ESTIMATING THE SEASONAL COEFFICIENT OF PERFORMANCE OF HEAT PUMP WATER HEATER IN NORTH CYPRUS

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCHENCES OF NEAR EAST UNIVERSITY

By
AHMAD SABO MUHAMMAD

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

NICOSIA, 2016

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Approval of Director of Graduate School of
Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify that, this thesis is satisfactory for the award of the degree of Master of Science In Mechanical Engineering

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I hereby declare that all information in this document has been obtained and presented in agreement with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name:

Signature:

Date:

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I am indeed most grateful to my parents Late Alhaji Sabo Muhammad and Hajiya Khadijah Muhammad whose constant prayers, love, support and guidance have been my source of strength and inspiration throughout these years.

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To my Parents

ABSTRACT

In this research a method was devised in order to estimate the maximum possible COP_{hp} for a heat pump water heater by employing a number of serial reversible Carnot heat pumps. Each increases the water side temperature only by 1℃ which is negligible.

Also COP_{hp} for both the reversed Carnot cycle operated as a heat pump and that of the ideal vapor compression refrigeration cycle were determined by using the parameters i.e. the condensation and evaporation temperatures, and the parameters were used in the region of interest (North Cyprus). The values are calculated and represented graphically and as well compared. For a heat pump water heater which is available in North Cyrus market (Aldea AL- IPB 190).SCOP is obtained theoretically for local usage conditions.

For five months period i.e. from November 2006 – March 2007 the calculations based on this five months were used for the comparism with another different heating system other than solar water heaters i.e. the electric water heaters.

Furthermore, in this study the metrological data for Nicosia from November 2006 – March 2007 were obtained from the North Cyrus metrological laboratory. For three different working mode of the unit, the water is to be heated for the range of temperature 15℃ – 45℃ , 15℃ – 55℃ *and* 15℃ – 60℃ . Daily COP values were obtained for daily minimum surrounding temperatures, circadian average and daily maximum surrounding temperatures, and were obtained by using the COP surrounding temperature graph given by the user's manual of the unit, and SCOP was defined based on the values of the five months Period with COP values.

Finally, for heating the water, electric consumption cost is compared by using the electric heater and the Aldea heat pump cases only by considering criteria and payback period was obtained for the heat pump unit.

Keywords: Heat pump water heater; heat pump; reversed Carnot cycle; COP; SCOP

ÖZET

Bu çalışmada bir ısı pompası su ısıtıcısına yönelik en yüksek performans katsayının belirlenmesi için bir hesplama yöntemi önerilmiştir. Bu yöntem her biri su tarafında sadece 1°C'lik ihmaledilebilir bir sıcaklık farkı yaratan, seri olarak çalışan bir dizi tersinir Carnot ısı pompasını içermektedir.

Ayrıca, ısı pompası şeklinde kullanılan ters Carnot ve İdeal Buhar Sıkıştırmalı Soğutma Çerimlerine ait COP_{hp} değerleri, ilgi çalışma aralığında çevrimlerdeki sabit yoğuşma ve buharlaşma sıcaklıkları parametre olarak kullanılarak hesaplanıp, grafiksel olarak verilmiş ve karşılaştırılmıştır.

Kuzey Kıbrıs piyasasında mevcut bir ısı pompası su ısıtıcı için (Aldea AL- IPB 190) lokal kullanım koşullarındaki Sezonluk Performans Katsayısı SCOP, teorik olarak elde edilmiştir. Hesplama, sıcak kullanım suyu elde etmek için güneş enerjisi dışında bir başka ısıtma sisteminin yaygın olarak kullanıldığı Kasım – Mart ayları arasındaki beş aylık bir periyodu baz almaktadır. Çalışmada Lefkoşa için Kuzey Kıbrıs Türk Cumhuriyeti Meteoroloji Dairesinden temin edilmiş Kasım 2006 – Mart 2007 dönemine ait meteorolojik veriler kullanılmıştır. Ürüne ait üç farklı çalışma şekli için (suyun 15°C'den 45°C'ye ısıtılması, suyun 15°C'den 55°C'ye ısıtılması, suyun 15°C'den 60°C'ye ısıtılması) günlük en düşük, günlük ortalama ve günlük en yüksek dış ortam sıcaklıklarında ürünün kullanma kılavuzunda belirtilen Performans Katsayısı - Dış Ortam Sıcaklığı grafiği kullanılarak günlük Performans Katsayıları belirlenmiş ve bunların beş aylık periyottaki ortalama değerleriyle Sezonluk Performans Katsayısları elde edilmiştir.

Son olarak suyun elektrikli ısıtıcı ve Aldea ısı pompası kullanılarak ısıtılması durumlarındaki elektrik tüketim maliyetleri karşılaştırılmış ve sadece bu kriter göz önüne alınarak ürün için bir geri ödeme süresi elde edilmiştir.

Anahtar kelımeler:Isı pompası su ısıtıası;Ters Carnot çevırmı;Isı pompası;COP;SCOP

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ABBREVIATIONS AND SYMBOLS

WHs: Water heaters

HPs: Heat Pumps

HPWHs: Heat pump water heaters

COP_{hp}: Coefficient of performance of heat pump

SCOP: Seasonal coefficient of performance

ASHP**:**Air source heat pump

$W_{net,in}$: Net work done on the system

Q_{out}: Useful work done

T_H: High temperature or the condenser temperature

T_L: Low temperature or the evaporator temperature

h:Enthalpy

IVCRC: Ideal vapor compression refrigeration cycle

N:Number of stages

Ti: Initial temperature for the tank

T_f: Final temperature for the tank

ΔT**:**Change in temperature

T_{max}: Maximum temperature

T_{avg}: Average temperature

T_{min}: Minimum temperature

C_P: Specific heat capacity of water

M:Mass of water

RCC: Reversed carnot cycle

CHAPTER 1
INTRODUCTION

1.1 Introduction

Hot water supply in residential buildings, is for both public and commercial purposes among the largest energy end uses that accounts for approximately 19-50% of the sum total of the energy consumption of countries worldwide, for which there is a significant ability for energy savings (Abel et al., 2015). Most of the residential water heaters (WHs) in usetoday are equipped with conventional heaters that generate heat in exchange by consuming fuels or electricity. For example, the installation and operation of electric water heaters seem convenient, but the overall efficiency of the conversion process i.e. from the potential energy of fossils fuels into electric energy, then to thermal energy is absolutely low, Compared to those WHs, Heat pump (HP) water heating system can supply much more heat with just the same electric input used for conventional heaters (Arif and Yildiz, 2009).

1.2 Water Heaters

Water heaters are efficient way in which water is been heated and supplied to homes and other places for various uses, depending on the consumer choice and demand. The nature of the environment, the amount of hot water needed to be supplied i.e. either it is for small number of family or a larger family helps the consumers select the most appropriate type of water heater that will be economically wise for their consumption.

1.3 Types of Water Heaters

Water heaters are of different types among which includes conventional storage water heaters, solar water heaters, and Heat pump water heaters.

1.3.1 Conventional storage water heaters

Conventional storage water heaters are the most commonly and popularly type of water heater systems used in homes and buildings, the sources of energy for this type of water heaters includes natural gas, propane, fuel oil and electricity.

They consist of the cold water inlet and a tap for the hot water from the top of it.

It operates by releasing hot water from the top simply by putting the hot water tap on, and to replace back the hot water that has been used, cold water enters the bottom of the tank which get heated by the gas burner at the bottom of the tank. As shown in the Figure 1.1a below.

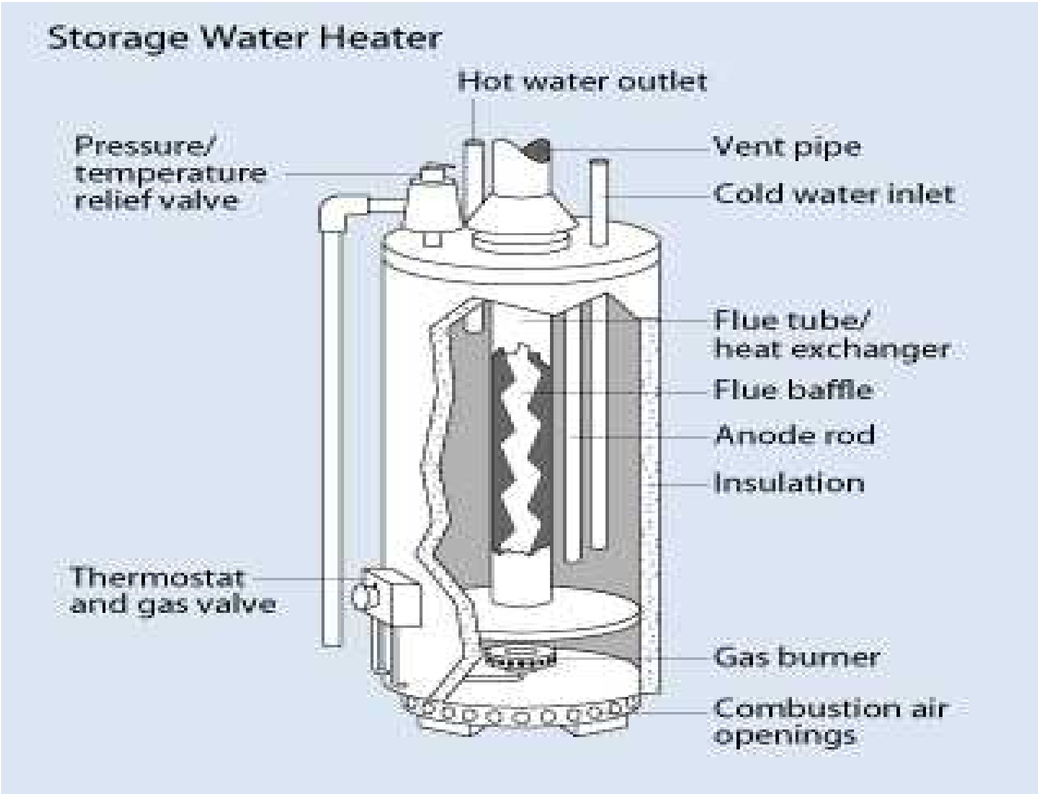

Figure 1.1a: Conventional Storage Water Heater

Gas valves are open by the thermostat as the water temperature falls, and closes when the temperature of the water rises and insulation is made to prevent or minimize heat loss from the water heater to the surrounding.

1.3.2 Solar water heaters

This are also called solar domestic hot water systems, they can be a cost-effective means of generating hot water in homes, also can be used in almost all the climates, and they used direct sun shine as their source of energy through the flat plate collector to heat water. They are mainly of two types i.e. the active solar water heating systems and the passive solar water heating systems.

For active direct circulation system, pump is used to circulate water through the collectors and then into the home. Hence they work better in climates that rarely freezes. On the other hand for the active indirect circulating systems a pump circulate a non-freezing heat-transfer fluid through the collectors and then to the heat exchanger as demonstrated in Figure 1.1b below.

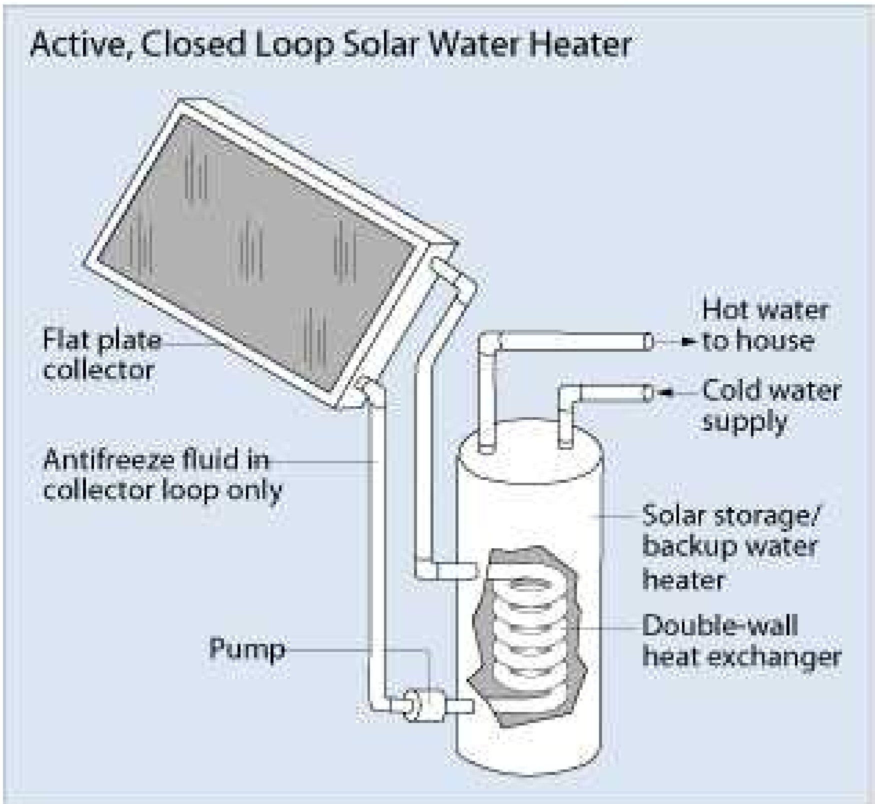

Figure 1.1b: Active solar water heating system

This heats the water and then move it to the home. They work well in climate that is prone to freezing temperatures.

The passive solar water heating system requires no pump, rather water is moved by natural convection from solar collector to the storage tank as the water is getting heated.

They are basically less expensive than the active systems, but usually not efficient as the active types. However they are considered to be reliable and may also last longer.

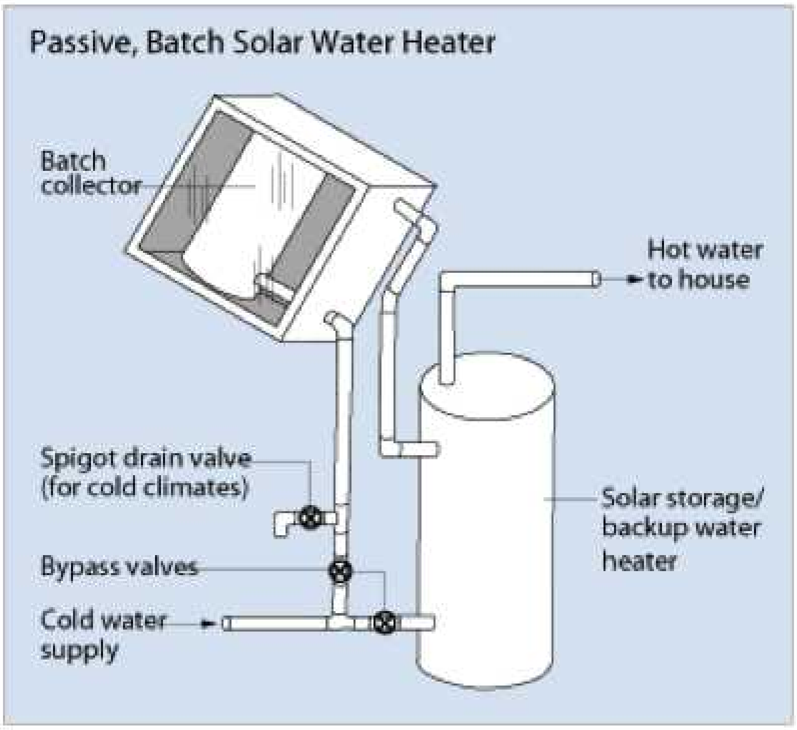

Figure 1.2: Passive solar water heating system

1.4 Heat Pump Water Heaters

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. Therefore, they can be three times more energy efficient than the conventional electric resistance water heaters. As an example the unit COP under consideration in this study is declared as 3.6. In order to move the heat, heat pump work like a refrigerator in reverse.

While a refrigerator extracts heat from inside box and disperse it into the surrounding, an air source heat pump water heater pulls heat from the surrounding air and dumps it at a higher temperature into a tank to heat water. Therefore the aim of the heat pumps here is to heat water. They are available for purchase either as an integrated unit with a built in water storage tank or as a separate unit i.e. the heat pump and the tank are separated. (EEFS, 2008).

1.4.1Benefits of heat pump water heaters

Heat pump water heaters serves as an alternative way of providing hot water, the heat pump when in use, continuouslyexhausts cool air as a result of the heat they extract from the ambient air.

Also HPWH units are purposely designed and manufactured for low power consumption when compared to electric resistance water heaters. As such they provide the potential for a highly reduced electrical demand costs especially in areas where the site demand for hot water is high but with insufficient electricity supply (Ted et al., 1995).

1.4.2 Disadvantages of heat pump water heaters

The major disadvantage of this type of water heaters is lower COP when the ambient temperature is very low, high initial cost, i.e. the cost of purchase as well as the installation cost is also a huge problem with this systems. Also technical difficulties in installing these units of heat pumps is another major problem i.e. (poor installation) will result in a high running cost of the unit.

Another disadvantage of heat pump water heaters is that they are scarce, that is they are not sufficiently available in the markets.

1.5 Coefficient of Performance of a Heat Pump (COP_{hp})

The coefficient of performance is a measure of the amount of power input to a system compared to the amount of power output by the system.

Also defined as the energy produced by the heat pump (in watts) divided by the energy consumed by the heat pump (in watts) therefore it gives the electricity consumption needed to meet heating demand at a given temperature (USDE, 1995).

1.5.1 Seasonal coefficient of performance (SCOP)

Seasonal Coefficient of Performance (SCOP) describes the heat pump's average annual efficiency performance, as such SCOP is therefore an expression for how good and efficient a specific heat pump will be for a given heating demand. Hence knowing the SCOP will help the consumer in purchasing the proper unit of heat pump to consider (USDE, 1995).

1.6 Aim of the Research

The aim of this research is to estimate theoretically the seasonal coefficient of performance (SCOP) of a heat pump water heater in north Cyprus. Also to estimate the benefits and the payback period for heat pump used in heating water.

CHAPTER 2
SURVEY

2.1 Literature Survey

Heat pump systems offer theeconomical alternative of providing heat from different sources for use in various industrial, commercial and residential application. As the cost of energy continues to rise, it becomes imperative to save energy and improve overall energy efficiency. In this view, the heat pump becomes a key component in an energy utilization system with great potential for energy saving. Improving heat pump performance, reliability, and its environmental impact has seen an ongoing concern.

Recent progress in heat pump systems have centered upon advanced cycle designs for both heating and cooling systems, improved cycle component including the choice of the working fluid. For aheat pump to be a better economical proposal, continuous efforts need to be devoted in other toprolong its performance and durability while discovering novel applications.Some of the recent research findings and efforts have significantly improved the efficiency of the heat pump (Abel et al., 2015).

Findings also indicate that the level of service and energy performance of an air source heat pump water heaters (ASHPWH) are mostly influenced by their coefficient of performance and site- specific electricity tariff respectively, Therefore there is need for a careful consideration of ASHPWH technical specifications based on environmental characteristics so as to support the development of energy efficiency for the heat pump water heaters (Abel et al., 2015).

A study on the performance of a reversible Ground Source Heat Pump GSHP coupled to a city water distribution system was carried out, and compared the experimental work with simulation to a typical Air -Source Heat Pump ASHP. For space conditioning i.e. both heating and cooling. GSHPs have displayed the ability of lowering high demands and the total consumption of electricity. The use of this water distribution system as a heat source/ sink promote the annual advancement of 13% in capacities and an annual improvement of 14% in COPs respectively. Particularly at low ambient air temperatures, GSHPs have essential heating capacity (24%) and improved efficiency of (20%) over the ASHPs. The cycle layout is shown in Figure 2.1 (Swardt and Meyer, 2001).

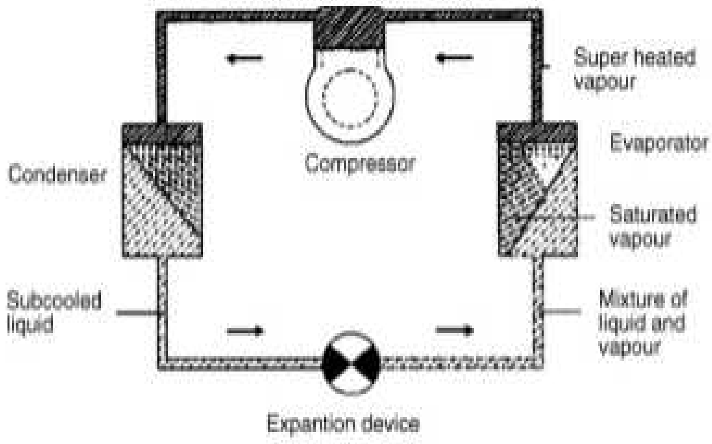

Figure 2.1: Cycle layout

The most basic and popularly type of HP for domestic use, are termed as “conventional” HP, the air source system which extract heat from the air (heat source) at a given point and convey it to air (heat sink) at another location. While in the winter period, a heat pump acquires heat from the outside air and transfer the heat to the required space or home via the working fluid. When temperature of the outside surrounding drops below -3.88, -1.1 , the ASHP then uses electric resistance heat. During the summer period the HP reverses the process by removing heat from the required space and transfer it to outside air (Hepbasli et al., 2003).

A new – air conditioning product that could accomplish the multi – functions with enhanced energy performance was brought into practice. According to the basic design principles and laboratory test results. The results revealed that by incorporating a WH in the outdoor unit of a split – type air conditioner, in order that space cooling and water heating could take place at the same time, the energy performance could be raised significantly. Two slightly different prototypes design were constructed for testing performance. COP averaged, for space cooling and water heating, space heating only and water heating only, was obtained as 4.02, 2.91, 2.72 and 2.00 respectively at 4.5 ambient temperature (Ji et al., 2003).

Seasonal performance evaluation methods for WHs was surveyed, and the experimental method for scaling ASHPWHs was presented. It follows that the method of rating this units was based on the performance measured during heating operation of a specific products rather than a very comprehensive simulation model of HP performance.

The performance measured was used in a correlation model of the HP unit in an annual cycle system performance. The two tested ASHPWHs had a noticeable lower performance than the normal solar WHs or solar – boosted HPWHs. The ASHPWHs could be used in places where solar WHs can not be applicable. The schematic diagrams are given in Figure 2.2 (Morrison et al., 2004).

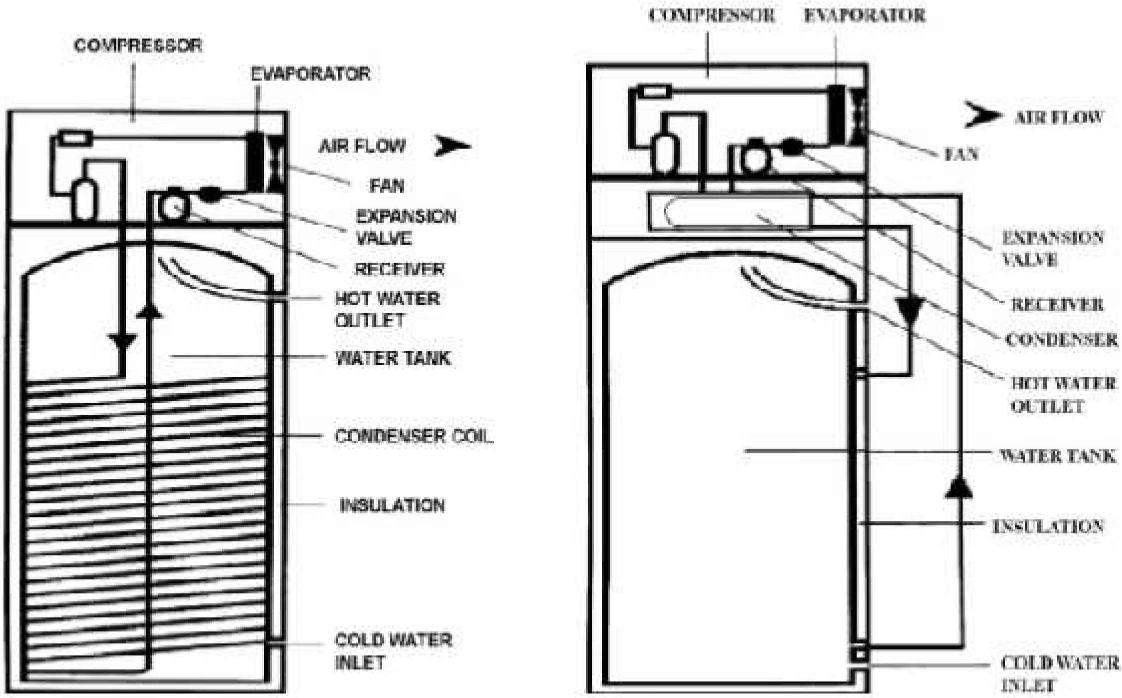

Figure 2.2: ASHPWH with wrap- around condenser coil and ASHPWH with external condenser

A specific heat pump system that could work out the problem of low heating capacity at low ambient temperature is described. This is one of the enormous difficulty in the ASHP systems. In a sequence to reduce the collector area required during the daytime, the HP system worked by the air – source, and at night or at a very low ambient temperature it could be operated with hot water, which has been produced during the daytime by the collector. The hot water supply system included a supplementary electric heater. The experiment was carried out with a prefabricated test house, which was constructed with double glazed windows with high thermal insulation. The outcome of this experiment reveals that solar energy improved the total electric energy savings, also at low ambient temperature increased the heating capacity and eliminated the requirement for reverse cycle defrosting operation (Arif and Yildiz, 2009).

A simulation study on the performance operation of a new designed solar- air source heat pump water heater (SAS- HPWH) was carried out, it follows that the SAS-HPWH operates with a specially designed flat- flate heat collector/evaporator with spiral- finned tubes in order to acquire energy from both solar irradiation and ambient air for heating water. According to the data used for this experiment, based on 150L water heating capacity. Showed that SAS-HPWH could heat the water up to 55℃ efficiently subject to different weather conditions all year round. Figure 2.3 shows the schematic diagram for illustration purposes (Guoying et al., 2006).

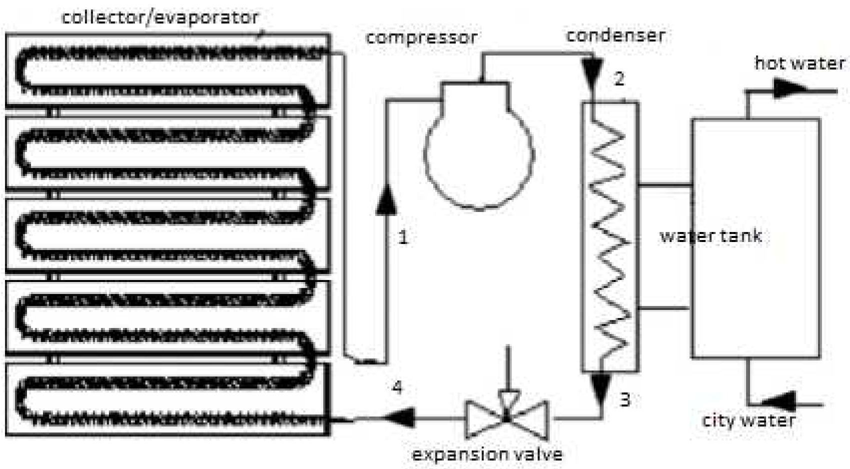

Figure 2.3. Schematic diagram of the experimental set- up

2.1.1A brief historical development of heat pumps

Heat pump used for heating water or space conditioning were initiated in the year 1948, which is indeed a great achievement in the western hemisphere. The theoretical conception of the HP was described in a neglected book, published in the year 1824. Written by young French army officer, Sadi Carnot. Its practical application on a large scale is attributable to some building engineers, and designers.A tremendous credit is usually given to Irish scientist William Thomson (Lord Kelvin) for the concept of the heat pump even though he did not have the resource to construct one. The first English inventor of this device T.G.N Haldane was awarded in 1927 (Arif and Yildiz, 2009).

The first commercial Heat pump installation was in the United States in 1948, whereas in early 1950s commercial distribution of heat pump units was initiated, suffered declines in the 1960s due to a poor record of reliability, but rapid growth were registered in the 1970s, when higher electricity costs made electric furnace less competitive and the improved quality control increases the attractiveness of HPs.

Geothermal HPs world largest installation was recorded in 1996, at the United StatesArmy's fort Polk military base in Leesville, Louisiana. The installation of these units replaced 3243 ASHPs and 760 central air conditioning and natural gas forced air furnace system for up to 4003 housing units (Arif and Yildiz, 2009).

2.2 Market Survey

Heat pump market is anticipated to grow at an estimated growth of more than 7% from 2015 to 2022. The growth is characterized based on the increased demand for renewable energy sources along with a wider support from government in form of like subsidies and other monetary benefits.

Only few models of heat pump water heater (HPWHs) are presently available on the market and are sold at high cost e.g. the Aldea heat pump model (AL-IPB 190) that cost up to about $2000 due to the unavailability of the heat pump units, even more in countries like United State and Japan that manufacture most of the world consumed units also experience such a decline in their respective markets with just few models available. The market for heat pump water heaters has been steadily declining since the 1980s (EEFS, 2008).

Furthermore, Heat pump water heaters are also available in the market from several U.S manufacturers, including, Parker Davis, Nyle international, and Aqua products. Similarly some models of heat pump water heaters from Japanese manufacturers also include Toshiba, Hitachi, Sanyo Electric, Mitsubishi, Corona and Matsushita (EEFS, 2008).

Increasing awareness regarding greenhouse gas emission from conventional heating activities is expected to lift the market of heat pumps over the forecasted period thereby replacing the conventional heating appliances. Also with daily increasing energy demand, depleting oil & gas resources, legislative support, and higher investments are the major factors driving the product demand. But lack of awareness alongside with higher initial investment costs are expected to restrain the market growth over this period. Technical difficulties in installing these units in existing infrastructures is also a major restraint for the overall growth. Lack of government support in some regions is also a key factor restraining the demand of heat pumps (Arif and Yildiz, 2009).

CHAPTER 3
THEORETICAL BACKGROUND

3.1 Refrigeration

Refrigeration is the process of moving heat from one place to another in a controlled environment. It can also be defined as the transfer of heat from low temperature region to a high temperature region. Hence the devices resulting in refrigeration are referred to as refrigerator or heat pumps (Billy, 2002).

3.2 Refrigerators and Heat Pumps

It is known from experience heat flows in the direction of decreasing temperature, that is, from higher temperature regions to that of the lower temperature regions. As it is stated by the 2nd law of thermodynamics such heat transfer occurs naturally without requiring any devices. But reversing the process however is not possible just like that, otherwise heat transfer from low-temperature to high temperature regions requires a special devices called refrigerators (Yunus and Michael, 1998).

Refrigerators are cyclic devices, and the working fluids used in refrigeration cycle are known as refrigerants. A refrigerator is schematically shown in the Figure 3.1.

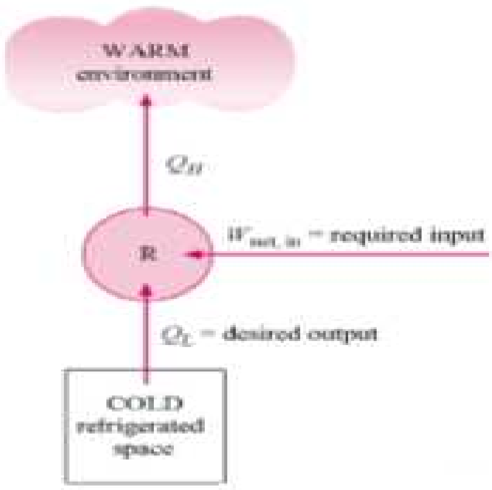

Figure 3.1: Refrigerator

Here, Q_L is the magnitude of heat removed from the refrigerated space at temperature T_L, and Q_H is the magnitude of the rejected heat to the warm space at temperature T_H, and $W_{net,in}$ is the network input to the refrigerator (Yunus and Michael, 1998). Therefore, the performance of refrigerators is expressed in terms of Coefficient of Performance (COP) which is defined as

$$COP_R = \frac{Desired\ output}{Required\ input} = \frac{Cooling\ effect}{Work\ input} = \frac{Q_L}{W_{net,in}} \qquad (3.1)$$

This relation can also be in rate form by replacing Q_L by $\dot{Q}_L$ and $W_{net,in}$ by $W_{net,in}$.

The conservation of energy or in other words the 1st law of thermodynamics for a cyclic device requires that

$$W_{net,in} = Q_H - Q_L \qquad (3.2)$$

Then the relation for the COP given in equation (3.1) can also be expressed as:

$$COP_R = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1} \qquad (3.3)$$

From equation 3.3 the value for COP_R can be greater than unity. That is, the amount of the heat removed from the refrigerated space can be greater than the amount of work input.

A heat pump is another device that transfers heat from low- temperature region to a high-temperature medium. Hence heat pumps and refrigerators are essentially the same devices, but only differs in their objectives. The objective of refrigerator is to maintain low temperature at the refrigerated space by removing heat from it. But to discharge this heat to a higher temperature medium is merely a necessary part of the operation, not the purpose.

The purpose of heat pump, however, is to keep up a heated space at a high temperature. This is achieved by absorbing heat from low temperature source, such as the cold outside air during winter, well water or any other source and supplying this heat to a warmer medium such as hot storage tank or a house. Figure 3.2 shows a schematic representation of heat pump (Yunus and Michael, 1998).

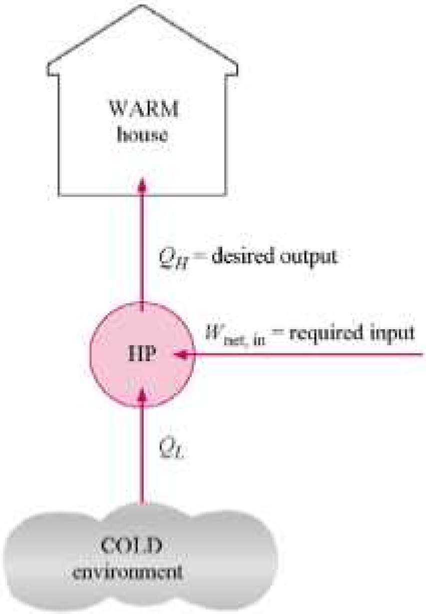

Figure 3.2: Heat Pump

Similarly, the performance of heat pump is also expressed in terms of the Coefficient of performance (COP) and is defined as

$$COP_{HP} = \frac{Desired\ output}{Required\ input} = \frac{Heating\ effect}{Work\ input} = \frac{Q_H}{W_{net,in}} \qquad (3.4)$$

This relation can also be written in rate form by replacing Q_H $by \dot{Q}_H$ and $W_{net,in}$ by $\dot{W}_{net,in}$

Equation 3.4 can also be expressed as

$$COP_{HP} = \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}} \qquad (3.5)$$

3.3 Reversed Carnot Cycle

Carnot cycle is a completely reversible cycle consisting of two reversible isothermal processes and two isentropic processes. For a given temperature limits it has the maximum thermal efficiency, and serves a standard against which the actual cycles are compared.

Since the cycle is reversible, then all the four processes comprising the Carnot cycle can be reversed. And reversing the cycle will definitely reverse the direction of heat and work interactions. This result in a cycle that operate in a different direction, and is referred to as reversed Carnot cycle, hence a refrigerator or heat pump operating on the reversed Carnot cycle is termed as a Carnot refrigerator or a Carnot heat pump (Yunus and Michael, 1998). Consider a reversed Carnot cycle shown in the Figure 3.3.

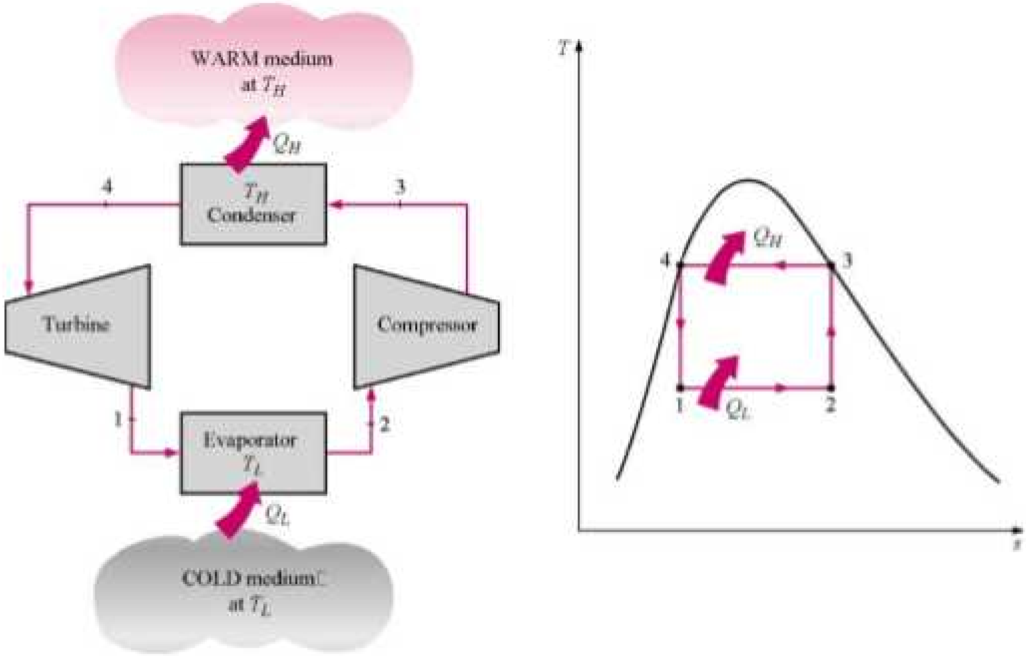

Figure 3.3: Reversed Carnot cycle component and T-s Diagram

Heat is absorbed isothermally by the refrigerant from the low- temperature source at T_L in the amount of Q_L (process 1-2), is compressed isentropically to state 3 in which temperature rises to $T_{H,}$ (process 2 – 3), heat is rejected isothermally to high – temperature sink at T_H in an amount of Q_H (process 3 - 4), and is isentropically expanded to state 1 temperature drops to T_L (process 4 – 1).

From Clausius theorem and inequality,

$$\frac{Q_H}{Q_L} = \frac{T_H}{T_L} \quad (3.6)$$

Therefore, the Coefficient of performance of Carnot refrigerators and Carnot heat pumps respectively can be defined as

$$COP_{R,Carnot} = \frac{1}{\frac{T_H}{T_L} - 1} \quad (3.7)$$

$$COP_{HP,Carnot} = \frac{1}{1 - T_L / T_H} \quad (3.8)$$

Notice that the Coefficient of performance for both in equations 3.7 and 3.8 increases as the difference between the two temperatures decreases, i.e. as T_H falls or T_L rises.

The reversed Carnot cycle is considered the most efficient cycle that is operating between two temperature levels. Hence it is in order to look it as an ideal cycle for refrigerators and heat pumps even though it is known that the reversed Carnot cycle is not suitable model for refrigeration cycles due to some difficulties stated in the next paragraph (Michael and Howard, 1998).

It is not difficult to achieve the two isothermal heat transfer processes in practice since maintaining a constant pressure automatically fixed the temperature of a two- phase mixture at the saturation value. Therefore, processes 1-2 and 3-4 can be achieved closely in evaporators and condensers. However, processes 2-3 and 4-1 cannot be closely approximated in practice, because process 2-3 involves the compression of a mixture of liquid –vapor which requires a different compressor that will handle two phases, which sometimes even requires two compressors that will do the same job. And process 4-1 is the expansion of high – moisture – content refrigerant.

It seems as if the reversed Carnot cycle is executed outside the saturation region will eliminate these problems, but in such a case it will be difficult to achieve isothermal conditions during the heat absorption and heat – rejection processes. Therefore due to this problems it is concluded that the reversed Carnot cycle can not be approximated in actual devices and is not at all a realistic model for refrigeration cycles. However the reversed Carnot cycle can serve as a standard for which actual refrigeration cycles can be compared (Yunus and Michael, 1998).

3.4 The Ideal Vapor – Compression Refrigeration Cycle

Vaporizing the refrigerant completely before it is compressed and additionally by replacing the turbine with a throttling devices such as a capillary tube or an expansion valve is a simple way in which many of the impracticalities associated with the reversed Carnot cycle can be eliminated. The resulting cycle is called the ideal vapor compression refrigeration cycle, it is shown schematically and on the T-s diagram in the Figure 3.4 (Yunus and Michael, 1998).

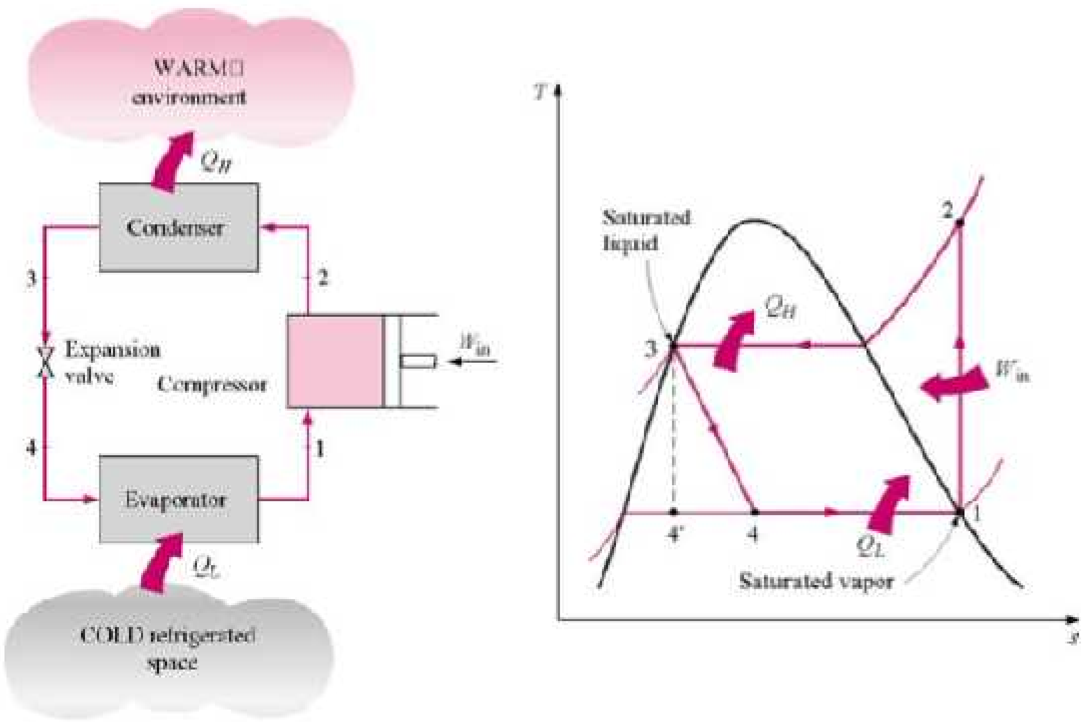

Figure 3.4: Schematic and T-s diagram for the ideal vapor-compression refrigeration cycle

The vapor- compression refrigeration cycle is considered to be the most frequently used cycle for refrigerators, heat pumps and air- conditioning systems. This cycle consist of four vital processes.

By writing the 1st law of thermodynamics for the related process the following can be obtained.

Process 1 – 2 is the isentropic compression taking place at the compressor.

$$w_C = h_2 - h_1 \tag{3.9}$$

Process 2 – 3 is the constant pressure heat rejection in a condenser.

$$q_H = h_2 - h_3 \tag{3.10}$$

Process 3 – 4 throttling in an expansion device.

$$h_3 = h_4 \tag{3.11}$$

Process 4 – 1 is the constant pressure heat absorption in the evaporator.

$$q_L = h_1 - h_4 \tag{3.12}$$

In an ideal vapor- compression refrigeration cycle, at state 1 the refrigerant enters as a saturated vapor where it is isentropically compressed to the condenser pressure. During this isentropic compression the temperature of the refrigerant increases well above the surrounding temperature of the medium.

Next the refrigerant enters the condenser as a superheated vapor at state 2 and leaves the condenser as saturated liquid at state 3 because of the heat rejected to the surrounding.

At state 3 the saturated liquid refrigerant undergo a throttling process where the refrigerant is throttled to the evaporation pressure by passing the refrigerant through an expansion valve. During this process the temperature of the refrigerant drops below that of the refrigerated space.

At state 4 the refrigerant enters the evaporator as a low- quality saturated mixture, and therefore evaporate completely by absorbing heat from the refrigerated space.

Finally the refrigerant leaves the evaporator as a saturated vapor and again enters the compressor, completing the cycle.

In the Figure 3.4 the area under the process curve on the T-s diagram represent the heat transfer for internally reversible processes. Process 4 – 1 represent the heat absorbed by the refrigerant in the evaporator, while the process 2 – 3 under the curve represent the heat rejected in the condenser (Yunus and Michael, 1998).

The P-h diagram is another way used in the analysis of vapor – compression refrigeration cycle, as shown in Figure 3.5.

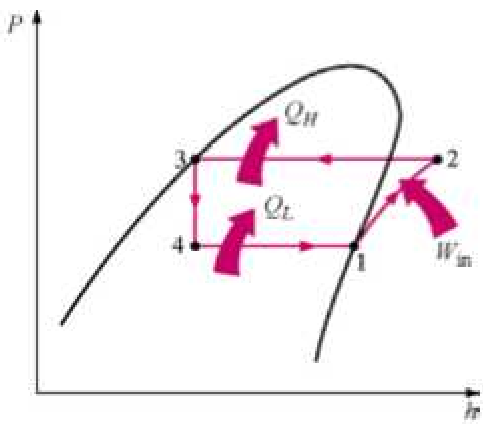

Figure 3.5: P- h diagram for an ideal vapor compression refrigeration cycle

Three of the four processes in Figure 3.5 appears as straight lines, and the heat transfer in the evaporator and the condenser is proportional to the length of the corresponding process curves (Yunus and Michael, 1998).

Unlike the reversed Carnot cycle discussed earlier, the ideal vapor compression refrigeration cycle is not an internally reversible cycle as it involves an irreversible throttling process. As such the throttling process is maintained in the cycle so as to make it more realistic model for actual vapor- compression refrigeration cycle. But replacing this process by an isentropic turbine then the refrigerant will enter the evaporator at state 4 instead of state 4. There by increasing the refrigerant capacity i.e. (area under process curve 4 – 4 in Figure 3.4) and the network input would decrease (by the amount of work output of the turbine).

Hence replacing the expansion valve by a turbine is not practically suitable even more it is more expensive and complicated than the expansion valve.

The COPs of refrigerators and heat pumps operating on the vapor- compression refrigeration cycle can be expressed as: (Yunus and Michael, 1998).

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{h_1 - h_4}{h_2 - h_1} \tag{3.13}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1} \tag{3.14}$$

Where,

$h_1 = h_g$ at point 1 and $h_3 = h_f$ at point 3.

CHAPTER 4

CALCULATIONS

4.1 Estimating the Maximum Possible COP_{hp} for a HPWH

Using the reversed Carnot cycle as a heat pump to heat water have difficulty simply because the condensation temperature is not constant, otherwise it is impossible to heat the water. Therefore T_H is to be changing continuously, as such this is a method devised in order estimate the maximum possible COP_{hp}. This can be achieved by employing a series number of heat pumps connected in an N- stages as described by the equations below i.e. (Equations 4.1, 4.2 & 4.3)

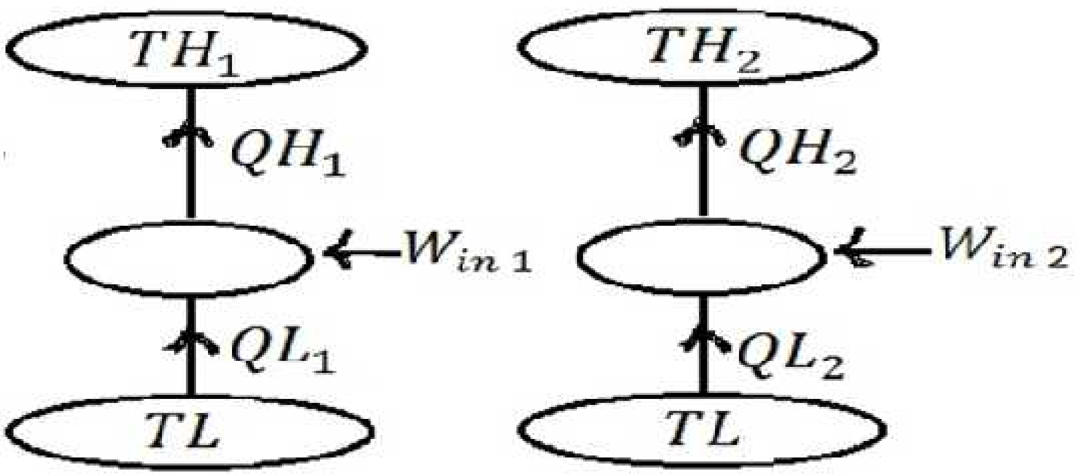

Figure 4.1: Heat pumps series connection.

For one- stage i.e.using one Carnot heat pump

$$COP_1 = \frac{T_H}{T_H - T_L}$$

For two- stages;using only two Carnot heat pump for heating the water

The COPvalue is calculated by:

$$COP_2 = \frac{2}{\frac{T_{H1}-T_L}{T_{H1}} + \frac{T_{H2}-T_L}{T_{H2}}} \tag{4.2}$$

For N-stages; using N-number of Carnot heat pump for heating the water

$$COP_N = \frac{N}{\sum_{i=1}^{N} 1/COP_i} = \frac{N}{\sum_{i=1}^{N} T_{Hi} - T_L \;/\; T_{Hi}} \tag{4.3}$$

Where COP_1, COP_2, and COP_N represents the Coefficient of performance of the heat pump for the first stage, second stage, for individual COP composing the cycle and N- stages respectively.

The given parameters that were considered in estimating the maximum possible COP_{hp} are as shown in Table 4.1

Table 4.1: Parameters considered

PARAMETERS		**[ ]**
Air reservoir temperature	T_L	7
Water reservoir temperature	T_H	60
Initial temperature for the tank	Ti	15
Final temperature of the tank	T_f	60
Change in the temperature	T_f-T_i	45
Stage Number	45	
ΔT= (between T_f and T_i)	1	

Carnot heat pump one will transfer limited amount of heat, therefore T_H there will only be affected as small amount such as 1 in our case, and we still consider this as a constant value i.e. ΔT = 1 .

Now from equations 4.1, 4.2 and 4.3 using the parameters in Table 4.1, the results in Table 4.2 were obtained as shown.

Table 4.2: Individual COP_{hp} and overall COP_{hp}

Stage no.	T_L [K]	T_H [K]	T_i [K]	T_f [K]	COP for each cycle	COP for N stage
1	280	289	288	289	32.11	32.11
2	280	290	289	290	29.00	30.48
3	280	291	290	291	26.45	29.01
4	280	292	291	292	24.33	27.68
5	280	293	292	293	22.54	26.47
6	280	294	293	294	21.00	25.37
7	280	295	294	295	19.67	24.36
8	280	296	295	296	18.50	23.43
9	280	297	296	297	17.47	22.58
10	280	298	297	298	16.56	21.78
11	280	299	298	299	15.74	21.05
12	280	300	299	300	15.00	20.36
13	280	301	300	301	14.33	19.73
14	280	302	301	302	13.73	19.13
15	280	303	302	303	13.17	18.57
16	280	304	303	304	12.67	18.04
17	280	305	304	305	12.20	17.55
18	280	306	305	306	11.77	17.08
19	280	307	306	307	11.37	16.64
20	280	308	307	308	11.00	16.23
21	280	309	308	309	10.66	15.83
22	280	310	309	310	10.33	15.46
23	280	311	310	311	10.03	15.10
24	280	312	311	312	9.75	14.77
25	280	313	312	313	9.48	14.44
26	280	314	313	314	9.24	14.14
27	280	315	314	315	9.00	13.84
28	280	316	315	316	8.78	13.56
29	280	317	316	317	8.57	13.30
30	280	318	317	318	8.37	13.04
31	280	319	318	319	8.18	12.80
32	280	320	319	320	8.00	12.56
33	280	321	320	321	7.83	12.33
34	280	322	321	322	7.67	12.12
35	280	323	322	323	7.51	11.91
36	280	324	323	324	7.36	11.71
37	280	325	324	325	7.22	11.52
38	280	326	325	326	7.09	11.33
39	280	327	326	327	6.96	11.15
40	280	328	327	328	6.83	10.98
41	280	329	328	329	6.71	10.81
42	280	330	329	330	6.60	10.65
43	280	331	330	331	6.49	10.49
44	280	332	331	332	6.38	10.34
45	280	333	332	333	6.28	10.19

In order to show the variations of COP_{hp} with respect to T_H and the number of stages, the graphs of individual COP_{hp} and the overall COP_{hp} against number of stages and that against T_H were shown as follows.

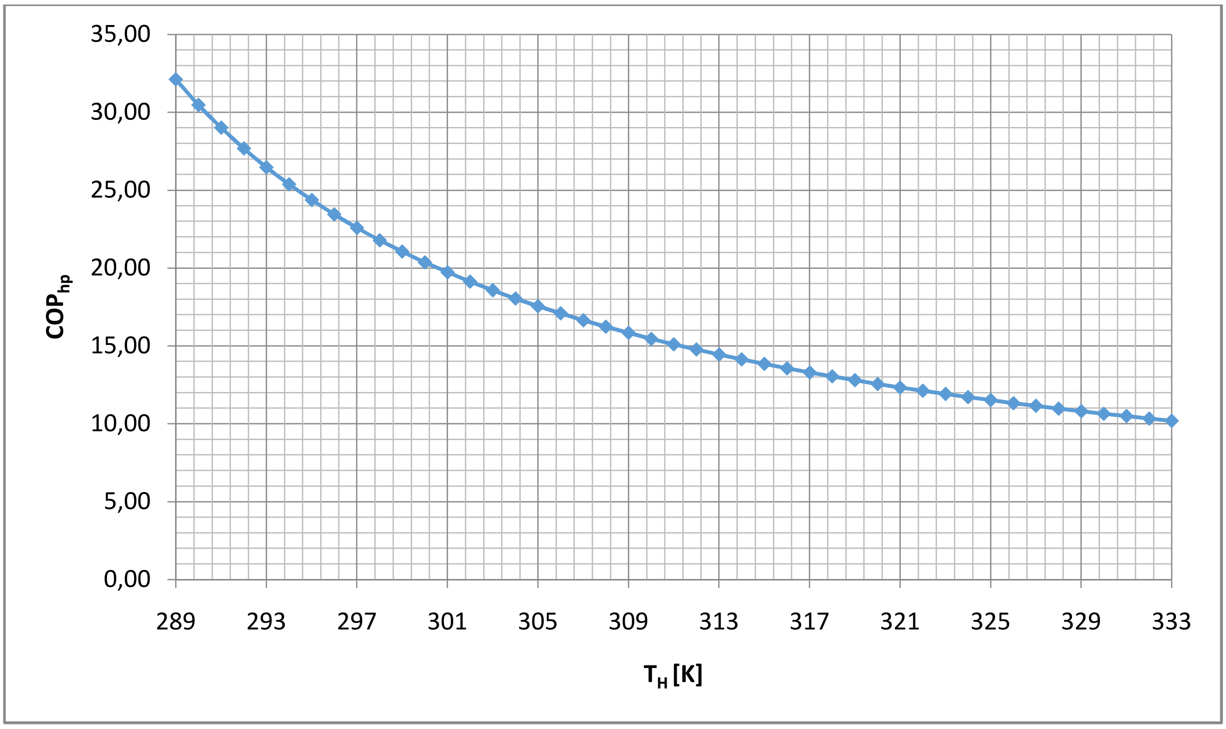

Figure 4.2: Overall COP_{hp} against T_H

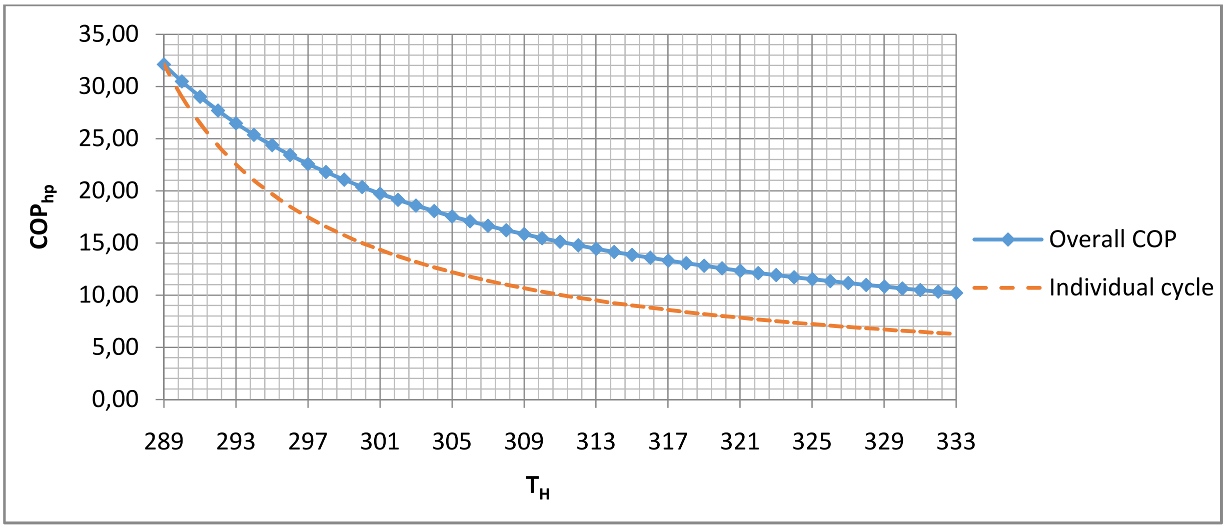

Figure 4.3: Individual COP_{hp} and the Overall COP_{hp} against T_H

4.2 Determination of COP_{hp} for Reversed Carnot Cycle

The COP_{hp} for the reversed Carnot is determined from equation (3.8) earlier described as shown below.

$$COP_{HP,Carnot} = \frac{1}{1 - \frac{T_L}{T_H}}$$

Also the ranges of temperature for both T_H and T_L are respectively given below.

T_H range: 20℃ → 60℃

T_L range: 5℃ → 15℃

Using equation 3.8 and the given ranges of temperatures the result were shown graphically in Figures 4.4 and 4.5.

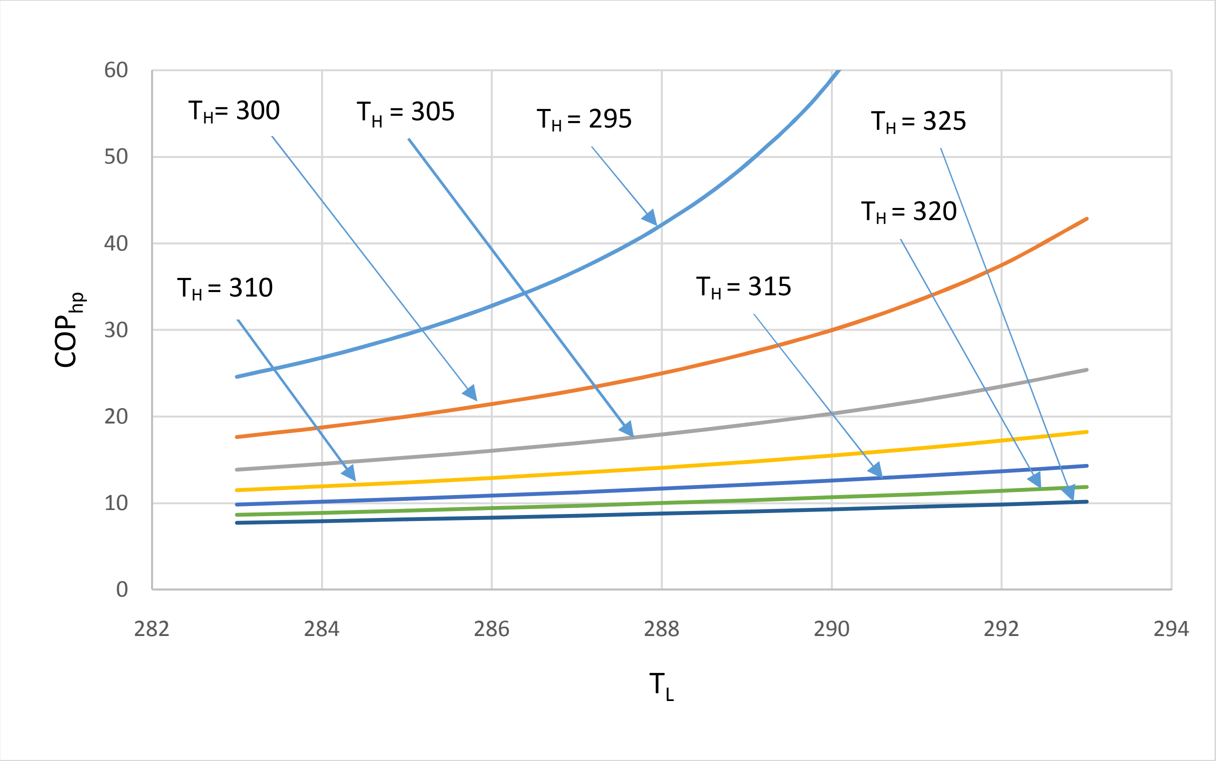

Figure4.4: Graph of COP_{hp}against T_L

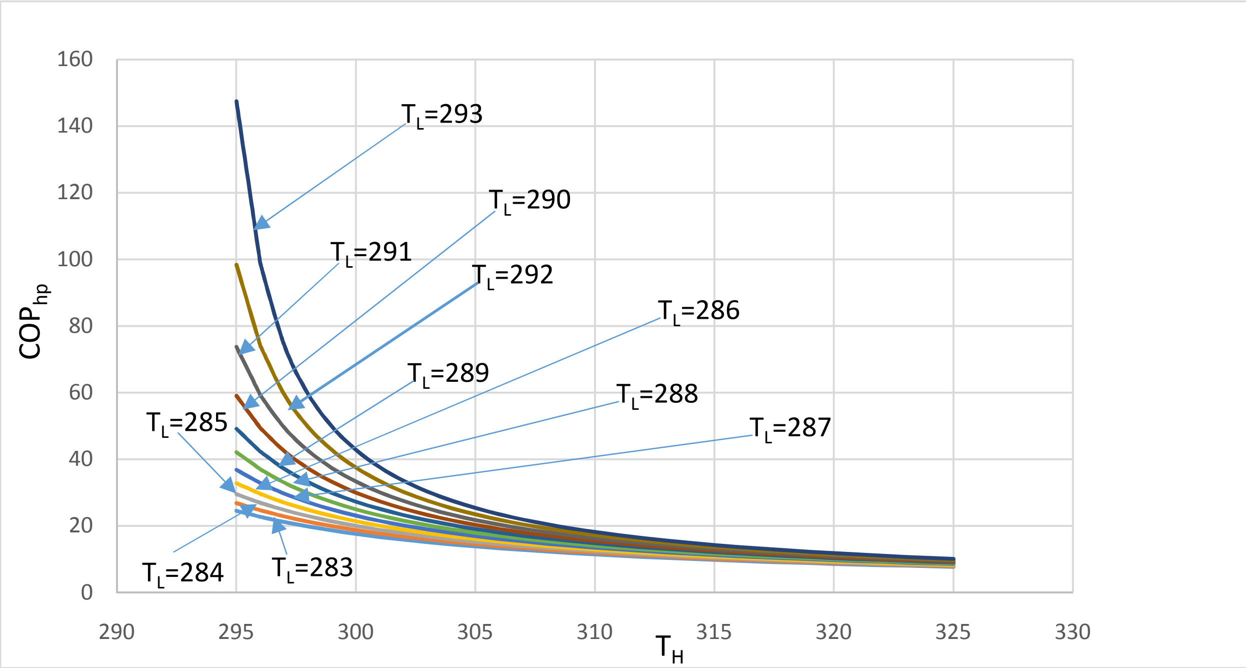

Figure 4.5: COP_{hp} variation with T_H

4.3 Determination of COP_{hp} for Ideal Vapor Compression Refrigeration Cycle

In orderto determine the COP_{hp} for an ideal vapor compression refrigeration cycle, consider the use of equation 3.14 given below

$$COP_{hp} = \frac{Q_H}{W_{net,in}} = \frac{h_2 - h_3}{h_2 - h_1}$$

In our case the evaporator temperature was considered to be constant and taken as $T_E = 4°C$ with different condenser temperatures.

Assumptions

● Refrigerant flows at constant pressure through the two heat exchanger (evaporator and condenser)

● Compression process is isentropic

● Irreversibility within the evaporator, condenser and compressor are ignored

● No frictional pressure drop

The refrigerant in our case is considered to be 134a from Appendix 1.1, saturated Refrigerant 134a (liquid-vapor) temperature table.

At $T_E = 4℃$, $h_1 = h_g = 249.53 \, {}^{kJ}\!/_{kg}$, $and \; S_1 = S_2 = S_g = 0.9169 \, {}^{kJ}\!/_{kgK}$

Also from Appendix 1.2, superheated Refrigerant 134a vapor tables,

At $P = 10bar, T_C = 39.39℃$, $h_2 = ?$

But at $T_C = 40℃$, $S = 0.9066 \, {}^{kJ}\!/_{kgK}$, $and \; h = 268.68 \, {}^{kJ}\!/_{kg}$

Also at $T_C = 50℃$, $S = 0.9428 \, {}^{kJ}\!/_{kgK}$, $h = 280.19 \, {}^{kJ}\!/_{kg}$

Now to get $h_2 \; at \; T_C = 39.39℃$. we interpolate between the enthalpies and the entropies between$T_C = 40℃ \; and \; T_C = 50℃$. From Appendix 2.

Hence

$$0.9066 \rightarrow 268.68$$

$$0.9169 \rightarrow h_2$$

$$0.9428 \rightarrow 280.19$$

$$\frac{0.9169 - 0.9066}{0.9428 - 0.9066} = \frac{h_2 - 268.68}{280.19 - 268.68}$$

$$\frac{0.0103}{0.0362} = \frac{h_2 - 268.68}{11.51}$$

$$0.118553 = 0.0362 \; h_2 - 268.68$$

$$3.2749 = h_2 - 268.68$$

$$h_2 = 271.9549 \, {}^{kJ}\!/_{kg}$$

Then from Appendix 1.3, saturated refrigerant 134a (liquid- vapor) pressure table

At $P = 10bar, h_3 = h_f = 105.29 \, {}^{kJ}\!/_{kg}$.

Therefore,

$$COP_{hp} = \frac{271.9549 - 105.29}{271.9549 - 249.53} = \frac{166.6649}{22.4249} = 7.432$$

Similar calculations for other condenser temperatures were done and summarized in Table 4.3. But before providing the Table 4.3 let us now make a comparism between the COP_{hp} for both IVCRC and that of the RCC. As such a sample calculation for RCC with the same evaporator and condenser temperatures as used for the IVCRC is given below:

$$COP_{hp} = \frac{T_C}{T_C - T_E} = \frac{T_H}{T_H - T_L}$$

$$COP_{hp} = \frac{(39.39 + 273)}{39.39 + 273 - (4 + 273)} = \frac{312.39}{35.39} = 8.827$$

Similar calculation was carried out in the same way for other condenser temperature values. The summarized result together with the comparism is given in Table 4.3 below

Table 4.3: Comparism between COP_{hp} for IVCRC and that of RCC.

S/N	**T_E = T_L (°C)**	**T_H = T_C (°C)**	**P (Bar)**	**h_1Kj/kg**	**S_1 = S_2 Kj/kg.K**	**h_2 Kj kg**	**h_3Kj/kg**	**$COP_{hP\ IVCRC}$**	**COP_{hpRCC}**
1	4	39.39	10	249.53	0.9169	271.9549	105.29	7.432	8.827
2	4	46.32	12	249.53	0.9196	275.6842	115.76	6.115	7.545
3	4	52.43	14	294.53	0.9169	278.8769	125.26	5.234	6.719
4	4	57.92	16	294.53	0.9196	281.584	134.02	4.603	6.137

4.4 Estimation of Seasonal Coefficient of Performance (SCOP)

Seasonal Coefficient of Performance as described earlier determines the average annual efficiency of a heat pump, i.e. it gives the actual performance of the heat pump.

As such in this respect we consider the use of northern Cyprus metrological data for (Nicosia) five months i.e. from November – March 2006/2007 daily minimum, daily average and daily maximum temperatures in estimating the theoretical SCOP for three different range of temperatures.

The unit of heat pump technical specifications under consideration for this research are given in Appendix 2.

Similarly, the weather data i.e. maximum daily temperatures, average daily temperatures and minimum daily temperatures for the year 2006/2007 were provided in Tables 4.5, 4.6 and 4.7 below for the calculation of SCOP.

Table 4.4: Maximum daily temperatures for Nicosia

Maximum Daily Temperatures 2006/2007					
Days	**November**	**December**	**January**	**February**	**March**
1	20.1	20.2	17.5	16.4	19.3
2	23.0	21.4	18.4	15.9	19.8
3	23.8	19.0	16.8	14.0	20.7
4	20.0	18.0	17.4	14.4	20.4
5	15.6	18.8	15.7	13.7	20.4
6	16.8	18.2	15.1	12.6	19.8
7	20.9	19.5	14.6	14.6	18.5
8	19.6	19.8	16.9	15.7	19.3
9	21.8	17.0	16.6	16.7	20.8
10	21.5	18.0	16.1	16.9	20.2
11	21.4	21.5	15.6	17.4	20.0
12	21.6	17.0	15.6	18.7	21.6
13	23.3	19.0	16.6	17.4	19.4
14	23.1	21.0	17.5	18.7	13.4
15	20.6	17.0	16.8	15.9	12.8
16	21.0	18.5	17.8	17.7	18.2
17	23.6	21.0	19.8	17.8	16.7
18	23.6	20.5	18.5	17.9	19.6
19	22.4	20.5	16.8	19.4	19.7
20	22.1	21.5	14.8	17.8	18.4
21	21.3	22.0	15.7	18.9	19.9
22	21.0	16.5	18.7	19.2	20.5
23	21.4	13.2	18.0	18.5	21.4
24	23.3	19.8	19.0	19.4	19.4
25	24.0	18.5	19.0	17.3	20.4
26	22.7	12.3	18.8	18.6	19.4
27	23.8	8.5	18.8	17.4	20.1
28	24.6	12.0	16.7	18.7	20.6
29	24.8	15.9	14.2		19.4
30	21.4	17.0	15.7		19.6
31		15.1	15.4		19.2

Table 4.5: Average daily temperatures for Nicosia

	Average Daily Temperatures 2006/2007				
Days	**November**	**December**	**January**	**February**	**March**
1	17.4	14.1	8.6	11.0	14.3
2	17.5	12.8	10.1	13.5	14.5
3	17.7	11.3	12.5	12.6	15.2
4	17.6	11.2	13.0	10.7	14.2
5	13.1	11.7	13.6	9.1	15.4
6	12.1	11.5	11.4	8.1	14.0
7	12.1	11.0	11.1	8.4	12.0
8	13.1	11.6	8.8	9.9	12.1
9	13.8	11.0	9.7	14.4	13.8
10	14.8	11.6	14.0	13.3	13.3
11	15.7	12.1	14.0	11.0	17.6
12	15.7	11.8	13.0	13.1	15.2
13	16.6	15.0	8.8	12.8	13.7
14	17.4	13.2	9.9	13.1	9.3
15	15.9	13.7	10.7	11.9	7.0
16	14.0	11.5	10.8	12.0	10.8
17	14.6	11.9	11.9	13.8	12.4
18	16.2	12.2	10.4	16.1	12.7
19	15.6	12.8	11.0	12.9	13.8
20	14.3	13.3	12.4	12.7	14.0
21	13.7	15.1	12.8	16.1	17.0
22	13.6	14.6	9.8	14.1	15.0
23	13.7	11.1	11.1	13.5	18.0
24	13.8	10.2	13.9	14.9	15.0
25	14.5	11.2	13.7	13.7	14.1
26	14.4	11.4	11.8	14.5	13.1
27	13.4	6.7	11.3	13.3	13.9
28	14.6	7.9	10.9	12.8	14.1
29	15.6	7.2	9.6		14.0
30	14.3	9.8	9.6		14.3
31		10.4	8.9		14.6

Table 4.6: Minimum daily temperatures for Nicosia

Minimum Daily Temperature 2006/2007					
Days	**November**	**December**	**January**	**February**	**March**
1	15.3	8.6	2.4	4.0	10.4
2	12.0	6.5	4.8	7.6	10.4
3	11.3	4.6	8.4	10.9	9.8
4	15.5	5.7	7.4	7.3	8.5
5	8.2	4.5	12.2	5.7	12.8
6	8.3	5.0	6.6	4.7	11.4
7	4.7	5.0	7.3	2.9	6.7
8	8.5	5.5	2.5	4.4	5.7
9	7.0	5.0	3.0	8.7	8.2
10	7.6	7.0	12.6	10.0	6.5
11	9.0	7.0	12.7	4.9	12.2
12	9.0	6.6	8.5	6.5	9.8
13	9.4	10.0	1.9	7.9	8.6
14	9.5	7.4	4.1	8.6	6.3
15	11.7	10.0	5.0	8.3	3.1
16	7.5	5.5	4.6	6.9	5.4
17	5.0	4.5	5.8	7.0	6.5
18	9.5	6.0	3.4	14.8	7.3
19	9.2	6.5	5.2	7.3	7.1
20	5.2	6.5	9.0	7.4	8.2
21	6.4	9.1	8.9	13.3	10.5
22	7.1	3.3	3.1	10.0	8.0
23	6.5	6.5	4.5	9.4	16.8
24	6.6	4.5	6.7	9.2	12.4
25	4.3	4.5	6.6	9.9	7.9
26	6.0	9.5	5.2	11.7	8.4
27	7.0	5.0	4.6	10.3	8.7
28	7.5	3.0	5.4	7.0	7.7
29	4.8	-1.0	5.5		8.2
30	6.2	4.0	4.4		8.1
31		6.0	2.0		10.5

Representing the weather data graphically gives the figure below.

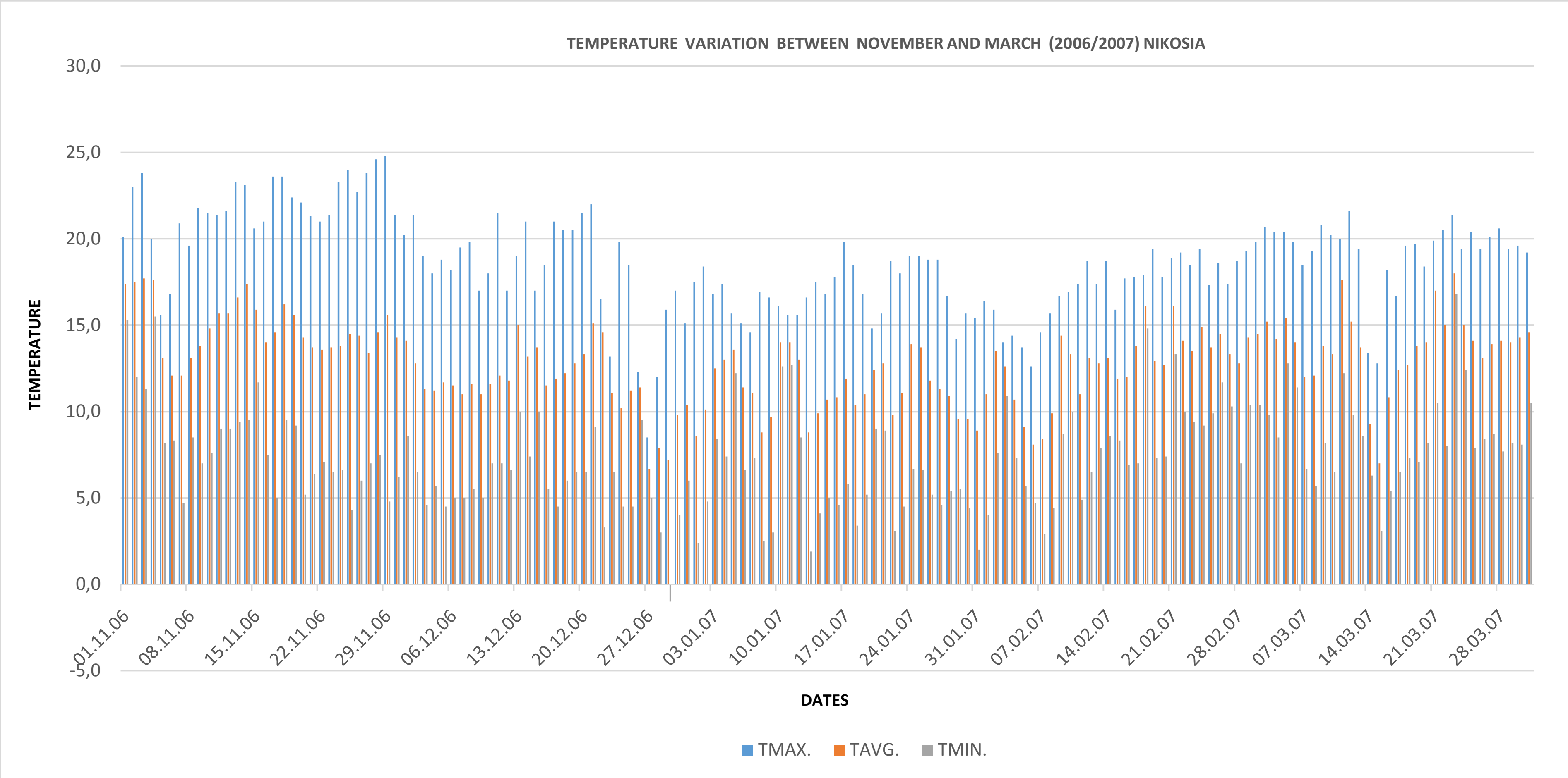

Figure 4.6: Temperature Variation between November and March (2006/2007) Nicosia

Having provided all the required informations about the unit and the weather data we can now proceed with the SCOP calculations. Now Consider the Table 4.7 obtained from the technical specifications for the specific unit of heat pump under consideration as declared by the manufacturer given in Appendices 2.2 and 2.3 (Figures).

Table 4.7: COP_{hp} for different temperatures for range (15□ - 60^{O}C)

	(15□ - 60□) TEMPERATURE RANGE		
S/N	**Temperature °C**	**COP - AL- IPB 190**	**COP - AL - IPB 300**
1	7	2.2	2.2
2	15	2.75	2.75
3	20	3.1	3.1
4	25	3.3	3.3
5	30	3.6	3.6

From Table 4.7 the graph of COP_{hp} against the surrounding temperatures is plotted.

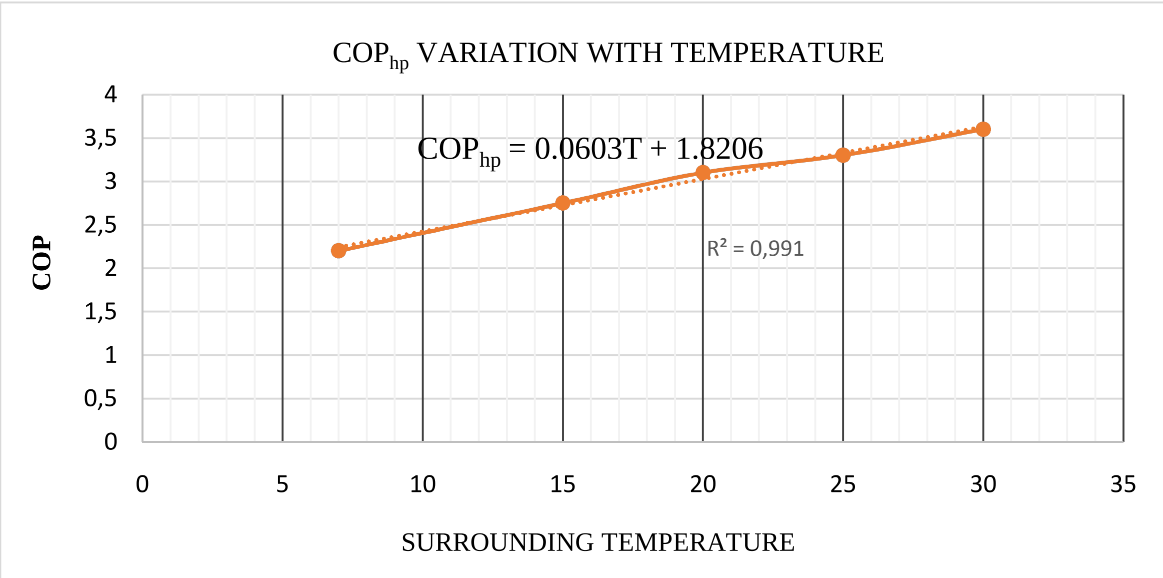

Figure 4.7: COP_{hp} variation with temperature

$$COP_{hp} = 0.0603(T) + 1.8206 \tag{4.4}$$

From equation (4.4) the temperatures provided for Nicosia from November - March 2006/2007 were substituted in order to determine the COP_{hp} as shown in Table 4.9

Table 4.8: COP_{hp} for maximum, average and minimum temperatures for November

(15 □ – 60 □) Range for The Month of November 2006						
DATE	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/11/06	20.1	17.4	15.3	2.87	2.74	3.03
02/11/06	23.0	17.5	12.0	2.88	2.54	3.21
03/11/06	23.8	17.7	11.3	2.89	2.50	3.26
04/11/06	20.0	17.6	15.5	2.88	2.76	3.03
05/11/06	15.6	13.1	8.2	2.61	2.32	2.76
06/11/06	16.8	12.1	8.3	2.55	2.32	2.83
07/11/06	20.9	12.1	4.7	2.55	2.10	3.08
08/11/06	19.6	13.1	8.5	2.61	2.33	3.00
09/11/06	21.8	13.8	7.0	2.65	2.24	3.14
10/11/06	21.5	14.8	7.6	2.71	2.28	3.12
11/11/06	21.4	15.7	9.0	2.77	2.36	3.11
12/11/06	21.6	15.7	9.0	2.77	2.36	3.12
13/11/06	23.3	16.6	9.4	2.82	2.39	3.23
14/11/06	23.1	17.4	9.5	2.87	2.39	3.21
15/11/06	20.6	15.9	11.7	2.78	2.53	3.06
16/11/06	21.0	14.0	7.5	2.66	2.27	3.09
17/11/06	23.6	14.6	5.0	2.70	2.12	3.24
18/11/06	23.6	16.2	9.5	2.80	2.39	3.24
19/11/06	22.4	15.6	9.2	2.76	2.38	3.17
20/11/06	22.1	14.3	5.2	2.68	2.13	3.15
21/11/06	21.3	13.7	6.4	2.65	2.21	3.10
22/11/06	21.0	13.6	7.1	2.64	2.25	3.09
23/11/06	21.4	13.7	6.5	2.65	2.21	3.11
24/11/06	23.3	13.8	6.6	2.65	2.22	3.23
25/11/06	24.0	14.5	4.3	2.69	2.08	3.27
26/11/06	22.7	14.4	6.0	2.69	2.18	3.19
27/11/06	23.8	13.4	7.0	2.63	2.24	3.26
28/11/06	24.6	14.6	7.5	2.70	2.27	3.30
29/11/06	24.8	15.6	4.8	2.76	2.11	3.32
30/11/06	21.4	14.3	6.2	2.68	2.19	3.11

Table 4.9: COP_{hp} for maximum, average and minimum temperatures for December

(15□ – 60□) RANGE FOR THE MONTH OF DECEMBER 2006						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/12/06	20.2	14.1	8.6	2.67	2.34	3.04
02/12/06	21.4	12.8	6.5	2.59	2.21	3.11
03/12/06	19.0	11.3	4.6	2.50	2.10	2.97
04/12/06	18.0	11.2	5.7	2.50	2.16	2.91
05/12/06	18.8	11.7	4.5	2.53	2.09	2.95
06/12/06	18.2	11.5	5.0	2.51	2.12	2.92
07/12/06	19.5	11.0	5.0	2.48	2.12	3.00
08/12/06	19.8	11.6	5.5	2.52	2.15	3.01
09/12/06	17.0	11.0	5.0	2.48	2.12	2.85
10/12/06	18.0	11.6	7.0	2.52	2.24	2.91
11/12/06	21.5	12.1	7.0	2.55	2.24	3.12
12/12/06	17.0	11.8	6.6	2.53	2.22	2.85
13/12/06	19.0	15.0	10.0	2.73	2.42	2.97
14/12/06	21.0	13.2	7.4	2.62	2.27	3.09
15/12/06	17.0	13.7	10.0	2.65	2.42	2.85
16/12/06	18.5	11.5	5.5	2.51	2.15	2.94
17/12/06	21.0	11.9	4.5	2.54	2.09	3.09
18/12/06	20.5	12.2	6.0	2.56	2.18	3.06
19/12/06	20.5	12.8	6.5	2.59	2.21	3.06
20/12/06	21.5	13.3	6.5	2.62	2.21	3.12
21/12/06	22.0	15.1	9.1	2.73	2.37	3.15
22/12/06	16.5	14.6	3.3	2.70	2.02	2.82
23/12/06	13.2	11.1	6.5	2.49	2.21	2.62
24/12/06	19.8	10.2	4.5	2.44	2.09	3.01
25/12/06	18.5	11.2	4.5	2.50	2.09	2.94
26/12/06	12.3	11.4	9.5	2.51	2.39	2.56
27/12/06	8.5	6.7	5.0	2.22	2.12	2.33
28/12/06	12.0	7.9	3.0	2.30	2.00	2.54
29/12/06	15.9	7.2	-1.0	2.25	1.76	2.78
30/12/06	17.0	9.8	4.0	2.41	2.06	2.85
31/12/06	15.1	10.4	6.0	2.45	2.18	2.73

Table 4.10: COP_{hp} for maximum, average and minimum temperatures for January

(15□ – 60□) RANGE FOR THE MONTH OF JANUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COPMAX.**
01/01/07	17.5	8.6	2.4	2.34	1.97	2.88
02/01/07	18.4	10.1	4.8	2.43	2.11	2.93
03/01/07	16.8	12.5	8.4	2.57	2.33	2.83
04/01/07	17.4	13.0	7.4	2.60	2.27	2.87
05/01/07	15.7	13.6	12.2	2.64	2.56	2.77
06/01/07	15.1	11.4	6.6	2.51	2.22	2.73
07/01/07	14.6	11.1	7.3	2.49	2.26	2.70
08/01/07	16.9	8.8	2.5	2.35	1.97	2.84
09/01/07	16.6	9.7	3.0	2.41	2.00	2.82
10/01/07	16.1	14.0	12.6	2.66	2.58	2.79
11/01/07	15.6	14.0	12.7	2.66	2.59	2.76
12/01/07	15.6	13.0	8.5	2.60	2.33	2.76
13/01/07	16.6	8.8	1.9	2.35	1.94	2.82
14/01/07	17.5	9.9	4.1	2.42	2.07	2.88
15/01/07	16.8	10.7	5.0	2.47	2.12	2.83
16/01/07	17.8	10.8	4.6	2.47	2.10	2.89
17/01/07	19.8	11.9	5.8	2.54	2.17	3.01
18/01/07	18.5	10.4	3.4	2.45	2.03	2.94
19/01/07	16.8	11.0	5.2	2.48	2.13	2.83
20/01/07	14.8	12.4	9.0	2.57	2.36	2.71
21/01/07	15.7	12.8	8.9	2.59	2.36	2.77
22/01/07	18.7	9.8	3.1	2.41	2.01	2.95
23/01/07	18.0	11.1	4.5	2.49	2.09	2.91
24/01/07	19.0	13.9	6.7	2.66	2.22	2.97
25/01/07	19.0	13.7	6.6	2.65	2.22	2.97
26/01/07	18.8	11.8	5.2	2.53	2.13	2.95
27/01/07	18.8	11.3	4.6	2.50	2.10	2.95
28/01/07	16.7	10.9	5.4	2.48	2.15	2.83
29/01/07	14.2	9.6	5.5	2.40	2.15	2.68
30/01/07	15.7	9.6	4.4	2.40	2.09	2.77
31/01/07	15.4	8.9	2.0	2.36	1.94	2.75

Table 4.11: COP_{hp} for maximum, average and minimum temperatures for February

(15℃ – 60℃) RANGE FOR THE MONTH OF FEBUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/02/07	16.4	11.0	4.0	2.48	2.06	2.81
02/02/07	15.9	13.5	7.6	2.63	2.28	2.78
03/02/07	14.0	12.6	10.9	2.58	2.48	2.66
04/02/07	14.4	10.7	7.3	2.47	2.26	2.69
05/02/07	13.7	9.1	5.7	2.37	2.16	2.65
06/02/07	12.6	8.1	4.7	2.31	2.10	2.58
07/02/07	14.6	8.4	2.9	2.33	2.00	2.70
08/02/07	15.7	9.9	4.4	2.42	2.09	2.77
09/02/07	16.7	14.4	8.7	2.69	2.35	2.83
10/02/07	16.9	13.3	10.0	2.62	2.42	2.84
11/02/07	17.4	11.0	4.9	2.48	2.12	2.87
12/02/07	18.7	13.1	6.5	2.61	2.21	2.95
13/02/07	17.4	12.8	7.9	2.59	2.30	2.87
14/02/07	18.7	13.1	8.6	2.61	2.34	2.95
15/02/07	15.9	11.9	8.3	2.54	2.32	2.78
16/02/07	17.7	12.0	6.9	2.54	2.24	2.89
17/02/07	17.8	13.8	7.0	2.65	2.24	2.89
18/02/07	17.9	16.1	14.8	2.79	2.71	2.90
19/02/07	19.4	12.9	7.3	2.60	2.26	2.99
20/02/07	17.8	12.7	7.4	2.59	2.27	2.89
21/02/07	18.9	16.1	13.3	2.79	2.62	2.96
22/02/07	19.2	14.1	10.0	2.67	2.42	2.98
23/02/07	18.5	13.5	9.4	2.63	2.39	2.94
24/02/07	19.4	14.9	9.2	2.72	2.38	2.99
25/02/07	17.3	13.7	9.9	2.65	2.42	2.86
26/02/07	18.6	14.5	11.7	2.69	2.53	2.94
27/02/07	17.4	13.3	10.3	2.62	2.44	2.87
28/02/07	18.7	12.8	7.0	2.59	2.24	2.95

Table 4.12: COP_{hp} for maximum, average and minimum temperatures for March

(15℃ – 60℃) RANGE FOR THE MONTH OF MARCH 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/03/07	19.3	14.3	10.4	2.68	2.45	2.98
02/03/07	19.8	14.5	10.4	2.69	2.45	3.01
03/03/07	20.7	15.2	9.8	2.74	2.41	3.07
04/03/07	20.4	14.2	8.5	2.68	2.33	3.05
05/03/07	20.4	15.4	12.8	2.75	2.59	3.05
06/03/07	19.8	14.0	11.4	2.66	2.51	3.01
07/03/07	18.5	12.0	6.7	2.54	2.22	2.94
08/03/07	19.3	12.1	5.7	2.55	2.16	2.98
09/03/07	20.8	13.8	8.2	2.65	2.32	3.07
10/03/07	20.2	13.3	6.5	2.62	2.21	3.04
11/03/07	20.0	17.6	12.2	2.88	2.56	3.03
12/03/07	21.6	15.2	9.8	2.74	2.41	3.12
13/03/07	19.4	13.7	8.6	2.65	2.34	2.99
14/03/07	13.4	9.3	6.3	2.38	2.20	2.63
15/03/07	12.8	7.0	3.1	2.24	2.01	2.59
16/03/07	18.2	10.8	5.4	2.47	2.15	2.92
17/03/07	16.7	12.4	6.5	2.57	2.21	2.83
18/03/07	19.6	12.7	7.3	2.59	2.26	3.00
19/03/07	19.7	13.8	7.1	2.65	2.25	3.01
20/03/07	18.4	14.0	8.2	2.66	2.32	2.93
21/03/07	19.9	17.0	10.5	2.85	2.45	3.02
22/03/07	20.5	15.0	8.0	2.73	2.30	3.06
23/03/07	21.4	18.0	16.8	2.91	2.83	3.11
24/03/07	19.4	15.0	12.4	2.73	2.57	2.99
25/03/07	20.4	14.1	7.9	2.67	2.30	3.05
26/03/07	19.4	13.1	8.4	2.61	2.33	2.99
27/03/07	20.1	13.9	8.7	2.66	2.35	3.03
28/03/07	20.6	14.1	7.7	2.67	2.28	3.06
29/03/07	19.4	14.0	8.2	2.66	2.32	2.99
30/03/07	19.6	14.3	8.1	2.68	2.31	3.00
31/03/07	19.2	14.6	10.5	2.70	2.45	2.98

Below are the graphs showing the relationship between respective COP_{hp} and the days of the months.

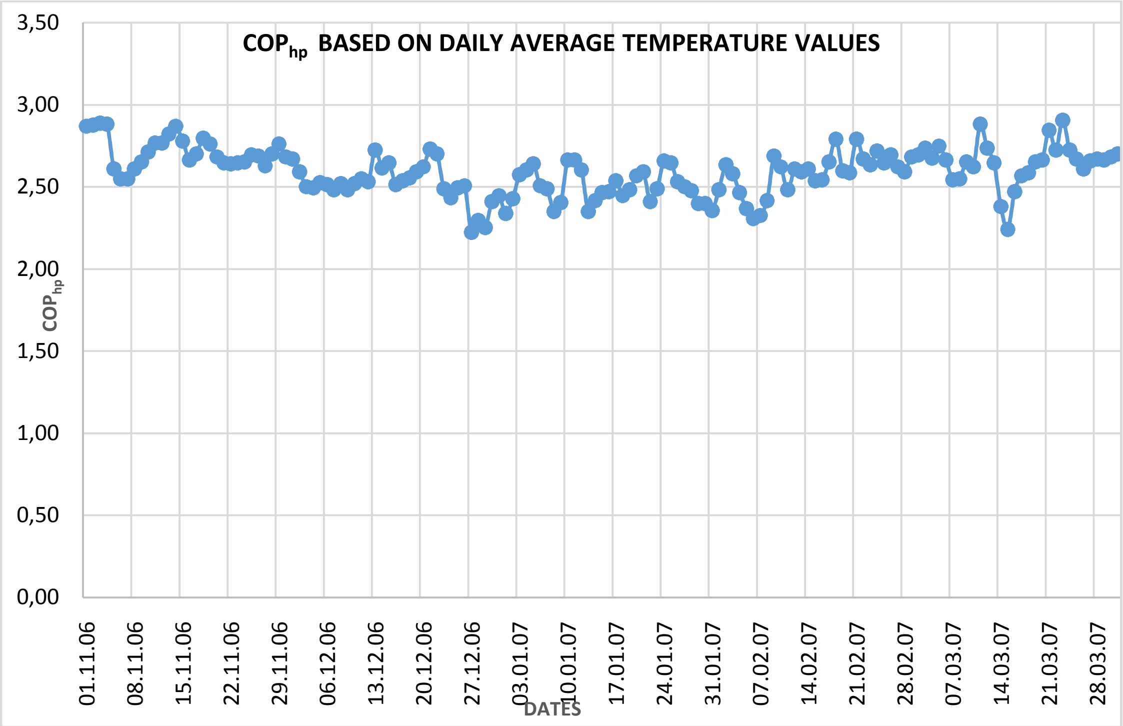

Figure 4.8: COP_{hp} based on the daily average temperatures

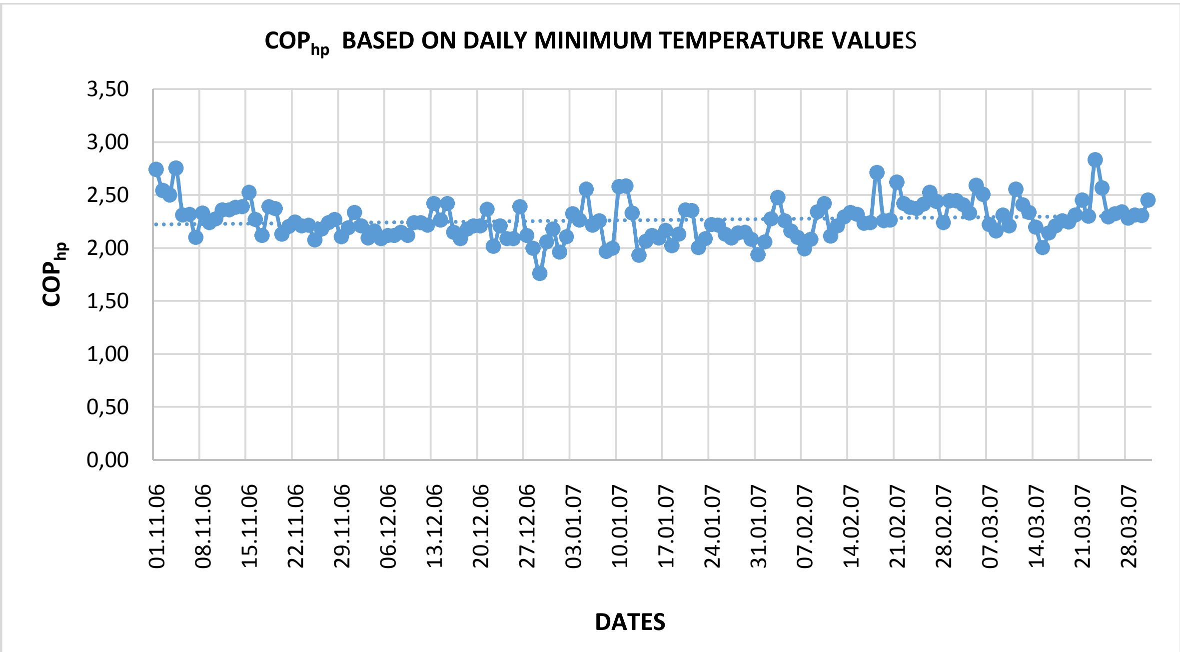

Figure 4.9: COP_{hp} based on the daily minimum temperatures

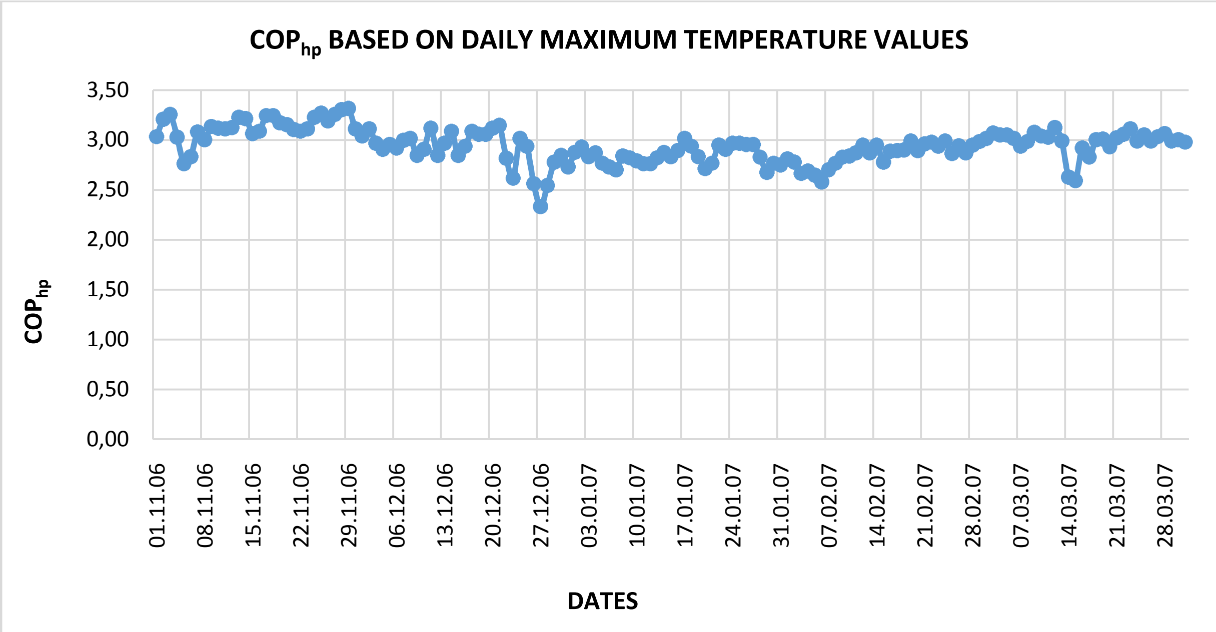

Figure 4.10: COP$_{hp}$ based on the daily maximum temperatures

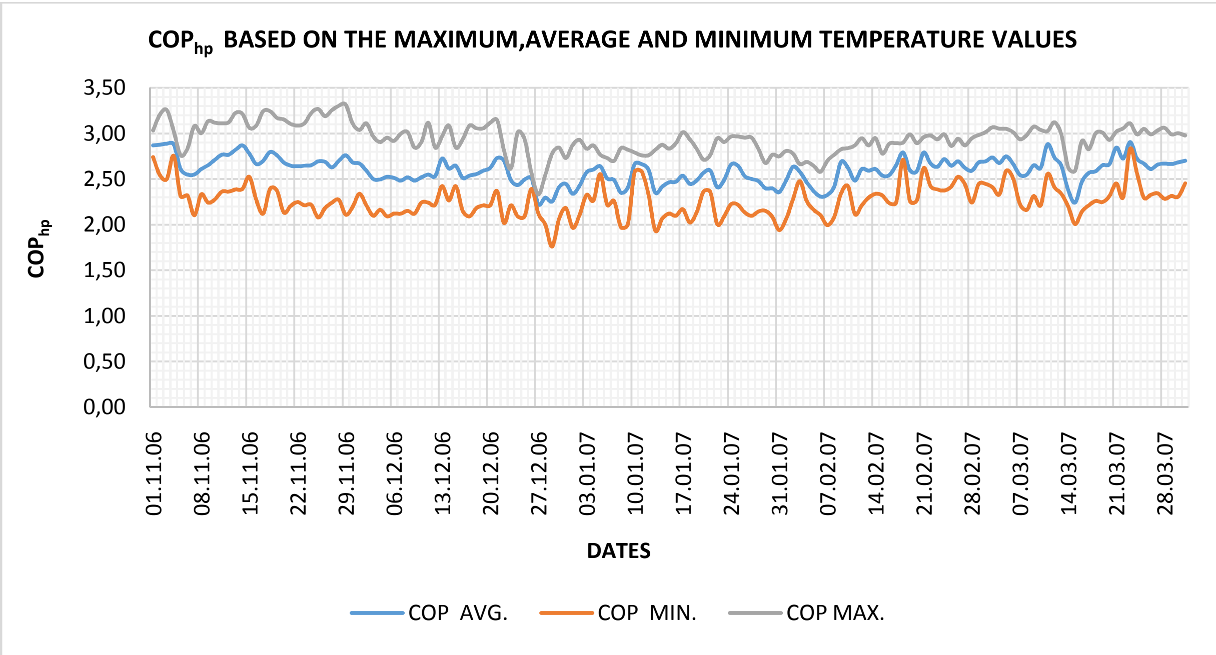

Figure 4.11: COP$_{hp}$ based on the maximum, average and minimum temperature

If we consider another range of temperature i.e. (15℃ – 45℃) the same calculation procedure is used in obtaining the following results as shown in Table 4.14 below.

Table 4.13: COP_{hp} for different temperatures for range (15℃ - 45℃)

	(15℃ - 45℃) TEMPERATURE RANGE		
S/N	**TEMPERATURE ℃**	**COP - AL- IPB 190**	**COP - AL - IPB 300**
1	7	3.1	3.1
2	15	3.5	3.5
3	20	3.9	3.9
4	25	4.1	4.1
5	30	4.5	4.5

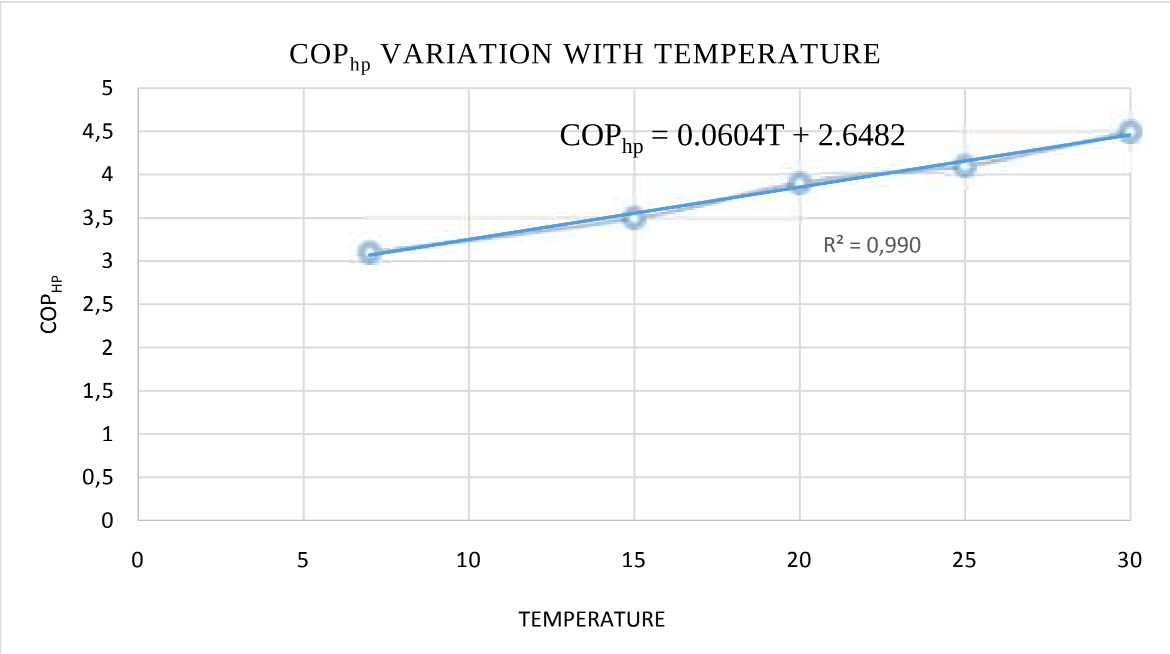

Figure 4.12: COP_{hp} variation with temperatures for the range (15℃ - 45℃)

$$COP_{hp} = 0.0604T + 2.6482 \quad (4.5)$$

With equation (4.5) COP_{hp} was determined as shown in Table 4.15

Table 4.14: COP_{hp} for maximum, average and minimum temp for Nov. range (15℃ - 45℃)

(15℃ - 45℃) RANGE FOR THE MONTH OF NOVEMBER 2006						
DATES	TMAX.	TAVG.	TMIN.	COP AVG.	COP MIN.	COP MAX.
01/11/06	20.1	17.4	15.3	3.70	3.57	3.86
02/11/06	23.0	17.5	12.0	3.71	3.37	4.04
03/11/06	23.8	17.7	11.3	3.72	3.33	4.09
04/11/06	20.0	17.6	15.5	3.71	3.58	3.86
05/11/06	15.6	13.1	8.2	3.44	3.14	3.59
06/11/06	16.8	12.1	8.3	3.38	3.15	3.66
07/11/06	20.9	12.1	4.7	3.38	2.93	3.91
08/11/06	19.6	13.1	8.5	3.44	3.16	3.83
09/11/06	21.8	13.8	7.0	3.48	3.07	3.96
10/11/06	21.5	14.8	7.6	3.54	3.11	3.95
11/11/06	21.4	15.7	9.0	3.60	3.19	3.94
12/11/06	21.6	15.7	9.0	3.60	3.19	3.95
13/11/06	23.3	16.6	9.4	3.65	3.22	4.06
14/11/06	23.1	17.4	9.5	3.70	3.22	4.04
15/11/06	20.6	15.9	11.7	3.61	3.35	3.89
16/11/06	21.0	14.0	7.5	3.49	3.10	3.92
17/11/06	23.6	14.6	5.0	3.53	2.95	4.07
18/11/06	23.6	16.2	9.5	3.63	3.22	4.07
19/11/06	22.4	15.6	9.2	3.59	3.20	4.00
20/11/06	22.1	14.3	5.2	3.51	2.96	3.98
21/11/06	21.3	13.7	6.4	3.48	3.03	3.93
22/11/06	21.0	13.6	7.1	3.47	3.08	3.92
23/11/06	21.4	13.7	6.5	3.48	3.04	3.94
24/11/06	23.3	13.8	6.6	3.48	3.05	4.06
25/11/06	24.0	14.5	4.3	3.52	2.91	4.10
26/11/06	22.7	14.4	6.0	3.52	3.01	4.02
27/11/06	23.8	13.4	7.0	3.46	3.07	4.09
28/11/06	24.6	14.6	7.5	3.53	3.10	4.13
29/11/06	24.8	15.6	4.8	3.59	2.94	4.15
30/11/06	21.4	14.3	6.2	3.51	3.02	3.94

Table 4.15: COP_{hp} for max., average and min. temp for Dec. Range (15℃ - 45℃)

(15℃ - 45℃) RANGE FOR THE MONTH OF DECEMBER 2006						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/12/06	20.2	14.1	8.6	3.50	3.17	3.87
02/12/06	21.4	12.8	6.5	3.42	3.04	3.94
03/12/06	19.0	11.3	4.6	3.33	2.93	3.80
04/12/06	18.0	11.2	5.7	3.32	2.99	3.74
05/12/06	18.8	11.7	4.5	3.35	2.92	3.78
06/12/06	18.2	11.5	5.0	3.34	2.95	3.75
07/12/06	19.5	11.0	5.0	3.31	2.95	3.83
08/12/06	19.8	11.6	5.5	3.35	2.98	3.84
09/12/06	17.0	11.0	5.0	3.31	2.95	3.68
10/12/06	18.0	11.6	7.0	3.35	3.07	3.74
11/12/06	21.5	12.1	7.0	3.38	3.07	3.95
12/12/06	17.0	11.8	6.6	3.36	3.05	3.68
13/12/06	19.0	15.0	10.0	3.55	3.25	3.80
14/12/06	21.0	13.2	7.4	3.45	3.10	3.92
15/12/06	17.0	13.7	10.0	3.48	3.25	3.68
16/12/06	18.5	11.5	5.5	3.34	2.98	3.77
17/12/06	21.0	11.9	4.5	3.37	2.92	3.92
18/12/06	20.5	12.2	6.0	3.39	3.01	3.89
19/12/06	20.5	12.8	6.5	3.42	3.04	3.89
20/12/06	21.5	13.3	6.5	3.45	3.04	3.95
21/12/06	22.0	15.1	9.1	3.56	3.20	3.98
22/12/06	16.5	14.6	3.3	3.53	2.85	3.64
23/12/06	13.2	11.1	6.5	3.32	3.04	3.45
24/12/06	19.8	10.2	4.5	3.26	2.92	3.84
25/12/06	18.5	11.2	4.5	3.32	2.92	3.77
26/12/06	12.3	11.4	9.5	3.34	3.22	3.39
27/12/06	8.5	6.7	5.0	3.05	2.95	3.16
28/12/06	12.0	7.9	3.0	3.13	2.83	3.37
29/12/06	15.9	7.2	-1.0	3.08	2.59	3.61
30/12/06	17.0	9.8	4.0	3.24	2.89	3.68
31/12/06	15.1	10.4	6.0	3.28	3.01	3.56

Table 4.16: COP_{hp} for maximum, average and minimum temp for Jan. range (15℃ - 45℃)

(15℃ - 45℃) RANGE FOR THE MONTH OF JANUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/01/07	17.5	8.6	2.4	3.17	2.79	3.71
02/01/07	18.4	10.1	4.8	3.26	2.94	3.76
03/01/07	16.8	12.5	8.4	3.40	3.16	3.66
04/01/07	17.4	13.0	7.4	3.43	3.10	3.70
05/01/07	15.7	13.6	12.2	3.47	3.39	3.60
06/01/07	15.1	11.4	6.6	3.34	3.05	3.56
07/01/07	14.6	11.1	7.3	3.32	3.09	3.53
08/01/07	16.9	8.8	2.5	3.18	2.80	3.67
09/01/07	16.6	9.7	3.0	3.23	2.83	3.65
10/01/07	16.1	14.0	12.6	3.49	3.41	3.62
11/01/07	15.6	14.0	12.7	3.49	3.42	3.59
12/01/07	15.6	13.0	8.5	3.43	3.16	3.59
13/01/07	16.6	8.8	1.9	3.18	2.76	3.65
14/01/07	17.5	9.9	4.1	3.25	2.90	3.71
15/01/07	16.8	10.7	5.0	3.29	2.95	3.66
16/01/07	17.8	10.8	4.6	3.30	2.93	3.72
17/01/07	19.8	11.9	5.8	3.37	3.00	3.84
18/01/07	18.5	10.4	3.4	3.28	2.85	3.77
19/01/07	16.8	11.0	5.2	3.31	2.96	3.66
20/01/07	14.8	12.4	9.0	3.40	3.19	3.54
21/01/07	15.7	12.8	8.9	3.42	3.19	3.60
22/01/07	18.7	9.8	3.1	3.24	2.84	3.78
23/01/07	18.0	11.1	4.5	3.32	2.92	3.74
24/01/07	19.0	13.9	6.7	3.49	3.05	3.80
25/01/07	19.0	13.7	6.6	3.48	3.05	3.80
26/01/07	18.8	11.8	5.2	3.36	2.96	3.78
27/01/07	18.8	11.3	4.6	3.33	2.93	3.78
28/01/07	16.7	10.9	5.4	3.31	2.97	3.66
29/01/07	14.2	9.6	5.5	3.23	2.98	3.51
30/01/07	15.7	9.6	4.4	3.23	2.91	3.60
31/01/07	15.4	8.9	2.0	3.19	2.77	3.58

Table 4.17: COP_{hp} for max., average and min. temp for Feb.range (15℃ - 45℃)

(15℃ - 45℃) RANGE FOR THE MONTH OF FEBUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COPMAX.**
01/02/07	16.4	11.0	4.0	3.31	2.89	3.64
02/02/07	15.9	13.5	7.6	3.46	3.11	3.61
03/02/07	14.0	12.6	10.9	3.41	3.31	3.49
04/02/07	14.4	10.7	7.3	3.29	3.09	3.52
05/02/07	13.7	9.1	5.7	3.20	2.99	3.48
06/02/07	12.6	8.1	4.7	3.14	2.93	3.41
07/02/07	14.6	8.4	2.9	3.16	2.82	3.53
08/02/07	15.7	9.9	4.4	3.25	2.91	3.60
09/02/07	16.7	14.4	8.7	3.52	3.17	3.66
10/02/07	16.9	13.3	10.0	3.45	3.25	3.67
11/02/07	17.4	11.0	4.9	3.31	2.94	3.70
12/02/07	18.7	13.1	6.5	3.44	3.04	3.78
13/02/07	17.4	12.8	7.9	3.42	3.13	3.70
14/02/07	18.7	13.1	8.6	3.44	3.17	3.78
15/02/07	15.9	11.9	8.3	3.37	3.15	3.61
16/02/07	17.7	12.0	6.9	3.37	3.06	3.72
17/02/07	17.8	13.8	7.0	3.48	3.07	3.72
18/02/07	17.9	16.1	14.8	3.62	3.54	3.73
19/02/07	19.4	12.9	7.3	3.43	3.09	3.82
20/02/07	17.8	12.7	7.4	3.42	3.10	3.72
21/02/07	18.9	16.1	13.3	3.62	3.45	3.79
22/02/07	19.2	14.1	10.0	3.50	3.25	3.81
23/02/07	18.5	13.5	9.4	3.46	3.22	3.77
24/02/07	19.4	14.9	9.2	3.55	3.20	3.82
25/02/07	17.3	13.7	9.9	3.48	3.25	3.69
26/02/07	18.6	14.5	11.7	3.52	3.35	3.77
27/02/07	17.4	13.3	10.3	3.45	3.27	3.70
28/02/07	18.7	12.8	7.0	3.42	3.07	3.78

Table 4.18: COP_{hp} for max., average and min. temp for March. Range (15℃ - 45℃)

(15℃ - 45℃) RANGE FOR THE MONTH OF MARCH 2007						
DATES	TMAX.	TAVG.	TMIN.	COP AVG.	COP MIN.	COP MAX.
01/03/07	19.3	14.3	10.4	3.51	3.28	3.81
02/03/07	19.8	14.5	10.4	3.52	3.28	3.84
03/03/07	20.7	15.2	9.8	3.57	3.24	3.90
04/03/07	20.4	14.2	8.5	3.51	3.16	3.88
05/03/07	20.4	15.4	12.8	3.58	3.42	3.88
06/03/07	19.8	14.0	11.4	3.49	3.34	3.84
07/03/07	18.5	12.0	6.7	3.37	3.05	3.77
08/03/07	19.3	12.1	5.7	3.38	2.99	3.81
09/03/07	20.8	13.8	8.2	3.48	3.14	3.90
10/03/07	20.2	13.3	6.5	3.45	3.04	3.87
11/03/07	20.0	17.6	12.2	3.71	3.39	3.86
12/03/07	21.6	15.2	9.8	3.57	3.24	3.95
13/03/07	19.4	13.7	8.6	3.48	3.17	3.82
14/03/07	13.4	9.3	6.3	3.21	3.03	3.46
15/03/07	12.8	7.0	3.1	3.07	2.84	3.42
16/03/07	18.2	10.8	5.4	3.30	2.97	3.75
17/03/07	16.7	12.4	6.5	3.40	3.04	3.66
18/03/07	19.6	12.7	7.3	3.42	3.09	3.83
19/03/07	19.7	13.8	7.1	3.48	3.08	3.84
20/03/07	18.4	14.0	8.2	3.49	3.14	3.76
21/03/07	19.9	17.0	10.5	3.68	3.28	3.85
22/03/07	20.5	15.0	8.0	3.55	3.13	3.89
23/03/07	21.4	18.0	16.8	3.74	3.66	3.94
24/03/07	19.4	15.0	12.4	3.55	3.40	3.82
25/03/07	20.4	14.1	7.9	3.50	3.13	3.88
26/03/07	19.4	13.1	8.4	3.44	3.16	3.82
27/03/07	20.1	13.9	8.7	3.49	3.17	3.86
28/03/07	20.6	14.1	7.7	3.50	3.11	3.89
29/03/07	19.4	14.0	8.2	3.49	3.14	3.82
30/03/07	19.6	14.3	8.1	3.51	3.14	3.83
31/03/07	19.2	14.6	10.5	3.53	3.28	3.81

Similar graphs based on this range of temperatures are also plotted in other to show the relationship between the COP_{hp} and the dates as shown in Figures below.

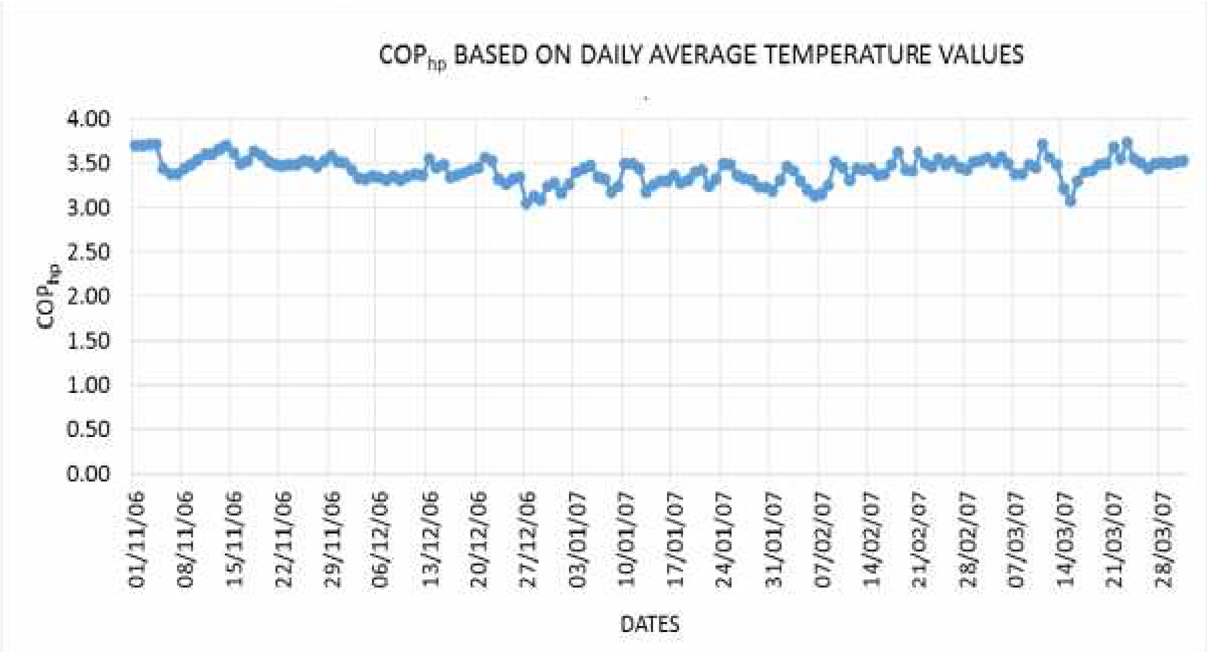

Figure 4.13: COP$_{hp}$ based on the daily average temperatures for the range (15℃ - 45℃)

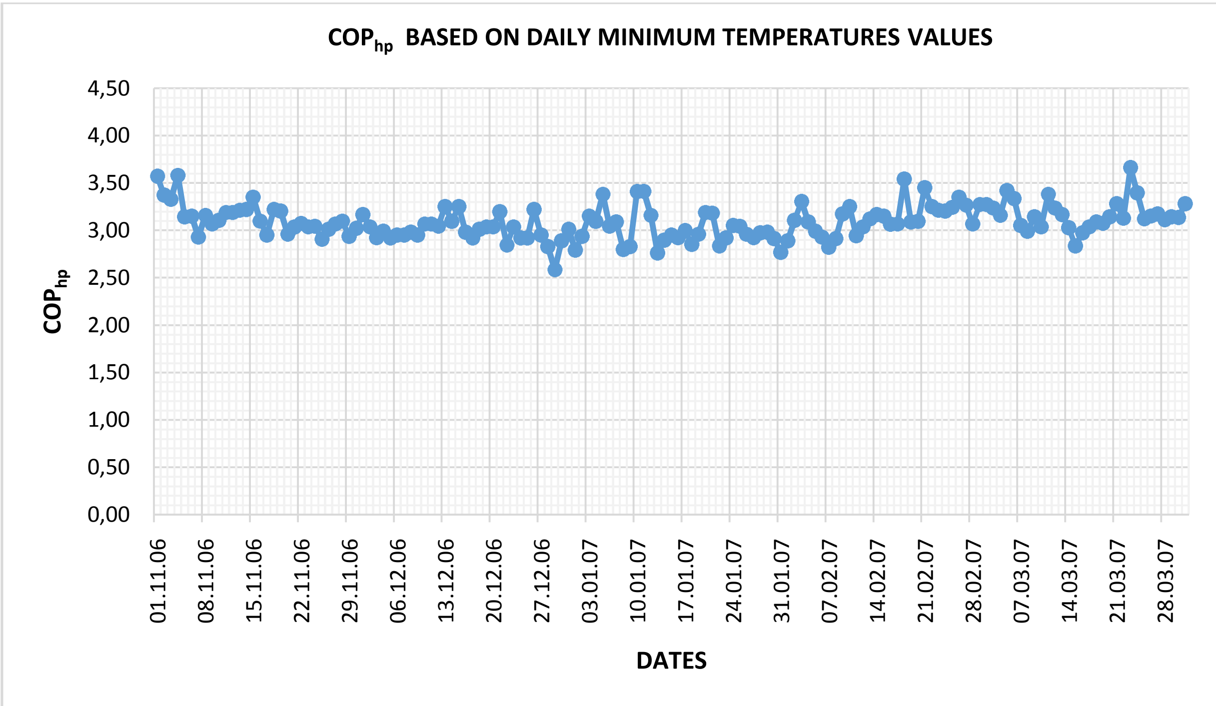

Figure 4.14: COP$_{hp}$ based on the daily minimum temperatures for the range (15℃ - 45℃)

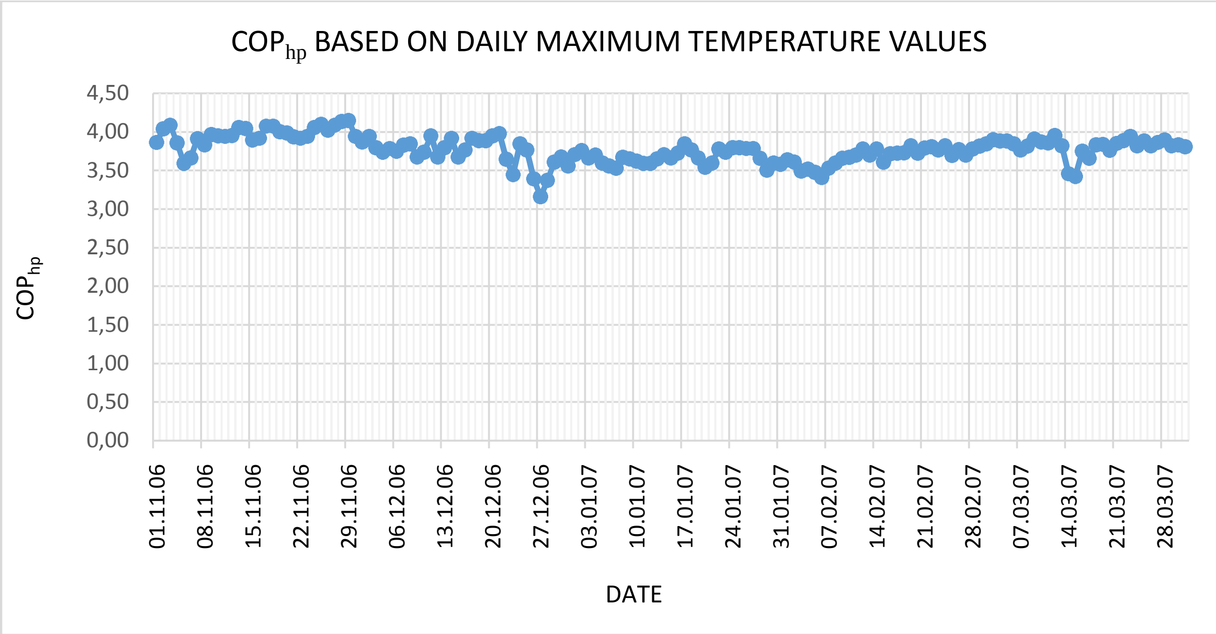

Figure 4.15: COP$_{hp}$ based on the daily maximum temperatures for the range (15℃ - 45℃)

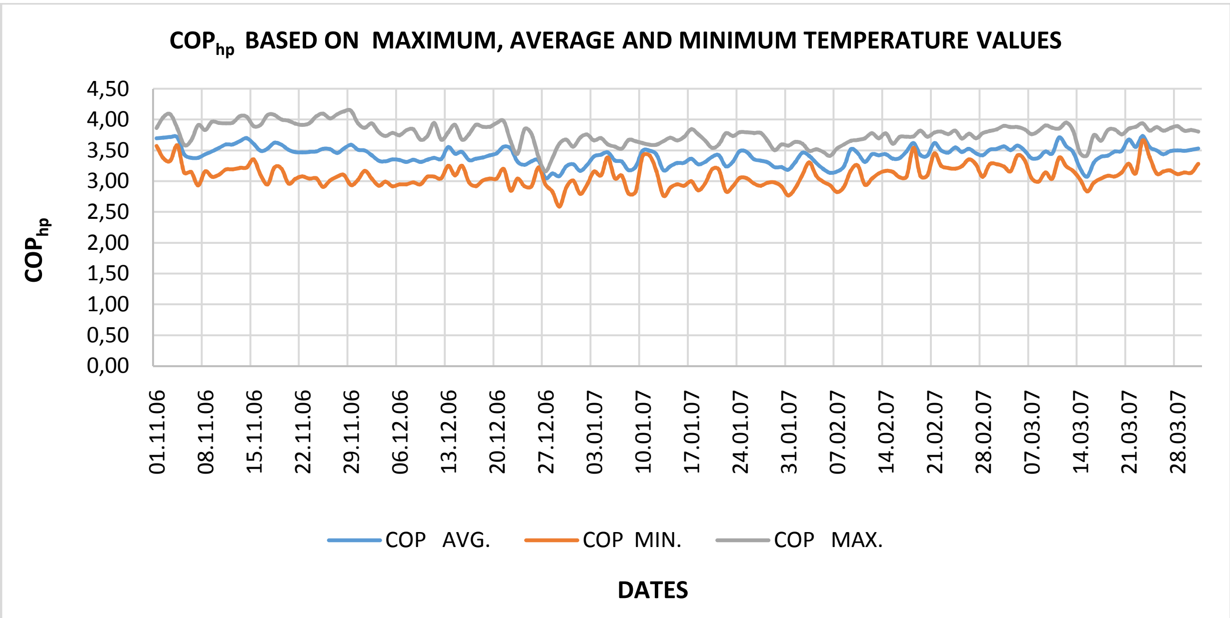

Figure 4.16: COP$_{hp}$ based on the daily minimum, average and maximum temperature

Now considering the last range of temperatures that is (15℃ – 55℃) similar calculation procedures are adopted in obtaining the given tables and the graphs as shown below.

Table 4.19: COP_{hp} at different temp. In the range (15℃ - 55℃)

	(15℃ - 55℃) TEMPERATURE RANGE		
S/N	**TEMPERATURE◦C**	**COP - AL- IPB 190**	**COP - AL - IPB 300**
1	7	2.5	2.5
2	15	3.2	3.2
3	20	3.5	3.5
4	25	3.7	3.7
5	30	4	4

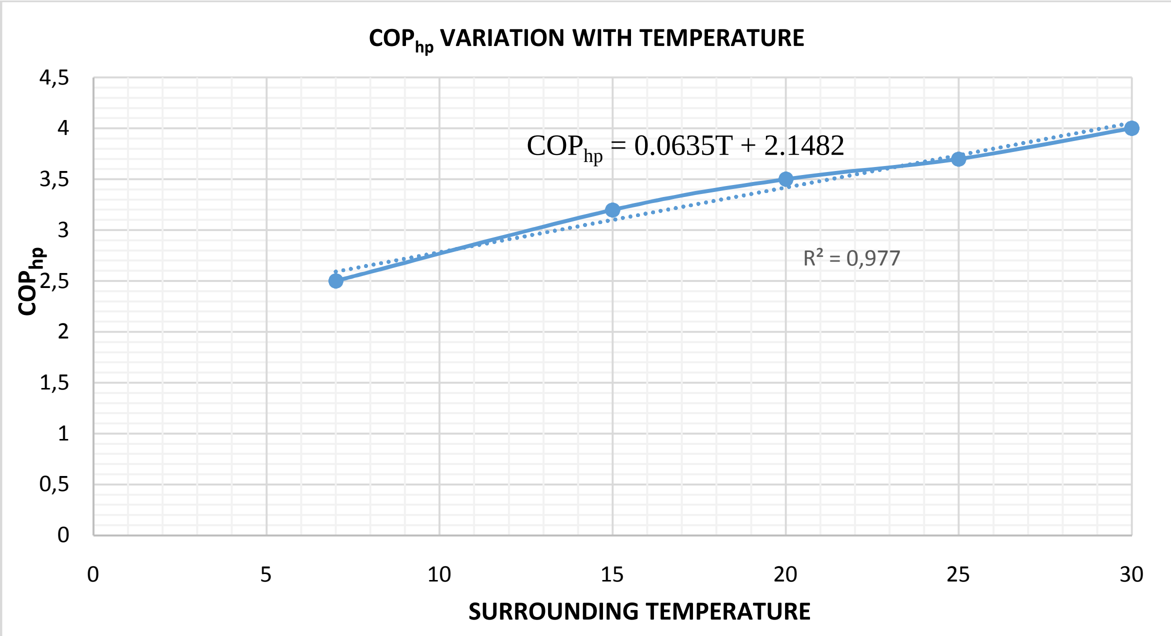

Figure 4.17: COP_{hp} variation with temperatures for the range (15℃ − 55℃)

$$COP_{hp} = 0.0635T + 2.1482 \qquad (4.6)$$

Hence from equation (4.6) respective $COP_{hp}$for average, minimum and maximum daily temperatures were determined as shown in the Table 4.20

Table 4.20: COP_{hp} for min., average and max. temp. for Nov. range (15℃ - 55℃)

(15℃ - 55℃) RANGE FOR THE MONTH OF NOVEMBER 2006						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/11/06	20.1	17.4	15.3	3.25	3.12	3.42
02/11/06	23.0	17.5	12.0	3.26	2.91	3.61
03/11/06	23.8	17.7	11.3	3.27	2.87	3.66
04/11/06	20.0	17.6	15.5	3.27	3.13	3.42
05/11/06	15.6	13.1	8.2	2.98	2.67	3.14
06/11/06	16.8	12.1	8.3	2.92	2.68	3.22
07/11/06	20.9	12.1	4.7	2.92	2.45	3.48
08/11/06	19.6	13.1	8.5	2.98	2.69	3.39
09/11/06	21.8	13.8	7.0	3.02	2.59	3.53
10/11/06	21.5	14.8	7.6	3.09	2.63	3.51
11/11/06	21.4	15.7	9.0	3.15	2.72	3.51
12/11/06	21.6	15.7	9.0	3.15	2.72	3.52
13/11/06	23.3	16.6	9.4	3.20	2.75	3.63
14/11/06	23.1	17.4	9.5	3.25	2.75	3.62
15/11/06	20.6	15.9	11.7	3.16	2.89	3.46
16/11/06	21.0	14.0	7.5	3.04	2.62	3.48
17/11/06	23.6	14.6	5.0	3.08	2.47	3.65
18/11/06	23.6	16.2	9.5	3.18	2.75	3.65
19/11/06	22.4	15.6	9.2	3.14	2.73	3.57
20/11/06	22.1	14.3	5.2	3.06	2.48	3.55
21/11/06	21.3	13.7	6.4	3.02	2.55	3.50
22/11/06	21.0	13.6	7.1	3.01	2.60	3.48
23/11/06	21.4	13.7	6.5	3.02	2.56	3.51
24/11/06	23.3	13.8	6.6	3.02	2.57	3.63
25/11/06	24.0	14.5	4.3	3.07	2.42	3.67
26/11/06	22.7	14.4	6.0	3.06	2.53	3.59
27/11/06	23.8	13.4	7.0	3.00	2.59	3.66
28/11/06	24.6	14.6	7.5	3.08	2.62	3.71
29/11/06	24.8	15.6	4.8	3.14	2.45	3.72
30/11/06	21.4	14.3	6.2	3.06	2.54	3.51

Table 4.21: COP_{hp} for max., average and min. temp. for Dec. for the range (15℃ - 55℃)

(15℃ - 55℃) RANGE FOR THE MONTH OF DECEMBER 2006						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/12/06	20.2	14.1	8.6	3.04	2.69	3.43
02/12/06	21.4	12.8	6.5	2.96	2.56	3.51
03/12/06	19.0	11.3	4.6	2.87	2.44	3.35
04/12/06	18.0	11.2	5.7	2.86	2.51	3.29
05/12/06	18.8	11.7	4.5	2.89	2.43	3.34
06/12/06	18.2	11.5	5.0	2.88	2.47	3.30
07/12/06	19.5	11.0	5.0	2.85	2.47	3.39
08/12/06	19.8	11.6	5.5	2.88	2.50	3.41
09/12/06	17.0	11.0	5.0	2.85	2.47	3.23
10/12/06	18.0	11.6	7.0	2.88	2.59	3.29
11/12/06	21.5	12.1	7.0	2.92	2.59	3.51
12/12/06	17.0	11.8	6.6	2.90	2.57	3.23
13/12/06	19.0	15.0	10.0	3.10	2.78	3.35
14/12/06	21.0	13.2	7.4	2.99	2.62	3.48
15/12/06	17.0	13.7	10.0	3.02	2.78	3.23
16/12/06	18.5	11.5	5.5	2.88	2.50	3.32
17/12/06	21.0	11.9	4.5	2.90	2.43	3.48
18/12/06	20.5	12.2	6.0	2.92	2.53	3.45
19/12/06	20.5	12.8	6.5	2.96	2.56	3.45
20/12/06	21.5	13.3	6.5	2.99	2.56	3.51
21/12/06	22.0	15.1	9.1	3.11	2.73	3.55
22/12/06	16.5	14.6	3.3	3.08	2.36	3.20
23/12/06	13.2	11.1	6.5	2.85	2.56	2.99
24/12/06	19.8	10.2	4.5	2.80	2.43	3.41
25/12/06	18.5	11.2	4.5	2.86	2.43	3.32
26/12/06	12.3	11.4	9.5	2.87	2.75	2.93
27/12/06	8.5	6.7	5.0	2.57	2.47	2.69
28/12/06	12.0	7.9	3.0	2.65	2.34	2.91
29/12/06	15.9	7.2	-1.0	2.61	2.08	3.16
30/12/06	17.0	9.8	4.0	2.77	2.40	3.23
31/12/06	15.1	10.4	6.0	2.81	2.53	3.11

Table 4.22: COP_{hp} for max., average and min. temp. for Jan. for the range (15℃ - 55℃)

(15℃ - 55℃) RANGE FOR THE MONTH OF JANUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/01/07	17.5	8.6	2.4	2.69	2.30	3.26
02/01/07	18.4	10.1	4.8	2.79	2.45	3.32
03/01/07	16.8	12.5	8.4	2.94	2.68	3.22
04/01/07	17.4	13.0	7.4	2.97	2.62	3.25
05/01/07	15.7	13.6	12.2	3.01	2.92	3.15
06/01/07	15.1	11.4	6.6	2.87	2.57	3.11
07/01/07	14.6	11.1	7.3	2.85	2.61	3.08
08/01/07	16.9	8.8	2.5	2.71	2.31	3.22
09/01/07	16.6	9.7	3.0	2.76	2.34	3.20
10/01/07	16.1	14.0	12.6	3.04	2.95	3.17
11/01/07	15.6	14.0	12.7	3.04	2.95	3.14
12/01/07	15.6	13.0	8.5	2.97	2.69	3.14
13/01/07	16.6	8.8	1.9	2.71	2.27	3.20
14/01/07	17.5	9.9	4.1	2.78	2.41	3.26
15/01/07	16.8	10.7	5.0	2.83	2.47	3.22
16/01/07	17.8	10.8	4.6	2.83	2.44	3.28
17/01/07	19.8	11.9	5.8	2.90	2.52	3.41
18/01/07	18.5	10.4	3.4	2.81	2.36	3.32
19/01/07	16.8	11.0	5.2	2.85	2.48	3.22
20/01/07	14.8	12.4	9.0	2.94	2.72	3.09
21/01/07	15.7	12.8	8.9	2.96	2.71	3.15
22/01/07	18.7	9.8	3.1	2.77	2.35	3.34
23/01/07	18.0	11.1	4.5	2.85	2.43	3.29
24/01/07	19.0	13.9	6.7	3.03	2.57	3.35
25/01/07	19.0	13.7	6.6	3.02	2.57	3.35
26/01/07	18.8	11.8	5.2	2.90	2.48	3.34
27/01/07	18.8	11.3	4.6	2.87	2.44	3.34
28/01/07	16.7	10.9	5.4	2.84	2.49	3.21
29/01/07	14.2	9.6	5.5	2.76	2.50	3.05
30/01/07	15.7	9.6	4.4	2.76	2.43	3.15
31/01/07	15.4	8.9	2.0	2.71	2.28	3.13

Table 4.23: COP_{hp} for max., average and min. temp. for Feb. for the range (15℃ - 55℃)

(15℃ - 55℃) RANGE FOR THE MONTH OF FEBUARY 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/02/07	16.4	11.0	4.0	2.85	2.40	3.19
02/02/07	15.9	13.5	7.6	3.01	2.63	3.16
03/02/07	14.0	12.6	10.9	2.95	2.84	3.04
04/02/07	14.4	10.7	7.3	2.83	2.61	3.06
05/02/07	13.7	9.1	5.7	2.73	2.51	3.02
06/02/07	12.6	8.1	4.7	2.66	2.45	2.95
07/02/07	14.6	8.4	2.9	2.68	2.33	3.08
08/02/07	15.7	9.9	4.4	2.78	2.43	3.15
09/02/07	16.7	14.4	8.7	3.06	2.70	3.21
10/02/07	16.9	13.3	10.0	2.99	2.78	3.22
11/02/07	17.4	11.0	4.9	2.85	2.46	3.25
12/02/07	18.7	13.1	6.5	2.98	2.56	3.34
13/02/07	17.4	12.8	7.9	2.96	2.65	3.25
14/02/07	18.7	13.1	8.6	2.98	2.69	3.34
15/02/07	15.9	11.9	8.3	2.90	2.68	3.16
16/02/07	17.7	12.0	6.9	2.91	2.59	3.27
17/02/07	17.8	13.8	7.0	3.02	2.59	3.28
18/02/07	17.9	16.1	14.8	3.17	3.09	3.28
19/02/07	19.4	12.9	7.3	2.97	2.61	3.38
20/02/07	17.8	12.7	7.4	2.95	2.62	3.28
21/02/07	18.9	16.1	13.3	3.17	2.99	3.35
22/02/07	19.2	14.1	10.0	3.04	2.78	3.37
23/02/07	18.5	13.5	9.4	3.01	2.75	3.32
24/02/07	19.4	14.9	9.2	3.09	2.73	3.38
25/02/07	17.3	13.7	9.9	3.02	2.78	3.25
26/02/07	18.6	14.5	11.7	3.07	2.89	3.33
27/02/07	17.4	13.3	10.3	2.99	2.80	3.25
28/02/07	18.7	12.8	7.0	2.96	2.59	3.34

Table 4.24: COP_{hp} for max., average and min. temp. for March. For the range (15℃ - 55℃)

(15℃ - 55 ℃) RANGE FOR THE MONTH OF MARCH 2007						
DATES	**TMAX.**	**TAVG.**	**TMIN.**	**COP AVG.**	**COP MIN.**	**COP MAX.**
01/03/07	19.3	14.3	10.4	3.06	2.81	3.37
02/03/07	19.8	14.5	10.4	3.07	2.81	3.41
03/03/07	20.7	15.2	9.8	3.11	2.77	3.46
04/03/07	20.4	14.2	8.5	3.05	2.69	3.44
05/03/07	20.4	15.4	12.8	3.13	2.96	3.44
06/03/07	19.8	14.0	11.4	3.04	2.87	3.41
07/03/07	18.5	12.0	6.7	2.91	2.57	3.32
08/03/07	19.3	12.1	5.7	2.92	2.51	3.37
09/03/07	20.8	13.8	8.2	3.02	2.67	3.47
10/03/07	20.2	13.3	6.5	2.99	2.56	3.43
11/03/07	20.0	17.6	12.2	3.27	2.92	3.42
12/03/07	21.6	15.2	9.8	3.11	2.77	3.52
13/03/07	19.4	13.7	8.6	3.02	2.69	3.38
14/03/07	13.4	9.3	6.3	2.74	2.55	3.00
15/03/07	12.8	7.0	3.1	2.59	2.35	2.96
16/03/07	18.2	10.8	5.4	2.83	2.49	3.30
17/03/07	16.7	12.4	6.5	2.94	2.56	3.21
18/03/07	19.6	12.7	7.3	2.95	2.61	3.39
19/03/07	19.7	13.8	7.1	3.02	2.60	3.40
20/03/07	18.4	14.0	8.2	3.04	2.67	3.32
21/03/07	19.9	17.0	10.5	3.23	2.81	3.41
22/03/07	20.5	15.0	8.0	3.10	2.66	3.45
23/03/07	21.4	18.0	16.8	3.29	3.22	3.51
24/03/07	19.4	15.0	12.4	3.10	2.94	3.38
25/03/07	20.4	14.1	7.9	3.04	2.65	3.44
26/03/07	19.4	13.1	8.4	2.98	2.68	3.38
27/03/07	20.1	13.9	8.7	3.03	2.70	3.42
28/03/07	20.6	14.1	7.7	3.04	2.64	3.46
29/03/07	19.4	14.0	8.2	3.04	2.67	3.38
30/03/07	19.6	14.3	8.1	3.06	2.66	3.39
31/03/07	19.2	14.6	10.5	3.08	2.81	3.37

Below are the graphs showing the relationship between the respective COP_{hp} and the dates.

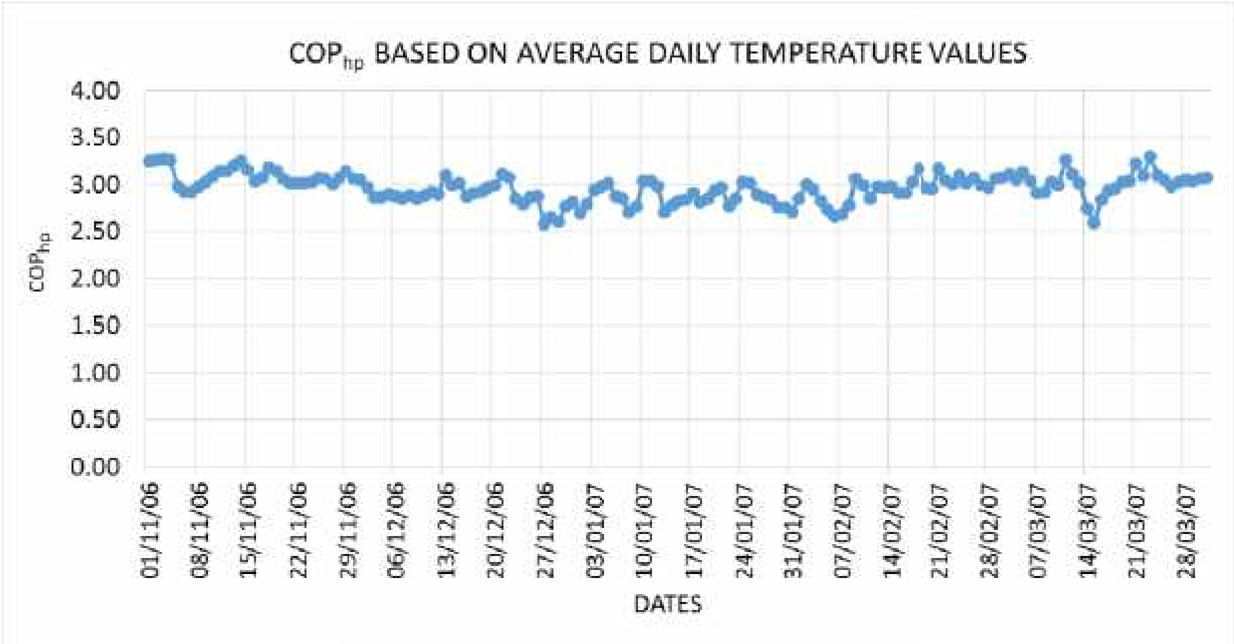

Figure 4.18: COP$_{hp}$ based on average daily temperatures for the range $(15℃-55℃)$

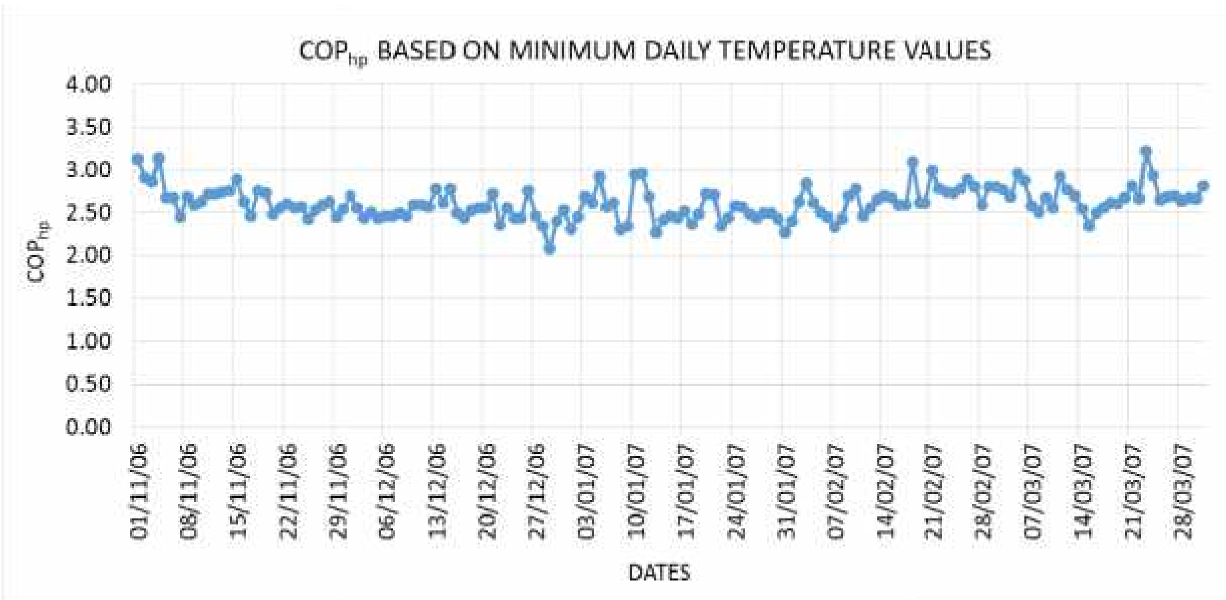

Figure 4.19: COP$_{hp}$ based on minimum daily temperatures for the range $(15℃-55℃)$

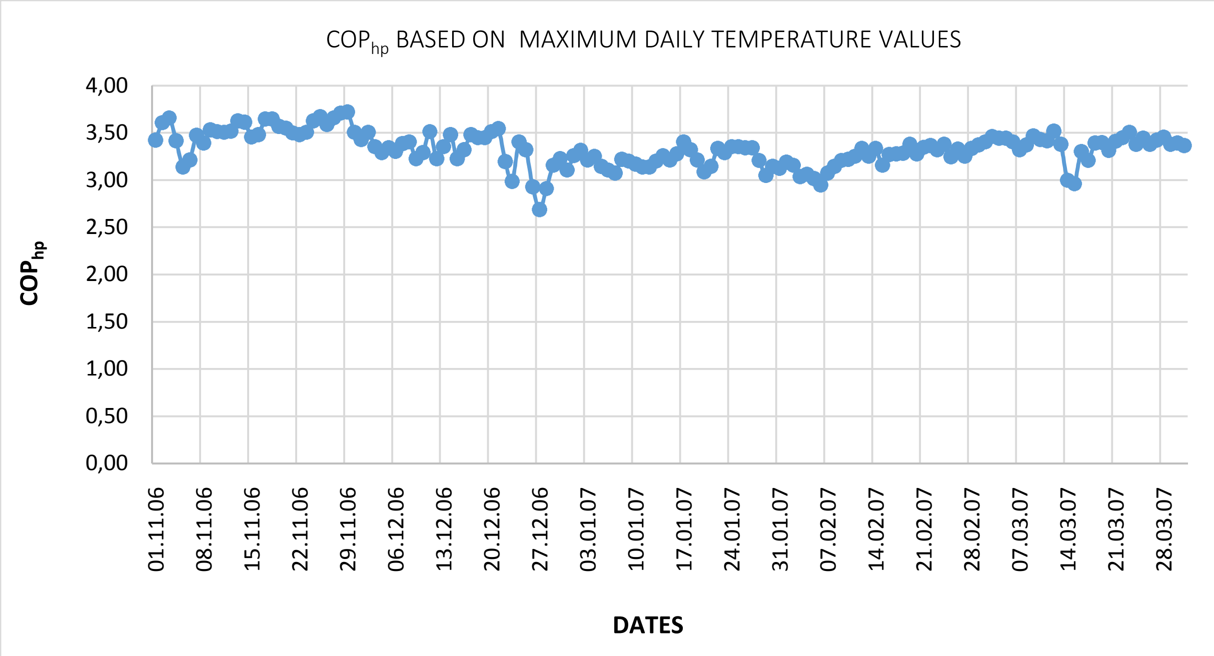

Figure 4.20: COP$_{hp}$ based on maximum daily temperatures for the range (15℃ – 55℃)

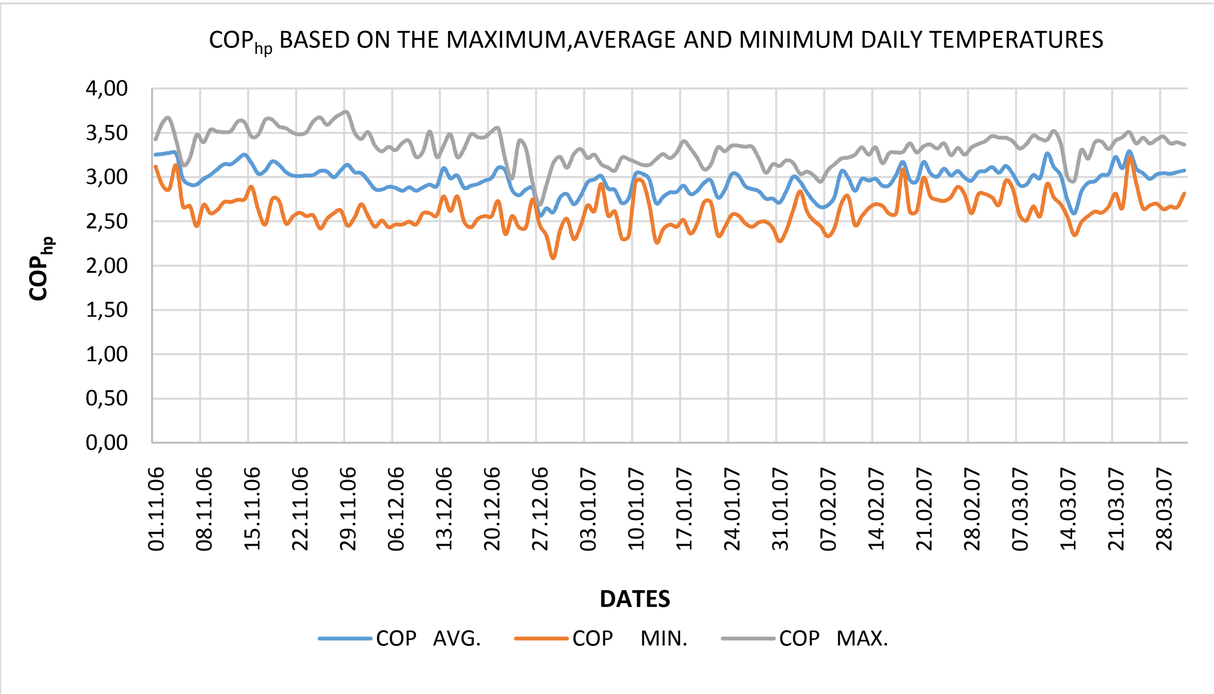

Figure 4.21: COP$_{hp}$ based on minimum, average and maximum daily temperature

4.5 Payback Analysis

The Electricity Authority of the northern Cyprus issues its bills based on a bi- monthly basis. Charges are said to be incremental, That is to say, the cost per kWh of electricity consumed increases with consumption. Although northern Cyprus power stations are fossils – fuels driven, as such there is what is called a fuel – adjustment surcharge. This is in accordance with the prevailing cost of oil, and is passed onto customers based on a per – kWh basis. Appendix 3.1 provide the 2016 northern Cyprus electricity bills. For our own case we consider the minimum value i.e. 1kWh is to 0.44 Turkish Lira.

Consider the one unit of the heat pump i.e. 190-liter capacity for hot water supply under the following range of temperatures i.e. $15^{\circ}C - 45^{\circ}C$, $15^{\circ}C - 55^{\circ}C$ and $15^{\circ}C - 60^{\circ}C$ respectively.

4.6 Unit with 190Liters Capacity

The energy consumed by electrical heater and that by heat pump are calculated for each of the range of the temperatures under this unit as shown below.

$$W_1 = mC_p \Delta T \qquad (4.7)$$

Where m = is the mass of water in kg (190liters ≈ 190kg),

C_P = specific capacity of water 4.186kJ/kg K,

ΔT = is the change in temperature between the surrounding temperature and the condensing temperature i.e. ΔT = (45 +273) – (15 +273) = 30K

$$W_1 = 190 \times 4.186 \times 318 - 288$$

$$= 190 \times 4.186 \times 30$$

$$W_1 = 23860.2\ kJ$$

And the corresponding energy consumed by the heat pump is calculated by

$$W_{hp_1} = \frac{W_1}{COP} = \frac{23860.2}{3.42} = 6976.67kJ$$

Similarly to calculate the energy consumed by electrical heater W_2 for the range of temperature $15^{\circ}C - 55^{\circ}C$ it follows the same footprint with the first calculation above i.e.

$$W_2 = mC_p \Delta T$$

$$W_2 = 190 \times 4.186 \times 328 - 288$$

W_2 = 190 × 4.186 × 40

$$W_2 = 31813.6\ kJ$$

And the corresponding energy consumed by the heat pump for the same range of temperatures is calculated by

$$W_{hp_2} = \frac{W_2}{COP} = \frac{31813.6}{3.00} = 10604.53kJ$$

Now to calculate the energy consumed by electrical heater W_3 for the range of temperature $15℃ - 60℃$ it follows the same footprint with the second calculation above i.e.

$$\Delta T_3 = 333 - 288 = 45℃$$

$$W_3 = MC_p\,\Delta T$$

$$W_3 = 190 \times 4.186 \times 45$$

$$W_3 = 35790.3\ kJ$$

And the corresponding energy consumed by the heat pump for the same range of temperatures i.e. $15℃ - 60℃$ is calculated by

$$W_{hp_3} = \frac{W_3}{COP} = \frac{35790.3}{2.59} = 13818.65kJ$$

To compare the costs when an electric water heater is used in heating water and that when a heat pump system is used for the same purpose and for the same period of time let us make an analysis from the calculated values obtained for W_1, W_2, W_3 respectively.

Now consider them one after the other to see how much it will cost for either the electric water heater or the heat pump water heater system.

But $W_1 = 23860.2\ kJ$ which equal to $6.633\ kWh$. Also from Appendix 3.1 $1kWh = 0.44TL$ i.e. for each kilowatt hour of electricity consumed.

Therefore,

$$6.633kWh \times 0.44TL = 2.9186TL \quad \text{Per day.}$$

Therefore, if we consider heating water for 5months, with 30days in each of the months, we have a total of 150days hence,

$150 \times 2.9186TL = 437.79TL$ Per year with electrical heater.

Now consider the use of heat pump to do the same job and assuming the unit is to be run once daily for 5months period, noting that the calculated SCOP for the range of temperature $15℃ - 45℃$ is 3.42

Then,

$$\frac{437.79TL}{3.42} = 128.01TL \text{ Per year with heat pump}$$

So the benefits of using the heat pump over the electrical heater to heat the water is given below

$$437.79TL - 128.01TL = 309.78TL$$

This simply means that the system has to be run for about 19 $years$ for it to pay back for the unit price which is approximately $5927TL$.

Also$W_2 = 31813.6\ kJ$ which equal to $8.844\ kWh$. and from Appendix 3.1, $1kWh = 0.44TL$ i.e. for each kilowatt hour of electricity consumed.

Therefore

$$8.844kWh \times 0.44TL = 3.891TL \text{ Per day } with\ electrical\ heater$$

Therefore, 5months with 30days in each of the months, we have a total of 150days.

Hence,

$$150 \times 3.891TL = 583.72TL \text{ Per year with electrical heater}$$

Now for heat pump to do the same job and for a 5months period, note that the SCOP obtained for the range of temperature $15℃ - 55℃$ is3.00

Then,

$$\frac{583.72TL}{3.00} = 194.57TL \text{ Per year with heat pump}$$

So the benefits of using the heat pump over the electrical heater is given below

$$583.72TL - 194.57TL = 389.15TL$$

This means that the system has to be run for about 15 $years$ for it to pay back for the unit price which is approximately $5927TL$.

Similarly $W_3 = 35790.3\ kJ$ which equal to $9.95\ kWh$. Also from Appendix 3.1, $1kWh = 0.44TL$ i.e. for each kilowatt hour of electricity consumed.

Therefore,

$$9.95kWh \times 0.44TL = 4.378TL \quad Per\ day.$$

Therefore, for 5months period assuming 30days in each of the months, we have a total of 150 days then,

$$150 \times 4.378TL = 656.7TL \quad Per\ year\ with\ electrical\ heater$$

With heat pump and for 5months period, recall that the SCOP for the range of temperature $15℃ - 60℃$ is 2.59

Then,

$$\frac{656.7TL}{2.59} = 253.55TL \text{ Per year with heat pump}$$

So the benefits of using the heat pump over the electrical heater is given below

$$656.7TL - 253.55TL = 403.15TL$$

Meaning that the system has to be run for about 14.5 $years$ for it to pay back for the unit price which is approximately $5927TL$.

For heat pump to do the same job and assuming the unit to work for a 5months duration, with the SCOP obtained for this range of temperature $15℃ - 45℃$ is 3.42

Then,

$$\frac{695.24TL}{3.42} = 202.12TL \quad Per\ year\ with\ heat\ pump$$

So the benefits of using the heat pump over the electrical heater is given below

$$695.24TL - 202.12TL = 489.12TL$$

This simply means that the system has to be run for about 12 $years$ for it to pay back for the unit price which is approximately $5927TL$.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Results

Table 5.1 gives a tabular result of the method suggested for estimating the maximum possible COP_{hp} by employing a number of cycles of heat pumps connected in series in an N- stages, notice that $T_H$is to be changing continuously while maintaining a constant $T_{L.}$

Table 5.1: Summary table foroverall COP_{hp} and individual COP_{hp}

Stage number	T_L [K]	T_H [K]	COP for each cycle	COP for N- stage
1	280	289	32.11	32.11
2	280	290	29.00	30.48
3	280	291	26.45	29.01
4	280	292	24.33	27.68
5	280	293	22.54	26.47
6	280	294	21.00	25.37
7	280	295	19.67	24.36
8	280	296	18.50	23.43
9	280	297	17.47	22.58
10	280	298	16.56	21.78
11	280	299	15.74	21.05
12	280	300	15.00	20.36
13	280	301	14.33	19.73
14	280	302	13.73	19.13
15	280	303	13.17	18.57
16	280	304	12.67	18.04
17	280	305	12.20	17.55
18	280	306	11.77	17.08
19	280	307	11.37	16.64
20	280	308	11.00	16.23
21	280	309	10.66	15.83
22	280	310	10.33	15.46
23	280	311	10.03	15.10
24	280	312	9.75	14.77
25	280	313	9.48	14.44
26	280	314	9.24	14.14
27	280	315	9.00	13.84
28	280	316	8.78	13.56
29	280	317	8.57	13.30
30	280	318	8.37	13.04
31	280	319	8.18	12.80
32	280	320	8.00	12.56
33	280	321	7.83	12.33
34	280	322	7.67	12.12
35	280	323	7.51	11.91
36	280	324	7.36	11.71
37	280	325	7.22	11.52
38	280	326	7.09	11.33
39	280	327	6.96	11.15
40	280	328	6.83	10.98
41	280	329	6.71	10.81
42	280	330	6.60	10.65
43	280	331	6.49	10.49
44	280	332	6.38	10.34
45	280	333	6.28	10.19

Based on the assumptions used here, the difference between the final and the initial water tank temperature is 45⍰ and since we consider the value of ΔT to be equal to 1⍰ , then we have 45 number of heat pumps to be connected in N- stages.

The evaporator temperature was kept constant while varying the condenser temperatures as seen in the Table 5.1 above

The COP_{hp} for both individual cycles of heat pumps and that of the overall stages of the heat pumps were determined and were shown graphically.

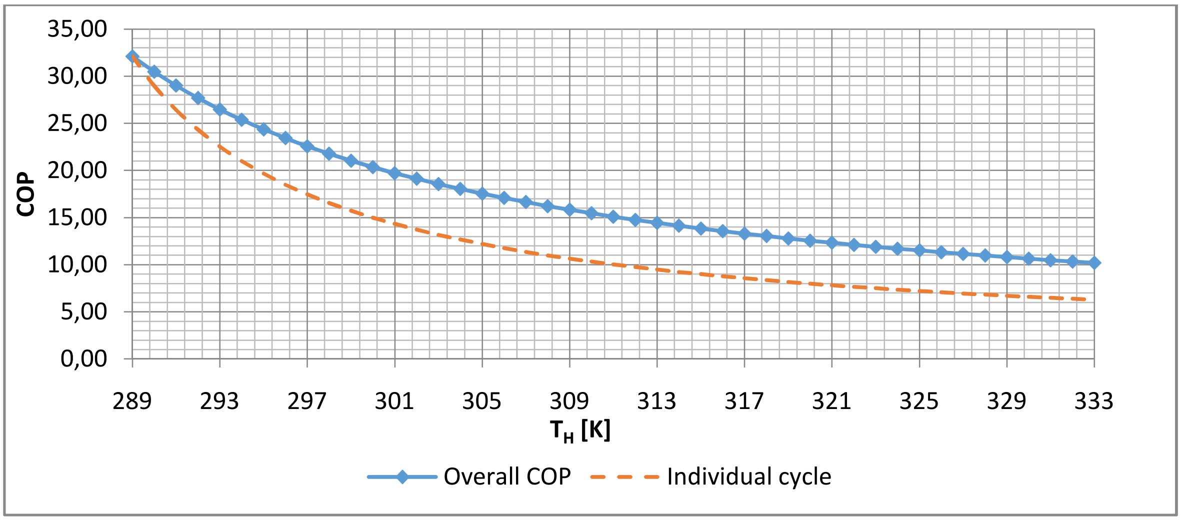

Figure 5.1: Comparism between individual COP_{hp} and the overall COP_{hp} with T_H

And it is shown clearly in Figure 5.1 that employing number of heat pumps in an N-stages improves the COP_{hp} value much higher than if the heat pumps were not. This shows that employing more cycles of heat pumps gives a more precise value of the COP_{hp}.

As shown in the Figure 5.2, is a comparism between the COP_{hp} of a vapor compression refrigeration cycle and that of the Reversed Carnot cycle. At different condenser temperatures and the evaporator temperature been constant.

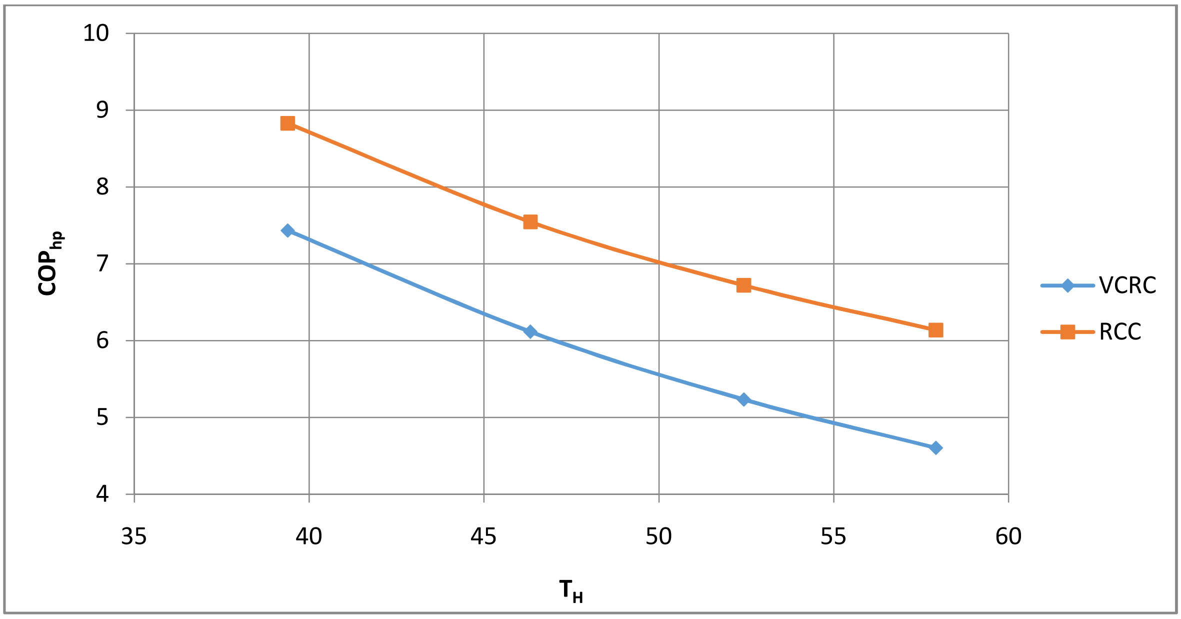

Figure 5.2: Comparism betweenCOP_{hp} for IVCRC and RCC

The COP_{hp} for the reversed Carnot cycle is always greater than that of the vapor compression refrigeration cycle because it is completely reversible cycle. Additionally the COP_{hp} here is a function of the evaporator temperature and the condenser temperature and hence the COP_{hp} increases sharply with evaporator temperatures, especially at high condenser temperatures, and it reduces as the condenser temperature increases but the effect tends to be marginal at low evaporator temperatures.

Although to build and operate reversed Carnot cycle in reality is impossible due to the difficulties in the compression of liquid-vapor at the compressor in which the reciprocating compressors especially high speed ones easily get damaged with the present of liquid in the vapor, and also the expansion process i.e. using turbine to extract work during the isentropic expansion of liquid refrigerant which is uneconomical and affect the blades of the turbine. But still the reversed Carnot cycle set the highest theoretical COP_{hp} and is used as reference against which the real cycles are compared.

Table 5.2: Rated COP_{hp} and Cal.SCOP

RATED COP	3.60
MIN. SCOP	3.09
AVG. SCOP	3.42
MAX. SCOP	3.77

As shown in the Table 5.2 are the rated COP_{hp} for a specific unit of heat pump for the range of temperature of (15℃ – 45℃) as declared by the manufacturer at a particular surrounding temperature of 15℃, and the calculated SCOP that was obtained from our previous calculations with several different temperaturesas shown in Figure 5.3 below

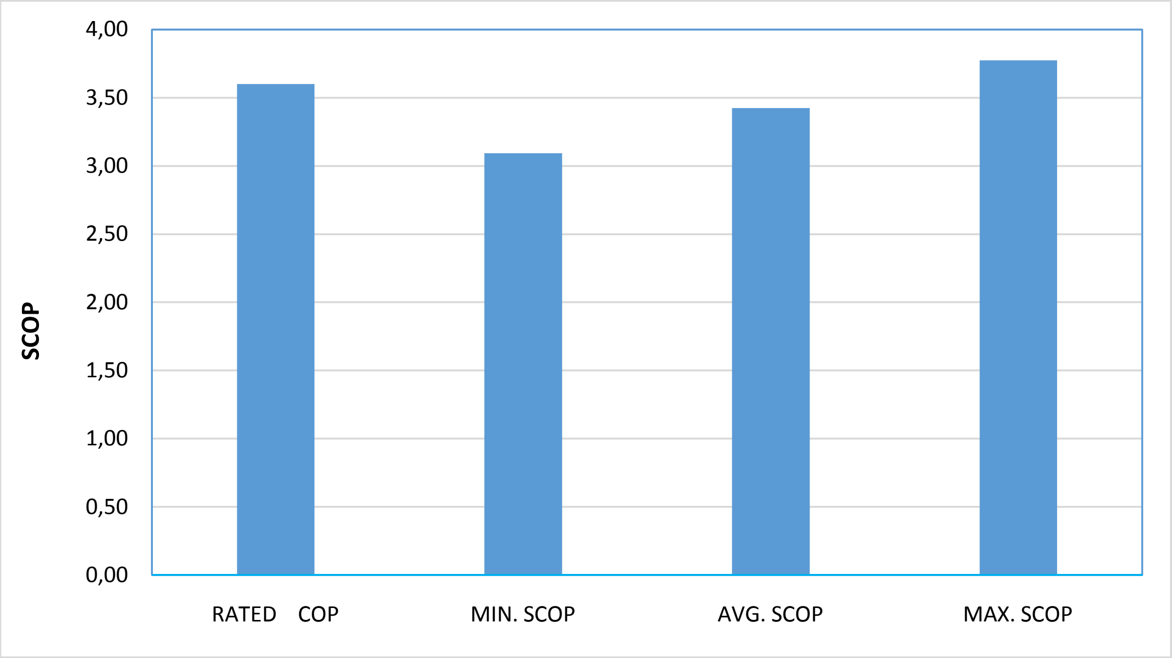

Figure 5.3: Rated COP_{hp} and calculated SCOP

The abovechart is comparing the rated COP_{hp} and the calculated SCOP for the given range of temperature as stated above.

It is obvious that the surrounding temperature plays a significant role towards these results. The SCOP for the minimum and the average daily temperatures are less than that of the rated COP, and the SCOP for the maximum daily temperatures is higher than the rated COP, all this variations are as a result of the surrounding temperatures i.e. which for both the minimum and the average daily temperatures are mostly less than 15℃ which affect the SCOP value for this two categories of temperatures hence given a value less than that of the rated COP_{hp} which is declared with 15℃ surrounding temperature.

Furthermore, for the maximum daily temperatures that are higher than 15℃ provides an SCOP greater than the rated COP_{hp} simply due to the temperature difference i.e. maximum daily temperatures are greater than 15℃ .

Hence the higher the surrounding temperature the higher the COP_{hp} and as well the SCOP and the more efficient the heat pump will be, as well the less running cost of the unit will be and vise-versa.

5.2 Payback outcome

Table 5.3: Water heating cost per year

Range	Energy consumed with electrical heater (W)	Energy consumed with Heat pump(W_h)	Cost per year with Electrical heater	Cost per year with Heat Pump	Benefits of using Heat Pump	Payback period
15℃ - 45℃	23860.2kJ	6976.7kJ	437.79TL	128.01TL	309.78TL	19years
15℃ – 55℃	31813.6kJ	10604.5kJ	583.72TL	194.57TL	389.15TL	15years
15℃ – 60℃	35790.3 kJ	13813.6kJ	656.70TL	253.55TL	403.15TL	14.5years

It is seen clearly that for each category and at different ranges of temperature the cost per year for heating water with electrical heater is much higher almost three times more than that when a heat pump is used, as such using the heat pump to heat the water provides so much benefits as provided in Table 5.3 above.

Although the payback period seems to be much longer especially in the case of the first and second i.e. 19years and 15years and even though it could be possible to run the unit for even more than such a years especially with proper installation, since a refrigerator last for several years operating without failing, and that the heat pump works as a refrigerator but in reversed which follow almost the same footprint with the refrigerator.

Additionally, with the new versions of heat pumps that have a better controls that are more robust than the old versions, it could be economically wise employing the use of the heat pump for heating water and possibly space conditioning since most of the people that uses heat pumps, used it for both purposes, and with heat pumps used in homes for either water heating or for both including space conditioning.

The environment is less polluted since the air is continually extracted and been used by the heat pump to generate the heat that will be used in heating water or space condition.

CHAPTER 6
CONCLUSION

6.1 Conclusions

Heat pump water heating system is an essential energy saving mechanism that save a lot of energy and cost as compared to electric resistance water heater that consumes more than three times the energy used by the heat pump systems as the unit COP_{hp} is declared to be 3.6.

A method was suggested in other to estimate the maximum possible COP_{hp} of a heat pump water heaters by employing a number of series connection of heat pumps in an N-stage,since using the reversed Carnot cycle as a heat pump to heat water have difficulties, therefore $T_H$has to be changing continuously so as to heat the water to the required temperature.

Reversed Carnot cycle operating as a Carnot heat pump is used in determining the coefficient of performance of a heat pump and compared with that of the vapor compression refrigeration cycle and was found to have a higher COP_{hp},

Seasonal coefficient of performance SCOP was determined by the Northern Cyprus meteorological data for Nicosia 2006/2007 based on the daily maximum, average and minimum temperatures and compared with that of the specified unit as declared by the manufacturer, which shows that the surrounding temperature has a significant effect towards the COP_{hp} value, the higher it becomes the more precise the COP_{hp} and as well the SCOP and vise- versa.

Finally, the cost of heating water per year with heat pump and that with electrical heater were analyzed, and it was clearly seen that using the heat pump provide additional benefits of saving costs as it is much lesser as compared to the electrical heater costs. Even though the payback period is a bit longer, but with proper installation and maintenance the unit could run for even more years.

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APPENDICES

APPENDIX 1

THEMODYNAMICS TABLES

Table 1.1: Properties of saturated refrigerant 134a (liquid – vapor) temperature table

TABLE A-10

Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

Properties of Saturated Refrigerant 134a (Liquid–Vapor): Temperature Table

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Temp. °C	Press. bar	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Temp. °C
−40	0.5164	0.7055	0.3569	0.04	204.45	0.00	222.88	222.88	0.0000	0.9560	−40
−36	0.6332	0.7113	0.2947	4.68	206.73	4.73	220.67	225.40	0.0201	0.9506	−36
−32	0.7704	0.7172	0.2451	9.47	209.01	9.52	218.17	227.90	0.0401	0.9456	−32
−28	0.9305	0.7233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411	−28
−26	1.0199	0.7265	0.1882	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390	−26
−24	1.1160	0.7296	0.1728	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370	−24
−22	1.2192	0.7328	0.1590	21.68	214.70	21.77	212.32	234.08	0.0897	0.9351	−22
−20	1.3299	0.7361	0.1464	24.17	215.84	24.26	211.05	235.31	0.0996	0.9332	−20
−18	1.4483	0.7395	0.1350	26.67	216.97	26.77	209.76	236.53	0.1094	0.9315	−18
−16	1.5748	0.7428	0.1247	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298	−16
−12	1.8540	0.7498	0.1068	34.25	220.36	34.39	205.77	240.15	0.1388	0.9267	−12
−8	2.1704	0.7569	0.0919	39.38	222.60	39.54	203.00	242.54	0.1583	0.9239	−8
−4	2.5274	0.7644	0.0794	44.56	224.84	44.75	200.15	244.90	0.1777	0.9213	−4
0	2.9282	0.7721	0.0689	49.79	227.06	50.02	197.21	247.23	0.1970	0.9190	0
4	3.3765	0.7801	0.0600	55.08	229.27	55.35	194.19	249.53	0.2162	0.9169	4
8	3.8756	0.7884	0.0525	60.43	231.46	60.73	191.07	251.80	0.2354	0.9150	8
12	4.4294	0.7971	0.0460	65.83	233.63	66.18	187.85	254.03	0.2545	0.9132	12
16	5.0416	0.8062	0.0405	71.29	235.78	71.69	184.52	256.22	0.2735	0.9116	16
20	5.7160	0.8157	0.0358	76.80	237.91	77.26	181.09	258.36	0.2924	0.9102	20
24	6.4566	0.8257	0.0317	82.37	240.01	82.90	177.55	260.45	0.3113	0.9089	24
26	6.8530	0.8309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082	26
28	7.2675	0.8362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076	28
30	7.7006	0.8417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070	30
32	8.1528	0.8473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064	32
34	8.6247	0.8530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058	34
36	9.1168	0.8590	0.0223	99.47	246.11	100.25	166.15	266.40	0.3678	0.9053	36
38	9.6298	0.8651	0.0210	102.38	247.09	103.21	164.12	267.33	0.3772	0.9047	38
40	10.164	0.8714	0.0199	105.30	248.06	106.19	162.05	268.24	0.3866	0.9041	40
42	10.720	0.8780	0.0188	108.25	249.02	109.19	159.94	269.14	0.3960	0.9035	42
44	11.299	0.8847	0.0177	111.22	249.96	112.22	157.79	270.01	0.4054	0.9030	44
48	12.526	0.8989	0.0159	117.22	251.79	118.35	153.33	271.68	0.4243	0.9017	48
52	13.851	0.9142	0.0142	123.31	253.55	124.58	148.66	273.24	0.4432	0.9004	52
56	15.278	0.9308	0.0127	129.51	255.23	130.93	143.75	274.68	0.4622	0.8990	56
60	16.813	0.9488	0.0114	135.82	256.81	137.42	138.57	275.99	0.4814	0.8973	60
70	21.162	1.0027	0.0086	152.22	260.15	154.34	124.08	278.43	0.5302	0.8918	70
80	26.324	1.0766	0.0064	169.88	262.14	172.71	106.41	279.12	0.5814	0.8827	80
90	32.435	1.1949	0.0046	189.82	261.34	193.69	82.63	276.32	0.6380	0.8655	90
100	39.742	1.5443	0.0027	218.60	248.49	224.74	34.40	259.13	0.7196	0.8117	100

R-134a

Table 1.2: Properties of superheated refrigerant 134a vapor table

TABLE A-12

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 8.0 bar = 0.80 MPa (T_{sat} = 31.33°C)				p = 9.0 bar = 0.90 MPa (T_{sat} = 35.53°C)			
Sat.	0.02547	243.78	264.15	0.9066	0.02255	245.88	266.18	0.9054
40	0.02691	252.13	273.66	0.9374	0.02325	250.32	271.25	0.9217
50	0.02846	261.62	284.39	0.9711	0.02472	260.09	282.34	0.9566
60	0.02992	271.04	294.98	1.0034	0.02609	269.72	293.21	0.9897
70	0.03131	280.45	305.50	1.0345	0.02738	279.30	303.94	1.0214
80	0.03264	289.89	316.00	1.0647	0.02861	288.87	314.62	1.0521
90	0.03393	299.37	326.52	1.0940	0.02980	298.46	325.28	1.0819
100	0.03519	308.93	337.08	1.1227	0.03095	308.11	335.96	1.1109
110	0.03642	318.57	347.71	1.1508	0.03207	317.82	346.68	1.1392
120	0.03762	328.31	358.40	1.1784	0.03316	327.62	357.47	1.1670
130	0.03881	338.14	369.19	1.2055	0.03423	337.52	368.33	1.1943
140	0.03997	348.09	380.07	1.2321	0.03529	347.51	379.27	1.2211
150	0.04113	358.15	391.05	1.2584	0.03633	357.61	390.31	1.2475
160	0.04227	368.32	402.14	1.2843	0.03736	367.82	401.44	1.2735
170	0.04340	378.61	413.33	1.3098	0.03838	378.14	412.68	1.2992
180	0.04452	389.02	424.63	1.3351	0.03939	388.57	424.02	1.3245
	p = 10.0 bar = 1.00 MPa (T_{sat} = 39.39°C)				p = 12.0 bar = 1.20 MPa (T_{sat} = 46.32°C)			
Sat.	0.02020	247.77	267.97	0.9043	0.01663	251.03	270.99	0.9023
40	0.02029	248.39	268.68	0.9066				
50	0.02171	258.48	280.19	0.9428	0.01712	254.98	275.52	0.9164
60	0.02301	268.35	291.36	0.9768	0.01835	265.42	287.44	0.9527
70	0.02423	278.11	302.34	1.0093	0.01947	275.59	298.96	0.9868
80	0.02538	287.82	313.20	1.0405	0.02051	285.62	310.24	1.0192
90	0.02649	297.53	324.01	1.0707	0.02150	295.59	321.39	1.0503
100	0.02755	307.27	334.82	1.1000	0.02244	305.54	332.47	1.0804
110	0.02858	317.06	345.65	1.1286	0.02335	315.50	343.52	1.1096
120	0.02959	326.93	356.52	1.1567	0.02423	325.51	354.58	1.1381
130	0.03058	336.88	367.46	1.1841	0.02508	335.58	365.68	1.1660
140	0.03154	346.92	378.46	1.2111	0.02592	345.73	376.83	1.1933
150	0.03250	357.06	389.56	1.2376	0.02674	355.95	388.04	1.2201
160	0.03344	367.31	400.74	1.2638	0.02754	366.27	399.33	1.2465
170	0.03436	377.66	412.02	1.2895	0.02834	376.69	410.70	1.2724
180	0.03528	388.12	423.40	1.3149	0.02912	387.21	422.16	1.2980

Pressure Conversions:
1 bar = 0.1 MPa
= 10² kPa

Table 1.3: Properties of saturated refrigerant 134a (liquid – vapor) pressure table

R-134a

TABLE A-11

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

Properties of Saturated Refrigerant 134a (Liquid–Vapor): Pressure Table

		Specific Volume m³/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Press. bar
0.6	−37.07	0.7097	0.3100	3.41	206.12	3.46	221.27	224.72	0.0147	0.9520	0.6
0.8	−31.21	0.7184	0.2366	10.41	209.46	10.47	217.52	228.39	0.0440	0.9447	0.8
1.0	−26.43	0.7258	0.1917	16.22	212.18	16.29	215.06	231.35	0.0678	0.9395	1.0
1.2	−22.36	0.7323	0.1614	21.23	214.50	21.32	212.54	233.86	0.0879	0.9354	1.2
1.4	−18.80	0.7381	0.1395	25.66	216.52	25.77	210.27	236.04	0.1055	0.9322	1.4
1.6	−15.62	0.7435	0.1229	29.66	218.32	29.78	208.19	237.97	0.1211	0.9295	1.6
1.8	−12.73	0.7485	0.1098	33.31	219.94	33.45	206.26	239.71	0.1352	0.9273	1.8
2.0	−10.09	0.7532	0.0993	36.69	221.43	36.84	204.46	241.30	0.1481	0.9253	2.0
2.4	−5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222	2.4
2.8	−1.23	0.7697	0.0719	48.18	226.38	48.39	198.13	246.52	0.1911	0.9197	2.8
3.2	2.48	0.7770	0.0632	53.06	228.43	53.31	195.35	248.66	0.2089	0.9177	3.2
3.6	5.84	0.7839	0.0564	57.54	230.28	57.82	192.76	250.58	0.2251	0.9160	3.6
4.0	8.93	0.7904	0.0509	61.69	231.97	62.00	190.32	252.32	0.2399	0.9145	4.0
5.0	15.74	0.8056	0.0409	70.93	235.64	71.33	184.74	256.07	0.2723	0.9117	5.0
6.0	21.58	0.8196	0.0341	78.99	238.74	79.48	179.71	259.19	0.2999	0.9097	6.0
7.0	26.72	0.8328	0.0292	86.19	241.42	86.78	175.07	261.85	0.3242	0.9080	7.0
8.0	31.33	0.8454	0.0255	92.75	243.78	93.42	170.73	264.15	0.3459	0.9066	8.0
9.0	35.53	0.8576	0.0226	98.79	245.88	99.56	166.62	266.18	0.3656	0.9054	9.0
10.0	39.39	0.8695	0.0202	104.42	247.77	105.29	162.68	267.97	0.3838	0.9043	10.0
12.0	46.32	0.8928	0.0166	114.69	251.03	115.76	155.23	270.99	0.4164	0.9023	12.0
14.0	52.43	0.9159	0.0140	123.98	253.74	125.26	148.14	273.40	0.4453	0.9003	14.0
16.0	57.92	0.9392	0.0121	132.52	256.00	134.02	141.31	275.33	0.4714	0.8982	16.0
18.0	62.91	0.9631	0.0105	140.49	257.88	142.22	134.60	276.83	0.4954	0.8959	18.0
20.0	67.49	0.9878	0.0093	148.02	259.41	149.99	127.95	277.94	0.5178	0.8934	20.0
25.0	77.59	1.0562	0.0069	165.48	261.84	168.12	111.06	279.17	0.5687	0.8854	25.0
30.0	86.22	1.1416	0.0053	181.88	262.16	185.30	92.71	278.01	0.6156	0.8735	30.0

v_f = (table value)/1000

APPENDIX 2

ALDEA HEAT PUMP TECHNICAL SPECIFICATIONS

Figure 2.1: Aldea Heat Pump

ALDEA HAVADAN SUYA ISI POMPASI

ISI POMPALI BOYLER
AL- IPB 190
AL- IPB 300

KULLANIM KILAVUZU

Model	Ebatlar (mm: D x Y)	Net / brüt ağırlık (kg)	Güç Kaynağı
AL-IPB 190	Φ568×1640	94/110	220~240V-1ph-50Hz
AL-IPB 300	Φ650×1,920	123/150	220~240V-1ph-50Hz

Table 2.1:AL – IPB 190 technical specification

Model			AL-IPB 190	
Çalışma modu			Ekonomi	E-ısıtıcı
Çalışma ortamı sıcaklığı		℃	-7 ~ 43	-30 ~ 43
Çıkış suyu sıcaklığı		℃	Varsayılan 55℃,38℃ ~ 70℃	
Güç kaynağı		Ph-V-Hz	1-220 ~ 240-50	
Depolama boyutu		L	190	
Su ısıtma	Kapasite	KW	1.5	3.00
	Perform. katsayısı (PK)	KW/KW	3.6	1.00
	Mak. akım	A	3.4	13.0
Ortam sıcaklığı		℃	-30 ~ 43	
Unite	Ebatlar (D×H)	mm	Φ568×1640	
	Ambalaj (W×H×D)	mm	675×1715×690	
	Net/brüt ağırlık	kg	94/110	
Gurultu seviyesi		dB(A)	41	
Soğutucu tipi /miktarı		kg	R134a/0.95	
Soğutucu tasarım basıncı		MPa	2.6/ 1.2	
Depo tasarım basıncı		MPa	0.15 ~ 1.0	
Kısma tipi			Elektronik genleşme valfi	
Sistem koruması			TCO1, TCO2, PT valfi, otomatik buz çözme, aşırı yuk koruması sıcaklığı, elektrik kaçağına karşı koruma	
Hava akışı (filtre elekli)		m³/h	218/202/178	
Kompresör	Model		PJ125G1C-4DZDE	
	Tip Marka		Döner GMCC	
	Kapasite	Btu/h	4740	
	Giriş	KW	0.515	
	Nominal akım (RLA)	A	2.32	
	Kilitli rotor Amp (LRA)	A	15	
	Termal koruyucu Kapasitör	 μF	125 25	
	Soğutucu yağ	ml	400	
Fan motor	Model		YDK12-6A	
	Marka		welling	
	Giriş	W	28	
	Hız Yalıtım sınıfı	r/dak.	900/815/680 B	
	Güvenlik sınıfı		IPX4	
	Giriş	W	20	
	Çıkış	W	9	
	Nominal akım	A	0.12	
	Kapasitör	μF	1.2	

Table 2.2:AL – IPB 300 technical specifications

Model			AL-IPB 300	
Çalışma modu			Ekonomi	Elektrik
Çalışma ortamı sıcaklığı		°C	7 ~ 43	-30 ~ 43
Çıkış suyu sıcaklığı		°C	Varsayılan 55°C,38°C ~ 60°C	
Güç kaynağı		Ph-V-Hz	1-220 ~ 240-50	
Depolama ebadı		L	300	
Su ısıtma	Kapasite	k	3.00	3.00
	Performans katsayısı (PK)	kW/kW	3.60	1.00
	Maks. akım	A	6.5	13.0
Ortam sıcaklığı		°C	-30 ~ 43	
Ünite	Ebatlar (D×H)	mm	Φ650×1,920	
	Ambalaj (W×H×D)	mm	750×2,150×780	
	Net/brüt ağırlık	k	120/150	
Gürültü seviyesi		dB(A)	48	
Soğutucu tipi/miktarı		k	R134a/1.2	
Soğutucu tasarım basıncı		MPa	3.0/1.2	
Depo tasarım basıncı		MPa	1	
Kısma tipi			Elektrikli genleşme valfi	
Sistem koruması			TCO1, TCO2, PT valfi, otomatik buz çözme aşırı yük koruması sıcaklığı, elektrik kaçağına karşı koruma	
Hava akımı		m³/saat	414/355/312	
Kompresör	Model		RB233GRDC	
	Tip		Döner	
	Marka		Guangzhou Mitsubishi electric	
	Kapasite	Btu/saat	9500	
	Girdi	k	0.9	
	Nominal akım (RLA)	A	4.1	
	Kilitli rotor Amp (LRA)	A	30	
	Termal koruyucu		115	
	Kapasitör	µ	30	
	Krank kutusu	W	25	
	Soğutucu yağ	m	440	
	Model		YDK30-6H	
	Marka		welling	

Table 2.3:AL – IPB 300 technical specifications

ALDEA Isı Pompası Teknik El Kitabı-ISI POMPALI BOYLER

Fan motor	Girdi	w	68
	Hız	r/dak	620/530/435
	Yalıtım sınıfı		B
Buharlaştırıcı bobini	Güvenlik sınıfı		IPX4
	Nominal Akım	A	0.3
	Kapasitör	μF	2.5
	Dizi sayısı		3
	Tüp aralığı(a)x dizi aralığı (b)	mm	22×19.05
	Kanat mesafesi	mm	1.5
	Kanat tipi (kod)		Hidrofilik alüminyum
	Tüpün dış çapı ve tipi	mm	8
			İç vida dişi
	Bobin uzun. x yüksek	mm	482×352
	Devre sayısı		4
Su borusu hattı	Su girişi borusu	mm	DN20
	Su çıkışı borusu	mm	DN20
	Drenaj borusu	mm	DN20
	PT valf matsalı	mm	DN20
Isı eşanjörü			Bölücü duvar tipi ısı eşanjörü
Güneş ısısı eşanjörü	Su girişi borusu	mm	DN20
	Su çıkışı borusu	mm	DN20
	Isı eşanjörü		Paslanmaz çelik SUS316L
	Dim. x Uzunluk	mm	22×10000
	Mak. basınç	MPa	0.7
E-ısıtıcı		kW	3
Sıcak su randımanı		m³/saat	0.086
Yükleme Miktarı	20'/40'/40H	Pcs	21/47/47

Açıklamalar:

1. Test koşulları: dış [illegible] 15/12°C [illegible], giriş suyu sıcaklığı 15°C, çıkış suyu sıcaklığı 45°C

2. [illegible]

Figure 2.2:AL – IPB 190 COP/ Ambient temperature chart

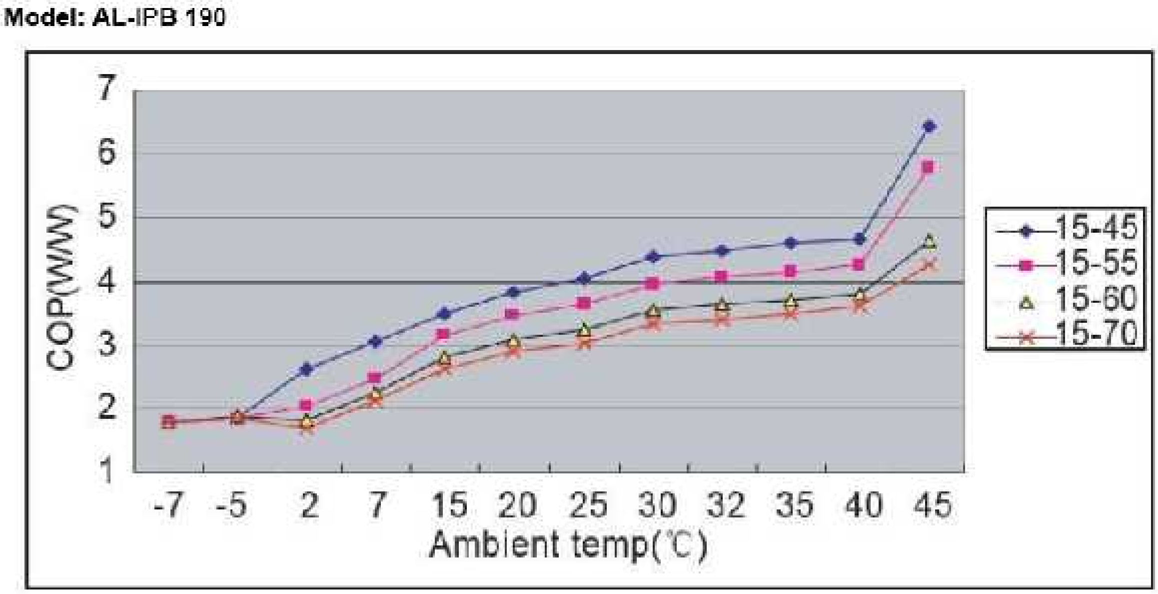
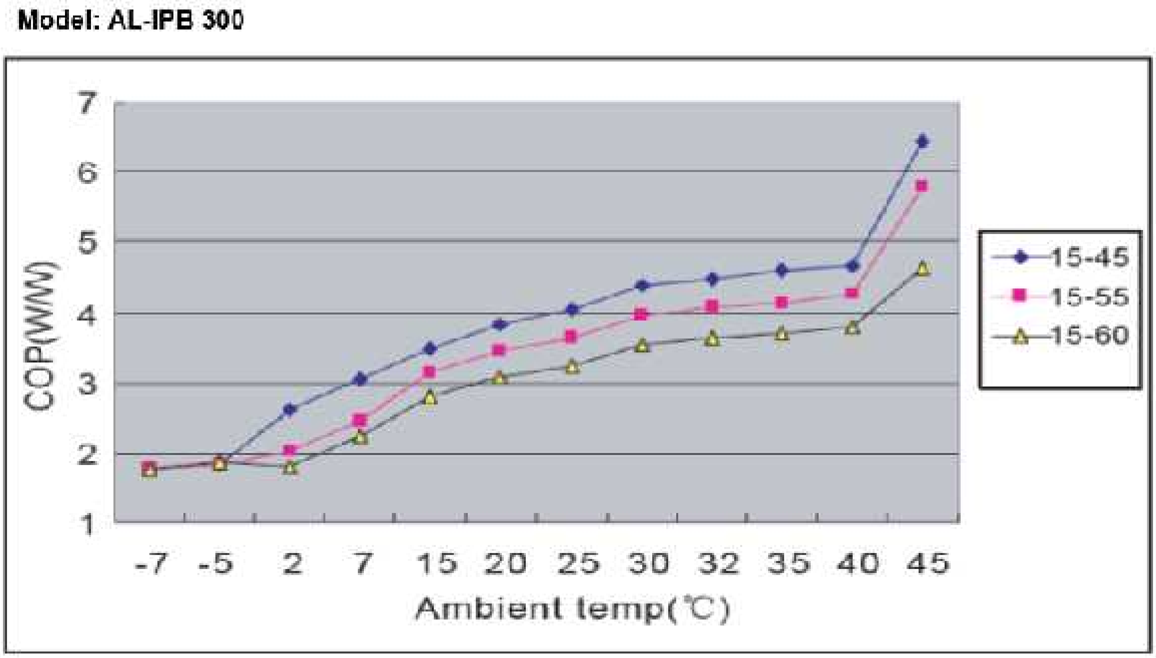


Figure 2.3:AL – IPB 300 COP/ Ambient temperature Chart



APPENDIX 3

ELECTRICTY CONSUMPTION RATES

Table 3.1: Electricity bill per kilowatt hour for Nicosia 2016

KKTC ELEKTRİK KURUMU

01 Nisan 2016 TARİHİNDEN İTİBAREN UYGULAMADA OLAN TARİFE ÜÇRETLERİ

Bu tarihli uygulamada sadece maktu ücretlerde değişiklik yapılmıştır.

Tarife Kod ve Tarife İsmi	Eski Maktu Ücreter		Yeni Maktu Ücretler *	Yeni Maktu Ücretler **	TÜKETİM ÜCRETLER ESKİ		Yeni Tarife Ücretleri	artış oranı
01 Geçici Akım Tarifesi					Her kWs için	0,98	0,98	0,00%
14 Geçici Akım Tarifesi II						0,87	0,87	0,00%
02 konut Tarifesi (ilk 250 Kws için) Yoksul		16,95	16,95	12,00	Her kWs için	0,25	0,20	-20,00%
02 konut Tarifesi (0- 250 Kws)		16,95	16,95	12,00	Her kWs için	0,44	0,40	-9,09%
02 konut Tarifesi (251-500 Kws)		16,95	16,95	12,00	Her kWs için	0,48	0,45	-6,25%
02 konut Tarifesi (501-750 Kws)		16,95	16,95	12,00	Her kWs için	0,52	0,49	-5,77%
02 konut Tarifesi (751 Kws üzeri)		16,95	16,95	12,00	Her kWs için	0,54	0,52	-3,70%
03 Ticari Tarife	Tek faz	18,17	18,17		Her kWs için	0,40	0,40	0,00%
	Çok faz	31,50	31,50					
04 Ticari Tarife	Her KVA	7,00	7,00		1.Dilim	0,40	0,40	0,00%
	için				2.Dilim	0,39	0,39	0,00%
05 Erdüsiri Tarife	Tek faz	18,17	18,17		Her kWs için	0,40	0,40	0,00%
	Çok faz	31,50	31,50					
06 Erdüsiri Tarife	Her KVA	7,00	7,00		1.Dilim	0,40	0,40	0,00%
	için				2.Dilim	0,39	0,39	0,00%
06 (a) Erdüsiri Tarife	Her KVA	3,50	3,50		1.Dilim	0,40	0,40	0,00%
	için				2.Dilim	0,39	0,39	0,00%
07 Turizm Tarife	Tek faz	18,17	18,17		Her kWs için	0,40	0,40	0,00%
	Çok faz	31,50	31,50					
08 Turizm Tarife	Her KVA	7,00	7,00		1.Dilim	0,40	0,40	0,00%
	için				2.Dilim	0,39	0,39	0,00%
09 Su Motorları	Tek faz	18,17	18,17		Her kWs için	0,40	0,40	0,00%
	Çok faz	31,50	31,50					
10 Sokak Işıkları						0,45	0,435	-3,33%
12 Savunma Tarifesi					Her kWs için	0,45	0,435	-3,33%
13 Devlet Daireleri Tarifesi	Tek faz	18,17	18,17		Her kWs için	0,56	0,56	0,00%
	Çok faz	31,50	31,50					

Kıb-Tek Bilgi İşlem Birimi 01 Nisan 2016

* Fatura talebinde bulunan tüketiciler için alınacak maktu ücret

** Fatura talebince bulunmayan tüketiciler için alınacak maktu ücret

https://www.kibtek.com/tarifeler