling out the Pexgol pipe from its conduit pipe, allowing easy and convenient access to every part of the system, and easy reinsertion of the new pipe.

Hot water, always clear...

With Pexgol, you'll see the difference - a clear stream of water - quality of life!

Domestic water supply systems made of Pexgol pipes have been and are being installed in domestic housing, hotels and office buildings in Israel and all over the world!

For more information, please ask for "Pexgol - Instructions for Installation of a Residential Water Supply System".

Municipal Water Supply Pipes

Municipal steel water supply lines are attacked by corrosion due to the following reasons:

* Poor water quality with increasing chlorine content.
* Corrosive environment
* Unprofessional faulty installations

Thanks to their unique resistance against corrosion in any of the above conditions, Pexgol pipes may be installed anywhere and will operate without leaking. No need for repair or replacement!
Large continuous lengths of Pexgol pipes may be supplied on drums, thus minimizing the need for connections.
Each pipe connection, even the best one, is a weak spot!

Pexgol pipes have been laid in municipal water supply lines in various countries as well as in Israel. Settlements in the Arava region in the southern part of Israel consider the Pexgol pipe to be their only choice!

The reason for this is simple:

No failures in Municipal water supply during the last 20 years!

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Municipal Water Supply Pipes

Today the Pexgol pipe is without doubt the leading pipe in municipal supply lines in Israel and is used in the following applications:

Main pipe lines.
Secondary pipe lines in the building areas.
Inlet connections in buildings and fire extinguishing pipelines.
A computerized catalogue for design of Pexgol water lines may be obtained upon request from the Pexgol marketing Dept.

Pexgol pipes for sewer lines

Pexgol piping's has been used in pressurized sewer lines. Due to its excellent chemical and abrasion resistance Pexgol pipe, is not vulnerable to the H_2S gasses which may develop and attack the cement inner coating of the steel pipings very smooth surface of the Pexgol pipes prevents scale sediments.
Pexgol pipes have also been laid in gravity sewer lines and sea out fall lines.

Riser mains for Boreholes

One of the most recent Pexgol pipe applications is for pumping water from boreholes (at a depth of over 200m) by means of a continuous Pexgol pipe with a submersible pump and motor.

Industrial applications

The Pexgol pipe with its excellent abrasion resistance and chemical resistance is an ideal conduit for a wide range of industrial applications where conventional pipes would be unsatisfactory due to the abrasives of conveying slurries or because of vulnerability to chemical attack of solutions and acids - Pexgol pipes present a successful and cost-effective solution.

The industrial applications of Pexgol pipes include:
- handling slurries (gypsum; sand; salt; phosphates; silts; potash, ect).
- handling various chemicals.
- handling industrial wastes.

List of projects is available from our sales department or at our internet site.

Pexgol pipes for Natural Gas Transportation

Pexgol pipe shows an excellent durability for natural gas and L.P.G. This plastic pipe will without doubt be in the near future one of the leading pipes in municipal gas supply lines.
One of its outstanding advantages is:

NO SAND BEDDING REQUIRED!

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PEXGOL Pex - a Dimensions and Pressure Ratings

Pexgol pipes are produced according to the DIN Standards 16892/16893 and the Israeli Standard 1519 Part 1. These Standards show the working pressures of Pexgol pipes at various temperatures.

The working pressures for PEXGOL pipe are determined by the following equation:

$$P= \frac{2\sigma t}{D-t} \text{ or } P= \frac{2\sigma t}{SDR-1} \text{ or } \frac{\sigma}{s}$$

Where:

P = Maximum working pressure (kg/cm^2)

σ = Long term strength at the design temperature (kg/cm^2)

D = Outside diameter (mm)

t = Wall thickness (mm)

S = ISO 4065 series

SDR (Standard Dimensions Ratio) = $\frac{D}{t}$ = 2s + 1

The values of σ change with the temperature as follows:

Temp.(!c)	20	60	95
σ (kg/cm^2)	76	48	32

Notes:

The design stress σ is calculated with a safety factor of 1.25, according to DIN 16893-2000 Table 4.

Pexgol pipes maybe ordered with oxygen barrier (EVOH) coating in different colors (red, yellow etc.)

PEXGOL PIPE CLASS "10" (SDR 16.2 S7.6)

Working pressures: 10 bar at 20!C , 4 bar at 95!C , 6 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
63	3.9	0.72
75*	4.7	1.03
90	5.6	1.47
110	6.8	2.18
125*	7.7	2.81
140*	8.7	3.55
160	9.9	4.62
200	12.4	7.23
225	13.9	9.12
250	15.5	11.30
280	17.3	14.12
315	19.5	17.91
355	21.9	22.67
400	24.7	28.81
450	27.8	36.48
500	30.9	45.05

PEXGOL PIPE CLASS "12" (SDR 13.6 S6.3)

Working pressures: 12 bar at 20!C , 5 bar at 95!C , 7.5 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
63	4.7	0.85
75	5.6	1.21
90	6.7	1.73
110	8.1	2.57
125*	9.2	3.31
140	10.3	4.15
160	11.8	5.43
200	14.7	8.47
225	16.6	10.75
250	18.4	13.42
280	20.6	16.60
315	23.2	21.04
355	26.1	26.68
400	29.4	33.86
450	33.1	42.89
500	36.7	52.85

*Available on special order

Other pipe dimensions (according to page 5.1) are also available.

PEXGOL PIPE CLASS "15" (SDR 11 S5)

Working pressures: 15 bar at 20!C , 6 bar at 95!C , 9 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
16	2.0	0.09
20	2.0	0.11
25	2.3	0.16
32	2.9	0.26
40	3.7	0.42
50	4.6	0.65
63	5.8	1.03
75	6.8	1.44
90	8.2	2.09
110	10.0	3.11
125	11.4	4.03
140	12.7	5.02
160	14.6	6.60
200	18.1	10.23
225	20.4	12.97
250	22.7	16.05
280	25.4	20.10
315	28.6	25.46
355	32.2	32.30
**450	50.0	62.16

** Class "19"

PEXGOL PIPE CLASS "24" (SDR 7.4 S3.2)

Working pressures: 24 bar at 20!C , 10 bar at 95!C , 15 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
12	2.0	0.06
16	2.2	0.09
20	2.8	0.15
25	3.5	0.23
32	4.4	0.38
40	5.5	0.59
50	6.9	0.92
63	8.6	1.45
75	10.3	2.07
90	12.3	2.97
110	15.1	4.45
125 *	17.1	5.73
140 *	19.2	7.21
160	21.9	9.40
200	27.3	14.65
225	30.8	18.59

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Pexgol pipes are produced according to the DIN Standards 16892/16893 and the Israeli Standard 1519 Part 1. These Standards show the working pressures of Pexgol pipes at various temperatures.

The working pressures for PEXGOL pipe are determined by the following equation:

$$P = \frac{2\sigma t}{D-t} \text{ or } P = \frac{2\sigma t}{SDR-1} \text{ or } \frac{\sigma}{s}$$

Where:

P = Maximum working pressure (kg/cm²)
σ = Long term strength at the design temperature (kg/cm²)
D = Outside diameter (mm)
t = Wall thickness (mm)
S = ISO 4065 series
SDR (Standard Dimensions Ratio) = $\frac{D}{t} = 2s + 1$

The values of σ change with the temperature as follows:

Temp.(!c)	20	60	95
σ (kg/cm²)	76	48	32

Notes:
The design stress σ is calculated with a safety factor of 1.25, according to DIN 16893-2000 Table 4.

Please note !

1. Pexgol Pex-c pipes are available in various colors: Natural, Black, Red, Blue etc.
2. The pipes may be ordered with oxygen barrier (EVOH) coating.

PEXGOL PIPE CLASS "19" (SDR 9 S4)

Working pressures: 19 bar at 20!C , 8 bar at 95!C , 11.5 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
8.0	1.0	0.02
10.5	1.25	0.04
16.0	1.8	0.08
16.0	2.0	0.09
17.0	2.0	0.09
18.0	2.0	0.10
Pexgol "INCH" pipes (class 19) - Produced according to ASTM F876		
3/8" (12.7)	1.78	0.06
1/2" (15.88)	1.78	0.08
5/8" (19.05)	2.12	0.11
3/4" (22.22)	2.47	0.15

PEXGOL PIPE CLASS "24" (SDR 7.4 S3.2)

Working pressures: 24 bar at 20!C , 10 bar at 95!C , 15 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
10	1.8	0.05
12	1.8	0.06
12	2.0	0.06
14	2.0	0.07
15	2.5	0.10
16	2.2	0.09
18	2.5	0.12
20	2.8	0.15
22	3.0	0.18

PEXGOL PIPE CLASS "15" (SDR 11 S5)

Working pressures: 15 bar at 20!C , 6 bar at 95!C , 9 bar for gas

O.D. (mm)	wall thickness (mm)	weight (kg/m)
12	1.1	0.04
16	1.5	0.07
20	1.9	0.11
20	2.0	0.11
25	2.3	0.16
Pexgol IRISH "INCH" pipes		
1/2" (14.63)	1.70	0.07
3/4" (20.98)	2.15	0.13
1" (27.33)	2.70	0.21

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Pexgol Crosslinked polyethylene pipes for Municipal Supply lines

Auxiliary page for Pipeline Designer.

1. Cross-linked polyethylene (Pexgol), UV Stabilized (black) pipe, class 10 (SDR 16.2)or class 15 (SDR 11) or class 12(SDR 13.6) (depending on the temperature and design pressure) is suitable for municipal supply lines.

2. The pipe is supplied on coils that fit into standard 6' or 12' containers. Total coil length depends on the pipe diameter, see page " Transportation of Pexgol pipes".

3. The pipe should be connected only by fittings approved by Golan and according to Golan's specifications.

4. The pipe should be connected by an authorized contractor.

4.1 Pipe connection is normally executed outside the trench.

4.2 See appendix "Recommendations for Pexgol pipe connections".

5. Laying the pipe in the trench should be done according to "Installation instructions for Pexgol Pipes in trenches".

5.1 Pexgol pipes may be laid in trenches with no sand bedding. The trenches may be backfilled using the original material from the trench.

6. Pressure test should be made according to the page "Instructions for pressure testing of Pexgol pipes".

6.1 After having carried out the pressure test in the presence of Golan's representative, a certificate will be submitted confirming that the test has been carried out properly.

7. It is possible to make side outlets from Pexgol pipe in diameters of up to half of the leading pipe's diameter, using Branch-off saddles.The saddles are made from brass, stainless steel or plastic. (See pages referring to Pexgol saddles and their Installation instructions)

8. It is recommended to design the line with as few connections as possible. For this purpose it is recommended to consult Golan's field service department.

Appendix: Recommendations for Pexgol pipe connections

1. Plasson's Mechanical connections (including saddles).

1.1 Available up to 160mm diameter.

1.2 Can be used for class 10, 12 or 15 up to a temperature of 60!C.

1.3 For pipe classes 12 and 15 it is recommended to use Plasson's "series 18".

2. Electrofusion couplers (including saddles).

2.1 Available up to 500mm diameter.

2.2 Use only products which are approved by Golan.

2.3 The working pressures of the couplers are the same as for class 15 Pexgol pipe at temperatures between 20!C and 60!C.

2.4 For higher temperatures please consult Golan's field service department.

2.5 Additional couplers prepared for electrofusion welding can be ordered (T-branches, elbows etc).

3. DZR brass fittings Hela GP

3.1 Available from 32mm to 160mm including male straight connectors, Tee's, elbows and Branch saddles.

3.2 Hela GP fittings can be used for all temperature and pressure range allowed for Pexgol pipes.

4. Stainless steel saddles

4.1 Available from 110mm up to 500mm outside diameter.

4.2 The saddles are available either with flanged or threaded outlet.

4.3 The maximum outlet diameter is up to half the main pipe's diameter.

4.4 Stainless steel branch-off saddles can be used for all temperature and pressure ranges allowed for Pexgol pipes.

4.5 Saddles with internal rubber coating including the flange can be ordered in case corrosive materials are used, which stainless steel fittings would not withstand.

5. Golan's Flanged Couplers

5.1 Available from 63mm to 500mm outside diameter.

5.2 All couplers comply with ASA 150 standard, some of them comply with other standards as well.

5.3 Golan's flanged couplers can be used for the same temperature and pressure range allowed for Pexgol pipes.

Please ask for our publications on municipal pipeline installations.

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PEXGOL

Industrial Pexgol Pipelines

1. Pipe Class Selection According To:

1.1 Design Temperature.
1.2 Working Pressure.
1.3 Influence of the chemical resistance of Pexgol pipe on permitted working pressures (see"chemical resistance table of Pexgol pipes").

2. Design Temperature Definition Rules:

2.1 Buried Pipes: according to the temperature of the liquid flowing through the pipe.
2.2 Exposed pipes: Design temperature should be calculated by adding 20!C to the maximum ambient temperature (e.g. a design temperature of 60!C for max. ambient temperature of 40!C).
2.3 Alternatively according to the temperature of the liquid flowing through the pipe (if it is higher than 60!C).

3. Pipes Under Vacuum Conditions

Minimum pipe class should be class 15. (see page Nº. 11).

4. Selection of Fittings for Pexgol Pipes

4.1 Only fittings approved by Pexgol pipes Service Dept. may be used.
4.2 The installation instructions published by Pexgol Pipes Service Dept. state service limitations (if existing) for each type of fitting.
4.3 Special fixpoint clamps should be used as before and after the fittings, see page 15.
4.4 In case of any questions, please contact Pexgol Pipes Service Department.

5. G.P Flanged Couplings:

5.1 Available from 63mm (with 2" flange) to 500mm (with 20" flange).
5.2 All couplings comply with ASA 150 flange standard.
5.3 Flanged couplings may be used throughout all the range of allowable working temperatures and pressures for Pexgol Pipes
54. Special fixpoint clamps should be used as before and after the fittings, see page 15.

6. Electrofusion Couplers (including saddles).

6.2 Other fittings - according to the supplier catalog.
6.3 Working pressures for electrofusion fittings are compatible with class 15 Pexgol Pipes at temperatures up to 40!C.
6.4 For higher temperatures please consult the service department of Pexgol Pipes.
6.5 Additional fittings (such as T, transition etc) ready for electrofusion welding may be specially ordered.

7. Stainless Steel Saddles.

7.1 Available for Pexgol Pipes from 110mm up to 500mm.
7.2 Flanged or threaded outlets (internal thread).
7.3 Maximum outlet diameter - up to half of the pipe's outside diameter.
7.4 In case of corrosive liquids for which stainless steel is not resistant, the saddles may be ordered with a special rubber coating over the flange and neck.
7.5 Stainless steel saddles may be used throughout all the range of allowable working temperatures and pressures for Pexgol pipes.

8. "Plasson" Mechanical Fittings (Incl. Saddles).

8.1 Available up to 160mm .
8.2 May be used for classes 10, 12 or 15 Pexgol pipes up to 60!C.
8.3 For pipe classes 12 or 15 Plasson fittings of "series 18" should preferably be used in diameters up to 63mm.
8.4 Special fixpoint clamps should be used as before and after the fittings, see page 15.

9. Pexgol Pipes with Flared Ends.

9.1 Pexgol pipes up to 160mm, in lengths according to the table at parag. 8, may be ordered with flared ends and metal flanges.
9.2 Larger diameter Pexgol pipes (up to 500mm) may be ordered in any length up to 11.5 meters (to fit into 40' containers) with one or tow flared ends.
9.3 Flared ends may connect two Pexgol pipes or a Pexgol pipe to a fitting.
9.4 There is no need for an additional gasket.
9.5 The flanges may be supplied according to the industrial standard ASA 150. Other flanges may be available on special orders.
9.6 A flared end connection may be used throughout all the range of allowable working temperatures and pressures for Pexgol pipes.
9.7 Prefabricated Pexgol elbows with flared ends are also available.
9.8 Special fixpoint clamps should be used as before and after the flared ends, see page 15.

10. Pre-fabricated Pexgol Elbows

10.1 Prefabricated elbows may be ordered up to diameters of 500mm.
10.2 The standard bending radius is approximately R = 3D OR R=1.5D .
10.3 The elbows may be ordered with plain ends, for either flanged couplings or electrofusion fittings.
10.4 Elbows with flared ends can also be ordered.
10.5 A flared end connection may be used throughout all the range of allowable working temperatures and pressures for Pexgol pipes.
10.6 Special fixpoint clamps should be used as before and after the flared ends, see page 15.

11. Influence of Temperature changes on Pexgol Pipes

11.1 Pexgol Pipes placed above the ground or over bridges,tend to get longer when temperature rises (snaking phenomenon) and will get shorter as the temperature goes down.
11.2 Fixpoints or guiding clamps may be used for restraining the elongation of the pipe (mainly due to aesthetic considerations).
11.3 There is no need to protect the pipe itself against thermal stresses, as they are absorbed by the pipe.
11.4 No need for installation of "expansion points" or omegas.
11.5 Special fixpoint clamps should be used as before and after the fittings, see page 15.

12. Pexgol pipes above the ground

12.1 Pexgol pipes can be placed on a ground which is free from rocks or sharp stones.
12.2 There is no need for special bedding!

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Web site: www.pexgol.com E-mail: golan@golan-plastic.com

Supplying Pexgol pipes to the installation site.

The Pexgol pipe's flexibility and its memory effect is one of its outstanding features, enabling the pipe to return to its original diameter after transportation on relatively small drums or in coils. As a result we can supply longer continuous lengths as compared to any other pipe:

1. Coils

From diameter 25mm to 160mm Pexgol pipes may be ordered in standard coils of 50m or 100 meters.
Longer pipe lengths may be ordered in coils according to customer's specifications.
see table below for details.

2. Pipes with Flared Ends

Pipes with a diameter of up to 160mm with two flared ends may be ordered in coils in lengths according to the table. Pexgol pipes in larger diameters up to 500mm with or without Flared ends may be ordered in a maximum length of 11.5m (to fit into standared 40' containers)

Pexgol pipes in coils

5 coils in 20ft container (external coil diameter: 2.20m. Width of coil: 1m)

Pipe dia.	Wall thickness	length of each coil	Total langth in 20ft container
22	3.0	6500m	32,500m
25	2.3	5000m	25,000m
25	3.5	5000m	25,000m
28	4.0	4000m	20,000m
32	2.9	3000m	15,000m
32	4.4	3000m	15,000m
40	3.7	2000m	10,000m
40	5.5	2000m	10,000m
50	4.6	1200m	6,000m
50	6.9	1200m	6,000m
63	4.7	800m	4,000m
63	5.8	800m	4,000m
63	8.6	800m	4,000m
75	4.6	500m	2,500m
75	5.6	500m	2,500m
75	6.8	500m	2,500m
75	10.3	500m	2,500m
90	5.6	300m	1,500m
90	6.7	350m	1,750m
90	8.2	350m	1,750m
90	12.3	350m	1,750m
110	8.1	140m	700m
110	10.0	210m	1,050m
110	15.1	210m	1,050m
125	11.4	120m	600m
*140	12.7	75m	375m
*160	14.6	62m	310m
*160	21.9	80m	400m

*** Available by special order, even with greater length.**
May be supplied on drums - according to customer's specifications.

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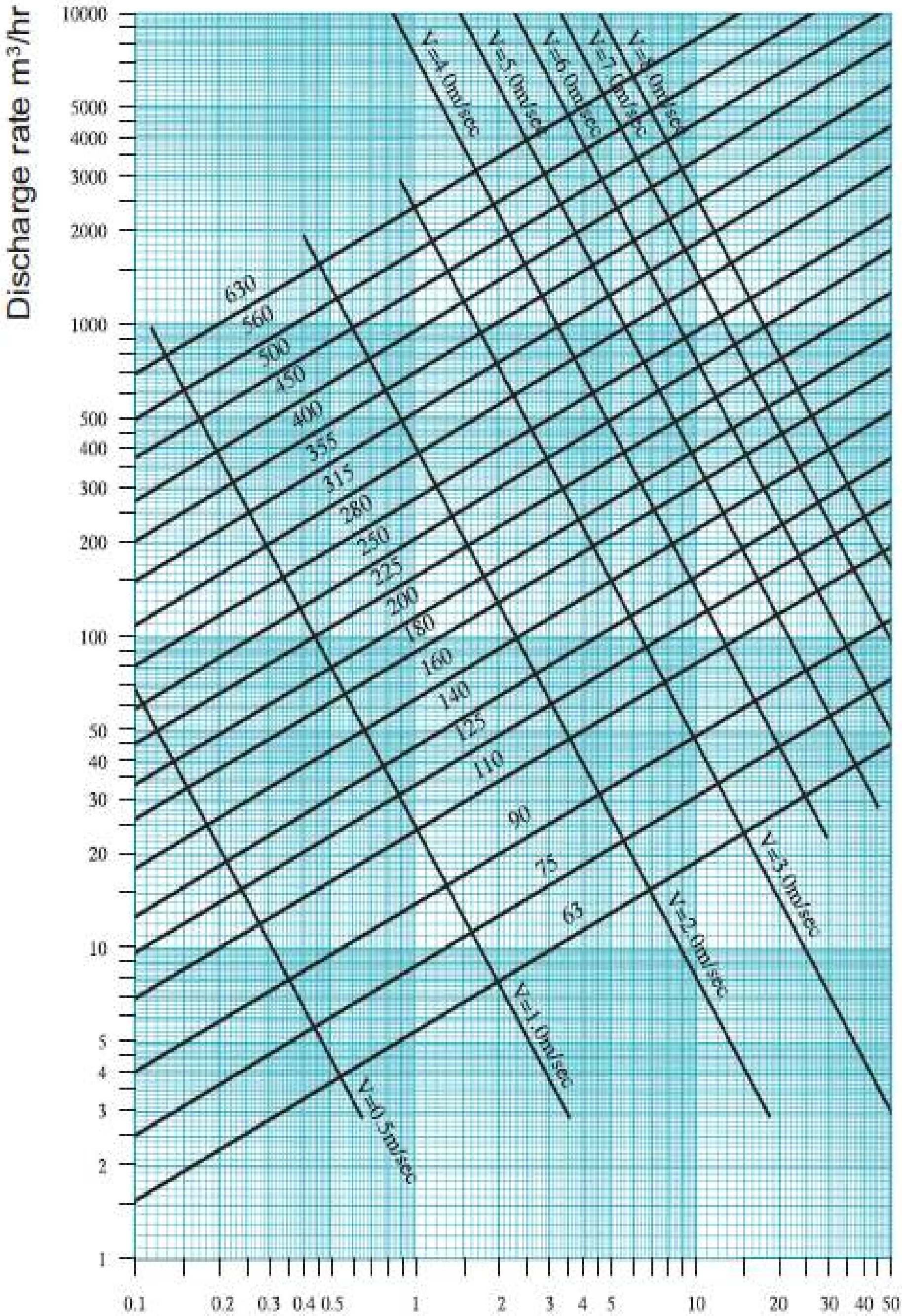
Kibbutz Shaar-Hagolan15145 Israel. Tel: +972-4-6677432, Fax: +972-4-6677451
Web site: www.pexgol.com E-mail: golan@golan-plastic.com

PEXGOL

Flow chart for full flow conditions

Class 15 (SDR 11)



Head Loss (meters) for 100 meters Pexgol pipe

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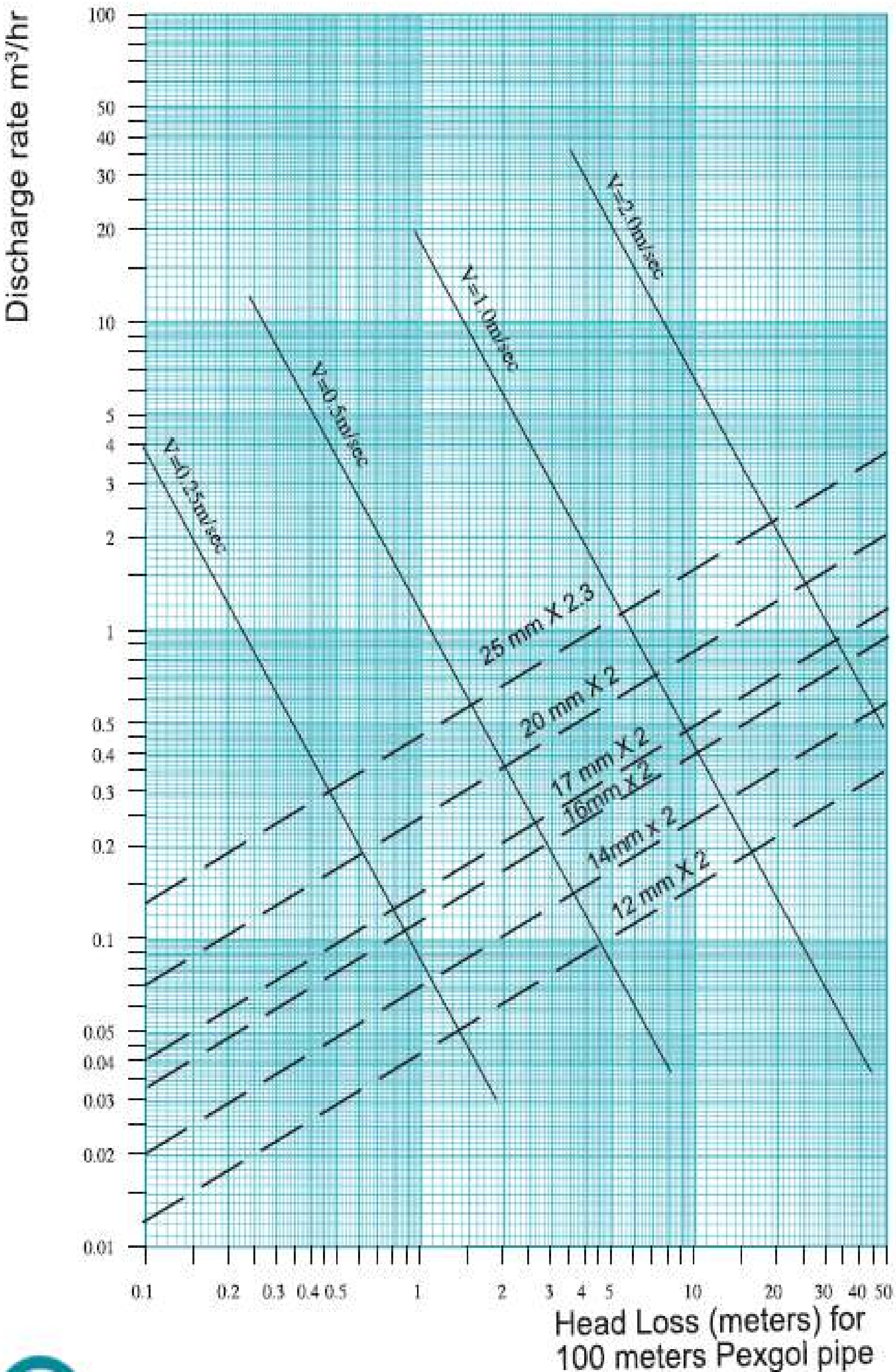
Web site: www.pexgol.com E-mail: golan@golan-plastic.com

Underfloor heating pipes



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Kibbutz Shaar-Hagolan15145 Israel. Tel: +972-4-6677432, Fax: +972-4-6677451
Web site: www.pexgol.com E-mail: golan@golan-plastic.com

Appendix (2)

Pip Properties

Heat Transfer Fluid= Water @ 50 F	Pressure Drop per 100 ft of PVC Piping (Using D'arcy-Weisbach Equation)								
Fluid Viscosity= .0012 (lb/ft*s) Fluid Density= 63 (lb/ft^3)	3/4" SDR 11 ID (in)= .61"			1" SDR 11 ID (in)= .92"			1 1/4" SDR 11 ID (in)= 1.13"		
Flow Rate (GPM)	Rd	PD (ft of H2O)	Vel (ft/s)	Rd	PD (ft of H2O)	Vel (ft/s)	Rd	PD (ft of H2O)	Vel (ft/s)
1	2930	1.60	1.10	1943	0.23	0.48	1582	0.09	0.32
1.5	4395	3.25	1.65	2914	0.46	0.72	2373	0.17	0.48
2	5860	5.38	2.20	3886	0.76	0.97	3163	0.29	0.64
2.5				4857	1.13	1.21	3954	0.42	0.80
3				5828	1.55	1.45	4745	0.58	0.96
3.5				6800	2.03	1.69	5536	0.77	1.12
4				7771	2.57	1.93	6327	0.97	1.28
4.5				8742	3.16	2.17	7118	1.19	1.44
5				9714	3.79	2.41	7909	1.43	1.60
5.5				10685	4.48	2.65	8700	1.69	1.76
6				11657	5.22	2.90	9490	1.97	1.92
6.5							10281	2.26	2.08
7							11072	2.57	2.24
7.5							11863	2.91	2.40
8							12654	3.25	2.56
8.5							13445	3.62	2.72
9							14236	4.00	2.88
9.5							15026	4.39	3.04
10							15817	4.81	3.20
10.5							16608	5.23	3.36
11							17399	5.68	3.52

Heat Transfer Fluid= Water @ 50 F	Pressure Drop per 100 ft of PVC Piping (Using D'arcy-Weisbach Equation)								
Fluid Viscosity= .0012 (lb/ft*s) Fluid Density= 63 (lb/ft^3)	3/4" SDR 9 ID (in)= .58"			1" SDR 9 ID (in)= .88"			1 1/4" SDR 9 ID (in)= 1.07"		
Flow Rate (GPM)	Rd	PD (ft of H2O)	Vel (ft/s)	Rd	PD (ft of H2O)	Vel (ft/s)	Rd	PD (ft of H2O)	Vel (ft/s)
1	3066	1.98	1.20	2033	0.28	0.53	1670	0.11	0.36
1.5	4599	4.03	1.80	3050	0.57	0.79	2506	0.23	0.54
2	6132	6.67	2.40	4067	0.95	1.06	3341	0.37	0.71
2.5				5083	1.40	1.32	4176	0.55	0.89
3				6100	1.93	1.59	5011	0.76	1.07
3.5				7117	2.52	1.85	5846	0.99	1.25
4				8134	3.19	2.12	6682	1.25	1.43
4.5				9150	3.92	2.38	7517	1.54	1.61
5				10167	4.71	2.64	8352	1.85	1.78
5.5				11184	5.57	2.91	9187	2.19	1.96
6				12200	6.48	3.17	10023	2.55	2.14
6.5							10858	2.93	2.32
7							11693	3.34	2.50
7.5							12528	3.76	2.68
8							13363	4.21	2.85
8.5							14199	4.69	3.03
9							15034	5.18	3.21
9.5							15869	5.69	3.39
10							16704	6.23	3.57
10.5							17539	6.78	3.75
11							18375	7.36	3.93

Appendix (3)

Antifreeze Properties

Ethylene Glycol Correction Factors			Propylene Glycol Correction Factors		
Cooling Capacity	10%	0.9950	Cooling Capacity	10%	0.9900
	20%	0.9920		20%	0.9800
	30%	0.9870		30%	0.9700
	40%	0.9830		40%	0.9600
	50%	0.9790		50%	0.9500
Heating Capacity	10%	0.9910	Heating Capacity	10%	0.9870
	20%	0.9820		20%	0.9750
	30%	0.9770		30%	0.9620
	40%	0.9690		40%	0.9420
	50%	0.9610		50%	0.9300
Pressure Drop	10%	1.0700	Pressure Drop	10%	1.0700
	20%	1.1300		20%	1.1500
	30%	1.1800		30%	1.2500
	40%	1.2600		40%	1.3700
	50%	1.2800		50%	1.4200

Methanol			Ethanol		
Cooling Capacity	10%	0.9980	Cooling Capacity	10%	0.9910
	20%	0.9720		20%	0.9510
	30%			30%	
	40%			40%	
	50%			50%	
Heating Capacity	10%	0.9950	Heating Capacity	10%	0.9950
	20%	0.9700		20%	0.9600
	30%			30%	
	40%			40%	
	50%			50%	
Pressure Drop	10%	1.0230	Pressure Drop	10%	1.0350
	20%	1.0570		20%	1.0680
	30%			30%	
	40%			40%	
	50%			50%	

Weekday occupancy from 8 a.m. until [illegible] p.m.; summer break June through August.

Office:

Sizing ratio of peak daily load to daily capacity was maintained at 0.40.

Heating EFLH =

At 0.6 W/ft^2: 0.20 x HDD_{65} [for HDD_{65} < 5,000] & EFLH = 1,000 [for HDD_{65} > 5,000]

At 2.5 W/ft^2: 0.15 x HDD_{65} [for HDD_{65} < 6,000] & EFLH = 900 [for HDD_{65} > 6,000]

(At 6.5 W/m^2: 0.36 x HDD_{18} [for HDD_{18} < 2,800] & EFLH = 1,000 [for HDD_{18} > 2,800])

(At 27 W/m^2: 0.27 x HDD_{18} [for HDD_{18} < 3,300] & EFLH = 900 [for HDD_{18} > 3,300])

Cooling EFLH =

At 0.6 W/ft^2: 225 + 0.45 x CDD_{65}

At 2.5 W/ft^2: 670 + 0.40 x CDD_{65}

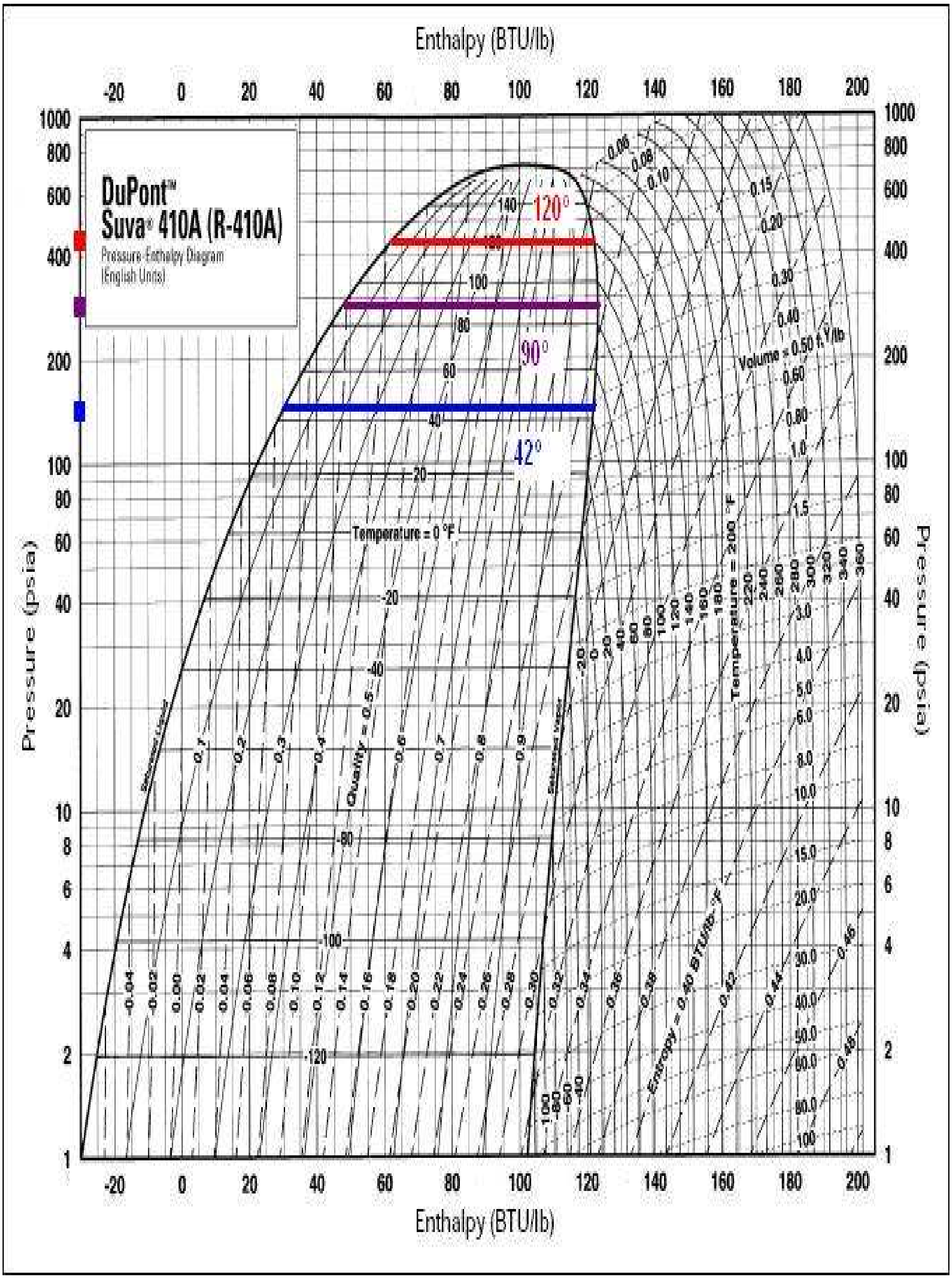
(At 6.5 W/m^2: 225 + 0.81 x CDD_{18})

(At 27 W/m^2: 670 + 0.72 x CDD_{18})

Weekday occupancy from 8 a.m. until 5 p.m.

Appenix (4)

P-H diagram R410-a



Adapted from DuPont company web site (Fluor chemicals properties)

Appendix (5)

Hazen- Wiliams Formula

EQUATION TERMINOLOGY

The following terms are used in the equations contained within Appendix III and Appendix IV of this report:

C	Hazen-Williams Flow Coefficient
D	Inside diameter of pipe in feet
d	Inside diameter of pipe in inches
f	Darcy-Weisbach Friction Factor
g	Gravitational acceleration, generally accepted as being 32.2 feet per second per second
HL	Head loss in feet of water
L	Length of pipe in feet
n	Manning Flow Coefficient
Q	Volumetric flow rate in cubic feet per second
q	Volumetric flow rate in gallons per minute
R	Hydraulic radius in feet (the ratio of flow area to wetted perimeter)
R_N	The Reynolds Number (a dimensionless number relating flow, diameter, and fluid viscosity)
S	Slope of hydraulic grade line in feet per foot
V	Average flow velocity in feet per second
μ	Kinematic fluid viscosity in feet - feet per second

FORMS OF THE HAZEN-WILLIAMS FORMULA

Velocity:

$$V = 1.318CR^{0.63}S^{0.54}$$

$$V = 0.115Cd^{0.63}S^{0.54}$$

$$V = 0.550CD^{0.63}S^{0.54}$$

Flow:

$$Q = 16.66CR^{2.63}S^{0.54}$$

$$q = 7427CR^{2.63}S^{0.54}$$

$$Q = 0.432CD^{2.63}S^{0.54}$$

$$q = 193.9CD^{2.63}S^{0.54}$$

$$Q = 0.000627Cd^{2.63}S^{0.54}$$

$$q = 0.281Cd^{2.63}S^{0.54}$$

Head Loss:

$$HL = 0.600 \times \frac{V^{1.85}}{C^{1.85}R^{1.17}}$$

$$HL = \frac{841500 \times Q^{1.85}}{C^{1.85}d^{4.87}}$$

$$HL = 3.04 \times \frac{V^{1.85}}{C^{1.85}D^{1.17}}$$

$$HL = \frac{6.936 \times 10^{-8} \times q^{1.85}}{C^{1.85}R^{4.87}}$$

$$HL = 54.66 \times \frac{V^{1.85}}{C^{1.85}d^{1.17}}$$

$$HL = \frac{5.8616 \times 10^{-5} \times q^{1.85}}{C^{1.85}D^{4.87}}$$

$$HL = 0.00556 \times \frac{Q^{1.85}}{C^{1.85}R^{4.87}}$$

$$HL = \frac{10.47 \times q^{1.85}}{C^{1.85}d^{4.87}}$$

$$HL = 4.72 \times \frac{Q^{1.85}}{C^{1.85}D^{4.87}}$$

Appendix (6)

Approximate Friction Loss in Thermal pipe Fittings

APPROXIMATE FRICTION LOSS IN THERMOPLASTIC PIPE FITTINGS
(in feet of pipe)

Type of Fitting	Equivalent Length of Pipe (in feet)
Tee, flow through main	20D*
Tee, flow through branch	60D
90° Elbow, molded, R = 1.5 D	30D
90° Elbow, mitered, R = 1.5 D	24D
60° Elbow, mitered, R = 1.5	16D
45° Elbow, molded, R = 1.5 D	16D
45° Elbow, mitered, R = 1.5 D	12D
30° Elbow, mitered, R = 1.5 D	8D
Insert Couplings	12D
Male-Female Insert Adapters	18D

Appendix (7)

Intrest Rate Tables

APPENDIX B

Compound Interest Tables

Values of Interest Factors When N Equals Infinity

Single Payment:

$(F/P, i, \infty) = \infty$

$(P/F, i, \infty) = 0$

Arithmetic Gradient Series:

$(A/G, i, \infty) = 1/i$

$(P/G, i, \infty) = 1/i^2$

Uniform Payment Series:

$(A/F, i, \infty) = 0$

$(A/P, i, \infty) = i$

$(F/A, i, \infty) = \infty$

$(P/A, i, \infty) = 1/i$

10% **Compound Interest Factors** 10%

	Single Payment		Uniform Payment Series				Arithmetic Gradient		
	Compound Amount Factor	Present Worth Factor	Sinking Fund Factor	Capital Recovery Factor	Compound Amount Factor	Present Worth Factor	Gradient Uniform Series	Gradient Present Worth	
	Find F Given P	Find P Given F	Find A Given F	Find A Given P	Find F Given A	Find P Given A	Find A Given G	Find P Given G	
n	**F/P**	**P/F**	**A/F**	**A/P**	**F/A**	**P/A**	**A/G**	**P/G**	**n**
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	6
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	7
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	8
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	9
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	10
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396	11
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901	12
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377	13
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.801	14
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152	15
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416	16
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582	17
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640	18
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583	19
20	6.728	.1486	.0175	.1175	57.275	8.514	6.508	55.407	20
21	7.400	.1351	.0156	.1156	64.003	8.649	6.719	58.110	21
22	8.140	.1228	.0140	.1140	71.403	8.772	6.919	60.689	22
23	8.954	.1117	.0126	.1126	79.543	8.883	7.108	63.146	23
24	9.850	.1015	.0113	.1113	88.497	8.985	7.288	65.481	24
25	10.835	.0923	.0102	.1102	98.347	9.077	7.458	67.696	25
26	11.918	.0839	.00916	.1092	109.182	9.161	7.619	69.794	26
27	13.110	.0763	.00826	.1083	121.100	9.237	7.770	71.777	27
28	14.421	.0693	.00745	.1075	134.210	9.307	7.914	73.650	28
29	15.863	.0630	.00673	.1067	148.631	9.370	8.049	75.415	29
30	17.449	.0573	.00608	.1061	164.494	9.427	8.176	77.077	30
31	19.194	.0521	.00550	.1055	181.944	9.479	8.296	78.640	31
32	21.114	.0474	.00497	.1050	201.138	9.526	8.409	80.108	32
33	23.225	.0431	.00450	.1045	222.252	9.569	8.515	81.486	33
34	25.548	.0391	.00407	.1041	245.477	9.609	8.615	82.777	34
35	28.102	.0356	.00369	.1037	271.025	9.644	8.709	83.987	35
40	45.259	.0221	.00226	.1023	442.593	9.779	9.096	88.953	40
45	72.891	.0137	.00139	.1014	718.905	9.863	9.374	92.454	45
50	117.391	.00852	.00086	.1009	1 163.9	9.915	9.570	94.889	50
55	189.059	.00529	.00053	.1005	1 880.6	9.947	9.708	96.562	55
60	304.482	.00328	.00033	.1003	3 034.8	9.967	9.802	97.701	60
65	490.371	.00204	.00020	.1002	4 893.7	9.980	9.867	98.471	65
70	789.748	.00127	.00013	.1001	7 887.5	9.987	9.911	98.987	70
75	1 271.9	.00079	.00008	.1001	12 709.0	9.992	9.941	99.332	75
80	2 048.4	.00049	.00005	.1000	20 474.0	9.995	9.961	99.561	80
85	3 299.0	.00030	.00003	.1000	32 979.7	9.997	9.974	99.712	85
90	5 313.0	.00019	.00002	.1000	53 120.3	9.998	9.983	99.812	90
95	8 556.7	.00012	.00001	.1000	85 556.9	9.999	9.989	99.877	95
100	13 780.6	.00007	.00001	.1000	137 796.3	9.999	9.993	99.920	100

Prefix	**Symbol(s)**	**Power of 10**	**Power of 2**
yocto-	y	10^{-24} *	--
zepto-	z	10^{-21} *	--
atto-	a	10^{-18} *	--
femto-	f	10^{-15} *	--
pico-	p	10^{-12} *	--
nano-	n	10^{-9} *	--
micro-	□	10^{-6} *	--
milli-	m	10^{-3} *	--
centi-	c	10^{-2} *	--
deci-	d	10^{-1} *	--
(none)	--	10^{0}	2^{0}
deka-	D	10^{1} *	--
hecto-	h	10^{2} *	--
kilo-	k or K **	10^{3}	2^{10}
mega-	M	10^{6}	2^{20}
giga-	G	10^{9}	2^{30}
tera-	T	10^{12}	2^{40}
peta-	P	10^{15}	2^{50}
exa-	E	10^{18} *	2^{60}
zetta-	Z	10^{21} *	2^{70}
yotta-	Y	10^{24} *	2^{80}

* Not generally used to express data speed

** k = 10^3 and K = 2^{10}

Appendix (8)

Fittings used in building the model

ss wall plate elbow

CODE	SIZE
50-3130	1/2"(16mm)

Brass elbow with screw

CODE	SIZE
50-3131	1/2"(16mm)

ble brass angle
90° with screw

CODE	SIZE (Inch)
50-3135	1/2"X 16mm

Double brass angle
base 180° with screw

CODE	SIZE (Inch)
50-3138	1/2"X 16mm

male strength
nipple

CODE	SIZE
50-3140	1/2"(16mm)
50-3141	3/4"(16mm)
50-3142	1/2"(20mm)
50-3143	3/4"(20mm)
50-3144	3/4"(25mm)
50-3145	1"(25mm)
50-3146	1"(32mm)
50-3147	1"(20mm)

Brass female strength
nipple

CODE	SIZE
50-3150	1/2"(16mm)
50-3151	3/4"(16mm)
50-3152	1/2"(20mm)
50-3153	3/4"(20mm)
50-3154	3/4"(25mm)
50-3155	1"(25mm)
50-3156	1"(32mm)
50-3157	1"(20mm)

double straight
nipple

CODE		SIZE (Inch)
50-3160		16-16
50-3161		20-20
50-3162		25-25
50-3163		32-32
50-3165	Reducer	20-16
50-3166	Reducer	25-20

Brass tee with
three nuts

CODE		SIZE (mm)
50-3170		16-16-16
50-3171		20-20-20
50-3172		25-25-25
50-3175	Reducer	16-20-16
50-3176	Reducer	20-16-20
50-3177	Reducer	20-25-20
50-3178	Reducer	25-20-25

Brass Fittings for pex pies

63

Brass check valve (plastic core)-IMT

CODE	SIZE (Inch)
44-5220	1/2
44-5221	3/4
44-5222	1

Italy

IMT® SWITZERLAND

Brass check valve

CODE	SIZE (Inch)
44-5150	1/2
44-5151	3/4
44-5152	1
44-5153	1.25
44-5154	1.5
	2

Galvanized nipple - 1/2"
(M-M)

CODE	Long(cm)
54-3003	3
54-3005	5
54-3008	8
54-3010	10
54-3012	12
54-3015	15
54-3020	20
54-3030	30

Galvanized nipple - 3/4"
(M-M)

CODE	Long(cm)
54-3103	3
54-3105	5
54-3108	8
54-3110	10
54-3112	12
54-3115	15
54-3120	20
54-3130	30

Galvanized nipp
(M-M)

CODE	Long(
54-3203	3
54-3205	5
54-3208	8
54-3210	10
54-3212	12
54-3215	15
54-3220	20
54-3230	30

Apendix (9)

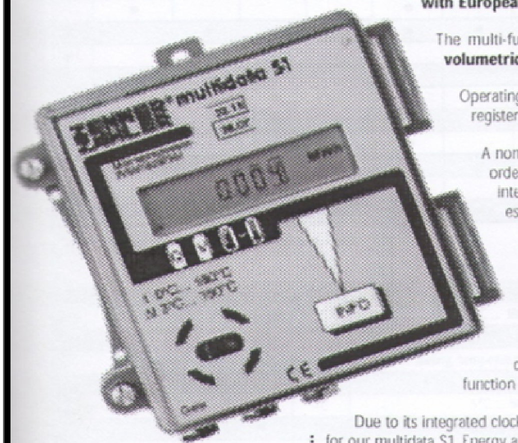
Multidata S1 Catalgue

Heat computer

multidata S1

Zenner Zähler is once again at the forefront of technology with the development of the **multidata S1 heat computer**. Employing the latest generation microprocessors and innovative measuring techniques has resulted in a system with accuracy, measurement stability and functionality unprecedented in the history of heat computer development. Volumetric measuring units for heat meters with both reed pulser outputs or high-frequency electronic outputs can be used together with either Pt-500 or Pt-100 temperature sensors.

As one of the first heat computers, multidata S1 has already been given **approval in compliance with European Standard EN 1434** (22.55/98.02).



The multi-functional multidata S1 can of course work together **with all sizes of volumetric measuring units**.

Operating failures and faults are detected automatically and can be shown on the register with the date it occurred, its duration and the type of fault.

A non-volatile memory **backs up** all determinative data **at regular intervals** in order to ensure that it cannot be lost. In addition, all devices have an optical interface for **on-site data acquisition** along with programming of the most essential parameters.

Apart from the volumetric measuring unit, with all standard devices it is possible to connect two additional pulse output meters, e.g. a cold and hot water meter, whose consumption both appears on the register and can also be determined via the remote read-out systems.

The additional connections however have a multiple function, i.e. they can be programmed not only as inputs but also as outputs, so that they function as remote meter outputs for energy and volume, for instance.

Due to its integrated clock with calendar, **specified reading date (S.R.D.) data** is also no problem for our multidata S1. Energy and volume along with the volumes of the additional meters are written into the memory on a date specified by the user, year after year, and can be read or transferred remotely via the S.R.D. menu.

In order to remove the requirement to take readings on a specific date, we have integrated a previous-month memory in standard models. Consumption is stored on the first of each month. In this way, **up to 21 previous-month values** can be called up on the register with the accompanying data.

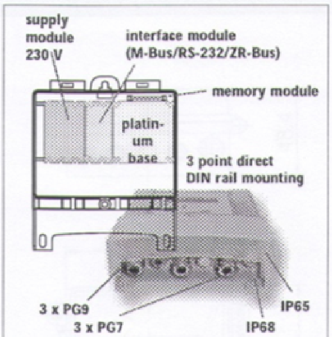
A detailed performance specification is available on request in English (order no.: 98W 003).

multidata N1

user friendly

adaptable

easy mounting



The net version for industrial use:

The specially developed industrial version of the multidata N1, an innovative module design offering a wide range of possibilities, e.g. **230 V mains supply** and connection to **practically all bus systems**. **6 connectors** in both PG9 and PG7 sizes are available. A **versatile range of possibilities** includes easy fitting into control panels and DIN rail mounting.

Moreover, the multidata N1 has adopted the modern technology and the technical database from its successful predecessor.

For more information, please turn to the special "multidata N1" prospectus.

CE

Approvals

22.15 / 96.07

22.55 / 98.02

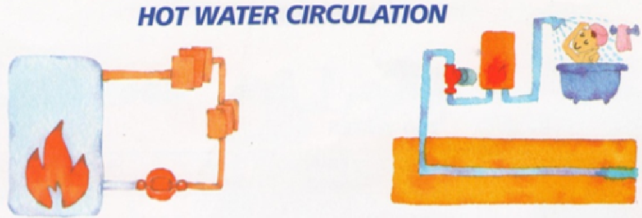
along with approvals outside the EU

Appendix (10)

Circulating Pump Used in Geothermal heat pump

LG WATER PUMPS

HOT WATER CIRCULATION



USE

Most suitable for hot water circulation and heating system for houses, schools, hospitals and factories and apartment complexes.

FEATURES

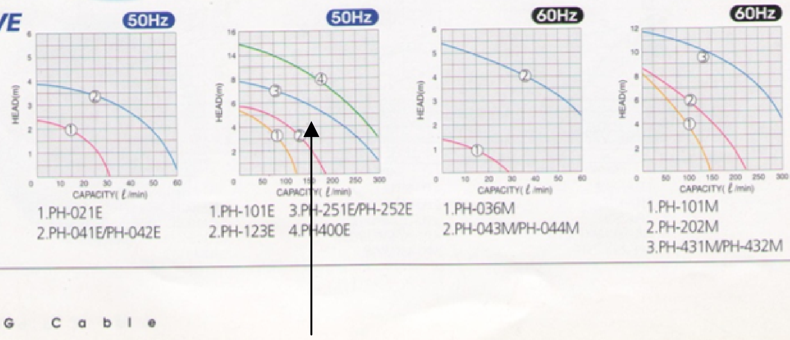
- In-line type.
- Motor built with thermal protector for safety.
- No leakage of water with a specialized design.
- Suitable to handle hot water not exceeding 80℃.

Model	Power source	Input (W(HP))	Total Head(m) (shut-off)	Q max. (ℓ/min)	Flange (mm("))
PH-021E	1 220V 50Hz	50(0.06)	2	32	25(1)
PH-041E		90(0.12)	3.5	60	
PH-042E					32(1-1/4)
PH-036M	1ø 220V 60Hz	30(0.03)	1	25	25(1)
PH-043M		95(0.12)	4.5	60	25(1)
PH-044M					32(1-1/4)

Model	Power source	Input (W(HP))	Total Head(m) (shut-off)	Q max. (ℓ/min)	Flange (mm("))
PH-101E	1ø 220V 50Hz	200(0.26)	4.5	120	40(1-1/2)
PH-123E		265(0.35)	5	180	50(2)
PH-251E		520(0.69)	7.5	320	65(2-1/2)
PH-252E					80(3)
PH-400E		800(1.06)	15.5	320	80(3)
PH-101M	1ø 220V 60Hz	240(0.32)	7	125	40(1-1/2)
PH-202M		390(0.52)		215	50(2)
PH-431M		620(0.82)	11	340	65(2-1/2)
PH-432M					80(3)

Model	Power source	Input (W(HP))	Total Head(m) (shut-off)	Q max. (ℓ/min)	Flange (mm("))
PIN-4001E	3ø 220V 50Hz	500(0.70)	8.5	270	40(1-1/2)
PIN-5002E		760(1.00)		440	50(2)
PIN-6502E		1300(1.80)	9	790	65(2-1/2)
PIN-4001	3ø 220V 60Hz	850(1.10)	12	330	40(1-1/2)
PIN-5002		1300(1.73)		530	50(2)
PIN-6503		2200(3.00)	13	960	65(2-1/2)

CURVE



1.PH-021E
2.PH-041E/PH-042E

1.PH-101E 3.PH-251E/PH-252E
2.PH-123E 4.PH400E

1.PH-036M
2.PH-043M/PH-044M

1.PH-101M
2.PH-202M
3.PH-431M/PH-432M

Appendix (11)

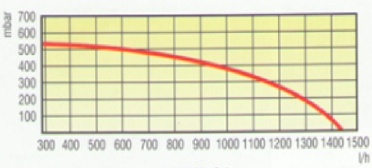
LPG Boiler Data Sheet

Sheet

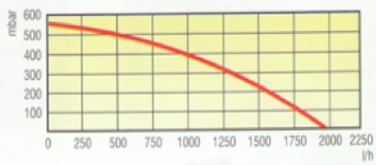
Technical data

ALMA			24 MB W TOP	28 MB W TOP	24 MBS W TOP	28 MBS W TOP	32 MBS W TOP
Output	min.	kW	10,43	12,2	10,5	12,16	14
	max.	kW	23,4	27,24	23,92	27,8	31,9
	min.	kcal/h	8.970	10.492	9.030	10.458	12.040
	max.	kcal/h	20.124	23.426	20.571	23.908	27.434
Input	max.	kW	26	30,2	26	30,45	34,5
	max.	kcal/h	22.360	25.972	22.360	26.187	29.670
Efficiency at 100%		%	90	90,2	92	91,2	92,5
Energy efficiency rating (EEC 92/42)			★★	★★	★★	★★	★★
Efficiency at 30% flow		%	86,8	86,9	88,7	88,9	88,9
Shell loss		%	2,6	2,5	0,85	1,6	0,85
Sealed combustion chamber			-	-	•	•	•
Ignition			Electronic	Electronic	Electronic	Electronic	Electronic
Heating circuit pressure	max.	bar	3	3	3	3	3
Heating circuit expansion tank		l	8	8	8	8	8
Heating temp. adjustment range		°C	35/80	35/80	35/80	35/80	35/80
Methane gas pressure (G20)		mbar	20	20	20	20	20
Liquid gas pressure (G30/G31)	mbar	29/37	29/37	29/37	29/37	29/37	
Hot water adjustment range		°C	35/60	35/60	35/60	35/60	35/60
Hot water supply ΔT 30°C	max.	11,2	13	11,4	13,3	15,2	
Peak flow in first 10 minutes		l	157	172	157	172	192
Water-heater capacity		l	50	50	50	50	50
Hot water circuit pressure	max.	bar	8	8	8	8	8
Hot water circuit expansion tank		l	2	2	2	2	2
Heating delivery		Ø	3/4"	3/4"	3/4"	3/4"	3/4"
Heating return		Ø	3/4"	3/4"	3/4"	3/4"	3/4"
Cold water inlet		Ø	1/2"	1/2"	1/2"	1/2"	1/2"
Hot water outlet		Ø	1/2"	1/2"	1/2"	1/2"	1/2"
Gas connector		Ø	3/4"	3/4"	3/4"	3/4"	3/4"
Total absorbed electrical power	W	120	123	150	153	160	
Power supply		V/Hz	230/50	230/50	230/50	230/50	230/50
Weight		kg	70	70	75	75	76
Packaging		mm.	640x980x480	640x980x480	640x980x480	640x980x480	640x980x480
Type of gas			Methane/LPG	Methane/LPG	Methane/LPG	Methane/LPG	Methane/LPG
Protection rating			IP X4D	IP X4D	IP X4D	IP X4D	IP X4D
LPG version also available			•	•	•	•	•

Circulator characteristics



ALMA 24



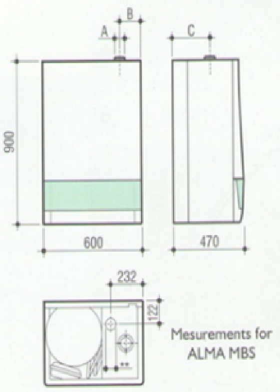
ALMA 28 - ALMA 32

Dimensions mm.

ALMA	A	B	C
24 MB W Top	132,5	173	222
24 MBS W Top	*	132	222
28 MB W Top	152,5	173	222
28 MBS W Top	*	132	222
32 MBS W Top	*	132	222

* Flue connector: concentric or double outlet

** Air intake Ø 80



Appendix (12)

Diesel Boiler Data Sheet

Technical data

EXA boilers

EXA		20	27	32	40	50	60	70	80
Output	kW	20,9	30,6	34,9	46,5	58,1	69,8	81,4	93,3
	kcal/h	17.974	26.316	30.014	39.990	49.966	60.028	70.004	80.238
Input	kW	23,25	34	38,6	51,4	64,1	77,2	89,7	103,2
	kcal/h	19.995	29.240	33.196	44.204	55. 126	66.392	77.142	88.752
Efficiency at 100%	%	90	90	90,4	90,4	90,6	90,4	90,7	90,4
Efficiency at 30%	%	92	92	92,08	92,14	92,23	92,17	92,25	92,2
Loss on the casing	%	1,25	1,16	1,12	0,9	0,75	0,72	0,69	0,54
Heating circuit pressure	max	bar	4	4	4	4	4	4	4 4
Heating temperature adjustment	°C	0/80	0/80	0/80	0/80	0/80	0/80	0/80	0/80
Water content	l	11	14	14	17	20	23	26	29
ΔP water circuit (ΔT 10°C)	mbar	1	1,8	2,4	4,2	7,2	11	15	20
ΔP fumes circuit	mbar	0,12	0,1	0,12	0,13	0,15	0,17	0,18	0,2
Elements	n°	2	3	3	4	5	6	7	8
Heating supply (a1)	Ø	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"
Heating return (a2)	Ø	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"	1 1/2"
Boiler drain (a3)	Ø	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Mains supply	V/Hz	230/50	230/50	230/50	230/50	230/50	230/50	230/50	230/50
Weight	kg	80	105	105	130	155	180	205	230
Packaging	mm.	570x530x1020	570x530x1020	570x530x1020	570x730x1020	570x730x1020	570x940x1020	570x940x1020	570x1040x1020

EXA boiler with PAC S heater

EXA		20		27		32		40	
PAC S heater		80	120	80	120	80	120	80	120
Peak delivery over first 10 minutes	l.	135	210	140	215	150	220	155	230
Continuous supply (ΔT 30°C)	l/h	665	655	816	900	816	1000	816	1000
Reset time (ΔT 30°C)	min.	7	8,5	6,5	8	6	7,5	6	7,5

- Coil inlet temperature 85°C; coil outlet temperature 70°C; hot water inlet temperature Te 10°C; hot water outlet temperature Tu 40°C; storage temperature 60°C.
- Peak delivery: this is the delivery that the heater is able to provide over the first 10 minutes of output, until a minimum water outflow temperature of 25°C is reached.
- Reset: this is the time necessary to raise the temperature of the water in the heater from 10°C to 40°C (ΔT=30°C).

Lamborghini
CALORECLIMA

Lamborghini Calor s.p.a.
Via Statale 342 - 44040 Dosso (Ferrara) - Italia
Tel. Italia 0532 / 359811 - Tel. Export 0532 / 359913
Fax Italia 0532 / 359952 - Fax Export 0532 / 359947
Internet: http://www.lamborghinicalor.it
E-mail: info@lamborghinicalor.it

The illustrations and details reported are indicative only. Lamborghini Calor reserves the right to introduce alterations and/or amendments as it deems fit and proper for the development of the product without the obligation of providing prior notice. 12/02 cod C114/UK Mc Parker - Pn

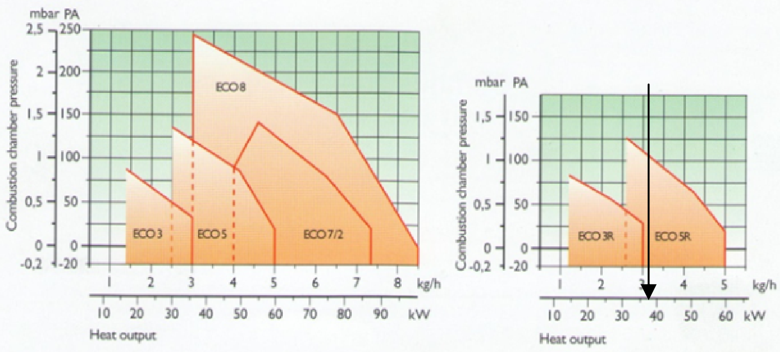
Appendix (13)

Burner Data Sheet For Diesel Boiler

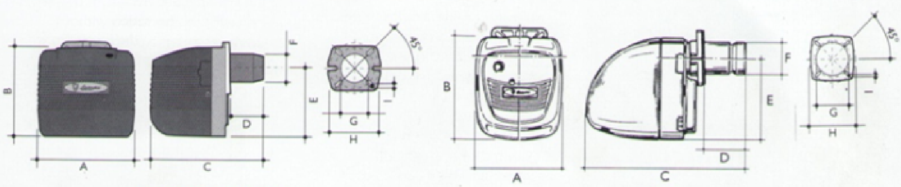
Technical data

ECO		3	3R	5	5R	8	7/2
Heat input	kg/h	1,4	1,2	2,5	2,6	3	4
	kg/h	3	3	5	5	8,5	7,3
Heat output	kW	16,6	14,2	29,6	30,8	35,6	47,4
	kW	35,6	35,6	59,3	59,3	100,8	86,6
	kcal/h	14.300	12.200	25.500	26.500	30.600	40.800
	kcal/h	30.600	30.600	51.000	51.000	86.700	74.500
Total absorbed power	W	280	380	300	400	300	300
Motor 2800 rpm	W	100	100	100	100	90	100
Preheater	W	-	110	-	110	-	-
Weight	kg	10,5	10,7	11,3	11,5	13	12,5
Packaging	mm.	450x340x310				550x280x370	450x340x310
Power supply		230V - 50 Hz					
Fuel		Light oil - Max. viscosity at 20°C: 1.5°E = 6cSt = 41 sec. R1					

Pressure curves



Dimensions



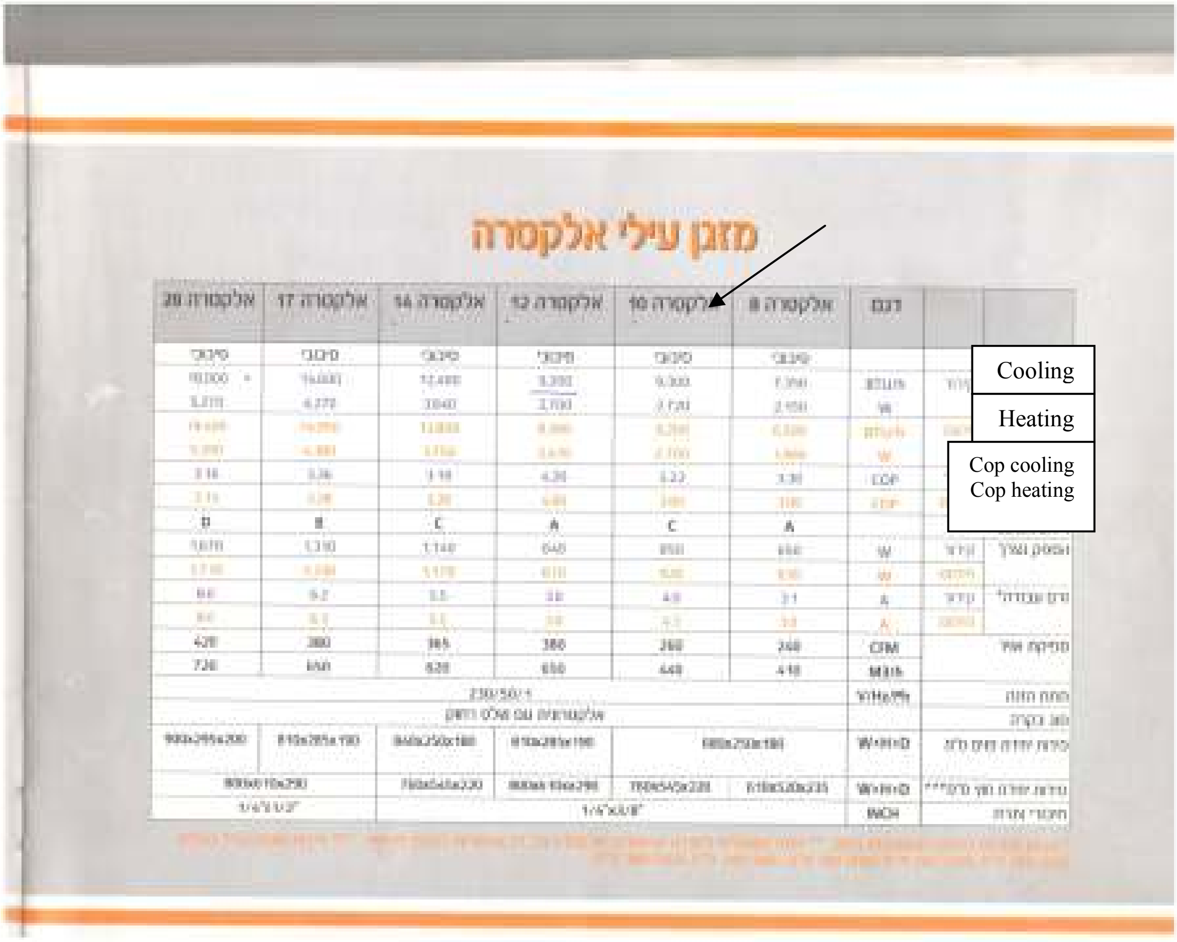
ECO 3 - 3R - 5 - 5R - 7/2

ECO 8

	A	B	C	D min.	D max	E	ØF	ØG	ØH min.	ØH max	I
ECO 3 - 3R	250	215	320	-	90	160	80	85	135	160	M 8
ECO 5 - 5R	280	247	342	-	90	195	80	85	135	160	M 8
ECO 8	230	285	465	60	120	232	89	95	90	140	M 8
ECO 7/2	280	247	410	40	140	195	90	95	135	160	M 8

Appendix (14)

Air Conditioner Data



Appendix (15)

Data taken during tests

Testing mood

Date: 12/06/2011 Location : welding Lab

T room= 26

Water (70 cmx50cmx30cm)

Cooling								
Time	P ev. In(ps	Pev out(Psi)	Ti ev C	To ev C	Tw C	I(A)	V(V)	P(kw)
10:01	550	550	-5.9	20.2	26	1.63	220	0.2869
10:03	350	350	-3.4	22.9	26	1.67	220	0.2939
10:05	400	380	-4.2	22.3	26	1.75	220	0.308
10:07	400	380	-2.4	21.3	26	1.77	220	0.3115
10:08	400	380	-1	20.8	27	1.82	220	0.3203
10:10	400	380	-0.7	20.4	30	1.84	220	0.3238
10:11	400	390	-1.2	19.1	27	1.87	220	0.3291
10:12	400	390	-0.5	17.8	30	1.9	220	0.3344
10:15	400	390	-0.7	16.9	29	1.89	220	0.3326
10:20	400	390	-0.9	15.8	28	1.92	220	0.3379
10:25	400	390	-1	15.5	29	1.94	220	0.3414
10:30	400	390	-2	15.3	29	1.9	220	0.3344
10:35	400	390	-2	15.1	29	1.91	220	0.3362
10:40	400	390	-2	14.9	29	1.93	220	0.3397
10:45	400	390	-1.05	14.7	29	1.95	220	0.3432
10:50	400	390	-1.08	14.5	29	1.98	220	0.3485
10:55	400	390	-1	14.3	29	1.98	220	0.3485
11:00	400	390	-1	14.1	29	1.98	220	0.3485
11:05	400	390	-1	13.9	29	2.01	220	0.3538
11:10	400	390	-1	13.7	29	2.01	220	0.3538
11:15	400	390	-1	13.5	29	2.03	220	0.3573
11:20	400	390	-1	13.3	29	2.03	220	0.3573
11:25	400	390	-1.05	13.1	29	2.05	220	0.3608
11:30	400	390	-1.08	12.9	29	2.11	220	0.3714
11:35	400	390	-1	12.7	30.05	2.11	220	0.3714
11:40	400	390	-1	12.5	30	2.11	220	0.3714
11:45	400	390	-1	12.5	30	2.11	220	0.3714
11:50	400	390	-1	12.5	30.08	2.11	220	0.4642
11:55	400	390	-1	12.5	30	2.11	220	0.4642
12:00	400	390	-1	12.5	30	2.11	220	0.4642
12:05	400	390	-1	12.5	30	2.11	220	0.4642
12:10	400	390	-1	12.3	30	2.11	220	0.4642
12:15	400	390	-1	12.2	30.08	2.11	220	0.4642
12:20	400	390	-1	12.3	30.08	2.11	220	0.4642
12:25	400	390	-1	12.3	30	2.11	220	0.4642
12:30	400	390	-1.05	12.3	30	2.11	220	0.4642
12:35	400	390	-1.08	12.3	29	2.11	220	0.4642
12:40	400	390	-1	12.3	29.5	2.11	220	0.4642
12:45	400	390	-1	12.3	30	2.11	220	0.4642
12:50	400	390	-1	12.3	30	2.11	220	0.4642
12:55	400	390	-1	12.3	30	2.11	220	0.4642
13:00	400	390	-1	12.3	30	2.11	220	0.4642
13:05	400	390	-1	12.3	30.08	2.11	220	0.4642
13:10	400	390	-1.05	12.3	30	2.11	220	0.4642
13:15	400	390	-1.08	12.3	29	2.11	220	0.4642
13:20	400	390	-1	12.3	30	2.11	220	0.4642

Date: 13/06/2011		Table ( )		Location : welding Lab				
T room= 26								
Water (70 cmx50cmx30cm)								
Cooling								
Time	P ev. In(ps	Pev out(Psi)	Ti ev C	To ev C	Tw C	I(A)	V(V)	P(kw)
9:05	550	550	-2.5	18.5	24.4	1.63	220	0.2869
9:10	350	350	-2.5	23.9	24.4	1.67	220	0.2939
9:15	400	380	-4.3	23	25.4	1.75	220	0.308
9:20	400	380	-9	22.7	25	1.77	220	0.3115
9:25	400	380	-10.3	22.6	25.2	1.82	220	0.3203
9:30	400	380	-7	22.1	26.5	1.84	220	0.3238
9:35	400	390	-7.2	22.2	26.6	1.87	220	0.3291
9:40	400	390	-6.5	21.9	27	1.9	220	0.3344
9:45	400	390	-6.3	21.7	27.8	1.89	220	0.3326
9:50	400	390	-5.9	21.2	27.9	1.92	220	0.3379
9:55	400	390	-5.9	21	28.2	1.94	220	0.3414
10:00	400	390	-5.3	20.1	28.8	1.9	220	0.3344
10:05	400	390	-5.2	19.6	29.1	1.91	220	0.3362
10:10	400	390	-5.1	18.4	28.9	1.93	220	0.3397
10:15	400	390	-5.2	18.5	28.7	1.95	220	0.3432
10:20	400	390	-5.2	19	28.5	1.98	220	0.3485
10:25	400	390	-5.2	19.2	28.3	1.98	220	0.3485
10:30	400	390	-5.2	18.8	28.1	1.98	220	0.3485
10:35	400	390	-5.2	18.6	27.9	2.01	220	0.3538
10:40	400	390	-5.1	18.6	27.7	2.01	220	0.3538
10:45	400	390	-5	18.7	27.5	2.03	220	0.3573
10:50	400	390	-5.2	18.4	27.3	2.03	220	0.3573
10:55	400	390	-5.1	18.3	27.1	2.05	220	0.3608
11:00	400	390	-5	18.3	26.9	2.11	220	0.3714
11:05	400	390	-5.3	18.4	26.7	2.11	220	0.3714
11:10	400	390	-5.3	18.4	26.5	2.11	220	0.3714
11:15	400	390	-5.2	18.4	26.5	2.11	220	0.3714
11:20	400	390	-5.1	18.4	26.5	2.11	220	0.4642

Date: 14/06/2011		Table ( )		Location : welding Lab				
T room= 25								
Water (70 cmx50cmx30cm)								
Cooling								
Time	P ev. In(ps	Pev out(Psi)	Ti ev C	To ev C	Tw C	I(A)	V(V)	P(kw)
8:00	550	550	-2.5	18.5	24.4	1.63	220	0.2869
8:15	350	350	-2.5	23.9	24.4	1.67	220	0.2939
8:30	400	380	-4.3	23	25.4	1.75	220	0.308
8:45	400	380	-9	22.7	25	1.77	220	0.3115
9:00	400	380	-10.3	22.6	25.2	1.82	220	0.3203
9:15	400	380	-7	22.1	26.5	1.84	220	0.3238
9:30	400	390	-7.2	22.2	26.6	1.87	220	0.3291
9:45	400	390	-6.5	21.9	27	1.9	220	0.3344
10:00	400	390	-6.3	21.7	27.8	1.89	220	0.3326
10:15	400	390	-5.9	21.2	27.9	1.92	220	0.3379
10:30	400	390	-5.9	21	28.2	1.94	220	0.3414
10:45	400	390	-5.3	20.1	28.8	1.9	220	0.3344
11:00	400	390	-5.2	19.6	29.1	1.91	220	0.3362
11:15	400	390	-5.1	18.4	28.9	1.93	220	0.3397
11:30	400	390	-5.2	18.5	28.7	1.95	220	0.3432
11:45	400	390	-5.2	19	28.5	1.98	220	0.3485
12:00	400	390	-5.2	19.2	28.3	1.98	220	0.3485
12:15	400	390	-5.2	18.8	28.1	1.98	220	0.3485
12:30	400	390	-5.2	18.6	27.9	2.01	220	0.3538
12:45	400	390	-5.1	18.6	27.7	2.01	220	0.3538
13:00	400	390	-5	18.7	27.5	2.03	220	0.3573
13:15	400	390	-5.2	18.4	27.3	2.03	220	0.3573
13:30	400	390	-5.1	18.3	27.1	2.05	220	0.3608
13:45	400	390	-5	18.3	26.9	2.11	220	0.3714
14:00	400	390	-5.3	18.4	26.7	2.11	220	0.3714
14:15	400	390	-5.3	18.4	26.5	2.11	220	0.3714
14:30	400	390	-5.2	18.4	26.5	2.11	220	0.3714
14:45	400	390	-5.1	18.4	26.5	2.11	220	0.4642

Date: 15/06/2011		Table ( )	Location : welding Lab					
T room= 27								
Water (70 cmx50cmx30cm)								
Cooling								
Time	P ev. In(ps	Pev out(Psi)	Ti ev C	To ev C	Tw C	I(A)	V(V)	P(kw)
8:30	550	550	-2.5	18.5	24.4	1.63	220	0.2869
8:45	350	350	-2.5	23.9	24.4	1.67	220	0.2939
9:00	400	380	-4.3	23	25.4	1.75	220	0.308
9:15	400	380	-9	22.7	25	1.77	220	0.3115
9:30	400	380	-10.3	22.6	25.2	1.82	220	0.3203
9:45	400	380	-7	22.1	26.5	1.84	220	0.3238
10:00	400	390	-7.2	22.2	26.6	1.87	220	0.3291
10:15	400	390	-6.5	21.9	27	1.9	220	0.3344
10:30	400	390	-6.3	21.7	27.8	1.89	220	0.3326
10:45	400	390	-5.9	21.2	27.9	1.92	220	0.3379
11:00	400	390	-5.9	21	28.2	1.94	220	0.3414
11:15	400	390	-5.3	20.1	28.8	1.9	220	0.3344
11:30	400	390	-5.2	19.6	29.1	1.91	220	0.3362
11:45	400	390	-5.1	18.4	28.9	1.93	220	0.3397
12:00	400	390	-5.2	18.5	28.7	1.95	220	0.3432
12:15	400	390	-5.2	19	28.5	1.98	220	0.3485
12:30	400	390	-5.2	19.2	28.3	1.98	220	0.3485
12:45	400	390	-5.2	18.8	28.1	1.98	220	0.3485
13:00	400	390	-5.2	18.6	27.9	2.01	220	0.3538
13:15	400	390	-5.1	18.6	27.7	2.01	220	0.3538
13:30	400	390	-5	18.7	27.5	2.03	220	0.3573
13:45	400	390	-5.2	18.4	27.3	2.03	220	0.3573
14:00	400	390	-5.1	18.3	27.1	2.05	220	0.3608
14:15	400	390	-5	18.3	26.9	2.11	220	0.3714
14:30	400	390	-5.3	18.4	26.7	2.11	220	0.3714
14:45	400	390	-5.3	18.4	26.5	2.11	220	0.3714
15:00	400	390	-5.2	18.4	26.5	2.11	220	0.3714
15:15	400	390	-5.1	18.4	26.5	2.11	220	0.4642

Date: 16/06/2011		Table ( )	Location : welding Lab					
T room= 27								
Water (70 cmx50cmx30cm)								
Cooling								
Time	P ev. In(ps	Pev out(Psi)	Ti ev C	To ev C	Tw C	I(A)	V(V)	P(kw)
8:30	550	550	-2.5	18.5	24.4	1.56	222	0.2771
8:45	350	350	-2.5	23.9	24.4	1.67	220	0.2939
9:00	400	380	-4.3	23	25.4	1.75	220	0.308
9:15	400	380	-5.9	21	28.2	1.94	220	0.3414
9:30	400	380	-5.3	20.1	28.8	1.9	220	0.3344
9:45	400	380	-5.2	19.6	29.1	1.91	220	0.3362
10:00	400	380	-5.1	18.4	28.9	1.93	220	0.3397
10:15	400	380	-5.2	18.5	28.7	1.95	220	0.3432
10:30	400	380	-5.2	19	28.5	1.98	220	0.3485
10:45	400	380	-5.2	19.2	28.3	1.98	220	0.3485
11:00	400	380	-5.2	18.8	28.1	1.98	220	0.3485
11:15	400	380	-5.2	18.6	27.9	2.01	220	0.3538
11:30	400	380	-5.1	18.6	27.7	2.01	220	0.3538
11:45	400	380	-5	18.7	27.5	2.03	220	0.3573
12:00	400	380	-5.2	18.4	27.3	2.03	220	0.3573
12:15	400	380	-5.1	18.3	27.1	2.05	220	0.3608
12:30	400	380	-5	18.3	26.9	2.11	220	0.3714
12:45	400	380	-5.3	18.4	26.7	2.11	220	0.3714
13:00	400	380	-5.3	18.4	26.5	2.11	220	0.3714
13:15	400	380	-5.2	18.4	26.5	2.11	220	0.3714

04/07/2011	H water 28 cm							
Time	Pin ev	Pout ev	Tin ev	Toev	T w	T4 comp	I	v
9:00	18	18	20.4	18.5	24.4	13	0	220
9:05	21	22	-2.5	23.9	24.4	20.7	1.63	220
9:10	25	25	-4.3	23	25	35.1	1.67	220
9:15	30	30	-9	22.7	25.2	59.5	1.75	220
9:20	33	33	-10.3	22.6	25.5	64.2	1.77	220
9:25	35	35	-7	22.1	26.5	74.8	1.82	220
9:30	39	39	-7.2	22.2	26.6	77.1	1.84	220
9:35	40	40	-6.3	21.9	27	84.5	1.9	220
9:40	40	40	-6.3	21.7	27.8	88.3	1.89	220
9:45	40	40	-5.9	20.1	28.2	93.8	1.94	220
9:50	40	40	-5.3	19.6	28.8	95.7	1.9	220
9:55	40	40	-5.2	18.4	29.1	97.2	1.91	220
10:00	40	40	-5.2	17.9	29.2	97.9	1.93	220

05/07/2011

Time	Tin ev	Toev	T3 w	T4 comp	Pin ev	Pout ev			
10:25	-2.1	19.3	26	36.5	7	7	2.9	220	0.8
10:35	3.1	18	28.3	49.8	7	7	2.9	220	0.8
10:40	5.3	14.9	30.3	58.3	7.1	7	2.9	220	0.8
10:45	8.6	11.1	32.6	61.9	7.1	7.1	2.9	216	0.8
10:50	11.2	11.3	33.7	62.5	7.1	7	2.9	216	0.8
10:55	11.1	11.1	35.1	64.2	7.1	7.1	2.91	216	0.8
11:00	9.7	11.5	38	66.2	7.1	7	2.92	216	0.8
11:10	10.6	11.3	41	66.5	7.1	7	2.97	216	0.8
11:15	10.3	11.3	42.1	66.3	7.1	7	3.07	216	0.8
11:20	10.3	11.7	44.3	65.9	7.1	7.1	3.15	216	0.8
11:25	11.3	12.3	45.7	66.6	7.1	7	3.22	216	0.8
11:30	11.5	11.5	46.9	67.3	7.1	7.05	3.23	216	0.8
11:32	11.7	12.5	47.2	67.3	7.1	7	3.23	216	0.8
11:35	11.8	12.5	48.6	67.8	7.1	7	3.33	216	0.8
11:37	11.6	13.3	50.1	68.1	7.1	7	3.38	216	0.8
11:45	12.5	12.5	52.5	68.3	7.1	7	3.48	216	0.8
12:13	11.1	14.8	61.8	74.8	7.1	7	4	216	0.8
12:16	10	15	63.2	75.1	7.1	7	4.11	216	0.8
						15238.61			

07/07/2011	Tin ev	Toev	T3 w	T4 comp	Pin ev	Pout ev			
0:00	26.2	27.1	27.2	27.3	14	14	3	214	0.8
1:05	37.5	50	27.2	26.6	14	14	4.58	214	0.8
1:10	45.5	54.6	27.3	26.4	14	14	4.6	214	0.8
1:15	52	58	27.3	24.5	14	14	4.89	214	0.8
									0.8
1:18	3.6	18.7	27.2	54	7	7	2.12	214	0.8
1:20	7.5	19.5	28.1	57	7.1	7	2.25	214	0.8
1:25	7.8	16.3	30.5	59.9	7.1	7.1	2.37	214	0.8
1:30	9.1	13.8	32.5	62.3	7.1	7	2.45	214	0.8
1:33	8.8	14	34.4	63.4	7.1	7	2.54	214	0.8
1:43	9.6	14.2	37.6	64.6	7.1	7	2.66	214	0.8
1:46	10.1	14.6	38.6	65.3	7.1	7.1	2.72	214	0.8
1:50	10	14.5	39.5	65.7	7.1	7	2.77	214	0.8

Cooling mood

Date:	24/08/2011			Location :	Phe playground												
T a= 26																	
Water connected				TG = 17											W=QH-QC		
Time	T ev	To ev	Tw i	Tw o	To comp	V	I	flow	Q(l/s)	DT	W(watt)	W pump	W total	QH(watt)	QC	Cop r	Cop r geothermal
11:05	26.1	27	25	25.89	27.2	229	0	0	0.067	0.89	0	125	125	249.25	249.25		
11:10	-5	21	25	26.02	29.9	230	1.5	21.6	0.067	1.02	276	125	401	285.66	9.66	0.04	0.02
11:22	-4.5	23	24	26.6	53.3	230	2	27.5	0.067	2.6	368	125	493	728.16	360.16	0.98	0.73
11:30	-4	21	26	27.43	62.2	229	2	33.4	0.067	1.43	366.4	125	491.4	400.49	34.09	0.09	0.07
11:48	-3.9	28	26	28.5	67.7	230	2.34	52.9	0.067	2.5	430.56	125	555.56	700.15	269.59	0.63	0.49
12:05	-4	29	26	29.46	69.1	230	2.37	73.4	0.067	3.46	436.08	125	561.08	969.01	532.93	1.22	0.95
12:15	-4.1	29	27	29.74	69.1	230	2.38	76.4	0.067	2.74	437.92	125	562.92	767.36	329.44	0.75	0.59
12:25	-4.2	28.5	26	30	70	230	2.4	79.4	0.067	4	441.6	125	566.6	1120.24	678.64	1.54	1.20
12:35	-4.2	29	27	30.07	72	229	2.5	82.4	0.067	3.07	458	125	583	859.78	401.78	0.88	0.69
12:45	-4.1	28.8	27	30.15	72	228	2.5	85.4	0.067	3.15	456	125	581	882.19	426.19	0.93	0.73
12:55	-4	28.8	26	30.2	73	228	2.55	88.4	0.067	4.2	465.12	125	590.12	1176.25	711.13	1.53	1.21
13:05	-4.2	28.7	26	30.5	74	229	2.5	91.4	0.067	4.5	458	125	583	1260.27	802.27	1.75	1.38
13:15	-4.4	29	26	31	75	228	2.55	94.4	0.067	5	465.12	125	590.12	1400.30	935.18	2.01	1.58
13:25	-4.6	29	26	32	76	228	2.58	97.4	0.067	6	470.592	125	595.592	1680.36	1209.77	2.57	2.03
13:35	-4.5	29	26.35	33.5	77	228	2.58	100.4	0.067	7.15	470.592	125	595.592	2002.43	1531.84	3.26	2.57
13:45	-5	28.8	26.45	33.5	77.5	228	2.58	103.4	0.067	7.05	470.592	125	595.592	1974.42	1503.83	3.20	2.52
13:55	-4.5	28.9	26.46	33.4	78	228	2.58	106.4	0.067	6.94	470.592	125	595.592	1943.62	1473.02	3.13	2.47
14:05	-4.3	28.8	26.46	33.5	80	228	2.56	109.4	0.067	7.04	466.944	125	591.944	1971.62	1504.68	3.22	2.54

Date:	25/08/2011			Location :	Phe playground												
T a= 26																	
Water connected				TG = 17											W=QH-QC		
Time	T ev	To ev	Tw i	Tw o	To comp	V	I	flow	Q(l/s)	DT	W(watt)	W pump	W total	QH(watt)	QC	Cop r	Cop r geothermal
11:05	26.1	27.1	25	25.89	27.2	229	0	0	0.067	0.89	0	125	125	249.25	249.25		
11:10	-5	20.6	24.5	26.02	29.9	229	1.5	21.6	0.067	1.52	274.8	125	399.8	425.69	150.89	0.55	0.38
11:22	-4.5	22.5	24	26.6	53.3	229	2	27.5	0.067	2.6	366.4	125	491.4	728.16	361.76	0.99	0.74
11:30	-4	21	25.84	27.43	62.2	229	2	33.4	0.067	1.59	366.4	125	491.4	445.30	78.90	0.22	0.16
11:48	-3.9	28	26.03	28.5	67.7	229	2.34	52.9	0.067	2.47	428.688	125	553.688	691.75	263.06	0.61	0.48
12:05	-4	28.5	26.33	29.46	69.1	229	2.37	73.4	0.067	3.13	434.184	125	559.184	876.59	442.40	1.02	0.79
12:15	-4.1	28.3	26.45	29.74	69.1	229	2.38	76.4	0.067	3.29	436.016	125	561.016	921.40	485.38	1.11	0.87
12:25	-4.2	28.5	26.5	30	70	229	2.4	79.4	0.067	3.5	439.68	125	564.68	980.21	540.53	1.23	0.96
12:35	-4.2	28.6	26.6	30.07	72	228	2.5	82.4	0.067	3.47	456	125	581	971.81	515.81	1.13	0.89
12:45	-4.1	28.8	26.65	30.15	72	228	2.5	85.4	0.067	3.5	456	125	581	980.21	524.21	1.15	0.90
12:55	-4	28.8	26.1	30.2	73	225	2.55	88.4	0.067	4.1	459	125	584	1148.25	689.25	1.50	1.18
13:05	-4.2	28.7	26.15	30.5	74	229	2.5	91.4	0.067	4.35	458	125	583	1218.26	760.26	1.66	1.30
13:15	-4.4	28.9	26.2	31	75	228	2.55	94.4	0.067	4.8	465.12	125	590.12	1344.29	879.17	1.89	1.49
13:25	-4.6	28.9	26.25	32	76	228	2.58	97.4	0.067	5.75	470.592	125	595.592	1610.35	1139.75	2.42	1.91
13:35	-4.5	29	26.35	33.5	77	228	2.58	100.4	0.067	7.15	470.592	125	595.592	2002.43	1531.84	3.26	2.57

13:45	-5	28.8	26.45	33.5	77.5	228	2.58	103.4	0.067	7.05	470.592	125	595.592	1974.42	1503.83	3.20	2.52
13:55	-4.5	28.9	26.46	33.4	78	228	2.58	106.4	0.067	6.94	470.592	125	595.592	1943.62	1473.02	3.13	2.47
14:05	-4.3	28.8	26.46	33.5	80	228	2.56	109.4	0.067	7.04	466.944	125	591.944	1971.62	1504.68	3.22	2.54

Date:	14/09/2011			Location :	Phe playground												
T a= 25																	
Water connected				TG = 17													
time	Tev in	Tout ev	Tin tank	Tout Tank	V	I(A)	Q(l)		Q(l/s)	DT	W(watt)	W pump	W total	QH(watt)	QC	Cop r	Cop r geothermal
1:45	17	23.1	19.2	26.6	223	2.35	110		0.067	7.4	419	125	544.24	2072	1653	3.9	3.0
1:50	-4	23	16.7	25.5	223	2.1	112		0.067	8.8	375	125	499.64	2465	2090	5.6	4.2
1:55	-3	22.1	16	26	223	2.08	114		0.067	10	371	125	496.072	2801	2430	6.5	4.9
2:00	-1.5	21	15	26.1	223	2.28	115		0.067	11.1	407	125	531.752	3109	2702	6.6	5.1
2:05	-1.5	22	15	26.2	223	2.29	118		0.067	11.2	409	125	533.536	3137	2728	6.7	5.1
2:10	-1.5	21	16	26.3	223	2.3	121		0.067	10.3	410	125	535.32	2885	2474	6.0	4.6
2:15	-1	21	15.5	26.5	223	2.32	124		0.067	11	414	125	538.888	3081	2667	6.4	4.9
2:20	-1	20	16	28.3	223	2.32	127		0.067	12.3	414	125	538.888	3445	3031	7.3	5.6
2:25	-1	20	15.5	26.7	223	2.31	130		0.067	11.2	412	125	537.104	3137	2725	6.6	5.1
2:30	-1.5	20	15	27	223	2.32	133		0.067	12	414	125	538.888	3361	2947	7.1	5.5

	17/09/2011			Location :	Phe playground											
Date:																
T a= 25				TG = 17		I pump	1.93 A									
Water connected						ground	27.6 c									
Time	Tevp	Twin	Twout	V(volt)	I(A)	Q (l)	Q(m3/h)	Q(l/s)	DT	W(watt)	W pump	W total	QH(watt)	QC	Cop r	Cop r geothermal
9:20	26.1	27	26.5	233	0	136	0.575	0.15972	-0.5	0	125	125.0	-334	-334		-3
9:30	-5	26.5	27	233	1.9	138	0.575	0.15972	0.5	363	126	489.0	334	-29	0	0
9:40	-4.5	26.6	27.2	233	2.1	140	0.575	0.15972	0.6	401	127	528.2	401	-1	0	0
9:50	-4	25.5	27.4	233	2.07	142	0.575	0.15972	1.9	395	128	523.5	1269	873	2	2
10:00	-3.9	24	27.5	233	2.2	143	0.575	0.15972	3.5	420	129	549.3	2337	1916	5	3
10:10	-4	24.5	27.9	233	2.2	145	0.575	0.15972	3.4	420	130	550.3	2270	1850	4	3
10:20	-4.1	24.5	28.1	233	2.12	147	0.575	0.15972	3.6	405	131	536.0	2404	1998	5	4
10:30	-4.2	24.5	27.79	233	2.12	148	0.575	0.15972	3.29	405	132	537.0	2197	1791	4	3
10:35	-4.2	25	28.42	233	2.12	150	0.582	0.16167	3.42	405	133	538.0	2311	1906	5	4
10:45	-4.1	25	28.42	233	2.27	151	0.58	0.16111	3.42	434	134	567.7	2303	1869	4	3
10:50	-4	24.5	28.98	233	2.38	161	0.58	0.16111	4.48	455	135	589.7	3017	2562	6	4
10:55	-4.2	24.5	29.32	233	2.38	165	0.579	0.16083	4.82	455	136	590.7	3240	2786	6	5
11:00	-4.4	24	29.65	233	2.38	171	0.57	0.15833	5.65	455	137	591.7	3739	3285	7	6
11:05	-4.6	24	30	233	2.41	196	0.574	0.15944	6	460	138	598.5	3999	3538	8	6
11:20	-4.5	23.1	30.88	233	2.42	196.9	0.571	0.15861	7.78	462	139	601.4	5158	4696	10	8
11:31	-5	23	31.17	233	2.42	209	0.571	0.15861	8.17	462	140	602.4	5417	4954	11	8
11:45	-5	22.1	31.47	233	2.42	223	0.571	0.15861	9.37	462	141	603.4	6212	5750	12	10
12:00	-5	21	31.9	233	2.43	228	0.571	0.15861	10.9	464	142	606.3	7227	6762	15	11

12:05	-5	22	31.99	233	2.5	359	0.556	0.15444	9.99	478	143	620.7	6449	5972	13	10
2:25	-5	20.98	33.69	233	2.53	368	0.557	0.15472	12.71	483	144	627.4	8220	7737	16	12
3:35	-5	20.56	33.8	233	2.53	381	0.556	0.15444	13.24	483	145	628.4	8547	8064	17	13
3:50	-5	20.14	33.73	233	2.56	530	0.5569	0.15469	13.59	489	146	635.1	8788	8298	17	13
5:30	-5	19.72	34.94	233	2.56	533	0.5569	0.15469	15.22	489	147	636.1	9842	9352	19	15

	19/09/2011			Location :	Phe playground											
Date:																
T a= 26				TG = 17		I pump	1.93 A									
Water connected						ground	27.6 c									
Time	Tevp	Twin	Twout	V(volt)	I(A)	Q (l)	Q(m3/h)	Q(l/s)	DT	W(watt)	W pump	W total	QH(watt)	QC	Cop r	Cop r geothermal
5:45		25.19	25.89	227	2.05	536	0.549	0.1525	0.7	382	147	528.6	446	65	0	0
5:50		25.33	25.99	227	2.05	542	0.549	0.1525	0.66	382	148	529.6	421	39	0	0
5:55		25.91	26.6	227	2.11	547	0.547	0.15194	0.69	393	149	541.8	438	45	0	0
6:00		25.84	27.43	227	2.21	552	0.546	0.15167	1.59	411	150	561.4	1008	597	1	1
6:10		26.03	28.5	227	2.28	559	0.547	0.15194	2.47	424	151	575.4	1569	1144	3	2
6:20		26.33	29.46	227	2.33	563	0.548	0.15222	3.13	434	152	585.7	1992	1558	4	3
6:25		26.45	29.74	227	2.35	572	0.547	0.15194	3.29	437	153	590.4	2090	1652	4	3
6:30		26.64	30.09	227	2.35	579	0.547	0.15194	3.45	437	154	591.4	2191	1754	4	3

Winter mood

27/12/2011	Tout 18	T ground 14													
Time	T w in	Tw out	T c in	T c out	Q fm	low(m3/h	V(v)	I(A)	DT	Wcomp	QC	copr	QH	coph	cop geoh
9:25	20.5	21	23	23	5843	5.25	230	0	0.5	0	0.306		0.31		
9:30	18	19	58.8	40	5.21	5.21	223	1.9	1	0.34	0.606	1.79	0.95	2.79	2.04
9:35	16.8	17.3	58	45.2	5930	5.11	223	3	0.5	0.54	0.297	0.56	0.83	1.56	1.26
9:40	16.48	17.34	70.6	49.9	5970	5.03	223	3.12	0.86	0.56	0.503	0.90	1.06	1.90	1.56
9:45	15.9	17.3	74.7	54.2	6010	4.9	223	3.3	1.4	0.59	0.798	1.36	1.39	2.36	1.94
9:50	15.45	17.18	78.4	56.4	6050	4.92	223	3.23	1.73	0.58	0.991	1.72	1.57	2.72	2.23
9:55	15.11	17.13	81.6	54	6090	4.9	223	3.18	2.02	0.57	1.152	2.03	1.72	3.03	2.48
10:00	14.94	17	81.9	58	6110	4.86	220	3.23	2.06	0.57	1.165	2.05	1.73	3.05	2.50
10:05	14.7	17	82	56	6110	4.824	220	3.18	2.3	0.56	1.291	2.31	1.85	3.31	2.70
10:10	14.7	16.84	82	55	6210	4.81	220	3.11	2.14	0.55	1.198	2.19	1.75	3.19	2.60
10:15	14.7	16.84	82	55	6250	4.81	220	3.11	2.14	0.55	1.198	2.19	1.75	3.19	2.60
10:20	14.19	16.58	81.7	58	6280	4.8	220	3.09	2.39	0.54	1.335	2.46	1.88	3.46	2.81
10:25	14.16	16.56	80	58	6320	4.8	220	3.09	2.4	0.54	1.341	2.47	1.88	3.47	2.82
10:30	14.13	16.54	80	58	6360	4.8	220	3.09	2.41	0.54	1.346	2.48	1.89	3.48	2.83
10:35	14.1	16.52	80	58	6400	4.8	220	3.09	2.42	0.54	1.352	2.49	1.90	3.49	2.83
10:40	14.07	16.5	80	58	6440	4.8	220	3.09	2.43	0.54	1.358	2.50	1.90	3.50	2.84
10:45	14.04	16.48	80	58	6480	4.8	220	3.09	2.44	0.54	1.363	2.51	1.91	3.51	2.85
10:50	14.01	16.46	80	58	6520	4.8	220	3.09	2.45	0.54	1.369	2.52	1.91	3.52	2.86
10:55	13.98	16.44	80	58	6560	4.8	220	3.09	2.46	0.54	1.374	2.53	1.92	3.53	2.87
11:00	13.95	16.42	81.7	58	6600	4.8	220	3.09	2.47	0.54	1.380	2.54	1.92	3.54	2.88
11:05	13.92	16.4	81.7	58	6640	4.8	220	3.09	2.48	0.54	1.385	2.55	1.93	3.55	2.88
11:10	13.89	16.38	80	58	6680	4.8	220	3.09	2.49	0.54	1.391	2.56	1.93	3.56	2.89
11:15	13.86	16.36	80	58	6720	4.8	220	3.09	2.5	0.54	1.397	2.57	1.94	3.57	2.90
11:20	13.83	16.34	80	58	6760	4.8	220	3.09	2.51	0.54	1.402	2.58	1.95	3.58	2.91
11:25	13.8	16.32	80	58	6800	4.8	220	3.09	2.52	0.54	1.408	2.59	1.95	3.59	2.92
11:30	13.77	16.3	80	58	6840	4.8	220	3.09	2.53	0.54	1.413	2.60	1.96	3.60	2.93
11:35	13.74	16.28	80	58	6880	4.8	220	3.09	2.54	0.54	1.419	2.61	1.96	3.61	2.93
11:40	13.71	16.26	80	58	6920	4.8	220	3.09	2.55	0.54	1.425	2.62	1.97	3.62	2.94

11:45	13.68	16.24	81.7	58	6960	4.78	220	3.09	2.56	0.54	1.424	2.62	1.97	3.62	2.94
11:50	13.65	16.22	80	58	7000	4.78	220	3.09	2.57	0.54	1.430	2.63	1.97	3.63	2.95
11:55	13.62	16.2	80	58	7040	4.78	220	3.09	2.58	0.54	1.435	2.64	1.98	3.64	2.96
12:00	13.59	16.18	80	58	7080	4.78	220	3.09	2.59	0.54	1.441	2.65	1.98	3.65	2.97
12:05	13.56	16.16	81.7	58	7120	4.78	220	3.09	2.6	0.54	1.446	2.66	1.99	3.66	2.98
12:10	13.53	16.14	80	58	7160	4.78	220	3.09	2.61	0.54	1.452	2.67	2.00	3.67	2.98
12:15	13.5	16.12	80	58	7200	4.78	220	3.09	2.62	0.54	1.458	2.68	2.00	3.68	2.99
12:20	13.47	16.1	81.7	58	7240	4.79	220	3.09	2.63	0.54	1.466	2.70	2.01	3.70	3.01
12:25	13.44	16.08	80	58	7280	4.79	220	3.09	2.64	0.54	1.472	2.71	2.02	3.71	3.01
12:30	13.41	16.06	80	58	7320	4.79	220	3.09	2.65	0.54	1.477	2.72	2.02	3.72	3.02
12:35	13.38	16.04	80	58	7360	4.79	220	3.09	2.66	0.54	1.483	2.73	2.03	3.73	3.03
12:40	13.35	16.02	80	58	7400	4.79	220	3.09	2.67	0.54	1.489	2.74	2.03	3.74	3.04
12:45	13.32	16	80	58	7440	4.79	220	3.09	2.68	0.54	1.494	2.75	2.04	3.75	3.05
12:50	13.29	15.98	80	58	7480	4.79	220	3.09	2.69	0.54	1.500	2.76	2.04	3.76	3.06
12:55	13.26	15.96	80	58	7520	4.79	220	3.09	2.7	0.54	1.505	2.77	2.05	3.77	3.06
13:00	13.23	16	80	58	7560	4.79	220	3.09	2.77	0.54	1.544	2.84	2.09	3.84	3.12
13:05	13.2	16	80	58	7600	4.79	220	3.09	2.8	0.54	1.561	2.87	2.10	3.87	3.15
13:10	13.17	16	80	58	7640	4.79	220	3.09	2.83	0.54	1.578	2.90	2.12	3.90	3.17
13:15	13.14	16.01	81.7	58	7680	4.79	220	3.09	2.87	0.54	1.600	2.94	2.14	3.94	3.21
13:20	13.11	16	80	58	7720	4.79	220	3.09	2.89	0.54	1.611	2.96	2.16	3.96	3.22
13:25	13.08	16	80	57.5	7760	4.79	220	3.09	2.92	0.54	1.628	2.99	2.17	3.99	3.25
13:30	13.08	15.98	80	57.5	7800	4.79	220	3.09	2.9	0.54	1.617	2.97	2.16	3.97	3.23
13:35	13.05	15.96	80	57.5	7840	4.79	220	3.09	2.91	0.54	1.622	2.98	2.17	3.98	3.24
13:40	13.02	15.94	80	57.5	7880	4.79	220	3.08	2.92	0.54	1.628	3.00	2.17	4.00	3.25
13:45	12.99	15.98	80	57.5	7920	4.79	220	3.04	2.99	0.54	1.667	3.12	2.20	4.12	3.34
13:50	13	15.96	80	57.5	7960	4.79	220	3.01	2.96	0.53	1.650	3.12	2.18	4.12	3.33
13:55	13	16	80	57.5	8000	4.79	220	3.03	3	0.53	1.673	3.14	2.21	4.14	3.35
14:00	13	15.98	80	57.5	8040	4.79	220	3.03	2.98	0.53	1.661	3.12	2.19	4.12	3.33
14:05	13	15.96	80	57.5	8080	4.79	220	3.03	2.96	0.53	1.650	3.09	2.18	4.09	3.32
14:10	13.01	15.94	80	57.5	8120	4.79	220	3.02	2.93	0.53	1.633	3.07	2.17	4.07	3.30
14:15	13.02	15.92	80.2	57.5	8160	4.79	220	3.01	2.9	0.53	1.617	3.05	2.15	4.05	3.28
14:20	13.02	15.9	80.05	57.5	8200	4.79	220	3	2.88	0.53	1.606	3.04	2.13	4.04	3.27
14:25	13.01	15.88	80.02	57.5	8240	4.79	220	3	2.87	0.53	1.600	3.03	2.13	4.03	3.26
14:30	13	15.86	80	57.5	8280	4.79	220	3	2.86	0.53	1.594	3.02	2.12	4.02	3.25
14:35	13	16	80.1	57.5	8310	4.79	220	2.91	3	0.51	1.673	3.27	2.18	4.27	3.43
14:40	12.93	15.92	79.6	57.5	8390	4.77	220	2.92	2.99	0.51	1.660	3.23	2.17	4.23	3.40

28/12/2011	Troom =21		T amp= 13		Tearth	14									
Time	T w in	Tw out	T c in	T c out	Q fm	low(m3/h	V(v)	I(A)	DT	work	Qc	copr	QH	coph	cop geoh
9:30	18.24	18.9			8760	4.1	222	2.56	0.66	0.45	0.315	0.69	0.77	1.69	
9:35	16.2	17.27	84.9	76.9	8790	4.2	222	2.87	1.07	0.51	0.523	1.03	1.03	2.03	1.63
9:40	16.05	16.75	97	65	8820	4.45	222	3.76	0.70	0.67	0.363	0.54	1.03	1.54	1.30
9:45	15.02	16.98	104	72.6	8860	4.54	223	3.87	1.96	0.69	1.036	1.50	1.73	2.50	2.12
9:50	14.6	16.89	110	71	8810	4.5	223	3.9	2.29	0.70	1.199	1.72	1.90	2.72	2.31
9:55	14.47	16.84	115	70.1	8852	4.58	220	3.91	2.37	0.69	1.263	1.84	1.95	2.84	2.40
10:00	14.46	16.81	114	73	8894	4.59	223	3.91	2.35	0.70	1.255	1.80	1.95	2.80	2.37
10:05	14.45	16.8	112	72	8936	4.59	223	3.92	2.35	0.70	1.255	1.80	1.95	2.80	2.37
10:10	14.43	16.79	112	71	8978	4.59	223	3.93	2.36	0.70	1.261	1.80	1.96	2.80	2.37
10:15	14.41	16.77	111	71	9020	4.59	223	3.94	2.36	0.70	1.261	1.79	1.96	2.79	2.37
10:20	14.38	16.77	111	71	9062	4.59	223	3.95	2.39	0.70	1.277	1.81	1.98	2.81	2.39
10:25	14.36	16.75	111	71	9104	4.59	223	3.96	2.39	0.71	1.277	1.81	1.98	2.81	2.39
10:30	14.32	16.74	112	71	9146	4.59	223	3.97	2.42	0.71	1.293	1.83	2.00	2.83	2.40
10:35	14.3	16.74	112	70	9188	4.59	223	3.98	2.44	0.71	1.304	1.84	2.01	2.84	2.41
10:40	14.3	16.72	111	72	9230	4.59	223	3.99	2.42	0.71	1.293	1.82	2.00	2.82	2.40
10:45	14.3	16.72	112	72	9272	4.59	223	4	2.42	0.71	1.293	1.81	2.01	2.81	2.39
10:50	14.28	16.7	111	71	9314	4.59	223	4.01	2.42	0.72	1.293	1.81	2.01	2.81	2.39
10:55	14.27	16.69	112	72	9356	4.59	223	4.02	2.42	0.72	1.293	1.80	2.01	2.80	2.39
11:00	14.25	16.68	111	71	9398	4.59	223	4.03	2.43	0.72	1.298	1.81	2.02	2.81	2.39
11:05	14.23	16.62	110	70	9440	4.59	223	4.04	2.39	0.72	1.277	1.77	2.00	2.77	2.36
11:10	14.2	16.58	112	72	9482	4.59	223	4.05	2.38	0.72	1.271	1.76	1.99	2.76	2.35
11:15	14.15	16.55	111	71	9524	4.59	223	4.06	2.40	0.72	1.282	1.77	2.01	2.77	2.36
11:20	14.15	16.52	111	71	9566	4.59	223	4.07	2.37	0.73	1.266	1.74	1.99	2.74	2.34
11:25	14.09	16.51	111	71	9608	4.59	223	4.08	2.42	0.73	1.293	1.78	2.02	2.78	2.37
11:30	14.08	16.5	112	72	9650	4.59	223	4.09	2.42	0.73	1.293	1.77	2.02	2.77	2.37
11:35	14.05	16.49	112	72	9692	4.59	223	4.1	2.44	0.73	1.304	1.78	2.03	2.78	2.38
11:40	14.03	16.49	111	71	9734	4.59	223	4.11	2.46	0.73	1.314	1.79	2.05	2.79	2.39
11:45	14	16.48	111	71	9776	4.59	223	4.12	2.48	0.74	1.325	1.80	2.06	2.80	2.40
11:50	13.98	16.48	111	71	9814	4.59	223	4.13	2.50	0.74	1.336	1.81	2.07	2.81	2.40
11:55	13.98	16.47	111	71	9852	4.59	223	4.14	2.49	0.74	1.330	1.80	2.07	2.80	2.40
12:00	13.95	16.47	112	72	9890	4.59	223	4.15	2.52	0.74	1.346	1.82	2.09	2.82	2.41
12:05	13.93	16.47	112	72	9928	4.59	223	4.16	2.54	0.74	1.357	1.83	2.10	2.83	2.42
12:10	13.93	16.45	111	71	9966	4.59	223	4.17	2.52	0.74	1.346	1.81	2.09	2.81	2.41

12:15	13.91	16.45	111	71	10004	4.59	223	4.18	2.54	0.75	1.357	1.82	2.10	2.82	2.41
12:20	13.9	16.45	112	72	10042	4.59	223	3.95	2.55	0.70	1.362	1.93	2.07	2.93	2.49
12:25	13.86	16.4	110.5	70	10080	4.59	223	3.94	2.54	0.70	1.357	1.93	2.06	2.93	2.49
12:30	13.82	16.36	112	72	10122	4.59	223	3.93	2.54	0.70	1.357	1.94	2.06	2.94	2.49
12:35	13.68	16.32	110	71	10164	4.56	223	3.93	2.64	0.70	1.401	2.00	2.10	3.00	2.54
12:40	13.66	16.28	110	71	10204	4.57	223	3.94	2.62	0.70	1.394	1.98	2.10	2.98	2.53
12:45	13.45	16.25	110	71	10244	4.57	223	3.94	2.80	0.70	1.489	2.12	2.19	3.12	2.65
12:50	13.2	16.25	110	71	10282	4.59	223	3.95	3.05	0.70	1.629	2.31	2.33	3.31	2.81
12:55	13.1	16.23	110	71	10312	4.59	223	3.94	3.13	0.70	1.672	2.38	2.38	3.38	2.87
13:00	13	16.2	110.2	71	10342	4.59	223	3.94	3.20	0.70	1.710	2.43	2.41	3.43	2.91
13:05	12.85	16.18	110.6	73	10370	4.56	220	3.93	3.33	0.69	1.767	2.56	2.46	3.56	3.01
13:10	12.75	16.1	110	73	10420	4.56	220	3.93	3.35	0.69	1.778	2.57	2.47	3.57	3.02
13:15	12.71	16.1	108	71	10460	4.56	220	3.93	3.39	0.69	1.799	2.60	2.49	3.60	3.05
13:20	12.66	16.1	107	69	10480	4.55	220	3.92	3.44	0.69	1.822	2.64	2.51	3.64	3.08
13:25	12.62	16.1	105	78.5	10500	4.56	220	3.87	3.48	0.68	1.847	2.71	2.53	3.71	3.14
13:30	12.57	16.1	98	68	10550	4.55	220	3.9	3.53	0.69	1.869	2.72	2.56	3.72	3.15
13:35	12.56	16.1	100	71	10590	4.55	220	3.9	3.54	0.69	1.875	2.73	2.56	3.73	3.16
13:40	12.55	16.1	101	71	10630	4.55	220	3.9	3.55	0.69	1.880	2.74	2.57	3.74	3.16
13:45	12.56	16.1	102	72	10670	4.55	220	3.9	3.54	0.69	1.875	2.73	2.56	3.73	3.16
13:50	12.55	16.1	100	70	10710	4.55	220	3.9	3.55	0.69	1.880	2.74	2.57	3.74	3.16
13:55	12.56	16.1	100	70	10750	4.55	220	3.9	3.54	0.69	1.875	2.73	2.56	3.73	3.16
14:00	12.53	16.1	100	70	10790	4.55	220	3.9	3.57	0.69	1.891	2.75	2.58	3.75	3.18
14:05	12.52	16.1	98	68	10830	4.55	220	3.9	3.58	0.69	1.896	2.76	2.58	3.76	3.18
14:10	12.5	16.1	98	68	10870	4.55	220	3.9	3.60	0.69	1.906	2.78	2.59	3.78	3.20
14:15	12.49	16.1	97	67	10910	4.55	220	3.9	3.61	0.69	1.912	2.79	2.60	3.79	3.20
14:20	12.47	16.1	98	68	10950	4.55	220	3.9	3.63	0.69	1.922	2.80	2.61	3.80	3.22
14:25	12.46	15.95	98	68	10990	4.55	220	3.9	3.49	0.69	1.848	2.69	2.53	3.69	3.12
14:30	12.45	15.94	98	68	11030	4.55	220	3.9	3.49	0.69	1.848	2.69	2.53	3.69	3.12
14:35	12.44	15.92	97	67	11070	4.55	220	3.9	3.48	0.69	1.843	2.68	2.53	3.68	3.12
14:40	12.43	15.89	99	69	11110	4.55	220	3.9	3.46	0.69	1.832	2.67	2.52	3.67	3.10
14:45	12.42	15.89	108	78	11150	4.55	220	3.9	3.47	0.69	1.838	2.68	2.52	3.68	3.11
14:50	12.41	15.88	106	76	11190	4.55	220	3.9	3.47	0.69	1.838	2.68	2.52	3.68	3.11
14:55	12.4	15.88	107	77	11230	4.55	220	3.9	3.48	0.69	1.843	2.68	2.53	3.68	3.12
15:00	12.4	15.88	108	78	11270	4.55	220	3.9	3.48	0.69	1.843	2.68	2.53	3.68	3.12
15:05	12.39	15.88	109	79	11310	4.55	220	3.9	3.49	0.69	1.848	2.69	2.53	3.69	3.12

15:10	12.38	15.87	109	79	11350	4.55	220	3.9	3.49	0.69	1.848	2.69	2.53	3.69	3.12
15:15	12.37	15.87	108	78	11390	4.55	220	3.85	3.50	0.68	1.853	2.74	2.53	3.74	3.15
15:20	12.37	15.87	107	77	11430	4.55	220	3.85	3.50	0.68	1.853	2.74	2.53	3.74	3.15
15:25	12.36	15.87	105	75	11470	4.55	220	3.9	3.51	0.69	1.859	2.71	2.55	3.71	3.14
15:30	12.35	15.86	110	73	11510	4.55	220	3.85	3.51	0.68	1.859	2.74	2.54	3.74	3.16
15:35	12.33	15.86	110	73	11550	4.55	220	3.85	3.53	0.68	1.869	2.76	2.55	3.76	3.17
15:40	12.33	15.86	110	73	11590	4.55	220	3.87	3.53	0.68	1.869	2.74	2.55	3.74	3.16
15:45	12.34	15.85	119	75	11630	4.55	220	3.88	3.51	0.68	1.859	2.72	2.54	3.72	3.15
15:50	12.33	15.85	110	72	11670	4.55	220	3.85	3.52	0.68	1.864	2.75	2.54	3.75	3.17
15:55	12.32	15.85	110	71	11710	4.55	220	3.84	3.53	0.68	1.869	2.77	2.55	3.77	3.18
16:00	12.3	15.85	110.4	71	11750	4.54	220	3.83	3.55	0.67	1.876	2.78	2.55	3.78	3.19

29/12/2011															
Time	Troom =21		T amp= 13		Tearth	14									
Time	T w in	Tw out	T c in	T c out	Q fm	low(m3/h	V(v)	I(A)	DT	W(watt)	Qc(watt)	copr	QH	Cop H	Cop r geo
9:30	18.48	19.88	105	41.7	11760	4.57	223	3.83	1.4	0.815	0.74	0.91	1.56	1.91	1.91
9:35	16.2	17.2	98	68	11793	4.57	220	3.83	1.0	0.804	0.53	0.66	1.34	1.66	1.66
9:40	16.3	16.7	102	74	11826	4.57	220	3.83	0.4	0.804	0.21	0.26	1.02	1.26	1.26
9:45	15.02	16.98	105	70	11859	4.57	220	3.83	2.0	0.804	1.04	1.30	1.85	2.30	2.30
9:50	14.6	16.89	111	70	11892	4.44	220	3.83	2.3	0.781	1.18	1.51	1.96	2.51	2.51
9:55	14.47	16.84	110	73	11925	4.54	222	3.83	2.4	0.806	1.25	1.55	2.06	2.55	2.55
10:00	14.46	16.81	110	72	11958	4.54	220	3.83	2.4	0.799	1.24	1.55	2.04	2.55	2.55
10:05	14.45	16.8	110	71	11991	4.56	220	3.83	2.4	0.803	1.25	1.55	2.05	2.55	2.55
10:10	14.43	16.79	105	70	12024	4.57	220	3.83	2.4	0.804	1.26	1.56	2.06	2.56	2.56
10:15	14.41	16.77	111	70	12057	4.57	220	3.83	2.4	0.804	1.26	1.56	2.06	2.56	2.56
10:20	14.38	16.77	111	69	12090	4.57	221	3.83	2.4	0.808	1.27	1.57	2.08	2.57	2.57
10:25	14.3	16.7	112	71	12123	4.57	221	3.83	2.4	0.808	1.28	1.58	2.08	2.58	2.58
10:30	14.32	16.74	112	70	12156	4.57	220	3.83	2.4	0.804	1.29	1.60	2.09	2.60	2.60
10:35	14.3	16.74	111	72	12189	4.57	222	3.83	2.4	0.812	1.30	1.60	2.11	2.60	2.60
10:40	14.3	16.72	112	72	12222	4.57	223	3.83	2.4	0.815	1.29	1.58	2.10	2.58	2.58
10:45	14.3	16.72	111	71	12255	4.57	220	3.83	2.4	0.804	1.29	1.60	2.09	2.60	2.60
10:50	14.28	16.7	112	72	12288	4.57	220	3.83	2.4	0.804	1.29	1.60	2.09	2.60	2.60
10:55	14.27	16.69	111	71	12321	4.57	223	3.83	2.4	0.815	1.29	1.58	2.10	2.58	2.58
11:00	14.25	16.68	110	70	12354	4.57	223	3.83	2.4	0.815	1.29	1.59	2.11	2.59	2.59

11:05	14.23	16.62	112	72	12387	4.54	221	3.83	2.4	0.803	1.26	1.57	2.07	2.57	2.57
11:10	14.2	16.58	111	71	12420	4.54	221	3.83	2.4	0.803	1.26	1.57	2.06	2.57	2.57
11:15	14.15	16.55	111	71	12453	4.56	220	3.83	2.4	0.803	1.27	1.59	2.08	2.59	2.59
11:20	14.15	16.52	111	71	12486	4.55	220	3.83	2.4	0.801	1.26	1.57	2.06	2.57	2.57
11:25	14.09	16.51	112	72	12519	4.57	220	3.83	2.4	0.804	1.29	1.60	2.09	2.60	2.60
11:30	14.08	16.5	112	72	12552	4.57	220	3.83	2.4	0.804	1.29	1.60	2.09	2.60	2.60
11:35	14.05	16.49	111	70	12585	4.56	221	3.83	2.4	0.806	1.29	1.61	2.10	2.61	2.61
11:40	14.03	16.49	111	70	12618	4.57	220	3.83	2.5	0.804	1.31	1.63	2.11	2.63	2.63
11:45	14	16.48	111	70	12651	4.57	220	3.83	2.5	0.804	1.32	1.64	2.12	2.64	2.64
11:50	13.98	16.48	111	70	12684	4.56	220	3.83	2.5	0.803	1.33	1.65	2.13	2.65	2.65
11:55	13.98	16.47	112	72	12717	4.57	220	3.83	2.5	0.804	1.32	1.65	2.13	2.65	2.65
12:00	13.95	16.47	112	72	12750	4.55	220	3.83	2.5	0.801	1.33	1.67	2.14	2.67	2.67
12:05	13.93	16.47	111	71	12783	4.57	220	3.83	2.5	0.804	1.35	1.68	2.16	2.68	2.68
12:10	13.93	16.45	111	71	12816	4.55	220	3.83	2.5	0.801	1.33	1.67	2.14	2.67	2.67
12:15	13.91	16.45	112	72	12849	4.55	220	3.83	2.5	0.801	1.35	1.68	2.15	2.68	2.68
12:20	13.9	16.45	110.5	70	12883	4.57	220	3.83	2.6	0.804	1.36	1.69	2.16	2.69	2.69
12:25	13.86	16.4	112	70	12917	4.56	220	3.83	2.5	0.803	1.35	1.68	2.15	2.68	2.68
12:30	13.82	16.36	110	70	12951	4.57	220	3.83	2.5	0.804	1.35	1.68	2.16	2.68	2.68
12:35	13.68	16.32	110	70	12985	4.56	220	3.83	2.6	0.803	1.40	1.75	2.20	2.75	2.75
12:40	13.66	16.28	110	71	13019	4.57	220	3.83	2.6	0.804	1.39	1.73	2.20	2.73	2.73
12:45	13.45	16.25	110	71	13056	4.57	220	3.83	2.8	0.804	1.49	1.85	2.29	2.85	2.85
12:50	13.2	16.25	110	71	13093	4.57	220	3.83	3.1	0.804	1.62	2.02	2.43	3.02	3.02
12:55	13.1	16.23	110.2	71	13130	4.57	220	3.83	3.1	0.804	1.66	2.07	2.47	3.07	3.07
13:00	13	16.2	110.6	73	13167	4.57	220	3.83	3.2	0.804	1.70	2.12	2.51	3.12	3.12
13:05	12.85	16.18	110	73	13204	4.57	220	3.83	3.3	0.804	1.77	2.20	2.58	3.20	3.20
13:10	12.75	16.1	108	71	13241	4.57	220	3.83	3.4	0.804	1.78	2.22	2.59	3.22	3.22
13:15	12.71	16.1	107	69	13278	4.57	220	3.83	3.4	0.804	1.80	2.24	2.61	3.24	3.24
13:20	12.66	16.1	105	78.5	13315	4.57	220	3.83	3.4	0.804	1.83	2.27	2.63	3.27	3.27
13:25	12.62	16.1	98	68	13352	4.56	220	3.83	3.5	0.803	1.85	2.30	2.65	3.30	3.30
13:30	12.57	16.1	100	71	13389	4.55	220	3.83	3.5	0.801	1.87	2.33	2.67	3.33	3.33
13:35	12.56	16.1	101	71	13426	4.57	220	3.83	3.5	0.804	1.88	2.34	2.69	3.34	3.34
13:40	12.55	16.1	102	72	13463	4.57	220	3.83	3.6	0.804	1.89	2.35	2.69	3.35	3.35
13:45	12.56	16.1	100	70	13500	4.57	220	3.83	3.5	0.804	1.88	2.34	2.69	3.34	3.34
13:50	12.55	16.1	100	70	13535	4.57	220	3.83	3.6	0.804	1.89	2.35	2.69	3.35	3.35
13:55	12.56	16.1	100	70	13570	4.57	220	3.83	3.5	0.804	1.88	2.34	2.69	3.34	3.34
14:00	12.53	16.1	98	68	13605	4.57	220	3.83	3.6	0.804	1.90	2.36	2.70	3.36	3.36
14:05	12.52	16.1	98	68	13640	4.57	220	3.83	3.6	0.804	1.90	2.37	2.71	3.37	3.37
14:10	12.5	16.1	97	67	13675	4.57	220	3.83	3.6	0.804	1.91	2.38	2.72	3.38	3.38
14:15	12.49	16.1	98	68	13690	4.5	220	3.84	3.6	0.792	1.89	2.39	2.68	3.39	3.39

Heating mood

Date:	29/12/2011		Location : weldi playground												
T a= 13															
Water connected				TG = 17											
Time	Tw i	Tw o	T con in	Tocon	Qfm	flow	V	I	DT	W(watt)	Qc	copr	QH	Cop H	Cop r geoth
9:30	18.48	19.88	105	41.7	11760	4.57	223	3.76	1.4	0.671	0.745	1.1	1.8	2.65	2.24
9:35	18.48	19.88	98	68	11795	4.5	223	3.76	1.4	0.671	0.733	1.1	1.8	2.63	2.22
9:40	16.2	17.2	102	74	11830	4.5	223	3.76	1.0	0.671	0.524	0.8	1.5	2.16	1.82
9:45	16.3	16.7	105	70	11865	4.5	223	3.76	0.4	0.671	0.209	0.3	1.0	1.47	1.24
9:50	15.02	16.98	111	70	11900	4.5	223	3.76	2.0	0.671	1.027	1.5	2.2	3.28	2.77
9:55	14.6	16.89	110	73	11935	4.5	223	3.76	2.3	0.671	1.199	1.8	2.5	3.67	3.09
10:00	14.47	16.84	110	72	11970	4.5	223	3.76	2.4	0.671	1.241	1.9	2.5	3.76	3.17
10:05	14.46	16.81	110	71	12005	4.5	223	3.76	2.4	0.671	1.231	1.8	2.5	3.74	3.15
10:10	14.45	16.8	105	70	12040	4.5	223	3.76	2.4	0.671	1.231	1.8	2.5	3.74	3.15
10:15	14.43	16.79	111	70	12075	4.5	223	3.76	2.4	0.671	1.236	1.8	2.5	3.75	3.16
10:20	14.41	16.77	111	69	12110	4.5	223	3.76	2.4	0.671	1.236	1.8	2.5	3.75	3.16
10:25	14.38	16.77	112	71	12145	4.5	223	3.76	2.4	0.671	1.252	1.9	2.5	3.78	3.19
10:30	14.3	16.7	112	70	12180	4.5	223	3.76	2.4	0.671	1.257	1.9	2.5	3.79	3.20
10:35	14.32	16.74	111	72	12215	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
10:40	14.3	16.74	112	72	12250	4.5	223	3.76	2.4	0.671	1.278	1.9	2.6	3.84	3.24
10:45	14.3	16.72	111	71	12285	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
10:50	14.3	16.72	112	72	12320	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
10:55	14.28	16.7	111	71	12355	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
11:00	14.27	16.69	110	70	12390	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
11:05	14.25	16.68	112	72	12425	4.5	223	3.76	2.4	0.671	1.273	1.9	2.6	3.83	3.23
11:10	14.23	16.62	111	71	12460	4.5	223	3.76	2.4	0.671	1.252	1.9	2.5	3.78	3.19
11:15	14.2	16.58	111	71	12495	4.5	223	3.76	2.4	0.671	1.247	1.9	2.5	3.77	3.18
11:20	14.15	16.55	111	71	12530	4.5	223	3.76	2.4	0.671	1.257	1.9	2.5	3.79	3.20
11:25	14.15	16.52	112	72	12565	4.5	223	3.76	2.4	0.671	1.241	1.9	2.5	3.76	3.17
11:30	14.09	16.51	112	72	12600	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
11:35	14.08	16.5	111	70	12635	4.5	223	3.76	2.4	0.671	1.267	1.9	2.6	3.82	3.22
11:40	14.05	16.49	111	70	12670	4.5	223	3.76	2.4	0.671	1.278	1.9	2.6	3.84	3.24
11:45	14.03	16.49	111	70	12705	4.5	223	3.76	2.5	0.671	1.288	1.9	2.6	3.86	3.26
11:50	14	16.48	111	70	12740	4.5	223	3.76	2.5	0.671	1.299	1.9	2.6	3.89	3.28
11:55	13.98	16.48	112	72	12775	4.5	223	3.76	2.5	0.671	1.309	2.0	2.6	3.91	3.30
12:00	13.98	16.47	112	72	12810	4.5	223	3.76	2.5	0.671	1.304	1.9	2.6	3.90	3.29
12:05	13.95	16.47	111	71	12845	4.5	223	3.76	2.5	0.671	1.320	2.0	2.6	3.93	3.32
12:10	13.93	16.47	111	71	12880	4.5	223	3.76	2.5	0.671	1.330	2.0	2.7	3.96	3.34
12:15	13.93	16.45	112	72	12915	4.5	223	3.76	2.5	0.671	1.320	2.0	2.6	3.93	3.32
12:20	13.91	16.45	110.5	70	12950	4.5	223	3.76	2.5	0.671	1.330	2.0	2.7	3.96	3.34
12:25	13.9	16.45	112	70	12985	4.5	223	3.76	2.6	0.671	1.336	2.0	2.7	3.97	3.34
12:30	13.86	16.4	110	70	13020	4.5	223	3.76	2.5	0.671	1.330	2.0	2.7	3.96	3.34
12:35	13.82	16.36	110	70	13055	4.5	223	3.76	2.5	0.671	1.330	2.0	2.7	3.96	3.34
12:40	13.68	16.32	110	71	13090	4.5	223	3.76	2.6	0.671	1.383	2.1	2.7	4.07	3.43
12:45	13.66	16.28	110	71	13125	4.5	223	3.76	2.6	0.671	1.372	2.0	2.7	4.05	3.41
12:50	13.45	16.25	110	71	13160	4.5	223	3.76	2.8	0.671	1.467	2.2	2.9	4.26	3.59
12:55	13.2	16.25	110.2	71	13195	4.5	223	3.76	3.1	0.671	1.597	2.4	3.1	4.55	3.84
13:00	13.1	16.23	110.6	73	13225	4.5	223	3.76	3.1	0.671	1.639	2.4	3.1	4.64	3.91
13:05	13	16.2	110	73	13255	4.5	223	3.76	3.2	0.671	1.676	2.5	3.2	4.72	3.98
13:10	12.85	16.18	108	71	13285	4.5	223	3.76	3.3	0.671	1.744	2.6	3.3	4.88	4.11
13:15	12.75	16.1	107	69	13315	4.5	223	3.76	3.4	0.671	1.755	2.6	3.3	4.90	4.13
13:20	12.71	16.1	105	78.5	13345	4.5	223	3.76	3.4	0.671	1.776	2.6	3.3	4.95	4.17
13:25	12.66	16.1	98	68	13375	4.5	223	3.76	3.4	0.671	1.802	2.7	3.4	5.00	4.22
13:30	12.62	16.1	100	71	13405	4.5	223	3.76	3.5	0.671	1.823	2.7	3.4	5.05	4.26
13:35	12.57	16.1	101	71	13438	4.5	223	3.76	3.5	0.671	1.849	2.8	3.4	5.11	4.31
13:40	12.56	16.1	102	72	13471	4.5	223	3.76	3.5	0.671	1.854	2.8	3.4	5.12	4.32
13:45	12.55	16.1	100	70	13504	4.5	223	3.76	3.6	0.671	1.859	2.8	3.4	5.13	4.33
13:50	12.56	16.1	100	70	13537	4.5	223	3.76	3.5	0.671	1.854	2.8	3.4	5.12	4.32
13:55	12.55	16.1	100	70	13570	4.5	223	3.76	3.6	0.671	1.859	2.8	3.4	5.13	4.33
14:00	12.56	16.1	98	68	13603	4.5	223	3.76	3.5	0.671	1.854	2.8	3.4	5.12	4.32
14:05	12.53	16.1	98	68	13636	4.5	223	3.76	3.6	0.671	1.870	2.8	3.5	5.16	4.35
14:10	12.52	16.1	97	67	13676	4.5	223	3.76	3.6	0.671	1.875	2.8	3.5	5.17	4.36
14:15	12.5	16.1	78.4	68	13690	4.5	236	3.78	3.6	0.714	1.886	2.6	3.4	4.70	4.00

Heating mood															
Date:	03/01/2012		Location : weldi playground												
T a= 7															
Water connected				TG = 17											
Time	Tw i	Tw o	T con in	Tocon	Q	flow	V	I	DT	W(watt)	Qc(watt)	copr	QH	Cop H	Cop r geot
8:37	18	20	56	39	13730	4.42	223	3.51	2	0.63	1.029	1.64	1.66	2.64	2.20
9	17	19.2	60	45	13913	4.4	223	3.51	2.2	0.63	1.127	1.80	1.75	2.80	2.33
10	15	18.5	70	47	14096	4.42	223	3.51	3.5	0.63	1.801	2.88	2.43	3.88	3.23
11	14	16.5	75	55	14279	4.5	223	3.51	2.5	0.63	1.309	2.09	1.94	3.09	2.58
12	13	16.2	78	60	14462	4.4	223	3.51	3.2	0.63	1.639	2.62	2.26	3.62	3.02
1	12.5	16	82	67	14645	4.2	223	3.51	3.5	0.63	1.711	2.73	2.34	3.73	3.11
2	11.3	15.8	90	78	14828		223	3.51	4.5	0.63	0.000	0.00	0.63	1.00	0.83
3:00	10	15.34	100	84	16120	4.4	223	3.49	5.34	0.62	2.735	4.39	3.36	5.39	4.49

05/02/2012															
Time	T w in	Tw out	T c in	T c out	Q fm	low(m3/h	V(v)	I(A)	DT	work	QC	cop	QH	Cop H	Cop solar
9:44	34	20.13	40	22	16540	5.6	230	2.5	14	0.46	9.125	19.8	9.6	29	21
9:46	22.36	21.56	56.4	22.4	16580	7.7	230	2.89	0.8	0.5318	0.717	1.348269	1.2	3	2
9:49	22.43	20.44	48.7	22.7	16600	5.64	230	3.55	1.99	0.6532	1.306	1.99985	2.0	4	3
9:52	22.41	20.54	59.2	22.8	16610	5.6	230	3.89	1.87	0.7158	1.219	1.70284	1.9	3	3
10:00	30	20	59.2	22.8	16680	5.6	230	3.89	10	0.7158	6.518	9.106094	7.2	12	10
10:30	28	19	59	22.8	16750	5.6	230	3.89	9	0.7158	5.866	8.195485	6.6	11	9
11:00	28	18.5	59.1	22.8	16820	5.6	230	3.89	9.5	0.7158	6.192	8.650789	6.9	12	10
11:30	28	19	59.2	22.8	16890	5.6	230	3.89	9	0.7158	5.866	8.195485	6.6	11	9
11:50	24.03	20	52.6	24.1	17730	5.6	230	4.5	4.03	0.828	2.627	3.1723	3.5	5	4

Time	T w in	Tw out	T c in	T c out	Q fm	low(m3/h	V(v)	I(A)	DT	w comp	QC	cop	QH	Cop H	Cop h sola	DT 1
12:30	25.9	20.70	22.00	23	19400	5.33	222	1.6	5.2	0.4163	3.226	7.749	3.6	9	7	14.9
12:35	21.6	20.00	57.00	22.9	19470	5.22	222	3.46	1.6	0.7549	0.972	1.288	1.7	2	2	10.6
12:40	20.39	20.00	61.90	21.2	19500	5.18	222	3.66	0.39	0.7913	0.235	0.297	1.0	1	1	9.39
12:50	19.65	19.00	55.60	23	19590	5.16	222	0	0.65	0.125	0.390	3.123	0.5	4	2	8.65
12:55	19.38	19.25	70.30	23.6	19630	5.13	222	4.06	0.13	0.8641	0.078	0.090	0.9	1	1	8.38
1:00	18.44	18.36	82.00	24	19680	5.13	222	4.12	0.08	0.875	0.048	0.055	0.9	1	1	7.44
1:15	17.62	17.26	80.10	23.9	19770	5.13	222	3.85	0.36	0.8259	0.215	0.260	1.0	1	1	6.62
1:30	15.94	15.70	81.90	23.9	19850	5.1	222	3.94	0.24	0.8422	0.142	0.169	1.0	1	1	4.94
									0.24	0.125	0.000		0.1	1	1	-11
9:15	34	19.00	22.00	37.7	19970	5.1	220	2.6	15	0.594	8.904	14.988	9.5	16	13	23
9:25	22.19	19.50	22.30	42	19990	5.12	220	2.7	2.69	0.6121	1.603	2.619	2.2	4	3	11.19
9:35	22.17	21.61	22.50	43.6	20060	5.12	220	3.3	0.56	0.7203	0.334	0.463	1.1	1	1	11.17
9:45	22.12	21.50	22.70	48.5	20130	5.05	220	3.3	0.62	0.7203	0.364	0.506	1.1	2	1	11.12
9:55	22.02	21.30	22.9	58	20200	5.05	220	3.5	0.72	0.7564	0.423	0.559	1.2	2	1	11.02
10:05	21.93	21.14	23.1	67.5	20270	5.05	220	4	0.79	0.8466	0.464	0.548	1.3	2	1	10.93
10:15	21.85	20.80	23.3	69	19960	5.05	220	4	1.05	0.8466	0.617	0.729	1.5	2	2	10.85
10:25	21.75	19.5	23.5	72	20030	5.05	220	4	2.25	0.8466	1.322	1.562	2.2	3	2	10.75
10:35	21.55	19	23.9	75	20100	5.05	220	4	2.55	0.8466	1.499	1.770	2.3	3	2	10.55
10:45	21.35	18.7	23.9	78	20170	5.05	220	4	2.65	0.8466	1.558	1.840	2.4	3	2	10.35
10:55	21	18.3	23.9	79.5	20240	5.05	220	4	2.7	0.8466	1.587	1.875	2.4	3	3	10
11:05	20.5	18	23.9	79.9	20310	5.05	220	4	2.5	0.8466	1.469	1.736	2.3	3	2	9.5
11:15	20	17.8	23.9	79.6	20380	5.05	220	4	2.2	0.8466	1.293	1.527	2.1	3	2	9
11:25	19.3	17.6	24	80	20450	5.05	220	4	1.7	0.8466	0.999	1.180	1.8	2	2	8.3
11:30	18.8	17.41	24.5	80.61	20520	5.05	220	4	1.39	0.8466	0.817	0.965	1.7	2	2	7.8

جامعة النجاح الوطنية
كلية الدراسات العليا

تحليل نظري وتجريبي لمضخة جيوحرارية افقية ولاقط شمسي

إعداد
إبراهيم محمد إبراهيم خصوان

إشراف
د عبد الرحيم أبو صفا

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة المتجددة وترشيد الاستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس, فلسطين.

2012م

تحليل نظري وتجريبي لمضخة جيوحرارية افقية ولاقط شمسي

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الملخص

مصادر الطاقة التقليدية ضارة بالبيئة, على عكس مصادر الطاقة المتجددة.فـــي نهايـــة القرن الماضي اتفق العالم على معالجة مشكلة التغير المناخي, الأمر الذي قاد الى التفكيير بطرق للتوفير بالطاقة وتخفيف الأنبعاثات الغازية. ان الطاقة الجيوحرارية هي من أهم الطرق للتوفير بالطاقة. يهدف هذا البحث الى تصميم وبناء مضخة جيوحرارية أفقية مربوطة بأنابيب ارضية , مع عمل مقارنة بين النظم التقليدية والنظام الجديد, كذلك ايجاد اثر درجة حرارة مبذر الحـــرارة على كفاءة النظام. لهذا الهدف تم تصميم النظام وبناءه وفحصة على التبريد والتدفئة قبل وبعـــد وصل النظام بالأرض و بعد ربط النظام بالسخان الشمسي. لقد وجد ان كفاءة النظام كانت بـــين 5 و 6 على االتبريد وبين 3.5 4 على التدفئة ومع ربط النظام بالسخان الشمسي كانت الكفاءة 9 عند فرق درجة حرارة 5 مؤي بين الخط الداخل والخارج.

لقد كانت فترة استرجاع الأستثمار لنظام الجيوحراري الفقي بين شهرين وسنتين, بالنسبة للتخفيف من النبعاثات الغازية لنظام 35 كيلوواط حوالي 157 طن من غاز ثاني اكسيد الكربون مما يحتاج الى 6277 شجرة من الصنوبر للتخفيف من اثر هذه الأنبعاثات.