# DEVELOPMENT AND DEMONSTRATION OF SOLAR AIR CONDITIONING SYSTEM

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**Abstract:** An advanced solar air conditioning system for commercial use was developed and the system has been demonstrated in one of branch offices of Tokyo Gas. Features of the system are (1) a single/double effect combined absorption chiller utilizes solar hot water by priority in single effect cycle and the consumption of natural gas that is for double effect cycle is minimized, (2) to reduce heat capacity and heat loss, the system has no buffer tank, and (3) a developed controller minimizes the electric consumption of the solar hot water pump and enhances the collector efficiency by measuring the condition of the absorption chiller and the hot water temperature. Through the demonstration, (1) the absorption chiller was driven only by the solar hot water when the air conditioning demand was low, (2) the temperature of the chilled water was stable by the control of the back-up gas burner of the absorption chiller, and (3) the pump was operated only when the solar hot water temperature reaches high enough but as low as possible to drive the absorption chiller. The volume of $CO_2$ emission was reduced by about 18% from April to December 2010, compared with the conventional system.

**Key Words: solar, absorption chiller, evacuated tube collector, no buffer tank system**

## 1 INTRODUCTION

The number of solar thermal energy systems is growing especially in Europe and China to reduce $CO_2$ emission and energy consumption, and most of the systems are for heating and hot water supply for domestic use (Weiss and Mauthner 2010). On the other hand, commercial buildings have large cooling demand, and heating or hot water supply demand in summer is much smaller than in winter.

Solar air conditioning system is the system that can utilize solar hot water in summer and supply chilled water by absorption or adsorption chillers. There have been some projects of the solar air conditioning system, mainly in Europe (Sparber et al. 2007). They attract attention as a technology to expand the market of solar thermal systems, but generally the systems have hot water boilers for back-up to drive chiller in single effect, large buffer tanks and controllers that are not specialized for solar air conditioning (Sparber et al. 2009) (Henning et al. 2004). So, it is estimated that their system efficiency is not very high.

Tokyo Gas developed and launched sales of an advanced system that has a single/double effect absorption chiller with a back-up gas burner of natural gas, has no buffer tank and a controller specialized for the solar air conditioning. It has higher efficiency because natural gas drives the absorption chiller in double effect cycle, free from heat loss and heat capacity of the

buffer tank, and higher collector efficiency and lower electric consumption of the solar hot water pump by the controller.

The demonstration plant has been operated to verify the effect of the absorption chiller, no buffer tank piping and the controller since April 2009.

## 2 FEATURES OF DEVELOPED SYSTEM

The basic equipments of the system are evacuated tube collectors, an absorption chiller and a controller. Because absorbers of the evacuated tube collector are insulated by evacuated tubes, it has higher efficiency to heat the solar hot water to about 70~90 deg.C that is necessary to drive absorption chiller than a flat plate collector.

### 2.1 Single / Double Effect Absorption Chiller

In general, conventional systems have absorption or adsorption chillers and hot water boilers for the back-up, so the system COP from heat sources to chilled water is not very high.

In our system, the single/double effect absorption chiller has a back-up gas burner and can be driven by both solar hot water and natural gas. Solar hot water is one of the heat sources for the low temperature generator to drive the absorption chiller in single effect, and natural gas is the heat source for the high temperature generator to drive in double effect. It utilizes solar hot water by priority and natural gas consumption is minimized by measuring the chilled water temperature and controlling the gas burner.

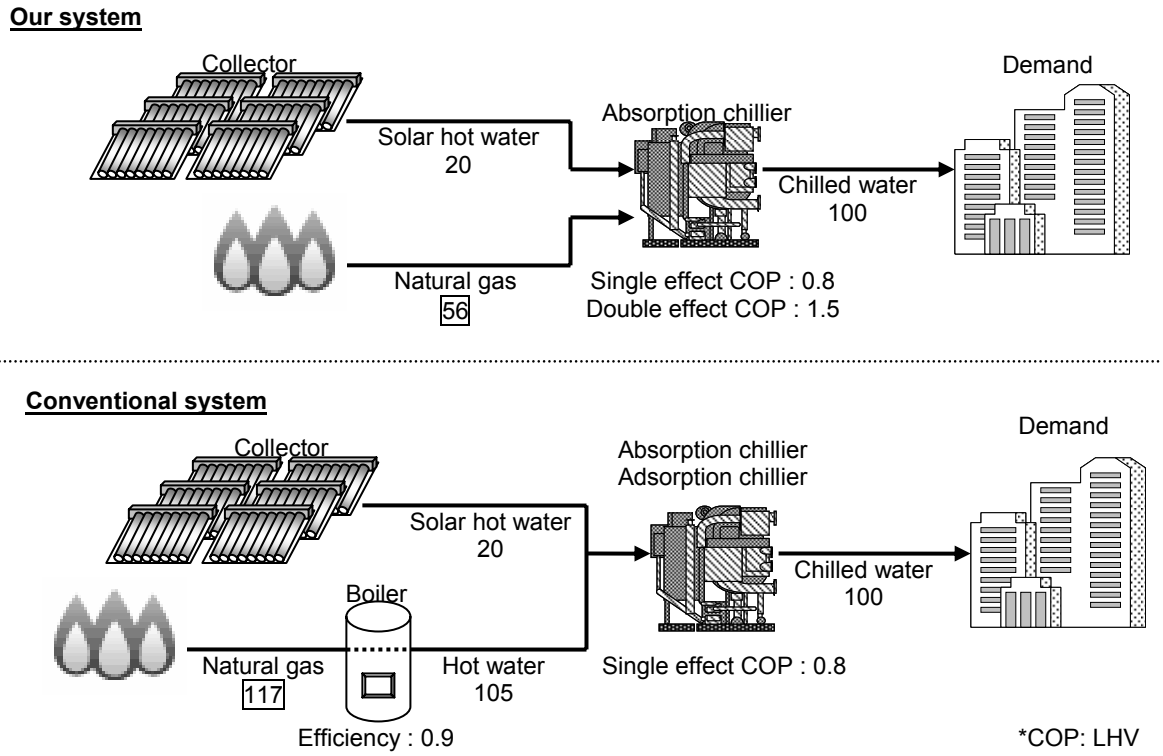



**Figure 1: Difference of Heat Source Supply between Our System and Conventional System**

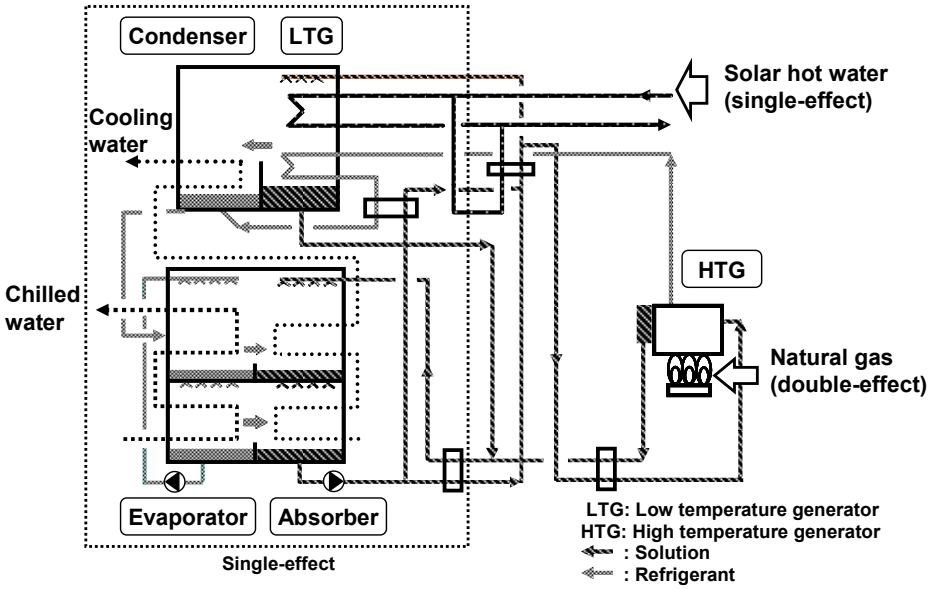



**Figure 2: Diagram of Absorption Chiller with Back-up Gas Burner**

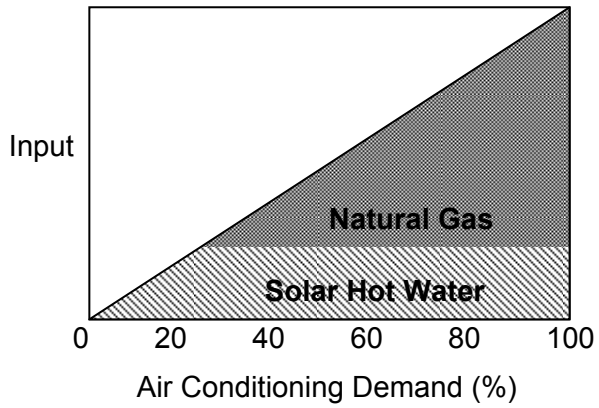



**Figure 3: Operation Mode of Absorption Chiller**

## 2.2 No Buffer Tank Piping

In general, conventional systems have buffer tanks to store solar hot water and stabilize the temperature, so it takes much time to heat the water in buffer tanks to the temperature that is enough to drive chillers, and heat losses from the buffer tanks are large.

Our system doesn't have a buffer tank based on following reasons.

- It is not necessary to store solar hot water, because air conditioning demand is much stable than hot water supply demand.
- The back-up gas burner of the absorption chiller can make the chilled water temperature stable even when the solar hot water temperature is unstable, because the heat capacity of the solution can be the buffer to stabilize the chilled water temperature.

## 2.3 Control of Solar Hot Water Pump

In general, controllers of conventional systems operate solar hot water pumps separately from operating conditions of chillers, so pumps can be operated even when the irradiance is not enough to heat solar hot water to the temperature that is necessary to drive chillers.

In our system, the controller always measures the operating condition of the absorption chiller and the solar hot water temperature, and it operates the pump only when the solar hot water temperature reaches high enough but as low as possible to drive the absorption chiller. This function minimizes the electric consumption of the pump, and enhances the system efficiency because the collector has higher efficiency at lower collector temperature and the absorption chiller COP doesn't depend on the hot water temperature. Also, it can prevent from boiling and freezing of solar hot water.

## 3 RESULTS OF DEMONSTRATION

The demonstration plant was constructed in one of our branch offices, and has been operated to verify the features described in chapter 2 since April 2009. Basically our system has only one type of collector for one system, but three types of collector has been installed in this plant for experiments. All these have U-shaped pipes inside the collectors and the heat medium (tap water) is heated directly.

**Table 1: Specification of Demonstration Plant**

| | | |
|---|---|---|
| Building | Place | Kanagawa Pref. Japan |
| | Floor Area | 3878m$^2$ |
| | Application | Office and Showroom |
| Collector | A-line | 39m$^2$ (with reflective mirror) |
| | B-line | 109m$^2$ (with reflective mirror) |
| | C-line | 56m$^2$ (without reflective mirror) |
| Absorption Chiller | Chilling Capacity | 422kW |
| | Rated COP without solar hot water<br>[output of chilled water] / [input of natural gas(LHV)] | 1.5 |
| | Rated COP with solar hot water<br>[output of chilled water] / [input of natural gas(LHV)] | 1.85 |
| | Chilled Water Temperature | 15 -> 7deg.C |
| | Cooling Water Temperature | 32 -> 37.4deg.C |

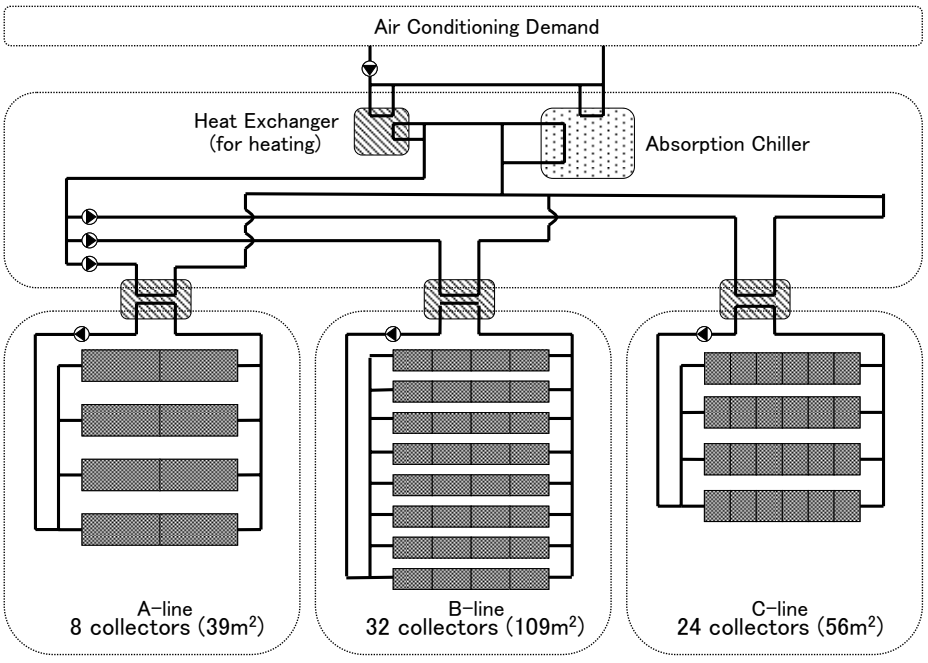



**Figure 4: Schematic Diagram of Demonstration Plant**

### 3.1 Single / Double Effect Absorption Chiller

As shown in Figure 5, natural gas was consumed only when the heat quantity of solar hot water wasn't enough to supply chilled water, and from 11:10 to 12:40 the absorption chiller was driven only by solar hot water without consuming natural gas.

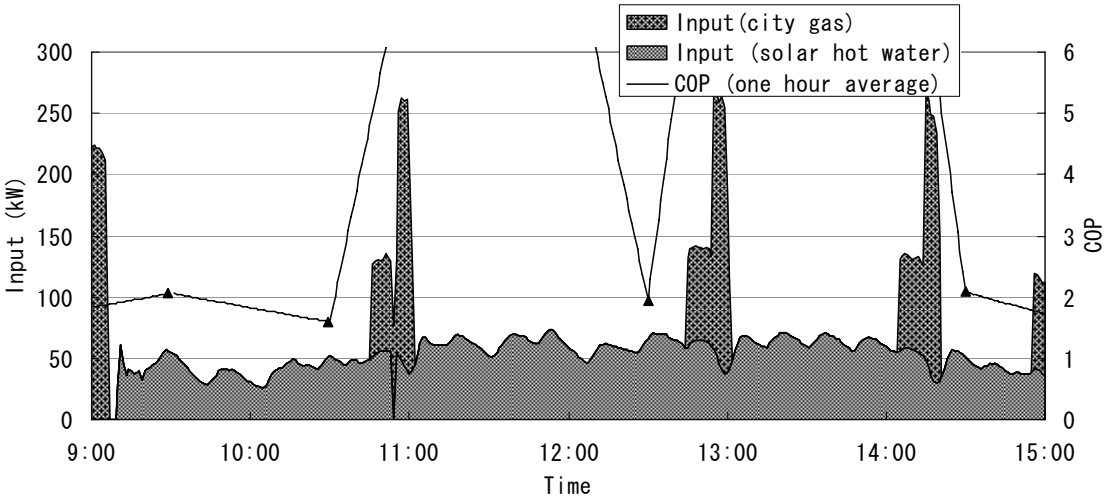



**Figure 5: Input and COP of Absorption Chiller (16th/Nov./2010)**

### 3.2 No Buffer Tank Piping

As shown in Figure 6, the output of the absorption chiller (air conditioning demand) was stable and all the heat of solar hot water was recovered by the absorption chiller just after it was generated. In addition, as shown in Figure 7, although the inlet solar hot water temperature into the absorption chiller was unstable because of the unstable irradiance, the gas burner of the absorption chiller made the chilled water temperature stable.

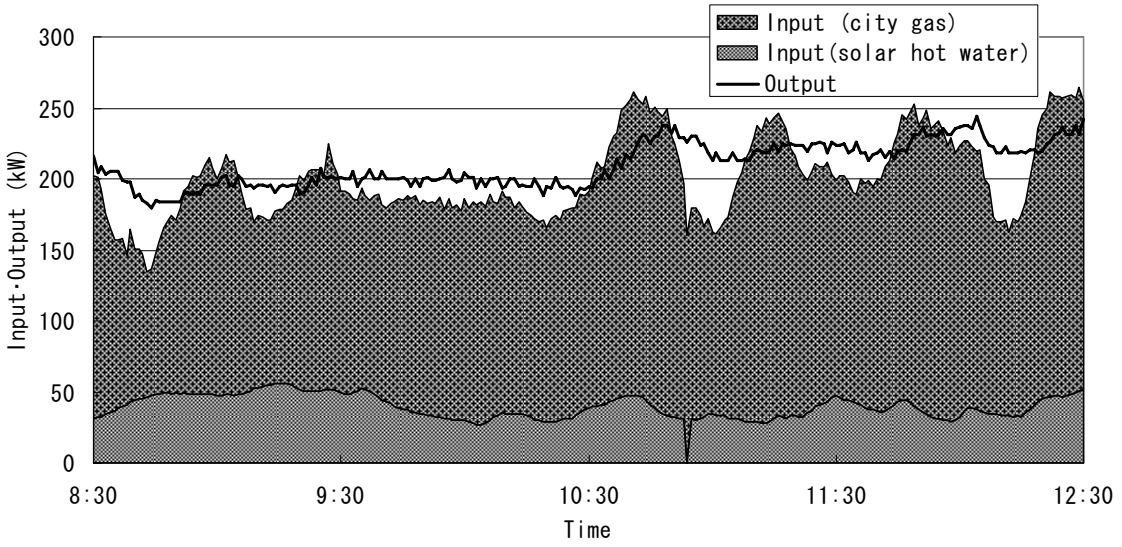



**Figure 6: Input and Output of Absorption Chiller (27th/Aug./2010)**

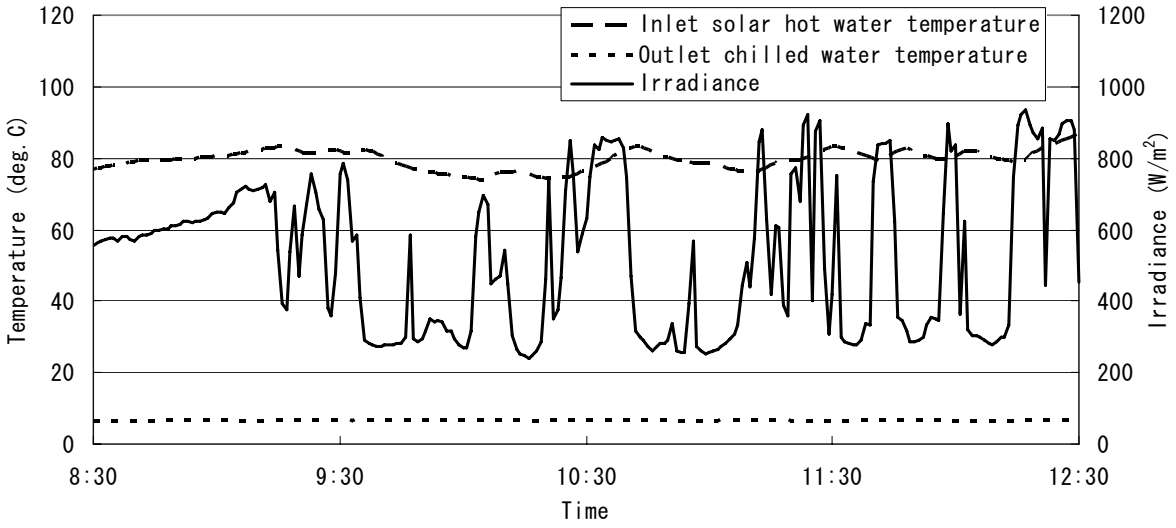



**Figure 7: Temperature of Absorption Chiller And Irradiance (27th/Aug./2010)**

### 3.3 Control of Solar Hot Water Pump

As shown in Fig.8, the controller operated the pump when the collector outlet temperature reached the minimum temperature that is enough to drive the absorption chiller. At 13:07, the pump was stopped because the outlet temperature was not enough, although the temperature was more than 70 deg.C. Also, during the pump operation, its average temperature was only 75 deg.C, although the rated inlet hot water temperature of the absorption chiller is 90 deg.C, because of lower air conditioning demand and cooling water temperature.

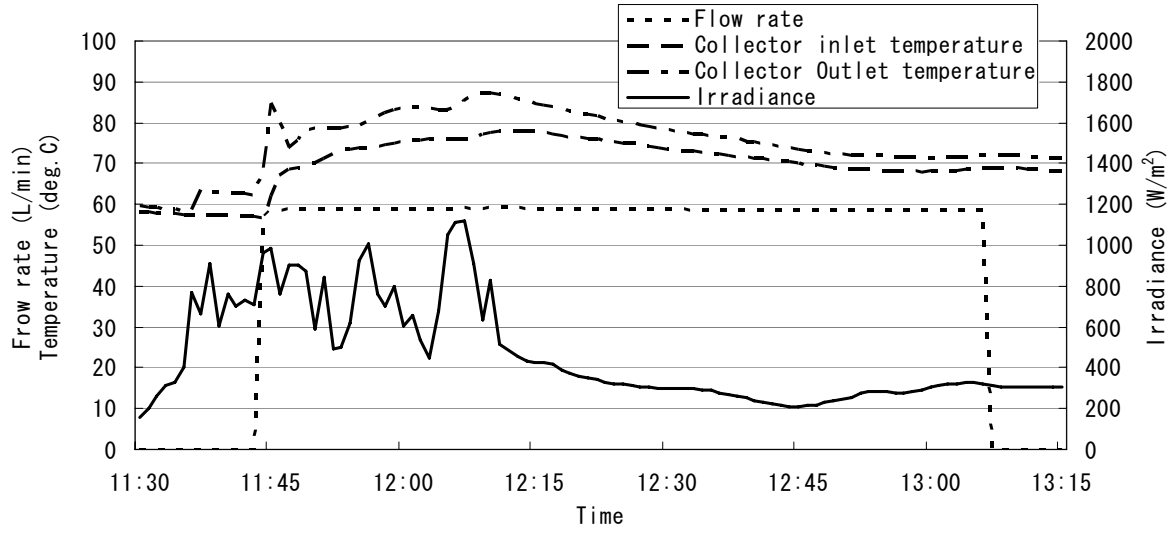



**Figure 8: Operating Data in B-line (20th/Sep./2010)**

### 3.4 Monthly Result

As shown in Figure 9, the volume of $CO_2$ emission was reduced by about 18% from April to December 2010, compared with the conventional system with the absorption chiller of COP 1.1 without collectors. About one half of the reduction volume came from the solar energy. Because some experiments were made in April and May, the volumes were lower. This result is based on following assumptions.

- $CO_2$ emission factor : 2.29 [kg-$CO_2$/$m^3$N], 0.69 [kg-$CO_2$/kWh]
- The electric consumption of all pumps (solar hot water pump, chilled water pump, cooling water pump), the cooling tower and the absorption chiller is also calculated.

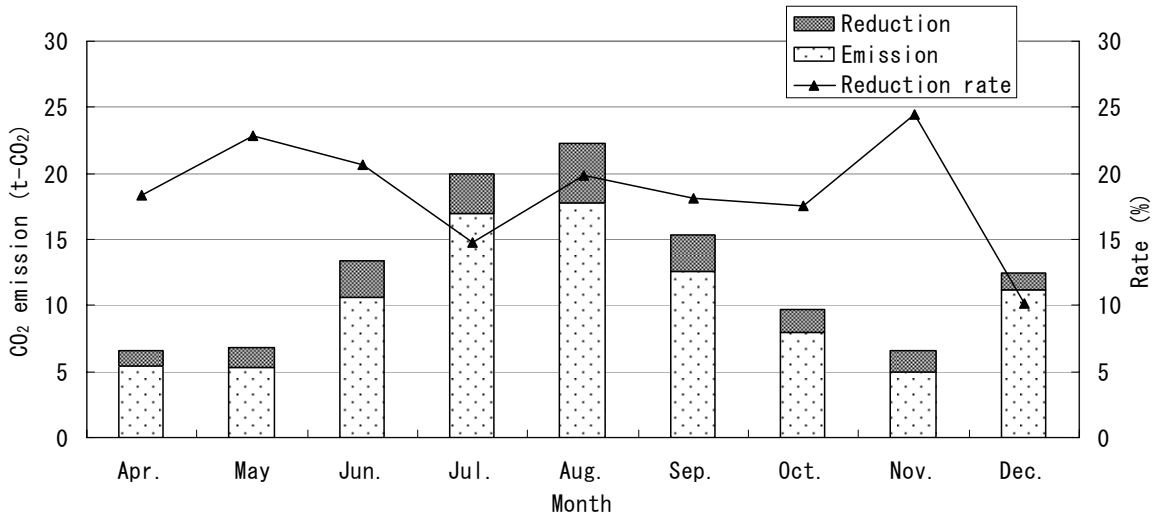



**Figure 9: Monthly Result of $CO_2$ Reduction**

## 4 CONCLUSION

An advanced solar air conditioning system for commercial use that has a single/double effect absorption chiller, no buffer tank and a controller specialized for the solar air conditioning was developed and launched sales of. Through the demonetization, followings were verified.

- The absorption chiller could convert solar hot water by priority to chilled water and made the system COP much higher than the conventional system.
- Although the system had no buffer tank, the temperature of the chilled water was stable even when the irradiance and the solar hot water temperature were unstable, because of the control of the back-up gas burner.
- The controller operated the pump only when the solar hot water temperature reaches high enough but as low as possible to drive the absorption chiller, to minimize the pump electric consumption and enhance the collector efficiency.
- The demonstration has been successfully operated and the volume of $CO_2$ emission was reduced by about 18% compared with the conventional system.

## 5 REFERENCES

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