STUDY OF ABSORPTION/COMPRESSION HYBRID HEATPUMP CHILLER UTILIZING SOLAR ENERGY

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Abstract: For the global warming prevention, attention has gathered in the renewable energy, such as heat pump (HP), solar energy and so on. Though the heat pump contributes to the global warming prevention, it is hoped to become common the heat pump, which uses the low global warming potential (GWP) refrigerant for a further contribution. Because the global warming potential of fluorocarbon, that is the popular refrigerant is high with 1000 or more. The carbon dioxide (CO_2) refrigerant is one of the low GWP refrigerants. But, it has the problem with low refrigerating performance on physical properties. To solve it, we have investigated the absorption/compression hybrid heat pump. In hybrid heat pump, efficiency of the CO_2 heat pump is improved by absorption heat pump that uses solar thermal energy for heat source. In this paper, we presented that result of comparative study by performance simulation, and detailed constitution of hybrid heat pump.

Key Words: renewable energy, heat pump, solar energy, CO_2, absorption

1 INTRODUCTION

For the global warming prevention, attention has gathered in the renewable energy, such as heat pump, solar energy and so on. For example the heat pump for hot water supply can output the heating capacity of three or more to the electrical power input of one. Energy conservation of hot water supply for heat pump is lower than for gas or electric heater. Generally, heat pumps use fluorocarbon for refrigerant. Fluorocarbon has a problem about green issue. Its global warming potential is very high, 1000 or more. It means that to widespread heat pumps, which use natural refrigerant, are very critical for the global warming prevention. For this purpose, CO_2 is widely used as natural refrigerant for heat pump boilers to supply hot water. CO_2 refrigeration cycle is trans-critical cycle for water heating use. It is suitable for the water heating because the temperature differential between refrigerant gas and water is small in the heat radiation process at CO_2 refrigeration cycle. However, for water chilling or air-cooling use, COP of the CO_2 heat pump is remarkably bad, compared with the fluorocarbon refrigeration cycle on physical properties. From the viewpoint of air-cooling and water-chilling efficiency, the CO_2 heat pump is not suitable, especially in the lower latitude region. Additionally, the amount of energy for the air-conditioning and hot-water-supply takes considerably a large part in the housing energy consumption. For these reasons, we investigated about making CO_2 heat pump air-cooling highly effective by using solar energy. And, we proposed several systems that use non-fluorocarbon HP and solar energy for air-conditioning and hot water supply. Comparative study was executed by simulating the amount of the consumption energy based on actual climate data. As one example of highly effective HP, we investigated the novel Absorption/Compression hybrid heat pump chiller that utilized solar heat as a key technology of the system. In this paper, we presented that result of comparative study of the solar energy use non-fluorocarbon HP system, and detailed constitution of hybrid heat pump.

2 COMPARATIVE STUDY OF SOLAR ENERGY USE HP SYSTEMS

2.1 Outline of calculation

First, we considered the air-conditioning and hot water supply system shown in Fig.1 that uses solar energy and non-fluorocarbon heat pump. For comparative study, we pick up two kinds of solar energy equipments and four kinds of non-fluorocarbon heat pump. Solar energy equipment variations are photovoltaic and solar collector. Non-fluorocarbon heat pumps' are CO_2 HP, CO_2 HP with expander, hybrid HP, and absorption HP. Hybrid HP is novel one. In the system, heat pump is driven by solar energy for air-conditioning and supplying hot water. If solar energy is insufficient, commercial power source or heat of combustion of fuel gas assist as energy of HP. We examined about non-fluorocarbon heat pumps below.

CO_2 HP: The CO_2 heat pump is vapor compression heat pump that uses CO_2 for the refrigerant and that is driven by electric energy. It is widespread as the water heater.

CO_2 HP with expander: The expander is a technology to make CO_2 heat pump more highly effective. It collects energy in the expansion process and this energy is recycled by heat pump. Various researches are done about the expander.[3]

Hybrid HP: Hybrid heat pump is a novel system that combines solar heat drive absorption heat pump and CO_2 heat pump to work together. Details are described later.

Absorption HP: Absorption heat pump is a heat drive type heat pump where LiBr(Lithium bromide) is used for absorbent, and water is used for refrigerant. It is widespread as a large-scale water chiller.[4]

We studied about the most effective combination of heat pump and solar energy. For comparative study, we calculate the energy consumption about the systems that heat pumps are combined solar energy equipment shown in Table 1. CO_2 HP and CO_2 HP with expander are combined with photovoltaic. Hybrid HP and Absorption HP are combined with solar collector. For the consideration of the numerical result, the system which heat pumps are not combined with solar energy equipments is also examined. The climatic condition for calculation is settled to Abu Dhabi where the cooling load is large. Because the feature of hybrid HP, the main issue of this paper is to improve the efficiency of CO_2 HP "in cooling".

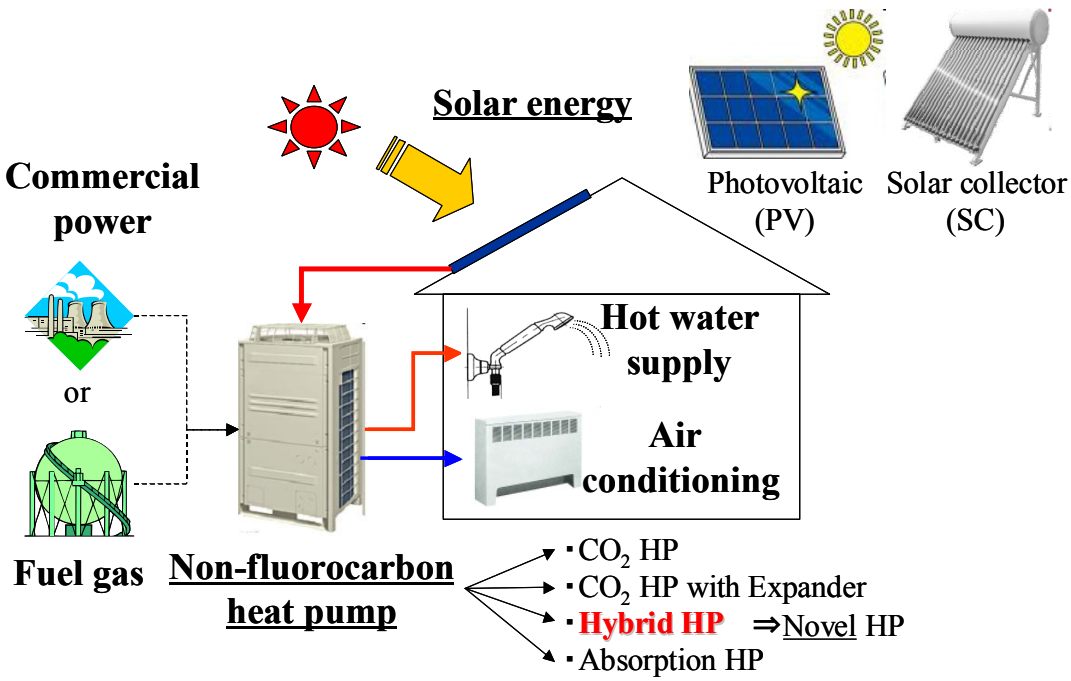


Figure 1: The Schematic View of The System

Table 1: The List of The Systems

No.	Solar energy	Heat Pump
1	None	CO_2HP
2	Photovoltaic	CO_2HP
3	Photovoltaic	CO_2HP with Expander
4	Solar collector	Hybrid HP
5	Solar collector	Absorption HP
6	None	Absorption HP
7	None	CO_2HP with Expander

2.2 Condition of calculation

The condition of the calculation is explained below. To make comparative study about several systems in Table 1 shown previously, the amount of the consumption energy was simulated according to an actual climatic condition. The climatic condition is the data quoted from the energy plus.[5] The climate data is averaged per hour every month. To calculate, we made a simulation model. On the simulation model, according to the outside temperature degree and the solar radiation intensity, the amount of the consumption energy of each per hour at each month is calculated. And the solar energy is assumed maximum use to the load about air-conditioning. Specifically, at daytime, the solar energy is used to process the air-conditioning load, but it also processes the load of supplying hot water at nighttime.
The solar energy bears surplus for the cooling and heating load, and the surplus is saved to be used for the load of supplying hot water every day. If solar energy is insufficient compared with the load, driving of CO_2 heat pump or combustion of gas covers it. The cooling and heating load is assumed to generate the cooling load when the outside temperature degree exceed 26 degrees, and for less than 20 ℃ to generate the heating load. And it is assumed the air conditioning load none from 20 to 26 ℃ the outside temperature degree. The load of supplying hot water is assumed that the hot water demand during a day is 50MJ/day. This is a load of supplying hot water in a general home.
The seven types of each system are already shown in Table 1. The climatic condition is settled to Abu Dhabi. And, Table 2 shows other calculation conditions. We assumed the conditions that are general value of them. Figure 2 shows the outside temperature degree and the cooling and heating load of Abu Dhabi. Figure 3 shows the solar radiation intensity, the thermal energy collection, and the amount of power generation of the photovoltaic.

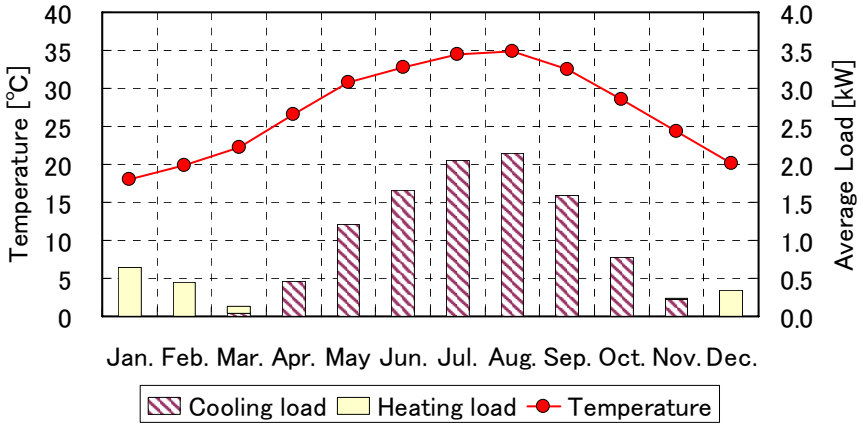


Figure 2: The Outside Temperature and Load of Air-conditioning

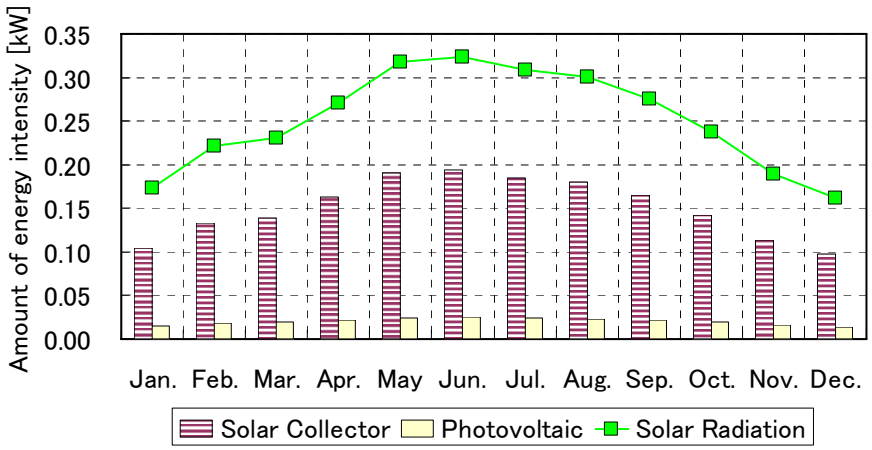


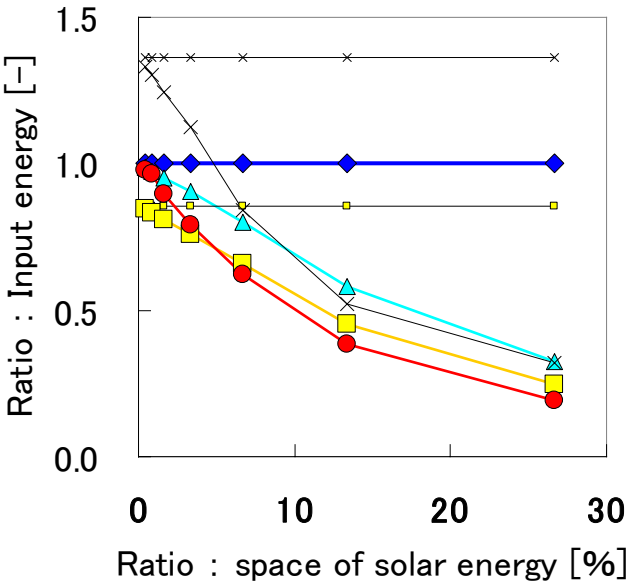
Figure 3: The Amount of Solar Energy

Table 2: Calculation Conditions

Subject	Value	Unit
Insulation efficiency of building	2.7	W/(m²·K)
Heat collection efficiency of solar collector	60	%
Rated power generation efficiency of Photovoltaic cell	10	%
Efficiency decreasing rate of solar battery by temperature	0.5	%/K

2.3 Results and discussion

Figure 4 shows the numerical result. The consumption energy ratio is shown in the vertical axis. It is made dimensionless by using the energy consumption of the CO_2 Heat Pump system driven only by the commercial power source, without solar energy. The consumption energy is arranged by the primary energy conversion. And the ratio of installation space of the solar energy equipment is shown in the horizontal axis. This ratio shows the percentage of the area of the air-conditioned space to the whole house area.
In case of ratio of installation space is 5% or less, the smallest consumption ratio drops to the combined system of the CO_2 heat pump with the expander and the photovoltaic. Because solar energy is insufficient in less than 5% to the required space for installation, compared with the load, the effect of extra-cooling of the absorption cycle is insufficient by Hybrid HP. On the other hand, in the CO_2 heat pump with expander, the amount of the consumption energy has become small because it can make the heat pump highly effective even if there is no solar energy. And in case of ratio of installation space is 5% or more, the consumption ratio of the combination system of the Hybrid heat pump with Solar Collector is the smallest. The consumption energy becomes small because solar collector can collect solar energy effectively, and the system can use the energy for the load of air-conditioning and supplying hot water without uselessness. It follows that the system of hybrid heat pump and solar collector is the best combination among these seven types mentioned in Figure 4, for maximizing solar energy to conserve energy consumption.



No.	Solar energy	Heat pump	
1	None	CO_2	
2	PV	CO_2	
3	PV	CO_2 &Exp.	
4	**SC**	**Hyb.**	
5	SC	ABS	
6	None	ABS	
7	None	CO_2 &Exp.	

$$\frac{\text{Setting space of solar energy equipment}}{\text{Floor space of building}}$$

Figure 4: Numerical Result of Calculation

3 ABOUT HYBRID HP

3.1 Introduction

A CO_2 refrigerant heat pump is widespread as a heat pump boiler to make the warm water. CO_2 refrigeration cycle is trans-critical cycle for water heating use. It is suitable for the water heating because the temperature differential between the refrigerant gas and water is small in the heat radiation process at CO_2 refrigeration cycle. However, for water chilling or air-cooling use, COP of the CO_2 heat pump is remarkably bad, compared with the fluorocarbon refrigeration cycle on physical properties. From the viewpoint of efficiency, the CO_2 heat pump is not suitable, especially in the lower latitudes region. To solve this problem, we investigated the novel heat pump to make CO_2 heat pump air-cooling highly effective by using solar energy. The novel heat pump calls “Hybrid heat pump” that combines solar heat drive absorption HP and CO_2 heat pump. In this chapter, we describe about Hybrid HP.

3.2 Hybrid HP principle and composition

First, hybrid heat pump uses solar heat for heat source. In absorption cycle, Lithium bromide(LiBr) is absorbent, water is refrigerant and CO_2 is refrigerant in CO_2 heat pump. Figure 5 shows the schematic of hybrid heat pump cooling system, using solar energy for heat source and non-fluorocarbon for refrigerant. Solar heat from solar collector is used for driving force of absorption cycle. The absorption HP extra-cools the CO_2 cycle. This extra-cooling improves the coefficient of CO_2 cycle.
Next, Hybrid HP composition is introduced. Figure 6 shows a flow seat of Hybrid HP. It consists of a compressor, a gas cooler, a gas cooler by ABS HP, an expansion valve, and an evaporator. Chilled water being cooled by the evaporator is used for air-conditioning. Figure 7 explains the effect of extra-cooling. The figure is P-h diagram of the CO_2 refrigeration cycle. The enthalpy is shown in a horizontal axis, and pressure is shown in a vertical axis. In the figure, the straight line shows an extra-cooling by the absorption cycle, and the broken line shows a no extra-cooling’. As shown in figure, pressure of the heat radiation process at the CO_2 cycle can be reduced by the absorption cycle. As a result, the input to the compressor becomes small and efficiency can be improved. Through this calculation, we understood that efficiency of heat pump could be up to around 60% by the extra-cooling at the absorption cycle.

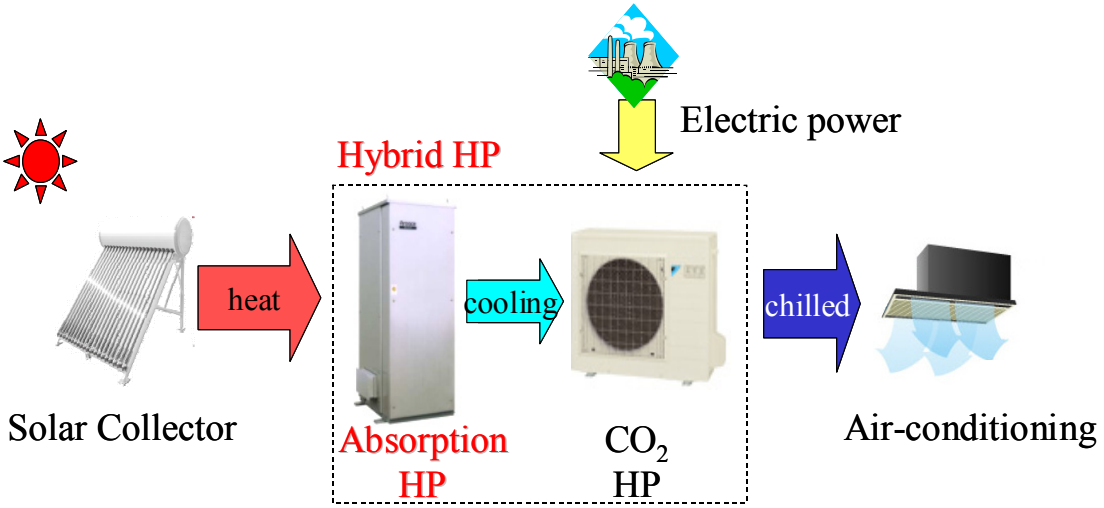


Figure 5: The Schematic of The Hybrid Heat Pump

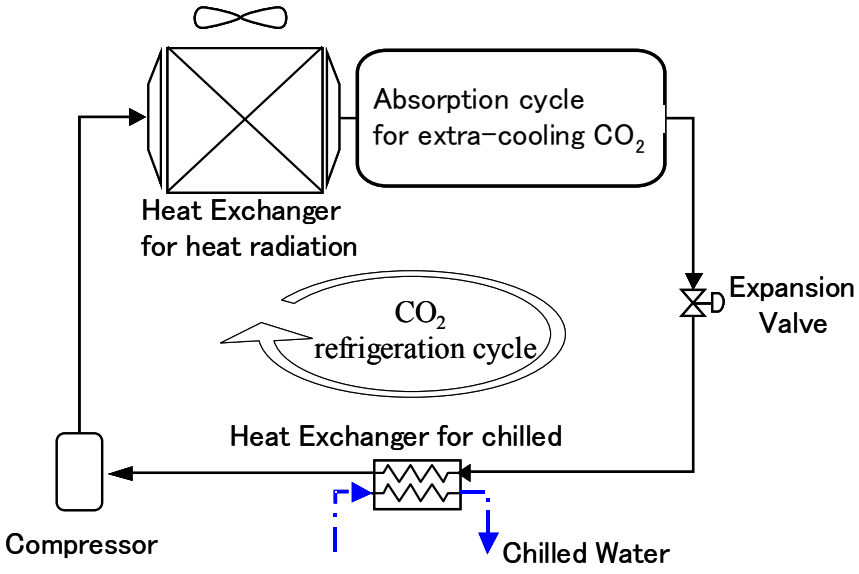


Figure 6: The Constitution of The Hybrid Heat Pump

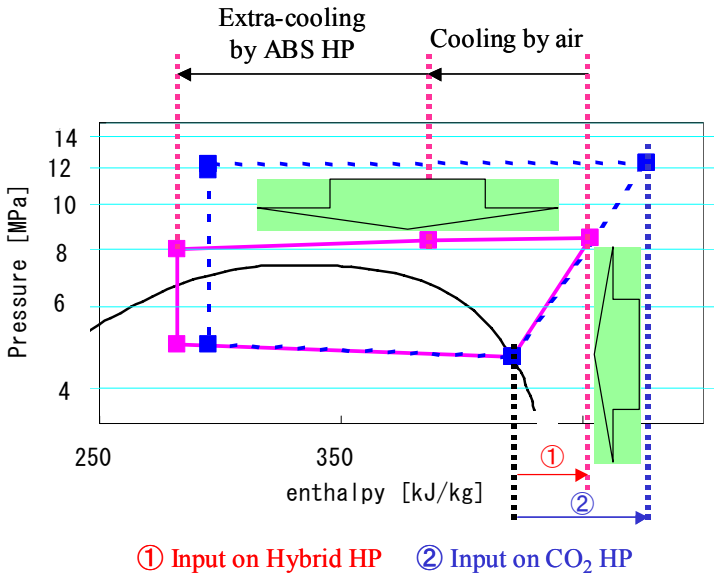


Figure 7: P-h Diagram of The CO_2 Refrigeration Cycle

3.3 Hybrid HP making for trial purposes

To confirm the effect of energy conservation of Hybrid HP, we had designed the chiller and made it for trial purpose. Figure 8 shows overview of the prototype. The size is width 930mm, depth 765mm, and height 1680mm. The rated cooling capacity is 8kW when ambient temperature is 35℃ and chilled water temperature is 18℃.The prototype is an air-cooled chiller, and the absorption cycle and the CO_2 cycle are built into the casing shown in figure 8. The detailed flow diagram of hybrid HP is shown in Fig.9. Hybrid HP consists of a single stage vapour compression heat pump and a single effect absorption heat pump. Refrigerant for vapour compression heat pump is CO_2, and for absorption heat pump is water. Absorbent of absorption heat pump is lithium bromide. The cooling capacity of absorption heat pump is used for cooling refrigerant in the gas cooler outlet of CO_2 HP, at chilling mode. And, we have started experiments.

3.3.1 About absorption HP

Absorption HP consists of an absorber, an evaporator, a generator, a LiBr pump, an internal heat exchanger, and a refrigerant tank. Generally, an absorption HP is Water-cooled type, so it needs cooling tower. This tower pushes up the initial cost for residential use. From the viewpoint of the cost reduction, we had decided to take on the air-cooled type absorption heat pump, and had designed it. Also in general absorber, absorption reaction of refrigerant and cooling of absorbent at the same time. But in air-cooled type, its size often becomes problem, so we had decided that absorption and cooling processes are divided into other processes. We called it “An Indirect cooling type”. On a generator, absorbent is heated by thermal input from the outside, and generate vapour refrigerant. A vapour refrigerant is condensed at air-cooled condenser, and refrigerant enter the evaporator. In evaporator, CO_2 refrigerant is cooled for making CO_2 HP highly effective. The vapour refrigerant that evaporates by the evaporator is absorbed to the absorbent in absorber. Diluted absorbent is mixed to high concentration absorbent concentrated by generator, and it pumped to generator and sub-cooler. Absorbent pumped to generator is heated again, and it generates vapour refrigerant. Absorbent pumped to sub-cooler is cooled by exchange of heat with air. This is the reason to remove the heat that generated by absorption reaction. As the result, the ability to absorb the refrigerant revives to absorbent.

3.3.2 About vapor compression HP

About vapor compression HP: HP consists of a compressor, an air-cooled heat exchanger, an evaporator of absorption HP, an expansion valve, a heat exchanger for chilled, and a four way valve. It can be switched from cooling mode to heating mode.



Figure 8: Overview of Prototype Hybrid Heat Pump Chiller

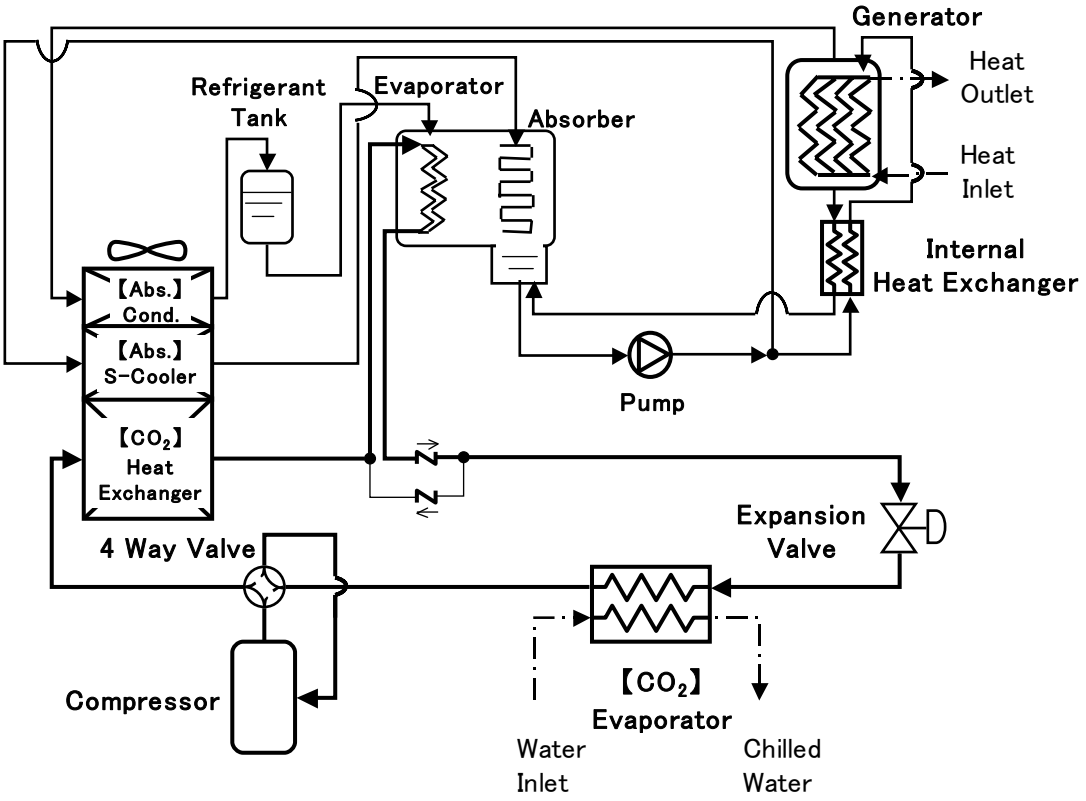


Figure 9: Refrigeration Diagram of Prototype Hybrid Heat Pump Chiller

4 CONCLUSION

We draw the following conclusions as the result of study of the method of making the non-fluorocarbon hybrid HP system for cooling, heating and hot water supply more effectively by using the most of solar energy.

1. As a result of the calculation of the consumption energy, in case of ratio of solar energy installation space is 5% or more, the consumption ratio of the combination system of the Hybrid heat pump with Solar Collector, is smallest.
2. Hybrid HP chillier was made for trial purposes to confirm the effect of Hybrid HP. For reducing the cost of this system, we decide to choose the air-cooled type absorption heat pump to clear off a cooling tower. And we had designed it. Now, we have just started experiments.

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