A Study on Greenhouse Heating System with

Air Source Heat Pump

by

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(Supervised by Professor Youn Cheol Park)

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Монголд байгаа Аав, Ээж, Ахдаа хол байгаа ч гэсэн үргэлж надад урам зориг өгч тусалж дэмждэгт маш их баярлалаа. Мөн бүх хамаатан садандаа та бүгдийн урмын үгс итгэл найдвараар сургуулиа төгсөж, дипломоо амжилттай хамгаалж чадсан юм шүү. Төгсгөлд нь бурхны оронд байгаа Эмээдээ талархал илэрхийлмээр байна. Магистраар суралцах болон эрдмийн мөр хөөх нь Эмээгийн маань том түлхэц, зөвлөмж, итгэл, хайр байсан юм. Бүгдэд нь маш их баярлалаа.

Contents

Nomenclature

COP	Coefficient of Performance
HP	Heat Pump
Com	Compressor
Eva	Evaporator
CO2	Carbon dioxide
°C	Celsius
W/m^2	Watt per square meter
Ha	Hectare
Km	Kilometer
M	Meter
Mm	Milometer
kW	Kilowatt
W	Watt
Q_{GHL}	Greenhouse heat loss rate (kW)
$A_{1}, A_{2},$	Surface area of various components in greenhouse (m2)
R_{1}, R_{2}	Thermal resistance of component in greenhouse (m2◦CW−1)
T_i	Inside temperature of Greenhouse (°C)
T_o	Outside temperature of Greenhouse (°C)
f_w	Wind or exposure factor for greenhouse

f_c	Construction type or quality factor for greenhouse
f_s	System factor for greenhouse
Q_{con}	Heat transfer rate condenser (kW)
Q_{eva}	Heat transfer rate evaporator (kW)
m_{ref}	Mass flowrate (LPM)
$h_{con,I}$	Specific enthalpy of inlet compressor (LPM)
$h_{con,o}$	Specific enthalpy of outlet compressor (LPM)
$h_{eva,i}$	Specific enthalpy of inlet evaporator (LPM)
$h_{eav,o}$	Specific enthalpy of outlet evaporator (LPM)
w_{comp}	Power input to compressor (kW)
w_{pump}	Power input to pump (kW)
$w_{fancoil}$	Power input to fan coil unit (kW)
τ_{SR}	Transmittance (Solar radiation)
τ_{PAR}	Transmittance (Photosynthetically active radiation)
τ_{LWIR}	Transmittance (long-wave infrared)

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Abstract

Energy conservation is an essential issue in greenhouse farming. Since greenhouse operations use significant amounts of fossil fuel oil, energy conservation is expected to protect farmer's profit and reduce global warming. To have good environmental conditions, several variables must be regulated. Inside a greenhouse, temperature, humidity, and light are the most significant parameters to be regulated, especially in winter and at low temperatures at night. This study was conducted greenhouse heating for using heat pump system that surplus air source and outdoor air source. The greenhouse experiment system performed on December 08, 2020, and December 13, 2020, selected days in similar environments of condition and experiment to measure the required parameters to be used in a greenhouse with a length, width, and height was 10.0m, 5.4m, 4.6m and located in Jeju National University, Korea. This system consists of a heat pump system including heat storage tanks, fan-coil-units in the greenhouse, and an electric heater for supplemental heating. The experiment condition was to run a heat pump system using a surplus air source and outdoor air source each day. The experiment of greenhouse inside the set temperature was between 12℃ to 15℃. The greenhouse heating system has two modes. The first mode was heating mode, the greenhouse inside temperature lower than 12℃ and heat it until 15℃. The second mode was storage mode that stored heat from heat pump to storage tanks when the greenhouse temperature was higher than 15℃. In the results storage mode: surplus heat source system was performed the average power consumption and COP were, 3.8 kW and 3.7 and outdoor heat source system was the average power consumption and COP were 3.7 kW and 2.9. Heating mode: The surplus heat source system evaluated with average power consumption and COP was 3.8 kW and 3.7 and outdoor heat source system. The average power consumption and COP were 3.7 kW and 2.9, respectively. In conclusion, experimental results show that surplus heat source of heat pump system was a high estimated average capacity 12.8 kW, while the outdoor heat source of heat pump system was 10.6 kW. Greenhouse heating system of surplus heat source energy saved 7.6 % than an outdoor heat source system. Furthermore, it saved power consumption by 16.6 % than the outdoor heat source system when heating mode performed. In COP of surplus heat source system installed an average of 3.6 and outdoor heat source system average of 2.7. The surplus heat source of heat pump was 0.9 higher than the outdoor heat source heat pump.

1 Introduction

1.1 Background

Population growth requires a higher output harvest. Greenhouses are used to increase efficiency and manage growth in all climates and are among the most energy consumption sectors in the horticultural field. The greenhouse is also one of the most productive sectors, which have a massive profit of 10 to 20 times higher than natural, free cultivation [1]. In order to produce improved quality, commercial greenhouses are used to grow plants and defend them against natural environmental impacts, such as wind or typhoon and rain. The ability to grow out of season is another advantage of a greenhouse. In several countries, horticultural production using greenhouses has risen dramatically over the past twenty years. [2][3]. A commercial greenhouse's key aim is to produce a high yield in the field outside the cultivation season by maintaining an optimal temperature at any point of the harvest [3]. In a greenhouse without a heating system, the air temperature can fall below the optimum range for crops in the cold winter, especially during the night, so that an appropriate heating system retains the optimum temperature. Fossil fuel heating methods are currently generally used for this aim, but they emit greenhouse gases (e.g., CO2) and air contaminants. (e.g., NOx, SOx) [4]. An energy-efficient alternative heating system for greenhouses is needed to reduce greenhouse gas emissions and air pollution and handle the fast diversity of oil prices [5]. Heat pumps have long been commonly accepted as energy-efficient heating and cooling systems and have been recommended since the oil shock in the early 1970s for greenhouse heating. [6][7]. Heat pumps, however, have not been widely used because of their poor coefficient of performance (COP) and high construction costs [5]. Nevertheless, heat pumps are now being amended as an alternative heating system as electricity prices have escalated and technological progress has been made. There are two types of heat pumps: heat pumps from the ground-source (geothermal or groundwater) and heat pumps from the air source. Ground-source heat pumps, which switch heat with outside air due to steady and moderate ground temperatures, are stated to be higher effective than air-source heat pumps [8], and ground-source heat pumps have been used in greenhouse heating experiments in recent years. The thermal efficiency of household air-air heat pumps has recently improved dramatically, mainly due to industry competitiveness, and Japan has registered COP values greater than 6 [9]. Therefore, the considerable scope has been predicted for greenhouse heating with the use of domestic air-air heat pumps. Nonetheless, few studies have been published on greenhouse air-source heat pumps and none, as far as we know, on household greenhouse air-air heat pumps.

Jeju island in 2018, a single-span greenhouse accounted for 89.04% with an area of 50,876 ha, while a multi-span greenhouse accounts for 10.95% with an area of 6,256 ha amount horticultural facilities of 57,132 ha in Korea. Furthermore, the total single-span green made of Polyethylene Film greenhouse 50,876 ha, Polycarbonate Panels 65 ha, and Glass 285 ha, respectively [10]. The productivity of crops depends on the climate and, more importantly, on the greenhouse system's thermal efficiency.

1.2 Climate conditions

Jeju Island, the largest island off the Korean peninsula, is positioned 450 km south of Seoul, the capital of the Republic of Korea (latitude of 33°06’-34°00' and longitude of 126°08-126°58'). The volcanic island was formed by several eruptions from 0.7 to 1.2 million years ago. The island is 32 km in length and 74 km wide, with a total area of 1,828 km2, and its summit, Halla Mountain (1,950 m elevation), is placed in the middle of the island. The topographical slopes are moderately steep (~5 °) in the north and east directions but mild (~3 °) in the west and south directions. The bulk of dwelling house is found in the coastal areas with low elevations (0 to 300 m height). Various farming operations have been carried out in the middle and high elevation regions, such as planting numerous tropical crops, vegetables, and flowers and raising goats, pigs, horses, and fowl. Worldwide tourists are attracted by unique geographical structures such as pillar-shaped joints and warm weather, and tourist facilities occupy 51.6 percent of the annual domestic product area.

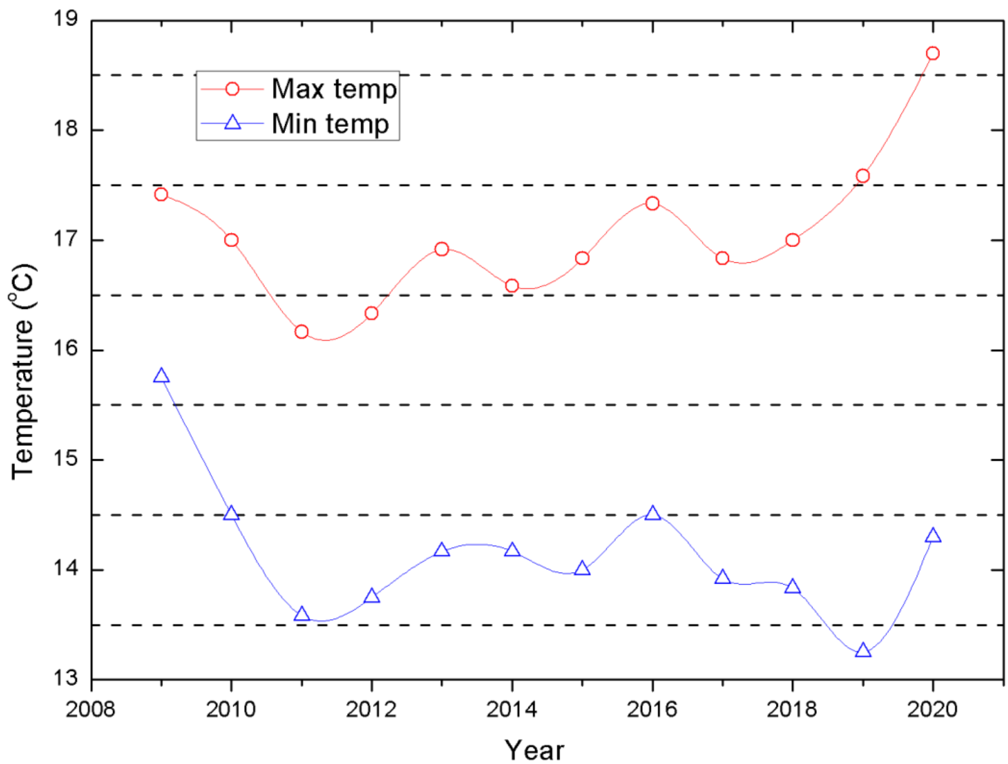

Fig. 1. Maximum and Minimum temperature in the last decade in Jeju Island.

As a result of the East Asian monsoon's influence, the weather of Jeju Island is characterized by hot, humid summers and cold winters. From June to September, the southeastern summer monsoon transports tropical climate from the West Pacific and the East China Sea, producing ample rainfall over the island and the Korean Peninsula. During the season, powerful typhoons are numerous. The island's mean annual temperature varies from 15.0 to 17.0°C. The yearly average temperature is 16.2 °C on the south coast, where Hanon Maar is located, and the average temperature is 26.6 °C and 6.6 °C in August and January. Over the year, the weather generally varies from 2.7°C to 29°C and is extraordinary under -1°C or over 33°C. [12]

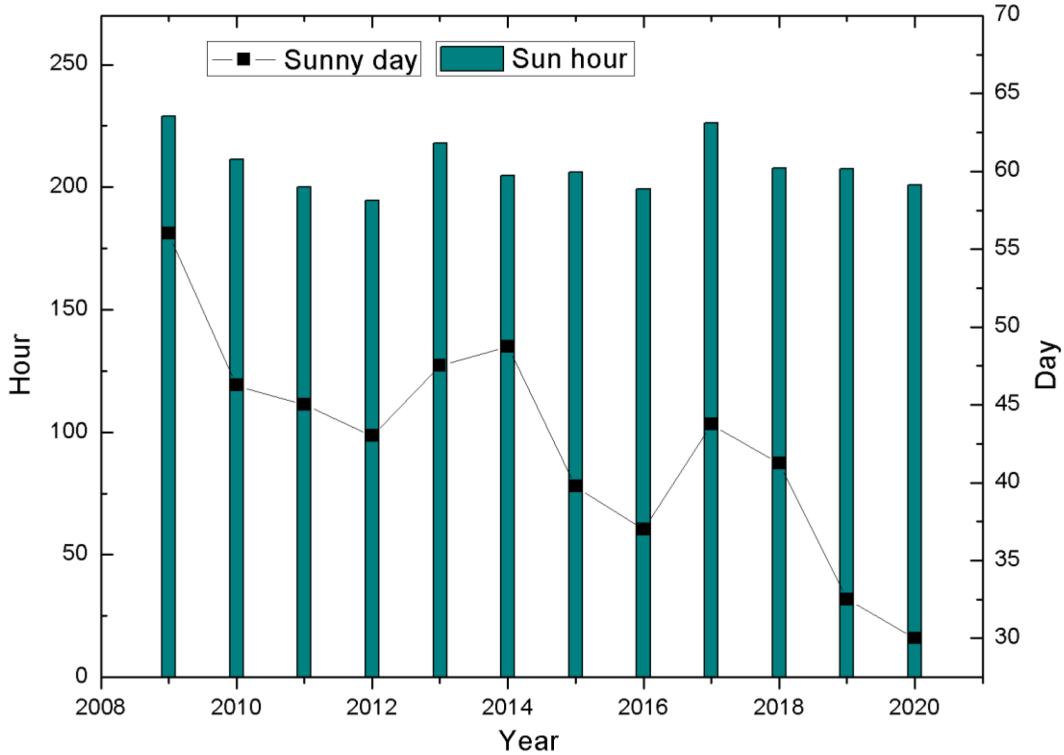

Fig. 2. Sunny day and Sun hour compared to the last decade in Jeju Island.

The length of the optimal sunny day in Jeju varies significantly throughout the year. The shortest day in 2020 was December 22, with 9 hours and 56 minutes of a sunny hour, so the longest day was June 22, and the daylight hours are 14 hours and 23 minutes [13]. Annual precipitation is considerable, averaging 1850 mm, and in summer (June-August) about 40 percent falls. The dry cold northwestern winter monsoon affects the winter climate. Still, the temperatures are mild and humid due to the maritime effect of the warm Kuroshio Current, contrasted with those of other regions at the same latitude. The weather of the island changes significantly with the topography [12].

2 Greenhouse construction

Greenhouse construction can be discussed for its style, Frame material, Glazing material, Flooring, and base. Choosing good materials means fewer heat losses and useful sun energy transmission, which are important for greenhouse's energy balance.

2.1 Greenhouse Style

Greenhouses can be categorized into two types in terms of style as free-standing and gutter connected.

Free-standing Gutter-connected

Fig. 3. Main two types of greenhouse.

Free-standing greenhouses

That is the typical style for small-scale greenhouses less than 1000 m2. A free-standing greenhouse can have a gothic, Quonset, or gable roof shape. This style has lots of advantages but on the other hand, some disadvantages compared with gutter-connected one. Here are some benefits of free-standing greenhouses [14].

- It is possible to start with one and add more when the business grows.
- It is reasonable and straightforward to create distinct environments for each house. Different temperatures and humidity levels can be set for each house since each is operated by its own heating and cooling system. In the wintertime, it can be shut down some of the houses without affecting the other houses.
- Best style for heavy snowing regions, there is no need to melt snow on the roof
- To construct is more straightforward and less costly.

Gutter-Connected Greenhouse

A greenhouse attached to the gutter is a series of gothic or gable arches connected around each other. This greenhouse style is recommended for large-scale more than 2000 m2. Gutter-connected greenhouses are more costly than free-standing ones in terms of construction cost but are less expensive in energy losses. Here are some advantages of gutter-connected greenhouses [14]:

- It has a smaller surface area to floor area ratio, and it means fewer heat losses, which can reach up to 25% saving on energy consumption.
- Less land is needed relative to a free-standing one for the same growing space.
- With the automatic and moving trays and bench, labor costs decrease remarkably.
- Suitable and easy to centralize heating, cooling, and controlling system for the greenhouse.

2.2 Greenhouse covering material type

The greenhouses were made entirely of cypress wood frames and single lite glass. Substantial advances in building methods and materials have been seen in recent years. In general, it can be considered that architecture falls under one of the following four categories:

- Glass
- Plastic film
- Fiberglass or similar rigid plastics
- Combination of two and three.

Glass greenhouses are the most expensive to build-up due to both the glazing material's cost and the demand for a more robust framework to carry the glass.

plastic film is high in that it generally demands replacement on 3-year intervals or less, depending on the quality of the material. [15]

Fig. 4. Covering material type of greenhouse.

Fiberglass greenhouses are identical to the glasshouses mentioned above in terms of design. They typically have a peaked roof style, but due to the fiberglass's lower weight, they need less structural support. The fiberglass house's heat loss is almost the same as that of a glasshouse. While the fiberglass content has a lower conductivity than glass, this has a low effect when considered in the house's general heat loss.

2.3 Frame material

Four types of frame materials are available, and each has its own advantages. Here comes some description for each class [16]:

Plastic or PVC

Inexpensive, easy to assemble, easy to move, or increase. But all depends on the location of the greenhouse, and this type of frame is not suitable for a windy and heavy snowing zone and is not compatible with all glazing materials.

Aluminum

The most significant advantage of aluminum is that it doesn't rust, making it suitable for humid conditions. It can withstand extreme weather, is easy to assemble, and is compatible with various glazing materials like; plastic, glass, and polycarbonate.

Wood

Wood is best compatible when combined with glass as a glazing material. It has a plus advantage of absorbing and saving heat during day time and releasing it during the night. Wood absorbs moisture, and it causes rot faster, so it is not recommended for high humid climates.

Galvanized Steel

This is the most expensive choice. It can be used if an extremely strong greenhouse is needed. Since steel is substantial, less framing elements will be required for your greenhouse, which means fewer shadows will be cast into the greenhouse. However, most steel doors, rather than solid glass or polycarbonate plates, are intended to be used with polyethylene film. Greenhouses are popular with commercial growers with galvanized steel frames and polyethylene film covering. Also, for galvanized steel, a significant drawback is that the galvanizing will inevitably wear, and the steel will rust.

2.4 Reduce Air Leaks

To have reasonable control of the greenhouse air exchange rate and have a tight greenhouse, it is essential to cover all the greenhouses' leakages and repair all broken glazing materials.

2.5 Flooring or Base

The floor must be free draining, so if a solid floor wants to be based, it must be placed for drainage. If slap is solid without drainage, collecting water on the floor can happen, and in the winter, it changes to solid ice, which is too slippery to work. Good insulation is required for the cold climate, and it is recommended to use a weed control mat below the floor.

2.6 Heat Exchangers

Heat exchanger means transferring of heat from one stream to another without mixing mostly because of contaminants in the high-temperature stream or different pressure levels. Heat exchangers are divided into three main types depending on the direction of flows:

- parallel flow
- counterflow
- crossflow

Heat exchangers are available in liquid to liquid, gas to gas, and gas to liquid or liquid to gas types and depend on the temperature and pressure range, have a variety of types to achieve the best efficiency in the system.

The most common use of heat exchangers in the industry is to transfer heat from exhaust gases to combustion-air, which goes to the furnace for reheating. It means less energy is required to achieve the final temperature in the furnace. There are a brief explanation of different types of heat exchangers [17].

- Recuperator
- Regenerator
- Passive air preheater
- Finned tube heat exchanger/Economizer
- Waste heat Boiler

Recuperator

Recuperators are made of ceramic or metal to support a large range of temperatures and are useful for medium to high range temperature systems. Heat transfer can be accomplished by radiation, convection, or a combination of radiation and convection, and are available in different models for best performance in different applications. The most common applications of recuperators are on annealing or soaking ovens, melting furnaces, gas incinerators, afterburners, radiant tube burners, and reheat furnaces [17].

Regenerator

Regenerators are constructed in two main models; furnace regenerator and rotary regenerator. Furnace regenerators consist of two brick chambers, in which hot combustion air flows through one and incoming combustion air through another. The other regenerators are named rotary or hot wheel, and as the name implies, it consists of a rotating porous disk located across two ducts that hot gas flows from one duct, and another duct flows cold gas. These types of exchanges are restricted to low to medium temperature applications, but with the ceramic material, they can support even high-temperature applications. In a hot wheel, two flows are mixed, which exhaust gas can transfer contaminants to another one. Hot wheels can be beneficial if a transfer of moisture is required [17].

Passive Air Preheater

Passive air preheater used for gas to gas systems there are available in two major types; plate type and heat pipes. The most common applications are for steam boilers, ovens, gas turbine exhaust, and recovery from the conditioned air.

The plate type consists of several parallel plates, in which hot and cold gas flows alternately between plates, and it means a large area for heat transfer. Heat pipes consist of several pipes with sealed ends, which each contains a capillary wick structure that uses for significant heat transferring of working fluid in hot and cold [17].

Finned Tube Heat Exchangers/Economizers

It is called for the most common and simple type of heat exchangers that are used for gas to the liquid system. It consists of round tubes which contain hot gases and liquid flow through the tubes to receive heat. They support low to medium temperature systems and are used mostly to heat water for space heating or domestic hot water or boiler feed water preheating applications [17].

Waste Heat Boilers

Waste heat boilers are water tube boilers used for medium to high systems to generate steam. They are available in a variety of capacities to support different flow levels of steams [17].

2.7 Control system and sensors

Greenhouse Indoor environment affects by the outdoor environment. A controlling system is required to control the CO_2 level, lighting, temperature, and humidity level inside the greenhouse for better cultivation. This can be accomplished by a simple system like a thermostat and timers or a very sophisticated system of unit computer controlling system. A control system for a greenhouse can control [18]:

- Temperature Control (heating & cooling)
- Air
- Water Supply and Storage Systems
- Heat Storage Systems

Sensors use in all-controlling systems, and it must be considered that the accuracy of a control system all is limited to responsiveness and accuracy of sensors. Sensors are available to control these parameters for a greenhouse [18]

3 Experimental devices and methods

3.1 Experimental methods and greenhouse properties

An experiment to measure the required parameters to be used in the study was conducted in a greenhouse with a length, width, and height was 10m, 5.4m, 4.6, covered with polyethylene film (2 mm thickness) Fig1. A greenhouse is located at Jeju National University (South Korea, Jeju Province latitude 33°27'34.4 N, longitude 126°33'44.5E). The greenhouse was placed towards the south along south-north the experiments were carried out on December 08, 2020, and December 13, 2020, selected days in similar environments of condition and working day in winter. The experiment started 00.00 min to continuously 24 hours, and inside, outside air temperatures sensor's data were automatically recorded at 10 min intervals, and the average of each sensor was used. This study continuously measured the inside, outside, storage tanks, and heat pump source temperatures of the greenhouses system, so heat pump power consumption and flow meter of each circulate pumps.

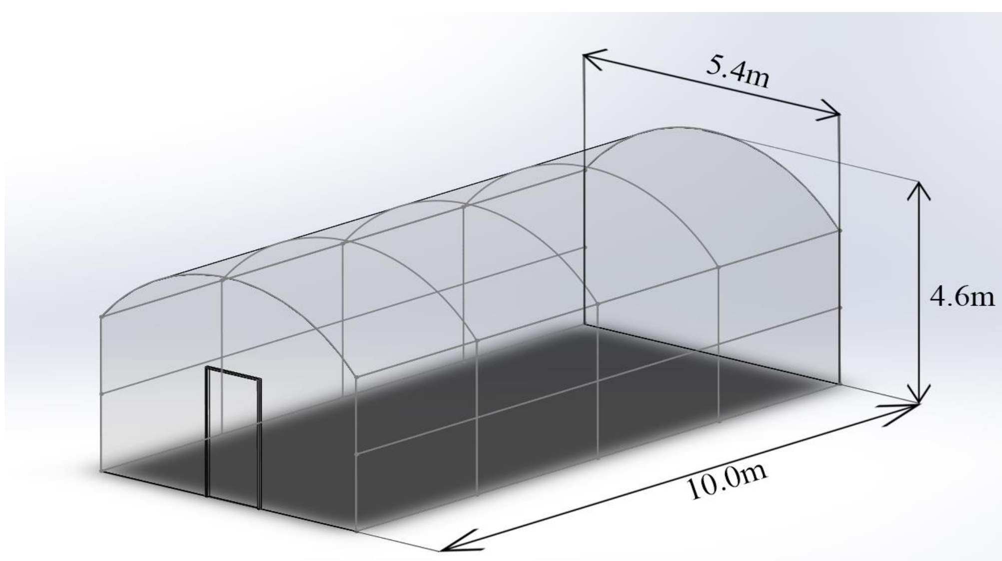

Fig. 5. Experimental facility of greenhouse heating system.

This experiment was mainly based on two separate parts as follows: First mode was heating mode that heating greenhouse inside temperature lower than 12℃ and heat it up until 15℃. The second mode was Storage mode that stored heat from heat pump to storage tanks when the greenhouse inside temperature was higher than 15℃.

Table 1. Greenhouse properties

Area (m^2)	54
Height (m)	4.6
Sidewall (m^2)	68
Front and back side (m^2)	45.5
Roof (m^2)	60
Volume (m^3)	4857
Thickness(mm)	0.2
Thermal resistance (m^2°C/W)	0.33

Fig. 6. Inside the structure of the greenhouse.

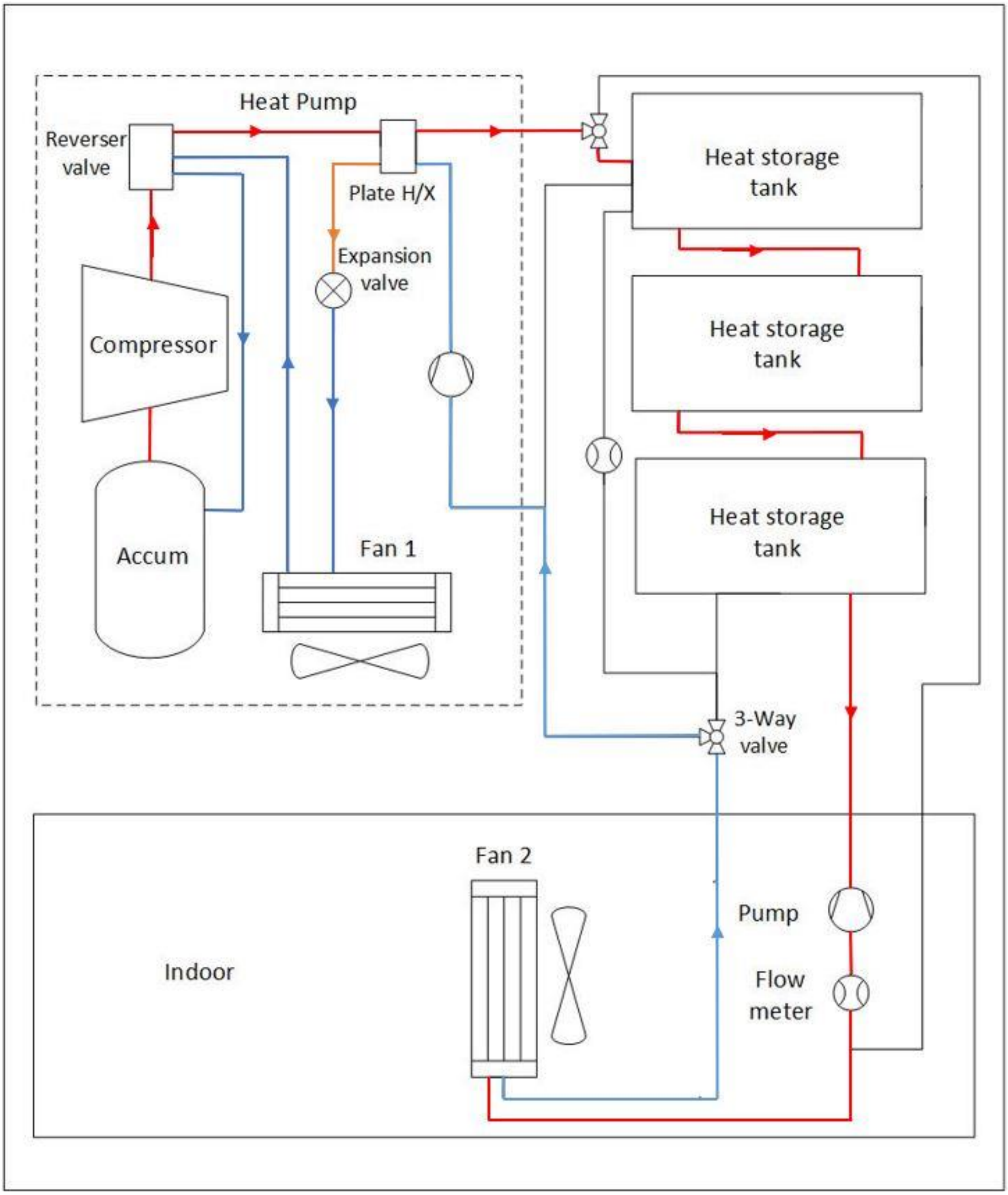

Fig. 7. The main components and schematic of the air source heat pump greenhouse.

In figure 7 shown. The main components and schematic of the air source of heat pump greenhouse. Surplus source heat system is heat greenhouse and utilizes surplus air from the inside greenhouse to heat pump air source. Outdoor source heat system was performed heat pump using outdoor air source, on the other hand used as the same as ambient temperature. Heat pump gain heat to tree storage tanks that heat pump automatically turn off when storage tank temperature reaches 50℃. Hot water permutated all system by circulate pumps when greenhouse inside temperature was higher than 12℃ and on that condition is unprovided under 12℃ change to heating mode that heating greenhouse using the fan coil unit utilize storage tank heat then heat pump automatically work when storage tank temperature was below than 50℃. The air source heat pump and water circulating pump were always working on experiment period time in order to permutate water all system and gain heat water storage tank's temperature reach for 50℃. Greenhouse inside temperate lower than 12℃ changed heat mode that additional fan coil work for maintaining warm in greenhouse temperature. This study aimed to compare the effectiveness of surplus heat source and outdoor heat source heat pump and COP of heat pump systems and how much power consumption is used.

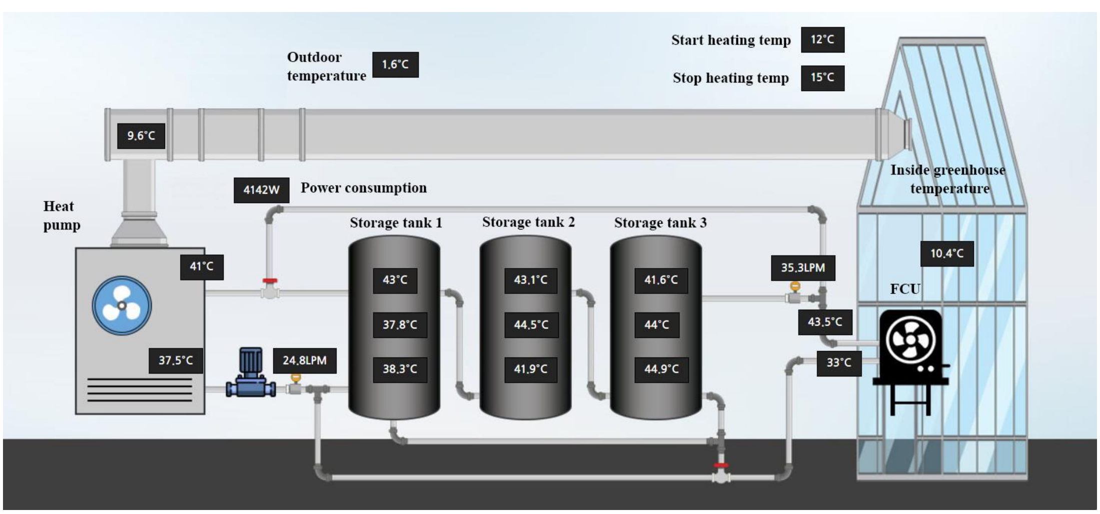

Fig. 8. Greenhouse heating system controlling monitor.

Table 2. Measured parameters total and average.

Number	Outdoor heat source	Surplus heat source	Unit
Average power consumption	3.4	3.3	kW
The temperature of the water heat pump inlet	27.2	35.5	℃
The temperature of the water heat pump outlet	31.1	37.2	℃
The supply water temperature of the fan coil unit	30.2	39.2	℃
The return water temperature of the fan coil unit	23.4	31.9	℃
Outdoor temperature	4.8	1.8	℃
Indoor temperature	13.9	10.4	℃

3.2 Heat losses of greenhouse

The first step in evaluating the greenhouse's heating system capability before choosing the system and its components is heat loss measurement. The heating system should also be correctly dimensioned to satisfy the greenhouse criteria in harsh weather conditions. Greenhouse heat loss is calculated by the following equation [19]:

$$Q_{GHL} = \left(\frac{A_1}{R_1} + \frac{A_2}{R_2}\right)(T_i - T_o)(f_w)(f_c)(f_s)\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Using the above equation, the heat loss (or heating load) of the greenhouse was found to be 7.6 kW by the following procedure:

$$A_1 = 2 * \left((5.4 + 10) * 2 + \left(\frac{5.4 * 1.2}{2}\right)\right) = 68m^2$$

$$A_2 = 2 * 10 * 3.4 = 68m^2$$

$$Q = \left(\frac{68}{0.30} + \frac{68}{0.30}\right)(18.9 - 2.1)(1)(1)(1) = 7615.4\,W = 7.6\,kW$$

The greenhouse heat loss is determined as the average value of 7.6 kW occurred average on December 08, 2020, and December 13, 2020, selected days during winter season. The ambient average temperature was measured as 2.1 ◦C on those days. Therefore, the average heating load value of the greenhouse was used in this study.

3.3 Solar radiation greenhouse

The productivity of crops depends on the climate and, more precisely, on the greenhouse system's thermal efficiency. The source receiving the most serious consideration for greenhouse heating is solar energy [20]. For two reasons, solar energy usage is widely significant. First, the advantage is a decrease in the usage of fossil fuels. Second, solar energy is a clean source of energy [21].

Solar energies two types of usage for the agricultural greenhouse sector is active and passive. Passive greenhouses are used and designed to optimize the gain of solar heat as a collector. Active greenhouses are equipped with solar systems that utilize a collecting system, which is separate from the greenhouse cell, with an independent heat storage system. [13]. The greenhouse is a structure used to cultivate and protect plants and crops that exploit solar radiation transmission under controlled conditions to improve the environment of growth, with dimensions that allow people to work inside. The greenhouse can be seen as a solar collector that exploits the sun's radiation to create optimal conditions for plant growth and development.

The solar radiation inside the greenhouse depends on

- incident radiation on the ground;
- shape and orientation of the greenhouse;
- type of structure;
- transmittance, absorption, and reflection of the covering material;
- size and position of the opaque system;
- dust on the cover;
- cover condensation

A greenhouse covering for low-light latitudes should transmit the maximum amount of natural sunlight in the bands required for plant growth. Light falling upon a material is either:

- Reflected
- Absorbed
- Transmitted

Figure 11 illustrates these three characteristics. Not all wavelengths are absorbed, reflected, or emitted equally by the various covering materials and are thus influenced by the nature (color) of light within a greenhouse. Reflection and absorption of the wavelength or bands vital to plant growth should be avoided. A material that allows for the passage of a significant portion of the light is considered translucent. A substance is called opaque, which blocks the fight. Light can travel in one of two directions through a transparent material: clear passage or diffuse. The direct light passage is best illustrated with plain window glass. Light rays pass directly through the glass, maintaining the same direction with minimal distortion or breaking apart [22].

Table 3. Transmissivity coefficients of different greenhouse covering materials.

Transmissivity coefficients, %	Glass 4mm	LDPE 0.2mm
τ_{SR}	80.4	88.6
τ_{PAR}	87.5	91.0
τ_{LWIR}	0.00	53.7

SR: solar radiation; PAR: photosynthetically active radiation; LWIR: long-wave infrared

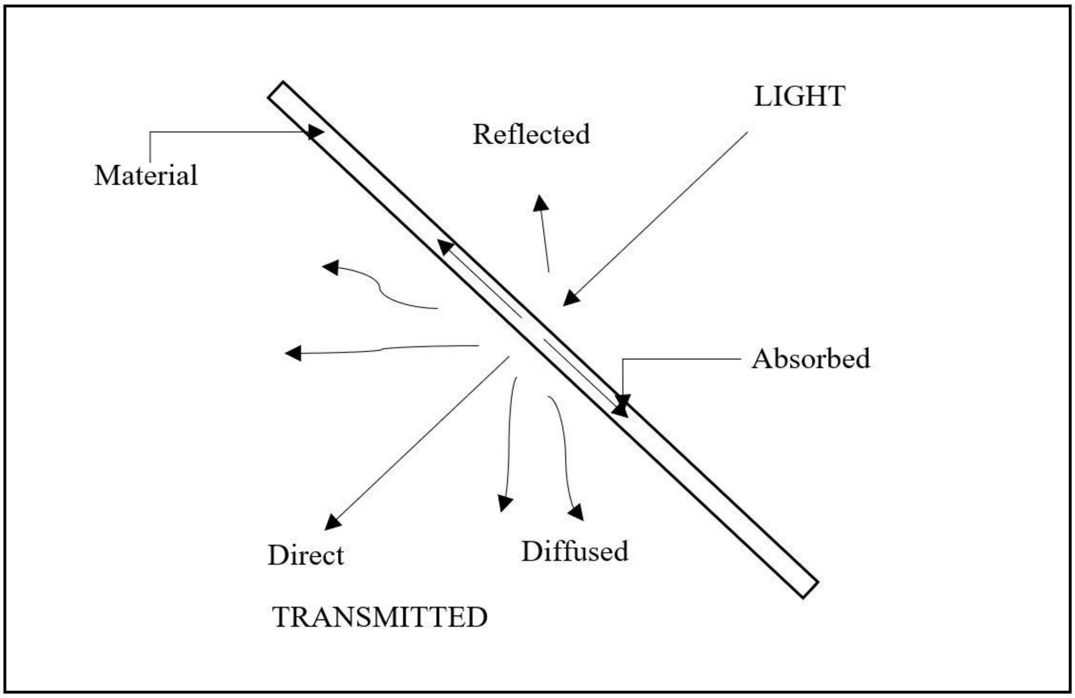

Fig. 9. Light falling upon Greenhouse material, and light is reflected, absorbed, and transmitted.

Solar energy is not only for the use of renewable energies but also widely using the greenhouse to gain the thermal free during day time. For heating greenhouse, two kinds of agricultural greenhouses use solar energy; passive and solar active solar greenhouses. Passive greenhouses are used and required to optimize the gain of solar heat. Active greenhouses are fitted with solar systems that provide an individual heat storage system utilizing a collection system separate from the greenhouse cell.

3.4 Greenhouse heating system

Air source heat pump and water circulate pump were always working on experiment period time in order to gain heat water storage tank's temperature reach for 50 ℃ while in this processing heat pump intake from inside of greenhouse air which means improving the capacity of heat. Water storage tank capacity is 1 ton. As we are known as heat pump power consumption, inlet, outlet water temperature, and flow rate, the coefficient of performance of the overall heating system (COPsys), which is the ratio of the condenser load to total work consumption of the compressor, circulation pump, and the condenser fan-coil unit, was computed by the following equation:

The heat rejection rate in the condenser is calculated by

$$Q_{con} = m_{ref}(h_{con,i} - h_{con,o}) \quad (2)$$

The heat transfer rate in the evaporator is

$$Q_{eva} = m_{ref}(h_{eva,i} - h_{eva,o}) \quad (3)$$

The work input rate to the compressor is

$$W_{comp} = \frac{m_{ref}(h_{con,i} - h_{con,o})}{\eta_{icomp} - \eta_{ocomp}} \quad (4)$$

Hence, the COP of the GSHP can be calculated as

$$COP_{hp} = \frac{Q_{con}}{W_{comp}} \quad (5)$$

The coefficient of performance of the overall heating system (COPsys), which is the ratio of the condenser load to total work consumptions of the compressor, the brine and water circulation pumps, and the fan-coil unit, is computed by the following equation:

$$COP_{sys} = \frac{Q_{con}}{W_{comp} + W_{pump} + W_{fancoil}} \quad \text{......................(6)}$$

3.5 Experimental conditions

In this study, the experiment was divided into two sections storage mode and heating mode. The greenhouse heating starts and stop temperatures were 12.0℃ and 15.0℃. Storage mode working requirements were over 15.0℃ of greenhouse indoor temperature when solar radiation high. The experiment of storage mode was performed that surplus heat source system conducted were average indoor temperature 17.8℃ and heat source temperature 16.4℃, while outdoor heat pump indoor temperature 20.1℃ and heat source temperature 8.1℃. Greenhouse heating mode was performed that surplus heat source system conducted were average outdoor temperature 0.8℃ and heat source temperature 12.5℃, while outdoor heat pump heat source and outdoor temperature 3.5℃.

Storage mode

Table 4. Experiment condition of storage mode.

System	Indoor temperature (℃)	Heat source temperature (℃)
Surplus heat pump	17.8	16.4
Outdoor heat pump	20.1	8.1

Heating mode

Table 5. Experiment condition of heating mode.

System	Outdoor temperature (℃)	Heat source temperature (℃)
Surplus heat pump	0.8	12.5
Outdoor heat pump	3.5	3.5

Table 6. Experiment condition of heating mode. (Operating time and capacity)

System	Capacity (kW)	Operating time (min)
Surplus heat pump	12.3	1010 (16hour 50min)
Outdoor heat pump	10.5	960 (16hour 10min)

Fig. 10. Air source heat pump.

3.6 Heat storage tank

Air source heat pump of water heater is a device that moves heat from the air around to heat water, then satisfies the user's daily demand for hot water heating. The hot water storage tank is widely used, suitable for house heating and greenhouse heating, commercial heating and hot water for big projects, and commercial greenhouse heating. Figure 15 shows the hot water storage tank used in the experiment; each size is one ton (total of three-ton).

Fig. 11. Hot water storage tank (each tank 1ton).

Figure 12, 13, is each storage tank's inside water temperature, specifically night and daytime. Experiment one of the aims is storage tank temperature reach and maintain 50℃ as shown figures surplus heat source of water temperature close to the purpose when the last section of storage mode.

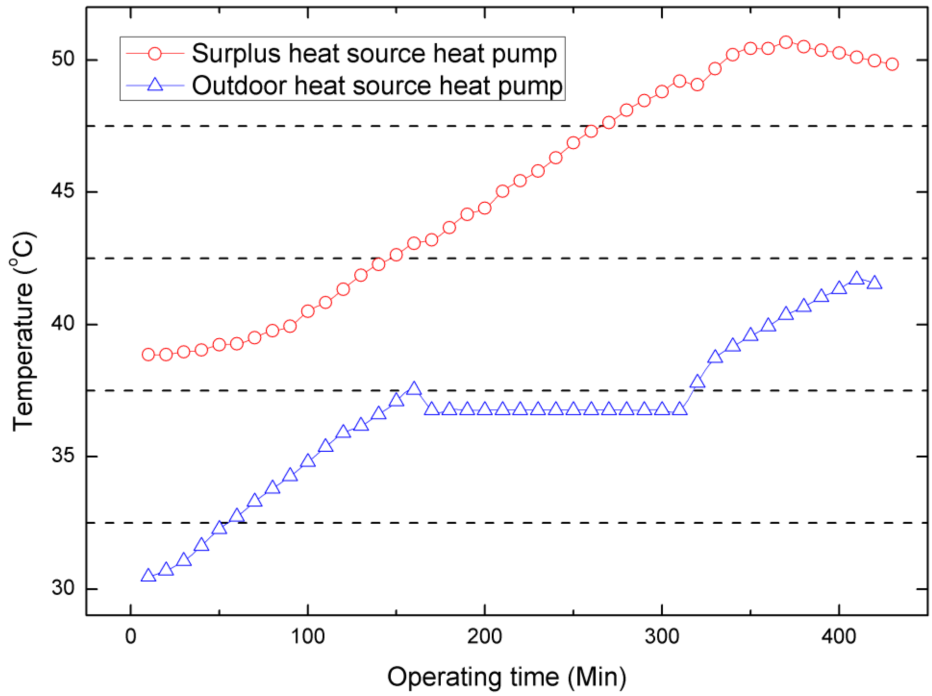

Fig. 12. Storage tanks temperature difference according to storage mode.

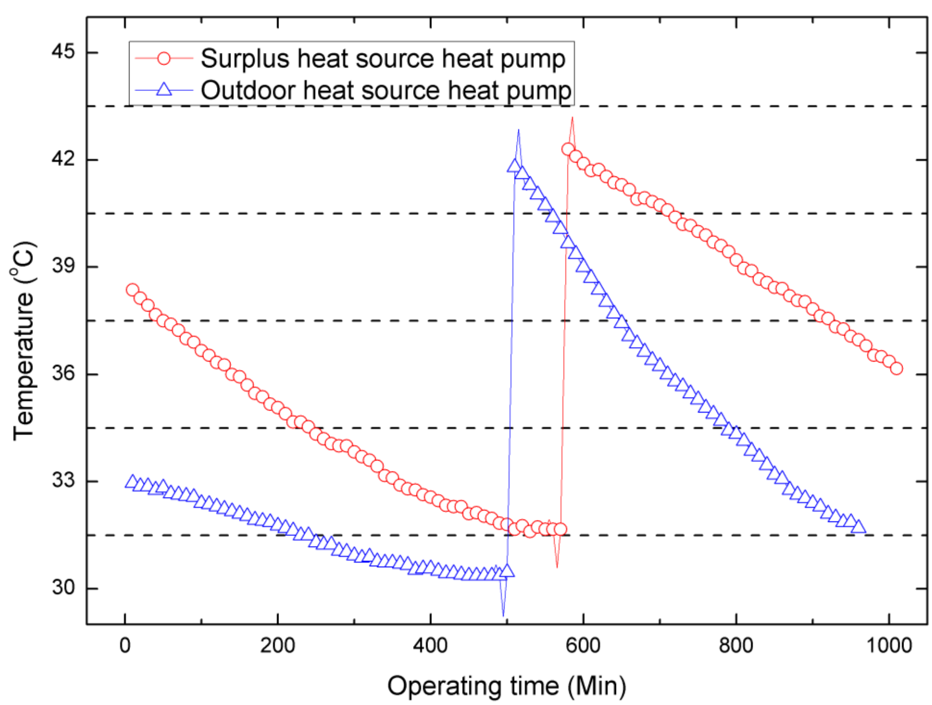

Fig. 13. Storage tanks temperature difference according to heating mode.

3.7 Circulating Pump

Pumps are needed to pump hot water for the heating system and the irrigation system. Circulation pumps are used for heating systems, which can be selected by the required suction capacity. For 4857 m3 greenhouse, so electricity consumption will be around 90 W.

Fig. 14. Circulate pump.

3.8 Fan Coil Unit

Fan Coil Unit is widespread in all types of greenhouse FCU used to condition the local air to suit the immediate space's temperature requirements. The fan coil units appear to be thin to be conveniently installed either on the ceiling or vertical on the floor as the customer's choice. The device's other benefits are that they are easy to run, standard in appearance, robust, and satisfy unique cooling and heating specifications.

Fig. 15. Fan Coil Unit.

4 Result and discussion

The heating system of greenhouse with an air source of heat pump utilized surplus heat source and outdoor heat source mode. The operating heating period was 1010 min (16hour 50min) and 970 min (16hour 10min). The heating mode was two separate starts from 00.00 min, and storage mode was operated when inside temperature reach and above 15.0℃ then begun again greenhouse inside temperature below than 12.0℃ for heating. Storage mode's starting time was depending on inside of greenhouse temperature and operating time were surplus hear source mode 430 min (7hour 10min) and outdoor heat source system 470 min (7hour 50min).

4.1 Storage mode

Storage mode experiment was conducted with a surplus air source and outdoor air source. Surplus heat source mode inside and outside temperature were 17.8℃ and 7.3℃. The heating source was temperature 16.4℃. The average capacity, power consumption, and COP were 13.9 kW, 3.8 kW, and 3.7. Outdoor heat source mode inside and outside temperature was 20.1℃ and 8.1℃ and hear source was temperature same as outdoor. The average capacity, power consumption, and COP were 10.8 kW, 3.7 kW, and 2.9, respectively.

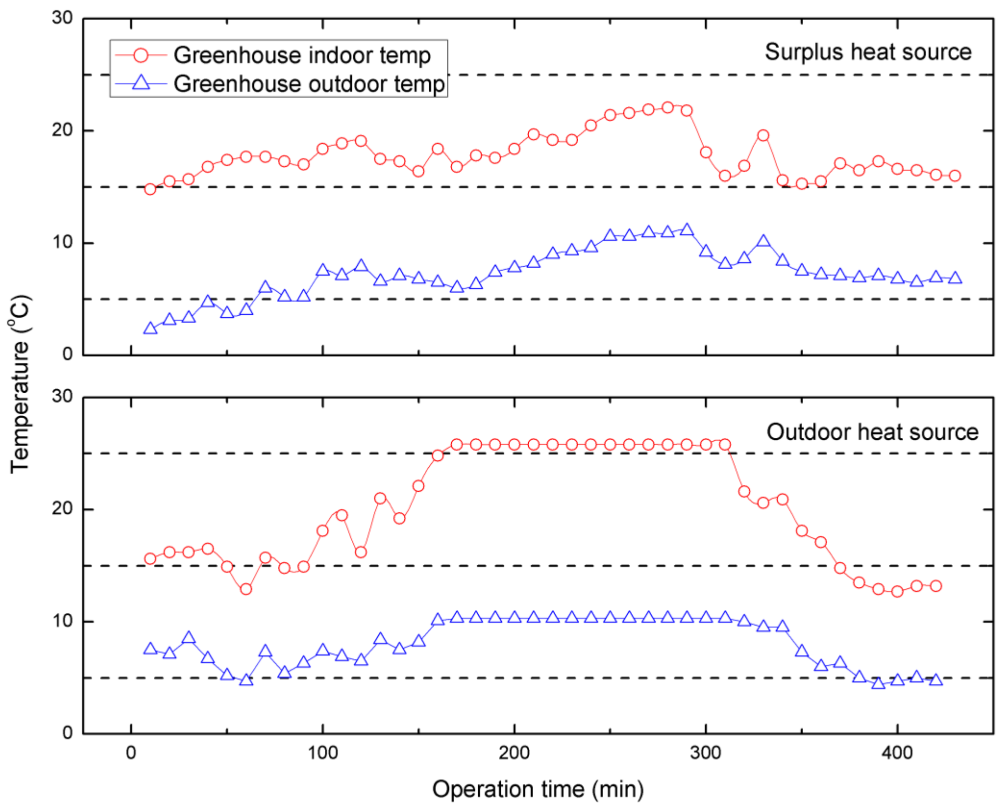

Fig. 16. Temperature changes inside and outdoor of greenhouse according to operating time with storage mode.

The experiment set points were starting heat below and 12.0℃; moreover, the condition that stopped hearing mode and switched to storage mode was 15.0℃ and above. There are several effects to shift storage mode, such as when solar radiation is high and environmental condition is not cold. The above figure selected data when storage mode ran. On the other hand, those all higher than 15.0℃. Surplus heat source and outdoor heat source storage mode and heating mode time similar period. In this figure, 400 min storage thermal energy from heat pump storage tanks.

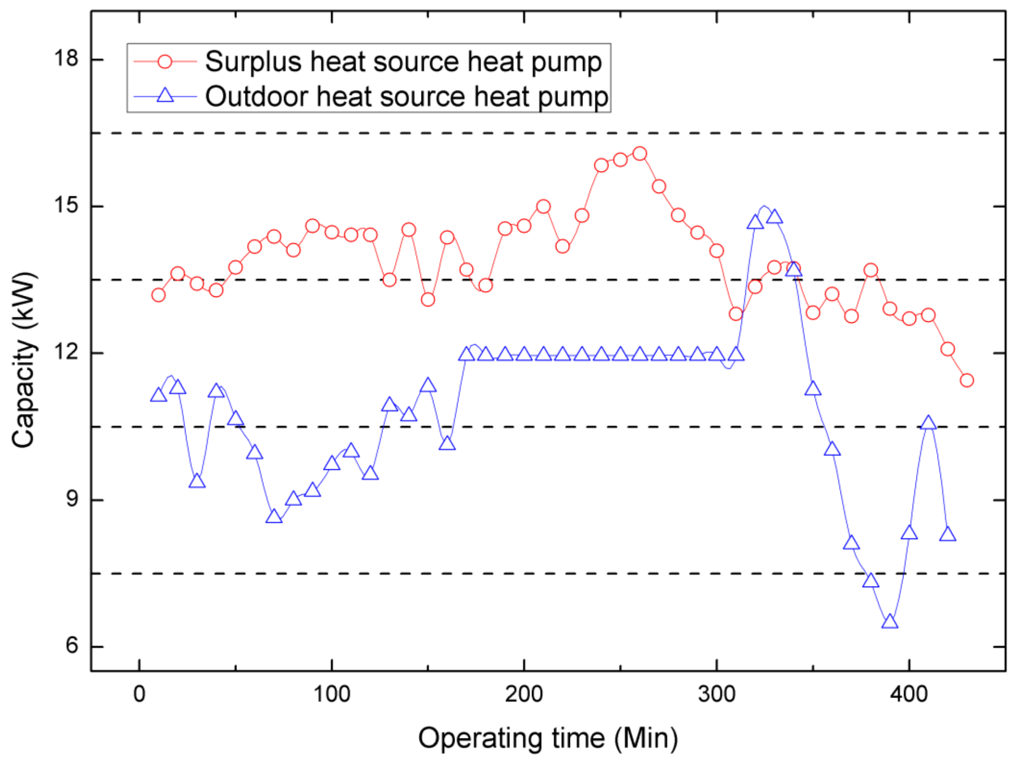

Fig. 17. Capacity difference between surplus heat source and outdoor heat source on operating time with storage mode.

In figure 17 shown. The heat pump capacity of air sources. Surplus heat source's heating capacity is slightly increased to 250 min and reach peak point 16 kW due to solar radiation. Environmental conditions also figure 1 same high peak at 250 min then decrease back until 11.5 kW at 430min. The outdoor heat source of heat pump capacity sharply goes up and down and after 300 min widely fluctuates from 14 kW to 6 kW then goes up 11 kW. The average capacities were 13.9 kW and 10.8 kW, respectively.

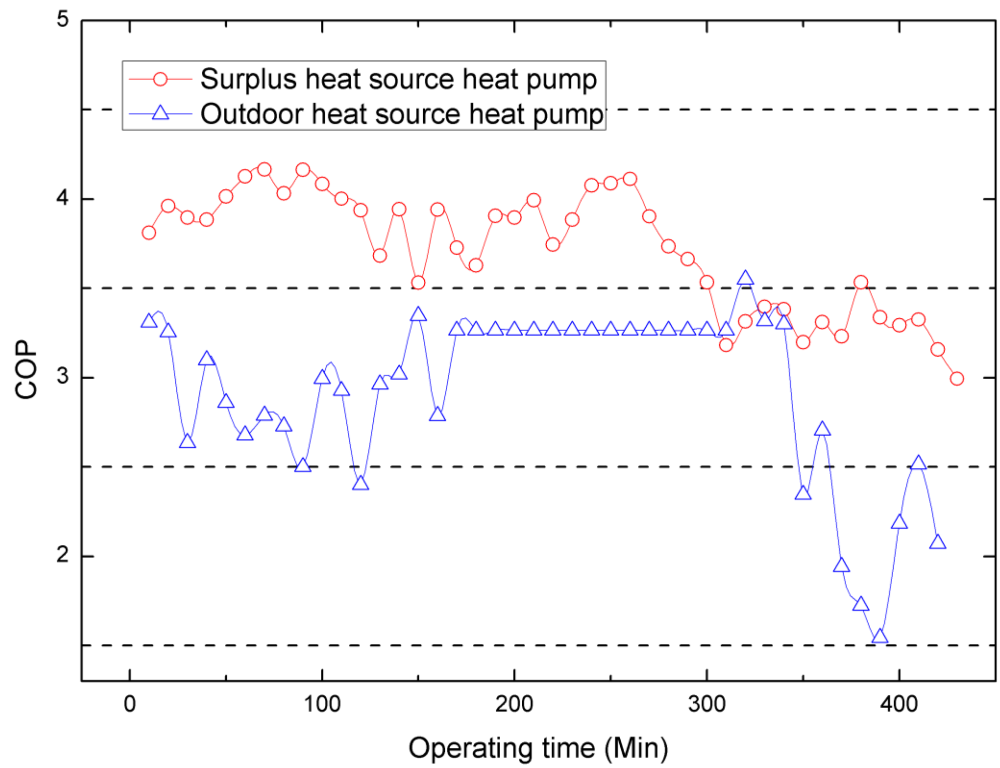

Fig. 18. Changes in COP of heat pump from surplus air sources and outdoor air sources according to operating time.

Power consumption of outdoor heat source was 3.7 kW, and the average coefficient of performance 2.9. Surplus heat source power consumption was higher 0.1 kW than outdoor heat source. COP of surplus heat source heat pump 3.7 power consumption was 3.8 kW.

Table 7. The average result of storage mode.

System	Capacity (kW)	Power consumption (kW)	COP
Surplus heat pump	13.9	3.8	3.7
Outdoor heat pump	10.8	3.7	2.9

4.2 Heating mode

The operating heating period was 1010 min (16hour 50min) and 970 min (16hour 10min). The heating mode was two separate starts from 00.00 min and storage mode was operated when inside temperature reach and above 15.0℃ then begun greenhouse inside temperature below than 12.0℃ for heating again. Storage mode's starting time was depending on the inside of greenhouse temperature. The heating mode experiment was also conducted with surplus air source and outdoor air source. Surplus heat source mode inside and outside temperature were 14.5℃ and 0.8℃. The heating source was temperature 12.5℃. The average capacity, power consumption, and COP were 12.3 kW, 3.5 kW, and 3.5, respectively. Outdoor heat source mode inside and outside temperature were 12.5℃ and 3.5℃, and the heat source was the same as outdoor. The average capacity, power consumption, and COP were 10.5 kW, 4.2 kW, and 2.5, respectively.

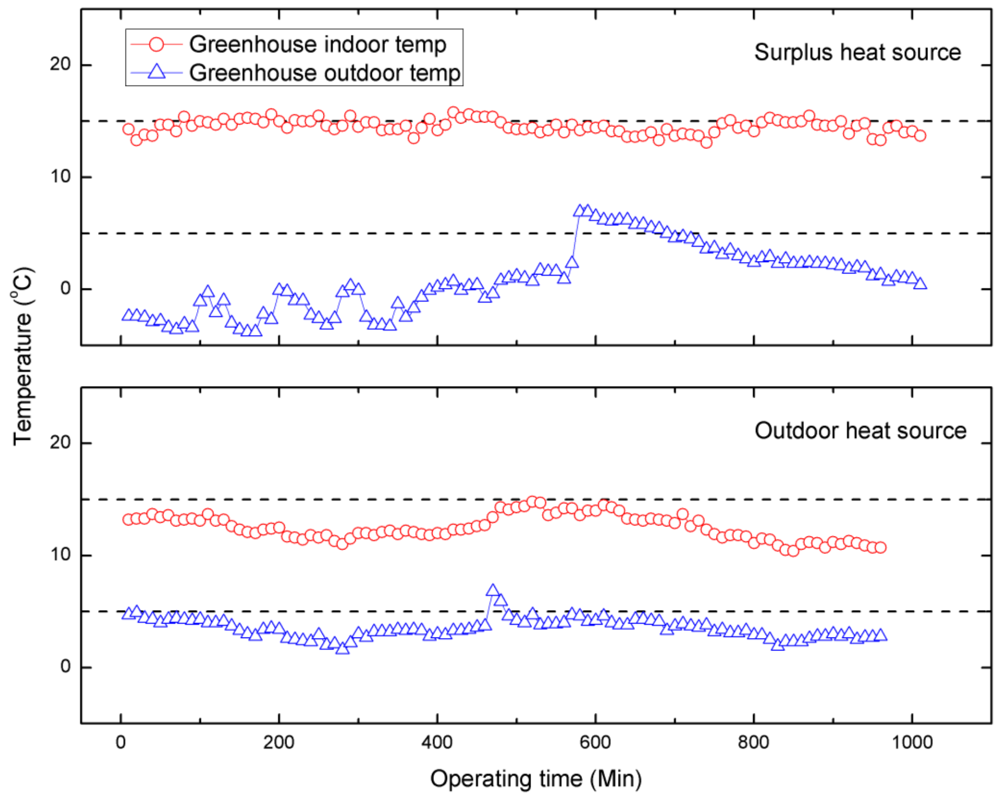

Fig. 19. Temperature changes inside and outdoor of greenhouse according to operating time with heating mode.

In figure 19 shown in inside and outside temperature difference of greenhouse. Experiment set temperatures were between 12℃ to 15℃, so indoor temperature was similar 14℃ surplus heat source and outdoor heat sources; the however outdoor temperature was different. The surplus heat source's average outside temperature was 0.2℃, but outdoor heat source's outside temperature was higher than 3℃. Inside temperature were not huge differences even in outdoor temperatures variation in heating mode.

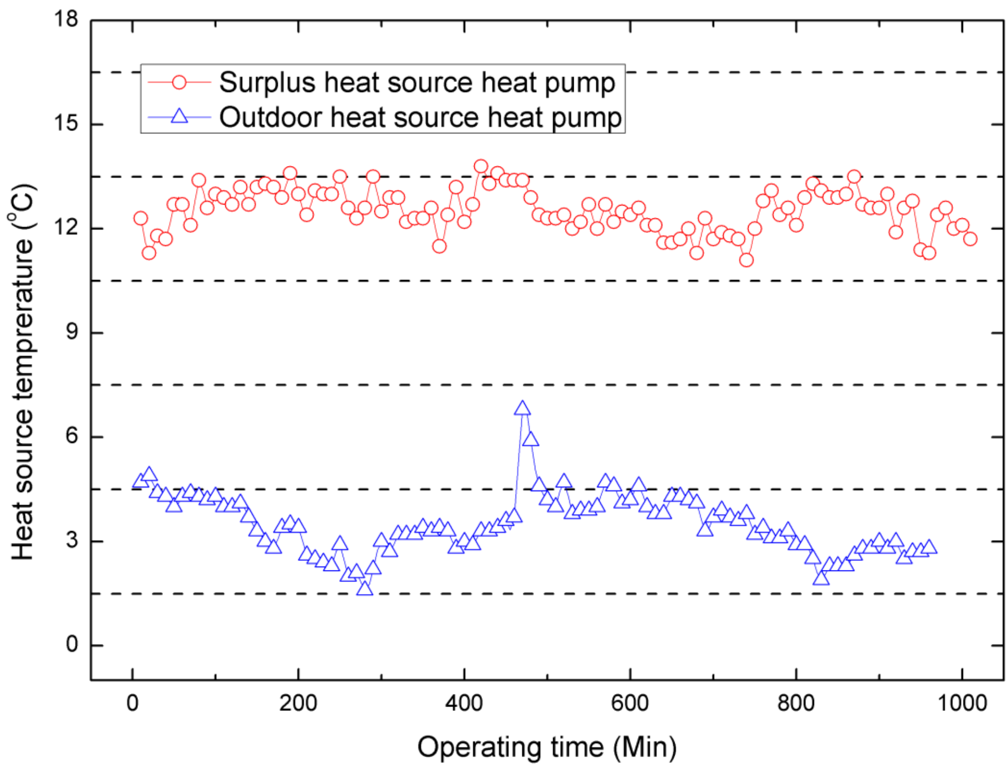

Fig. 20. Heat pump air sources temperature changes.

The greenhouse heating system was core difference of testing condition changed the heat pump's inlet air source, one from surplus air source inside the greenhouse other from the ambient air source, in figure 20 air source temperature changes of heat pump. Surplus heat source average temperature was 12.5℃, and 2.0℃ lowers than inside temperature. Outdoor heat source average temperature was 3.5℃, which means the same as outdoor temperature.

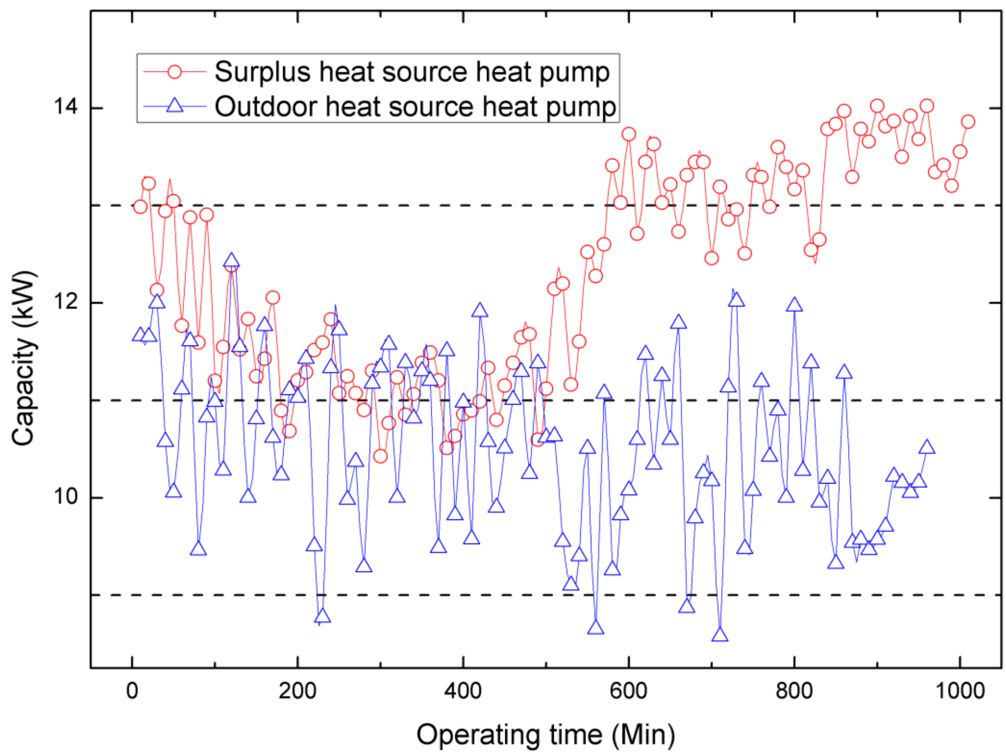

Fig. 21. Capacity difference between surplus heat source and outdoor heat source on operating time with storage mode.

The capacity of each heat source heat pump is shown in figure 21. The surplus heat source of heat pump capacity started from 13 kW then slightly decrease 11.5 kW at operating 400 min, sharply increase to 600 min and continuously constant trend line at the end. The outdoor heat source of heat pump capacity was dramatically up and down, so it did not show constant capacity. The average capacity surplus heat source was 12.3 kW, and outdoor heat source mode was 10.5 kW during heating mode.

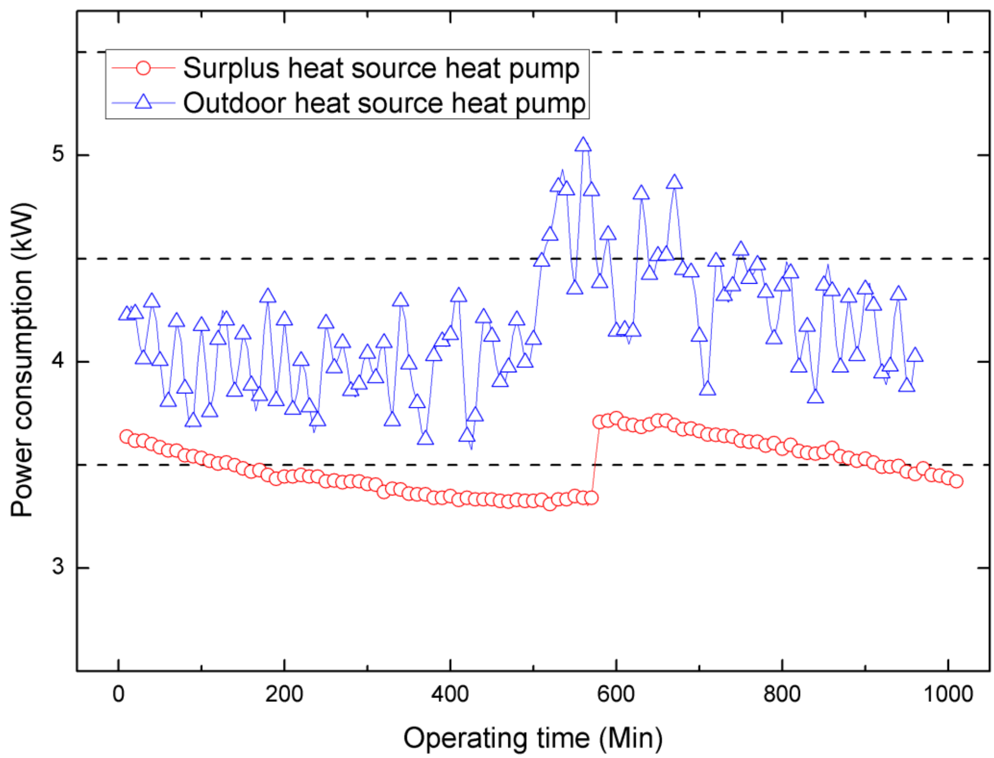

Fig. 22. Differences in power consumption of surplus air source and outdoor air source heat pump according to operating time.

The average power consumption of surplus heat source heat pump was 3.5 kW. Surplus heat source heat pump saving energy than outdoor heat source pump and typically 0.8 kW gap each section of operating time. Outdoor heat source heat pump's power consumption was 4.2 kW but dramatically zip-zagged.

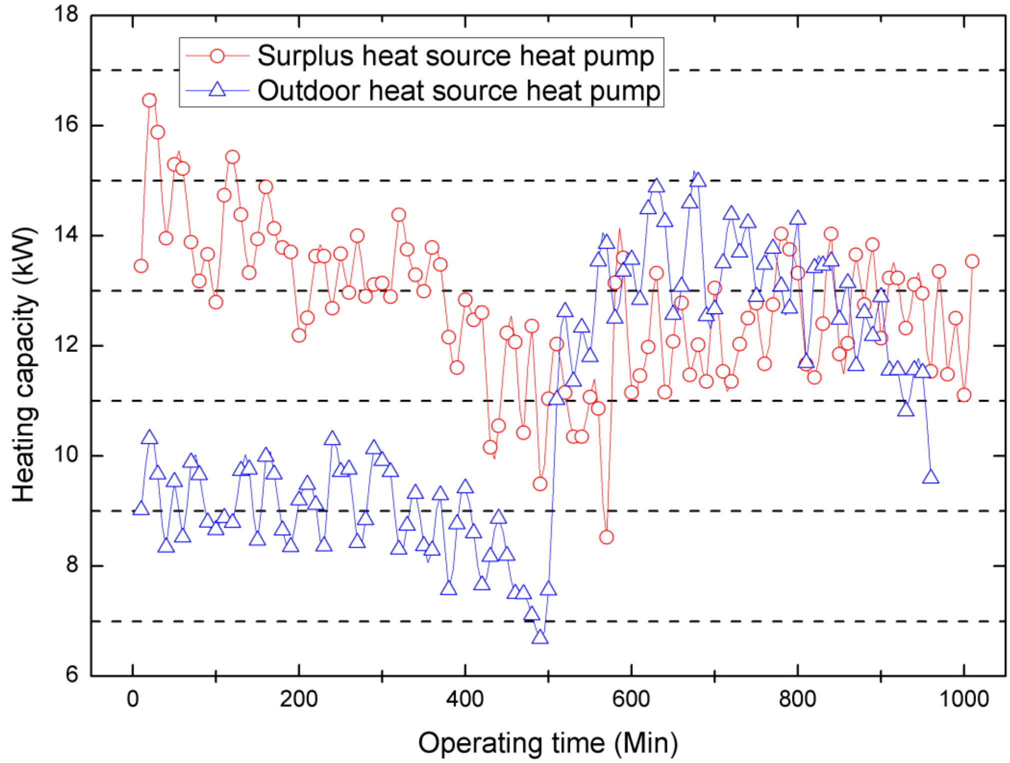

Fig. 23. Changes in heating capacity of heat pump from surplus air source and outdoor air source according to operating time.

Heating capacity is how much heating inside the greenhouse that utilizes hot water from the storage tank to the fan coil unit is used to condition the local air to suit the immediate space's temperature increase. The heating capacity of surplus heat source mode was showing gently dropped overall. In contrast, outdoor heat source mode was huge bounce at 500 operating min due to heating mode was two separate first part of heating mode start from 00:00 min to 09:20 min and second part start from 16:40 min until 23.50 min then storage mode was operated in this between those two parts. The average capacity surplus heat source was 12.7kW, and outdoor heat source mode was 10.8 kW during heating mode.

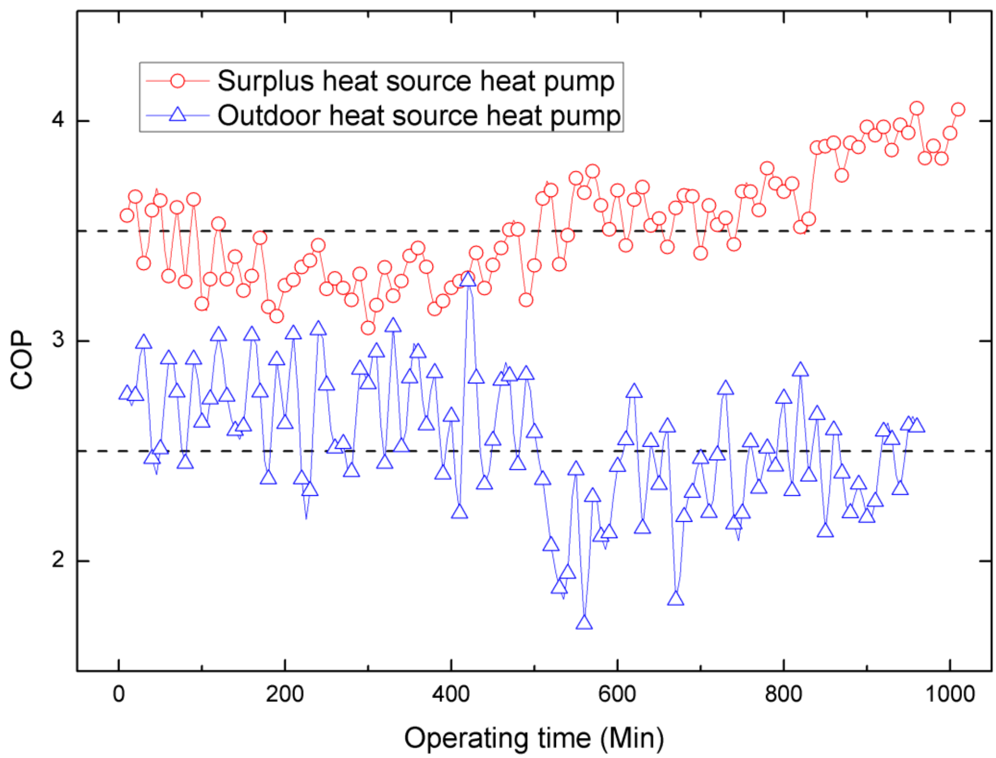

Fig. 24. Changes in COP of heat pump from surplus air sources and outdoor air sources according to operating time.

The surplus heat source of COP was gradually decreased to half of operating time and slightly increased trend line. The average COP of surplus mode was 3.5. The outdoor heat source of COP suddenly increased and decreased, but the overall COP was shown to drop the trend line, and the average COP of outdoor heat source was 2.5. As a result, was surplus heat source was higher 1 COP than the outdoor heat source.

Table 8. Average result of heating mode.

System	Capacity (kW)	Power consumption (kW)	COP
Surplus heat pump	12.7	3.5	3.5
Outdoor heat pump	10.8	4.2	2.5

5 Conclusions

An experimental conducted greenhouse heating for using heat pump system that surplus air source and outdoor air source. The greenhouse experiment system performed on December 08, 2020, and December 13, 2020, selected days in similar environments of condition and experiment to measure the required parameters to be used in a greenhouse with a length, width, and height was 10m, 5.4m, 4.6m and located in Jeju National University, Korea. This system consists of a heat pump system including heat storage tanks, fan-coil-units in the greenhouse, and an electric heater for supplemental heating. The experiment condition was to run a heat pump system using a surplus air source and outdoor air source each day. The experiment of greenhouse inside the set temperature was between 12.0℃ to 15.0℃. The greenhouse heating system has two modes. The first mode was heating mode that greenhouse inside temperature was lower than 12.0℃ and heat it until 15.0℃. The second mode was storage mode that stored heat from heat pump to storage tanks when the greenhouse temperature was higher than 15.0℃. In the results storage mode: surplus heat source system was performed the average power consumption and COP were, 3.8 kW and 3.7 and outdoor heat source system was the average power consumption and COP were 3.7 kW and 2.9. Heating mode: The surplus heat source system evaluated with average power consumption and COP was 3.8 kW and 3.7 and outdoor heat source system. The average power consumption and COP were 3.7 kW and 2.9, respectively. The main conclusions that may be drawn from the present study are listed below.

- Experimental results show that surplus heat source of heat pump system was a high estimated average capacity of 12.8 kW even ambient temperature lower than outdoor heat source system. In comparison, the heat pump system's outdoor heat source was 10.6 kW with ambient temperature at 3.5℃.

- Greenhouse heating system of surplus heat source of average power consumption was 3.6 kW, and outdoor surplus heat source system of average power consumption was 3.9 kW surplus heat source energy saved 7.6 %. Furthermore, it saved power consumption by 16.6 % than the outdoor heat source system when heating mode performed.
- In COP of surplus heat source system installed an average of 3.6 and outdoor heat source system average of 2.7. The surplus heat source of heat pump was 0.9 higher than outdoor heat source heat pump.

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