OPTIMIZATION OF A HEAT PUMP FOR A HYBRID PVT-HEAT PUMP SYSTEM; A CASE STUDY FOR BALE MOUNTAINS LODGE

A thesis submitted to the school of Mechanical and Industrial engineering in partial fulfillment of the requirement for the Degree of Master of Science in Mechanical Engineering (Thermal Engineering Stream)

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This is to certify that the thesis prepared by Abdi Mirgissa, entitled, "**Optimization Of A Heat Pump For A Hybrid PVT-Heat Pump System; A Case Study For Bale Mountains Lodge**" submitted in accordance with the requirements for the Degree of Master of Science (Thermal Engineering Stream) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "Optimization Of A Heat Pump For A Hybrid Pvt-Heat Pump System; A Case Study For Bale Mountains Lodge" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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Abdi Mirgissa Date

This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.

__________________________ ______________________

Dr.-Ing. Demiss Alemu (Advisor) Date

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ABSTRACT

As a greater part of the globe is facing the wrath of environmental illnesses, it is an undeniable fact that the new technologies coming into light should always play the role of curing the short comings faced related to these environmental problems. In line with this, there has been a set of laws and regulations that forces environmentally friendly lodges or eco-lodges to implement or put in place any form of equipment or technology that won't be an additional burden to the ecology. Putting this in perspective and considering the requirement from the site under analysis, a PVT-assisted heat pump has been recommended for the location under study.

In this thesis, as an extension of an existing research on the analysis concerned with the photovoltaic-thermal section, the final hot water output from the PVT panel has been used as an inlet working fluid to which more heat (thermal) energy would be added to come up with the required final domestic hot water temperature. In order to come up with the necessary results, the MATLAB code has been used for simulation. As an input for the analysis, a heat pump manufacturer's data based on inlet water and ambient temperature has been used. The study analyzes the performance of the proposed system without a thorough look into the thermo-physical property analysis of each component. Using the data from the manufacturer and the corresponding information of the location, a COP and Compressor Power surface plot has been generated. Utilizing that, thermal power from the heat pump has been developed for every hour of the year under study. And finally, a heat balance undertaken at the storage tank receiving the output heat from the heat pump has given the required raise in temperature of the water required for domestic use. the results from the generated code have shown that the parallel use of ten heat pumps simultaneously working to increase the temperature have come up with the required domestic hot water temperature. Finally, a total of ten heat pumps have been found to perfectly meet the required temperature in the storage tank. And it has also been observed that these heat pumps will operate simultaneously to come up with the required property of the domestic hot water lying between temperature ranges of 318 K and 343 K.

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CHAPTER 1
INTRODUCTION

1.1 Background

Energy stands as the driving force in many of the day to day human activities. It directly correlates to the development of a nation, and the world in general [1]. Ethiopia with a total area of 1,127,127 sq. km out of which 1,119,683 sq. km is land is known for its high plateau and amidst all these, grand rift valleys. The average elevation ranges between 1,500 to 3,000 meters above sea level. And With only 20% of the total population of the country living in the urban areas which is merely supported by the power almost all generated by the hydro power plants, it would only be logical to look for other forms of energy sources that have the potential to support the largely rural and off-grid zones of the country. Moreover, putting the environmental condition and related health issues into perspective while using other forms of energy generating systems, it is important to look into clean, sustainable, efficient and state of the art energy technologies that could eventually support the existing power systems and one of the most promising resources that could meet the criteria's listed above is the solar energy with its huge potential for reduction of emission and pollution adding to the many other pros of the system under analysis. [2] Moreover, it has also been seen that solar elevation angle, altitude and corresponding surface layer weather conditions hugely affect solar radiation resource. [3] And Ethiopia, being in a low altitude region with almost a perpendicular incidence of the sun's angle is gifted with a humongous amount of solar radiation resource.

But although the country is gifted with such terrains and natural attributes which could give way to different forms of renewable energy, the government has been duly focusing on power generation from hydro power plants only. With thirteen fully operational hydro power plants and two more expected to be operational in few years' time, the government has focused on meeting its long term plan of making sure Ethiopia will be one of the largest hydroelectric power producers in Africa. [4]

The solar energy being a very large and inexhaustible source of energy is a well-developed, clean and renewable source of energy, [5] which is correspondingly equally promising for meeting the far unmet power needs of rural Ethiopia. The sun generates power in the form of radiant energy at a rate of 3.8×10^{20} MW. And fraction of this meeting the earth is around 1.8×10^{11} MW. This magnitude makes solar energy the now and future remedy for existing power demands all over the world.

One additional unit in the system; a heat pump, is a device used to extract heat from a source at low temperature and dissipate off this heat at a relatively higher temperature. Unlike the customarily understood and utilized refrigeration system, the heat pump stands with the purpose of creating heat at a high temperature level. Normally, the production of heat at a very high temperature requires a primary energy source (Wind, Solar energy, Nuclear or fossil fuel). But in the case of heat pumps, it comes off as a device which only upgrades heat and does not inquire the input of primary energy.[6]

In general, the second law of thermodynamics inquires the existence of another energy source in order for the heat pump to be able to achieve the unnatural transfer of heat from low to high temperature. This additional energy input could be of mechanical or thermal type. Meaning, if the auxiliary source delivers mechanical energy, then the heat pump is of the mechanically operated type and on the other hand, if the driving source is of the thermal type, device would be classified accordingly. In order to succumb to the idea of having a good understanding of nature of the different heat pumps, it has been proven that it is important to assess the thermodynamic aspect of upgrading the heat at hand. The performance of a heat pump highly depends on the parameters defining the thermodynamic cycle; i.e: source temperature & compressor performance to mention a few. On the other hand, Heat pumps can also be generally classified as vapor compression or absorption type. [7] Depending on their scale of application the first type can generally be utilized for space heating purposes while the latter is assumed to be well suited for industrial applications and often for space heating as well. Many describe the rudimentary cycle of a heat pump as the same as that of refrigeration cycles only for a differing purpose. The Carnot cycle is used as the basic platform upon which the concept of heat pump is developed.

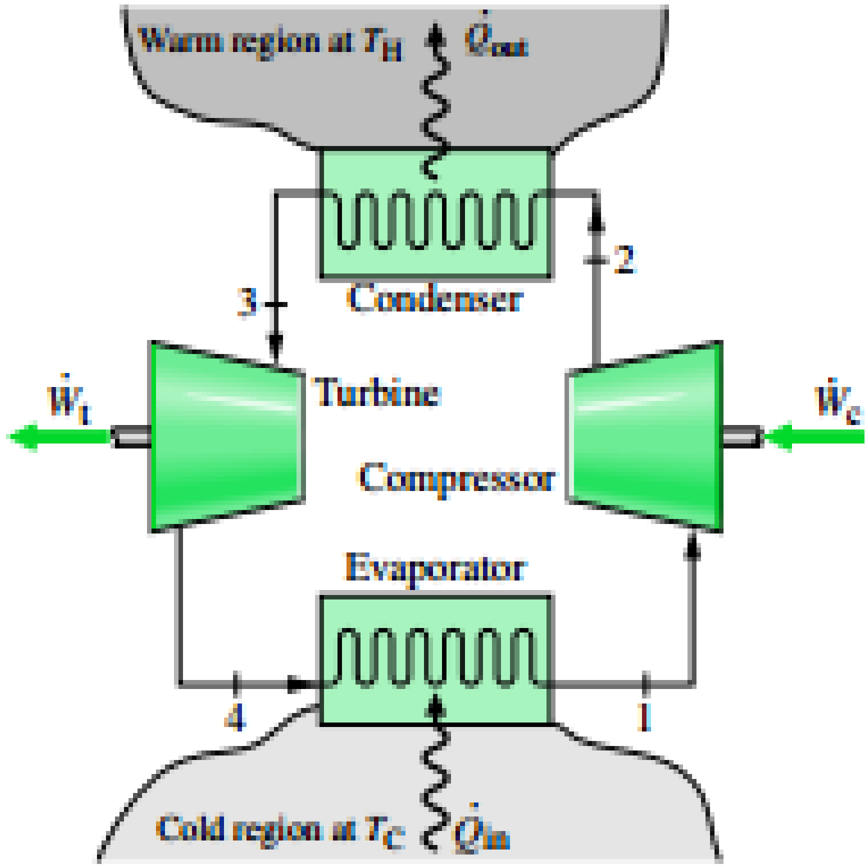

Figure 1 : Carnot refrigeration cycle

In this process, it has to be understood that the cycle is undertaken by a refrigerant fluid which circulates steadily through a series of components. It should also be noted that all the processes in the cycle are internally reversible. The cycle analysis starts from the inlet to the evaporator at which the refrigerant enters the system as a two phase liquid vapor mixture. In the evaporator, some portion of the refrigerant changes its phase from liquid to vapor due to a corresponding heat transfer from the region at a temperature T_C to the refrigerant. Pressure and temperature of the fluid are constant during the process from state 4 to state 1. As the Fluid proceeds forward into the compressor, the process will be undertaken adiabatically from state 1. At state 1 the fluid can be considered as a two phase liquid-vapor mixture. And as it passes to state 2, it alters its form to a saturated vapor. The process of compression will naturally add the required energy in the system to take the fluid temperature from the initial lowest temperature T_C to T_H increasing also its pressure. The next stop for the fluid in the system is the condenser where it changes its phase back to saturated liquid from the previous saturated vapor. This alteration of behavior is due to the heat lost to the high temperature sink. The turbine will take the fluid coming off the outlet of the condenser to expand it adiabatically and return the fluid to its initial conditions at the inlet to the evaporator. The process creates an abrupt decrease in both the temperature and pressure of the fluid. In general, the coefficient of performance of a given refrigeration cycle is the ratio of the effect of refrigeration to the net Work input required to attain that effect. The description used for the refrigeration cycle can be changed to the corresponding heat pump cycle by just changing the way one looks at the system and the corresponding objective. Unlike the refrigeration cycle, the objective of the cycle is to deliver heat to be transferred to the region at high temperature which could be a space to be heated up or a liquid water to be heated.

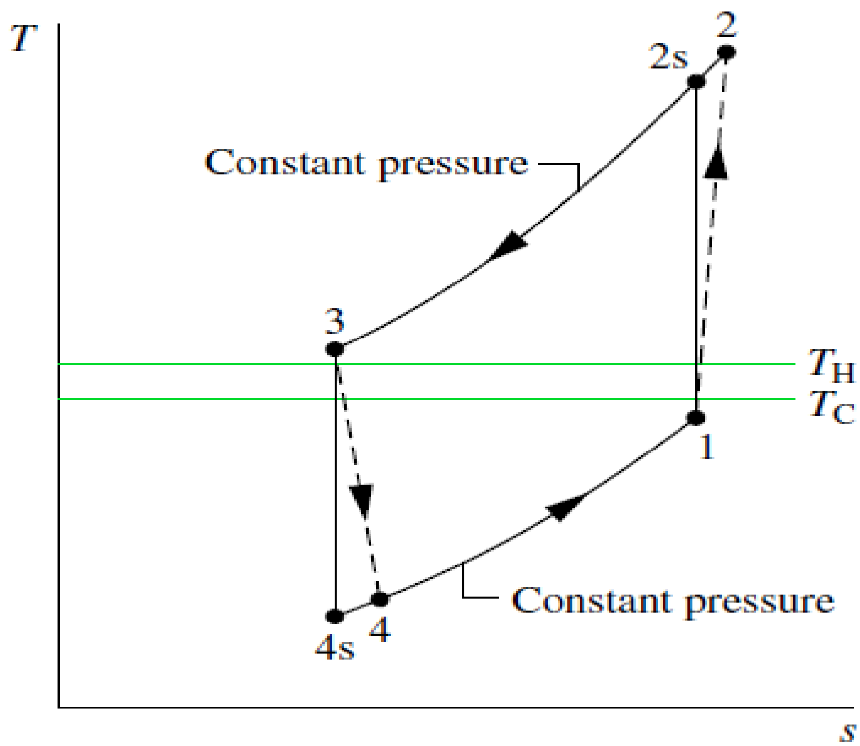

Figure 2 : Heat pump operation T-S diagram

The total rate at which energy is being supplied to the receiving end is the sum of the energy supplied to the working fluid from the cold region and the corresponding net rate of work input to the cycle. Similarly, the coefficient of performance of this sort of cycle is the ratio of the heating effect to the net Work input into the system used to attain the heating effect. It should be noted that the actual performance of a heat pump would not be the same with the theoretical. In the general sense it can be seen that as the temperature of the cold space decreases, it correspondingly triggers a decrease in the efficiency of the system. This is usually the case in air-source heat pumps; Heat pumps that utilize the ambient air temperature as the cold space. Although highly utilized in many places, it has become evident that these types of system need a backup heating system to provide heating on days when the ambient temperature becomes very low. And to mitigate these issues and avoid the humongous cost taken out on the backup system, sources such as well water or the ground are utilized.

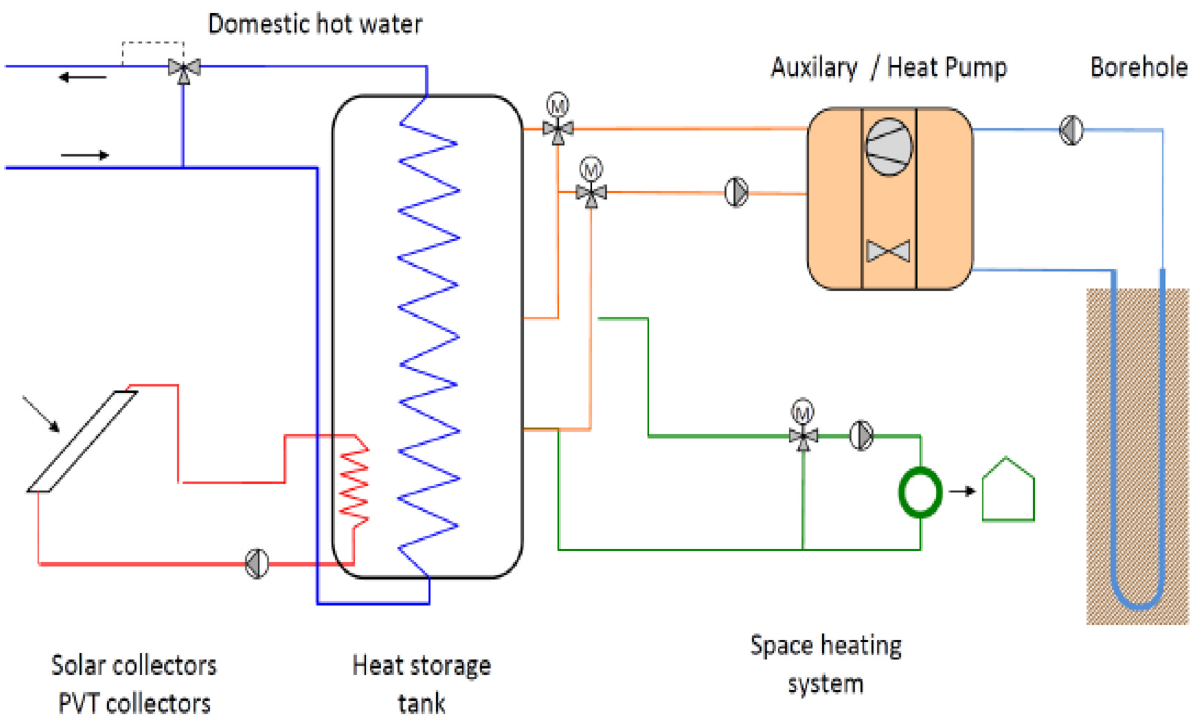

Figure 3 : a typical ground source heat pump

Many of the heat pumps used are of the vapor compression type. In this type of heat pumps the basic components defining the cycle include; compressor, condenser, expansion valve and evaporator. Although similar in arrangement to the refrigerators, the only difference one could find from the arrangement would be the objective of the system itself.

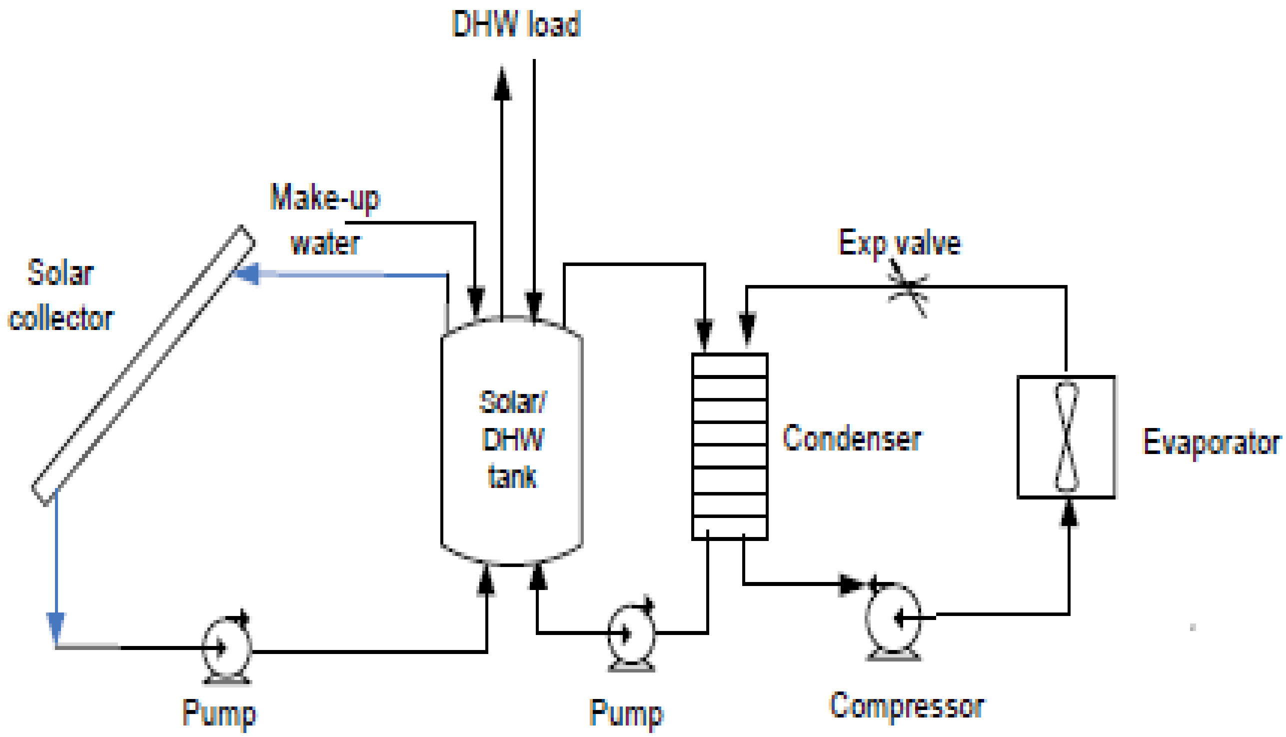

Figure 4 : parallel type PVT assisted air-source heat pump

The utilization of heat pumps for the conditioning of buildings is believed to have been started in the second half of the 1940's. Early manuscripts indicate that although the basic working theoretical conception of the science was developed and written by Sadi Carnot in 1824, its practicality manifested when designers J.Donald Kroaeker, Ray C. Chewning, Charles E. Graham and Pietro Belluschi took the idea and brought it to the ground. Although the standard for building design in 1948 did not require air conditioning in the Willametter Valley, Portland due to the moderate temperatures in the summer time, the first heat pump was installed for a building in Portland, Oregon, The US.[8] other manuscripts state that ideas, concepts and developments were being carried out at about the same time on other parts of the world. A good example for this would be, a renowned Irish scientist who T.G.N Haldane, an English inventor who was the first to patent a heat pump and William Thomson has already developed the concept but did not have the necessary resources to build one. Although installed for commercial purposes with increasing anticipations of continuing further developments, the distribution of these units which was avidly initiated right at the end of the 1940s came under a huge crisis in the 1960s due to records of poor reliability. This rapid decline found its way back up the ladder again in the 1970s when growing electricity costs made electric furnaces less competitive but at the same time, improved quality control increased the attractiveness of Heat Pumps. [8] On the other hand, the oil crisis that took place in the beginning of the 1980s triggered the world of science to look into other possible forms of energy sources for the production of energy. Later in the years, application of the heat pump technology started to flourish and outreach to the ends of heating and cooling. In this light, the ground source, air source and solar assisted heat pump technologies were proposed by many scientists. With a total capacity of 180 MW, the world's largest sea water heat pump was installed at the VartanRopsten Plant, Sweden. A total of six heat pump units were commissioned from 1984 – 1986. [9] Another such large installation came in 1996 at Fort Polk, Louisiana, the US; where the world's largest installation of geothermal heat pumps took place. In total, the installation replaced 3243 air source heat pumps and 760 central air conditioning units. Its application came in handy reducing the general electrical consumption by 26 million KWh close to 33%, eliminating consumption of 260,000 therms (27,429 MJ) of natural gas, and also reducing emissions of CO_2 by 22,400 tons (20,320,922 Kg) per year.

The refrigerants used in the operation of a heat pump till the 1930s included ammonia, carbon dioxide and other related fluids.[10] these fluids are usually toxic and/or flammable. As research and development went forward, strides were made to improve the safety of the fluids. After much study and development, Thomas Midgley and his associates came up with the new nonflammable and nontoxic refrigerant; R-12 in 1931 which was a he boost for the growing industry of refrigeration and heat pump technology. R-12, a CFC later was known to deplete the ozone layer by Sherwood Rowland and Mario Molina eventually leading to the phasing out of the refrigerant itself. Currently, a substitute for CFC, HFC has been introduced to the market, which is a group of substances that have no detrimental effect on the ozone layer although partially contribute to global warming. Presently, the refrigerants that are utilized in air to water type heat pumps include, R-134a, R-407c, R-410a, R-290 and R-744. [10]

From the many important applications of heat pumps, application for domestic hot water heating stands as the major one both in general and specifically for this study. Generically stated, a heat pump water heater (HPWH) functions by using an electrically driven cycle and delivers thermal energy to a water stored in a tank by using the ambient air as the sole source of the heat itself.[11]

Being the fourth largest energy consumer in the commercial buildings sector, following heating, air conditioning, and lighting; water heating stands as a major energy utilizer in the likes of restaurants, motels, hotels, assisted care centers and laundries. In the United States, the energy use of water heating accounts for 17% of the total residential site energy use. This makes it third in energy usage in homes. Statistically speaking, most of the residential water heater systems are simple but not energy efficient. As these conventional water heaters generate heat by consuming a certain amount of fossil fuel or electricity, the overall efficiency in changing the potential energy within the fossil fuels into electrical energy and consequently into thermal energy is very low. In generic terms, it can be said that the total thermal output of heat pump systems is quite large for an equal amount of input into a conventional water heater. The deciding factor for the successful utilization of heat pumps is the existence of a relatively cheaper and dependable heat source for the evaporator which should generally be at a higher temperature. And the temperature of the evaporator extends its importance in the process being the key for the efficiency of the cycle in general.

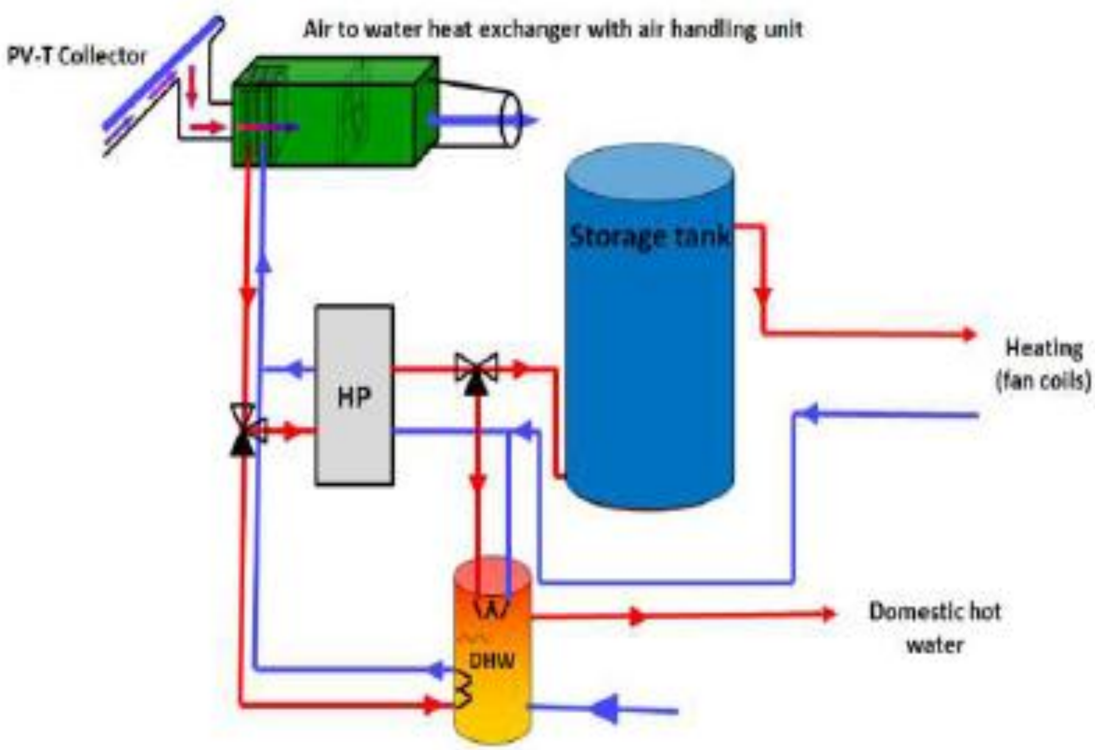

Figure 5 : PVT assisted heat pump generating domestic hot water (DHW) and simultaneously conditioning a room

Although the major driving energy of heat pumps is grid electricity, growing interests in the development of off-grid sites have called attention to the need to use other forms of energy sources; the likes of small scale renewable and fossil fuels. In light of this, one of the few important hybrid technologies that can be integrated with each other to give optimal and energy efficient system output is the hybrid PVT-heat pump system or the PVT assisted heat pump technology.

The photovoltaic/ Thermal system is a hybrid system that uses energy from the sun as a source to create both electrical and thermal (heat) energy. The photovoltaic cell is the basic entity that converts energy of light into electrical energy during a process known as the photovoltaic effect. [12] Studies indicate that, a standard solar collector converts around 14% of solar radiation into electricity. The remaining unconverted percentage of radiation is waste heat which is partially taken by the surrounding and PV module. It has been found that high temperature rise in the photovoltaic cells causes an equally high electrical resistance that limits efficiency of the system itself. This has called for the development of new technologies that break this barrier, in other words, combination of the PV and thermal system in one. PVT is a hybrid technology where the remaining heat from the panel is put to good use by the transfer of this heat into a running fluid below the panel itself which can in essence be used to heat a domestic cold water or condition a room. In retrospect, that very cold fluid running through pipes under the panel is responsible for keeping the temperature of the cells at the optimal range giving rise to an efficient electrical output. The result has showed that there is an undeniably large increase in the electricity production for PVT systems as compared to a similarly sized PV system under the same conditions. The combination of solar thermal systems with the corresponding heat pump systems is a path utilized to eliminate the grid connected heat pump system especially in the summer season. The hybrid system can generally be classified in to two as parallel and series Hybrid PVT- heat pump system. In state of the art parallel hybrid systems, both the solar collectors and the heat pump deliver the heat into one store for the heat load. In practice, the heat pump will serve as an auxiliary energy source for the combined system. Moreover the grid electricity use for the operation of the heat pump itself can be reduced by the use of the electricity generated by the PV panels. On the other hand, a series system allows the heat retrieved from the PV panels to be stored in a tank at which corresponding exchange of heat will be undertaken between circuits extended from the evaporator and a circuit extended from the panels. In essence, the heat from the panels replaces heat that would have otherwise been retrieved from the surrounding air in the case of air source heat pumps. Although some consider the PVT system itself as an independent hybrid system, most studies indicate that the PVT system is utilized in harmony with other energy systems. These kinds of systems are called Hybrid systems.

Hybrid energy system combines different types of energy generation and/or storage or utilizes two or more types of fuel to power a generator. A hybrid energy system has emerged as a valuable technology as compared to the critically outsmarted fossil fuel based system.[13] Hybrid energy systems dwell on the idea that existing independent energy infrastructure will be added up to mitigate shortcomings related to cost, environment and system disruptions. In other words, the analysis will boil down to selecting a set of energy technologies that are the most efficient and reliable to meet consumers' need.

Generally speaking, in these kinds of systems one or both of the independent energy systems is a renewable energy which is used to power the generator. Such system is utilized to increase the reliability of renewable energy sources by providing redundant production of energy from conventional sources. And more efficiently, by providing storage for electricity produced by intermittent sources. As important as these renewable energy systems are, it has been studied that it is difficult to depend on intermittent renewable sources for base load power. This means, even if wind or solar plants produce enough electricity to supply the peak and base load demand, it hardly competes with the more exercised fossil fuel based or nuclear base load energy generation. But, a network of intermittent energy sources arranged according to their best and optimized manner could be utilized to shave off some of the shortcoming discussed above. In this sense, these small and agile energy systems can be interconnected into the grid system and function as small power plants to fill the gaps created with respect to availability and magnitude. Hybrid systems are known to increase the eco-efficiency of production of energy and corresponding energy security. And the long term effect of these systems would be to offset fossil fuel use with renewable production. And the more obvious front runner in the advantages of this system happens to be the access to modern energy in remote settings and accordingly avoid the cost related to expensive distribution and transmission lines from a central grid. The reliability of these systems also relates to the relative availability of power in poor areas as compared to the fuel dependent nature of existing power sources which usually happen to be

Diesel engines. Although the aforementioned positive attributes of the system make it a blooming research and development area, it's also criticized for the heavy cost due to the multiple components required to form the system. Moreover these kinds of stand-alone systems appear to be a headache to governments that are known to have central power distribution which paves way to arguments concerning transmission interests and large electric utility interests relying on political clout or financial assets pointed in the direction of limiting the expansion of hybrid energy systems in general.

It is important to note that the arrangement in this specific study, a thermal unit within the pv panels, A PVT system have proved to be an up the ante in the total efficiency of the energy generation not to mention the additional thermal energy extracted from the unit itself.

In this case study, a stand-alone system comprised of a PVT and Heat pump system will be used as a backup energy system replacing a diesel generator and also an additional power source to meet the demands of newly built rooms for Bale Mountains lodge in Bale Mountains National Park. More importantly, Adding to the conventional pv-heat pump systems, this proposed system will add one new feature into the existing working method; a thermal system which will be combined with the pv modules to generate hot water from the excessive heat collected from the pv cells, this hot water will eventually be directed to the different rooms in the lodge.

1.2 Thesis Organization

In the first section of this work, generic introductory information on the Energy need of the world, continent and nation have accordingly been looked into focusing on the most inexhaustible and largest source of all, Solar Energy. This has in extension been connected to the needs of the rural section of the nation itself. In a smooth and intertwined fashion, the heat pump has been defined and accordingly connected to the very need of the study at hand. The basic concepts leading to the working principle of the device have also been extensively visited in the process. Moreover, the PV, PVT and the different system configurations have accordingly been gone through in this section.

In the second major section of this work, problem of the study which has served as a platform of the whole project has been extensively defined. Making the need for sustainable and renewable energy supply as a driving idea and carrying the computation based thermal heat pump analysis in its belly, it has ignited the set of activities that followed onwards towards the search for the required output heated domestic water temperature. Following that, objective and scope of the study have accordingly been defined. (Site description)

The next major and vital section of the study has been the literature review where the different related papers in the area of the study have all been studied with the idea in mind that the current study serve as a filling entity for the unvisited or looked over ideas and concepts in the papers, articles and theses that have all been seen. Its structure has followed an inward directed fashion, starting with generic information on Energy followed with the need to look for a clean and sustainable energy system, and a specific look into each section of the system. The theory and conceptual evaluation of the much intended thermal energy generating system, the heat pump has accordingly been defined. Solar study of the location and corresponding hourly temperature analysis has also been included in this section.

The final section comprised load calculations for different apparatus found at the site, including the domestic hot water need of the area which all has served as a stand point from which the analysis emanates. Moreover, all the required 2-D and 3-D plots have been drawn and the corresponding results have been retrieved using the generated MATLAB code.

1.3 Problem statement

Electricity stands as the altar in the development of any and all economic activities encircling our daily lives. But as it would be technically and economically unjustifiable to extend power cords to small patches of households and villages located far from grid lines, one should look for small and micro power systems that can meet the required demand of the area without compromising environmental conditions related to pollution and health risks. On the other hand, there is a running study which is being undertaken on optimization of a hybrid PV-thermal energy system for a selected location which is thought to be a starting platform for this paper. Considering the much acclaimed integration of heat pumps with a power supplying PVT system producing domestic hot water as the center of the study, and considering the corresponding economic problems related to the use of the existing diesel engine and micro hydro power plant on the other, the study will try and look for the best way out of the problem.

In this case study, the Bale Mountains lodge has been utilizing energy generated from a micro hydro power plant equipped with a locally manufactured cross flow turbine with a capacity to generate 18.5 KW's. But, power has been seen to fluctuate during off-design months when the amount of water would hugely decrease and down times when the mechanical components spend days on maintenance called for a back-up power source: a diesel generator. But the unnecessary outputs from the generator; the likes of the much eminent smoke and related noise goes strictly against the motto of the tourist spot, which is a clean, green, sustainable eco system.

Standing as the major undertaking in the proposed analysis of this study, the paper equally focuses on determining the performance of the heat pump which is proposed to serve as the gadget utilized for domestic hot water heating. Currently, although there are existing running heat pumps at site which are always subject to failure due to power fluctuations inhibiting the expected maximum performance, the primary heating component is a boiler utilized for heating up the water that is used in the rooms which is taking approximately 60% of the energy generated by the micro-hydro power plant. The other 40% is left for use of electrical appliances and lighting with inconsistent, fluctuating nature. Additionally, although different system optimizations and simulations have been undertaken throughout the years on the performance of thermal systems using commercial softwares which are always subject to analysis at full load only, a system model that is well defined using a credible and internationally well accepted mathematical coding environment which can also calculate performance at part load is still in lack. For this and more related fundamental backgrounds, a MATLAB coding environment will be utilized accordingly to define the working thermal system, Heat pump and correspondingly optimize its performance.

1.4 Site description

Located on the outskirts of Rira, a small village on the Bale Mountains, the Bale Mountain lodge is a forest wilderness lodge located deep within the Bale mountains National park of south central Ethiopia. Having a total of 40 rooms including the staff accommodation, the lodge is designed to meet the pristine eco- friendly limit. The lodge is basically located in the belly of the park within the Harena Forest at an average elevation of 2380 meters.

Figure 6 : Bale Mountains lodge, Google Earth

Upon its completion, there was an expected 25 Kw electrical power from a micro hydro power plant located along the river about a Kilometer away from the main lodge building. The power plant has been designed to convert 30 % of the river flow through a turbine located at the bottom of a 25 meters drop. Moreover, effective power management techniques have been implemented to ensure the generated constant power is sufficient to deliver all the required energy demands of the lodge. On the other hand, a diesel fueled backup generator has been planted to ensure that electricity will always be available even in the times when the discharge from the run-off river is low. Currently, due to extra additional projects being undertaken at the site and unexpected loss of discharge from the river on many occasions, the power being generated from the plant has deteriorated from time to time. During a brief visit to the site and corresponding interviews and collected data, it has been observed that power fluctuates on a regular basis becoming an ill issue to the site and business in general. Responsible site engineers at the site have confirmed that a couple of years after its installation, power from the micro hydro power plant have gone down to about 18.5 Kw and fearing it might have even got worse.

Figure 7 : High plateaus at the site

Figure 8 : Staff Accommodation at the site

In a document proposed by the Japan Ecolodge Association on April of 2012 [14], a checklist proposed entails that an ecolodge should be able to fulfill the standards proposed on seven points. An Ecolodge as can be understood from the name need to comply with the use, discharge and operation of these entailed points. These points are, sustainability, food and beverage, waste management and recycling, energy and water, green purchasing/chemicals/miscellaneous, care for surrounding environment and finally compliance with global sustainable tourism criteria.

Points are allocated for each depending on the magnitude of achievement and or future plans to approximate or implant the plan on ground. A single point will be given for each criteria's and double points for those with the potential to alleviate or mitigate a significant environmental impact, those with the potential to significant impacts on environmental and community welfare and also those that demonstrate innovative improvement or better environmental practices requiring originality, ingenuity, and/or significant capital investment.

It has also be noted that the criteria's and check list prepared can be subject to possible alterations or revision depending on possible change in social conditions and knowledge. In general birds' eye view, it can be seen that the lodge under study has fulfilled much of the enlisted requirements except currently generating hiccups related to power loss consistently pushing the management to extend its hands to the extensive utilization of diesel fuel based generators. This on the other hand hugely defies what ecofriendly sites stand for as the output from these types of engines heavily pollute the environment.

1.5 Objectives

Main objective

- Optimization of the heat pump system to meet the required electrical and thermal load with reasonable energy consumption and corresponding required efficiency/COP

Specific objectives

- Data collection for the selected location at hand
- Analyzing electrical load requirement of the selected location
- Analyzing domestic hot water load requirement of the selected location
- Generating approximation plots of manufacturer's performance data
- MATLAB coding with an expected output of an optimal running performance of the system, COP with a reasonable input power for the compressor considering a predetermined required output temperature of the hot water based on the existing performance maps generated without physically modeling the thermodynamic properties of the fluid

1.6 Scope of the study

The project extends from visiting the site at hand and collecting all the necessary information to coming up with the final energy layout for the site encompassing a heat pump with a justifiable amount of COP and energy consumption. And in this brief range, the study glides through determining the required electrical and thermal load of the location, generating performance plots depending upon data retrieved from different manufacturers, calculating the possible COP and power input depending on ambient temperature data using the MATLAB environment and finally sizing the whole system PVT setup. But in doing all these, there are certain edges that haven't planned to be gone through and studied. Although design and corresponding optimization of the energy and thermal systems is undertaken thoroughly, manufacture and installation of the different equipment and parts is not considered part of this project. Moreover, part wise performance simulation and characterization of the thermodynamic property of the working fluid as it passes through the different sections haven't been covered in this paper.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Energy is a hugely important commodity that plays a humongous role in the day today lives of human beings. The availability of electricity in one way or the other indicates the living standard, educational and health status of a certain community. About 600 million people in Africa have no access to electricity. [15] And North Africa consumes eight times more electricity in average than the rest if the continent except South Africa. From an average population of 303 million with an electricity kwh/capita of 91, east Africa has the smallest access to electricity at a staggering 23 %.

Electric power consumption (kWh per capita) in Ethiopia stands at 51.96 in 2011 compared to the USA with 13,246 Kw per capita on the same year. On top of all, access to electricity in rural areas of the nation and Africa in general is still a problem far from easy. [16]

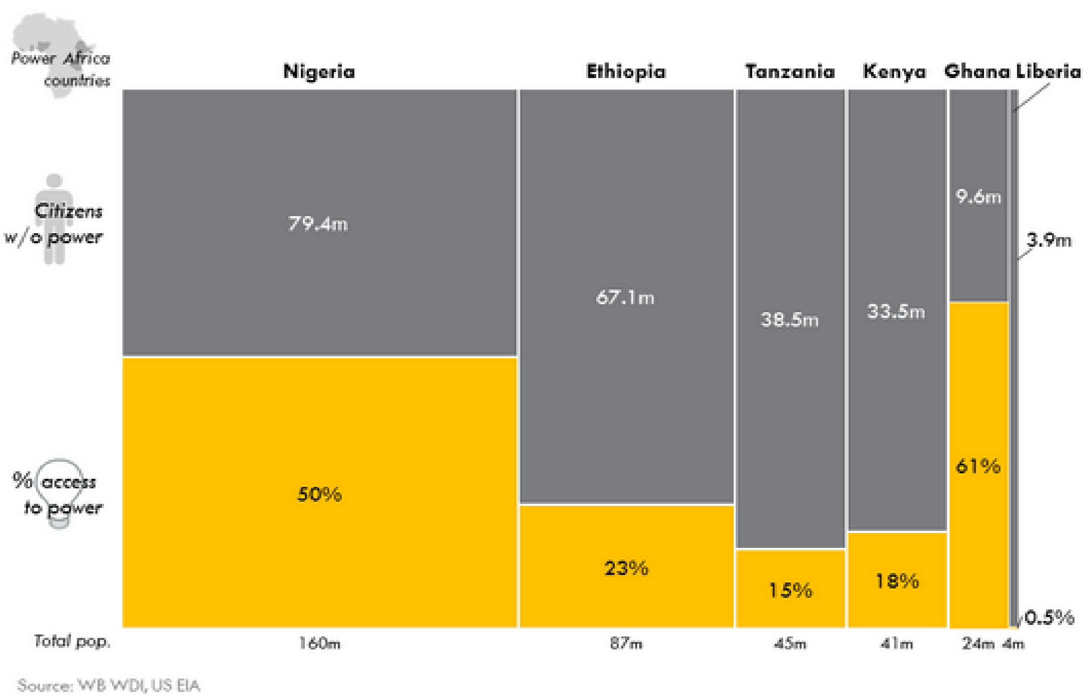

Figure 9 : Electrical consumption figure of Africa, the six power countries

In a related study by the united nations industrial development organization (UNIDO) and international center on small hydro power (ICSHP), Ethiopia having a population of 91,195,675 (2010) and area of 1,104,300 km^2 with 89 percent of the gross population living in the rural setting, have rural electrification at a mere 2 percent. [16]

In general, the production of electricity at power plants can be classified into two as renewable and non-renewable sources. Renewable generically refers to ways or methods that don't pollute (pollute less as compared to Non-renewable sources) and that are also friendly to the environment in comparison to the traditional methods. [17]

As one of the non –polluting sources of power, the solar resource can be utilized for generation of electricity and thermal applications. Parts of the northern Africa and still some parts of southern and eastern Africa get to be showered with sunlight having a humongous intensity of irradiation. [15] Africa's installed capacity at the end of 2014 was 1334 MW, which is more than ten times larger than in the year 2009 (127 MW).

Roaming down into the sub-Saharan section of the continent, a study by SWERA has shown that the multiyear average daily radiant quantity of Ethiopia is about 3.74 Kwh/m^2. Moreover, the national technical exploitable potentials of the off-grid application for household are about 4Twh/year.

Although the development of new green technologies is growing at a very fast pace, off grid areas have for long been utilizing the diesel engine as the prime source of electrical energy. The use of diesel engines for power generation at remote settings comes with a cost of fuel transportation and environmental issues [18]. The exponential growth in the science of the development of PV and battery technologies has paved the way for the use of these as an alternative to the conventional system. Moreover, not only independent single energy generating sets, but also a coalition of two or more renewable energy generating units has been developed throughout the years to increase the quality, availability and efficiency of the system. A hybrid system is the combination of two or more renewable energy sources; wind, solar, hydro or more which unlike the conventional energy sources provide a very clean and eco-friendly energy [19]. The system can be either stand alone or grid connected. On the other hand, a PVT (Hybrid photovoltaic / thermal) system is a newly proposed system that encapsulates the attributes of both electrical and thermal energies retrieved from a solar irradiation.

2.2 PV/ PVT system

Over the years, It has been observed that the distribution of electricity to areas remarkably far from the central grid system stand as a hugely expensive process. Considering the economic return from these areas that directly or indirectly connect to the development of a nation in general, it has been suggested by many studies that an independent/ stand-alone electricity generating system would be an answer. Although this arrangement has been serving perfectly in many locations around the globe, the environmental pollution related to the generation of the required power is undeniable. Thus, in order to avoid these hiccups, renewable and green energy systems have been flourishing all over the world in a staggering speed.

The generation of electricity in remote areas at reasonable price has called for the increase in the research and development of the PV system. As described in many studies, the price and sizing of the power supply system is the key in the design of these technologies. This system is therefore an excellent choice in remote areas for low to medium levels. [20]

An ordinary PV system or a photovoltaic power generation unit include cells, mechanical and electrical sub-units and regulating/ modifying means for the electrical output.[21] similar to other energy sources, PV energy systems can also be classified as stand-alone or grid connected. Although stand-alone systems constitute their own form of arrangement and distribution; a grid connected PV energy generating plant is connected to a large independent grid that injects power into the central grid system. These power systems range from few Kilowatts for residential purposes to large mega outputs that encompass the potential to power small towns and cities.

It has been observed and validated on different studies that the conventional silicon photovoltaic modules produce more electricity when they are cooler. The output power has shown to increase from 0.2% - 0.5% for every ^{o}c decrease of temperature. [22] It has also been seen that the amount of electricity retrieved from a commercial PV module is due to only 10 – 15 % of the incident solar energy. This shows that the heat produced due to the incident solar irradiation takes the larger share as compared to the developed electrical power.

The photovoltaic effect is the starting line in the conversion of light to electricity. The process initiates with light entering a PV cell and imparting a certain amount of energy to electrons and free them accordingly. In this regard, an internal potential barrier inside the cell will act on these electrons to produce a voltage known as the photo voltage, which will be used to drive current through a circuit.[23] a deeper study into the science behind the working principle of the PV system shows that the workings of this system emanates from the basic nature and relation of atoms. Electrons are known to rotate around the nucleus of an atom much like how planets revolve around the sun. Each and every electrons rotating inside the atom exhibit their own property and energy level that determines their corresponding orbital locations. But, only the furthest ones from the nucleus are known to interact with electrons from other atoms and define the way these atoms combine to form much larger structures like solids. [23]

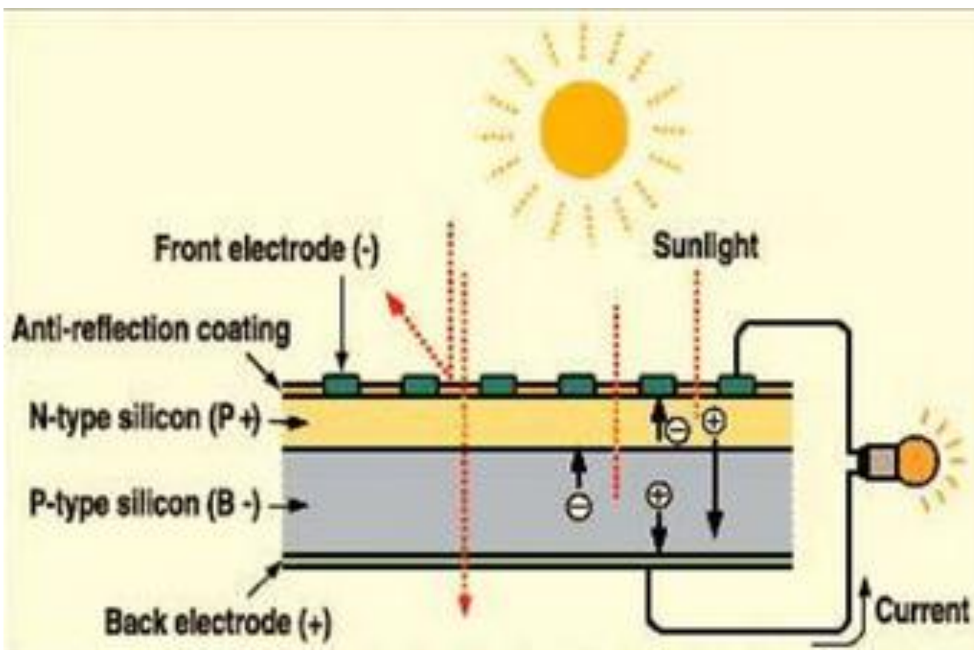

Figure 10 : Cross-section of a PV panel

Although there is always an increase in temperature on the surface of the modules, a PV module installed on roof tops or facades have shown to heat more than its relative other. The stride to decrease this huge increase in temperature of the panels have paved the way for the technological initiation and advancement of the "solar cogeneration", later best known as photovoltaic/ thermal (PV/T) collectors. [22]

This hybrid system (PV/T) allows noticeable growth of efficiency of electricity generation, which is caused by decreasing temperature of the cells to a certain optimal level by usually a system of hidden pipes at the backside of a photovoltaic panel through which the cooling medium passes. [24]. The thermal edge removes the unnecessary heat, cooling down the cells and increasing the electricity production to about 14.8 % as compared to similar cells in a similar condition.

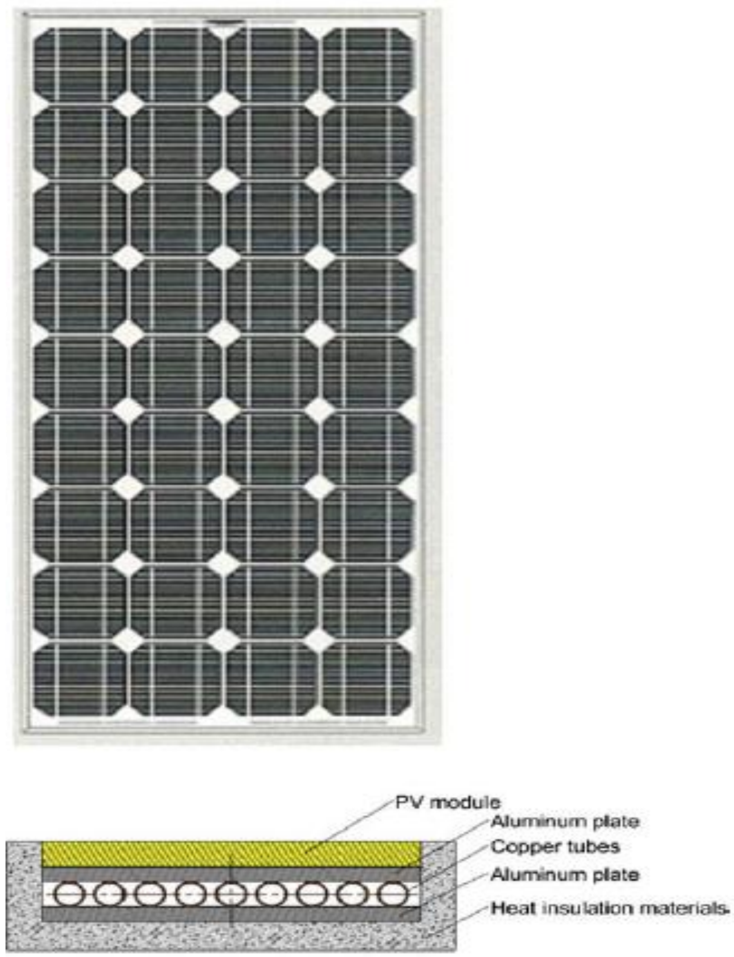

Figure 11 : PVT panel

The utilization of PVT collectors for the generation of heat and corresponding electricity for a solar heat pump system has been studied from both economic and technical (energy) point of view has been studied by both scholars and professionals along the way. The use of a PV only system integrated with a heat pump has shown a comparatively high cost and energy savings. The application of unglazed PVT collectors on the other hand still show a very poor thermal performance which cannot be compensated by the electricity utilization of the heat pump system.[25]

Similarly, a study undertaken on the energy performance analysis of a solar heat pump system combined with solar glazed PVT collectors have shown that replacement of standard solar collectors could bring electricity savings only if the glazed PVT collectors with low emissivity PV absorber have been used. But still, the Corresponding electricity use of this type of heat pump system with glazed PVT collectors range from 3 to 5 % lower than the PV only system.[25]

2.3 Heat Pump system

In an investigation on the performance of a combined solar thermal heat pump heating system, a combined solar thermal heat pump with seasonal storage both for space heating and hot water production has been undertaken [26]. The proposed system is composed of an air-to-water heat pump unit, a water to water heat pump unit, a solar collecting cycle and a seasonal storage tank. Moreover the installed DHW tank is connected to the solar collecting cycle which could in turn be heated by the solar collectors and electrical auxiliary heaters. The system has been designed for a six story building in Beijing covering an area of 225 m^2 with 20 rooms on every floor expected to house two persons each. With a standard required water temperature of 55^0c and 40 liters per person per day, the operating performance analysis of the system has been undertaken during a year carried out through TRNSYS. And verification of feasibility of the system is undertaken by a comparison study with the conventional space heating system. The solar fraction for DHW of the system showed to be 68.1% and the total solar collecting efficiency achieved 50.7%. It has been seen that the solar fraction can be increased by taking advantage of the seasonal solar thermal storage. During the heating seasons, total system performance varies between 3.3 and 4.2 and compared with the base system, the COP has increased 1.4 times. Finally, COP of the system has shown an average magnitude of 3.7 on heating months. With a proposed solar collector area of 130 m^2 – 160m^2, system performance for space heating is improved by 12.8% compared to the original design.

In a similar study, analysis has been undertaken on a solar heat pump system with hybrid PVT collectors for a family house [25]. The system simulation has been done for a building defined in frame of T44A38 for a single family house SFH 45 with a required water load of 73 m^3/s at 45 ^{0}c. Energy demand of the system ranges from electricity for heat pump, back-up water heater, circulation pumps and controls. And the operating system in general comprised of the main store, single glazed flat plate collectors and ground source heat pump with a 75 m bore hole. The main store included an integrated internal heat exchanger for DHW preparation. The heat pump has been designed as a system with a valence of 5 KW nominal heat pump output. Several variables of the system were investigated and compared including the REF replacing the often utilized PV system by PVT collectors in different designs including unglazed low cost ones and non selective glazed others with a new gel lamination that is resistant to temperatures above 200^0c.

The electricity demand of the system has been evaluated in the given variants and corresponding cost benefit analysis has been performed. The total 20 years cost difference per year has been evaluated including the annuity cost of investment and maintenance. Additionally, The use of PV only system that is combined with a solar heat pump system has shown high energy and cost savings. Moreover, unglazed PVT collectors showed poor thermal performance which cannot be compensated by the simultaneous electricity use for the SHP system. The glazed non selective PVT collectors have showed a much worse performance then the reference glazed collectors used on state of art system and high additional cost making the variable economically unreasonable.

In another experimental analysis on a hybrid photovoltaic heat pump system, the study tried to check to what magnitude the type of refrigerant utilized affects the performance of a PV cell in the production of electricity [27]. Although many similar researches have proved that the process of cooling the modules would eventually increase the efficiency, output or performance has not been as large as expected. In the study, the refrigerant R134a having a very low evaporative temperature has been used to check if it can deliver a better cooling effect in effect generating a much better electrical performance of the PV modules. For the analysis, three distinct testing modes have been proposed to investigate effect of solar radiation, condenser water flow rate and condenser water supply temperature on energy performance. The results have come up with a COP of 3.8, 4.3 and 4.0 under the three testing modes with variable radiation, condenser water supply temperature and water flow rate respectively. And these very values has shown an increase with increasing solar radiation but decreased with the increasing condenser water supply temperature and flow rate. Electrical efficiency have shown to improve by up to 1.9% based on a reference PV efficiency of 3.9% compared with that without cooling. Also, the condenser water supply temperature and water flow rate had lilt or no effect on the electrical performance of the system.

2.4 Theory

Heat pump is a device which applies external work to extract an amount of heat Qc from a cold reservoir and delivers the corresponding processed heat Q_h to a hot reservoir. Although, the system is subject to limitations from the second law of thermodynamics as any other heat engine, the ideal efficiency can be calculated from a Carnot cycle. Its corresponding characterization is undertaken by a mathematical relation known as coefficient of performance which signifies the number of units of energy delivered to the hot reservoir per unit work input. It can be stated that the basic operational principles of the well-known and utilized refrigeration devices and related heat pumps are more or less the same. The difference lies in the fact that for a heat pump, attention would be given to the heat delivered by the device rather than the heat picked up at the evaporator. [6] The heat that is generally delivered by the heat pump is equal to the heat absorbed from the low temperature source plus the input work through the compressor.

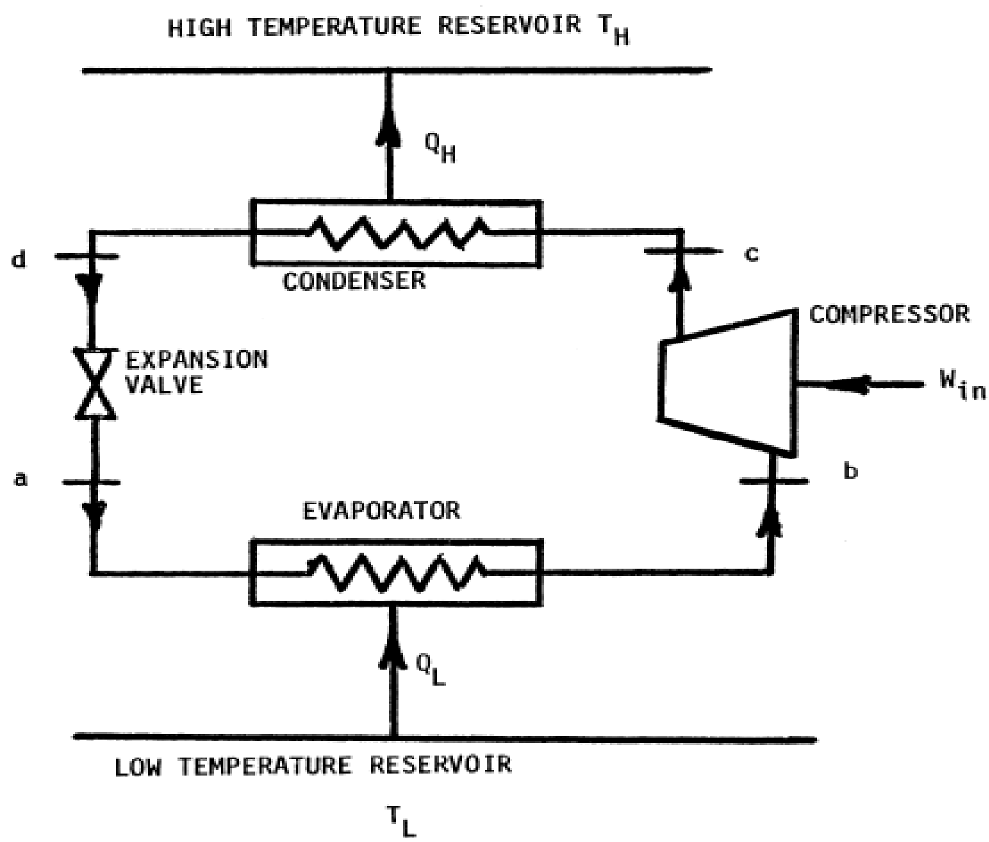

Figure 12 : schematic representation of a typical heat pump system

In other words, the ratio of heat transferred to the electric energy used in the process signifies the performance of the machine. A typical coefficient of performance for a commercial heat pump ranges from 3 to 4 units transferred per unit of electric energy supplied. Currently, the two main applications of a heat pump are air conditioning and water heating. The beauty of the science behind allows us to use one unit of electric energy to transfer more than one unit of energy from a cold area to a hot area. In comparison to an electric resistance heater, a heat pump taking in 1Kwh of energy from the cooler outside environment is expected to pump 3 Kwh of energy to the house for heating.

As the main altar of the study of heat pumps, the second law of thermodynamics is utilized. Generically speaking, the law puts constraints upon the direction of heat transfer and related attainable efficiencies of heat engines which give beyond limitations that are imposed by the 1^{st} law of thermodynamics.

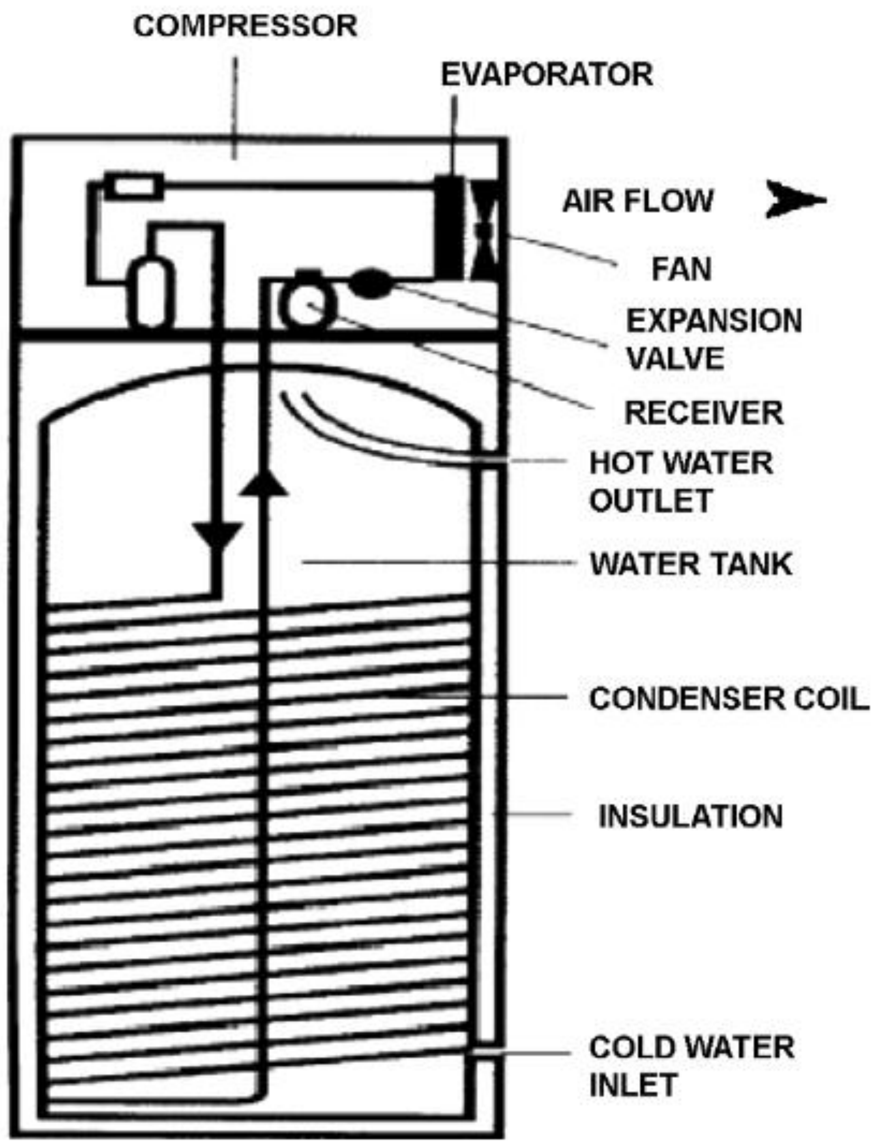

Figure 13 : Cross section of a heat pump

The law basically states that it is impossible to construct a device that operates in a cycle ad produces no effect other than the transfer of heat from a lower temperature body to a higher temperature body. In general, objective of a heat pump is to maintain a heated space or hot water tank at a high temperature which is accomplished by absorbing heat from a low temperature source such as well water or cold outside air and supplying this heat to the high temperature medium which could be a house as well as a domestic hot water. The idea can be extended to the simple operational characteristics of a refrigerator with a similar function only in the reverse direction. This stresses on the fact that an ordinary refrigerator placed by the window of a house with its door open to the cold outside air in winter will function as a heat pump since it will try to cool the outside by absorbing heat from it and rejecting this heat into the house through coils located behind it or use this same principle to heat a water and increase its temperature to the required magnitude.

2.4.1 Mathematical model of the Heat pump

Although the general thermodynamic and heat transfer relations of this machine can be undertaken using different computational software depending upon the required variables and corresponding specificity, in this paper the MATLAB environment has been extensively exploited in order to model the definite working principle with required optimized output. And generically, the environment accepts a set of numerical algorithms or codes to imitate the existing actual system of units which has been used in this paper. But on a more similar and simple platform, there are also inbuilt sets of functions put together within the environment to perfectly model any required system with its subsystems accordingly. Although in this thesis the previous has been utilized for thoroughly explored and justified reasons, the general mathematical deductions for each unit of a simple heat pump are considered almost the same.

2.4.1.1 MATLAB Simulink

Serving as an input for the MATLAB model, these mathematical relations serve as the standpoints from which the simulation and corresponding optimization will be initialized. The concepts arise from the basic heat transfer concepts and related energy consumption of the different components of the machine that would eventually lead to the analysis of performance of the system. [28] A thorough look into the evaporative effect which is clearly seen by the state points of the thermodynamic cycle and mass flow of the refrigerant can be clearly shown in the following way.

As these basic relations are drawn, there are certain assumptions that shall be made for simplification to get rid of the complication and bulkiness of the output from the system. The first in line of assumptions would be to consider a constant mass flow of refrigerant in the entire system. Secondly, the simulation calculates the energy value of the sub-components when some value is changed; the impact on the other calculation in compliance with precision of the calculation has to be considered.

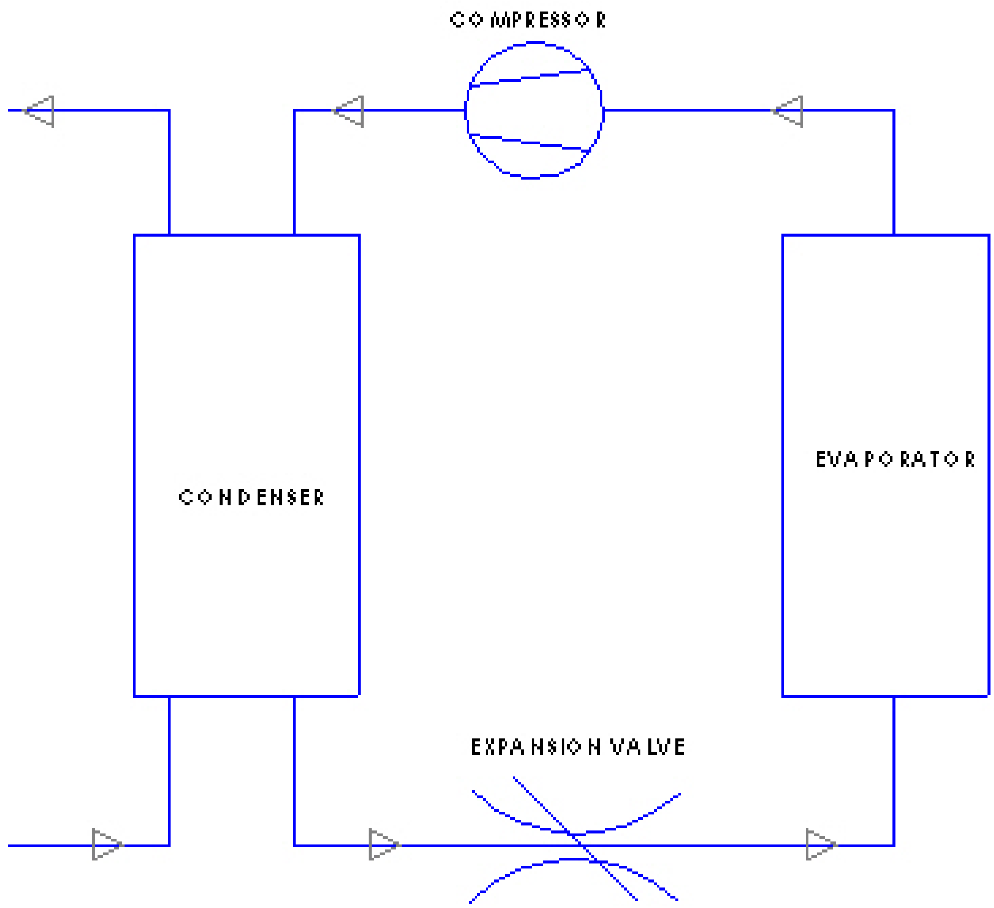

Figure 14 : a simple schematic diagram of the heat pump

Determining the temperatures at the different section of the sub-components is a vital move in analyzing the energy contained within the moving fluid of the system, refrigerant. These temperatures are utilized to calculate the enthalpy of the system. [28]

$$Q_{eva} = m_r * (h_1 - h_3)(W) \ldots\ldots\ldots\ldots (1)$$

The eminent energy of the refrigerant that is entering into the evaporator is well defined by the above mathematical model while the one stated below describes the energy that is retrieved by the moving fluid through its interaction with the ambient surrounding.

$$Q_{eva} = m_r * c_a * (T_1 - T_3)(W) \ldots\ldots\ldots\ldots (2)$$

And the corresponding thermal power delivered by the compressor into the circulating fluid is accordingly defined by the following relation;

$$W_{comp} = m_r * (h_2 - h_1)(W) \text{ ………..} (3)$$

Similarly, the energy output from the refrigerant to the tank, heat exchanger medium is well described by the energy/ heat transfer at the condenser section of the machine.

$$Q_{cond} = m_r * (h_2 - h_4)(W) \text{ ………..} (4)$$

Without presumably looking into the material and physical property of the different materials existing between the different heat transfer processes, Neglecting any and all sorts of losses in the system, the thermal performance of the system is well described by the coefficient of performance as; [28]

$$COP = \left(\frac{Q_{cond}}{W_{comp}}\right) \text{ ………..} (5)$$

Finally, a relation for the analysis of mass flow of the refrigerant flowing through the system and exchanging heat with the water in the storage tank is modeled by;

$$m_{ref} = \frac{NV\lambda(\pi)}{v_1} \text{ ………..} (6)$$

of the different variables enlisted in the above relation, N describes rotational speed of the compressor in revolutions per second while V stands to be the clearance volume of the same unit, $\lambda(\pi)$ decribes the efficiency per volume which depends on the pressure ratio π which is the ratio of the highest pressure to the corresponding lowest. And finally, $v_1$describes the specific volume at the first state of the heat pump cycle. [28]

$$\text{Where: } \lambda(\pi) = 1 - \Phi\left(\pi^{\frac{1}{k}} - 1\right), k = Cp/Cv \text{ ………..} (7)$$

Finally, the study in the specified paper proceeded with the model at the water tank assuming that the heat coming from the condenser will be stored in the tank taking the water in the tank as one body with a similar temperature.

$$\frac{dE}{dt} = m_w * c_{pw}\frac{dT}{dt} = Q_{cond} \text{ ………..} (8)$$

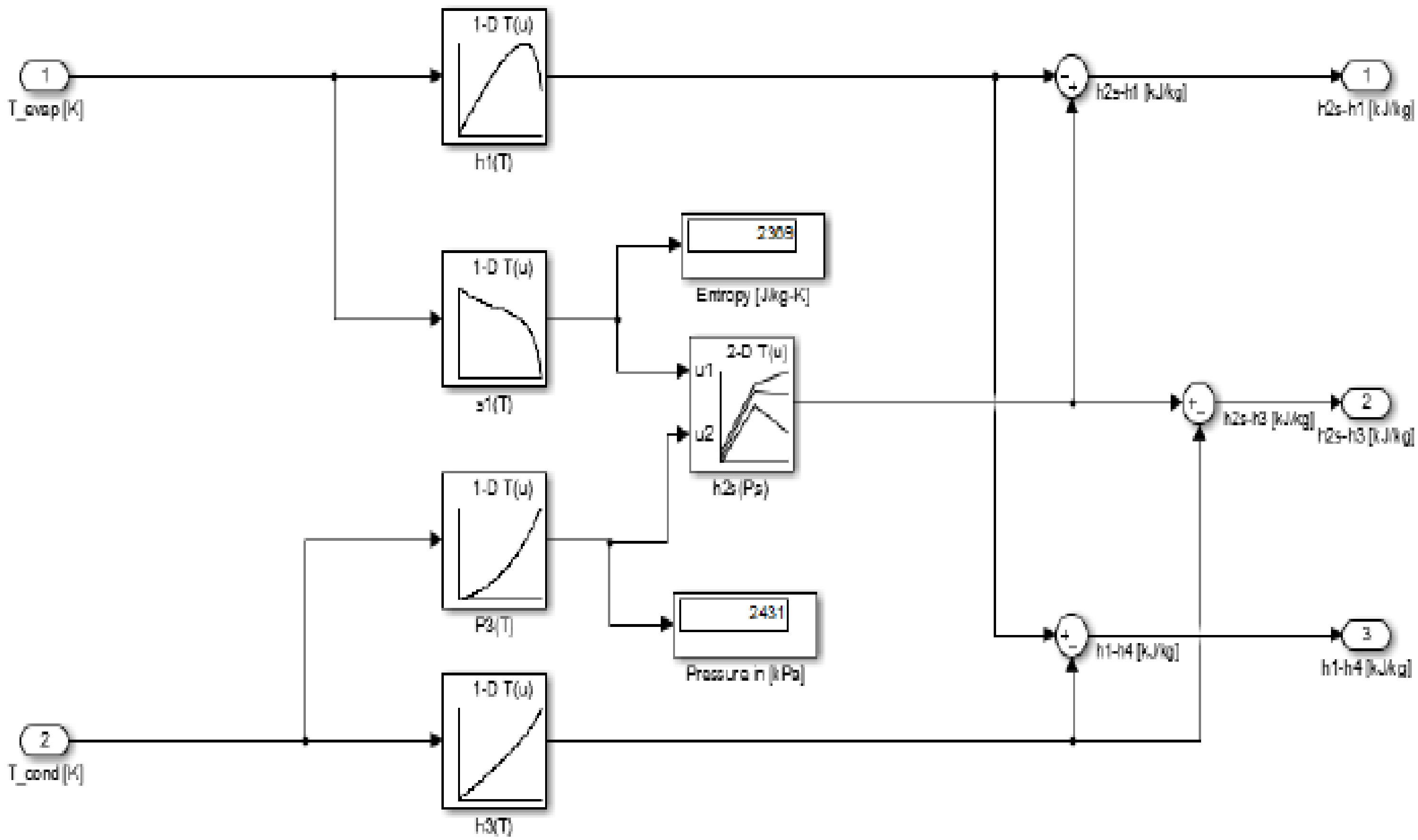

Figure 15 : Proposed Heat pump system by the study, Simulink MATLAB

2.4.1.2 Mathematical model, MATLAB

Another possible path in the determination of performance of the heat pump happens to be the utilization of appropriate approximation techniques manifested through the MATLAB coding environment using already existing data retrieved from manufacturers. The basis for the analysis of the proposed system is the use of performance maps to interpolate among number of heat pump characteristic points which will be fed into the system to model the heat pump behavior. Most dynamic modeling software's use temperatures of the heat pump sink and source in the process of evaluating the thermal power delivered and corresponding electrical power needed by the heat pump in each time step. One of the down sides of using commercial softwares of such sort happens to be the fact that it won't be possible to undertake direct calculations of heat pump efficiency at part loads.

A study undertaken to evaluate a heat pump behavior at part load has proposed a mathematical model. [29] the proposed mathematical model initiated under the premise that the seasonal performance of a heat pump is strongly influenced by the corresponding capacity to keep its high values of efficiency at part loads. The study has been conducted applying the model to evaluate the seasonal performance of different heat pumps for cooling and heating purposes. The energy requirement of the building which is attained from the hourly simulation is utilized to identify the heat pump part load conditions depending on the reference curves of the heat pump operating at full load. Following this, the hourly mean COP was calculated and approximated using the proposed model for part loads. And taking the ratio of the mean hourly capacity of the heat pump to the corresponding COP, the mean hourly electric consumption has been calculated and corresponding seasonal parameters were found.

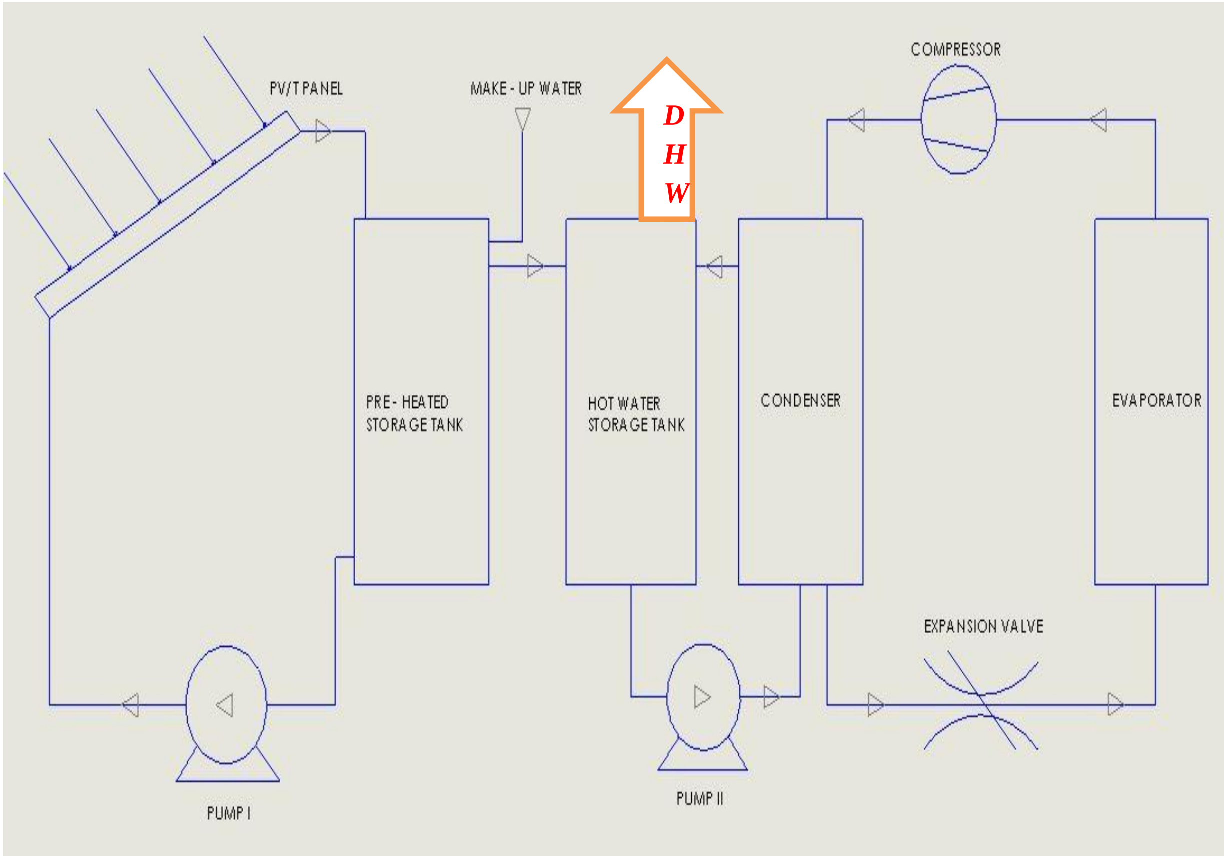

Figure 16 : The designed heat pump system

Input parameters for dynamic simulation of the heat pump operation are: hourly values of the external air temperature, hourly values of the building energy demand for DHW production, the thermal storage volume, imposed minimum and maximum values of the water temperature in the thermal storage, the storage heat loss coefficient, heat pump power and COP from the manufacturer in DHW production.

After the heat pump power and COP curves are evaluated through interpolations , the developed code evaluates the energy supplied by the heat pump in the production of the domestic hot water , mean temperature of the water in the storage tank and energy used by the heat pump through a proposed for loop. In the initialization of the water temperature, the mean temperature of the water in the storage tank is set equal to the minimum possible temperature of the water in the storage tank.

The values of the energy stored in the hot water tank for the different hours of performance of the heat pump are calculated using:

$$E_s(i) = \rho_w V_s C_{p,w}[T_s(i) - T_{in}] \text{ ……….. (9)}$$

$$T_{s,d}(i+1) = T_{s,d}(i) + (E_{b,d}(i) - E_{s,lost,d}(i))/(\rho_w V_s C_{p,w}) \text{ ……….. (10)}$$

Moreover, the hourly value of the thermal energy lost by the hot tank is $E_{s,lost,d}(i)$;

$$E_{s,lost,d}(i) = t_{hour} U_{s,d}[T_{s,d}(i) - T_{s,room}(i)] \text{ ……….. (11)}$$

The magnitude of the heat pump power and corresponding COP are known from interpolations of existing heat pumps. Accordingly, the COP value $COP_{d,\Phi eff}\,(i)$ will be obtained by applying a second order polynomial interpolation from existing data as a function of the heat pump power vector. For a capacity ratio evaluated as the ratio of $E_{HP,d}(i)\ and\ P_{HP,d\ \Phi eff}(i) *\ t_{hour}$, the effective coefficient of performance takes into account the heat pump efficiency decay for on-off cycles. Accordingly, the hourly electric energy utilized by the heat pump for DHW production is put as;

$$E_{HP,d,us}(i) = E_{HP,d}(i)/COP_{d,\Phi eff}\,(i) \text{ ……….. (12)}$$

Where $E_{HP,d}(i)$ is the energy needed to take into account the storage thermal losses, DHW demand and increase temperature of the water to its practically maximum value;$T_{s,d,max}$

$$E_{HP,d}(i) = E_{b,d}(i) + E_{s,lost,d}(i) + \rho_w V_{s,d} C_{p,w}[T_{s,d,max} - T_{s,d}(i)] \text{ ……….. (13)}$$

Unless of course the case where $T'_{s,d}(i)$is equal to or lower than the maximum achievable temperature$T_{s,d,max}$, for which the energy would be:

$$E_{HP,d}(i) = P_{HP,d,\Phi max}(i) t_{hour} \text{ ……….. (14)}$$

Where; $T'_{s,d}(i)$ is the temperature that the water in the DHW storage would reach if the heat pump generates the maximum energy which corresponds to the heat pump maximum power;$P_{HP,d,\Phi max}(i)$.

2.4 Solar radiation and related analysis

The sun is a spherically shaped hot gaseous matter with a dimension of 1.39 x 10^9 meters from one of its end to the other. It's famously known that the effective black body temperature of the sun is about 5777 kelvins, although temperature in its central interior regions could reach up to 40 x 10^6 kelvins. In relation, it has been studied that the sun can be perfectly assumed as a huge fusion reactor capable of supplying immense amount of energy to its surroundings, in effect; the earth. Accordingly, the energy that has been produced within the body of this sphere should have to be transferred out onto the surface and then be radiated deep in to space after which consecutive radiation and convection procedures will occur with successive emission, absorption and re-radiation. [30]

Deep within the core of the sun, the radiation is encapsulated within the x-ray and gamma-ray parts of the spectrum with constantly increasing wavelengths as the radial distance increases and accordingly temperature decreases.

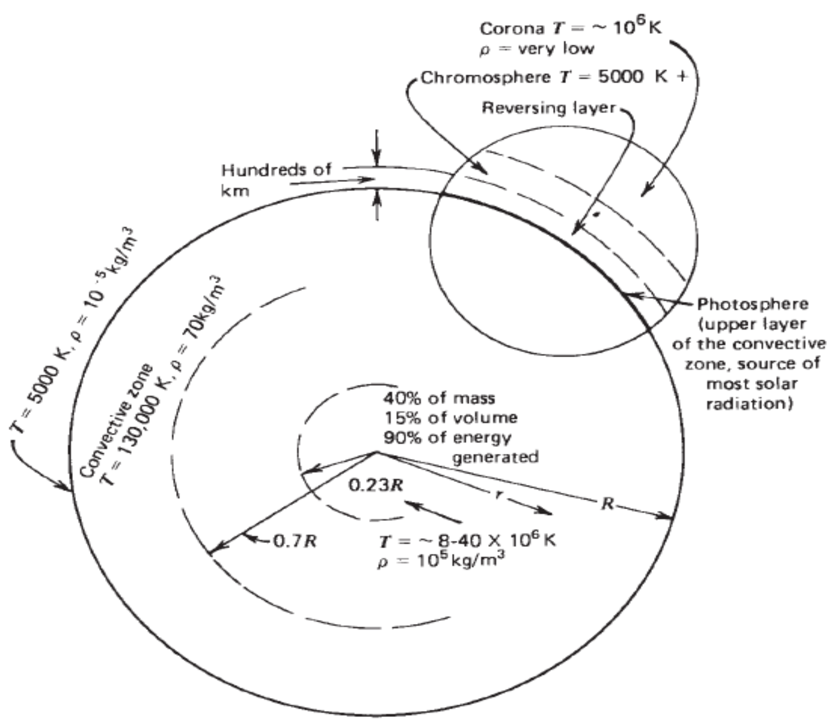

Figure 17 : a generic structure of the sun

Considering the relationship between the earth's surface and the sun, due to the eccentricity of the orbit of the earth, the corresponding distance between the sun and earth varies with a percentage magnitude equal to 1.7%. The corresponding radiation emitted by the sun and the relationship to the earth come up with an almost constant intensity of solar radiation just outside the earth's atmosphere. This energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mid earth-sun distance outside of the atmosphere is what is called the Solar constant G_{sc}. This solar constant has a magnitude equivalent to 1353 w/m^2. Added to the total energy embedded in the spectrum of the sun, it is also important to know the corresponding distribution of the radiation that would be received in the absence of the atmosphere. This irradiance curve has been proposed based on data collected from high altitude and space measurements.

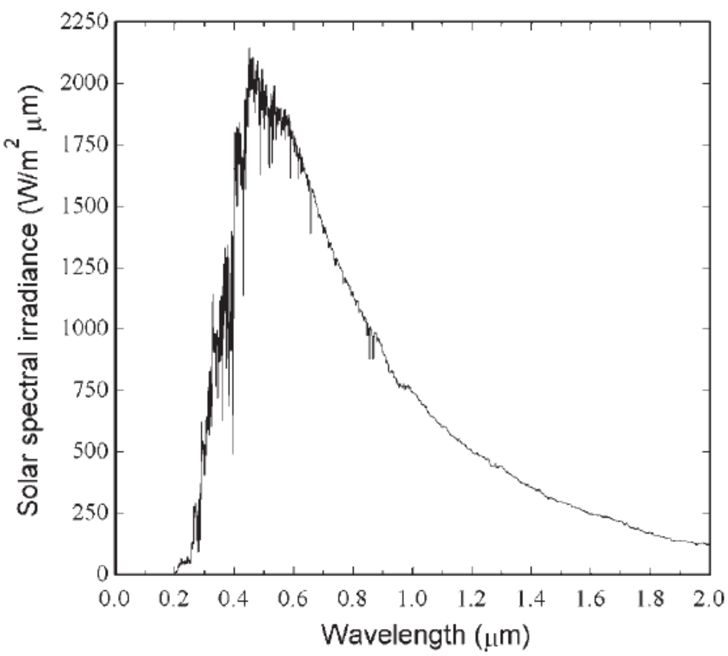

Figure 18 : standard spectral irradiance curve at mean earth-sun distance

2.4. 1 solar radiation data

Depending on the instrument utilized for measuring the solar irradiance, the orientation of angle of attack of the incident rays and form of acquisition of the data itself or even whether the measurements are of beam, diffuse or total radiation and corresponding averaging technique utilized in the process of averaging the data, the numerical values possessed at our hands at the end of the day vary in great regards. It is usually the case that most of the data that are available are for horizontal surfaces. And these data incorporate both diffuse and beam radiation measured appropriately using Thermopile pyranometers. [30]

In general, there are two basic types if solar radiation data available and accordingly widely available. One is the monthly averaged daily total radiation on a horizontal surface while the other one stands to be the hourly radiation on a horizontal surface.

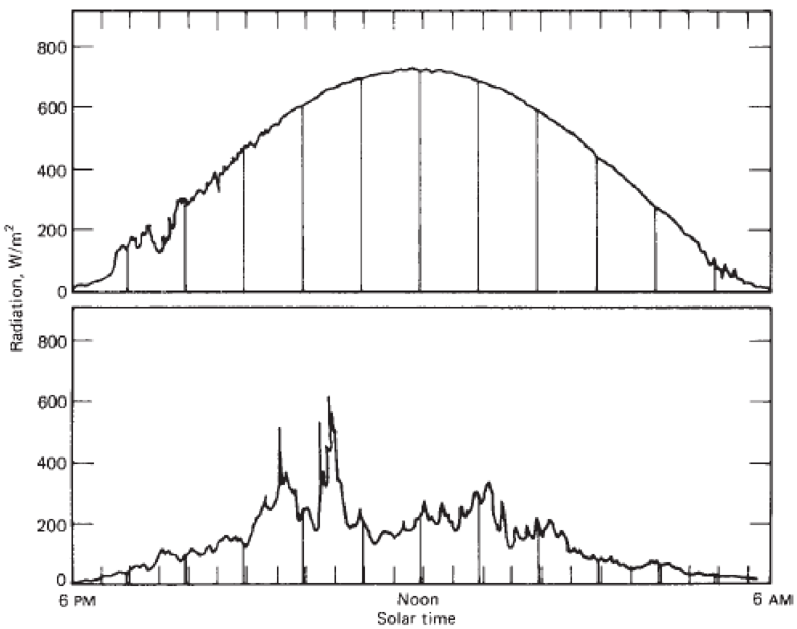

Figure 19 : beam and diffuse radiation on a horizontal surface with respect to time for both clear (upper) and cloudy (below) day

It has been discussed in different manuscripts that the solar data that should be utilized for calculating the time dependent behavior of solar energy equipment and corresponding processes and in extension related simulations for long term operations should have to be more detailed and should also encompass information such as ambient temperature and wind speed.

Although an existing incident radiation data would generally shorten the process that would have to be followed to analyze following mathematical deductions related to such studies, if such data are non-existent, it is very important to have the radiation data which would be the best source of information in the estimation of the average incident radiation. But if these are also not available, one can estimate the necessary radiation from sunshine hours or cloudiness of the location at hand.

Giving an emphasis for the determination of the incident radiation from existing sunshine hour, In order to start off with the mathematical deduction, one has to start with determining the monthly average clearness index. It should be clearly noted that the relation postulated and the different variables eminent inside the relation are all dependent on the location under analysis.

$$\frac{H}{H_o} = a + b\frac{s}{T_d} \text{ ……….. (15)}$$

Where a and b are the constant parameters depending on location, which are expressed as a function of latitude and sunshine hours respectively

$$a = -0.309 + 0.539 + \cos\phi - 0.0693 * Z + 0.290 * \frac{s}{T_d} \text{ ……….. (16)}$$

$$b = 1.449 - 0.553 * \cos\phi - 0.694 * \frac{s}{T_d} \text{ ……….. (17)}$$

Where s is sunshine hour in a day, Z is elevation of the site above sea level which is equal to 2800 meters and T_d is the time of sun set or rise, its equation is given below

$$T_d = \frac{2}{15}\omega_s = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \text{……….. (18)}$$

Where hourly angle is: $\omega_s = \cos^{-1}(-\tan\phi\tan\delta)$……….. (19)

Latitude of the site = 6.71 ^{o}

Month	n for i_{th} Day of month	For Average Day of month date	n	δ
January	I	17	17	-20.9
February	31+i	16	47	-13.9
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1

July	181+ i	17	198	21.2
August	212+i	16	228	13.5
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

Table 2.1 Recommended average day of month and value of n by month

The declination δ can be found from the approximate equation of Cooper (1969),

$$\delta = 23.5 \sin\left(360 + \frac{284+n}{365}\right) \text{……….. (20)}$$

Where n = average number of the days in month.

When we calculate daily solar radiation daily extraterrestrial solar radiation Ho (kW hr /m^2/day) are necessary, the equation of daily extraterrestrial solar radiation is given below

$$H_O = \frac{24 * G_{sc}}{\pi}\left(1 + 0.033 \cos\frac{360n}{365}\right) * \left(\cos\phi \cos\delta \sin w_s + \frac{\pi w_s}{180} \sin\phi \sin\delta\right) \text{…….. (21)}$$

Where G_{SC} is solar constant

The sunrise and set hour angle is greater than 81.4 ^{o} and the clearance index (k_t) are in the range of 0.3 to 0.8. The average daily diffuse radiation on the surface is given by the following relations.

$$\frac{H}{H_d} = 1.311 - 3.022 K_t + 3.427 K_t^{\,2} - 1.82 K_t^{\,3} \text{……….. (22)}$$

Therefore we can calculate the daily beam radiation from the total daily solar radiation:

$$H = H_b + H_d \text{……….. (23)}$$

Empirical data of the time distribution of total radiation on horizontal surfaces throughout the day has led to the development of charts that can clearly show the ratio of hourly total to daily total radiation, which is a function of day length and hour.

$$rt = I/H \text{.......... (24)}$$

Where I = hourly radiation

H= Daily radiation

And the curves represented by rt are portrayed by an equation from Collares-Pereira and Rabl;

$$rt = (\pi/24)(a + b cos\omega)\left(\frac{cos\omega - cos\omega s}{sin\omega s - \left(\frac{\pi}{180}\right) cos\omega s}\right) \text{.......... (25)}$$

Where the coefficients a and b are given by;

$$a = 0.409 + 0.5016 \sin(\omega s - 60) \text{.......... (26)}$$

$$b = 0.6609 - 0.4767 \sin(\omega s - 60) \text{.......... (27)}$$

Where ω is the hour angle in degrees for the time under study and ωs is the sunset hour angle. Accordingly, the hourly diffuse radiation and corresponding ratio has been found as follows;

$$rd = (\pi/24)\left(\frac{cos\omega - cos\omega s}{sin\omega s - \left(\frac{\pi\omega s}{180}\right) cos\omega s}\right) \text{.......... (28)}$$

$$rd = Id/Hd \text{.......... (29)}$$

Where Id = Hourly diffuse radiation

Hd = Daily diffuse radiation

The diffuse hourly to daily ratio of radiation is similarly found as that of the beam using collected empirical data which was proposed by Liu and Jordan in 1960.

2.4.2 Existing solar data of the study

As briefly discussed in the above section of this paper, solar irradiance data can be shown and presented in different forms. This difference emanates from the interest given to the data needed and also the existing data acquisition technique and capacity of the station. The Ethiopian Meteorology Agency has been responsible in delivering the necessary data for the study on hand.

As postulated above, due to a non-existing irradiance data, the agency was able to come up with the sun hour data of the location only. Although the location of the station syncs with the location at hand, the data that have been retrieved has been in need of steps of polishing and alteration to get it in its needed form, solar irradiance**.** The daily sun hour data retrieved from the agency has been inserted into a formulated MATLAB code which accordingly processes and goes through the analysis to come up with the daily solar irradiance of the location.
Dependent variables like, the declination angle, clearness index, sun rise and/or set hour, hourly angle and elevation have been appropriately utilized in the process of calculating and coming up with the final global irradiance of the location.

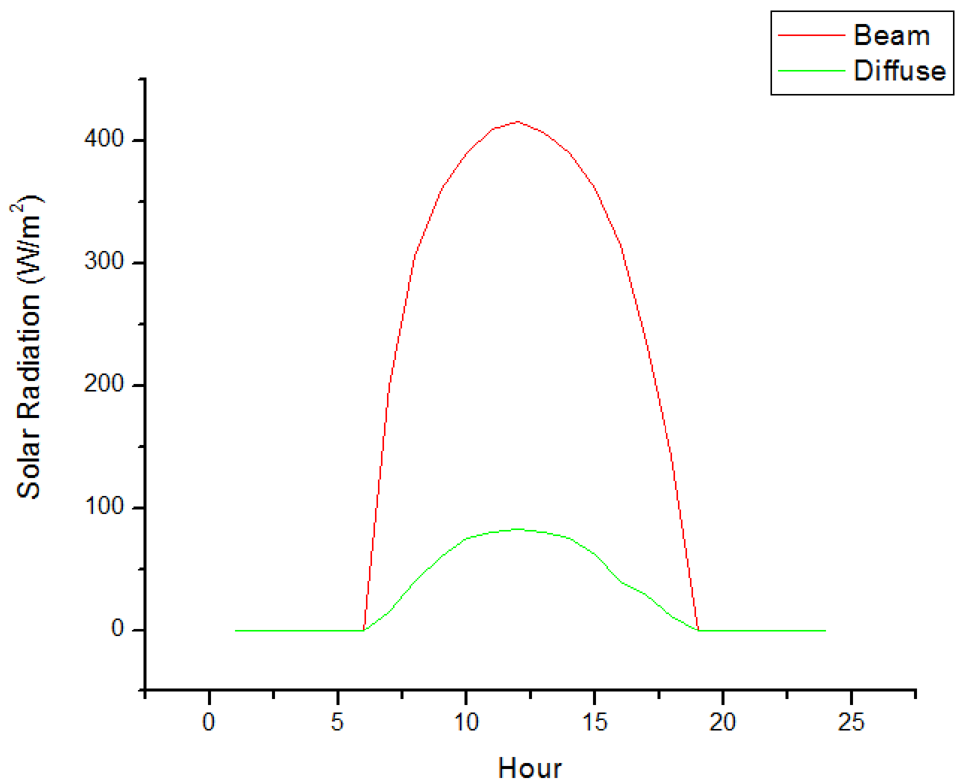

Figure 20 : Generated hourly average solar radiation for Rira, Bale

2.5 Hourly Temperature acquisition and synthesis

As discussed thoroughly in the previous sections, the temperature data that has been acquired from the Ethiopian Meteorology agency has only been able to show the daily maximum and minimum values. But since the analysis undertaken is transient on an hourly basis, the need for an hourly temperature data has given rise to the search of different mathematical models or formulas that can be best tailored to the requirement put forth. [31]

In the search towards this a study has come up with four years of hourly air temperature data that has been collected during a pertaining growing season at 2m over a well-watered grass to test different empirically developed and proposed models. The study advises that a direct hourly measurement would be more preferable although it also entails that that does not mean the proposed mathematical models come up with an erroneous result.

In this particular study, a method that was developed by Parton and Logan has been used. The routine divides the day into two distinct segments and utilized a truncated sine wave for the daylight hours and a corresponding exponential decrease in temperature at night. Assuming that daylight hours encompass both the daily maximum and minimum temperature just before sunset and within a few hours of sunrise respectively, the proposed equations for daylight and night time hours are as follows;

- For daylight hours;

$$T(H) = (Tmax - Tmin)\sin\left(\frac{\pi m}{y+2a}\right) + Tmin \text{ ……….. (30)}$$

- For night-time hours;

$$T(H) = Tmin + (Tsunset - Tmin)\exp\left(-\frac{bn}{z}\right) \text{ ……….. (31)}$$

Where

- $T(H)$ is the temperature at the required time during the day or night period
- y is day length (h)
- z is nigh length (h)
- $Tsunset$ is the temperature at sunset (^{o}C)

- m is number of hours between time of Tmin and sunset (h)
- n is number of hours from sunset to the time of Tmin (h)
- a is lag coefficient for Tmax = 1.8 (h)
- b is night time temperature coefficient = 2.2
- c is lag time of Tmin from time of sunrise = 0.88

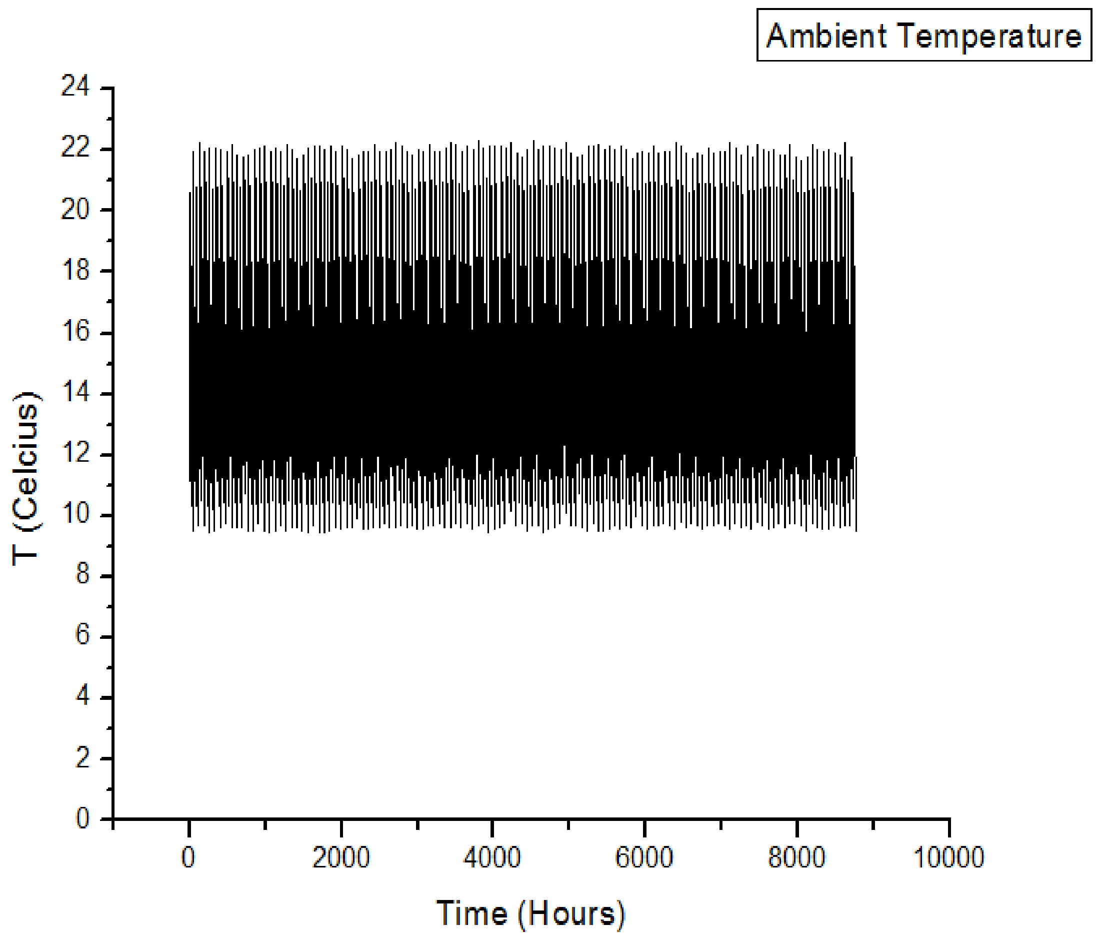

Figure 21 : Generated hourly ambient temperature

The literature discusses that the figure would mimic a sin curve finishing with an exponential decay which has been clearly the case for this study as well.

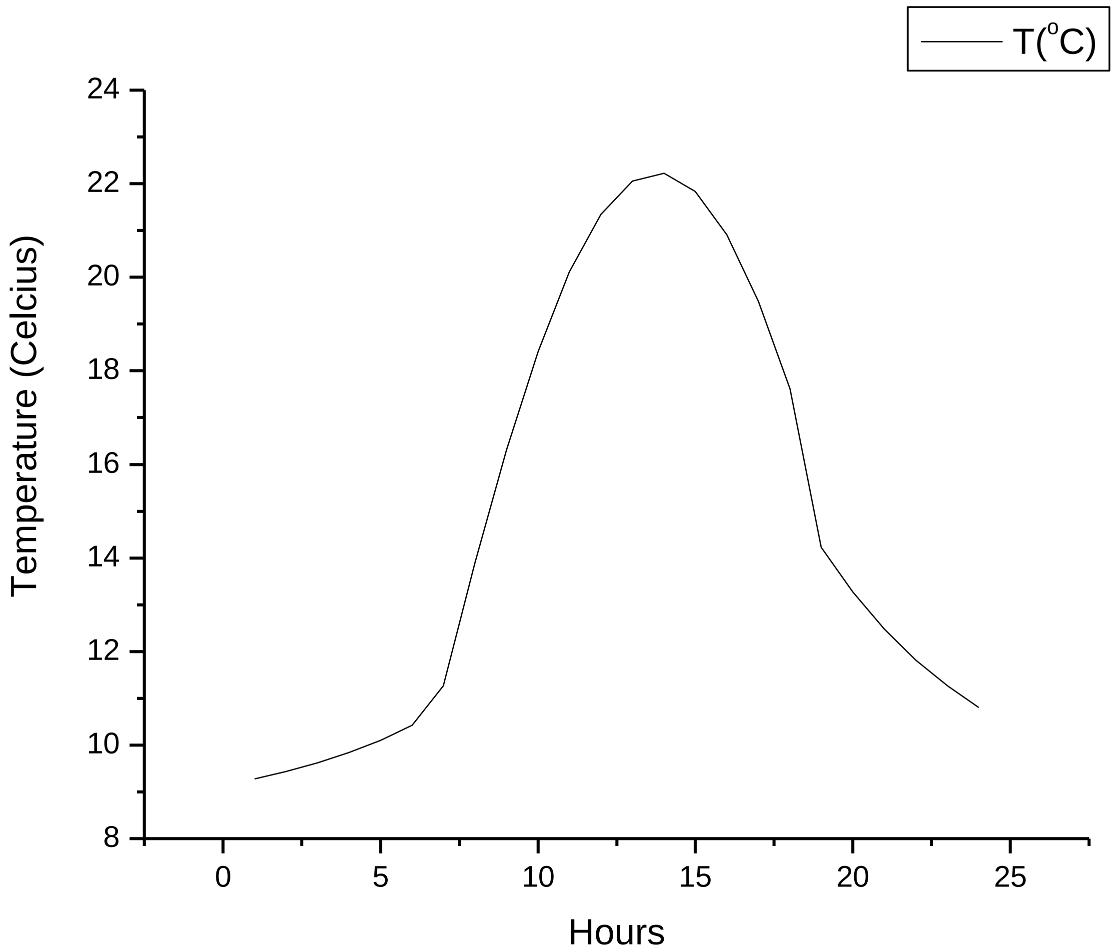

Figure 22 : a figure showing behavior of the plot for 24 Hours

CHAPTER 3
METHODOLOGY

3.1 General

The study initiated with determining both the thermal and electrical load requirement of the location under analysis. And for this very purpose, the corresponding solar reserve of the area has been thoroughly studied. The solar data has been taken from the Ethiopian Meteorology Agency. Moreover, since the data that could be retrieved from the site was the sunshine hour, the solar irradiance data has been calculated using the MATLAB code environment. Adding to this, taking the hot water output from the PVT panel which serves as an input for the heat pump system as a standpoint, performance of the system has been calculated using the maximum level of hot water demand from the site as a secondary input. It shall be known that the hot water output from the PVT panels has been directly influenced by the radiation level of the site under study.

After a thorough investigation of the practically required load, a mathematical model has been developed in MATLAB. The proposed mathematical relation is expected to define the heat pump's thermal behavior based on the weather and functioning conditions, so that the electrical and thermal performance can accordingly be evaluated generically. The major expected inputs into the system under analysis include input temperature of the ambient temperature and inlet water temperature of the location. On the other end, expected output parameters from the heat pump include the output temperature from the condenser and its corresponding energy efficiency (COP). The project starts from determining the resources at hand, followed by specifying the necessary components required to launch the system and building a simulation model. Following this, a thermal and electrical analysis of the system will be undertaken which in extension includes optimization of the proposed model.

3.3 Simulations

3.3.1 Background

The method generally utilized for the analysis of this study is a relatively detailed method used to evaluate the mean seasonal performance of the whole heat pump system. This dynamic simulation takes into account the dynamic variation of the building load, heat pump source temperature and also the heat pump performance. An additional attribute of this technique is the fact that it can be well consider the presence of a storage tank which is coupled to the heat pump itself.

The mathematical manipulations undertaken in these models are all undertaken at quasi-steady – state conditions; meaning at steady state conditions for each time interval equal to the proposed time step equal to an hour. To start off the calculation, performance maps are utilized as in most dynamic software's bypassing the necessity of modeling the thermodynamic properties of the heat pump working fluid. Rather interpolations are undertaken among the different heat pump characteristic points which are injected by the user which will accordingly be utilized to model the heat pump system.

3.3.2 MATLAB code simulating the system for DHW production

In this section, the numerical method implemented in MATLAB for the analysis/ simulation of an air-to-water heat pump for the production of domestic hot water is presented. The heat pump under analysis is coupled with a storage tank for DHW production for which the mean temperature of the water will be calculated using this platform.

Considering that the code will be iterating for the COP and Power of the HP at each hour, it has been seen that these performance parameters/figures have fallen in the ranges between the boundaries of the injected ambient temperature and hot water inlet temperature from the PVT panels. This has in turn enabled the study to be conducted with the idea in mind that the maximum and minimum system performance parameters will accordingly be found. With these assumptions, the maximum and minimum ambient temperatures of the location which have been retrieved from the agency have been extended in to a 24 hour period sinusoidal curve giving back the temperature for each hour during the day and night which will in turn serve as an input data for the dynamic simulation code each extending for 24 hours.

The temperature in the specified storage tanks ranges from a fixed minimum to a maximum value for the produced domestic hot water. In order to initiate the system, input data of the heat pump power and COP in DHW mode are required for different values of the ambient temperature and a varying inlet water temperature which will serve as another independent variable upon which the performance hugely depends. Using interpolations of the manufacturer data, curves of the heat pump power and COP in DHW mode are obtained as functions of the ambient temperature of the location at hand for fixed temperature of the hot water produced. Although taking an average fixed temperature of the inlet hot water in the process of deduction of the behavior of the curve helps to analyze how the two independent variables interact with each other in the description of the needed dependent variable, the synthesis and analysis of the system has been undertaken taking both of the independent variables and forming a surface rather than a curve from which the system by itself will iterate and take the prescribed COP or Power which will be used for the calculation of the corresponding total heat generated by the heat pump. This generated heat will eventually be utilized in the calculation of the temperature at the second storage tank just at the outlet from the heat pump using heat balance. The heat balance which basically describes or models the system serves as the mother equation from which all the other analysis emanate from.

$$Ts2 = Thp1 + \frac{(Qhp - mdotw * Cpw * (Thp1 - Ts1) - Us * As * (Thp1 - AmbT))}{(\rho * Vdot * Cpw)} \quad \text{....... (32)}$$

Where: Ts2 = Temperature at storage tank 2

Thp1 = Initial heat pump generated temperature at tank 2

Qhp = Total thermal power (heat) generated at from heat pump

mdotw = mass flow rate

Cpw = Specific heat of water

Ts1= Temperature at storage tank 1

Us = Heat Transfer coefficient of storage tank 2

As = Total storage tank area

AmbT = Hourly ambient temperature of the location at hand

ρ = density of water

Vdot = Volume flow rate of water

CHAPTER 4
ANALYSIS

4.1 Total Load requirement

Considering the nature of business at the site and corresponding equipment utilized, magnitude of load required is expected to be very large. Moreover, as a tourist vacation center able to meet the high standards of customers capable of paying the required immensely large sum of money for the services acquired, there are gadgets that are planted at the different section of the center that are there to facilitate the huge inquisitive appetite of the high class customers. And one of the downsides of this happen to be the fact that this very gadgets are also the ones responsible for consuming large sums of the energy generated by the hydro power plant.

Figure 23 : DHDW and electrical load data collection

In an act to simultaneously answer this very basic question and also keep the ecofreindliness of the proposed site, a PVT assisted heat pump has been proposed. And in order to move forward into analyzing and classifying which sections of the equipment should be handled by the newly designed system and which of these should be left to be engulfed by the already running micro hydro power plant, first a thorough analysis of load requirement at the site had to be done. And the total energy consumption analysis has proved that the site utilizes power more than 160 Kwh. The entitled power has been proved to be more than what the existing source of power can handle. And in an effort to alleviate this problem some of the huge power consuming gadgets have been left to be handled by the existing power plant at the site. While some remaining equipment including the heat pump itself are remained to be handled by the newly proposed system.

Figure 24 : a close evaluation on one of the installed heat pump system at the site

The load calculation started from determining the types of equipment existing at the site which are listed under the name Appliances in the table put below. Following that, the quantities of these appliances had been observed. Connected to this is the study related to analyzing the total hours that this appliances would be used. Most of these data have been retrieved from interviews undertaken at the site, observed conditions and filled questionnaires. But on the other hand some reasonable standards have been taken in determining some of the consumption of the gadgets which were unable to be written at the gadgets themselves.

Table 1 : Total power consumption at the site

No	Appliances	Qty	Rated Wattage	Total Rated Wattage	Adjustment Factor	Adjusted Wattage	Hours/day used	Energy/day (Watts)
1	Lighting	181	20	3620	0.85	4259	6	25553
2	Tea Maker	15	1500	22500	0.85	26471	1	26471
3	Boiler	4	1100	4400	0.85	5176	1	5176
4	Heat Pump	6	4450	9250	0.85	10882	1	10882
5	Freezer	5	250	1250	0.85	1471	24	35294
6	Ice cream Machine	1	500	500	0.85	588	1	588
7	Douph Mixer	1	2250	2250	0.85	2647	1	2647
8	Cheese/Beef slicer	1	154	154	0.85	181	1	181
9	Juice Maker	1	1120	1120	0.85	1318	1	1318
10	Microwave	1	1000	1000	0.85	1176	2	2353
11	Fan	1	100	100	0.85	118	9	1059
12	Water Filter + Freezer	1	80	80	0.85	94	24	2259
14	Television	2	150	300	0.85	353	8	2824
15	Washing Machine	1	500	500	0.85	588	1	588
16	Iron	1	2200	2200	0.85	2588	2	5176
17	Drier	1	2000	2000	0.85	2353	2	4706
18	Power Hacksaw	1	2000	2000	0.85	2353	2	4706

19	Pump	1	1100	1100	0.85	1294	24	31059
20	Electric Blanket	7	200	1400	0.85	1647	10	16471
		Total	20674	55724	0.85	65558		179,311

Table 2 : Revised version of the required electrical consumption at the site

No	Appliances	Qty	Rated Wattage	Total Rated Wattage	Adjustment Factor	Adjusted Wattage	Hours/day used	Energy/day (Watts)
1	Heat Pump	3	2120	6360	0.85	7482	1	7482
2	Ice cream Machine	1	500	500	0.85	588	1	588
3	Cheese/Beef slicer	1	154	154	0.85	181	1	181
4	Juice Maker	1	1120	1120	0.85	1318	1	1318
5	Fan	1	100	100	0.85	118	9	1059
		Total	3994	8234	0.85	9687		**10,628**

The values under the final table drawn are prone to change depending on the final number of heat pump required at the site, as it stands to be a major priority. If the number and corresponding required power meets the collected data's, a future study looking for the number of panel sizing would take the total amount of KW required, if not the corresponding electrical system would be forced to supply only the heat pump to create a self-sustaining cycle.

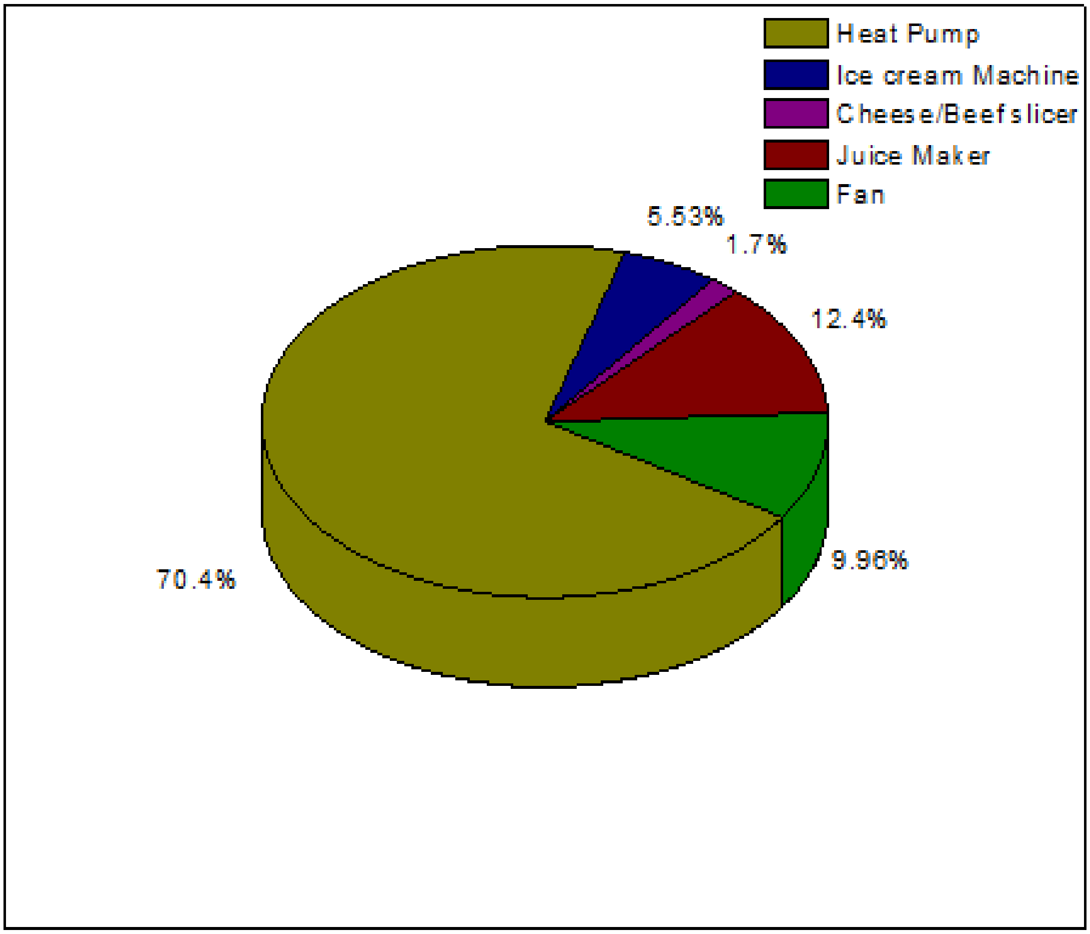

Figure 25 : Required electrical consumption of the site

4.2 Hot water requirement

As the principal objective of the project, it is very important to study the total domestic hot water demand of the site. This analysis helps to undertake future studies in the direction of determining the amount of power needed to heat the water coming in into the heat pump system and get it to the required temperature. The designed system is expected to generate both electrical and thermal power that would accordingly be a solution to the problems the site has faced concerning the humongous amount of power loss added to the large power consumption by boilers installed for the different rooms inside the lodge.

For the determination of these values, a standard has been studied from which the amount of consumption in liters per person is retrieved. [32]

Table 3 : DHW Consumption

<table>
<tr><td>No</td><td>Type of purpose</td><td>Consumption per occupant (L/day)</td><td colspan="2">Peak demand per occupant (L/hr)</td><td>Storage per occupant (Liter)</td></tr>
<tr><td>1</td><td>Hotels</td><td>90-160</td><td colspan="2">45</td><td>30</td></tr>
<tr><td></td><td></td><td>For an assumed average number of 20 occupants</td><td>20</td><td>0.9 (m^3/h)</td><td></td></tr>
</table>

The above number entails the total amount of domestic hot water need at the site. And in order to initialize the analysis, data has been collected from the site and existing standards have been used as a stand point to come up with the magnitude put forth. Standard that has been looked into entails the total amount of water consumption in liters per hour for different section of a lodge or hotel. [32]

On the other hand the total share of DHW consumed by the different utilities in the lodge has also been calculated with a standard which analyzes consumption per room. Although the method has repeatedly shown to over predict, it has been used in this study to show the fair share taken by each section of the lodge.[33]

As can be seen from the quick analysis undertaken, the total hot water demand of shower and service sinks take the lions share while the remaining appear to be relatively low in magnitude.

Hot water requirements for the purposes of dish washing, kitchen water related activities and laundry take fair share of the total consumption putting demand from the toilet at last.

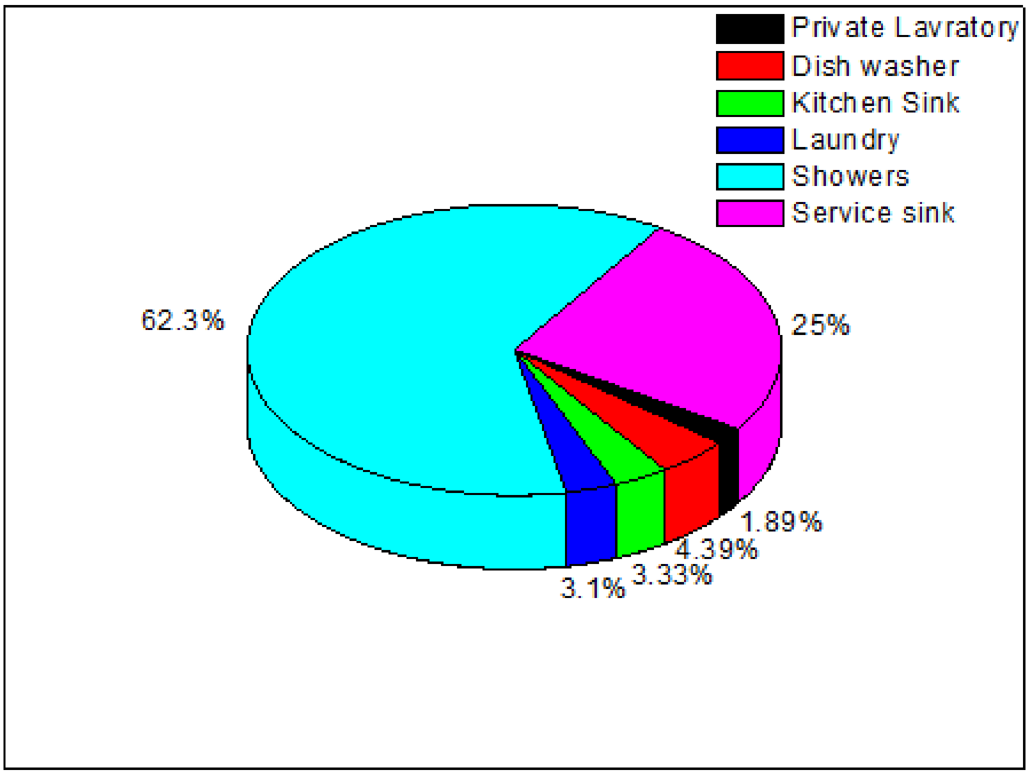

Figure 26 : Percentile share of the total amount of DHWD

4.2 Manufacturer data analysis

Hourly values of the ambient air temperature are utilized as an input data to kick start the dynamic simulation code. The annual data received from the Ethiopian Meteorology Agency is plotted for the Rira region of the Bale zone.

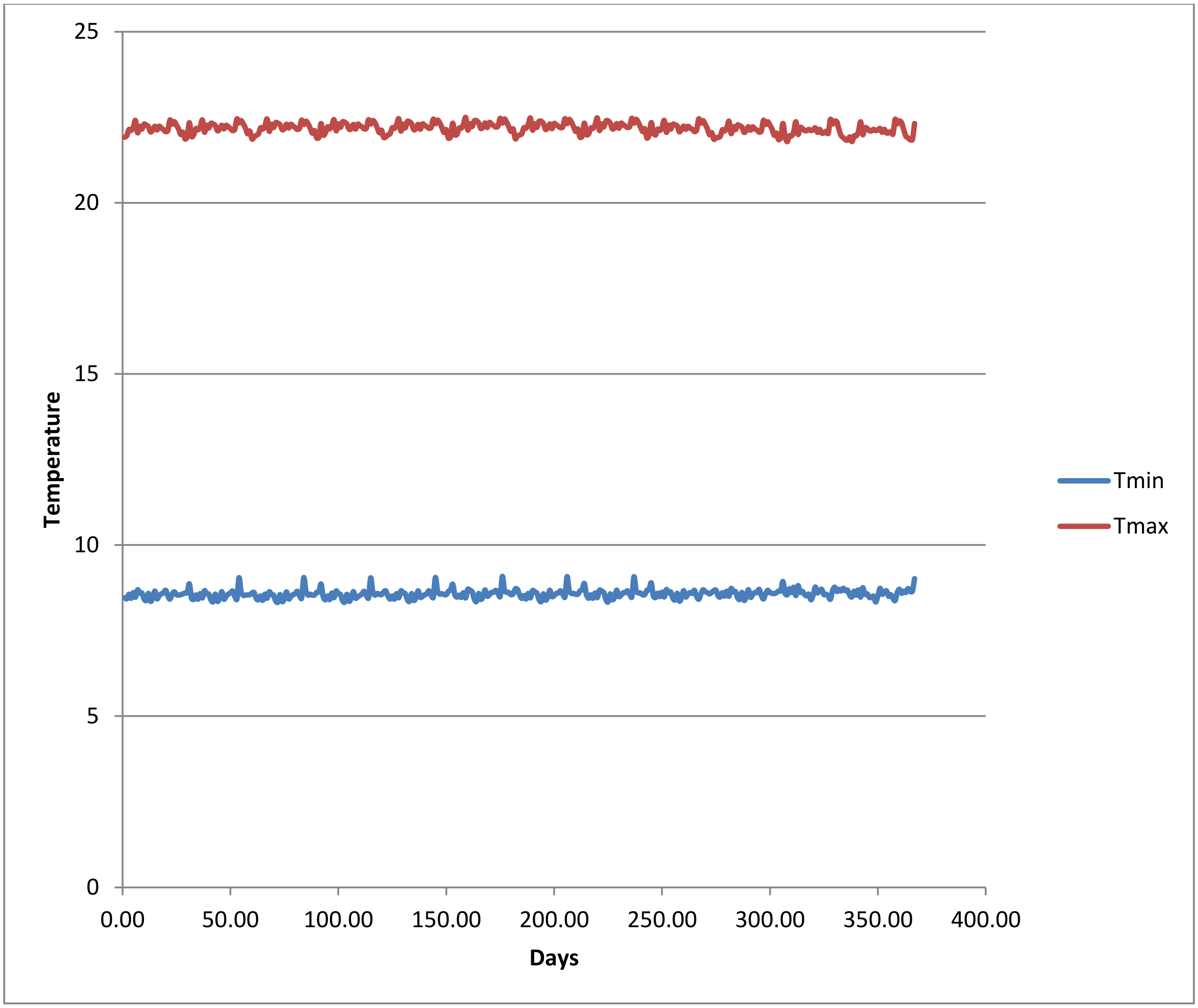

Figure 27 : Days VsT_{amb}

Assuming a heat pump working to produce DHW and water which will be delivered with a certain maximum output and corresponding minimum including the return temperatures and post analysis known return temperatures respectively, the following data curve is generated. The values of the COP and power of the heat pump under analysis for an evaporator consuming the external ambient air and corresponding hot water delivered at distinct inlet temperature magnitudes have been received from the manufacturer. [34]

Table 4 : Power Vs Tamb, min and Inlet water temperature

	Inlet water Temperature				
Tamb	**25**	**32**	**40**	**43**	**50**
-20	1749	1891	-	-	-
-10	2481	2772	3107	3230	-
-5	3030	3344	3750	3908	-
0	2951	3949	4363	4311	3578
2	3388	3641	3768	4030	4078

Table 5 : COP Vs Tamb, min and Inlet water temperature

	Inlet water Temperature				
Tamb	**25**	**32**	**40**	**43**	**50**
-20	1.65	1.3	-	-	-
-10	2.86	2.4	1.77	1.46	-
-5	3.19	2.76	2.27	2	-
0	1.92	2.77	2.36	2.15	1.8
2	3.31	2.91	2.5	2.28	2.03

Table 6 : Power Vs Tamb, max and Inlet water temperature

	Inlet water Temperature				
Tamb	**25**	**32**	**40**	**43**	**50**
7	3677	4049	3978	4171	3015
15	3682	4100	4056	4226	2618
25	2133	2436	2457	2365	2029
35	-	-	2432	2333	2031

Table 7 : COP Vs Tamb, max and Inlet water temperature

	Inlet water Temperature				
Tamb	**25**	**32**	**40**	**43**	**50**
7	4.05	3.5	2.92	2.7	1.98
15	4.76	4.22	3.62	3.32	2.68
25	5.82	5.36	4.41	3.36	3.1
35	-	-	4.72	4.31	3.4

The tabulations are presented in a way that the relation is put in between the range of ambient temperatures either maximum or minimum and the corresponding power or COP. The relation between COP of the heat pump and the maximum ranged ambient temperature shows a more or less smooth and linear regression for inlet water temperatures 40 and 50 while the others follow a polynomial behavior with a second degree order. The performance has been shown to increase extensively with an ever increasing temperature.

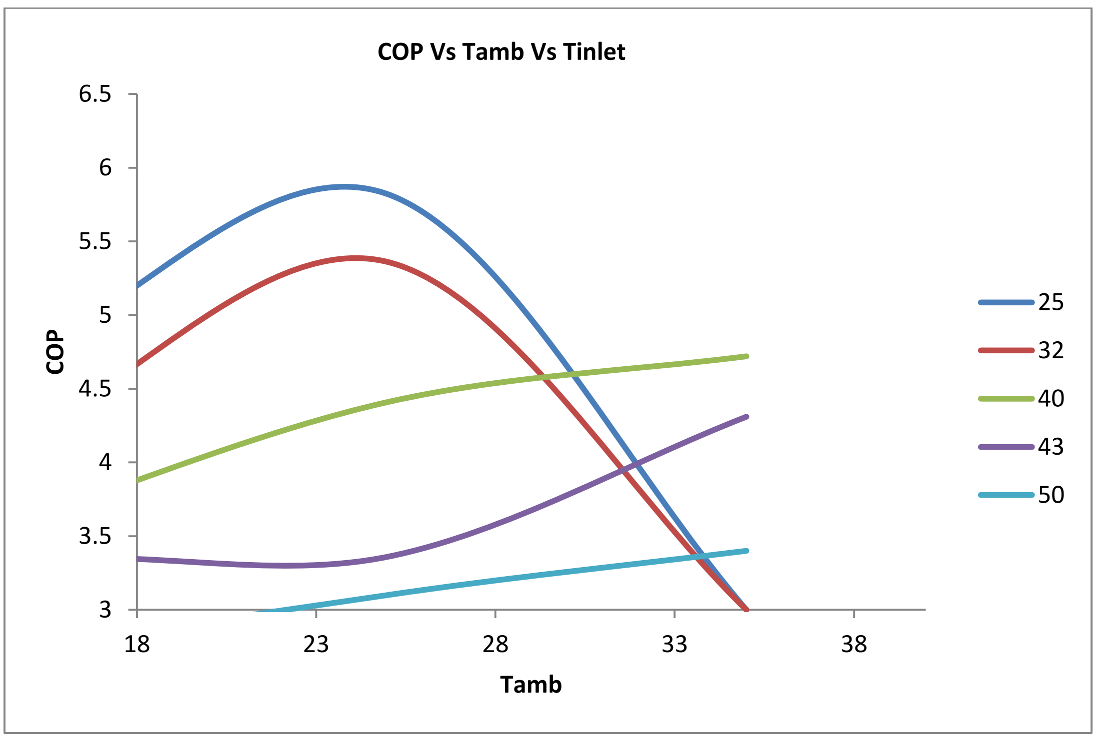

Figure 28 : COP Vs $T_{amb,\ max}$

On the other hand, a thorough analysis on the plots relating the Power required for the heat pump with the corresponding ambient temperature has shown a much linear decrease as the ambient temperature increases and stabilizing nature suffices ones the temperature of the air achieves temperature of around 25 Celsius.

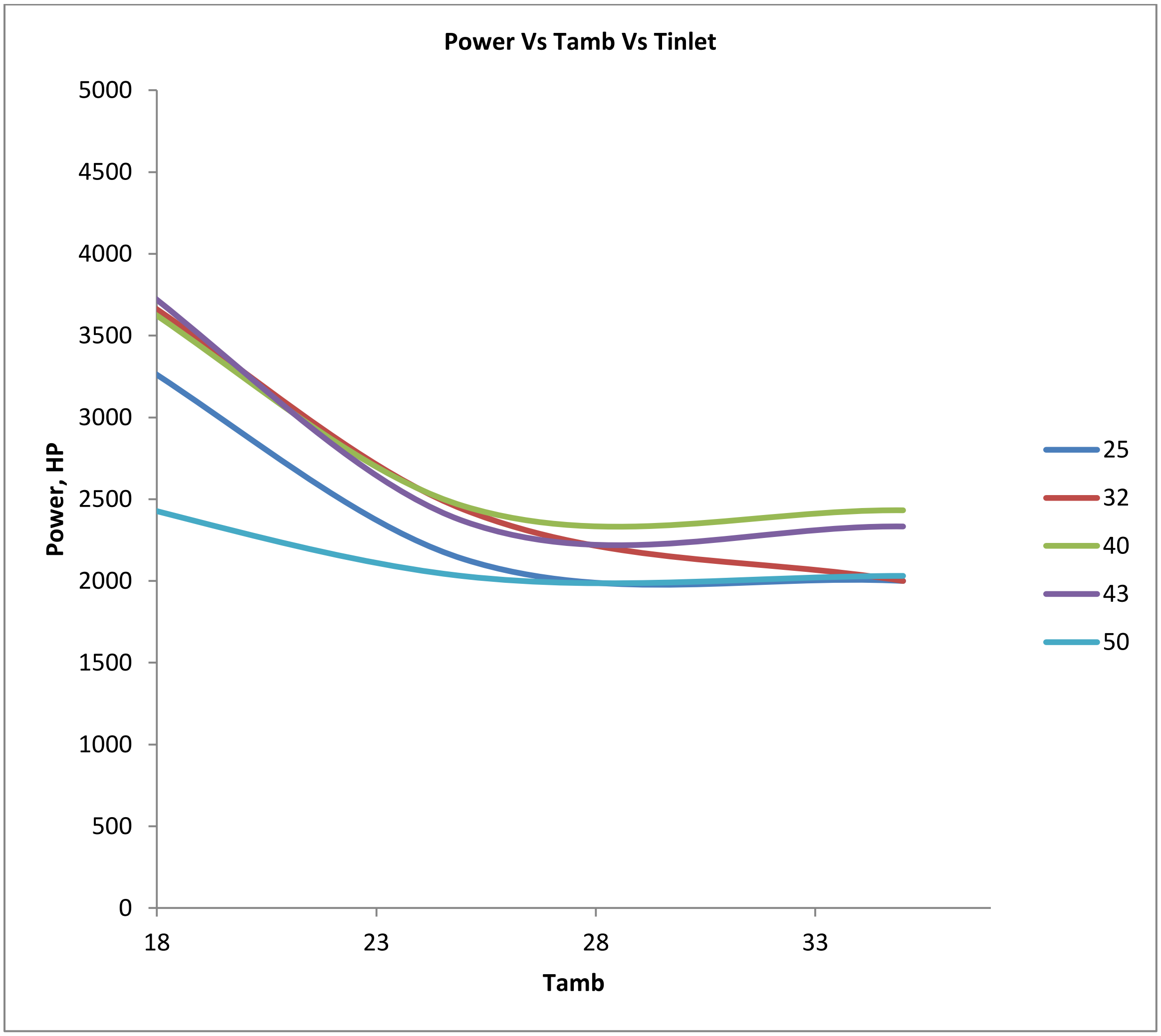

Figure 29 : Power Vs $T_{amb, max}$

Unlike the above two cases, the relation between COP, Power and ambient temperature during the night time or T_{min} is quite different. Although an increase in the ambient temperature of the location shows a remarkable increment in the corresponding performance of the system, the relation happens to be very different from a linear relation. Peculiarly enough, one of the behavior observed corresponding the performance of the system catches the attention. Although most of the performance curves follow the same routine for all the other inlet water temperatures, the characteristics of the curve for an inlet water temperature of 25 Celsius shows a huge dip at an ambient temperature of 0 Celsius increasing abruptly afterwards. Moreover, in both the minimum and maximum ambient temperature cases, an increase in the inlet water temperature has correspondingly given rise to a characteristic decrease in the performance of the system.

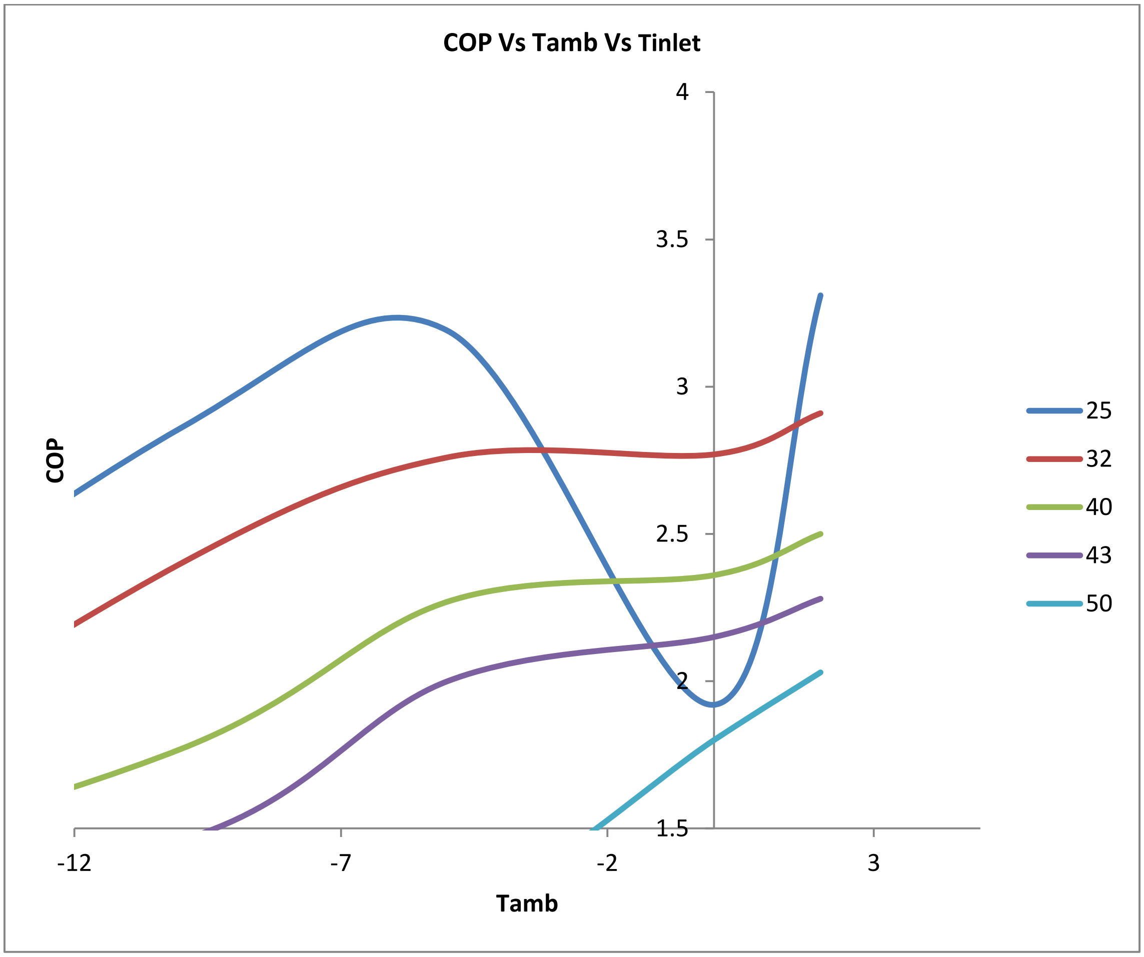

Figure 30 : COP Vs $T_{amb, min}$

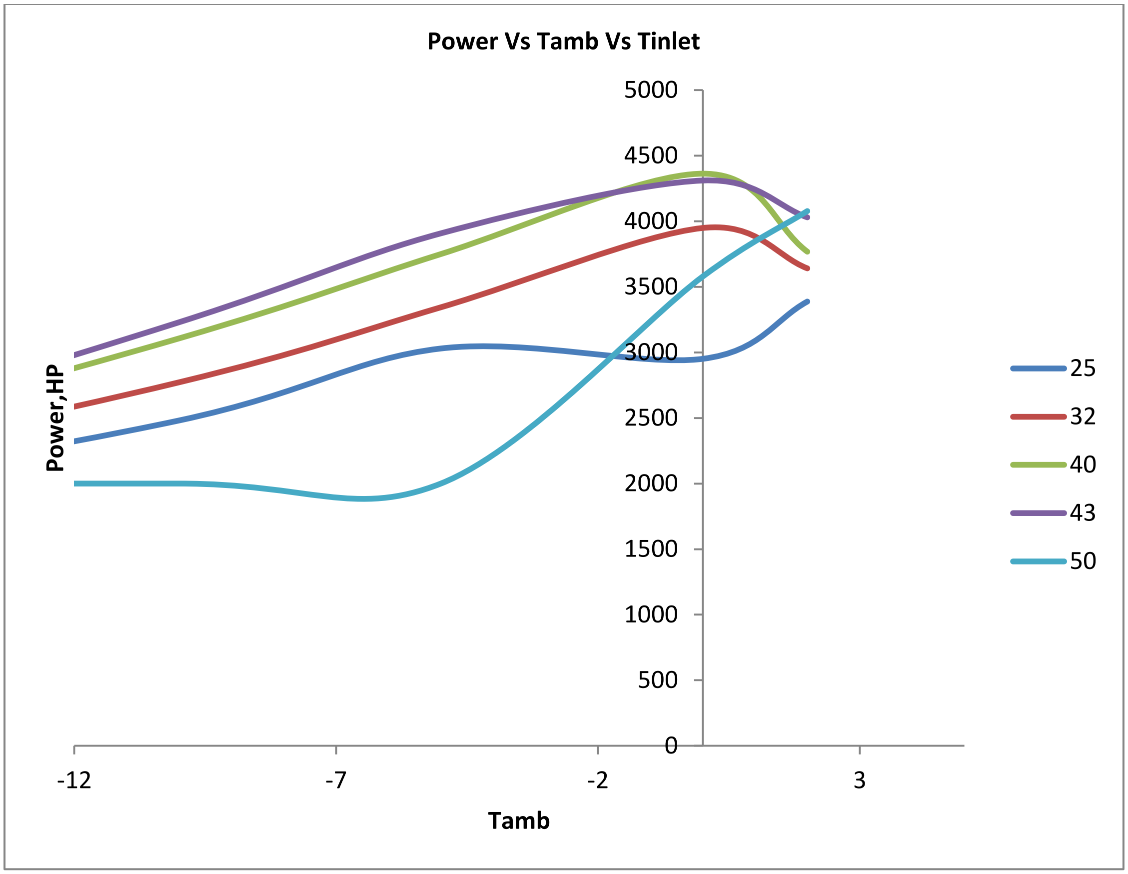

Figure 31 : Power Vs Tamb, min

As thoroughly discussed in previous sections, although the general informative figure of the heat pump have been depicted in the above plots, the corresponding analysis for the heat pump has been undertaken using a three dimensional plot that uses the two basic input information: inlet water temperature and ambient temperature, to iterate the corresponding coefficient of performance and power that would finally be used to generate the total heat that will be injected into the working fluid from the heat pump itself. And this 3D surface plot has been generated using the MATLAB environment. But, the generated surface plots have not been directly used in the look for the two dependent variables as a graph, rather the mathematical model that can clearly depict the graphical model has been generated using MATLAB including all the coefficients that are the conclusive output of behavior of the surface.

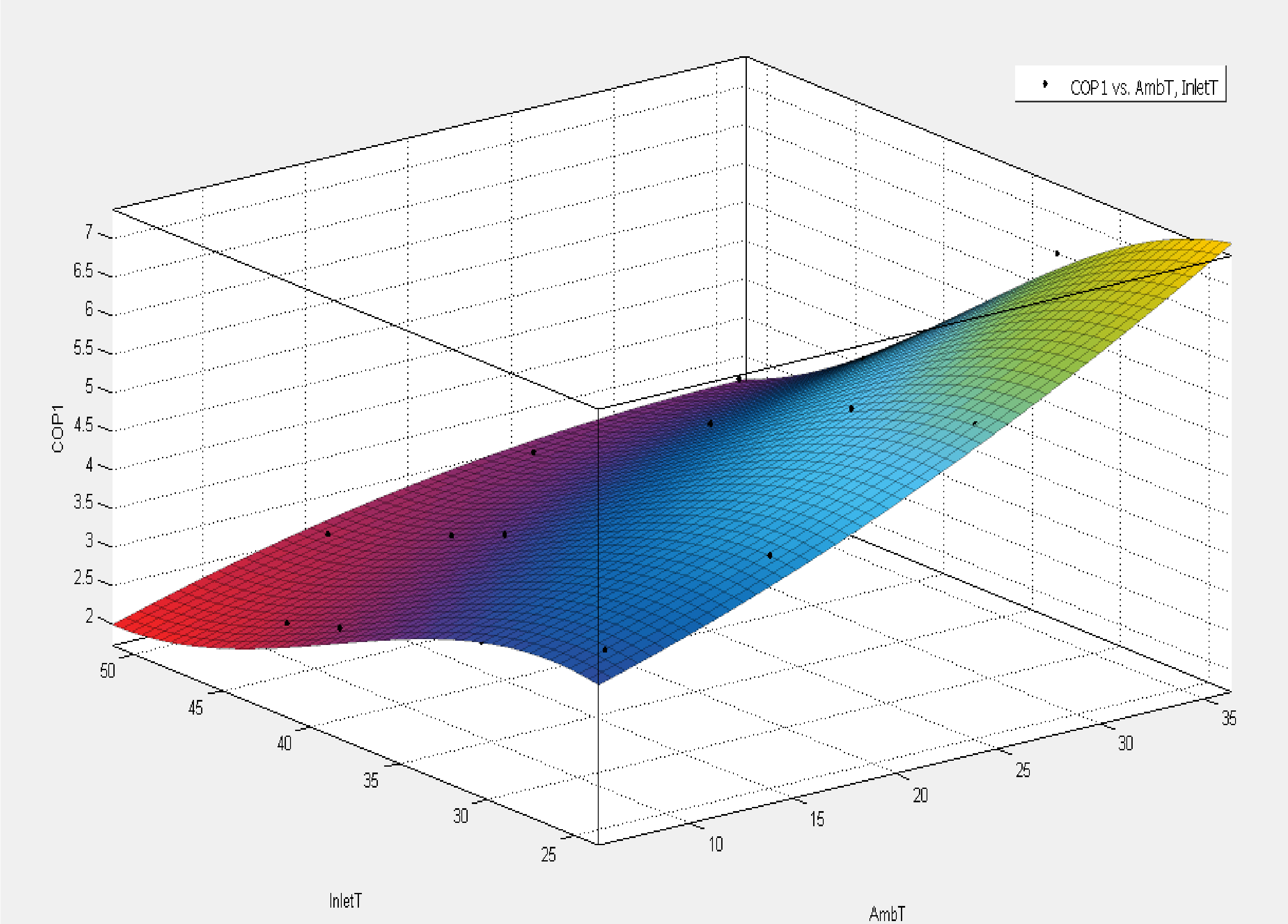

Figure 32: COP Vs Tamb, Tinlet

The surface generated from the inputs at hand has shown that it best fits a third order polynomial function with a relatively small error margin. And accordingly, the mathematical model generated by the MATLAB environment is as follows;

COP=((0.0002454*Inlet_T1(i)^3)+(0.000003505*Amb_T1(i)*Inlet_T1(i)^2)-(0.0001003*Amb_T1(i)^2*Inlet_T1(i))-(0.02849*Inlet_T1(i)^2)+(0.0009462*Amb_T1(i)*Inlet_T1(i))+(0.003841*Amb_T1(i)^2)+(0.9857*Inlet_T1(i))+(0.03574*Amb_T1(i))-7.206)
……….. (28)

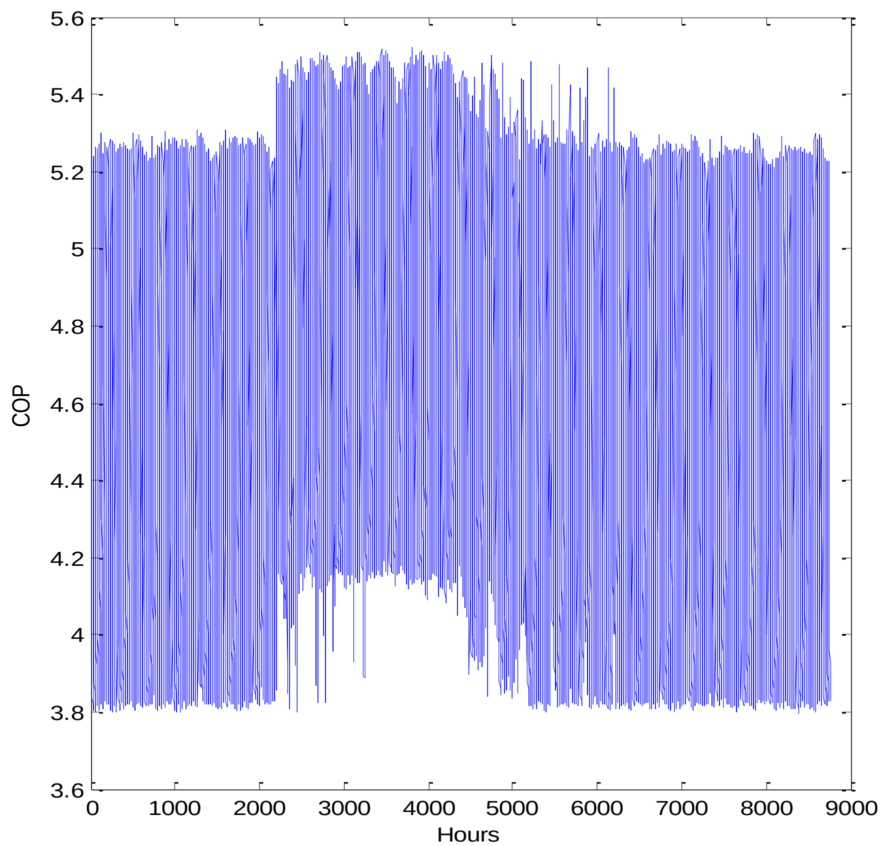

Figure 33 : Hourly COP generated for a year

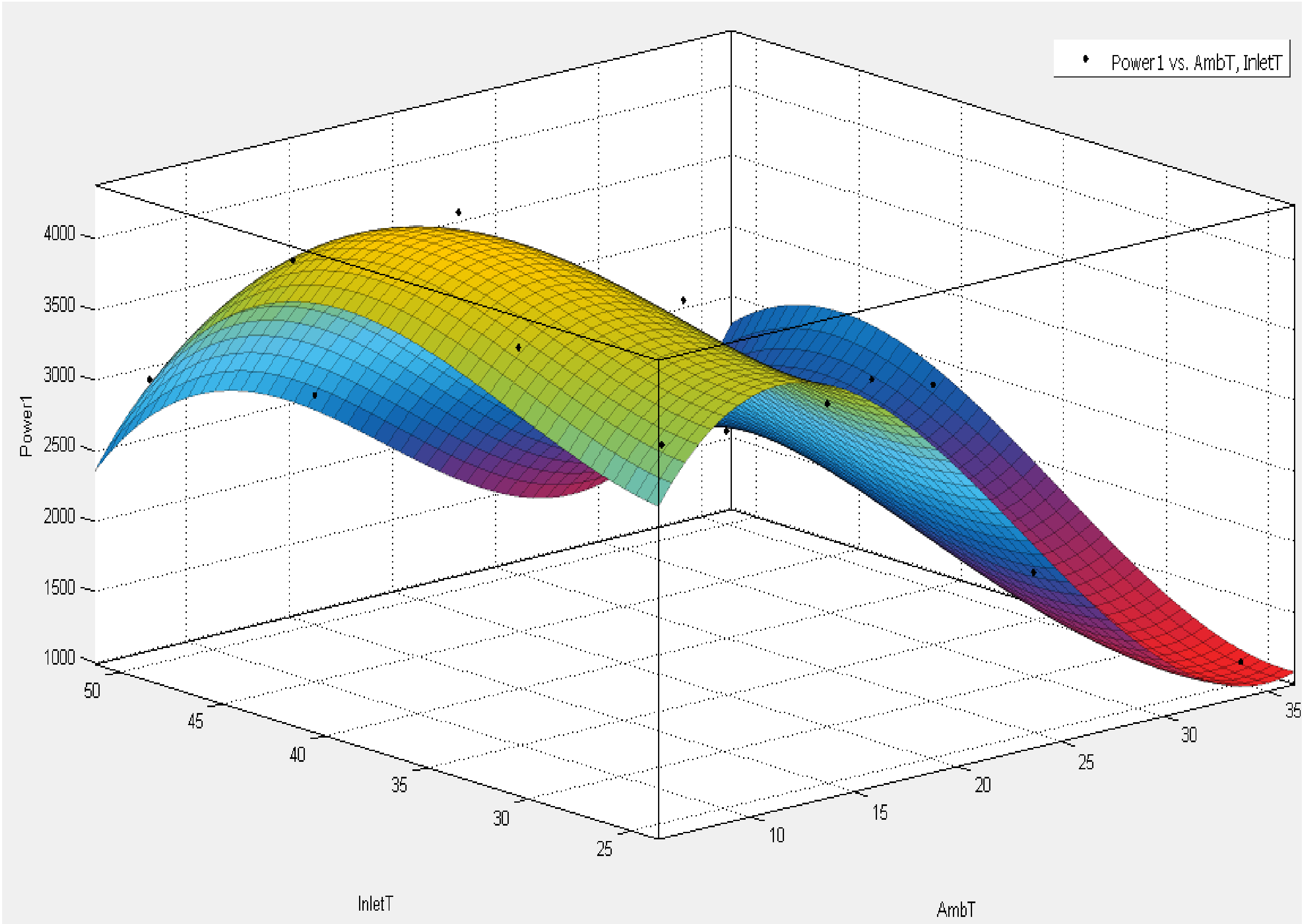

Figure 34 : Power Vs Tamb, Tinlet

Similarly, in the case of the compressor power that is required to operate the heat pump in the above put performance range, again a third order polynomial curve has been generated that is capable of best fitting the data points injected into the system.

Pcomp=((-0.3041*Inlet_T1(i)^3)+(0.1328*Amb_T1(i)*Inlet_T1(i)^2)+(0.1782*Amb_T1(i)^2*Inlet_T1(i))+(0.4539*Amb_T1(i)^3)+(27.25*Inlet_T1(i)^2)-(14.83*Amb_T1(i)*Inlet_T1(i))-(35.89*Amb_T1(i)^2)-(717.6*Inlet_T1(i))+(825*Amb_T1(i))+6937) ……….. (29)

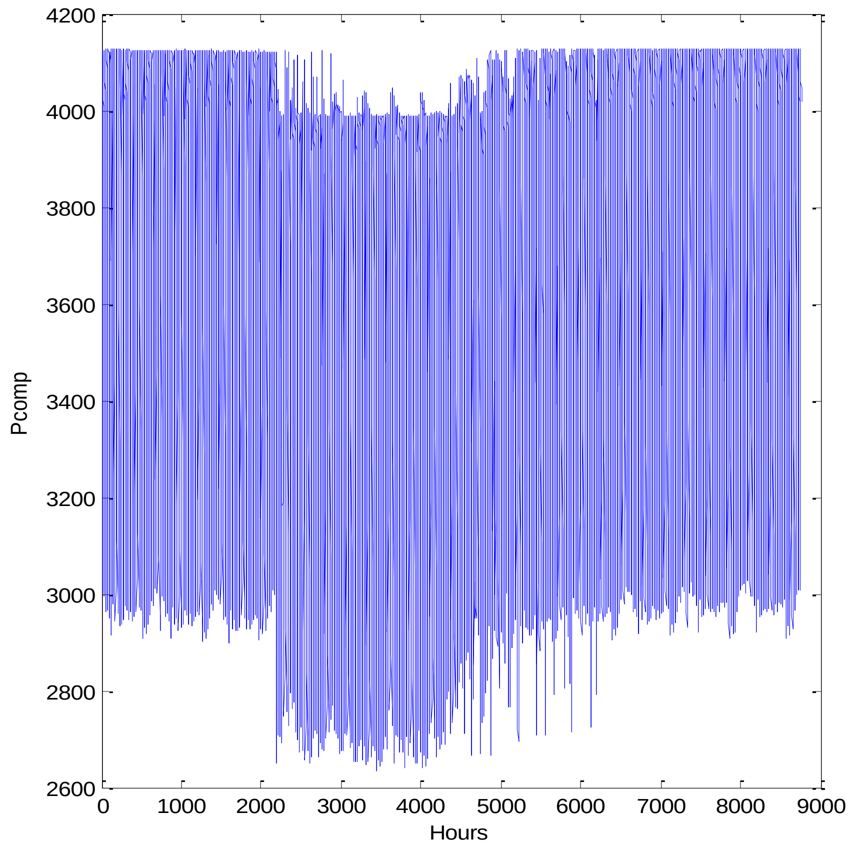

Figure 35 : Hourly compressor power generated for a year

CHAPTER 5

RESULT AND DISCUSSION

As the final intent of the study focuses on looking for a justifiable route to find a self- sustaining thermal system from which a certain necessarily required amount of thermal power will be retrieved to heat a domestic hot water, this section shows the results that have been possessed from the developed MATLAB code generated to give a direction as to what amount of thermal power is required and the corresponding number of thermal equipment that are capable of producing the required heat.

5.1 Available heat from the solar radiation

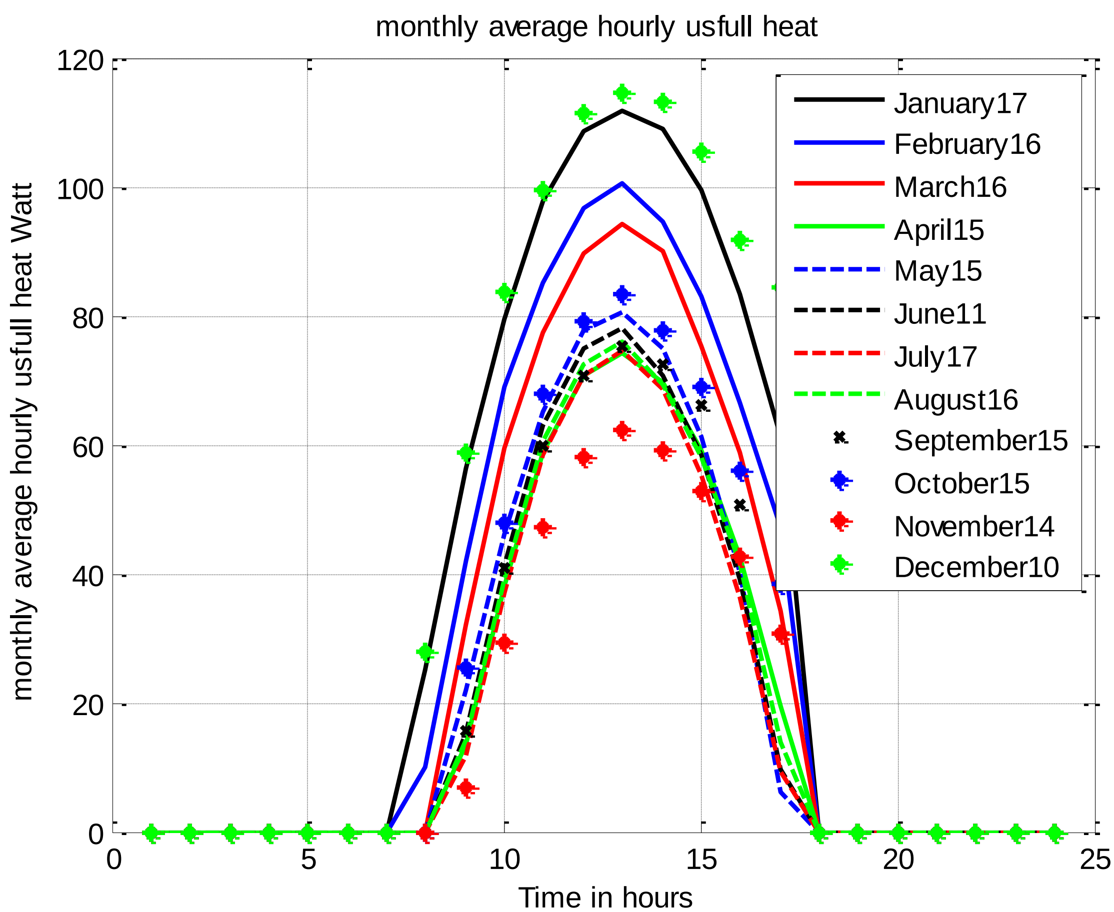

Figure 36 : Monthly average useful heats from solar radiation

The monthly average useful heat that uses the solar radiation as an input has shown that, throughout the day there will be an eminent increase in available heat till the vicinity of noon and decreasing accordingly before plummeting down to none just after the sun sets down. This shows the direct correspondence between existing useful heat and solar radiation.

5.2 Outlet water temperature from PVT and stored at tank 1

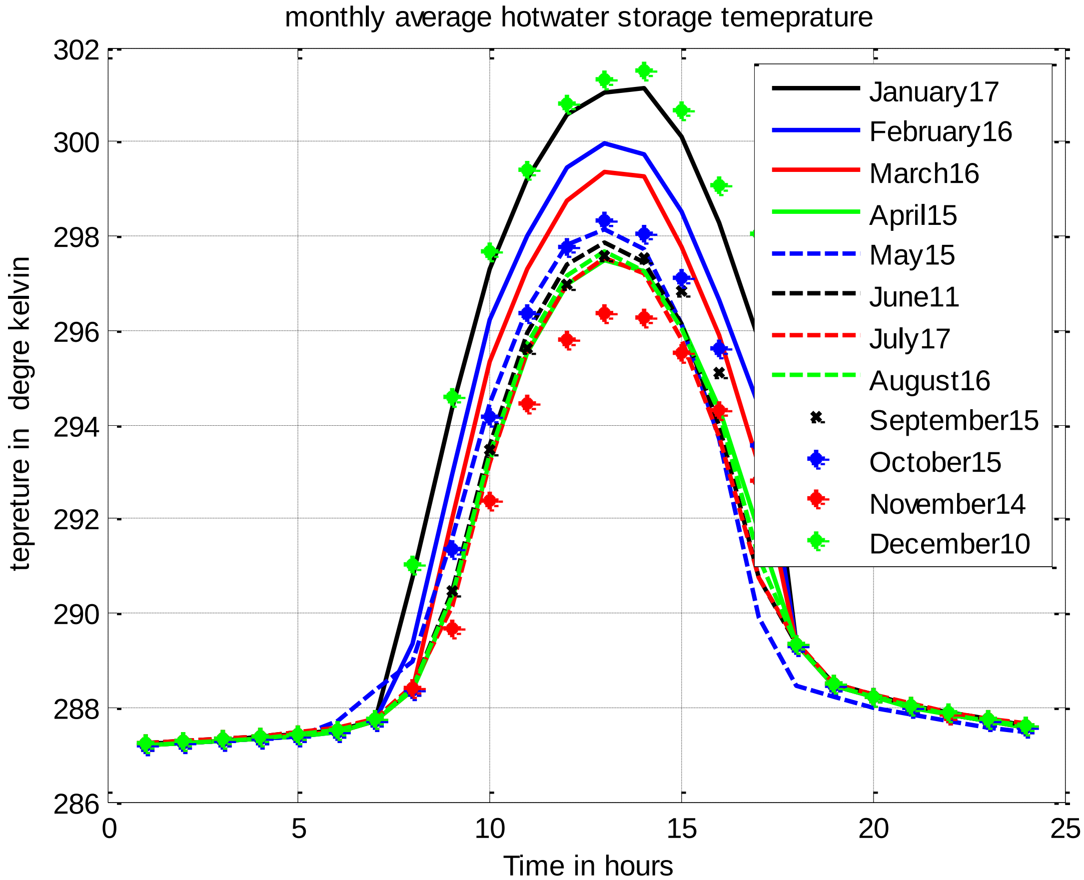

Figure 37 : Monthly average outlet water temperature

Similarly, the useful heat retrieved from both the solar beam and diffuse radiation has been utilized to heat the water running through the pipes fitted at the back of each panel. This figure has also shown a similar increase and decrease accordingly to that of the useful heat generated. Moreover, a maximum of water temperature equal to 301.8 K has been achieved that is still prone to increment after joining the air source heat pump fitted to the system.

5.3 Average storage tank 2 temperature

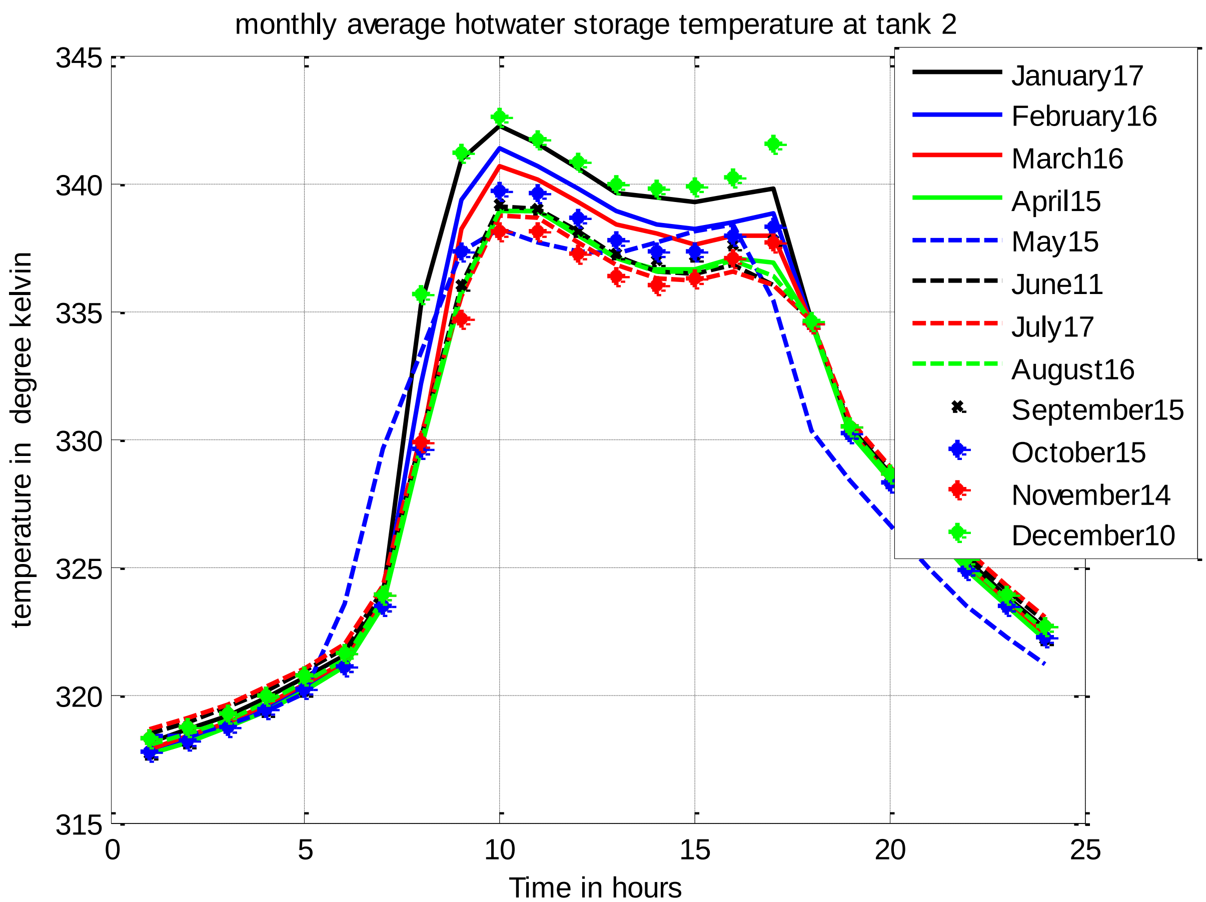

Figure 38 : Monthly average temperature at storage tank 2

Finally, the heat pump system has received the water temperature directly from storage tank 1 and utilized the ambient air and compressor power accordingly to generate the required increase in temperature expected for the domestic hot water need of the lodge. As it can clearly be seen in the figure above, the result which used the manufacturer data as a stand point in the necessary generation of the thermal power has an increase during the day time from eight in the morning to six in the evening, taking also into account the usage factor of the hot water users.

The result has vividly shown that the temperature at storage tank 2 is ranging between 318 k as minimum and 343 K as maximum which can be taken as an optimal increase in temperature for different requirements at the lodge, shower being the largest in magnitude for which the temperature is taken as more than enough. To increase the temperature to such range, ten equal magnitude heat pumps have been used each delivering the required thermal power and heating the warm water coming in from the PVT system. It should also be known that all the heat pumps perform in parallel fashion delivering to the same final storage tank from which the water will be distributed, storage tank 2.

5.4 Useful heat pump thermal power distribution

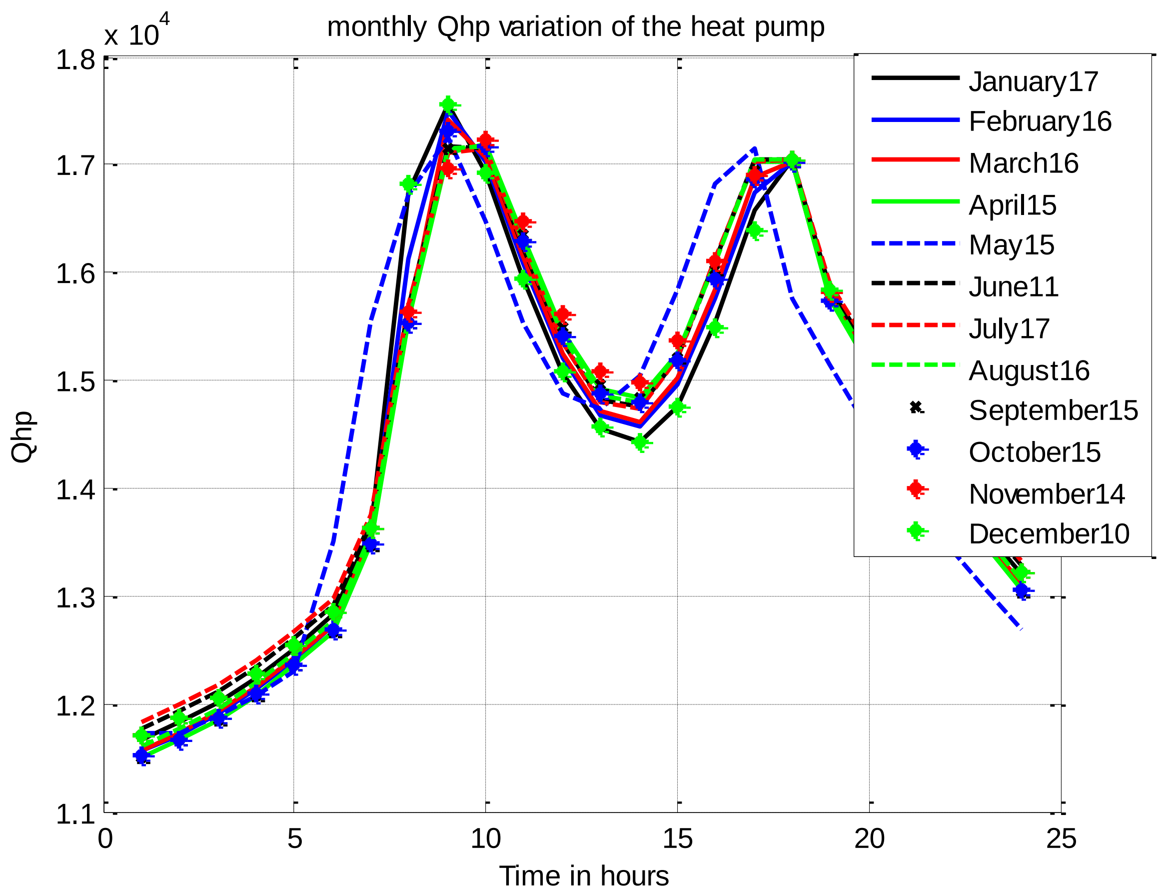

Figure 39 : Useful heat generated by the heat pump

The monthly useful heat pump thermal power generated has shown a remarkable increase in the vicinity where both the inlet water temperature and ambient temperature of the location have been able to come up with a justifiably high coefficient of performance and compressor power. As these points are purely the results of data retrieved from a manufacturer. The only changes seen are due to the two independent variables, Inlet water temperature getting into the system from storage tank 1 and corresponding ambient temperature of the location under study.

5.5 Average Electric output from the PV panel

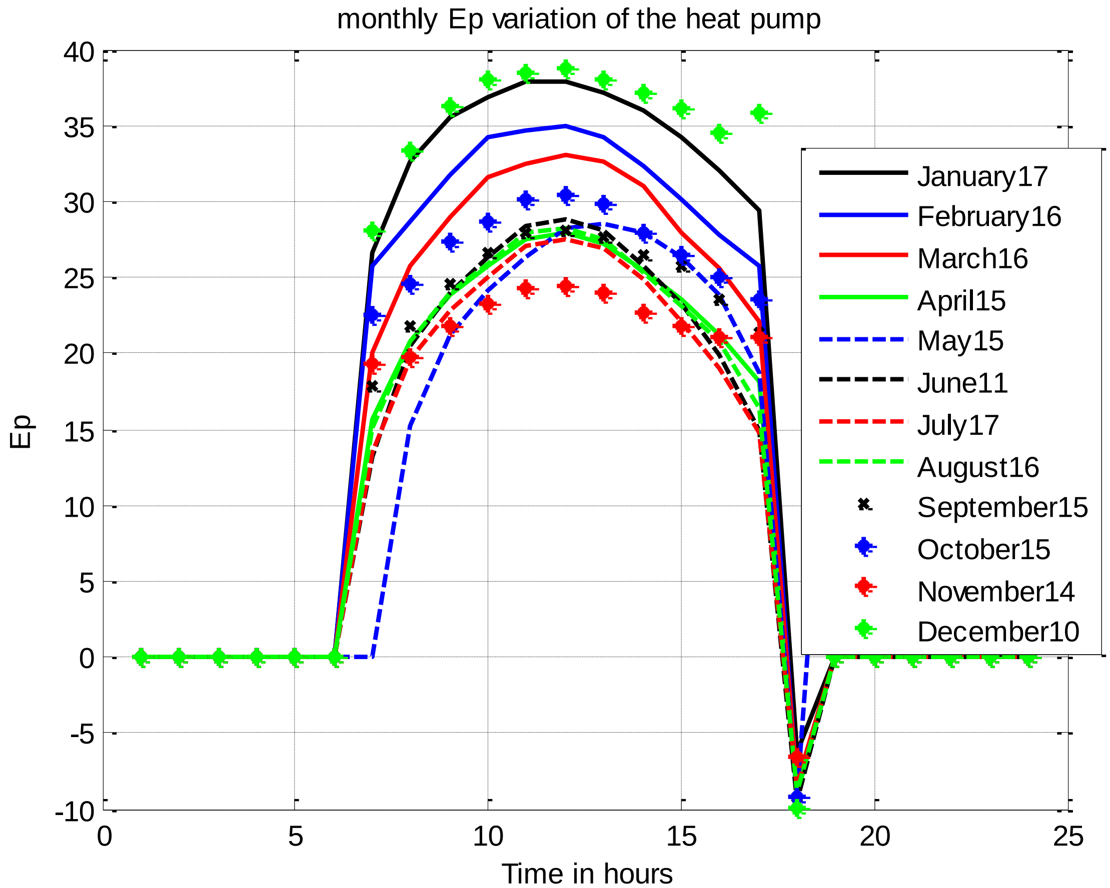

Figure 40 : Electric output from panel

Electric output from the panel has shown a maximum of 38 watts at its peak, directly corresponding to the solar radiation levels.

CHAPTER 6

CONCLUSION, RECOMMENDATION AND FUTURE WORK

6.1 Conclusion

It has been observed that using the ambient temperature and inlet water temperature as two independent inputs, the required domestic hot water property has been achieved. A total of ten heat pumps will run simultaneously to generate the necessary final water temperature at storage tank 2. The temperature in the tank has been shown to range between 318 K and 343 K which is known to be the optimal temperature for domestic hot water use including its potential to avoid the existence of deadly bacteria known to survive in temperatures below 315 K known as Legionella.

6.2 Recommendation

As a pivotal core of this study, the solar radiation has been used to come up with all the other required outputs. Added to this, the ambient temperatures have also played a vital role in defining the system. But it should be duly noted that, although the system has been seen to perform perfectly in the arrangement that it is current working at the site, the low remarkably low solar radiation and ambient temperature of the site have led for the increase in number of the heat pump to meet the required temperature. This entails, it would be much appropriate to use the system in areas where both the radiation level and ambient temperature is remarkably high.

6.3 Future work

The results retrieved from the analysis have more or less met the objective of the study, which was to increase temperature of the water to a level where it can be utilized for domestic hot water need of the location under analysis. But both in the process of this undertaking and its end result, there have been certain sections which have not been under reach due to differing reasons. And it's believed that these zones shall be of future study topics and would certainly add more sense and justification to this study. As part of the process of looking for the need to come up with an electric output from the PVT, an extensive study on the output from the location at hand and corresponding adjustment to at least self-sustain and meet the demands of the heat pump system is an important step forward.

Moreover, after an extensive energy auditing and budgeting of the site at hand, it would also be of a huge importance if future studies work on recommending the best energy system arrangement that would allow the site to use an all sustainable and renewable energy assembly without compromising the ever Increasing need of power.

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APPENDIX A
MATLAB CODES

A.1 Daily solar radiation MATLAB code

```
z = 2.424;       % elevation of the site above sea level
A=6.71;
phi= 3.14;
G = 1.367;          % solar constant
c='October.xlsx';
f=xlsread(c);
s=f(2,:);
n = 365;
decl = -9.6;
   %ws = 87.54
   ws=88.86;
 Td = 2/15*ws;
  a = -0.309 + 0.539*cos(A)-0.0693*(z)+ 0.290*(s/Td);
  r = 1.449-0.553*cos(A)- 0.694*(s/Td);
  Ho =
(24*G/phi)*(1+0.03*cos(360*n/365)*(cos(A)*cos(decl)*sin(ws)+(phi
*ws/180)*sin(A)*sin(decl)));
  for m=1:31
  H = Ho*(a+r*(G/Td));
  end
filename='October11.xlsx';
xlswrite(filename,H)
```

A.2 Daily diffuse radiation MATLAB code

```
z = 2.424;      % elevation of the site above sea level
A=6.71;
phi= 3.14;
e = 1.367;      %solar constant
u = 8.242;
c='April11.xlsx';
f=xlsread(c);
g=f(1,:);
n=1:29;
%wes = [87.54, 88.33, 89.71, 91.1, 92.3, 92.87, 92.6, 91.6,
90.26, 88.86, 87.7, 87.14];
decl = -9.4;
   ws = 91.1;
 Td = 2/15*ws;
  a = -0.309 + 0.539*cos(A)-0.0693*(z)+ 0.290*(u/Td);
  r = 1.449-0.553*cos(A)- 0.694*(u/Td);
  for n=1:30;
  Ho =
(24*e/phi)*(1+0.03*cos(360.*n/365)*(cos(A)*cos(decl)*sin(ws)+(ph
i*ws/180)*sin(A)*sin(decl)));
  H = Ho*(a+r*(g/Td));
  kt=H/Ho;
  Hd=1.311-3.022*kt+3.427*kt.^2-1.82*kt.^3;
  end
 filename='April2.xlsx';
xlswrite(filename,Hd)
```

A.3 COP and Compressor power calculation for every hour

```
clear all;
clc;
open='Hourly_TR.xlsx';
Z=xlsread(open);
c=Z(:,1);
open='Ts111.xlsx';
l=xlsread(open);
d=l(:,:);
Inlet_T1=l-273;
Amb_T1=c;
for i=1:8760
COP=((0.0002454*Inlet_T1(i)^3)+(0.000003505*Amb_T1(i)*Inlet_T1(i
)^2)-(0.0001003*Amb_T1(i)^2*Inlet_T1(i))-
(0.02849*Inlet_T1(i)^2)+(0.0009462*Amb_T1(i)*Inlet_T1(i))+(0.003
841*Amb_T1(i)^2)+(0.9857*Inlet_T1(i))+(0.03574*Amb_T1(i))-
7.206);
Pcomp=((-
0.3041*Inlet_T1(i)^3)+(0.1328*Amb_T1(i)*Inlet_T1(i)^2)+(0.1782*A
mb_T1(i)^2*Inlet_T1(i))+(0.4539*Amb_T1(i)^3)+(27.25*Inlet_T1(i)^
2)-(14.83*Amb_T1(i)*Inlet_T1(i))-(35.89*Amb_T1(i)^2)-
(717.6*Inlet_T1(i))+(825*Amb_T1(i))+6937);
COP_1(i)=COP;
Pcomp_1(i)=Pcomp;
Qhp= COP_1.*Pcomp_1;
end
  k = 'Total Heat Transfer.xlsx';
xlswrite(k,Qhp);
```

A.4 Hourly useful heat, radiation and heat pump performance

```
Ac=1.0;                              %Collector area
Acc1=105.0;    %Collector area, Mass flow rate correction factor
P=4.0;                                 %Collector perimeter
tbe=0.03;                              %Back insulation thickness
te=0.03;                               %Edge insulation thickness
de=0.05;                               %Depth of edge
E=0.88;                                %Emmisivity of glass
Ep=0.10;                               %Emmisivity of plate
Ki=0.045;                           %thermal conductivity of insulation
rho=0.2;                               %ground reflectivity factor
ff=[0,0,0,0,0,0.12,0.12,0.12,0.1,0,0.1,0.1,0.1,0,0,0,0,0.12,0.12
,0,0,0,0,0];
cpa=1.006;                              %heat capacity of air
Ka=0.0257;                             %thermal conductivity of air
mue=1.81e-5;                           %dynamic viscosity of air
sigma=5.67e-8;                        %Boltzman constant
Pabso=0.90 ;                          %absorbity of pv layer
Gtrans=0.96;                          %transmissivity of glass
S12=0.04;                             %distance b/n glass and plate
mcpa=1000;                            %mass* sp.heat of air
mcpp=6200;                           % Mass * Specific Heat of pv Plate
mcpc=5200;                            % Mass * Specific Heat of Plate
mcpg=5488;                            % Mass * Specific Heat of Glass
mcpw=5005;                            % Mass * Specific Heat of Water
mcps=98215;                            % Mass * Specific Heat of Water
Vw=2.4;                                %wind speed
beta=pi/12;                            %Collector  slope
phi=9.2*pi/180;                        %latitude
Pr=4.772;                              %Prandtl Number
Re=733;                                %Reynolds Number
```

```
sb=5.67*10.^-8;                 %Stefan-Boltzmann Constant
v=Pr*sb;                         %Viscosity
ka=0.026;                        %Thermal Conductivity of Air
kw=0.625;                        %Thermal Conductivity of Water
ki=0.045;                      %Thermal Conductivity of Insulation
ti=0.05;                         %Thickness of Insulation of Tank
Vs=1.0/Acc1;                     %Volume of Tank
Ls=nthroot(Vs,3);                %Length of one side of Tank
Rhow=998;                        %Density of Water
As=10.45;                       %Total Area of Tank
DWC=0.9/Acc1;                  % daily water consumption m3
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Tgoo=Tao+3;                         %initial glass temperature
Tpoo=Tao+10;                        %initial pvplate temperature
Taoo=Tao;
Tcoo=Tao+12;                   %initial obsorber plate temperature
Twoo=Tao-2;                    %initial obsorber water temperature
Ttoo=Tao+0.5;                  %initial heat pipe wall temperature
Tiioo=Tao;                     %initial insulation temperatue
Twio=Tao+10;                   %initial inlet water temperatue
Twolo=Tao+2;                   %initial exit  water  temperature
Taolo=Tao-0.5;
Twi0=12+273;                   %Temperature of Inlet Water
Two0=12.25+273;                %Temperature of Outlet Water
Ts0=25.5+273;                          %Temparature of Tanker
deltt=60;                             %time step ?????
tgab=0.9;                %transmitivit -absorbitivity of basebored
Bp=0.88;                               %packing factor
Bpv=0.8;                               %factor of pv layer
tabp=0.87;                 %transmitivit -absorbitivit of pv layer
NMEF=0.155;                          % nominal efficincy of the pv
```

```
Trc=300;                                    % referance tempretur of th
W=0.01;                          %center to center distance of pipe tube
D=0.019;                                      %outer diamter pipe
b=0.001;                 %center to center distance from finplat to pipe
d=0.016;                               %inner diamter of the pipe
h=0.003;
tk=0.003;                                    %tickness area of the pv
Ap=0.78;                                     %absorbing area of the pv
no=8;                                        %number of risers
Lr=10;                                       % lengeth of the pipe
L=1;
hkc_p=235;                                %conductive heat transfer
cofficinent between solar plat and pv layer
Rp_f=0.0035;
%=tkp/kp.*Ap+tkEVA/KEVA+thei/keiAP;
Al=P*de;                          %collector perimeter*depth of the edge
Upab=Ki/tbe;                      %bottom heat transfer coefficient
Upae=Upab*(Al/Ac);                %eadge heat transfer coeffiient
hc=2.8+3*Vw;             %convective heat transfer b/n glass and ambient
Adens=1.226;                                %density of air
nue=mue/Adens;                             %kinematic viscosity of air
Pr=0.72;                  %Prantdl number taken at the initial condition
tgap= 0.6;
Apt =pi*no*D*L/4;
At=0.005;
Tso=283;
Ts2o=288;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
cpw= 4187;                                     %spesific heat of water
refcpftf=485;                    %density*spesific heat of fin*thickness
Rf_hp=1.15;              %overall resistance form  fin shit to heat pipe
```

```
Rf_a=1.15;          %overall resistance form  fin shit to ambient
Afc =0.0011136;     %central fin area
Afs =0.31136;       %insulated area around fin area
hf=12;
open=('Data9.xlsx');
Z=xlsread(open);

for j=1:365
    data1(:,:,j)=Z(j+(23*(j-1)):j*24,:);   %Data given for the
end

for n=1:365
    decl(n)=(pi/180)*(23.45*sin((2*pi/365)*(284+n)));   %
Calculation of the declination angle )))
end

for  ii=1:24
    omega(ii)=(ii-12)*pi/12;          % Calculation of the hour
angle for each hour of the day. )))
end

%Epg=1/((1/Ep)+(1/Eg)-1);          %overall emittance factor

% This approximate the plate, glass, and exit temperature for
Jan.01 at 1:00AM.

for i=1
    Grr=data1(:,1,i);
    Drr=data1(:,2,i);
    Taa=data1(:,3,i);
    for j=1
        Gr=Grr(1);
```

```
        Dr=Drr(1);
        T=Taa(1);
        Ta=T+273;
        Taio=Ta;
        Rb=((cos(phi-
beta))*cos(decl(i))*cos(omega(j))+sin(decl(i))*(sin(phi-
beta)))/(cos(phi)*cos(decl(i))*cos(omega(j))+(sin(decl(i))*sin(p
hi)));
        In=Rb*(Gr-Dr)+(Dr*0.5*(1+cos(beta)))+(0.5*rho*((1-
cos(beta))*Gr));
        Ic=In*(Pabso*Gtrans);
        Tf=(Taolo+Taio)/2;
% Film Temperature
        Vbeta=2/(Taolo+Taio);
% the volume expansion coeffcent
        GrL=(9.81*Vbeta*abs(Tpoo-Tgoo)*(S12^3))/(nue^2);
% Grashoffs Number
        Ua=0.664*(Ka/S12)*((Pr*GrL*cos(beta))/(Pr+0.9524))^0.25;
% overhall heat transfer cofficenet of the air
        Upg=((0.06-
(0.017*(2*beta/pi)))*(Ka/S12)*(GrL^(1/3)))+(Epg*sigma*(((Tpoo)^2
)+((Tgoo)^2))*((Tpoo)+(Tgoo)));
        Tsky=Tao-6;
% sky temprature of the selected site
        hr=Eg*sigma*(((Tgoo)^4)-((Tsky)^4))/(Tgoo-Tsky);
% the radiational heat transfer cofficenet from the glass
        Uga=hc+hr;
% overhall heat transfer cofficenet between the glass and
atmosphre
        Dm=(Ua/cpa)*Ac;
        %   mass flow rateUpab=ki./tb;
```

```
        Upae=ki./te;
% overhall heat transfer cofficenet insulation eage
        Ulss=10;
        Uls=ki./ti;
% overhall heat transfer cofficenet total surface storage
        hkc_p=265;
% conductive  heat transfer cofficenet between pv layer to heat
observer plate
        hkc_t=225;
%conductive  heat transfer cofficenet of the fin  between the
coper pipe and obserber plateo heat observer plate
        hvt_f=150;
        Raw=12;
        Aw=0.0008;
% the crossectional area of the unit riser
        hw=15;
        Tpm = 30 + 0.0175.*(Ic-150) + 1.14*(Ta -25);
% mean tempreture of the pv layer
        df =(Tpm-Trc);
        E=Ic.*tabp.*Bp.*NMEF*((1-Bpv).*df);
% the amount of electrical energy per meter square
        Tpl=(deltt*Ac*Ic/mcpp)+(Tpoo)-
((deltt*Ac*Upg/mcpp)*(Tpoo-Tgoo))-E-((Ac*Upab/mcpp)*(Tpoo-
Tao)*deltt)-((Al*Upae/mcpp)*(((Tpoo+Tao)/2)-Tao)*deltt);
        Tgl=((deltt*Ac*In*(1-Gtrans))/mcpg)+((1-
((deltt/mcpg)*(Ac*Upg+Ac*Uga)))*(Tgoo))+
((deltt*Ac*Upg/mcpg)*(Tpoo))+((Ac*Uga/mcpg)*deltt*(Tao));
        Taoll=((1-
((deltt/(mcpa))*(Ac*Ua+Dm*cpa)))*(Taolo))+(((deltt/(mcpa))*(Dm*c
pa-
Ac*Ua))*(Taio))+((Ac*Ua/(mcpa))*deltt*(Tpoo))+((Ac*Ua/(mcpa))*de
ltt*(Tgoo));
```

```
        Tcl=(Tcoo)+((deltt*Ac*hkc_p/mcpc)*(Tpoo-
Tcoo))+((Ac/mcpc)*Apt/Ap*hkc_t*(Ttoo-Twoo)*deltt);
        Twl=(deltt*Ac/mcpw)*(Taoo-Twoo)/Raw-
((deltt*Ac*Aw*hw/(At*mcpw))*(Tcl-Twio))+(Twoo);

        %===ANALYSIS OF THE STORAGE TANK==============
        mdot=Aw*0.02*4180;
        s1=1-As.*Uls.*deltt./(Rhow.*cpw.*Vs);
        s2=0.4*(mdot.*deltt./(Rhow.*cpw.*Vs));
        s3=As.*Uls.*deltt./(Rhow.*cpw.*Vs);
        Tsi=s1.*Ts0+s2.*Ts0+s2.*(Two0-Twi0)+s3.*Ta;
        Twi=(Twi0+Twl)./2;
        Two=(Two0+Twl)./2;
        Ts=(Ts0+Tsi)./2;
        Ta=Tao;
    end
end

%Main Program
Tpo=(Tpl+Tpoo)/2;
Tgo=(Tgl+Tgoo)/2;
Tco=(Tcl+Tcoo)/2;
Two=(Twl+Twoo)/2;
Tao0=(Taoll+Taolo)/2;
Tiio=Tiioo+6;

Rb11=zeros(365,24);
It11=zeros(365,24);
Tp11=zeros(365,24);
Pac11=zeros(365,24);

for i=1:365
```

```
    Grr=data1(:,1,i);
    Drr=data1(:,2,i);
    Taa=data1(:,3,i);
    for j=1:24
        Gr=Grr(j);
        Dr=Drr(j);
        T=Taa(j);
        Ta=T+273;
        Taio=Ta;

        Rb=((cos(phi-
beta))*cos(decl(i))*cos(omega(j))+sin(decl(i))*(sin(phi-
beta)))/(cos(phi)*cos(decl(i))*cos(omega(j))+(sin(decl(i))*sin(p
hi)));
        In=Rb*(Gr-Dr)+(Dr*0.5*(1+cos(beta)))+(0.5*rho*((1-
cos(beta))*Gr));
        Ic=In*(Pabso*Gtrans);


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%

        for jj=1:60

            Tf=(Tao0+Taio)/2;
% Film Temperature
            Vbeta=2/(Tao0+Taio);
% the volume expansion coeffcent
            GrL=(9.81*Vbeta*abs(Tpo-Tgo)*(L^3))/(nue^2);
% Grashoffs Number

Ua=0.664*(Ka/L)*((Pr*GrL*cos(beta))/(Pr+0.9524))^0.25;
```

```
            Upg=((0.06-
(0.017*(2*beta/pi)))*(Ka/S12)*(GrL^(1/3)))+(Epg*sigma*(((Tpo)^2)
+((Tgo)^2))*((Tpo)+(Tgo)));
            Tsky=Ta-6;
            hr=Eg*sigma*(((Tgo)^4)-((Tsky)^4))/(Tgo-Tsky);
            Uga=(hc+hr);
            Dm=(Ua/cpa)*Ac;
% Mass Flow Rate
            Tpm = 30 + 0.0175.*(Ic-150) + 1.14*(Ta -25);
            df =(Tpm-Trc);
% mean tempreture of the pv layer
            Twi =273+12;
%inlet  water tempreture
            Acc= no*W*Lr;
%area of the collector pipe
            Ul=Uga+Upab+Upae;
%total heat loss
            m=(Ul/h*tk)^2;
            cb=167;
% thermal  conductance  of  the  bond
            Tws=288;
            w=0.015;
                Fe=tanh(m*(W-D)/2)/(m*(W-D)/2);
            zzz=1/Ul;
            zz=1/(Ul*(W-b)*Fe);
            zx=(1/cb);
            zc=(1/(pi*d*hf));
            fpr=zzz/(W*(zz+zx+zc));
            Ep=Ic*tabp*Bp*NMEF*((1-0.0045*(Tpm-Trc)));
            Eff=tabp*Bp*NMEF*((1-0.0045*(Tpm-Trc)));
            fr=Ic*cpw/Ul;
            see=(1-exp(-Ul*fpr/Ic*cpw));
```

```
            %Glass Temperature
            Tg1=((deltt*Ac*In*(1-Gtrans))/mcpg)+((1-
((deltt/mcpg)*(Ac*Upg+Ac*Uga)))*(Tgo))+((deltt*Ac*Upg/mcpg)*(Tpo
))+((Ac*Uga/mcpg)*deltt*(Ta));
            %Pv layer  Temperature
            Tp1=(deltt*Ac*Ic/mcpp)+(Tpo)-
((deltt*Ac*Upg/mcpp))*(Tpo-Tg1)+((Ac*hkc_p/mcpp)*(Tpo-
Tco)*deltt)-((Al*Upae/mcpp)*(((Tpo+Ta)/2)-(Ta))*deltt)-E;
            %Ee=NMEF*(1-0045*(Tp1-25));
            %cover plate tempreture
            Tcl=(Tco)+((deltt*Ac*hkc_p/mcpc)*(Tp1-
Tco))+((deltt*Apt*hkc_t)*(Tco-Twi)/mcpc);
            %Tcml=((deltt*Ac*Apt*hvt_f/(At*mcpt))*(Tto-Two));
            Taol=((1-
((deltt/(mcpa))*(Ac*Ua+(Dm*cpa))))*(Tao0))+(((deltt/(mcpa))*(Dm*
cpa-
Ac*Ua))*(Taio))+((Ac*Ua/(mcpa))*deltt*(Tpo))+((Ac*Ua/(mcpa))*del
tt*(Tgo));
            Qau=((W-D)*Fe+D)*((Ic*(tgab)-Ul.*(Twl-Ta)-Eff*Ic));
            mdot=0.002;
            Qu=Ac*(fpr*(Ic*(tgab)-Ul*(Tp1-Ta)));
            theeff=Ac*mdot*(cpw*(Twl-Two))/Qu;
            if Qu< 0
               Qu=0;
            end

            %ANALYSIS OF THE STORAGE TANK
            Tw1=Tao+Qu/Ulss+exp(-Ulss*Ac*fpr/mdot*cpw)*(Twi-Ta-
Qu/Ulss);


                Aload=(Rhow*cpw*DWC*ff(j)*(Tw1-Tws))/60;
```

```
                a11=Tw1-Twi;
                A11=mdot*cpw.*a11;
                %  if Tw1 < 320;
                %      mdot=0.002;
                %  else
                %      modt=0.002:0.01:0.04;
                %  end
                A12=Uls*As*(Ts-Ta)*60;
                A11=mdot*cpw*(Tw1-Twi)*60;
                A13=(A11-Aload-A12);
                Ts=Tw1+deltt/mcps*A13;
                A22=Uls*As*(Tws-Ta)*60;
                Ts1=Tw1+deltt/mcps*A13;

        end
        % Main program for storage tank 2
        Ts11=Ts1-273;
        T1=T+273;
        Rho=998;
        Cpw=4187;
        Ts2o1=Ts1;
        COP=((0.0002454*Ts11^3)+(0.000003505*T*Ts11^2)-
(0.0001003*T^2*Ts11)-
(0.02849*Ts11^2)+(0.0009462*T*Ts11)+(0.003841*T^2)+(0.9857*Ts11)
+(0.03574*T)-7.206);
        Pcomp=((-
0.3041*Ts11^3)+(0.1328*T*Ts11^2)+(0.1782*T^2*Ts11)+(0.4539*T^3)+
(27.25*Ts11^2)-(14.83*T*Ts11)-(35.89*T^2)-
(717.6*Ts11)+(825*T)+6937);
        Qhp= COP*Pcomp;
        Ts2= Ts2o1+((10.*Qhp)-ff(j)*DWC*Acc1*Cpw*(Ts2o1-Ts1)-
Uls*As*(Ts2o1-T1))/(DWC*Acc1*Cpw);
```

```
        Ts2o1=Ts2;
        % The mass flow rate, plate temperature, glass
temperature,and exit air temperature for each day of the year
        %are stored as;
        Rb11(i,j)=Rb;
        Eff111(i,j)=Eff;
        Qu111(i,j)=Qu;
        Tc111(i,j)=Tcl;
        Tw111(i,j) =Tw1;
        Ts111(i,j) =Ts1;
        Ts222(i,j)=Ts2;
        COP_1(i,j)=COP;
        Pcomp_1(i,j)=Pcomp;
        Qhp_1(i,j)=Qhp;
        Ep_1(i,j)=Ep;
    end
end
QulJ17=Qu111(17,:);QulF16=Qu111(47,:); QulM16=
Qu111(75,:);QulA15=Qu111(105,:); QulM15=Qu111(135,:);
QulJ11=Qu111(162,:);QulJu17=Qu111(198,:); QulA16=Qu111(228,:);
QulS15=Qu111(258,:);QulOct15=Qu111(288,:);QulN14=Qu111(318,:);Qu
lD10=Qu111(344,:);
jj=1:24;
x = 'Ts111.xlsx';
xlswrite(x,Ts111);
% Plots mean monthlly solar irradiance arrive to pv module
plot(jj,QulJ17,'k-',jj,QulF16,'b-',jj,QulM16,'r-',jj,QulA15,'g-
',jj,QulM15,'b--',...
    jj,QulJ11,'k--',jj,QulJu17,'r--',jj,QulA16,'g--
',jj,QulS15,'k x',jj,QulOct15,'b*',...
    jj,QulN14,'r*',jj,QulD10,'g*','linewidth',2);
xlabel(' Time in hours')
```

```
ylabel(' monthly average hourly usful heat in Watt')
title('monthly average hourly useful heat ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
pause
clf
TclJ17=Tc111(17,:);TclF16=Tc111(47,:);TclM16=
Tc111(75,:);TclA15=Tc111(105,:);...

TclM15=Tc111(135,:);TclJ11=Tc111(162,:);TclJu17=Tc111(198,:);Tcl
A16=Tc111(228,:);...

TclS15=Tc111(258,:);TclO15=Tc111(288,:);TclN14=Tc111(318,:);TclD
10=Tc111(344,:);...
    TclOct15=Tc111(288,:);

jj=1:24;

plot(jj,TclJ17,'k-',jj,TclF16,'b-',jj,TclM16,'r-',jj,TclA15,'g-
',jj,TclM15,'b--',...
    jj,TclJ11,'k--',jj,TclJu17,'r--',jj,TclA16,'g--
',jj,TclS15,'k x',jj,TclOct15,'b*',...
    jj,TclN14,'r*',jj,TclD10,'g*','linewidth',2);
xlabel(' Time in hours')
ylabel(' collector temperature in degree kelvin')
title('monthly average collector temperature ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....
```

```
'August16','September15','October15','November14','December10')
grid on
pause
clf

TwlJ17=Tw111(17,:);TwlF16=Tw111(47,:);TwlM16=Tw111(75,:);TwlA15=
Tw111(105,:);....
    Ts2M15=Tw111(135,:);TwlJ11=Tw111(162,:);
TwlJu17=Tw111(198,:);TwlA16=Tw111(228,:);....

TwlS15=Tw111(258,:);TwlO15=Tw111(288,:);TwlN14=Tw111(318,:);TwlD
10=Tw111(344,:);
TwlOct15=Tw111(288,:);

jj=1:24;

% Plots mean monthly water temperature

plot(jj,TwlJ17,'k-',jj,TwlF16,'b-',jj,TwlM16,'r-',jj,TwlA15,'g-
',jj,Ts2M15,'b--',...
    jj,TwlJ11,'k--',jj,TwlJu17,'r--',jj,TwlA16,'g--
',jj,TwlS15,'k x',jj,TwlOct15,'b*',...
    jj,TwlN14,'r*',jj,TwlD10,'g*','linewidth',2);
xlabel(' Time in hours')
ylabel('   temperature in  degree kelvin')
title('monthly average outlet water temperature ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
```

```
pause
clf
jj=1:24;
% Plots average monthly hot water storage tank  1 temperature
Ts1J17=Ts111(17,:);Ts1F16=Ts111(47,:);Ts1M16=Ts111(75,:);Ts1A15=
Ts111(105,:);....
    Ts1M15=Ts111(135,:);Ts1J11=Ts111(162,:);
Ts1Ju17=Ts111(198,:);Ts1A16=Ts111(228,:);....

Ts1S15=Ts111(258,:);Ts1O15=Ts111(288,:);Ts1N14=Ts111(318,:);Ts1D
10=Ts111(344,:);
Ts1Oct15=Ts111(288,:);
plot(jj,Ts1J17,'k-',jj,Ts1F16,'b-',jj,Ts1M16,'r-',jj,Ts1A15,'g-
',jj,Ts1M15,'b--',...
    jj,Ts1J11,'k--',jj,Ts1Ju17,'r--',jj,Ts1A16,'g--
',jj,Ts1S15,'k x',jj,Ts1Oct15,'b*',...
    jj,Ts1N14,'r*',jj,Ts1D10,'g*','linewidth',2);
xlabel(' Time in hours')
ylabel('   tepreture in  degre kelvin')
title('monthly average hotwater storage temeprature ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
pause
clf
jj=1:24;
% Plots average  monthly hot water storage tank  2 temperature
Ts2J17=Ts222(17,:);Ts2F16=Ts222(47,:);Ts2M16=Ts222(75,:);Ts2A15=
Ts222(105,:);....
```

```
    Ts2M15=Ts222(135,:);Ts2J11=Ts222(162,:);
Ts2Ju17=Ts222(198,:);Ts2A16=Ts222(228,:);....

Ts2S15=Ts222(258,:);Ts2O15=Ts222(288,:);Ts2N14=Ts222(318,:);Ts2D
10=Ts222(344,:);
Ts2Oct15=Ts222(288,:);
plot(jj,Ts2J17,'k-',jj,Ts2F16,'b-',jj,Ts2M16,'r-',jj,Ts2A15,'g-
',jj,Ts2M15,'b--',...
    jj,Ts2J11,'k--',jj,Ts2Ju17,'r--',jj,Ts2A16,'g--
',jj,Ts2S15,'k x',jj,Ts2O15,'b*',...
    jj,Ts2N14,'r*',jj,Ts2D10,'g*','linewidth',2);
xlabel('Time in hours')
ylabel('temperature in  degree kelvin')
title('monthly average hotwater storage temperature at tank 2')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
pause
clf
jj=1:24;
% Plots Qhp of the heat pump for different months
QhpJ17=Qhp_1(17,:);QhpF16=Qhp_1(47,:);QhpM16=Qhp_1(75,:);QhpA15=
Qhp_1(105,:);....
   QhpM15=Qhp_1(135,:);QhpJ11=Qhp_1(162,:);
QhpJu17=Qhp_1(198,:);QhpA16=Qhp_1(228,:);....

QhpS15=Qhp_1(258,:);QhpO15=Qhp_1(288,:);QhpN14=Qhp_1(318,:);QhpD
10=Qhp_1(344,:);
QhpOct15=Qhp_1(288,:);
```

```
plot(jj,QhpJ17,'k-',jj,QhpF16,'b-',jj,QhpM16,'r-',jj,QhpA15,'g-
',jj,QhpM15,'b--',...
    jj,QhpJ11,'k--',jj,QhpJu17,'r--',jj,QhpA16,'g--
',jj,QhpS15,'k x',jj,QhpO15,'b*',...
    jj,QhpN14,'r*',jj,QhpD10,'g*','linewidth',2);
xlabel(' Time in hours')
ylabel('Qhp')
title('monthly Qhp variation of the heat pump ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
pause
clf
jj=1:24;
% Plots Ep of the heat pump for different months
EpJ17=Ep_1(17,:);EpF16=Ep_1(47,:);EpM16=Ep_1(75,:);EpA15=Ep_1(10
5,:);....
   EpM15=Ep_1(135,:);EpJ11=Ep_1(162,:);
EpJu17=Ep_1(198,:);EpA16=Ep_1(228,:);....

EpS15=Ep_1(258,:);EpO15=Ep_1(288,:);EpN14=Ep_1(318,:);EpD10=Ep_1
(344,:);
EpOct15=Ep_1(288,:);
plot(jj,EpJ17,'k-',jj,EpF16,'b-',jj,EpM16,'r-',jj,EpA15,'g-
',jj,EpM15,'b--',...
    jj,EpJ11,'k--',jj,EpJu17,'r--',jj,EpA16,'g--',jj,EpS15,'k
x',jj,EpO15,'b*',...
    jj,EpN14,'r*',jj,EpD10,'g*','linewidth',2);
xlabel(' Time in hours')
ylabel('Ep')
```

```
title('monthly Ep variation of the heat pump ')
legend('January17','February16','March16','April15','May15','Jun
e11','July17',.....

'August16','September15','October15','November14','December10')
grid on
```

APPENDIX B
DATA COLLECTION FORM

B.1 General proposed Site data collection form

Data Collection Form

General

1. Heating (Domestic hot water) demand of the rooms

   1.1 Number of rooms ______

   1.2 Arrangement of rooms

   1.2.1 Distance between rooms and corresponding reservoir

No	Room number (description)	Room number (description)	Distance	From Reservoir
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Sketch of the arrangement and layout of the room

1.2.2 Elevation difference between rooms

No	Room number (description)	Room number (description)	Elevation	From Reservoir
1				
2				
3				
4				
5				
6				
7				
8				
9				

10				

2. Electricity Demand and situation

2.1 Gadgets and units utilized and corresponding number

Room No 9			
No	Description	Qty	Working Hours
1	Bulb		
2	Tea Maker		
3	Sockets		
4	Boiler		
Room No 4,5,6 & 8			
1	Heat Pump		
2	Pressure valve (???)		
3	Bulb		
4	Socket		
5	Tea Maker		
Room No 7			
1	Heat Pump		
2	Pressure valve (???)		
3	Bulb		
4	Socket		
5	Tea Maker		
Room No 1,2 & 3			
1	Bulb		
2	Socket		
3	Tea maker		
4	**Heat pump**		
Kitchen			
1	Fridge		
2	Bulb		
3	Ice cream machine		
4	Baker mixer		
5	Cheese/Beef Slicer		
6	Juice Maker		
7	Microwave		
8	Tea Maker		
9	Canopy size ----(estimate size of Fan)		
Guest center + Restaurant			
1	Water filter		
2	Fridge		
3	Bulb		
4	Socket		
Outside (Reception)			

1	Bulb		
Security office			
1	Bulb		
2	Socket		
Administrative Staff section (x 3)			
1	Bulb		
2	Socket		
3	Boiler		
Staff Section			
1	Bulb		
1	Socket		
3	TV		
Laundry Room			
1	Washing Machine		
2	Iron		
3	Drier + bulb		
Auxiliary			
1	Power Hacksaw		
2	Pump		
3	Electric Blanket (Total)		
Miscellaneous			

No	Description	Model No & Details	Size/ Capacity
1	Heat Pump		
2	Pressure valve (???)		
2	Boiler		
3	Heat pump (1-3)		
4	Ice cream machine		
5	Baker mixer		
6	Cheese/Beef Slicer		
7	Juice Maker		
8	Washing Machine		
9	Iron		
10	Drier		
11	Power Hacksaw		
12	Pump		
13	Electric Blanket		

2.2 Source of the existing power system --------------------------------

2.2.1 Total power generated by the unit

3. PVT – System installation site selection ***

4. Type of Heat pump ________
   4.1 Number of Heat pumps _________
   4.2 Model of Heat pumps _______
   4.3 Working mechanism of the existing HP system

Technical

1. Temperature and mass flow rate of Refrigerator at evaporator
   1.1 Temperature at evaporator inlet ____________
   1.2 Temperature at evaporator outlet ____________
   1.3 Mass flow rate at evaporator inlet ____________
   1.4 Mass flow rate at evaporator outlet ____________
2. Temperature and mass flow rate of Refrigerator at Condenser
   2.1 Temperature at condenser inlet ____________
   2.2 Temperature at condenser outlet ____________
   2.3 Mass flow rate at condenser inlet ____________
   2.4 Mass flow rate at condenser outlet ____________
3. Ambient Temperature of the location _16.5^{o}c (11:00 AM), 20^{o}c (11;05 AM), 23.5^{o}c (11:25 AM)
4. Temperature and mass flow rate of water
   4.1 Temperature at condenser inlet ____________
   4.2 Temperature at condenser outlet ____________
   4.3 Mass flow rate at condenser inlet ____________
   4.4 Mass flow rate at condenser outlet ____________
5. Quantity of water consumed by a single room ____________
6. Total quantity of water stored in the reservoir ____________
7. Wind speed ______0.96,2,2.1 (m/s)____
8. Surface temperature 24 ^{o}c, 25 ^{o}c (11:20 AM), 26^{o}c (11:25 AM)

B.2 Final data collected and corresponding format

Room No 9			
No	Description	Qty	
1	Bulb	21	
2	Tea Maker	1	
3	Sockets	16	
4	Boiler		
Room No 4,5,6 & 8			
1	Heat Pump	1	
2	Pressure valve (???)	1	
3	Bulb	8	
4	Socket	3	
5	Tea Maker	2	
Room No 7			
1	Heat Pump	1	
2	Pressure valve (???)	1	
3	Bulb	7	
4	Socket	5	
5	Tea Maker	2	
Room No 1,2 & 3			
1	Bulb	9	
2	Socket	3	
3	Tea maker	1	
4	**Heat pump**	1	
Kitchen			
1	Fridge	3	
2	Bulb	11	
3	Ice cream machine	1	
4	Baker mixer	1	
5	Cheese/Beef Slicer	1	
6	Juice Maker	1	
7	Microwave	1	
8	Tea Maker	1	
9	Canopy size ----(estimate size of Fan)	1.5 x 2.7 meters	
Guest center + Restaurant			
1	Water filter	1	
2	Fridge	2	
3	Bulb	25	
4	Socket	15	
Outside (Reception)			
1	Bulb	19	
Security office			
1	Bulb	1	

2	Socket	1	
Administrative Staff section (x 3)			
1	Bulb	4	
2	Socket	3	
3	Boiler	1	
Staff Section			
1	Bulb	25	
1	Socket	25	
3	TV	2	
Laundry Room			
1	Washing Machine	1	
2	Iron	1	
3	Drier	1	
Auxiliary			
1	Power Hacksaw	1	
2	Pump	1	
3	Electric Blanket (Total)	7	
Miscellaneous			

No	**Description**	**Model No & Details**	**Size/ Capacity**
1	Heat Pump	Gruppo Giona (Furora 080)	Max T - 95^{o}c, P= 0.6 MPa,
2	Pressure valve (???)	Zilmet (130 – CAL – PRO)	
2	Boiler	Florence, Ariston x 3,	50 L
3	Heat pump (1-3)	Gruppo Giona (HP 300)	2.05 KW
4	Ice cream machine	Musso (Mod. L2)	
5	Baker mixer	Baker Mix (Mix 80)	
6	Cheese/Beef Slicer	Type 250	0.154 KW
7	Juice Maker	Robot coupe R301 Ultra	
8	Washing Machine	Hlier (HWM 150 – 0623s)	
9	Iron	Russel Hobbs (M.No – 18742)	
10	Drier		
11	Power Hacksaw	Bosch (M.No – GCM 10 J)	
12	Pump	PERDROLLO (CPM – 170)	1.1 KW/ 1.5 HP

1.1 Source of the existing power system Micro Hydro Power plant

1.1.1 Total power generated by the unit 25 KW

2. PVT – System installation site selection *** (Selected)
3. Type of Heat pump ____known____

3.1 Number of Heat pumps ___6______

3.2 Model of Heat pumps ____known____

3.3 Working mechanism of the existing HP system

Generator = Yanmar, TS 190R, Continuous = 16 HP, Maximum 19 HP

B.3 AC Synchronous generator at the site

Figure 41 : synchronous generator attached to the cross flow turbine

APPENDIX C

C.3 Domestic water consumption for different building types [32]

Type of building	Consumption per occupant		Peak demand per occupant		Storage per occupant	
	liter/day	*gal/day*	*liter/hr*	*gal/hr*	*liter*	*gal*
Factories (no process)	22 - 45	5 - 10	9	2	5	1
Hospitals, general	160	35	30	7	27	6
Hospitals, mental	110	25	22	5	27	6
Hostels	90	20	45	10	30	7
Hotels	90 - 160	20 - 35	45	10	30	7
Houses and flats	90 - 160	20 - 35	45	10	30	7
Offices	22	5	9	2	5	1
Schools, boarding	115	25	20	4	25	5
Schools, day	15	3	9	2	5	1