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# Fundamental Study on a Green Roof Building Air-conditioning System – Experimental Analysis of Summer Mode using a Reduction Model Apparatus

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**Abstract**

In recent years, urban areas in Japan have been experiencing a phenomenon called the heat island effect, which causes the temperature in cities to increase to a few degrees warmer than the surrounding suburban areas. It has attracted attention as one of many environmental issues. By utilizing the green roof units as thermal storage tanks and combining it into the building air-conditioning system which has an auxiliary heat source apparatus, a new air-conditioning system with low energy consumption can be designed, and there is the possibility that this technology could provide a solution to both the heat island effect and global warming. This paper relates to an experimental apparatus as a reduction model which we produced to evaluate the effectiveness of this compound system. The reduction model apparatus has a heat storage planter, a tank of hot water, artificial solar heat and an air conditioner.

In this paper, we presented operation characteristics of summer mode on this reduction model apparatus, and results show that the green roof building air-conditioning system is one promising candidate as a new building air-conditioning system.

*Keywords: Heat pump; Green roof; Heat storage; Artificial sun; Heat recovery*

## 1. Introduction

In recent years, urban areas in Japan have been experiencing a phenomenon called the heat island effect, which causes the temperature in cities to increase to a few degrees warmer than the surrounding suburban areas. It has attracted attention as one of many environmental issues. The heat island effect is a phenomenon in which atmospheric temperature is elevated due to increases in artificial heat releases and artificial land surfaces. In urban areas, the heat release rate is high because of the higher energy consumption rate. Additionally, since the coverage of artificial land surfaces such as roads or concrete buildings is extensive in urban areas, these materials act as a thermal storage medium through energy consumption, causing temperature increases in these areas. Especially in summer time, there is concern about health issues related to heat exhaustion, etc. caused by the temperature rise, and it becomes a serious environmental issue when a vicious spiral occurs due to the temperature rise driving up energy consumption. As a preventive measure, attention is being given to green roof projects that allow for a reduction in asphalt or concrete surface coverage in urban cities and are expected to promote the transpiration effect of plants. Consequently, various types of green roof units have actually been made available for practical use.

In addition to the remedial measure against the heat island effect, green roofs are also expected to provide other positive impacts including prolonging a building's life span and saving energy consumption as a result of reductions in air conditioning usage, since it increases building insulation. One of the global environmental problems of importance is global warming. To suppress global warming requires a decrease in load in the power plants.

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Thus, increasing the energy efficiency of electrical equipment is an important policy. Especially, the energy efficiency of air-conditioning systems for buildings should be improved immediately, because they are less efficient than household air conditioners. From these facts, the author and other staff have been conducting fundamental researches by focusing on a combined system of a green roof and air-conditioning for buildings [1]. And the heat transfer characteristic of lightweight soil was clarified [2]. Current building air-conditioning systems are operated under excessive heat loads, and when a green roof unit is used as a thermal storage tank, the excessive heat can be utilized by establishing an energy saving type air-conditioning system which produces efficient energy use. However, a combined system of a green roof and air-conditioning is currently not on the market. By utilizing the green roof units as thermal storage tanks, and combining it into the building air-conditioning system which has an auxiliary heat source apparatus, a new air-conditioning system with low energy consumption can be designed, and there is the possibility that this technology could provide a solution to both the heat island effect and global warming. Furthermore, we developed an experimental apparatus of a reduction model which is designed to evaluate the effectiveness of this compound system [3].

This paper relates to the green roof air-conditioning system under summer times conditions by using collector as a function of a water retention rate by lightweight soil from results of experiments using this reduction model apparatus.

## 2. Reduction Model Apparatus

### *2.1. Outline of a system to target*

Figure 1 shows expected summer and winter mode of a system with a green roof unit for a building. If a green roof unit is utilized as a thermal storage unit for air conditioning, an air-conditioning system for a building can be made energy efficient. In winter time, excess waste heat is transferred from the interior to a green roof unit in the building, which allows the plants to grow without dying all year. A green roof improves the thermal insulating properties of the building, which increase the energy efficiency of the air conditioning. A green roof can also receive solar energy to heat water. The efficiency of these co-generation systems for buildings is around 0.5 as COP of a trial calculation which was predicted with an assumption.

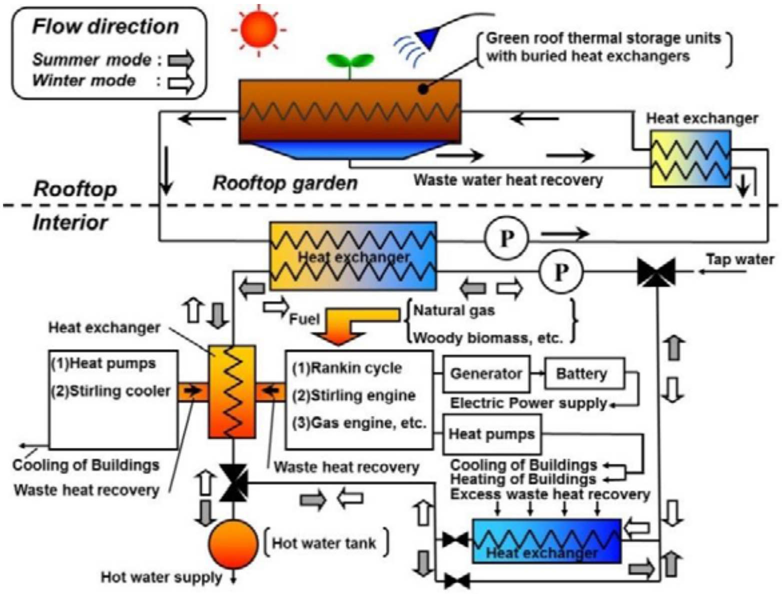


Fig. 1. Structure of a system

### 2.2. Reduction Model Apparatus

The author has designed an apparatus as a reduction model which we produced to evaluate the effectiveness of this compound system based on basic experimental results. We assumed a building which has 8 rooms of 23 $m^2$ and total floor area of 200 $m^2$. The reduction model reduced this to 1/15. Table 1 shows specifications of the reduction model apparatus.

Figure 2 shows the reduction model apparatus. Then also Figure 3 shows a circuit diagram of this model. This apparatus has a heat storage planter, a tank of hot water, and an air conditioner. The heat storage planter is heated by artificial solar heat, and collected heat is done heat storage of by hot water tank. The hot water tank is united with an air-conditioning system through a heat exchanger.

Table 1. Specifications of the reduction model

| | A building to assume | A reduction model |
|---|---|---|
| Floor area | 200 $m^2$ | 13.3 $m^2$ |
| Planter area | 3.75 $m^2$ | 0.25 $m^2$ |
| Hot water supply | 28 L/min. | 1.8 L/min. |
| Capacity of air conditioner | 40 – 46.8 kW (2 HP ×8) | 2.5 – 2.8 kW (1 HP) |
| Waste heat from a building | 6.51 kW | 0.43 kW |
| Solar irradiance from an artificial solar | | 800 W/$m^2$ (max.) |

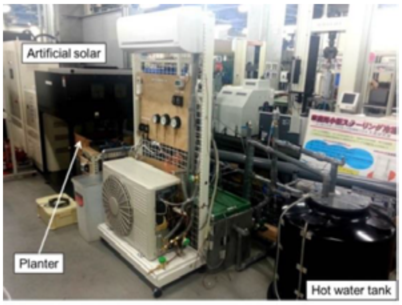


Fig. 2. The reduction model

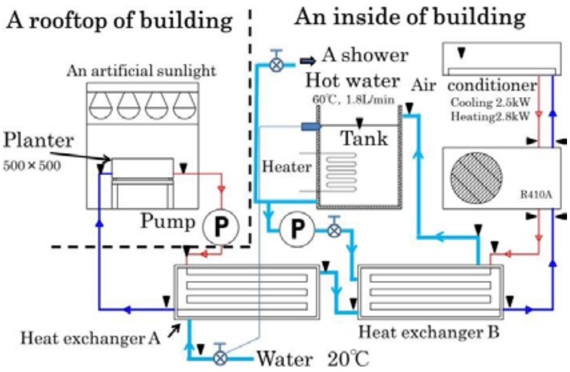


Fig. 3. Circuit diagram of the reduction model

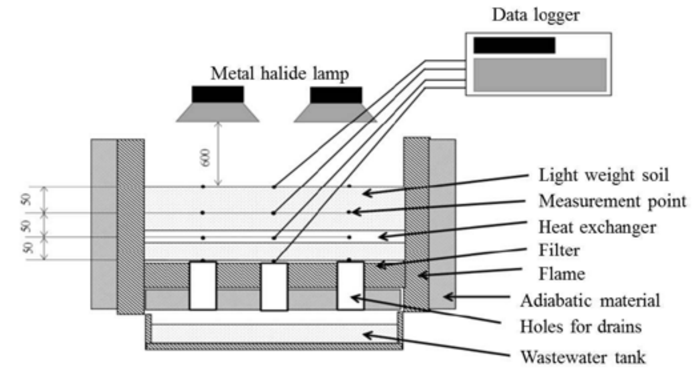


Fig. 4. Schematic view of the planter

A design of the planter used for the reduction model apparatus is shown in Figure 4 for greening units, the bottom part has holes for drains so that the excess water could always be discharged from the unit. Furthermore, on the ground, thermocouples are placed at five places numbered as No.1 to No.5, each place has depths of 0 mm, 50 mm, 100 mm, and 150 mm from the surface. Instead of the sun, we use artificial sunlight to adjust solar irradiance. The adjustment of solar irradiance was set between 700 and 800 W/m$^2$. The metal halide lamp has a distance of 600 mm from the soil surface. To avoid temperature effects from the outer environment, insulation materials are set at the side and bottom surface of the greening unit. The copper pipes are buried to 100 mm depth as a heat exchanger, and water passes through in it consecutively.

## 3. Experimental

### *3.1. Experimental conditions*

Table 2 shows the experimental conditions. The selection of water retention rate is on the mass of water to be 0 kg, 3kg, 6kg, 9kg and through Formula (1) to calculate the water retention rate.

Table 2. Experimental conditions

| | Conditions |
|---|---|
| Water retention rate (%) | 0%, 33%, 50%, 60% |
| Solar irradiance (W/m$^2$) | 700~800 (W/m$^2$) |
| Temperature of water (˚C) | 15(˚C) |
| Flow rate of water (L/min.) | 4.0~4.5 (L/min.) |
| Time of measurement (hours) | 6 (hours) |
| Mass of dry soil (kg) | 6 (kg) |

Here, the definition of water retention rate is shown as

$$u = W_w/(W_w + W_s) \times 100\% \tag{1}$$

where
$u$ = Water retention rate (%), $W_w$ = Mass of water (kg), $W_s$ = Mass of dry soil (kg)

### *3.2. Experimental results*

The experimental results are shown in Figure 5 to Figure 7.

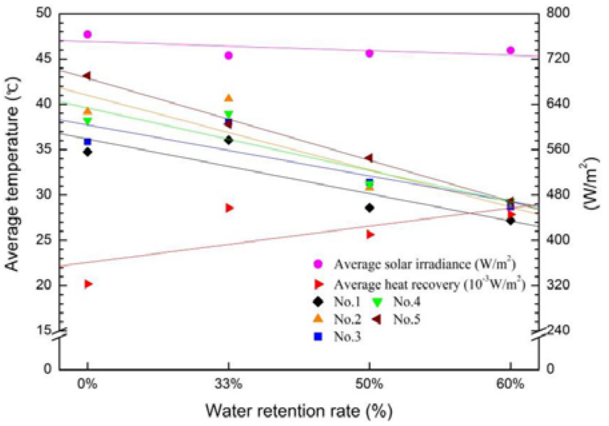


Fig. 5. Water retention rate affects average temperature and average heat recovery

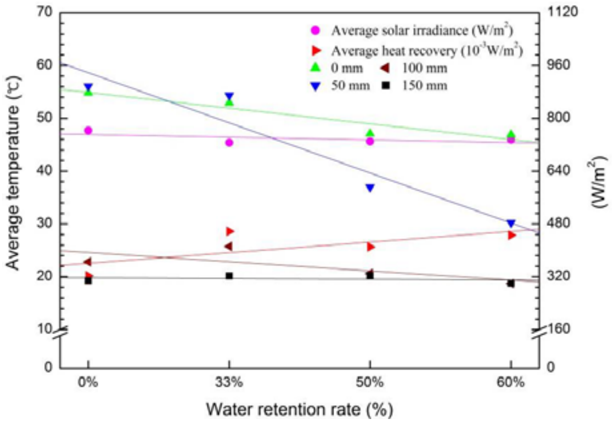


Fig. 6. Water retention rate affects different depth measurement point average temperature and average heat recovery

In Figure 5 to Figure 7, each point represents the average measurements in 6 hours and each linear regression is drawn by its points. The measurement point in average heat recovery represents the copper pipe with tap water which buried in the planet is heat-exchanged with the waste heat generated by the artificial sun.

As shown in Figure 5, a soil average temperature decrease as the water retention rate increase. In contrast, there is an increasing trend for average heat recovery. Also, at a water retention rate of 60%, the average temperature of No.1 to No.5 (about 28.7 ˚C) is more uniform than others.

In Figure 6, 0 mm and 50mm has a relatively large average temperature difference. The copper pipe with tap water is buried in depth 100 mm which has the average heat recovery about 0.45 (W/m$^2$) at a water retention rate of 60%.

Figure 7 shows the higher a water retention rate, the higher an average heat recovery efficiency tends to be. Finally, the average heat recovery efficiency has about 0.06% at a water retention rate of 60%.

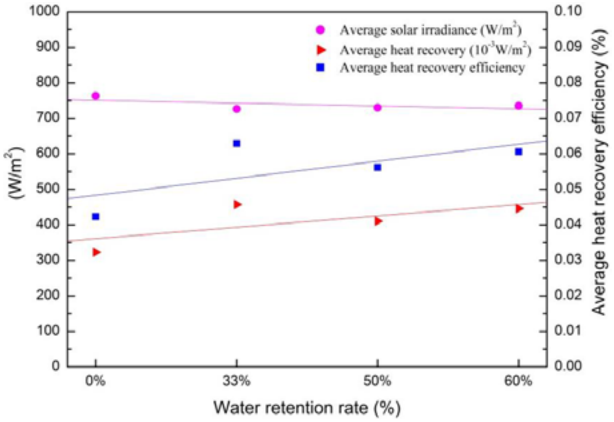


Fig. 7. Average heat recovery and average heat recovery efficiency

## 4. Conclusion

The thermal energy stored in the planter unit as a function of moisture content was recovered and a basic experiment was conducted to clarify the heat storage characteristics of this model device. In addition, since practicality is confirmed in this system, the function utilization test of this reduction model device is carried out and the result is reported. From this experiment result, it was seen that the heat recovery efficiency increased in proportion to the water retention rate. These results show that the green roof building air conditioning system is one promising candidate as a new building air conditioning system.

## 5. Acknowledgement

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