MARMARA UNIVERSITY
FACULTY OF ENGINEERING

GREENHOUSE HEATING AND COOLING WITH SOLAR ASSISTED HEAT PUMP

Ceyda YEŞİLYURT - 150416044
Mahmut KAYA - 150415042

GRADUATION PROJECT REPORT

Department of Mechanical Engineering

Supervisor

Arş. Gör. Dr. Mustafa Cem ÇELİK

ISTANBUL, 2022

MARMARA UNIVERSITY
FACULTY OF ENGINEERING

Greenhouse Climatization With Solar Assisted Heat Pump

by

Ceyda YEŞİLYURT,
Mahmut KAYA

June 29,2022, Istanbul

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF
BACHELOR OF SCIENCE
AT
MARMARA UNIVERSITY

Signature of Author(s) ....

Department of Mechanical Engineering

Certified By ....

Project Supervisor, Department of Mechanical Engineering

Accepted By ....

Head of the Department of Mechanical Engineering

ACKNOWLEDGEMENT

First of all, I would like to thank my supervisor, Arş. Gör. Dr. Mustafa Cem ÇELİK for the valuable guidance and advice on preparing this thesis and giving me moral and material support.

June, 2022 Ceyda YEŞILYURT**,** Mahmut KAYA

CONTENTS

ABSTRACT

Greenhouse Heating and Cooling with Solar Assisted Heat Pump

Greenhouses are widely used across the world, particularly in Mediterranean climates, to provide a suitable environment for the cultivation of a different range of agricultural crops. Producing, processing, and distributing these crops all need a significant amount of energy. In greenhouse climatization, a variety of technologies are used, including steam or hot water radiation systems and hot air heater systems. Because it can deliver both heating and cooling energy, a ground source heat pump system is a popular option. The objective of this study is to provide a sustainable heating and cooling system for greenhouse applications by utilizing solar energy and heat pump technologies. Our goal is to examine the heat requirements of a sample greenhouse located in the downtown area of Izmir for the winter and summer seasons using renewable energy sources. In order to provide the greenhouse's hourly calculated heat losses, a horizontal ground source heat pump with solar assistance was installed. It is more desirable to use soil as a source rather than air or water because the qualities of soil hardly change throughout the year. For this reason, ground source heat pump was chosen. The system's depreciation time which is 11 years was estimated by using present value theorem given in cost analysis of the system. Coefficient of Performance of heat pump (COP) was found as 2.9392 on January, 3.8470 on April, 5.8757 on June. The peak value is 7.4419 on August. Annual photovoltaic electricity generation was found as 18279,13508 kWh. It was observed that photovoltaic electricity generation can meet of greenhouse demand.

SYMBOLS

$\dot{Q}_{sun}$=Heat energy comes from sun
$\dot{Q}_{heatpump}$= Capacity of heatpump
$\dot{Q}_{transmission}$= Heat loss over greenhouse surface
$\dot{Q}_{infiltration}$=Heat loss over leakage from window/door
$\dot{Q}_{product}$= Heat taken from product
$\dot{Q}_{collector}$=Collector capacity
$\dot{Q}_{soil}$= Heat loss over soil
$\dot{Q}_{loss}$= Total heat loss from greenhouse
$\dot{Q}_{ther}$=Thermal capacity
$\dot{Q}_{el}$=Electrical capacity
$\dot{Q}_{cond}$=Condenser capacity
$\dot{Q}_{evap}$=Evaporator capacity
$\dot{q}_{greenhouse}$= Heat requirement per area
$A_{surface}$=Surface area of greenhouse
A_{floor} = Floor area of greenhouse
$A_{coll,surface}$=Collector surface area
R_1 =R_2= thermal conductivity
I =Solar radiation
I_T=Radiation to the sloping surface
τ= Solar irradiation transmissivity
α_s=Absorption rate of solar radiation energy to the surface
$\dot{m}_{water}$=mass flow rate of water
$c_{p,water}$ =specşfic heat of water
T_i= Inside temperature of greenhouse
T_d= Outside temperature
$T_{coll,out}$ =collector leaving water temperature
$T_{coll,in}$=collector entering water temperature
$\dot{W}_{fan}$=Fan power
$\dot{W}_{comp}$ =Work needs of compressor
η_c=Collector efficiency
η_{comp}=compressor efficiency
η_{mech}=mechanical efficiency of compressor
η_{belt}=belt efficiency of compressor
η_{elen}=electrical engine efficiency
$h_{comp,out}$=enthalpy of entering working fluid of compressor
$h_{comp,in}$=enthalpy of leaving working fluid of compressor
f_w=wind factor
f_c=structure factor
f_s=system factor

ABBREVIATIONS

COP **:** coefficient of performance of heat pump

PV **:** solar panel

PV-T **:** photovoltaic thermal collector

HP **:** heat pump

GSHP **:** ground source heat pump

WSHP **:** water source heat pump

WISC **:** wind and/or infrared sensitive collectors

TXV **:** thermostatic Expansion Valve

HVAC **:** heating, ventilating and air conditioning

O&M **:** the operation and maintenance

WS **:** workmanship and other equipment factor

SPBT **:** simple payback time

LIST OF FIGURES PAGE

LIST OF TABLES

PAGE

1. INTRODUCTION

Greenhouses are structures that provide various forms of protection for plants that are unable to grow outside due to harsh weather, diseases, or other hazardous conditions. They also provide an extended production season. Greenhouses provide for optimal efficiency from planting while also improving growing conditions. The production is influenced by the greenhouse climate, which has the best temperature, ventilation, light, and relative humidity values. One of the most important climatic parameters to generate in the greenhouse is temperature[1]. Heating is needed to keep the greenhouse environment at a certain temperature. The use of fossil fuels to meet heating needs contributes to increased greenhouse gas emissions and a larger carbon footprint. The main purpose in this study is reduce these carbon footprints by using renewable source which is photovoltaic thermal collectors (PV-T) in our design. PV-Ts are a great way to utilize solar energy to provide electricity and heat to greenhouses. This electrical and heating energy can be used to power a heat pump, which can provide year-round heating and cooling. Using a heat pump instead of a traditional system can provide a 20–50% energy saving [2].

Many systems have been investigated in the literature in order to reduce energy consumption and meet the heating needs of greenhouses. In a greenhouse in Turkey, Yildirim and Bilir (2017) investigated the solar panel (PV) assisted heat pump (HP) for cooling and heating loads. For the electrical supply of the HP, sixty-six PVs were employed in the growing of three crops: cucumber, tomato, and lettuce. This system was found to be capable of meeting 33.2 to 67.2 percent of Greenhouse demand [3]. Mohsenipour et al. (2020) conducted theoretical study on growing lettuce and tomatoes in a solar-powered greenhouse with a high-efficiency cooling, heating, and power system. When using R134a as a refrigerant, the annual electricity and water consumption produced by the turbine for tomatoes and lettuce was calculated as 2139233 kWh and 3090333 kWh, respectively, when compared to the conventional system, which consumed 1.841.29 m^3 and 266.5 m^3 for lettuce and 10.675.04 m^3 and 141.01 m^3 for tomatoes. The payback period for the lettuce and tomato scenarios was determined to be 12 and 15 years, respectively, in the cost analysis [4]. Zhang et al. (2015) developed and evaluated a low-cost solar collector-assisted earth heat storage system for GH. The system was shown to be capable of storing seasonal thermal energy after the experiments, which could help to partially solve the problem of solar heat demand and supply mismatch between summer and winter. The energy consumption of the developed system and the typical solar heating system were compared under the identical conditions, and it was found that the energy savings were 27.8 kWh when the greenhouse's indoor air temperature was kept above 12 °C throughout the year [5].

In the present study, we design greenhouse system with PV-T collectors and ground source heat pump (GSHP). After designing this system, we evaluate energy and exergy analysis, calculate coefficient of performance (COP) of heat pump and efficiency of the system. When we do these calculations, we will use MATLAB codes. In our greenhouse heating, cooling and humidification supply by air conditioner. The air will be distributed homogeneously with a fan.

2. DEFINITION OF SYSTEM

2.1 Definition of PV-T Collector

PVT collectors integrate solar energy and heat generation into a single component, resulting in higher overall efficiency and better exploitation of the solar spectrum than traditional PV modules [6]. Figure 1 depicts a common PV-T collector configuration (PV cells and tube heat exchanger for cooling). As a result, the tube heat exchanger allows for the use of excess (waste) heat from PV cells for heating applications while also increasing the overall efficiency of the system. The gathered heat can be used for a variety of purposes, including space heating in buildings. As a result, a PV-T collector can offer both thermal and electrical energy.

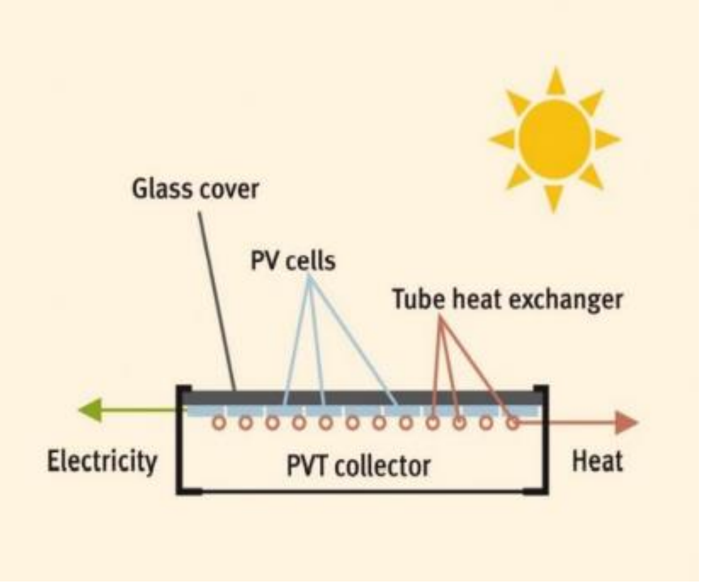

Figure-1: PV-T collector

2.1.1 Difference Between Traditional PV and PV-T Collectors

Thermal and photovoltaic (PV) technologies are routinely used to collect solar energy as heat and electricity, respectively. A hybrid photovoltaic-thermal (PV-T) system combines a solar thermal absorber and a photovoltaic (PV) system into a single unit. While the PV cells create electricity, the integrated thermal system absorbs the leftover heat energy generated by the cells, reducing their temperature and improving their performance. Water and air are the two most cost-effective operating fluids, with water being more efficient. Depending on the conditions, hybrid PV-T collectors can achieve net (electrical plus thermal) efficiencies of 70% or more, with electrical efficiencies of 15–20% and thermal efficiencies surpassing 50%. PV-T technologies have the ability to reduce the amount of materials used, the time it takes to install, and the amount of space needed. PV-Ts are useful for household applications since they can generate both electricity and thermal energy at the same time. Despite their enormous potential, commercial PV-T systems are still not as common as stand-alone PV and thermal systems that are installed separately [7].

2.1.2 Types of PV-T Collectors

2.1.2.1 PV-T Liquid Collector

Using piping attached directly or indirectly to the back of a PV module, the basic water-cooled arrangement uses channels to direct fluid flow. A working fluid, commonly water, glycol, or mineral oil, circulates in the heat exchanger behind the PV cells in a standard fluid-based system. The heat from the PV cells is transferred to the working fluid through the metal (assuming the working fluid is colder than the operating temperature of the cells).

2.1.2.2 PVT Air Collector

To install the solar panels, the basic air-cooled design uses either a hollow, conductive housing or a regulated flow of air to the back face of the PV panel. In a closed loop, PV-T air collectors either draw in fresh outside air or use air as a heat transfer medium. Because the heat transfer characteristics of air are poorer than those of commonly employed liquids, an equivalent PV-T liquid collector requires a proportionately larger mass flow rate. The benefit is that the infrastructure required is less expensive and complicated.

2.1.2.3 Uncovered PVT Collector (WISC)

Uncovered PVT collectors, also known as unglazed or wind and/or infrared sensitive PVT collectors (WISC), are made out of a PV module with a heat exchanger structure attached to the rear. While the majority of PV-T collectors are prefabricated systems, some are available as heat exchangers that may be retrofitted to commercial PV modules. In both circumstances, a good and long-lasting thermal contact between the PV cells and the fluid with a high heat transfer coefficient is necessary.

2.1.2.4 Covered PV-T Collector

PV-T collectors that are covered, or glazed, have a secondary glazing that encloses an insulating air layer between the PV module and the secondary glazing. As a result, heat losses are reduced and thermal efficiency is improved.
Furthermore, covered PV-T collectors can reach temperatures that are substantially greater than PV modules or uncovered PV-T collectors. The temperature of the working fluid determines the operating temperatures.

2.1.2.5 Concentrating PV-T collector (CPVT)

The advantage of a concentrator system is that it reduces the amount of photovoltaic (PV) cell area required. As a result, more expensive and efficient PV cells, such as multi-junction solar cells, can be used. The concentration of sunlight also minimizes the quantity of hot PV-absorber area, reducing heat losses to the environment and thus improving efficiency for higher application temperatures [6].

2.2 Heat Pump

There is a natural heat flow from the warm environment to the cold environment in nature. Heat transfer from a low-temperature environment to a high-temperature environment, on the other hand, cannot occur spontaneously. Heat pumps are a type of heat engine that transfers heat from a low-temperature source to a higher-temperature sink through mechanical work. Heat pumps are used to generate hot water or to heat the environment.

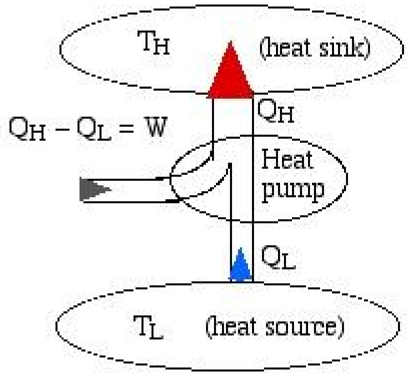

Figure-2: Heat pump thermal scheme [8]

2.2.1 Operating HP systems

A heat pump can convert a low temperature waste heat flow into useful high temperature heat. The mechanical heat pump is the most widely used of the various types of heat pumps that have been developed. Its operation is based on the compression and expansion of a working fluid, or 'refrigerant.' A heat pump is made up of four major components: an evaporator, a compressor, a condenser, and an expansion device. The refrigerant is the working fluid that circulates through all of these parts. The temperature range of the thermodynamic cycle and the size of the installation required determine the refrigerant used in a given application. Natural refrigerants (butane, ammonia, CO_2) and synthetic refrigerants are the two types of refrigerants (R134A, R407C, R410A). Heat is extracted from a waste heat source in the evaporator. This heat is delivered to the consumer at a higher temperature level by the condenser.

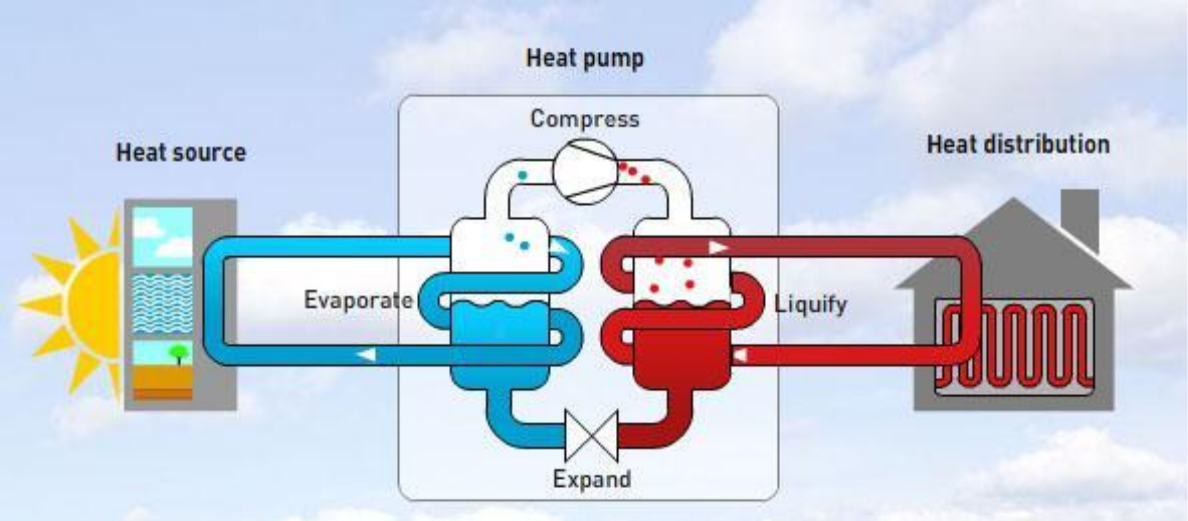

Figure-3: Working principle of heat pump [9]

2.2.2 Components of HP

Understanding what each component of your heat pump system does will help you better understand how it works. A heat pump installation typically consists of two parts: an indoor unit, which is typically a furnace or air handler, and an outdoor unit, which contains the compressor and evaporator coils. The evaporator is installed outdoors as part of the heating process to extract heat from the surrounding air, whereas the evaporator is installed indoors as part of the cooling process to extract heat from the condenser coil. A heat pump is made up of the following parts:

- Compressor
- Condenser
- Expansion Valve
- Evaporator
- Refrigerant
- Accumulator
- Compressor Contactor
- Crankcase heater
- ECM
- Reversing valve
- Thermostatic Expansion Valve (TXV)
- Thermostats
- Defrost system
- Fan
- Motors
- Refrigeration Coils

Compressor: The compressor is an important part of a heat pump. In the compressor, the refrigerant is compressed to extremely high pressures while also being heated. When refrigerant enters a compressor, it is in a gaseous state at low pressure and low temperature and exits the compressor in a gaseous state at high pressure and high temperature.

Condenser: The condenser is the next critical component of a heat pump. A heat pump's function includes heating, which is produced by the condenser inside a room. The refrigerator's primary function is to cool the substance or material, which is accomplished by the evaporator. Whereas the evaporator is the main component that produces cooling in refrigerators, the condenser is the main component that produces heating in heat pumps. The condenser of an air conditioner is located outside the room that needs to be cooled, whereas the condenser of a heat pump is located inside the room. When the refrigerant exits the compressor, it is extremely hot and pressurized. The refrigerant is then routed to the condenser, which is typically constructed of copper coils. The coil inside the condenser becomes very hot as a result of the high temperatures in the refrigerant, creating heat inside the room. A fan or blower located behind the condenser coil blows air over the hot condenser coil. As the air passes through the coil of the condenser, heat is transferred to it, and the heated air is expelled into the room, making it hot. The hot air is thrown into the room, while the air is continuously absorbed by the fan. The room is kept at a much higher temperature than the surrounding air. When it comes to condenser coil fans, there are two options: forced and induced fans.

Because air absorbs heat from the condenser, the temperature of the condenser and the refrigerant inside it decreases when air passes over it. At high pressure and medium temperature, the refrigerant exits the condenser partially as a liquid and partially as a gas. It will then enter the expansion valve or capillary tube, which is crucial.

Expansion valve: The expansion valve reduces pressure. The pressure and temperature of the refrigerant entering the expansion valve at high pressure and medium temperature suddenly drop. Copper capillary tubes are the most commonly used expansion valves in heat pumps. When pressure and temperature are extremely low, expansion valves release refrigerants in partially liquid and partially gaseous states.

Evaporator: Air conditioners have their evaporators inside the room, whereas heat pumps have their evaporators outside the room and are exposed to the extremely cold local atmosphere. The evaporator, like the condenser, is made up of copper coils. The refrigerant drastically reduces the temperature of the evaporator coil by entering at low pressure and temperature. Because of the low temperature of the refrigerant inside the evaporator, it absorbs heat from the environment. The blower or fan blows air over the evaporator, transferring heat to the refrigerant and heating it. The temperature of the refrigerant rises as a result of its ability to absorb heat from atmospheric air. Its pressure, however, remains constant, and it turns into a gas.
The refrigerant is introduced into the compressor as a gas at low pressure and medium temperature. Compressors compress gaseous refrigerants to extremely high pressures and temperatures. The refrigerant is then directed into the heat pump's condenser, where it heats the air in the room. Thus, the cycle continues. During each cycle, the refrigerant flows continuously through the closed cycle, being heated and cooled. Refrigerators and heat pumps use refrigerants that can change phases without undergoing any chemical changes[10].

2.2.3 Types of HP

The environments where heat pumps draw heat are called heat sources. Heat sources affect the performance and investment costs of the heat pump. Heat sources for heat pumps can be broadly classified as air, water, ground (soil).

2.2.3.1 Water Source Heat Pumps

A Water Source Heat Pump is one of the most efficient and reliable HVAC systems for your building (WSHP). A WSHP is a simple design that rejects heat during the cooling cycle via a Cooling Tower loop. The water loop is piped through the building, and each Heat Pump is individually connected.
Each unit is individually packaged, which relieves the stress of the building relying on a single HVAC unit to control the entire structure. Water Source Heat Pumps can be easily zoned and installed above the ceiling or in a closet. Each area it serves can have a tr1aditional thermostat or even integrated building controls, which can save even more energy[11].

2.2.3.2 Air Source Heat Pumps

Air source heat pumps are a type of renewable energy technology that uses heat from the outside air (even when it's freezing) to heat the home. Other heat pumps that use the warmth in the ground and in water can do the same thing, but air source heat pumps are more suitable for a wider range of properties. Because the sun heats the air (or ground, or water), the energy

produced by heat pumps is still considered "renewable," even though the pump itself is powered by electricity that may or may not be renewable.
Air source heat pumps are classified into two types. More commonly, air-to-water systems heat water, which is then circulated throughout the home via radiators or an underfloor heating system. They can also heat water in a storage tank for use in the bathroom or kitchen. Air-to-air systems, which cannot heat water, typically use fans to circulate warm air throughout the home. A low-boiling-point liquid refrigerant is pumped through a loop between two heat exchangers. As it warms up, this refrigerant absorbs heat energy from the outside ambient air temperature and converts to a gas. This gas is then compressed back into a liquid, raising its temperature even higher. The warm refrigerant is then passed through a heat exchanger, which transfers the warmth to a separate body of water that circulates throughout the central heating system. The liquid refrigerant then passes through an expansion valve, lowering the pressure and temperature, and the cycle is repeated.

2.2.3.3 Ground Source Heat Pumps

A ground source heat pump is a system that uses buried pipework to extract low-temperature solar energy stored in the ground or water and compresses it into a higher temperature. The large thermal capacity and stable operating conditions of the soil make it convenient to be used as a heat source. The soil, which is used as a heat source for heat pumps in the winter season, acts as a heat sink where the heat inside the space is discharged in the summer season. There are two types of system: horizontal and vertical. The choice of the type is depend on the space you have available and the cost of installation. The working principle of both is the same.

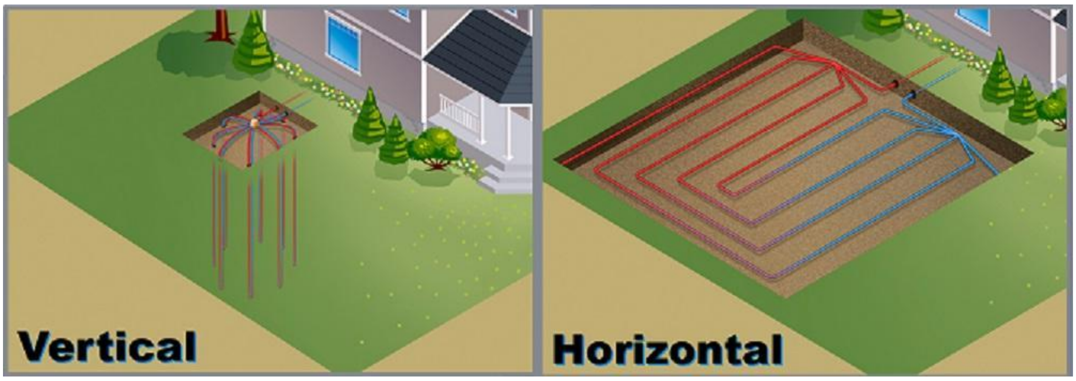

Figure-4 : Vertical and horizontal type of piping system[12]

Horizontal Ground Source Heat Pump System:

A horizontal piping system is generally preferred when there is large amount of outdoor space required. Digging trenches for a horizontal system installation is cheaper than drilling a borehole for a vertical system installation. Horizontal collectors should be placed at the most appropriate depth, which will both receive the energy from the sun and will not be easily affected by seasonal weather events. The most efficient depth for this is 1.2 – 1.5 m. Two meters is the dead zone and there is no heat flow. Concrete should not be poured on the area where the horizontal collector is laid, and the contact of the rain with the soil should not be blocked. Since the pipes are laid horizontally on a large area, their heat transfer area is greater. For this reason, the energy to be drawn is more than the energy drawn from drilling-type applications. After the pipes are laid, the soil removed from the trench needs to be compacted to increase its density while repositioning it in order to improve the heat transfer between the soil and the pipe.

Vertical Ground Source Heat Pump System:

The vertical borehole heat pump is generally used where plot space is limited. In this system, the heat from the magma is used to heat the environment. Generally, the depth of absorbing the heat from the magma is between 30 m and 150 m. In vertical drilling applications, pipes are suspended vertically into the wells drilled with drilling machines. A minimum of 3.5m, preferably 6m should be left for a healthy heat transfer between the drilled wells. Pipe costs are lower in vertical pipe hanging compared to horizontal pipe laying. However, drilling labor cost is higher. After the pipes are suspended, concrete can be poured over the wells[13].

Despite their initial high costs, horizontal and vertical ground source heat pump systems both provide a long-term return on investment and add value to your greenhouse by providing an eco-friendly method of heating.

2.3 System Details

Generally, on greenhouse climatization the traditional way of the supplying electricity to heat pump is using fossil fuels which this type of systems causes environmental pollution. Also, when we think about these systems, they are costly and less efficient. For example, in conventional methods they use more fossil fuels to generate electricity to work heat pump and heat greenhouse because decreasing temperature in nighttime but when we consider our solar assisted greenhouse system, we store thermal energy during the daytime, and we can use this energy during nighttime. Our main aim in this project is reducing carbon emission when we do climatization greenhouses. Also increase the efficiency with many ways during the greenhouse climatization. For this purpose, we use PV-T collectors to produce electricity for the GSHP and also use solar energy for our greenhouse climatization system as shown in Figure 6 . When we check our findings, we can easily saw that GSHP also very efficient and beneficial component of our system. Our calculations, data and articles that we mentioned in our project in later chapters show that for using solar assisted heat pump is an environmentally friendly, efficient and innovative solution for greenhouse climatization.

In our system, we will use solar assisted GSHP with horizontal piping. Because we have enough land for horizontal laying and we design our system with the minimum cost target during the installation phase. A battery may added to our system as a storage system for the days when the weather is cloudy and solar energy cannot be used. In the unlikely event that solar energy cannot be used we also connected to the electrical grid system. All heating and cooling process is done by soil piping system connected to the heat pump. The air in the GH will be distributed homogeneously inside with the help of a fan.

We chose İzmir as the study area because it has suitable areas for greenhouse cultivation and the sunshine duration is high throughout the year. An asymmetric roof with more area towards the south direction was designed to maximize the electrical power generation of PV-T panels. The roof's angle is 38.4, which corresponds to Izmir's latitude[14]. PV panels covered half of the southern surface of the greenhouse's asymmetric roof. The orientation was designed so that there is a one PV-T height gap between two PV-Ts in the same row. As a result, solar radiation will be more uniform inside the greenhouse. As a result, to avoid overshadowing cultivated crops, 50 percent of the south face of the roof is covered with on grid PV-T panels. As a result, 12 PV-T panels with 20 kW daily energy can be installed to generate electricity. 10 kW ground source heat pump is selected. The performance of a GSHP is dependent upon temperature of the ground. When you use a such a heat pump you must consider ground temperature also we will discuss about ground temperature.

Since the most basic purpose when designing a greenhouse is to grow quality food in optimum conditions, we determined many important factors such as choosing the right components, solar radiation time data, humidity and temperature needed by the plant, and correct sizing while designing the system. At this stage, we had difficulty in reaching up-to-date data after 2020. For this reason, we used data from 2020 in our calculations. Assuming that we grow tomatoes in the greenhouse, we took the needs of the tomato as a basis. The required indoor temperatures for 100% of possible growth of tomato is 18°C[15]. The operation conditions of heating and cooling system of tomato for summer and winter periods are summarized in Table 1. For healthy tomato development, the soil should be kept at the temperatures listed in Table 2. During the cold winter months, the plant's heat requirement is met more easily and efficiently by heating the soil[1].

Operation type and period	Design temperature (°C)	Set back temperature (°C)
Heating (Oct 1st–Apr 30th)	20	12
Cooling (May 1st–Jun 30th and Sep 1st–Sep 30th)	28	30

Table-1 Greenhouse heating and cooling system operation conditions

Crop	Minimum (°C)	Optimum range (°C)	Maximum (°C)
Tomato	10	18 - 29	35

Table-2 Suitable soil temperatures for germination of tomato

The greenhouse, which is planned to be heated and cooled, has been chosen to have an isosceles gable roof as shown in Fig -5. Double-layered polyethylene was preferred as greenhouse covering material.

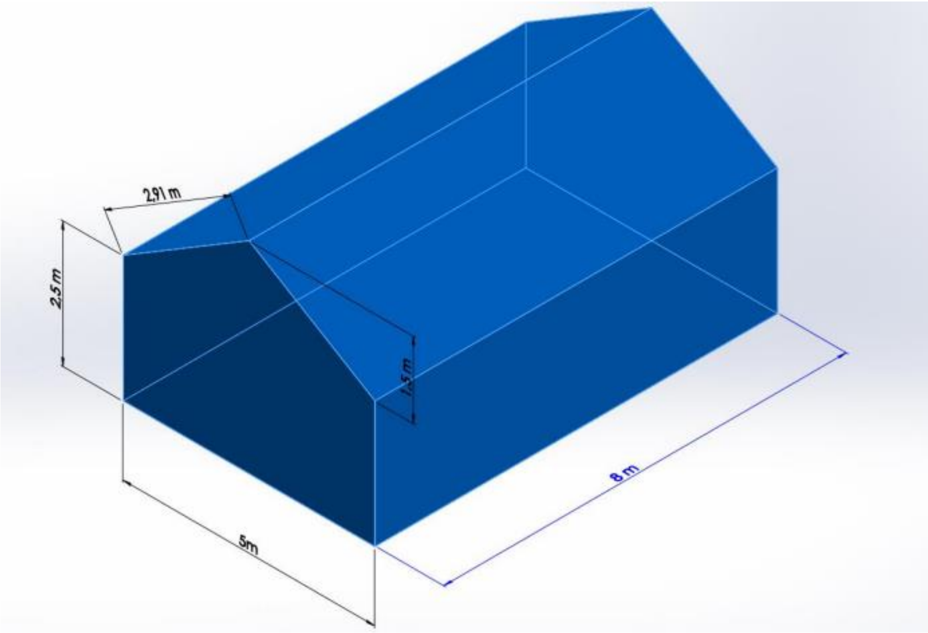

Figure-5: 3D view of the working greenhouse

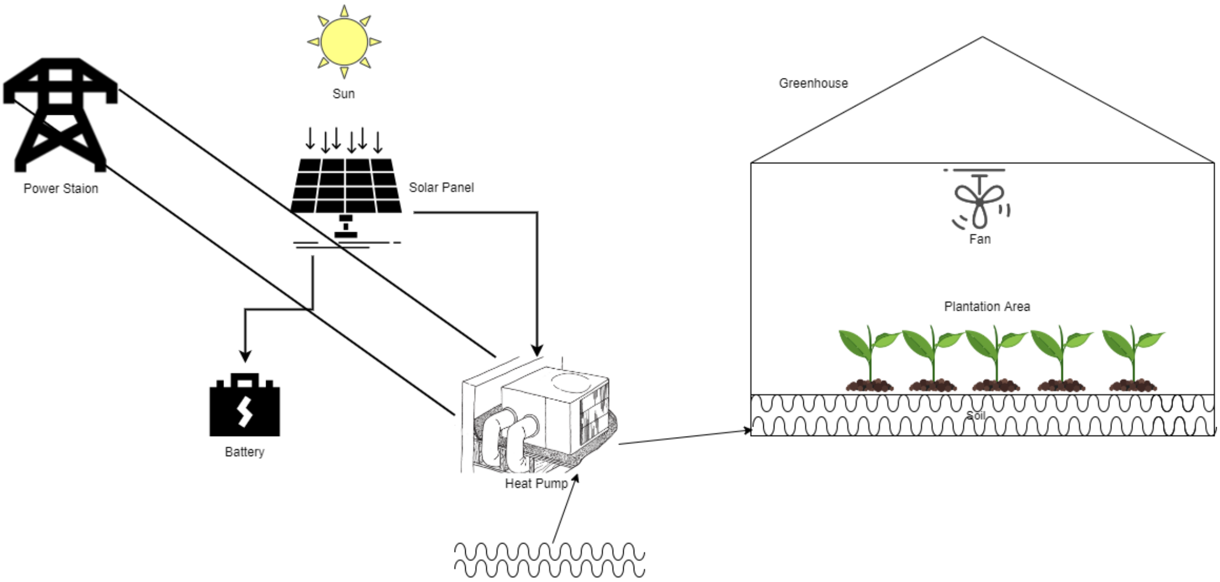

Figure-6: Basic sketch of system

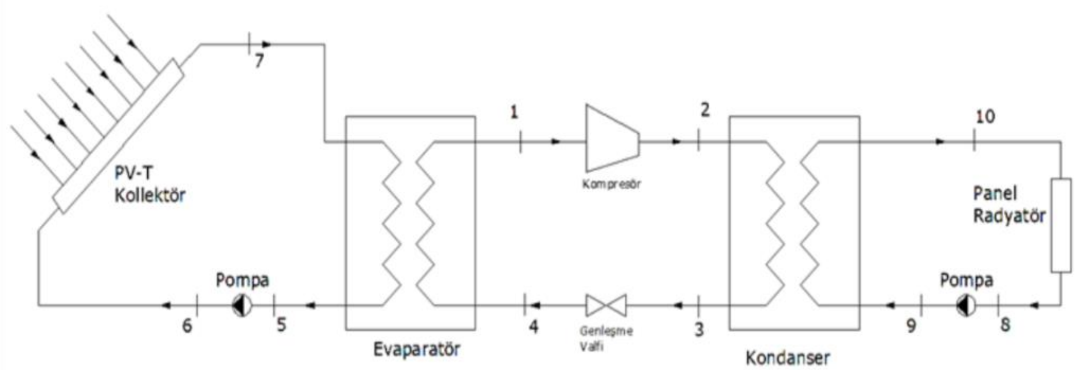

Figure-7: Thermodynamic cycle of system

The flow diagram of the solar assisted heat pump system is shown in Fig.6. As seen in the figure, water which is passing through the PV-T sends to the PV-T with pump(6). The heat is extracted by water from the collector and carries on to the evaporator of the heat pump(7). The heat is exchanged between water and refrigerant in evaporator(1). The water which is getting cold get back over to the pump for recycle to the close loop(5). Meanwhile, the refrigerant which is getting hot and evaporates passes through the compressor. At the exit of the compressor, the pressure and temperature of the refrigerant increase(2). The saturated liquid which is entering to the condenser transfers heat to radiator heating water(10). The temperature is dropping during condenser and the refrigerant exits high pressure and medium temperature. Then, it enters to the expansion valve to drop pressure and the close loop is completed here to be repeated(3). The space heating water is sent to the condenser by using pump(8) to heat load(9). By transferring the energy it receives to the environment via the panel radiator, the environment is heated.

3. THERMODYNAMIC ANALYSIS

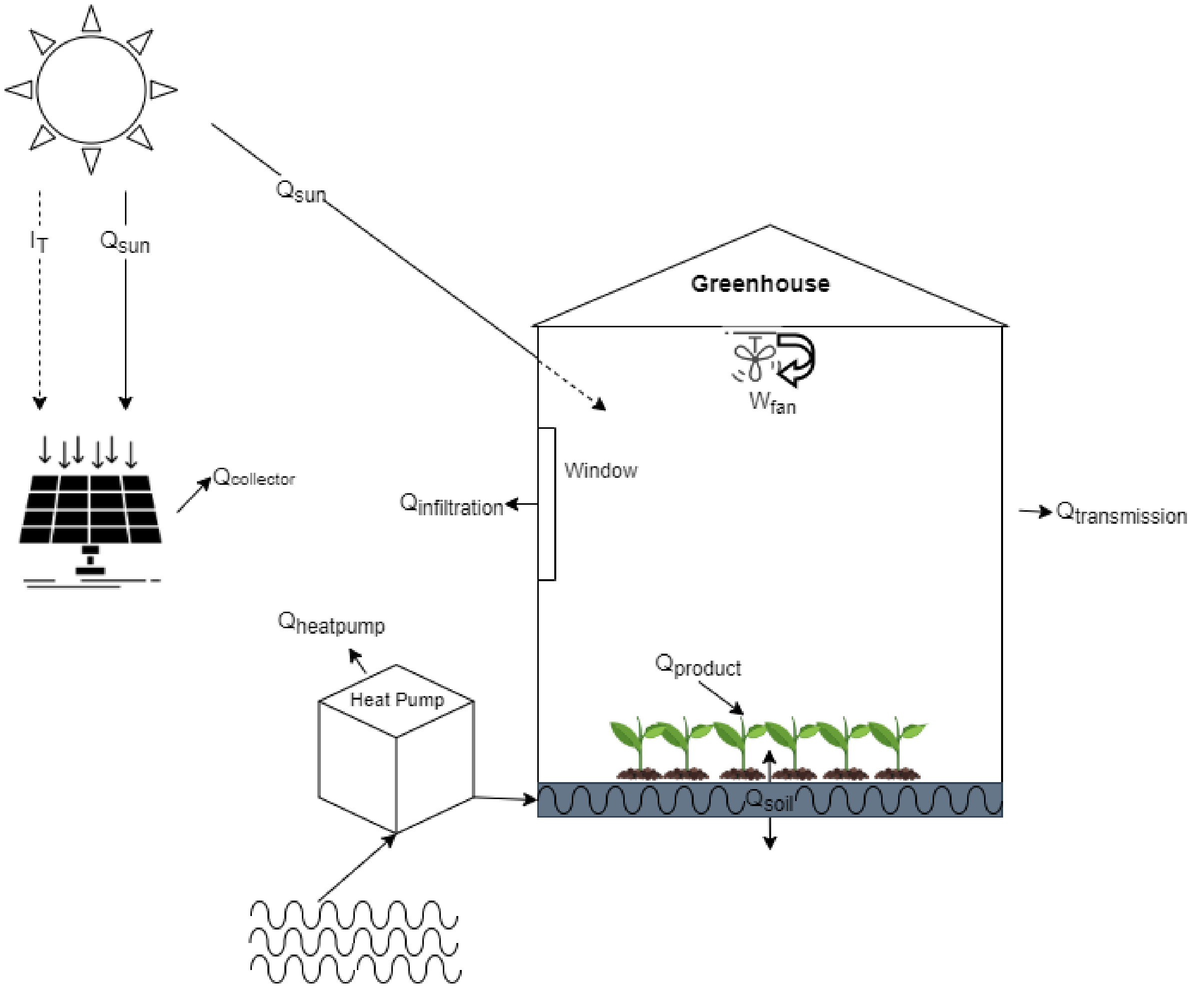

Figure-8: 2D sketch of heat flow

The operational conditions and assumptions about GSHP are listed below:

The R410a is used as working fluid for the GSHP.

The ground to water type of regarded heat pump is selected.

In cooling mode, water inlet and outlet temperatures of evaporator are 11℃ and 6℃ , respectively.

In heating mode, water inlet and outlet temperatures of condenser are 32℃ and 38 ℃, respectively.
Isentropic and mechanical efficiencies of the compressor are 80% and 80%, respectively.
The heating and cooling COP values are calculated with the condenser temperature of 45 ℃ and the evaporator temperature of 2℃.

Total heat energy balance of the system:

The heat energy balance occurring in the greenhouses can be stated with the following equation

$$\dot{Q}_{sun} + \dot{Q}_{heatpump} = \dot{Q}_{transmission} + \dot{Q}_{infiltration} + \dot{Q}_{product} + \dot{Q}_{soil} \qquad (kW) \qquad (1)$$

We can calculate heat loss in greenhouse like this;

$$\dot{Q}_{loss} = \left[\frac{A_1}{R_1} + \frac{A_2}{R_2}\right] + |T_i - T_d| f_w f_c f_s \qquad (kW) \qquad (2)$$

In order to calculate the HP and sun capacities, the total heat requirement must first be known. The heat load that must be met in greenhouses can be calculated as follows[16]:

$$\dot{q}_{greenhouse} = \frac{A_{surface}}{A_{floor}} U_{total}\left(T_{greenhouse,in} - T_{greenhouse,out}\right) - (I\tau\alpha_s) \qquad (\frac{kW}{m^2}) \qquad (3)$$

$$\dot{Q}_{greenhouse} = \dot{q}_{greenhouse} \times A_{floor} \qquad (kW) \qquad (4)$$

When we use PV-T Collectors and HP for thermal power use of greenhouse the equations:

$$\dot{Q}_{greenhouse} = \dot{Q}_{sun} + \dot{Q}_{heatpump} \qquad (kW) \qquad (5)$$

The heat collected from the PV/T panel in this designed greenhouse system is expressed as

$$\dot{Q}_{collector} = \dot{m}_{water} \times c_{p,water}\left(T_{coll,out} - T_{coll,in}\right) \qquad (kW) \qquad (6)$$

The surface area of the PV/T panel used in GH can be found with the equation given below

$$A_{coll,surface} = \frac{\dot{Q}_{collector}}{I_T \eta_c} \qquad (m^2) \qquad (7)$$

The total efficiency of the PV / T system used to meet the electricity and heat needs of the greenhouse are defined as follows[1]:

$$\eta_{PV-T} = \frac{\dot{Q}_{ther} \times \dot{Q}_{el}}{I \times A_{coll,surface}} \qquad (\%) \qquad (8)$$

$$\Delta T = \left(T_{coll,out} - T_{coll,in}\right) \qquad (°C) \qquad (9)$$

$$I_{th} = U_l \frac{\left(T_{coll,in} - T_{water}\right)}{\tau\alpha} \qquad (\frac{W}{m^2}) \qquad (10)$$

The following calculation can be used to compute the power of the fan that circulates hot air for the GH:

$$\dot{W}_{fan} = \frac{V\dot{\Delta}P}{\eta_f} \qquad (kW) \qquad (11)$$

The heat that can be obtained from HP can be expressed as follows[17]:

$$\dot{Q}_{heatpump} = \dot{Q}_{greenhouse} - \dot{Q}_{sun} \qquad (kW) \qquad (12)$$

The component that consumes electrical energy in HP system is the compressor. The following equation can be used to calculate the power of the compressor in designed this greenhouse process:

$$\dot{W}_{comp} = \dot{m}_{water}\left(h_{comp,out} - h_{comp,in}\right) \qquad (kW) \qquad (13)$$

We can also calculate electrical energy that consumes by compressor like this:

$$\dot{W}_{comp} = \frac{\dot{m}_{water}\left(h_{comp,actout} - h_{comp,in}\right)}{\eta_{comp}\eta_{mech}\eta_{belt}\eta_{elen}} \qquad (kW) \qquad (14)$$

The amount of heat drawn by the evaporator can be calculated from:

$$\dot{Q}_{evap} = \dot{m}_{water}\left(h_{evap,out} - h_{evap,in}\right) \qquad (kW) \qquad (15)$$

The amount of heat transfer from condenser can be calculated like:

$$\dot{Q}_{con} = \dot{m}_{water}\left(h_{con,out} - h_{con,in}\right) \qquad (kW) \qquad (16)$$

Heat energy transferred from heat pump can be calculated like that

$$\dot{Q}_{heatpump} = \dot{Q}_{con} - \dot{Q}_{evap} = \dot{W}_{comp} \qquad (kW) \qquad (17)$$

This equation for heat exchangers can be used for evaporator and condenser:

$$A_{hex,surface} = \frac{\dot{Q}_{hex}}{U_{hex}\Delta T_{ln}} \qquad (m^2) \qquad (18)$$

ΔT_{ln} : logarithmic temperature difference

ΔT_{ln} can be calculated like:

$$\Delta T_1 = T_{h,in} - T_{c,out} \qquad (℃) \qquad (19)$$

$$\Delta T_2 = T_{h,out} - T_{c,in} \qquad (℃) \qquad (20)$$

$$\Delta T_{ln} = \frac{\Delta T_1 - \Delta T_2}{ln ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \qquad (℃) \qquad (21)$$

COP of Heat Pump system can be calculated like:

$$COP_{heating} = \frac{\dot{Q}_{cond}}{\dot{W}_{comp}} \qquad (22)$$

$$COP_{cooling} = \frac{\dot{Q}_{evap}}{W_{comp}} \qquad (23)$$

After these defined formulas, we will do our calculations and get some results and we make some graphs using MATLAB program.

4. COST ANALYSIS OF THE SYSTEM

Investment Cost:

$C_i = C_p + C_{hp} + C_{col} + C_d$ (€) (24)

C_p : Pipe cost (€)

C_{hp} : Heatpump cost (€)

C_{col} : Collector cost (€)

C_d : Digging cost (€)

Pipe Cost:

$$C_p = L_p \times P_p \times WS$$

L_p : Length of pipe (m)

P_p : Price per meter of the pipe ($€/m$)

WS : workmanship and other equipments factor

For L= 95 m , number of modules=6, WS=1.32, for 25 mm radius price per meter is 2.40 €[18],

$$C_p = L_p \times P_p \times WS = 95 \times 6 \times 2.40 \times 1.32 = 1805\ €$$

Digging Cost :

As a result of our researching,

for 1 meter depth and workmanship our digging cost can be calculated as 2060 €.

Collector Cost:

According to our market research we preferred to buy the system as a package. This package includes 12 pieces solar panel, one 5 kW inverter, 2*30-meter solar cable, 8 accumulators, 4-meter accumulator cable plus KDV. Total cost of this package is 4500 €.

Heat Pump Cost:

According to our market research we preferred to buy Hiseer 10 kW GSHP. When we choose this GSHP we consider that it has to be economical and meet our needs. The price of the HP is 1007 €.

Initial investment cost is :

$$C_i = C_p + C_{hp} + C_{col} + C_d = 1805 + 2060 + 4500 + 1007 = 9372\ €$$

Annual Saving

$Anuual\ Saving = \left(C_g \times E_g\right) - (O\&M + I)$ (€) (25)

C_g : unit electricity price in Izmir (Euro/kWh)

E_g : annual electricity consumed by HP (kWh)

$O\&M$: annual operation and maintenance cost of the PV system (€)

I : annual insurance cost of the PV system (€)

When the consumption is 240 kWh or less in a month, the electricity price of 240 kW is 300

TL. (240kWh X 1,25TL). For the portion above 240 kWh, the unit price to be multiplied by the amount consumed will be 1.89 TL.
Our monthly electricity demand is 822 kWh.
822-240=582 kWh
582*1.89=1100 TL
1100+300=1400 TL
For a year, $(C_g \times E_g)$ =1400*12=16800 TL = 962 €
The insurance cost per year was taken as 0.25% of the initial investment cost which is;
I = 9372*0.25%=23.43 €
The operation and maintenance (O&M) cost per year is reported as 1% and 3% of the initial investment depending on the installed system capacity.
O&M = 9372*1% = 93.72 €

$$Anuual\ Saving = (C_g \times E_g) - (O\&M + I) = 962 - (23.43 + 93.72) = 844.85\ €$$

Simple Payback Time (SPBT):

$$SPBT = \frac{Initial\ Investment}{Annual\ Saving} = \frac{9372}{844.85} = 11\ years \qquad (year) \qquad (26)$$

Years	**Annual Savings**	**Payback Cumulative**
1	844,85	8527,15
2	1689,7	7682,3
3	2534,55	6837,45
4	3379,4	5992,6
5	4224,25	5147,75
6	5069,1	4302,9
7	5913,95	3458,05
8	6758,8	2613,2
9	7603,65	1768,35
10	8448,5	923,5
11	9293,35	78,65
12	10138,2	-766,2
13	10983,05	-1611,05

Table-3 : SPBT time data table

5. RESULT AND DISCUSSION

In our study, we try to evaluate a heating and cooling demand of greenhouse which has 40 m^2 floor area by using GSHP and PV-T collector. We are drawn the graphs by using MATLAB software. We also do cost analysis and compare with traditional methods like coal, fuel oil etc.

Firstly, we calculated heat loss $\dot{Q}_{loss}$ from greenhouse for every hour in 2022. We assume that our plant in greenhouse is tomato. The optimal grown up temperature of tomato is 18°C so the inside temperature of greenhouse is 18°C and we do calculations with respect to that.

```
%% Greenhouse Q_Loss Calculations for Every Hour in 2020
t=1:8784;  %2020 every hour time
A_1=72.5;  %Greenhouse lateral area m^2
R_1=0.26;  %Thermal conductivity of polyethilen m^2*k/W
A_2=46.56;  %Greenhouse roof area m^2
R_2=0.26;  %Thermal conductivity of polyethilen m^2*k/W
T_i=18;  %Greenhouse optimal inside temperature
T_d=xlsread('values','F:F'); %Outside temp
f_w=1;  %wind factor
f_c=0.95;  %structure factor
f_s=1.03;  %system factor
Q_loss=[(A_1/R_1)+(A_2/R_2)]*abs(T_i-T_d)*f_w*f_c*f_s;  %Heat loss of the greenhouse
Q_loss2timePlot=plot(t,Q_loss,'b');
xlabel('time(hour)');
ylabel('Heat loss of the Greenhouse');
```

Figure-9: MATLAB codes of hourly heat loss

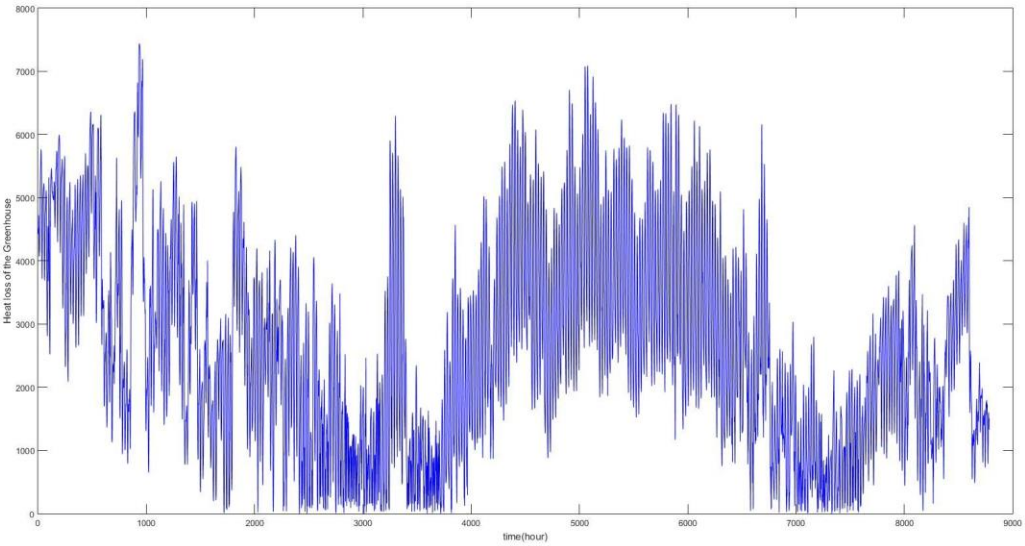

Figure-10 Heat loss over every hour in 2020

After these calculations we plotted a diagram heat loss vs time (hour). As we can observe in Fig-10,in summer and winter seasons heat loss is greater than spring and fall seasons because the temperature difference between greenhouse inside and outside much bigger. The heating demand is intense on 1st October- 31st march. The cooling demand is intense on 1st April- 30th September. The total heat loss overall year is 23139,23 kWh.

Then, we calculated COP of heat pump. COP value is varying depend on the outside temperature.

```
%% Heat Pump Calculations
Mon=1:1:12; %months
m_w=2; %mass flowrate of water
n_comp=0.80;   %efficiency of compressor
n_mech=0.80;   %mechanical efficiency
n_blt=0.95;    %belt efficiency
n_elen=0.96;    %electical engine efficiency
h_2s=[425,424,423,423,423,422,422,421,422,423,423,424]; %average monthly enthalpy values
h_1=[397,398,400,401,403,407,409,409,406,404,402,399]; %average monthly enthalpy values
h_2=[432,431,429,429,428,426,425,425,427,428,428,430]; %average monthly enthalpy values
h_3=[256,256,256,256,256,256,256,256,256,256,256,256]; %average monthly enthalpy values
h_4=[256,256,256,256,256,256,256,256,256,256,256,256]; %average monthly enthalpy values
W_comp=(m_w*(h_2s-h_1))/(n_comp*n_mech*n_blt*n_elen);  %%capacity of compressor
Q_evap=m_w*(h_1-h_4);  %%capacity of evaporator
Q_cond=m_w*(h_2-h_3);  %%capacity of condenser
Q_hp=W_comp;
COP=Q_evap./W_comp;
COP2Month=plot(Mon,COP,'ro-');
ylim([0 10]);
xlabel('Months');
ylabel('COP Values');
title('COPvsMonths Graph');
```

Figure-11: MATLAB codes of COP calculating

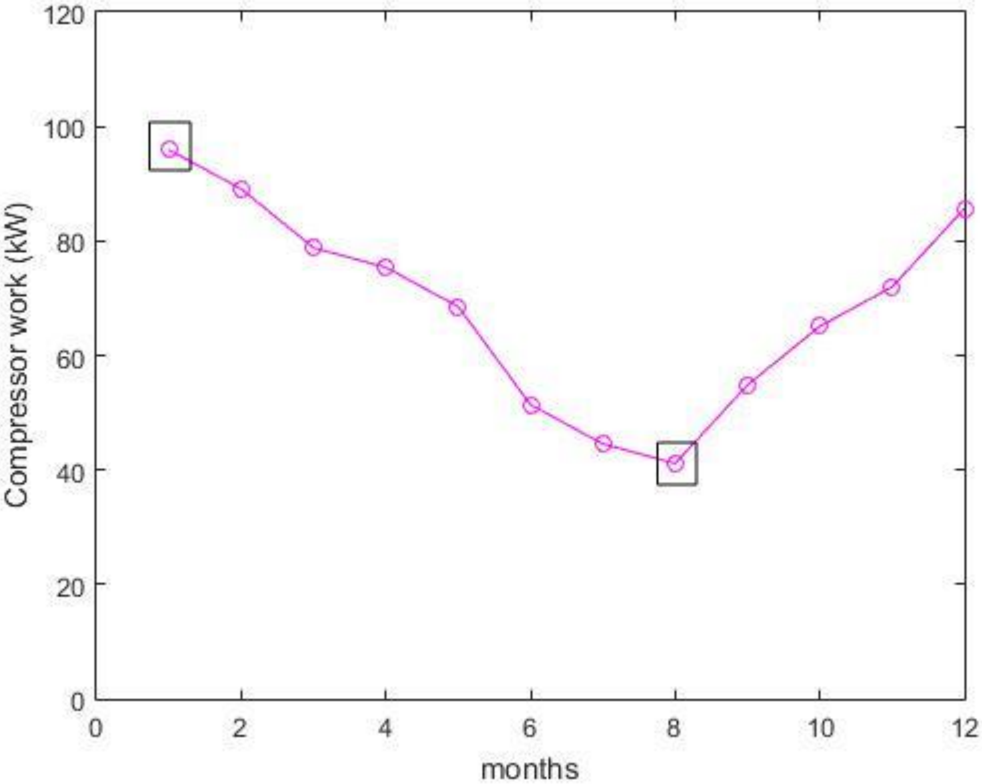

Figure-12: Work over month graphic

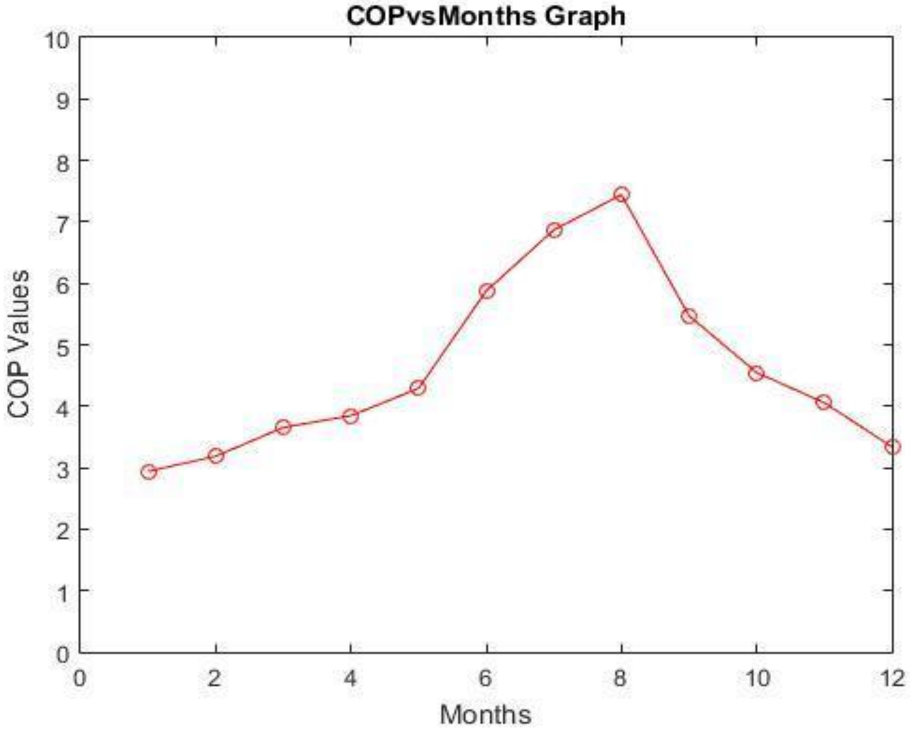

Figure-13: COP Values of heat pump over months

As we can see in Fig-13, the COP value is decreasing at winter season because of the soil temperature decreasing. Therefore, it has been observed that the operating costs of the system have increased. For example, COP value is 2.9392 on January, 3.8470 on April, 5.8757 on June. The peak value is 7.4419 on August.

We calculate electrical demand for every months by using eq-14 and plot the diagram in Fig-14.Compressor work is equal to electrical demand of heat pump. The corelation between compressor work and COP value is inversely proportional as we seen in the Fig-12&Fig-13. The electricity demand is highest in January when the COP value is the lowest. In August, when the COP value is the highest, the electricity requirement is the lowest. It has been found that the compressor in the ground source heat pump consumes 7105 kWh of energy over a 12-month period.

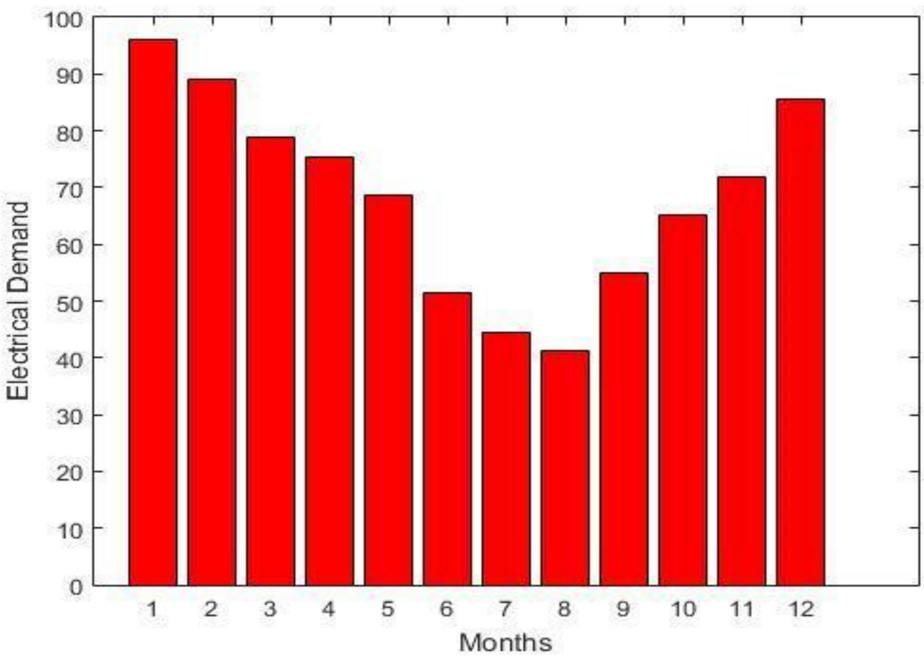

Figure-14: Electrical demand of heat pump over months

The graph of the amount of global solar irradiations per hour of Izmir province in 2020 is as follows in Fig-15. We took this graph from European Commission Photovoltaic Geographical Information site[19]. We use these values to calculate heat generation from PV-T collector.

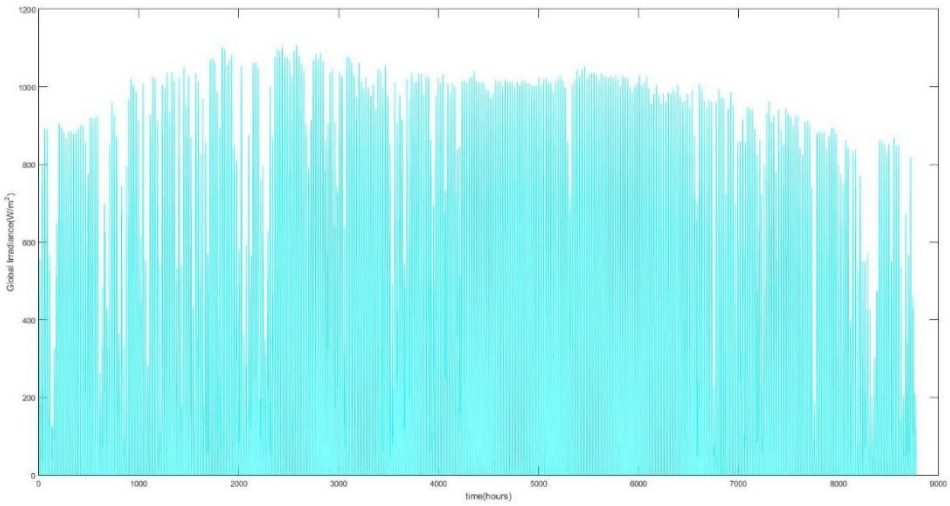

Figure-15: Global Irradiance Values Over Year

We calculated the heat energy produced by the collector based on the values in Figure 15 by using eq-7. When we look at the Fig-17, it can easily seen that heat generation decreases in winter months due to the decrease in solar radiation. The exact opposite, on summer days the heat generation is increasing thanks to the increase in sunny days. The total amount of heat generated from the collector for 12 months are 18279,13508 kW.

```
%% Collector Q Calculations
A_col=30;  %Collector surface area (m^2)
n_col=0.40;  %Collector efficiency
n_m=0.70;  %System efficiency wihtout collector
Q_col=A_col*I_t*n_col*n_m;  %Heat collected from PVT Collector
plot(t,Q_col,'g');
xlabel('time(hours)');
ylabel('PVT Collector Heat Collection');
```

Figure-16: MATLAB codes of heat generation from PV-T collector calculations

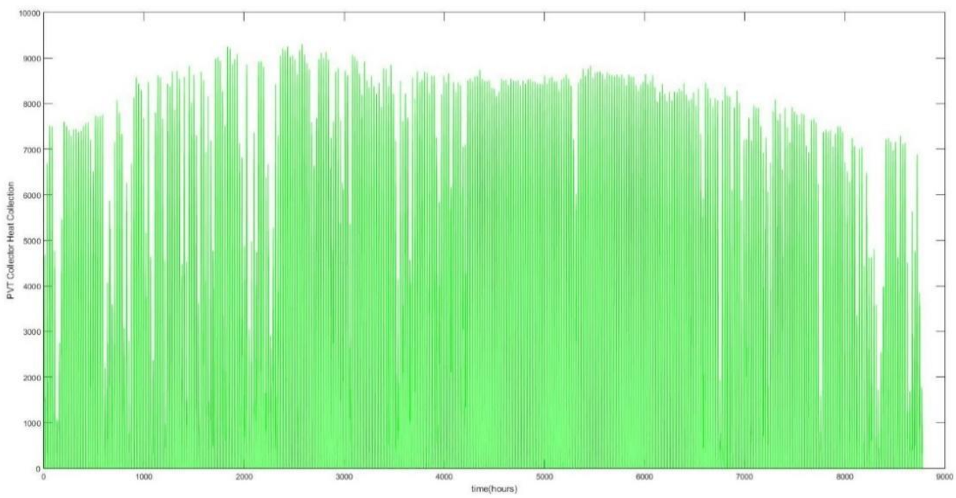

Figure-17: Q_Collector Values

In any energy conversion system, the economic decision to be made while making an investment is based on how many years the first investment will return during the economic life of the system. If the initial investment cost that will occur during the installation of the system is greater than the savings during the economic life of the system, then this system is not logical. In our system the payback time is 11 years. Although economic problems and the exchange rate affect the result to a high degree, our result is not so unreasonable. With the system improvements that can be made, even if it is costly in the short term, it starts to make profit in a period of 10 years. On the other hand, although it is not taken into account mathematically, since the internal temperature of the greenhouse is kept constant at 18 degrees, thanks to the heating process, an early harvest is made compared to normal and a quality product is obtained. Here, too, there is the possibility of making a profit.

```
%% Economical Calculation
O_M=93.72;
CE_g=962;
Insurance=23.43;
I_I=9372;
A_S=((CE_g)-(O_M+Insurance))*Years;
Years=1:12;
bar(Years,A_S,'g');
xlabel('years')
ylabel('Annual Savings Cumulative');
title('Years Over Annual Savings Cumulative')
```

Figure-18: MATLAB Codes of Economical Calculations

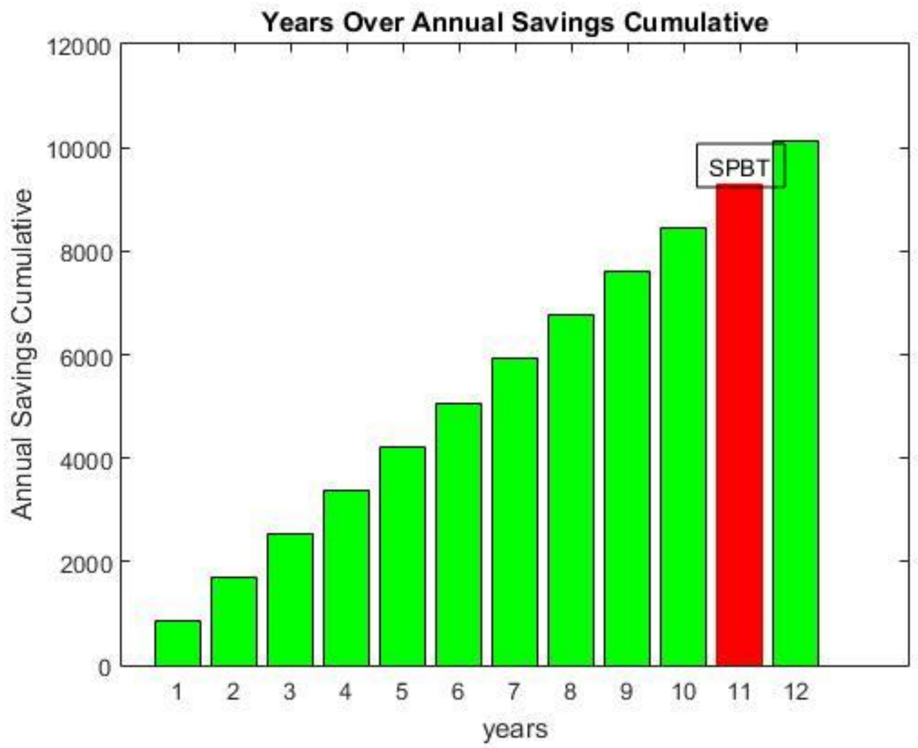

Figure-19 : Cumulative Annual Saving over Year Graph

These results show us that although the initial investment costs of the system we have established are high, its operating cost is low and it is advantageous in terms of cost, especially in regions where the winter season is cold, or the summer season is hot like İzmir.

Flow Chart of Our System

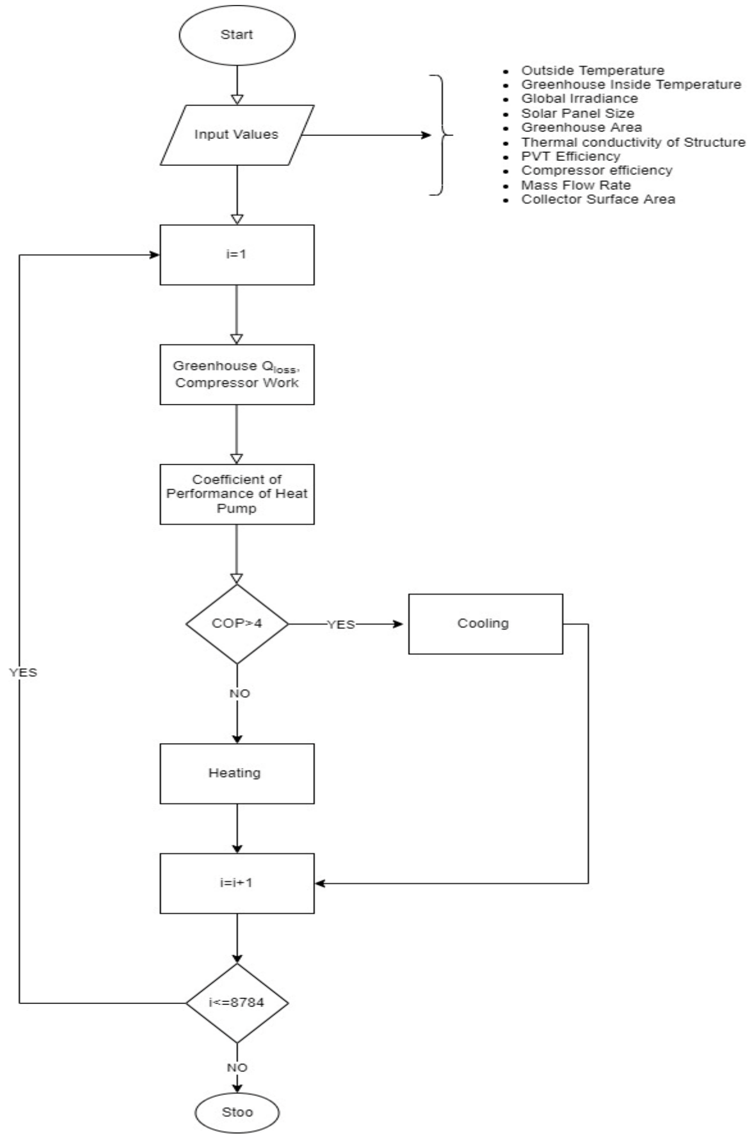

Figure-20: Flow Chart

6. CONCLUSION

This study focuses on a 160 m^2 greenhouse made of double-layered polyethylene and double-paned glass windows. The greenhouse is going to be built in Izmir, Turkey, which has a Mediterranean climate. The greenhouse's necessary heating and cooling requirements are considered to be met by the ground to water type heat pump. Temperatures for the condenser and evaporator are assumed to be 35°C and 2°C, respectively. The seasonal COP values are variable. These values are calculated monthly by using MATLAB and 2.9392 on January for heating, 7.4419 on August for cooling by using refrigerant 410a for the heat pump. Tomato cultivation is considered sour inlet temperature is constant at 18°C . Firstly, we decided to the sizing and material of the greenhouse. Then, we chose the type of heat pump and solar panel we will use according to the conditions. Assuming that our business is agriculture and the size of our land is sufficient, we chose a 10 kW ground to water source horizontal piping heat pump and a 20 kW PV-T collector for electricity needs. We designed our system based on this information. After design process, heat loss of greenhouse per hour for a year is calculated on MATLAB based on 2020 data. According to this heat loss, we determined how much heating and cooling we need. Then, by calculating the electricity need according to the heat pump efficiency, we determined the amount of electricity that the collector should produce. With a 18279,13508-kWh total electricity generation on PV-T system yearly coverage value of tomato is 100%. This coverage ratio supports the almost zero energy concept for the greenhouse under consideration. Although it is set out with the aim of a sustainable system, if the system is not efficient in terms of economic cost, the project will not be feasible. Therefore, the result of our comprehensive analysis, the economic analysis revealed a simple payback time of 11 years. Our goal was to create a system that pays for itself in 7 8 years, but we tried to achieve the best result with the options we had. We think that this system, which has made profit in 11 years, is still feasible.

7. REFERENCES

[1] Koşan, M, Akkoç, AE, Dişli, E, Aktaş, M. Design of an innovative PV/T and heat pump system for greenhouse heating. Journal of Energy Systems 2020; 4: 58–70. DOI:10.30521/jes.740587.

[2] State University of New York. ESF, Geothermal Heat Pumps (GHPs); 2017.<http://www.esf.edu/outreach/sure/2006spring/GHP/GHPSUREMar0306.pdf>[accessed 02.01.17].

[3] Yildirim, N, Bilir, L. Evaluation of a hybrid system for a nearly zero energy greenhouse. Energy Conversion and Management 2017; 148: 1278-1290, DOI: 10.1016/j.enconman.2017.06.068

[4] Mohsenipour, M, Ebadollahi, M, Rostamzadeh, H, Amidpour, M. Design and evaluation of a solar-based trigeneration system for a nearly zero energy greenhouse in arid region. Journal of Cleaner Production 2020; 254: 119990, DOI: 10.1016/j.jclepro.2020.119990

[5] Zhang, L, Xu, P, Mao, J, Tang, X, Li, Z, Shi, J. A low cost seasonal solar soil heat storage system for greenhouse heating: Design and pilot study. Applied Energy 2015; 156: 213–222, DOI: 10.1016/j.apenergy.2015.07.036

[6] Lammle, Herrando, Ryan, Basic concepts of PVT collector technologies, applications and markets 2020, DOI: 10.18777/ieashc-task60-2020-0002

[7] Ganiyu, Quansah, Ramde, Seidu, Adaramola, Investigation of Solar Photovoltaic-Thermal (PVT) and Solar Photovoltaic (PV) Performance: A Case Study in Ghana 2020, DOI: 10.3390/en13112701.

[8] Israel Urieli, The Second Law of Thermodynamics, https://www.ohio.edu/mechanical/thermo/Intro/Chapt.1_6/Chapter5.html/ 15.06.2022

[9] Heat pumps: a versatile solution for low-carbon cities, http://eu-gugle.eu/heat-pumps-a-versatile-solution-for-low-carbon-cities/ 15.06.2022

[10] 16 Parts of Heat Pump and Functions (Clear Guide), https://www.linquip.com/blog/parts-of-heat-pump/ 15.06.2022

[11] Water Source Heat Pumps Explained, https://www.controlairsystems.com/water-source-heat-pumps-explained/ 17.06.2022

[12]Horizontal vs vertical ground source heat pump systems, https://www.yesenergysolutions.co.uk/advice/ground-source-heat-pump/horizontal-vs-vertical-ground-source-heat-pump-systems/ 17.06.2022

[13] Güleryüz, 2019, Güneş Enerisi Destekli Isı Pompası Sisteminin Termodinamik Analizi, Yüksek Lisans Tezi, Kütahya Dumlupınar Üniversitesi, Kütahya, Türkiye,20-22.

[14] Google Maps. _Izmir-Turkey latitude value; 2016. <https://www.google.com.tr/ maps/place/%C4%B0zmir/@38.4178606,26.9396755,11z/data=!3m1!4b1! 4m5!3m4!1s0x14bbd862a762cacd:0x628cbba1a59ce8fe!8m2!3d38. 4237391!4d27.1427536> [accessed 16.04.22].

[15] Karademir, 2017, Toprak Kaynaklı ve Güneş Enerjisi Destekli Isı Pompasının Bursa'da Sera Isıtılmasında Kullanılabilirliğinin Araştırılması, Yüksek Lisans Tezi,Uludağ Üniversitesi, Bursa, Türkiye, 65-110.

[16] Ozturk, AH. Antalya iklimi koşullarında sera ısıtma amacıyla güneş enerjisinin duyulur ısı olarak depolanması için tasarım değişkenlerinin belirlenmesi [Determination of Design Variables for the Storage of Solar Energy as Sensible Heat for Greenhouse Heating in Antalya Climate Conditions] Tesisat Mühendisliği 2012; 129: 38- 50.

[17] Karaca, G, Dolgun, EC, Koşan, M, Aktaş, M. Photovoltaic-Thermal solar energy system design for dairy industry. Journal of Energy Systems 2019; 3(2): 86-95, DOI: 10.30521/jes.565174

[18]https://www.yakupyilmazboru.com/2022-guncel-boru-profil-fiyat-listesi.html/
22.06.2022
[19] European Commission Photovoltaic Geographical Information, https://re.jrc.ec.europa.eu/pvg_tools/en/#DR/ 22.06.2022

8. APPENDICES

MATLAB Codes

```
%% Greenhouse Q_Loss Calculations for Every Hour in 2020
t=1:8784;  %2020 every hour time
A_1=72.5;  %Greenhouse lateral area m^2
R_1=0.26;  %Thermal conductivity of polyethilen m^2*k/W
A_2=46.56;  %Greenhouse roof area m^2
R_2=0.26;  %Thermal conductivity of polyethilen m^2*k/W
T_i=18;  %Greenhouse optimal inside temperature
T_d=xlsread('values','F:F'); %Outside temp
f_w=1;  %wind factor
f_c=0.95;  %structure factor
f_s=1.03;  %system factor
Q_loss=[(A_1/R_1)+(A_2/R_2)]*abs(T_i-T_d)*f_w*f_c*f_s;  %Heat loss of the
greenhouse
Q_loss2timePlot=plot(t,Q_loss,'b');
xlabel('time(hour)');
ylabel('Heat loss of the Greenhouse');
%% Heat Pump Calculations
Mon=1:1:12; %months
m_w=2; %mass flowrate of water
n_comp=0.80;   %efficiency of compressor
n_mech=0.80;   %mechanical efficiency
n_blt=0.95;    %belt efficiency
n_elen=0.96;    %electical engine efficiency
h_2s=[425,424,423,423,423,422,422,421,422,423,423,424]; %average monthly
enthalpy values
h_1=[397,398,400,401,403,407,409,409,406,404,402,399]; %average monthly
enthalpy values
h_2=[432,431,429,429,428,426,425,425,427,428,428,430]; %average monthly
enthalpy values
h_3=[256,256,256,256,256,256,256,256,256,256,256,256]; %average monthly
enthalpy values
h_4=[256,256,256,256,256,256,256,256,256,256,256,256]; %average monthly
enthalpy values
W_comp=(m_w*(h_2s-h_1))/(n_comp*n_mech*n_blt*n_elen);  %%capacity of
compressor
Q_evap=m_w*(h_1-h_4);  %%capacity of evaporator
Q_cond=m_w*(h_2-h_3);  %%capacity of condenser
Q_hp=W_comp;
COP=Q_evap./W_comp;
COP2Month=plot(Mon,COP,'ro-');
ylim([0 10]);
xlabel('Months');
ylabel('COP Values');
title('COPvsMonths Graph');
bar(Mon,W_comp,'r');
xlabel('Months');
ylabel('Electrical Demand');
plot(Mon,W_comp,'-om'); ylim([0 120]);
xlabel('months');
ylabel('Compressor work (kW)');
%% Global Irradiance Calculation
t=1:8784;  %2020 every hour time
I_t=xlsread('gi','F:F');
plot(t,I_t,'c')
xlabel('time(hours)');
ylabel('Global Irradiance(W/m^2)');
%% Collector Q Calculations
A_col=30;  %Collector surface area (m^2)
n_col=0.40;  %Collector efficiency
n_m=0.70;  %System efficiency wihtout collector
Q_col=A_col*I_t*n_col*n_m;  %Heat collected from PVT Collector
plot(t,Q_col,'g');
xlabel('time(hours)');
```

```
ylabel('PVT Collector Heat Collection');
%% Economical Calculation
O_M=93.72;
CE_g=962;
Insurance=23.43;
I_I=9372;
A_S=((CE_g)-(O_M+Insurance))*Years;
Years=1:12;
bar(Years,A_S,'g');
xlabel('years')
ylabel('Annual Savings Cumulative');
title('Years Over Annual Savings Cumulative')
```

Heat pump catalog

Heat pump		Type	GS07/B	GS09/B	GS12/B	GS10/B	GS13/B	GS15/B	GS20/B	GS26/B	GS30/B
Dimensions,weights,connection dimensions											
Dimensions		HxWxD	1040x600X640							1040x800X640	
Weight		kg	107	132	142	132	142	130	162	192	197
Refrigerant		Type	R410A								
Filling weight		kg	1.60	1.75	1.90	1.80	1.80	2.20	2.75	3.10	3.60
Permissible operating pressure		Mpa	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Pipe connector-hot side		Inch	G1"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/2"	G1 1/2"	G1 1/2"
Pipe connector-cold side		Inch	G1"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/4"	G1 1/2"	G1 1/2"	G1 1/2"
Evaporator		Type	Brazed plate heat exchanger								
Condenser		Type	Brazed plate heat exchanger								
Compressor			1xRotary	1xScroll							
Running current at B0/W35		A	7.73	9.74	13.60	4.93	6.23	7.20	9.35	11.80	16.10
Starting current compressor (with st		A	23	38	52	49	58	62	80	110	124
Soft-start relay			Included as standard			none					
Performance Heat pump											
Heat output	at B0/W35	kW	6.9	8.6	11.4	9.5	12.6	14.7	19.2	27.3	34.0
Power consumption	at B0/W35	kW	1.75	2.25	2.96	2.42	3.23	3.80	4.92	7.05	8.80
Performance factor	at B0/W35		3.94	3.82	3.85	3.93	3.9	3.87	3.9	3.87	3.86
Indoor side volume flow	at B0/W35	m3/h	1.19	1.48	1.96	1.63	2.17	2.53	3.30	4.70	5.85
Indoor side pressure dr	at B0/W35	kpa	10	12	15	13	21	22	29	36	39
Outdoor side volume flo	at B0/W35	m3/h	1.63	2.01	2.67	2.24	2.96	3.44	4.51	6.40	7.96
Outdoor side pressure	at B0/W35	kpa	13	14	22	20	23	27	34	40	46
Heat output	at W10/W35	kW	10.0	11.4	15.2	12.8	17.3	19.8	25.8	35.2	44.7
Power consumption	at W10/W35	kW	1.82	2.12	2.85	2.36	3.2	3.72	4.85	6.58	8.38
Performance factor	at W10/W35		5.49	5.38	5.33	5.42	5.41	5.32	5.32	5.35	5.33
Indoor side volume flow	at W10/W35	m3/h	1.72	1.96	2.61	2.20	2.98	3.41	4.44	6.05	7.69
Outdoor side volume flo	at W10/W35	m3/h	2.23	2.66	3.54	2.99	4.04	4.61	6.01	8.20	10.41
Cool output	at W30/W7	kW	7.5	9.3	12.8	10.2	12.9	15.0	20.4	28.1	34.2
Power consumption	at W30/W7	kW	1.85	2.32	3.20	2.58	3.28	3.78	5.00	7.08	8.60
Performance factor	at W30/W7		4.05	3.99	4.01	3.95	3.92	3.96	4.08	3.97	3.98

Izmir Solar Radiation Data for Several Months
August

2020	8	8	00	00	0	0	23,29	3,03
2020	8	8	01	00	0	0	23,21	2,9
2020	8	8	02	00	0	0	23,11	2,76
2020	8	8	03	00	0	0	22,98	2,55
2020	8	8	04	00	47,21	8,33	22,96	2,34
2020	8	8	05	00	213,11	19,92	23,61	2,21
2020	8	8	06	00	437,51	31,67	24,6	2,21
2020	8	8	07	00	646,26	43,27	25,45	2,07
2020	8	8	08	00	768,13	54,19	26,6	2,76
2020	8	8	09	00	858,51	63,25	27,7	3,45
2020	8	8	10	00	851,57	67,8	28,55	3,86
2020	8	8	11	00	708,33	65,16	29,14	4,14
2020	8	8	12	00	816,2	57,04	29,36	4,28
2020	8	8	13	00	697,86	46,49	29,35	4,28
2020	8	8	14	00	507,96	35,01	28,95	4,55
2020	8	8	15	00	278,93	23,26	28,19	4,69
2020	8	8	16	00	78,5	11,6	27,25	4,28
2020	8	8	17	00	0	0	26,1	3,45
2020	8	8	18	00	0	0	25,35	3,03
2020	8	8	19	00	0	0	24,77	3,03
2020	8	8	20	00	0	0	24,46	2,69
2020	8	8	21	00	0	0	24,15	2,34
2020	8	8	22	00	0	0	23,84	2,07
2020	8	8	23	00	0	0	23,62	2
2020	8	9	00	00	0	0	23,51	2
2020	8	9	01	00	0	0	23,46	2,14
2020	8	9	02	00	0	0	23,46	2,48
2020	8	9	03	00	0	0	23,52	2,97
2020	8	9	04	00	40,08	8,18	23,68	3,45
2020	8	9	05	00	159,2	19,78	24,41	3,79
2020	8	9	06	00	431,09	31,53	25,34	4
2020	8	9	07	00	605,63	43,12	26,7	3,93
2020	8	9	08	00	672,69	54,01	27,65	4,21
2020	8	9	09	00	444,45	63,02	28,54	4

Thermal resistances of greenhouse building materials (R)

Malzeme		**Kalınlık**	**RSI değerleri** $(\frac{m^2\,{}^{\circ}C}{W})$
Cam	Tek cam	3	0.15
	Çift Cam (6 mm hava boşluklu)		0.27
	Fiberglas		0.16
	Plastik	0.15	0.14
	Çift Akrilik veya Polikarbonat	6 - 12	0.30 – 0.35
	Hava Boşluklu Çift Katlı Naylon		0.25 – 0.28
İnşaat Malzemeleri	Asbestos Çimento	6	0.16
	Ağaç	25	0.30
	Beton	100	0.20
		150	0.23
Beton Blok		200	0.35
	İzolasyonlu Rijid Polystrene	25	0.88
	Polietilen Foam	25	1.10

Yakup Yılmaz Boru Profil A.Ş. Fiyat Listesi 09/03/2022

EBAT (mm)				ET KALINLIĞI (mm) - TL / mt							
				1,20	1,50	2,00	2,50	3,00	4,00	5,00	6,00
15x15	10x20			20,05	23,47						
20x20	10x30	15x25		26,12	28,76	35,13	45,04				
25x25	20x30			32,45	34,77	42,01	52,82	62,48			
30x30	20x40			38,43	41,46	50,99	62,47	74,36	107,25		
30x40				45,37	47,60	58,89	73,24	86,64			
40x40	30x50			51,88	54,11	66,40	80,66	96,21	129,72	163,03	
50x50	40x60			66,26	68,74	84,72	101,79	121,45	162,30	198,21	
60x60	40x80				87,36	103,31	124,23	148,26	199,08	246,74	
70x70	60x80	50x90	40x100		108,04	127,19	147,94	176,61	234,09	289,88	383,41
50x100					126,67	135,27	158,44	188,56	245,98	307,78	384,26
80x80	60x100					145,40	169,43	201,14	263,67	329,99	402,76
90x90	60x120	80x100				164,02	190,47	226,85	299,35	373,71	464,55