Ground Water-Source Heat Pump

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ABSTRACT

Nowadays, most issues are associated with the growth of population and an increase in energy needs is no exception. Therefore, one of the ways to solve this problem is use of technologies based on renewable energy sources.

In this thesis, the effectiveness of the ground water-source heat pump (GWHP) is being analyzed in Famagusta conditions. Famagusta has been chosen because it has potential for renewable energy sources such as groundwater with a practically constant temperature throughout the year and solar energy, which can be used to generate electricity by photovoltaic panels for the needs of the heat pump.

TRNSYS software is used to simulate the process. The temperature of ground water was fixed at 20̊C. In order to gather information about ground water-source heat pump benefits, a comparison with an air-source heat pump was conducted.

The results show that the GWHP had a better COP both in summer and winter by 63% and 214% respectively. In winter the COP of GWHP reaches a value of 5.6, however in Summer this value is approximately 3. In addition, cost-benefits evaluation indicated that GWHP has profitable benefits and that the system is economically feasible.

Keywords: Heat pump, GWHP, ASHP, TRNSYS, Famagusta

ÖZ

Günümüzde çoğu sorunlar istisnasiz nüfus artışı ve enerji ihtiyaçlarındaki bir artış ile ilişkilidir. Bu nedenle, bu sorunu çözmenin yollarından biri yenilenebilir enerji kaynaklarına dayalı teknolojilerin kullanımıdır.

Bu tezde, yeraltı suyu kaynaklı ısı pompasının (GWHP) etkisi Gazimağusa koşullarında analizi yapılmıştır . Çalşma için Gazimağusa'nın seçilmiş olmasının nedeni, hemen hemen sabit sıcaklıkta yer altı suyu ve fotovoltaik paneller ile elektrik üretebilecek güneş enerjisi gibi yenilebilir enerji kaynakları potansiyelinin olmasıdır.

Uygulamayı simule etmek için TRNSYS yazılımı, kullanıldı. Yer altı suyunun sıcaklığı 20°C olarak sabitlenmiştir. GWHP'nin yararları hakkında bilgi toplamak için hava kaynaklı ısı pompası ile bir karşılaştırma yapılmıştır.

Sonuçlara göre GWHP yaz aylarında %63, kış aylarnda ise %214 daga iyi bir performans katsayısına (COP) sahiptir. Kışın GWHP'a ait COP 5.6 değerine ulaşırken yazın bu değer 3 civarlarındadr. Ayrıca, GWHP için yaplan maliyet kazanç değerlendirmesi, GWHP nin karlı olabileceğini ve sistemin ekonomik biçimde uygulanabilir olduğunu göstermiştir.

Anahtar kelimeler: Isı pompası, GWHP, ASHP, TRNSYS, Gazimağusa

To My Family

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TABLE OF CONTENTS

ABSTRACT……………………………………..………..……………........iii

ÖZ…………………………………………………………………………....iv

DEDICATION………………………………………………………………..v

ACKNOWLEDGMENT………………………………………………………vi

LIST OF TABLES…………………………………………………………...ix

LIST OF FIGURES…………………………………………………………..x

LIST OF SYMBOLS……………………………………………………….…xii

1 INTRODUCTION…………………………………………………………….1

1.1 Background to the study……………………..……………………………1

1.2 Aim of the study………...……………….….…...……………………….2

1.3 Significance of the study……………….……..………...…………………3

1.4 Organization of the thesis…………………………………………………..3

2 LITERATURE REVIEW……………………………………………..……4

2.1 Historical review...…………………………………………..………..4

2.2 Performance of challenges………………………………………...…..7

3 METHODOLOGY……………………………………………………………..12

3.1 Local conditions...……………………………………………………...12

3.2. Mathematical mode…………………………………………………14

3.2.1 Mathematical model of the heat pump….……………………….....14

3.2.2 Mathematical model of the simple zone…………………………...…16

3.2.3 Mathematical model of the PV…...……………………………………..18

3.3 Simulation tool...…………………………………………………………18

4 SIMULATION OF GWHP FOR CYPRUS CONDITION……………………….20

4.1 Description of the system…...……………………………………………….20
4.2 Detailed model design in TRNSYS..........…………………………….…….23
5 RESULT AND DISCUSSION……………………………………….……...29
5.1 Cooling mode…..………………………………………….………...31
5.2 Heating mode………..…………………………………….………...38
5.3 Summer and winter performance result discussion……….....…….………….43
5.4 Economic analysis………………………………………………………...44
5.4.1 Economic analysis governing equations……………..…………………45
5.4.2 Cost analysis……………………………...…………….…………………..46
6 CONCLUSION……...………………………………..…………………...48
REFERENCES……..…………………………………..…………………...50
APPENDIX…………...……………………………………………………..54
Appendix A: Description of used components in simulation design……….…..55

LIST OF TABLES

Table 3.1: Data required for the calculation for an externally insulated wall……….17

Table 4.1: Components used in simulation model…………………………………..24

Table 4.2 Detailed zone parameters…………………………………………………25

Table 4.3 Water source heat pump parameters……………………………………...26

Table 5.1: Economic analysis excel sheet, Input data required to calculate NPV, SIR, SPB and IRR. Comparison of GWHP system (new) and ASHP system (old)………..46

Table 5.2: Life Cycle Cost Analysis…………………………………….…………..46

Table 5.2 continue: Life Cycle Cost Analysis………………………………………46

Table 5.3: Life Cycle Cost Analysis………………………………………………...47

LIST OF FIGURES

Figure 2.1: The scheme of "heat multiplier" by William Thomson....…………….......5

Figure 2.2: Temperature of the ground during 1838-1854 as displayed in Ref. [6]….6

Figure 2.3: Scheme of closed loop ground heat pump as displayed in Ref. [14]….....9

Figure 2.4: GLHEPRO 25 years of simulation results as displayed in Ref. [18].....…11

Figure 3.1: Simulation process……………………………………………………...12

Figure 3.2a: Weather data for Famagusta...………….………………..…………....13

Figure 3.2b: Weather data for Larnaca…………………...…………………………...14

Figure 3.3: Scheme and temperature entropy diagram for refrigeration cycle…........15

Figure 3.4: View of part of the wall with insulation …..……………..………………16

Figure 4.1: Basic scheme of GWHP in heating mode …….………………………..21

Figure 4.2: Schematic diagram of the heat pump with reversed valve……………...22

Figure 4.3: Simulation model of GWHP……………………………………………...23

Figure 4.4: Simple zone………..…………………………………………………….25

Figure 4.5: Heat pump scheme in TRNSYS manual………………………………..26

Figure 4.6: A time-dependent profile……………………………………………......27

Figure 4.7: Simulation model of ASHP……………………………………………..28

Figure 5.1: The trend of zone and ambient temperature during whole year……......30

Figure 5.2: Trend of zone and ambient temperature during cooling mode…….…....31

Figure 5.3: Illustration of COP and compressor power of GWHP………………......33

Figure 5.4: Cooling mode in period from 1 to 4 of July for GWHP………………...35

Figure 5.5: Cooling mode in period from 1 to 4 of July for ASHP……………….....37

Figure 5.6: Trend of zone and ambient temperature during heating mode………….39

Figure 5.7: Heating mode in period from 1 to 4 of January for GWHP…………….41

Figure 5.8: Heating mode in period from 1 to 4 of January for ASHP……………...42

Figure 5.9: Comparison between COP of GWHP and ASHP……….………………43

LIST OF SYMBOLS

COP	Coefficient of performance
COP_{HP}	Coefficient of performance of the heat pump
$\dot{W}_{comp}$	Compressor power
Q_L	Cooling effect
$\dot{E}_{comp\ motor}$	Electrical power consumption
Rse	External surface resistance (m^2K/W)
GHE	Ground heat exchanger
GLERPO	Ground loop heat exchanger design software
GWHP	Ground water heat pump
GCHP	Ground-coupled heat pump
HP	Heat pump
U-value	Heat transfer coefficient
Q_H	Heating effect
Rsi	Internal surface resistance (m^2K/W)
PV_{LCI}	Life Cycle Investment
λi	Material thermal conductivity (W/mK)
di	Material thickness (m)
NPV	Net present value
PV	Photovoltaic
PV_{AS}	Present Value of Annual Savings
SIR	Savings-to-investment ratio
SPP	Simple Payback Period

SWHP	Surface water heat pump
E_{ann}	The annual electricity consumption
η_{EM}	The efficiency of the electric motor
$Z_{i,j}$	The heat transfer between elements i and j
$T_{s,i}$	The inside surface temperature of element
W_{PV}	The total capacity of PV
X_i	Time factor
A_{PV}	Total area of PV
TRNSYS	Transient system
TMY-2	Typical Meteorological Year
$W_{net,in}$	Work input

Chapter 1

INTRODUCTION

1.1 Background to the study

There has been a growth in the world's population and also an increase in energy needs in recent years. Furthermore, because of reducing the amount of fossil fuels around the world, as well as in view of their non-renewable nature, more attention must be paid to alternative energy sources, particularly in residential usage, since in many countries these accounts for the majority of energy consumption. In addition, the issue of energy expenditures for heating and cooling is important at the present time due to a tendency of increase in energy bills with CO_2 penalties [1].

S. Cyprus Government defines the energy needs of the country, taking into account commitments related to international agreements and European Standards and regulations [2]. However, due to the lack of fossil fuels in Cyprus on the one hand and the low energy efficiency of buildings in North Cyprus on the other, it is essential to conduct research on renewable sources, especially for private premises, that are major consumers of energy. Additionally, Cyprus has considerable potential regarding the alternative sources of energy sources which include solar, geothermal (ground water), wind energy and biomass. In many regions of Famagusta ground water (a few meters under the ground) is also readily available. This is salty water penetrating into the ground from the sea.

One of the best ways to use the available renewable resources (ground water in Famagusta as noted above) is by means of a heat pump. This system practically serves to maintain a climate in the building at a desired comfort level. On the whole, heat pumps can be used to heat air in winter and to cool it during the summer periods. Through the use of groundwater, it is possible to increase the performance of heat pumps and reduce dependence on fossil fuels.

Many studies have been conducted to study the ground-water source heat pump by means of a simulation in TRNSYS 16 program. These simulations were performed for a variety of countries such as China, India, America, some European countries [3]. However, in particular for Famagusta, the number of works of this character is hardly available.

1.2 Aim of the study

The aim of this thesis is to investigate the performance of ground water-source heat pumps (GWHP) in Famagusta conditions, as well as evaluation of the possibility of using them for residential buildings. The primary goal of the research is to design a simulation model permitting the estimation of GWHP performance for the area heating/cooling scenario of a dwelling building. It is also of interest to assess the possibility of using solar photovoltaic power to drive the compressor of the heat pumps.

The prospect of development and practical use of geothermal heat pump for increase of efficiency and ecological cleanliness of power supply and of energy consumption will also be considered.

1.3 Significance of the study

This thesis will be a substantial contribution in promoting the development of heat pumps in the given locality and a good motivation for further study. Furthermore, this study will give recommendations on how to evaluate the performance of the system in accordance to various initial data. The results can attract the attention of engineers towards the system of the water source heat pump.

1.4 Organization of the thesis

The thesis is structured as follows:

In Chapter 2, the information available in the literature is explored to confirm the relevance of the theme, as well as to identify the knowledge gap.

In Chapter 3, detailed information and explanations of the simulation work are provided.

Chapter 4 describes and justifies the mathematical calculations.

In chapter 5, a discussion of results is presented.

In chapter 6 the conclusions of the work carried out and the application of the results are shown.

Chapter 2

LITERATURE REVIEW

This chapter outlines scientific investigation pertinent to this thesis. By identifying the common findings of survey related to GWHP, only a small number of works for the Famagusta conditions was observed. The first part of this chapter briefly describes the notion of geothermal heat pump and makes proofs of the effectiveness of this system. In the second section the current literature is surveyed.

2.1 Historical review

In 1824 the dissertation of French mathematician and physicist Sadi Carnot was published, in which the basic principle of the HP was described. Nevertheless, the history of the creation of HP is considered to take its start from 1852, from the moment when the eminent British physicist and engineer William Thomson (Lord Kelvin) suggested practical heat pump system, which he called "multiplier of heat [Fig.2.1]." Moreover, he stated that the refrigerating machine can be used for heating purposes [4].

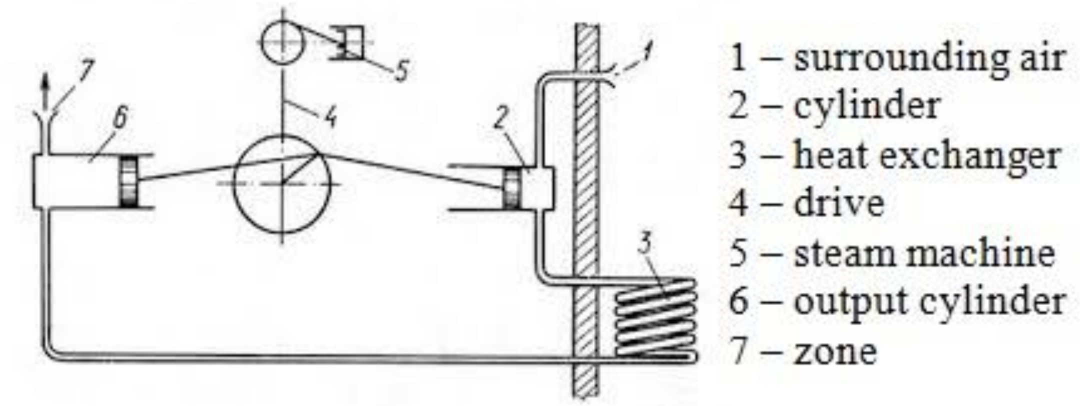


Figure 2.1: The scheme of "heat multiplier" by William Thomson

However, there are significant disadvantages in the provided model which was expressed in the use of ambient air as the working substance [5].

The earth, absorbing around half of the solar energy, is sustainable and an incredibly large storage of heat source. The soil temperature is approximately constant within the seasons, providing a warm source in winter and a cold source in summer. From a scientific point of view, a geothermal resource at stable a temperature was first discussed in Paris. Then in 1838, accurate temperature measurements began in the Royal Edinburgh Observatory in Scotland and Fig.2.2 describes the results of soil temperature measured in 1838-1854 year [6].

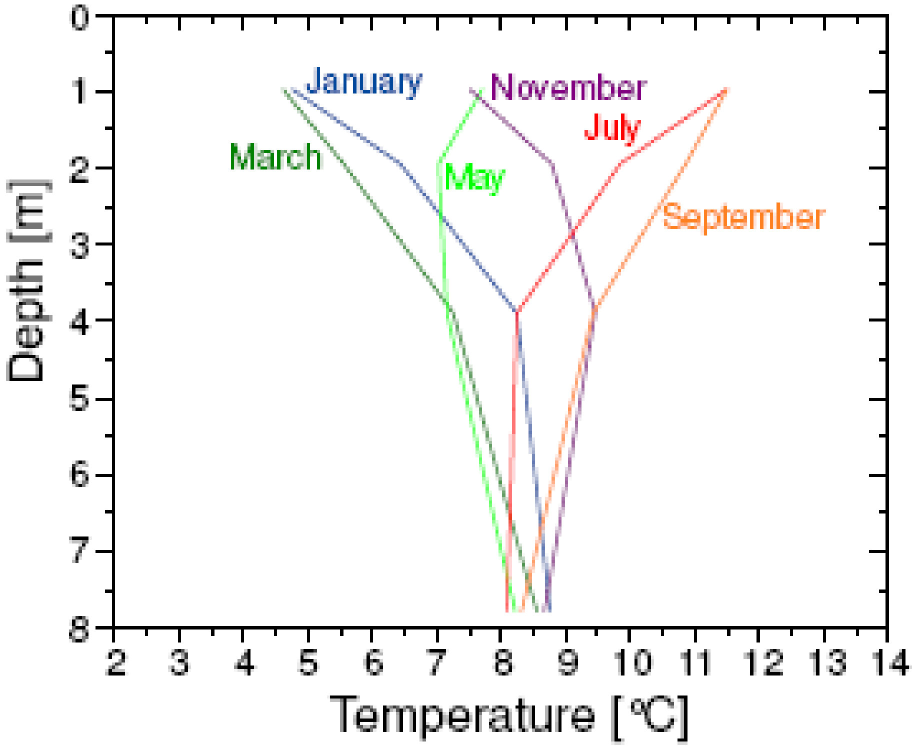


Figure 2.2: Temperature of the ground during 1838-1854, Scotland, as displayed in Ref. [6]

It should be noted that this steady energy source for heat pump began to be used only at the beginning of the 20th century. One of the first documentary evidence of ground use as a heat source is a right in 1912 by H. Zolly. However considering some technological problems associated with low level of technology in this area at the time the heat pump efficiency was insufficient.

Sumner was one the first who considered the earth as a source for heat pumps in the mid-1940s. His system was designed for one-storey house and includes a horizontal collector at a depth of one meter and COP of 2.8 was reached in UK. He applied a system of 12 prototypes of ground source heat pump in 1948, each with an output of 9 kW and the total COP of 3. However, these explorations were terminated after two years [7].

It should also be noted that commercial use of these systems began in the late 70s. In subsequent years discrete subsystems were upgraded and optimized, but the general concept of pumps was the same.

Overall interest in geothermal heat pumps is high until this day, due to the fact that the stable temperature of the source is the main parameter of efficiency of the system.

In the following section short review of the previous research based on GWHP technology is presented in detail.

2.2 Performance of challenges

In the closing of the Geothermal Heat Pump Consortium (1997) it was stated that ground sources can absorb about half of the sun's energy, which is clean and renewable. Corresponding to this fact, the amount of the absorbed solar energy can produce at least three units for each unit of electricity. Practically GWHP is a common technical term used for all kinds of geothermal heat pumps including the following heat pumps: ground-coupled (GCHP), groundwater (GWHP), and surface water (SWHP) [8].

This paper is focused on reviewing and simulation of groundwater source heat pump (GWHP).

According to Rafferty, Phetteplace, Florides and Kalogirou a relative experience foundation for understanding geothermal heat pump is allowed [9].

Jin and Spitler (2002) established a parameter-estimation-based water-to-water heat pump model which used a thermodynamic analysis of the refrigeration cycle, basic heat exchanger types, and a complete type of the refrigerant returning compressor [10].

Jin and Spitler in their paper (2003) provided some improvements related to sub-models of heat pumps with scroll compressors, which included rotary compressors, as well as the procedure of the adaptation of six models with anti-freeze solution were described. Algorithm of multi-variable optimization was established to evaluate the parameters of model from the manufacturers' catalog [11].

Jin (2002) carefully recorded multi-objectives optimization and valued dates. The accuracy of the system constructively likened with earlier distributed deterministic and equation-fit type models. In addition, he also offered a similar model for water-to-air heat pumps [12].

A simulated and experimental performance of solar assisted GHP was studied by Onder Ozgener, Arif Hepbasli in Ege University. The present study was directed to investigate of working characteristics of the 50m vertical heat pump by exergy analysis method. Exergy efficiency of the system was determined and was 67.7% while the COP of GWHP and the whole system are gotten to be 2.64 and 2.38, respectively [13].

Hwang et al. analyzed one day of operation of heat pump in Korea to get cooling performance. calculated the cooling performance of a GCHP system which was installed in Korea for 1 day of operation. The evaluation of the cooling effectiveness was carried out under the actual operation of GSHP system in the summer of year 2007. Ten HP units were installed in the building [Fig.2.3].

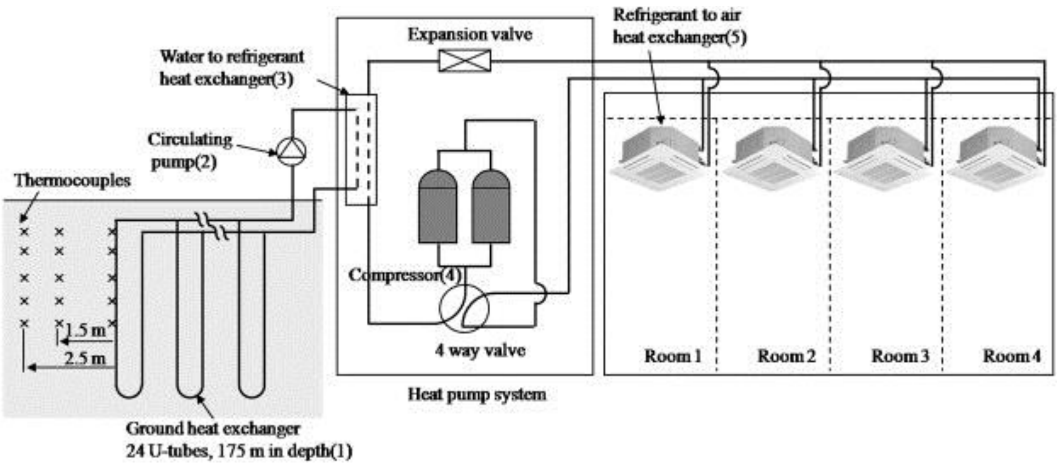


Figure 2.3: Scheme of closed loop ground heat pump as displayed in Ref. [14]

As Hwang et al. claims, effectiveness of HP toughly depends on the condensation temperature in cooling mode. In other words, lower condensation temperature provides higher efficiency of the heat pumps [14].

Yang et al. developed a trial system of a solar geothermal multifunctional HP. In consequence of this experiment they provided the heat transfer of a two-region vertical U-tube GHE (geothermal heat exchanger). The investigational model is included a solar-geothermal multifunctional heat pump with two vertical boreholes each with a 30 m vertical 1 1/4 in nominal diameter HDPE single U-tube GHE. The results indicate that the fluid outlet temperature corresponds to test data. In this case the relative error is around 6%; this inaccuracy is acceptable in engineering application. They allow that the outlet fluid and borehole temperatures and COP of HP all descent extremely for startup period, but after about 200 hours of operation this process slows down. In other words, system capacity depends on the initial soil temperature and unstable in the initial stage. They also suggested that heat transfer inside the borehole can be regarded as a stationary state in system [15].

The thermal properties of the soil to apply the geothermal heat pumps in Turkey were defined by Esen and Inalli in 2008 year. They set up that these properties are changing slightly depending on the depth and ground characteristic [16].

Experimental data in Man et al. research paper also indicate that COP of the system is related to mode and initial soil temperature. Evaluation of performance was carried out in a temperate area for cooling and heating provision [17].

Investigational and forming analysis of a GSHP was performed by Montagud, Corberan and Ruiz-Calvo for office building located in the Technical University in Spain. The HP was developed using program called GLHEPRO and it had been recorded from 2005. Furthermore, the whole construction model and GSHP system was implemented in TRNSYS to understand the dynamics of the system and to fully characterize its efficiency. Using GLHEPRO mean monthly outlet water temperature was estimated for 25 years of operation [Fig.2.4] [18].

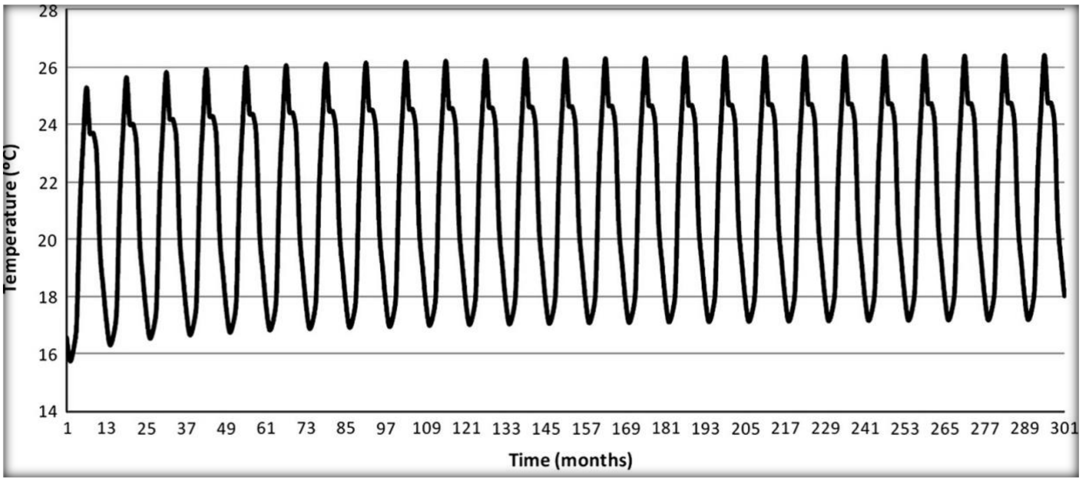


Figure 2.4: GLHEPRO 25 years of simulation results as displayed in Ref. [18]

Based on the studies that were carried out on the subject of heat pumps, the following conclusions were made:

- ground temperature remains relatively stable throughout the year. It can be used as renewable resource for geothermal heat pumps;
- the term “geothermal heat pump” is a common technical term for heat pumps utilizing geothermal energy which can be represented as a system based on the ground water or soil itself;
- the relevant studies carried out for Cyprus is hardly available;
- therefore, in this research, simulation of GWHP is explored to observe the performance of this system for heating/cooling mode for Cyprus conditions.

Chapter 3

METHODOLOGY

As has been shown in Fig. 3.1 the data related to local conditions are initially gathered. These data include weather conditions, the characteristics of the buildings, and the temperature of the underground water. Once the system has been designed and all the necessary inputs are then determined. TRNSYS software is used to simulate the process and the simulation is explained in details in Chapter 4.

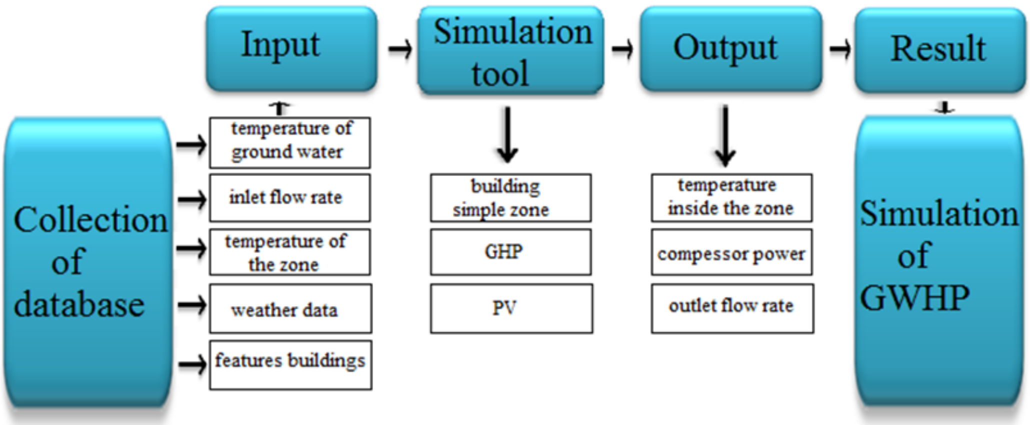


Figure 3.1: Simulation process

3.1 Local conditions

Famagusta is one of the coastal towns which are situated in Cyprus enjoying the Mediterranean weather, with north latitude and east longitude being 35.13° and 33.95° respectively. The population of the city is approximately 40900 people. Its close location to the sea is the main reason for the existence of groundwater at shallow depths. In addition, the amount of rainfall does not influence on this water resource [19]. The temperature of groundwater remains relatively constant; it fluctuates from 18°C to 22°C depending on the season. In accordance with this study the ground water temperature is supposed to be constant at 20°C. Figure 3.2a shows the changes in climatic conditions for Famagusta during 2015 year. But in the simulation the weather data input has been taken for Larnaca, as a typical meteorological year (TMY-2) provided by Meteonorm database in TRNSYS. Weather data for Larnaca shown in Fig.3.2b. The distance between the two mentioned cities (Larnaca and Famagusta) is approximately 40 km. Larnaca, as a Famagusta, has a Mediterranean hot climate. But the difference in average monthly temperatures is about 2.2°C [20], which allows using the data for Larnaca.

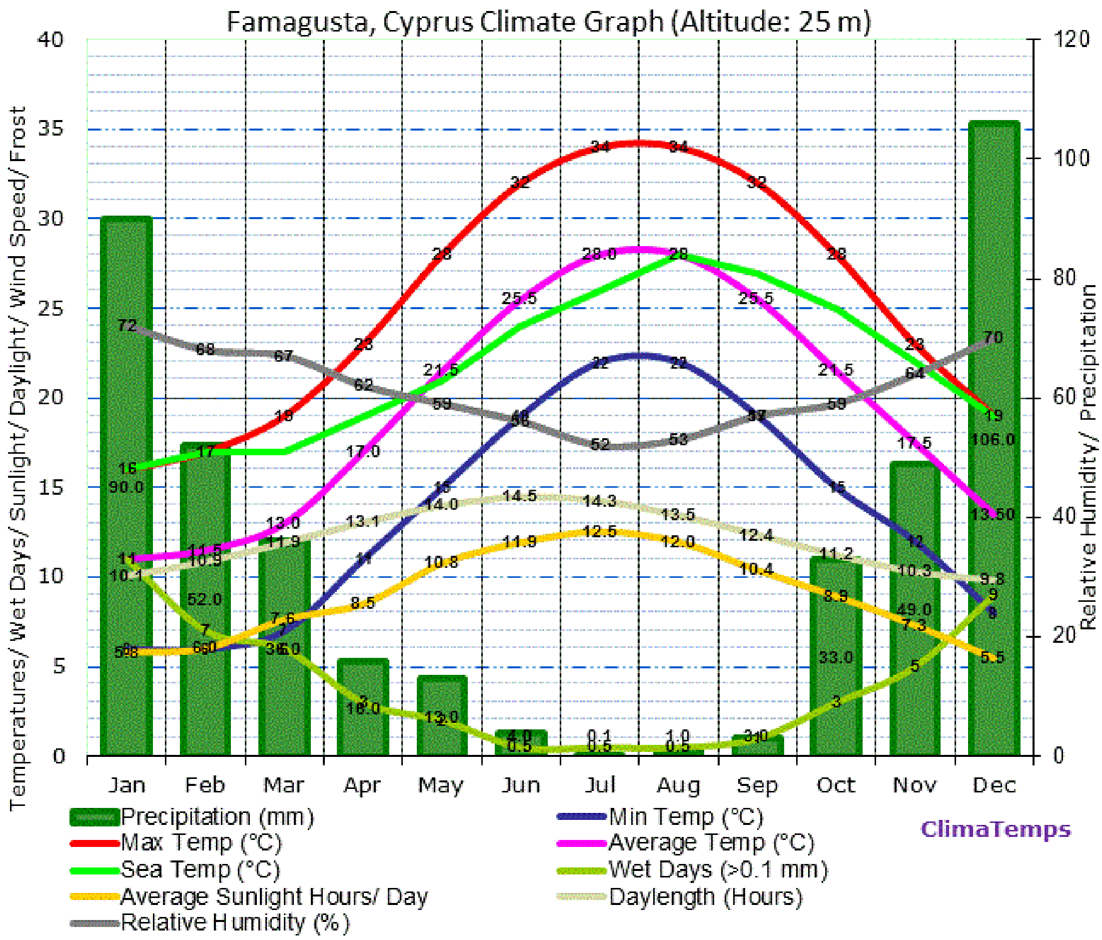


Figure 3.2a: Weather data for Famagusta was taken from Ref. [21]

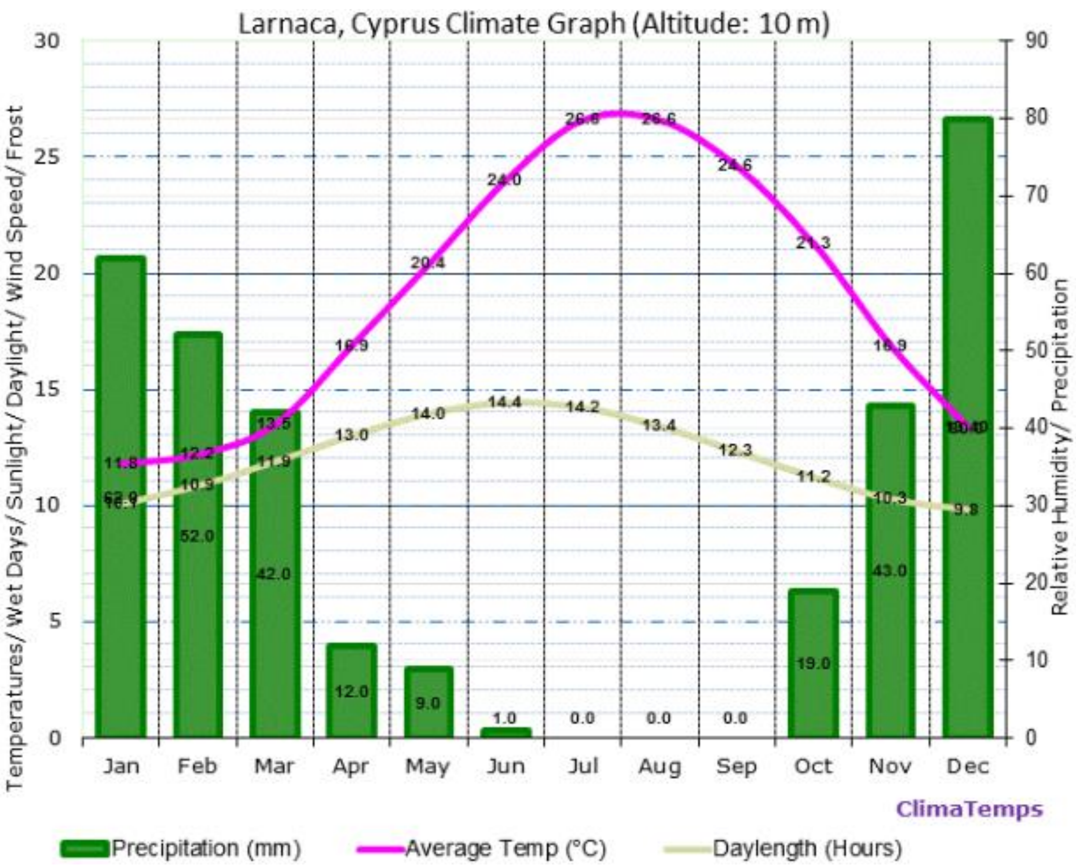


Figure 3.2b: Weather data for Larnaca was taken from Ref. [21]

3.2. Mathematical model

In order to investigate GWHP to maintain a comfortable temperature conditions in the room it is necessary to provide the mathematical equation used in the analysis.

3.2.1 Mathematical model of HP

The heat pump (HP) is mechanism produce heating/cooling and this device includes the main components such as evaporator, compressor, condenser and expansion valve. These components are characterized by various operating parameters particularly under transient conditions.

The COP of HP defined as:

$$COP_{HP} = \frac{Desired\ output}{Required\ input} = \frac{Heating(or\ cooling)effect}{Work\ Input} = \frac{Q_H\ (or\ Q_L)}{W_{net,in}} \quad (3.1)$$

Consisting of four processes, the vapor-compression refrigeration cycle is the most popular cycle for heat pumps [Fig.3.3]. These processes are:

1-2 Isentropic

2-3 Heat rejection with constant pressure

3-4 Throttling in an expansion valve

4-1 Heat absorption with constant pressure

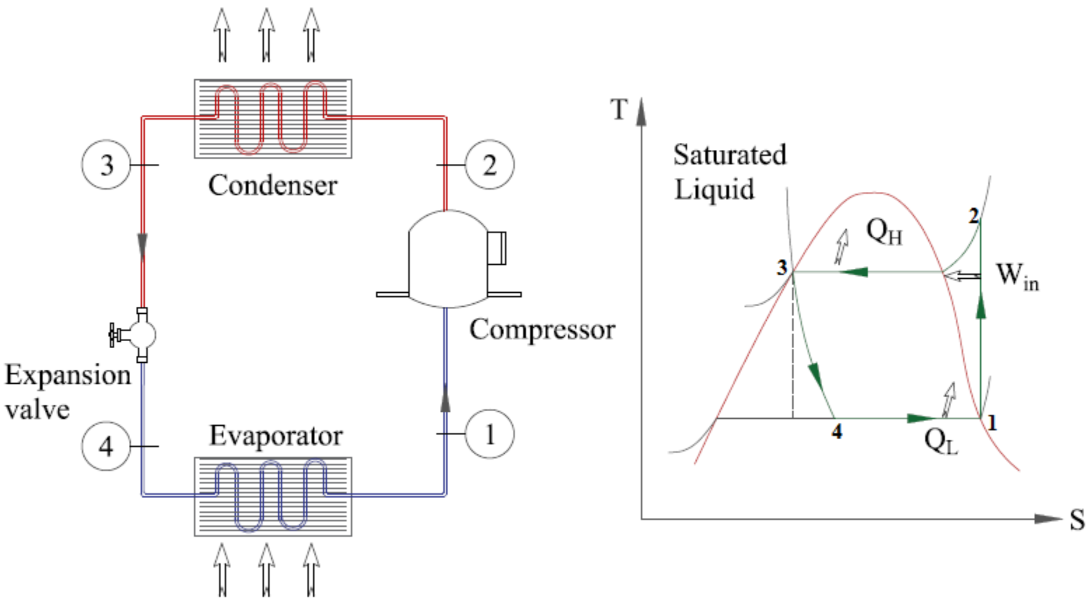


Figure 3.3: Scheme and temperature entropy diagram for refrigeration cycle

Therefore the steady flow energy equation on a unit-mass basis reduces to

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_e - h_i \tag{3.2}$$

In connection with the usage of photovoltaic panels (PV) to drive the compressor of the heat pump, providing the compressor capacity equation is necessary.

Expressing of the compressor power ($\dot{W}_{comp}$) is written as:

$$\dot{W}_{comp} = \dot{m}_{ref}(h_2 - h_1) \tag{3.3}$$

Then the electrical power consumption ($\dot{E}_{comp\ motor}$) of an electric motor is:

$$\dot{E}_{comp\ motor} = \frac{\dot{W}_{comp}}{\eta_{EM}} \qquad (3.4)$$

Where η_{EM} is electric motor efficiency.

The govering equations was taken from Ref. [22].

3.2.2 Mathematical model of the simple zone

A simple single-zone is assumed in which the thermal conductance is evaluated.

The walls are assumed to be facing the four cardinal directions without any inclination.

The wall with external insulation was examined. The suitable materials, which this type of the wall should consist of (include insulation), are:

1. Cement plaster (2, 5 cm);

2. Hollow clay brick (20cm);

3. Insulation layer (2-5cm);

4. Cement plaster (2, 5 cm) [Fig.3.4].

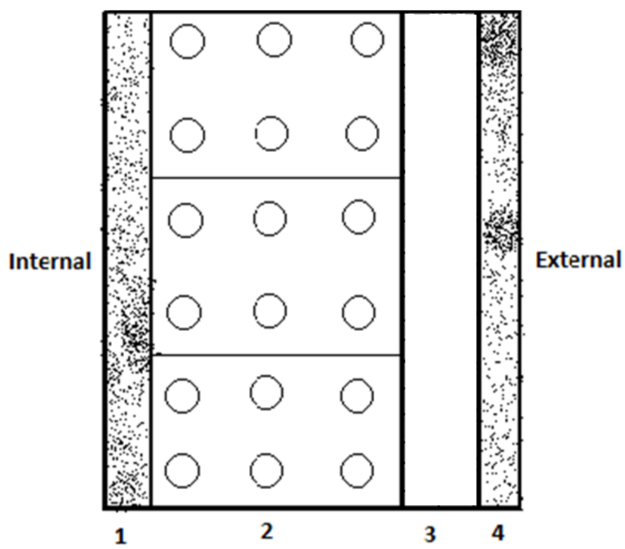


Figure 3.4: View of part of the wall with insulation

Particularly, the calculation is achieved by applying the data for each material from Figure 3.4 separately [Tab. 3.1].

Table 3.1: Data required for the calculation for an externally insulated wall

№	Material	Material thickness (cm)	Thermal conductivity (W/mK)
1	Cement plaster	2,5	1.39
2	Hollow clay brick	20	0.4
3	Expanded polystyrene	2	0.04
4	Plaster	2,5	1.39
Heat flow direction		Horizontal	

To complete the comprehensive understanding of heat transmission characteristics of composite walls, overall heat transfer coefficient (U-value) should be evaluated. The U-value is calculated by using the following formula:

$$U_{value} = \frac{1}{R_{si}+\sum\frac{d_i}{\lambda_i}+R_{se}} \tag{3.5}$$

Where

R_{si} - internal surface resistance between the internal environment and the internal surface of the structural element (m^2K/W),

R_{se} - external surface resistance between the external environment and the external surface of the structural element (m^2K/W),

d_i - material thickness (m),

λ_i - material thermal conductivity (W/mK).

Assume that surface resistances for external insulation wall with horizontal heat flow direction is 0.13 R_{si} (m^2K/W) and 0.04 R_{se} (m^2K/W). Thus considered wall heat transfer coefficient is 0.829 W/m^2K.

3.2.3 Mathematical model of the PV

The favorable location of a researched area allows using solar energy. In this study photovoltaic panels are used to drive compressor motor and according to Atikol et. al a 1kWp system delivers 1980kWh electricity in NC conditions [23]. It is desired to use the GWSHP during day time. Therefore electricity, that the system is provided with, can be supplied from PV panels. To estimate the capacity of PV-system the annual electricity consumption E_{ann} (in kWh) should be obtained from the transient simulation. Thus the total capacity of PV system:

$$W_{PV} = \frac{Annual\ Electricity\ Production\ (kWh)}{1980kWh/kWp} = \frac{E_{ann}}{1980} \tag{3.6}$$

It is known that 1-kW_p occupies an area of 8 m^2 (selected panel area). Then the total area required for PV panels can be estimated from:

$$A_{PV} = \frac{W_{PV}}{8} \tag{3.7}$$

3.3 Simulation tool

The application that was used to achieve the main objective (i.e. the study of the effectiveness of the use of GWHP in Famagusta conditions) is TRNSYS.

TRNSYS is a particularly flexible and graphically based device which is used to simulate the performance of transient systems with a modular structure.

The solution of complex energy problems carried by splitting them into smaller components are referred to ‘‘Types’’. All components have been grouped and configured by means of a virtual interface called as TRNSYS Simulation Studio, and input data entry for the building is carried out by using a special parallel interface. Simulation program allows the user to define the components of the system and how they are related to one another. After that, the simulation center solves a number of algebraic and differential equations, giving the result in the manner that is understandable and easy to read and analyze.

Thus TRNSYS is the most convenient program for solving the task.

Chapter 4

SIMULATION OF GWHP FOR CYPRUS CONDITIONS

This chapter describes the operating principle of the geothermal heat pump, as well as the process of GWHP modeling in TRNSYS step by step.

In addition, photovoltaic panels have been provided to drive the compressor motor and to decline electricity cost.

4.1 Description of the system

The geothermal heat pump is constituted of 3 basic parts: the ground loops that form the heat-exchange medium, a heat-pump unit, and ductwork to deliver the air to the building. [Fig. 4.1]. Open or close loops are a series of pipes, which are not deeply located under the ground. Continuous flow of water, running through these pipes (pumping water from a water source directly into a heat pump and circulate it back to the water source), absorbs or refuses heat within the earth, without requiring the burning of fossil fuels. Generally, the electricity is used to drive the motor of compressor, and to operate fans and a pump. For these needs a solar photovoltaic system is offered as one of the most effective solutions.

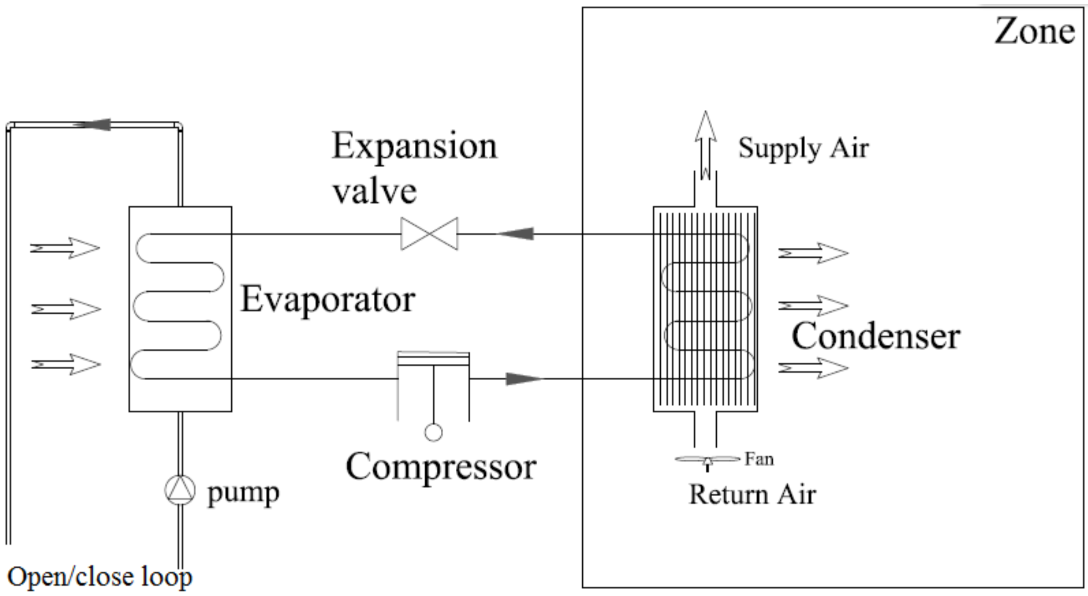


Figure 4.1: Basic scheme of GWHP in heating mode

Thermal pumps and air conditioners have identical components and so it is economically inexpedient to have separately both systems to produce heat and cold for a building. To use one scheme as the thermal pump for heating and the air conditioner for cooling, a reversing valve was added to system of thermal pumps, as shown in Fig.4.2. Thanks to it, in a warm season the condenser, which is located in a zone, works as the evaporator, and in its turn the evaporator which is outside a zone operates as the condenser. This feature of the thermal pump increases its value and need of reviewing of this system in details.

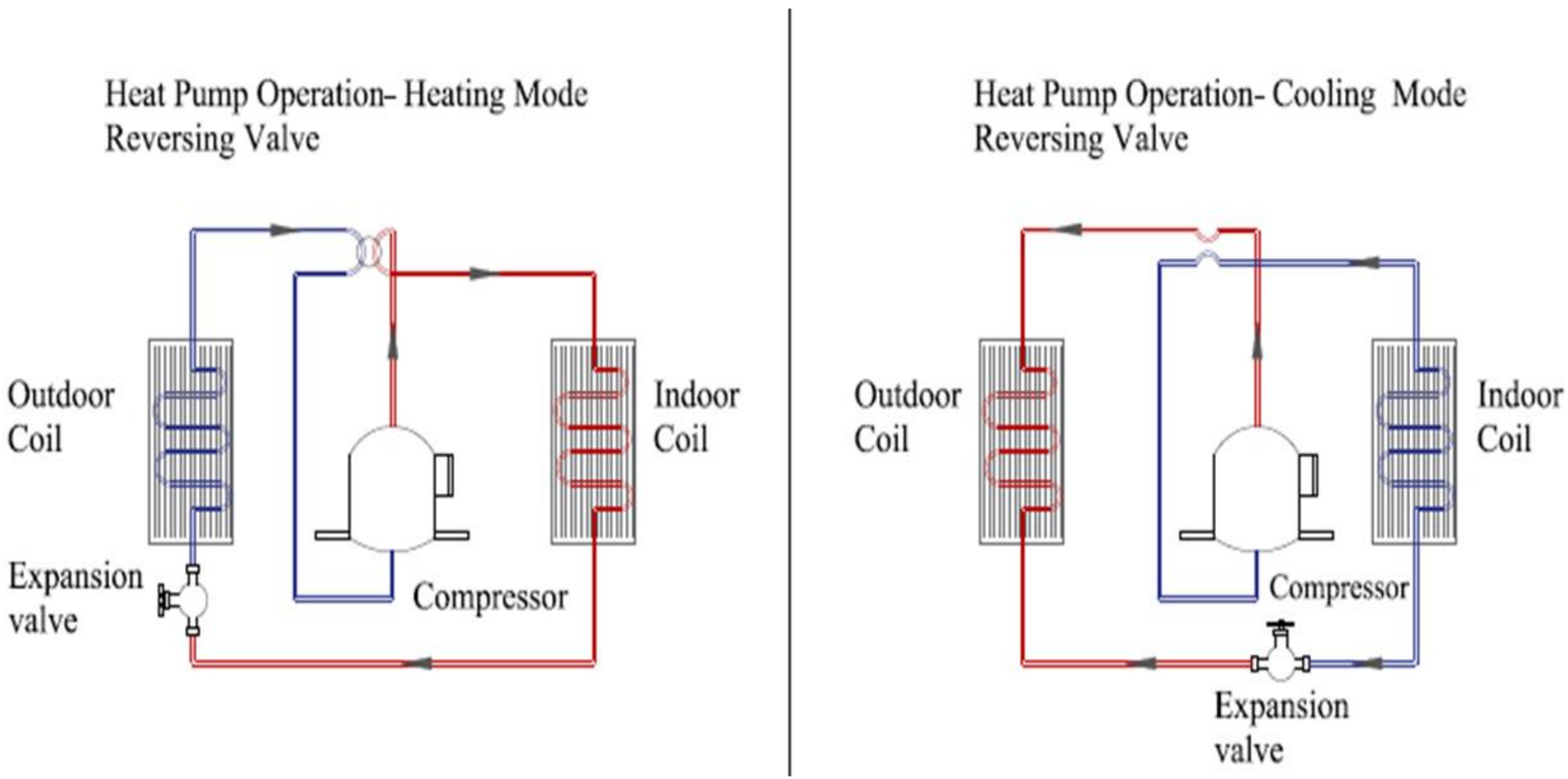


Figure 4.2: Schematic diagram of the heat pump with reversed valve

4.2 Detailed model design in TRNSYS

The first step in simulation design: simple zone corresponding to the objectives of the study has been selected from the list obtainable in the TRNSYS library. The parameters and conditions of the zone meet all the necessary characteristics for the researched area. The next step is creating the heat pump and its connection with the zone in order to achieve a comfortable temperature level.

Type 504b shown in Fig. 4.3 operates in a similar manner to the heat pump explained in Fig. 4.2. This modeling scheme has different components for each step of the calculation process. Moreover, connections between these components implemented appropriately to afford the initial goal defined in section 1.2.

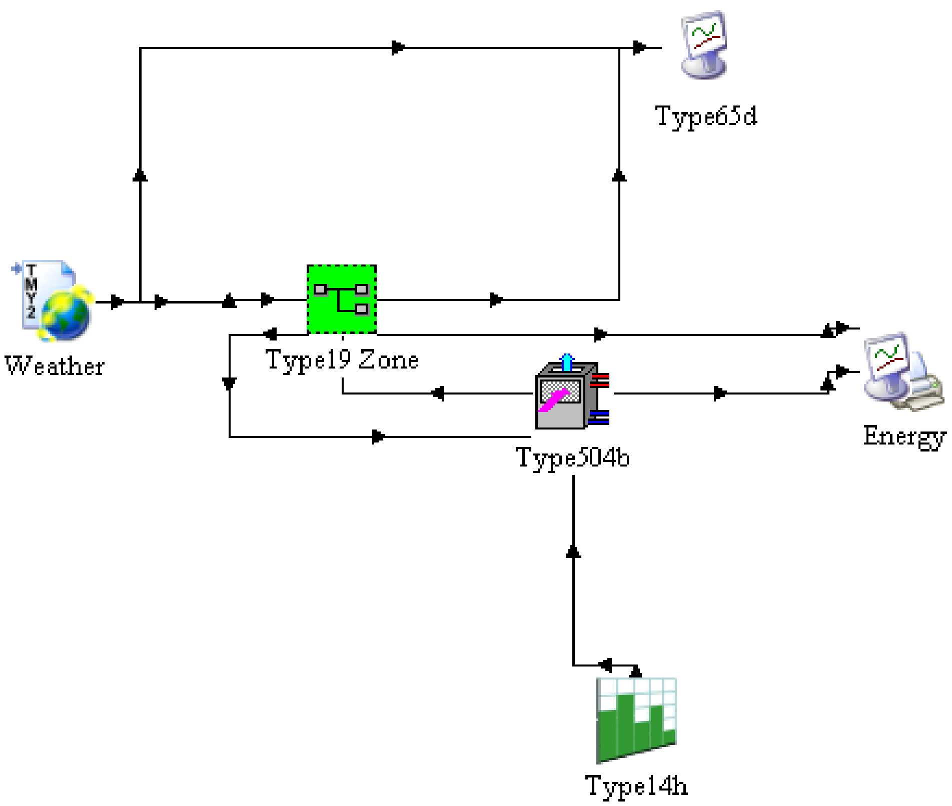


Figure 4.3: Simulation model of GWHP

Table 4.1: Components used in simulation model

Type in TRNSYS	**Type's description**
Type 109	TMY2 (weather data)
Type 65c	Online graphical plotter
Type 19	Temperature level simple zone
Type 14h	Forcing function
Type 504b	Geothermal heat pump

More detail descriptions of used components represented in Appendix A.

The key input data which are essential for modeling of the trivial building's zone are required by weather data and by settings house component. Definitely, Type 109 claims the explanation of the considering location (Cyprus) weather information for a year whereas Type 19 asks the specification of the zone. Moreover, Type 504b (water-source heat pump) was selected for a residential GWHP.

Established parameters for simple zone and GWHP are shown in Tables 4.2 and 4.3.

Type 109-TMY-2

Type 109 stands as Typical Meteorological Year and makes weather data for necessitating place. Generally, this type affords all data associated by other samples, which includes ambient temperature, humidity, all types of radiation.

Type 19- Detailed zone

This type includes walls, windows, roofs and floors, and is used for an assessment of cooling and heating load in the considered zone.

Typical simple zone illustrated on Fig.4.4 and has air volume $60m^2$.

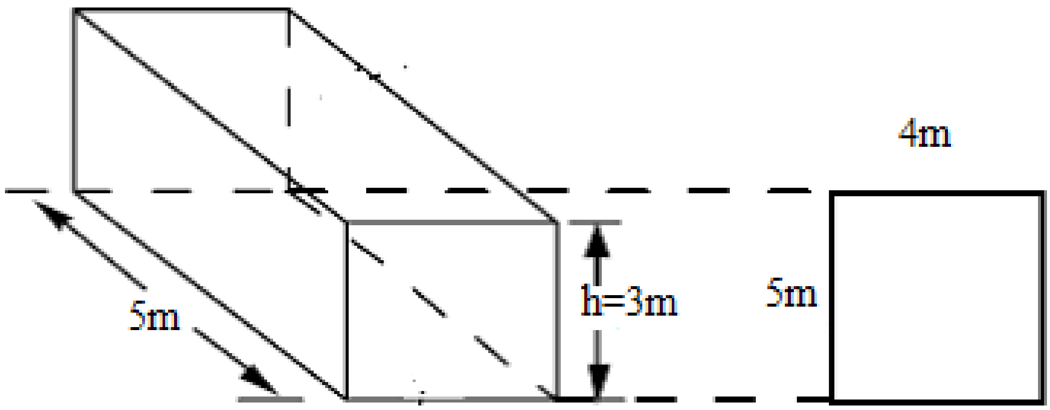


Figure 4.4: Simple zone

Table 4.2: Detailed zone parameters

Volume of air	60 m^3
Initial room temperature (winter/summer)	15/20℃
$Wall_1$ area	11 m^2
$Wall_2$ area	15 m^2
$Wall_3$ area	12 m^2
$Wall_4$ area	12 m^2
Roof area	20 m^2
Windows area	4 m^2
Radiative gains	50 kJ/hr

Type 504b - Water source heat pump

This component represents single-step liquid source heat pump. This model is based on the consumer-provided data files about capacity, and the power which depends on temperature of arriving water, the arriving flow rate of water and flow rate of air.

Schematic diagram of Type 504b in TRNSYS manual [Fig. 4.5] matches Fig. 4.1 and Fig. 4.2.

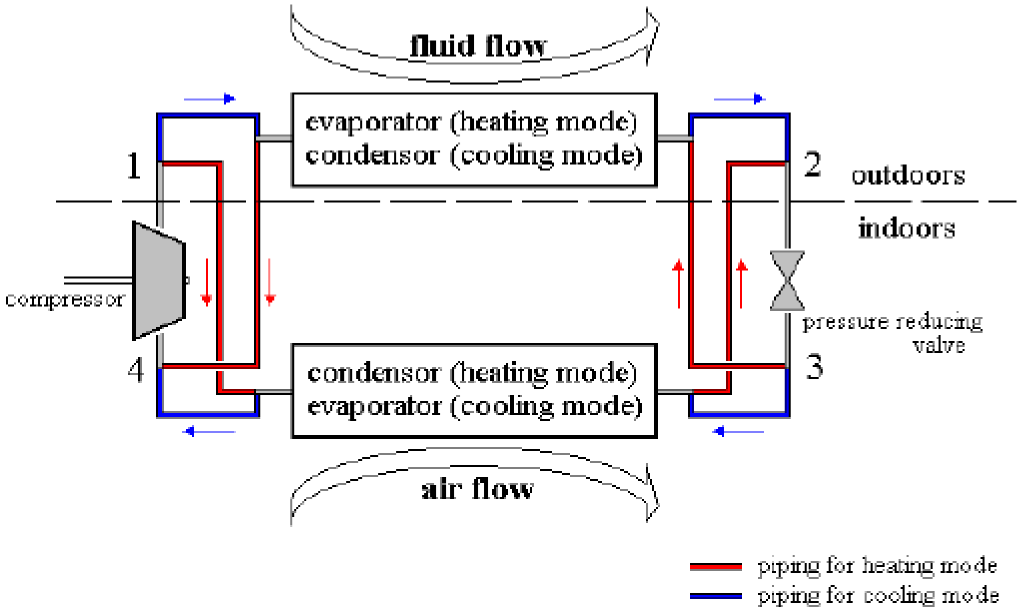


Figure 4.5: Heat pump scheme in TRNSYS manual

Table 4.3 Water source heat pump parameters

Total air flow rate	300 l/s
Inlet liquid temperature	20℃
Inlet liquid flow rate	1000 kg/hr
Return air temperature	20℃
Fresh air temperature	20℃
Fresh air %RH	50%
Fresh air pressure	1 atm.

Type 14-Forcing function

The forcing function defines a time-dependent profile. According to the diagram of operation of the thermal pump in the afternoon (daylight) of type 14h it was organized as follows:

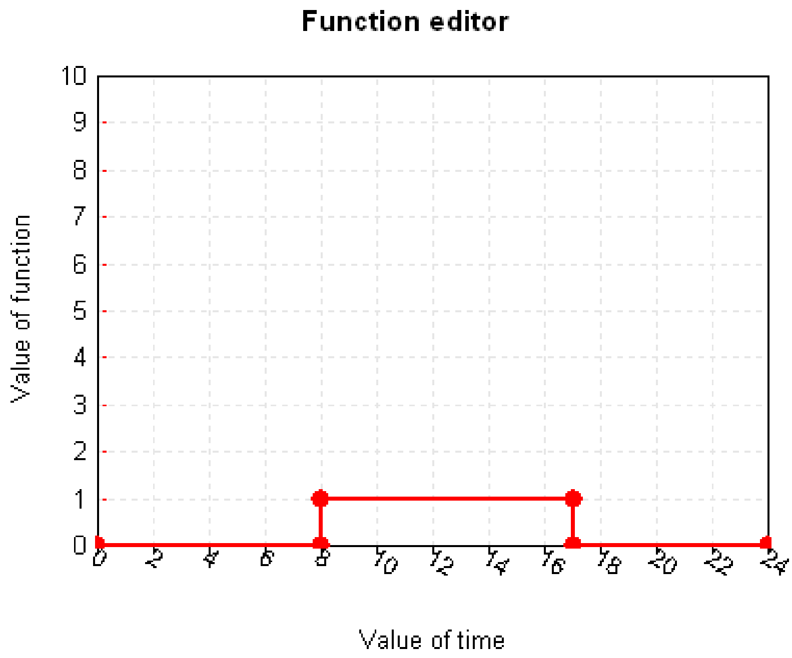


Figure 4.6: A time-dependent profile

Where one value of function means operating time and zero is system release.

Type 65 - Online graphical plotter

Plotter is used to derive the results graphically. Some structure variables, which were selected by user, are demonstrated in a single plot window while the simulation is running.

In order to compare GWHP and air-source heat pump (HP) simulation of HP was carried out on TRNSYS platform [Fig. 4.7]

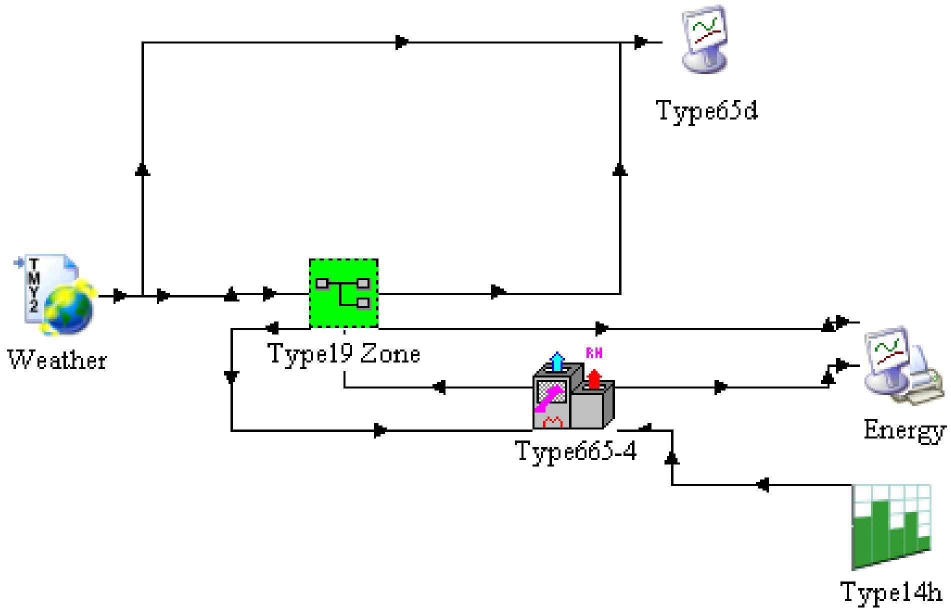


Figure 4.7: Simulation model of ASHP

The difference in the simulation models is a heat pump type. Therefore Type 665-4 was selected as air source heat pump. This type uses the directory of data of the vendor, for simulation of air source heat (air flows on both (the condenser and the evaporator) sides of the device [24].

Chapter 5

RESULT AND DISCUSSION

In this chapter the findings from the study are described and examined.

The simulation was implemented to investigate the performance of GWHP and compare it with ASHP. The data obtained are systematized and analyzed for cooling (summer period) and heating (winter period) mood separately. Furthermore, PV panel's area satisfying the electricity needs of the compressor motor is calculated.

The ambient temperature and zone temperature without applying heat pump are plotted in Fig.5.1 to confirm the need for the heating/cooling system. Due to the fact that 23-25 ° C - the most suitable temperature in summer and 22-24 ° C - the optimum during the cold season [25], it is obvious that summer and winter months, which include period from June to September (simulation time 3624-6552hh) and January-March and December (simulation time 0-2160hh and 8016-8760hh), required extra device to change temperature inside the zone to a comfortable level.

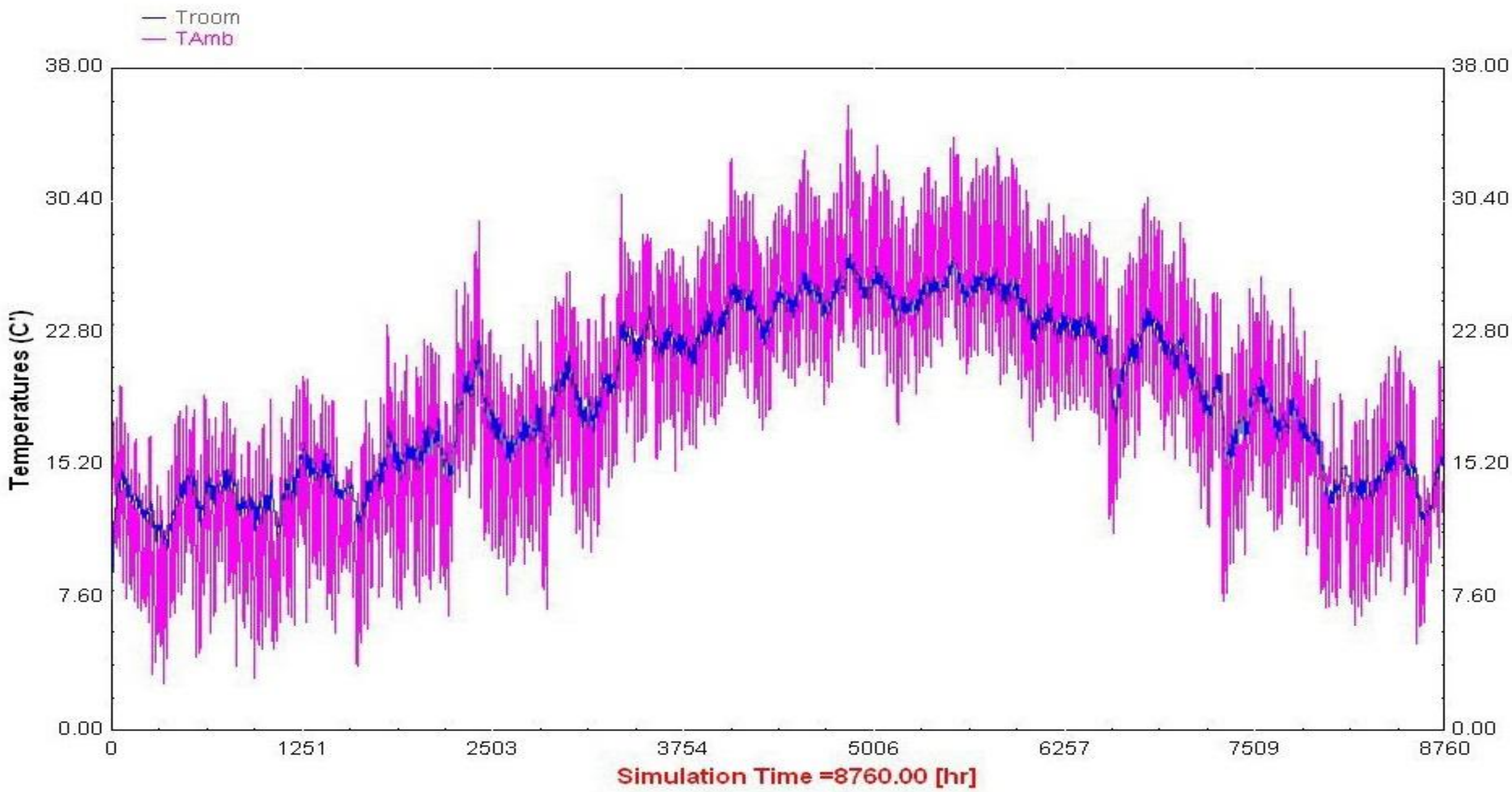


Figure 5.1: The trend of zone and ambient temperature during whole year

5.1 Cooling mode

July 1st and September 30 were the period of temperature, power and COP data collection. During the tested period, the ambient temperature varied between 20℃ and 35℃. Pump operation is carried out according to the schedule presented on fig 4.6. Thus the working hours comprise the period from 8:00 to 17:00, which explains the periodic blue simulation line in the Fig.2. The electricity consumptions in compressor were taken into consideration for PV area size calculations.

Figure 5.2 shows the trend of zone temperature (blue color plot) and ambient temperature (red color plot) plotted on the left Y axis.

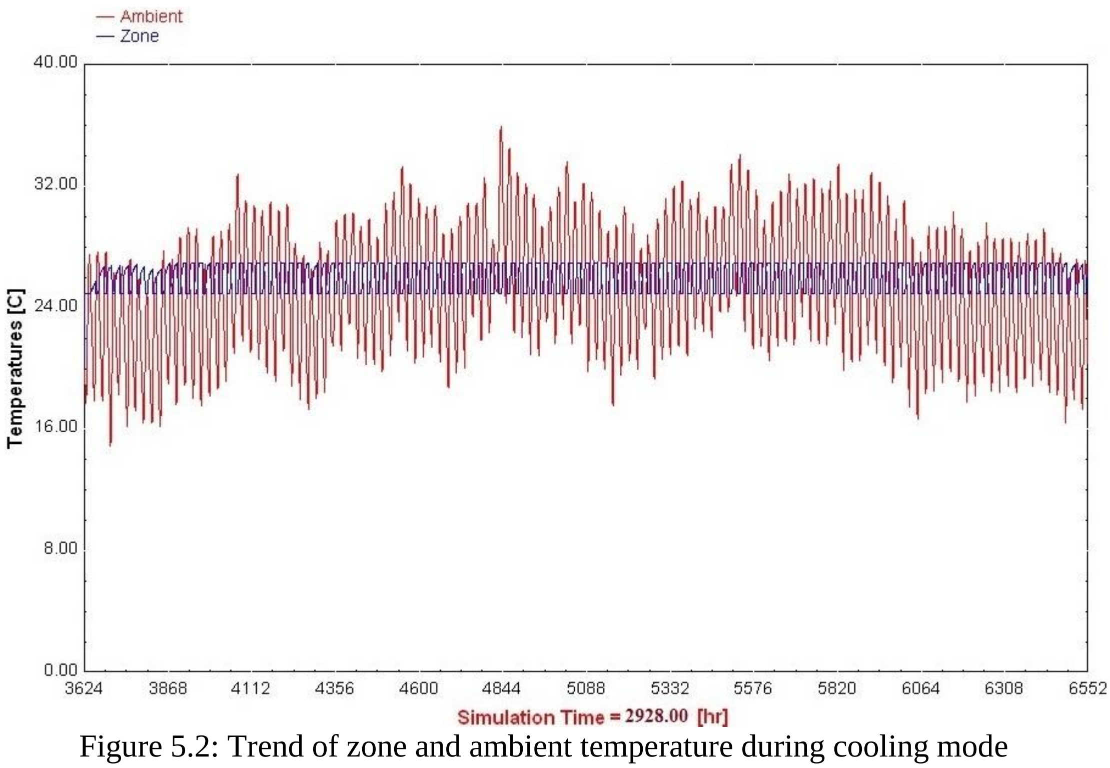


Figure 5.2: Trend of zone and ambient temperature during cooling mode

The coefficient of performance and compressor power curves illustrated in Fig 5.3. From these figures which are below it is clearly seen that compressor power is 3420 kJ/h during the summer months without any changes except the night time the when heat pump doesn't operate. These figures also illustrate that COP reaches 2.9 which than complies with standard average value.

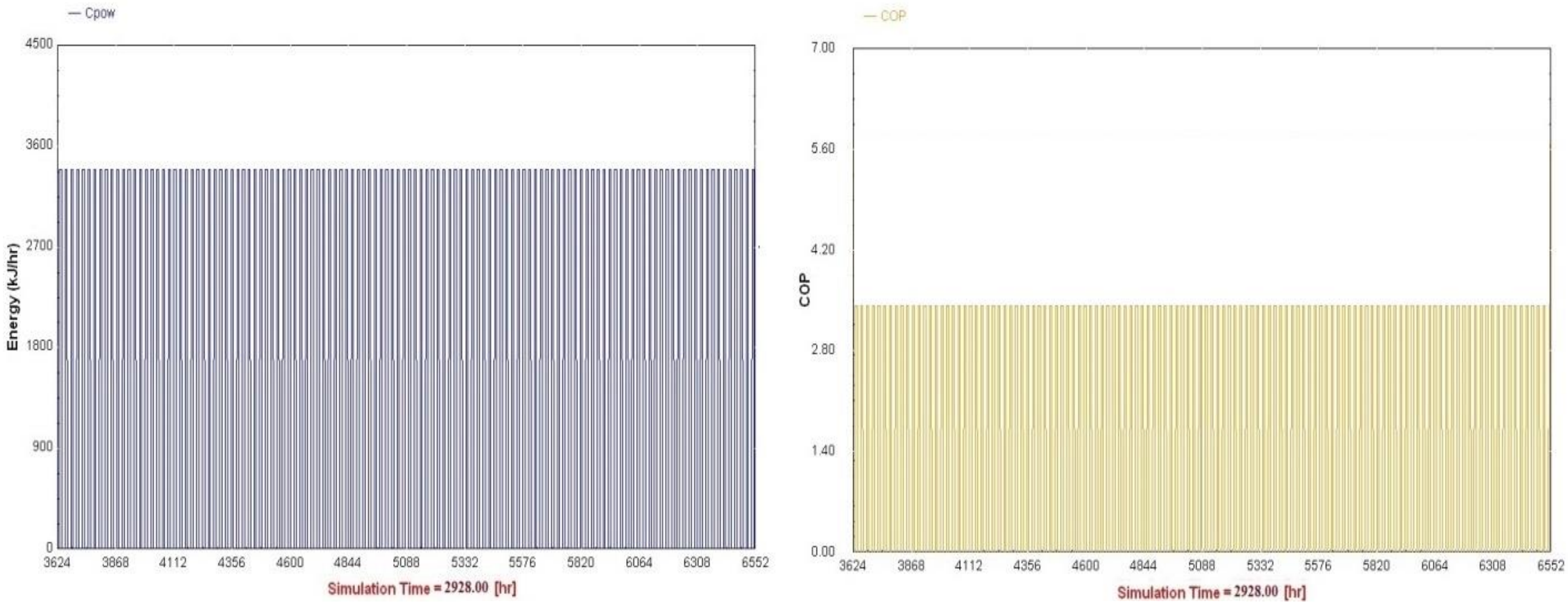
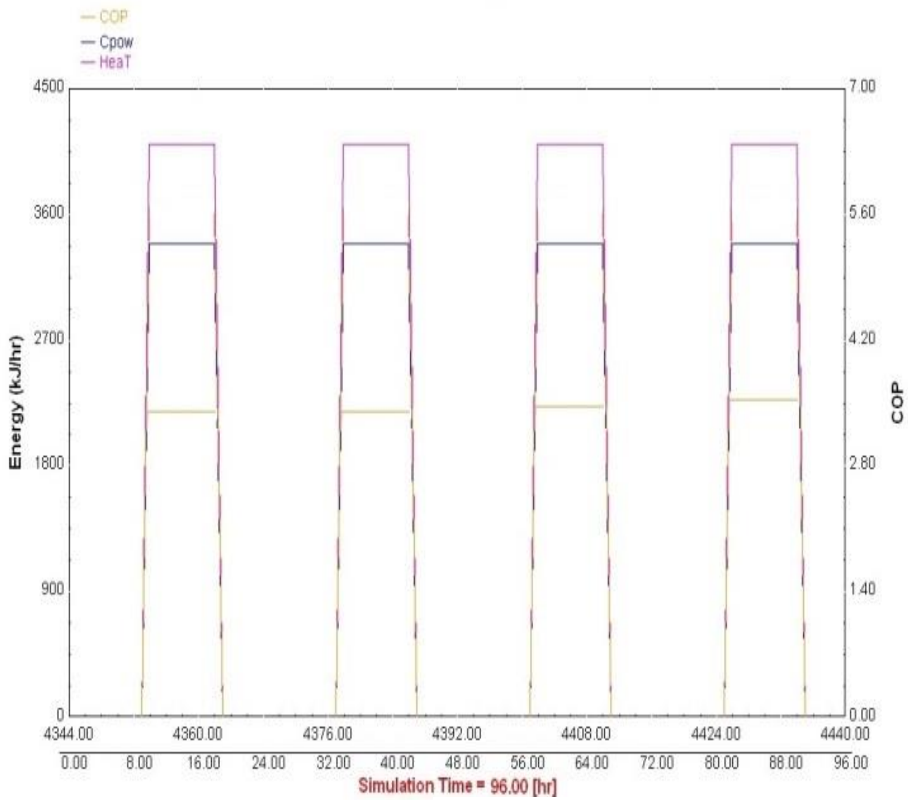


Figure 5.3: Illustration of COP and compressor power of GSHP

To analyze the system in more detail, 4 days in July (1-4 Jul.) were observed. Fig. 5.4 shows the TRNSYS cooling demand of the zone in period of 96 hours. All the variations were done within this time period. From the left side of the figure it is seen that COP, compressor power and heat pump power values are constant within operation hours all four days. In parallel, in the right side of the figure the change of the temperature inside the zone regarding to ambient temperature is depicted. According to this it can be said that the temperature mode is saved at comfort level of 24̊C due to work of GWHP from 8am to 5 pm. At other times due to high outside temperature, the temperature inside the zone increases, but slightly because of heat insulation of the house.



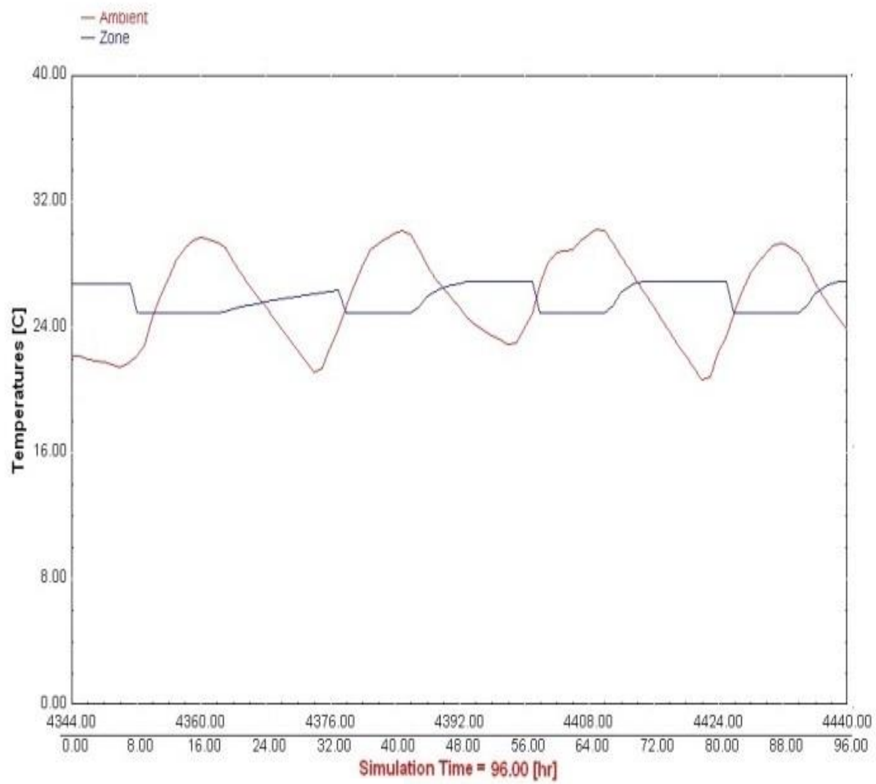


Figure 5.4: Cooling mode in period from 1 to 4 of July for GWHP

Similar to GWHP simulation model, ASHP TRNSYS model was sustained using the parallel way for output data collection at seasonal ambient temperature. In order to ensure the coherence with GWHP model, the cooling period also was estimated to begin on June 1 (3624 h) until September 30 (6552 h). Fig. 5.5 is displayed for TRNSYS simulation for cooling performance evaluation in four days to compare data for two systems.

It is necessary to note the fact that significant differences between temperatures inside the researched area during GWHP and ASHP operation are not visible. The reason is that in settings of simulation home model cooling and heating set points are installed at the same level.

As the left side of the figure are presented the differences between GWHP and ASHP in terms of energy are considerable. The COP of ASHP is 1.78 which is lower than COP of GWHP. The mark of the value of compressor's capacity reaches 4380kJ/h, while the total capacity is 5780kJ/h.

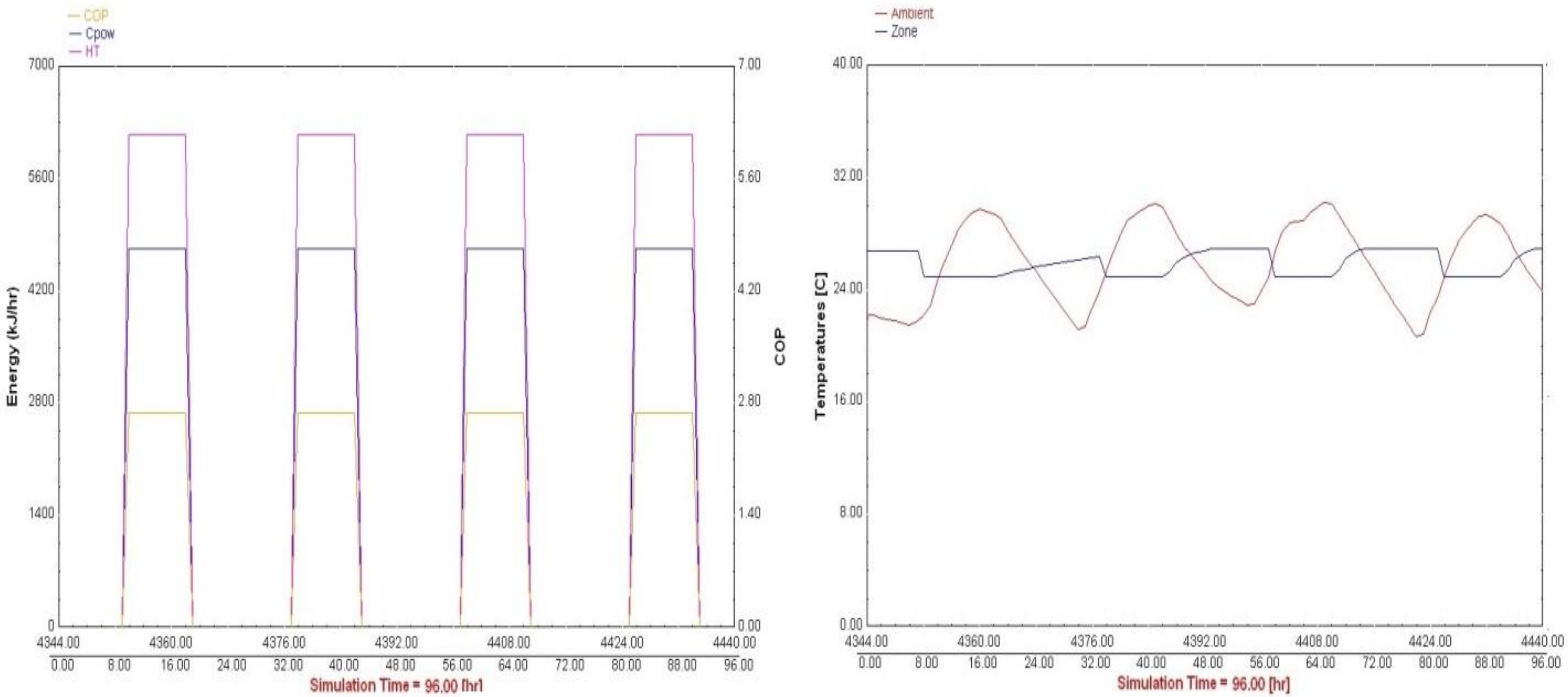


Figure 5.5: Cooling mode in period from 1 to 4 of July for ASHP

5.2 Heating mode

For the yearly GWHP routine, cooling season was supposed to start on December 1 (8016-8760 h) and completed on March 31 (January-March is 0-2160 h) as exhibited on Fig 5.6.

The blue line which indicates the temperature inside the zone increases gradually at the beginning of the year to the required level. This is justified by the beginning of the operation of the HP. The small decrease in temp in the house to 20̊C is associated with cold weather outside.

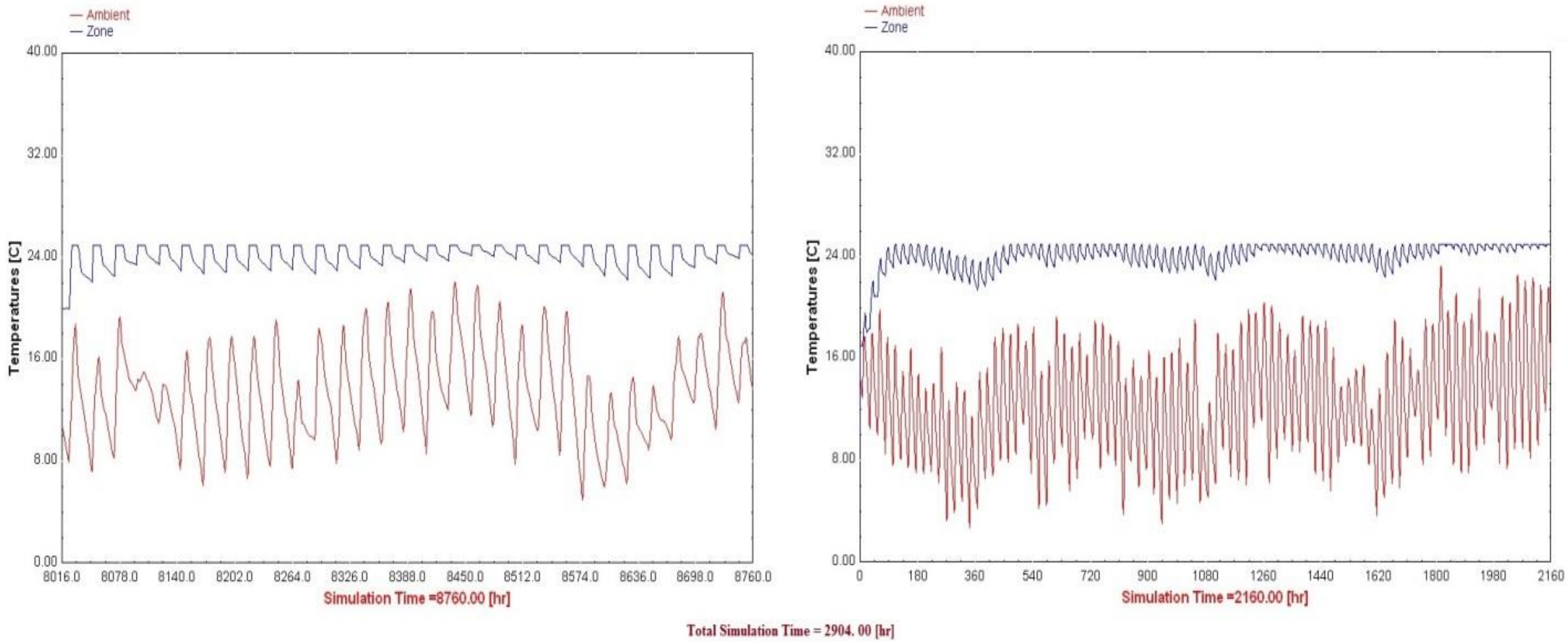


Figure 5.6: Trend of zone and ambient temperature during heating mode

Then it was assumed to select four days for a detailed review of the results in the beginning of January as the coldest period (Jan. 1-4, 0-96hs). It's indicated from the Fig. 5.7 that COP is much more during winter season in contrast to summer period and it is 5.6. Also, the heat pump reaches its peak capacity not immediately that means that mark of the value of compressor and heat pump increases during the operation time of 9 hours. This should be considered in more detailed economic and power calculation.

As it's mentioned above the temperature of the zone reaches a required level not right away, and as it is shown in the right part of the figure the heat pump comes out to a proper level of work after 16 hours of operation.

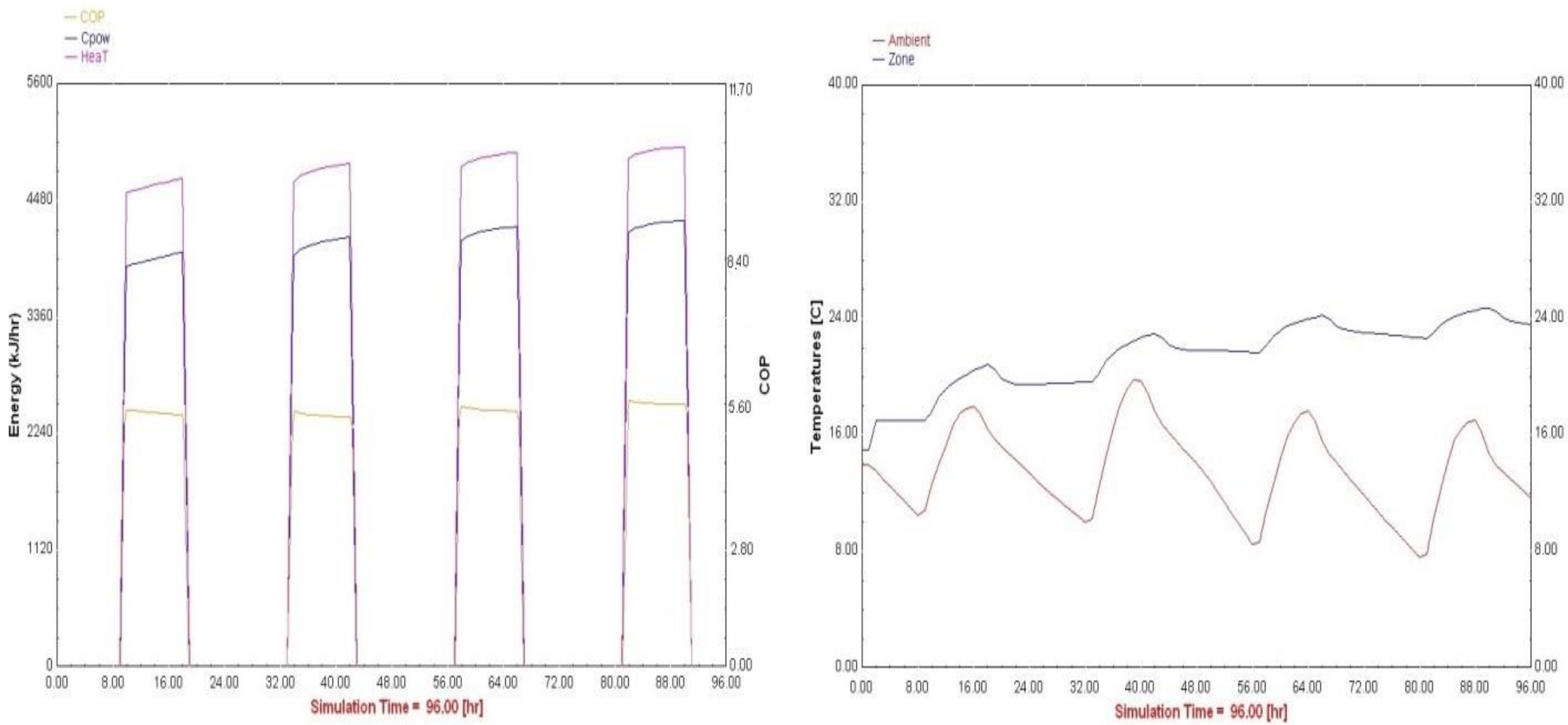


Figure 5.7: Heating mode in period from 1 to 4 of January for GWHP

The same way for data collection was recorded for ASHP, which has also been working from the 1st to 4th January in daytime period [Fig.5.8]. What is more as the blue line indicates (which plot inside temperature of the zone) ASHP creates pleasant temperature conditions at its 1st operational day.

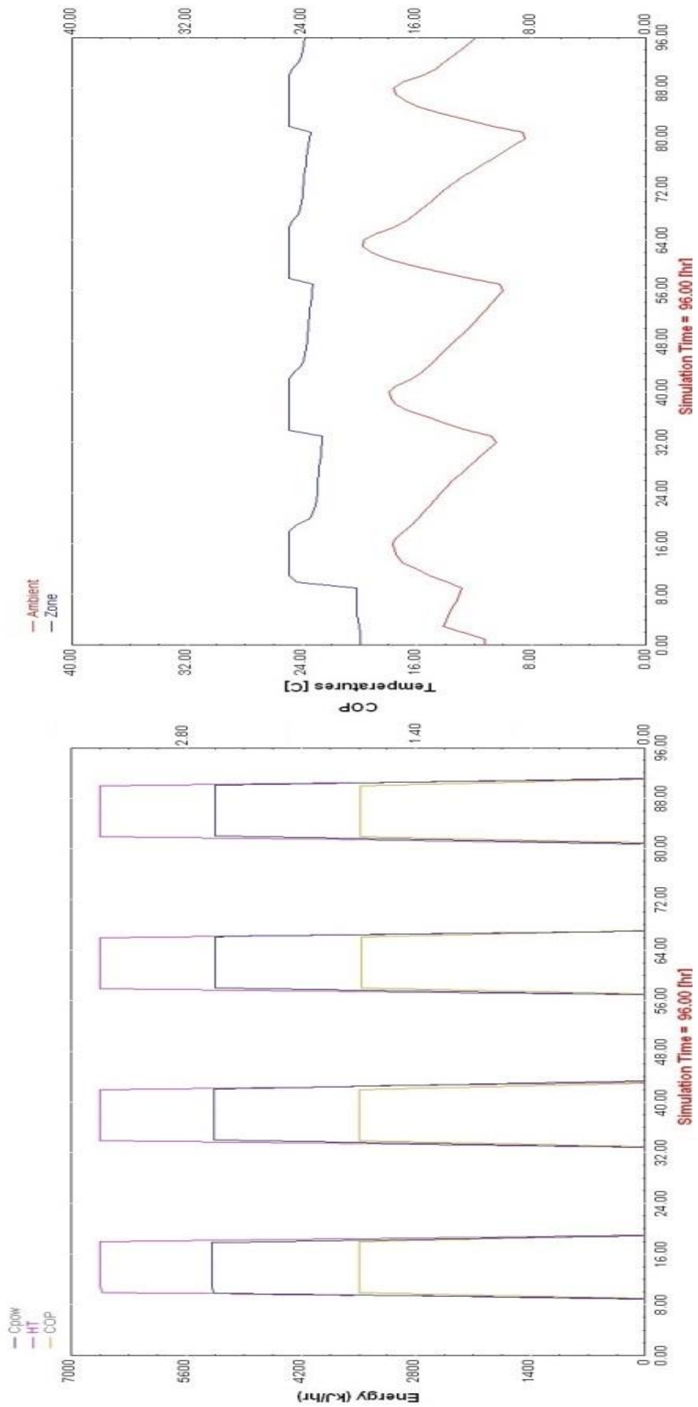


Figure 5.8: Heating mode in period from 1 to 4 of July for ASHP

It should also be mentioned that COP of the ASHP is 1.75 which is low than range of standard COP values for this type of heat pumps. In addition, compressor and heat pump powers are 4500kJ/h and 5900kJ/h respectively.

5.3 Summer and winter performance result discussion

One of the remarkable findings is shown in Fig. 5.9. The comparison of the COP of the two cooling/heating systems has led to following conclusions: (1) the difference between simulation GWHP and ASHP model is about 1.12 in the summer period, which is show that COP of GWHP greater by 63% than COP of ASHP. (2) Likewise, the term for heating mode the difference is about 3.85, which is indicates that the difference in COP is 214%. It specifies the profitability of using GWHP for heating in the conditions of Famagusta. Specific differences in the beneficial effect are not observed.

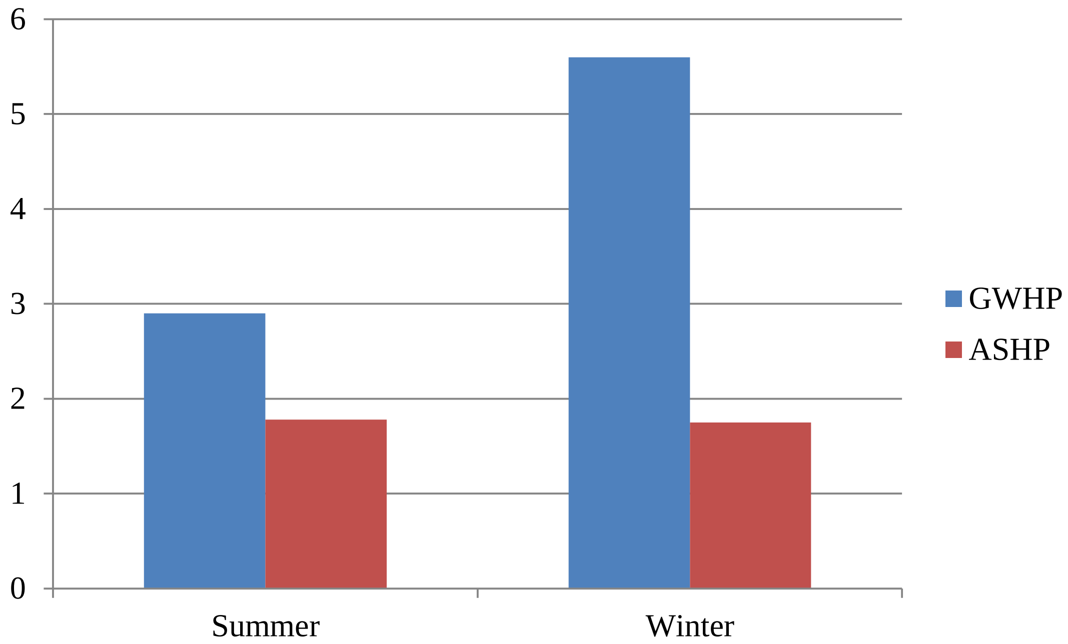


Figure 5.9: Comparison between COP of GWHP and ASHP

Another aspect of investigating the performance of GWHP is to count the amount of saved electrical energy the help of using PV panels. The calculation was made according to formulas 3.6 and 3.7. The estimation showed that the pump capacity of the compressor to 3420 kJ/h requires 8.4 kW of electricity per day (only operation hours were taken into account). Two PV panels of $8m^2$ each are required to meet the ‘electrical needs. Thus economically applying photovoltaic panels, which drive compressor motor of GWHP, can save approximately $5794 per year in term that the cost of 1kWh of electricity in Famagusta is 0.45tl.

5.4 Economic analysis

To investigate the efficiency and expediency of GWHP in Cyprus cost of production of the same amount of energy using the old method (ASHP) and new (GWHP) one were taken into comparison.

In comparison with the air-conditioning systems, in such rooms as refrigeration, boiler, air-conditioning, and bulky pipes for water and ventilation are not desperate for GWHP. The system can be put together in the facility, and it leads to decreasing the adjusting work on site. The temperature of the water in the pipeline of the heat pump system is standard; therefore there is no insulation for the cooling water pipe, which causes reducing the cost of insulating materials. Also the cost of the PV panels needed to drive compressor motor in GWHP was included to initial investment.

After taking all the good points and downsides of the question into account the following calculations were made.

The initial investment is \$ 6390 and \$4300 for GWHP and ASHP respectively and the purchase of major equipment with transportation and installation is included. According to this research, the cost of PV system also included to initial investment. In GWHP case every four years after the installation of required scheduled maintenance (\$ 80), and after 12 years of service, these costs will rise to 100. After 15 years residual value will be 639\$ (10% of purchase price).

GWHP and ASHP average prices are taken from Ref.[26].

5.4.1 Economic analysis governing equations

The NPV is calculated using the formula:

$$NPV = \sum PV(savings) - \sum PV(cost) \tag{5.1}$$

Savings-to-investment ratio SIR:

$$SIR = \sum PV(Annual\ savings) \,/\, \sum PV(Life\ cycle\ investment) \tag{5.2}$$

Simple Payback Period SPP:

$$SPP = {}^{initial\ investment}\!/_{Annual\ Savings} \tag{5.3}$$

Present Value of Annual Savings PV_{AS}:

$$\mathrm{PV} = \sum_{t=1}^{T} \mathrm{AS} * 1/(1 + \mathrm{r})^{\mathrm{t}} \tag{5.4}$$

Life Cycle Investment PV_{LCI}

$$PV = \sum_{t=10}^{T} LCI * 1/(1 + \mathrm{r})^{\mathrm{t}} \tag{5.5}$$

5.4.2 Cost analysis

Table 5.1: Economic analysis excel sheet, Input data required to calculate NPV, SIR, SPB and IRR. Comparison of GWHP system (new) and ASHP system (old)

Year	New	Old	Net Amount
0	$6 390	$4 300	$2 090
1			$0
2			$0
3		$200	-$200
4	$80		$80
5			$0
6		$200	-$200
7			$0
8	$80		$80
9		$200	-$200
10			$0
11			$0
12	$100	$250	-$150
13			$0
14			$0
15	$90	$230	-$140
16			$0
17			$0
18			$0
19			$0

Annual Savings	$178
Discount Rate	7%
Analysis period (years)	15
Residual value	$639

The Life Cycle Cost Analysis calculates PV_{AS} and PV_{LCI}.

Table 5.2: Life Cycle Cost Analysis

Investments								
Year	0	1	2	3	4	5	6	7
Net Life Cyle Investments	$2 090	$0	$0	-$200	$80	$0	-$200	$0
PV Life Cycle Investments	$2 090	$0	$0	-$163	$61	$0	-$133	$0
Σ PV Life Cycle Investments	$1 494							

Table 5.2 continue: Life Cycle Cost Analysis

Investments	8	9	10	11	12	13	14	Residual
Year	$100	-$150	$0	$0	-$80	$0	$0	-$739
Net Life Cyle Investments	$58	-$82	$0	$0	-$36	$0	$0	-$268
PV Life Cycle Investments								
Σ PV Life Cycle Investments								

To find out the economic feasibility of the investigating system the calculation of NPV, SIR, IRR and SPP are required. Table 5.3 indicates the outputs which are mentioned above.

Table 5.3: Outputs

Results	**OUTPUTS**
Net Present Value (NPV)	**$ 127**
Savings-to-Investment Ratio	**1,1**
Internal Rate of Return (IRR)	**8%**
Simple Payback (years)	**11,7**

Based on these results it can be argued that the GWHP system is feasible to invest in this project. Despite the large initial investment, the system pays off within 11, 7 years. Moreover NPV and SIR are more than 0.

By way of conclusion, it is obviously that from financial point of view the challenging technology is significantly profitable (economically feasible).

Chapter 6

CONCLUSION

The target of this thesis is to explore the performance of GWHP in Famagusta conditions and evaluation of advantages of using them for residential buildings. The main goal was to develop a simulation model for evaluating the performance of the GWHP in order to achieve a space comfortable temperature level. Moreover the possibility of using solar photovoltaic power to drive the heat pump compressor's motor has been considered.

To obtain the aims TRNSYS software has been used to simulate the process. From the Fig. 5.1 it is observed that the main periods of use of the heat pump are the winter and summer months. Energy consumption, zone and ambient temperatures, COP, the compressor power were analyzed and enrolled on selected days of January 1-4 (for winter period) and July 1-4 (summer period). To discover the performance of GWHP, it was compared with ASHP.

The coefficient of performance of the GWHP was estimated to be 2, 9 during cooling mode and 5, 6 during heating mode while the COP of ASHP was 1, 79 and 1, 75 for summer and winter respectively. To sum up, following conclusions was perfomed: COP of GWHP greater by 63% and 214% than COP of ASHP in summer and winter period accordingly.

Comparing the economic aspect of both systems was noticed that GSHP can expect to save around $538 per year through the use of PV panels. It was calculated that installing PV panels with 16 m^2 can produce that amount of electricity which required to drive compressor (8,245 kWh for 9 working hours per day according to schedule). In addition, the main economic indicators of the GWHP, such as NPV and SIR, is more than one plus small pay-back period (11, 7 years) and as a result, system has profitable benefits.

Implications of this research indicate that there is a need for a deeper study of the issue, especially for Cyprus conditions.

This study can promote the development of heat pumps in the given locality and motivate for further study. Furthermore, the executed simulation model in TRNSYS can serve as a basis for a more detailed modeling.

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APPENDIX

Appendix A: Description of used components in simulation design

Type in TRNSYS	Name of type	Type description
Type 109	TMY2 (weather data)	This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to a desired system of units and processing the solar radiation data to obtain tilted surface radiation and angle of incidence for an arbitrary number of surfaces. In this mode, Type 109 reads a weather data file in the standard TMY2 format. The TMY2 format is used by the National Solar Radiation Data Base (USA) but TMY2 files can be generated from many programs, such as Meteonorm.
Type 65d	Online graphical plotter	The online graphics component is used to display selected system variables while the simulation is progressing. This component is highly recommended and widely used since it provides valuable variable information and allows users to immediately see if the system is not performing as desired. The selected variables will be displayed in a separate plot window on the screen. In this instance of the Type65 online plotter, data sent to the online plotter is automatically

		printed, once per time step to a user defined external file. Unit descriptors (kJ/hr, kg/s, degC, etc.) are NOT printed to the output file.
Type 19	Temperature level simple zone	This model is useful for estimating heating or cooling loads for a single zone. Walls, windows, flat roofs, doors, and floors are included in this component. The set of equations for heat transfer from and within the zone are formulated in a matrix and solved in a computationally efficient manner each simulation timestep.
Type 14h	Forcing function	In a transient simulation, it is sometimes convenient to employ a time dependent forcing function which has a behavior characterized by a repeated pattern. The pattern of the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle. Linear interpolation is provided in order to generate a continuous forcing function from the discrete data. The cycle will repeat every N hours where N is the last value of time specified. While the code of Type14 is entirely general, this version of the component uses dimensionless units so that it too can be used in a very generic manner.
Type 504b	Geothermal heat pump	This component models a single-stage liquid source heat pump with an optional desuperheater for hot

		water heating. The heat pump conditions a moist air stream by rejecting energy to (cooling mode) or absorbing energy from (heating mode) a liquid stream. This heat pump model was intended for a residential ground source heat pump application, but may be used in any liquid source application.
Type 665-4	Air source heat pump	Type665 uses a manufacturer's catalog data approach to model an air source heat pump (air flows on both the condenser and evaporator sides of the device. The model includes mixing algorithms and damper settings so that the indoor air may be the result of two streams from different sources (recirculation and makeup air for example. In heating mode, the device is equipped with one of three auxiliary heater types: no auxiliary heat available, two element electric auxiliary heat, or gas fired auxiliary heat. The model is also equipped with a capacity multiplier parameter so that the heat pump may be quickly resized without having to resort to finding new data files.