12th IEA Heat Pump Conference 2017

# Study of an Air-conditioning System Combining a Green Roof as Heat Storage Unit - Analysis of Operating Characteristic of a Reduction Model Apparatus

Toshio Otaka[a]

[a]Kokushikan University, 4-28-1, Setagaya, Setagaya-ku, Tokyo, 154-8515, Japan

**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. 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. 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. 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. The hot water tank is united with an air-conditioning system through a heat exchanger. In this report, we perform a function usability test of this reduction model apparatus on summer mode, and report the result because utility was confirmed in analysis.

*Keywords:* Heat pump; Green roof; Heat storage; Artificial solar; 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. 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. Experiment was performed in which heat energy stored in the thermal storage unit is recovered, revealing thermal storage properties of this unit.

This paper relates to a thermal characteristic of an experimental apparatus and a reduction model which is designed to evaluate the effectiveness of this compound system.

## 2. Outline of a System to Target

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.

### *2.1. Summer mode of a system*

Figure 1 shows expected summer and winter mode of a system with a green roof unit for a building. In figure, heat energy is recovered in the following sequence in summer mode.

(1)Plants are cultivated in a green roof thermal storage unit installed on the roof of a building, resulting in the reduction of both wall temperature and $CO_2$ emissions. Hot water can be obtained, because pumped water circulates through buried heat exchangers. The heat of water extracted from the light-weight soil can also be recovered via heat exchangers. Water warmed by heat exchangers is fed into the interior of the building.

(2)Heat pumps and a Stirling cooler[3,4] for air cooling or refrigeration is operated in the interior of the building. The hot water obtained in the process (1) absorbs waste heat produced by the high-temperature-side heat exchanger of this cooler.

(3)In the interior of the building, a Rankin cycle system, a gas engine or a Stirling engine using a woody biomass pellet stove is also operated for generating electricity to meet power demand and driving heat pumps. The hot water obtained in the process (2) absorbs waste heat from the stove, the heat of exhaust gas, and waste heat produced by the low-temperature-side heat exchanger of the engine.

(4)The hot water obtained in the process (3) is recovered into the hot water storage tank installed downstairs (e.g., in the basement), and used for supplying hot water throughout in the building.

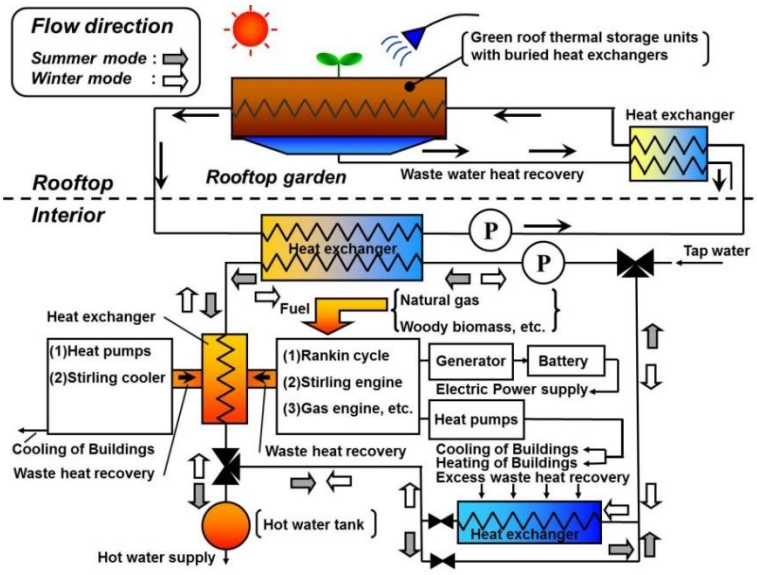



Fig. 1. Structure of a System

*2.2. Winter mode of a system*

In figure, energy is similarly recovered in the following sequence in winter mode.
(1)Excess waste heat produced by heating equipment, etc., is recovered through heat exchangers, producing hot water.
(2)A Stirling cooler for refrigeration is operated in the interior of the building. The hot water obtained in the process (1) absorbs waste heat produced by the high-temperature-side heat exchanger of this cooler.
(3)In the interior of the building, woody biomass pellet stoves are operated, the waste heat of which is used to operate a Stirling engine for electric power demands. The hot water obtained in the process (2) absorbs waste heat produced by the low-temperature-side heat exchanger of this engine.
(4)The hot water obtained in the process (3) is pumped into buried heat exchangers of the green roof thermal storage unit installed on the roof. Thus, the light-weight soil can be warmed to promote growth of the plants even in winter, while reducing $CO_2$ emissions.

## 3. 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.

Table 1. Specifications of the reduction model

| | A building to assume | A Reduction model |
|---|---|---|
| Floor area | 200 m2 | 13.3 m2 |
| Planter area | 3.75 m2 | 0.25 m2 |
| Hot water supply | 28 L/min. | 1.8 L/min. |
| Capacity of air conditioner | 40 – 46.8 kW | 2.5 – 2.8 kW |
| | (2 HP ×8) | (1 HP) |
| Waste heat from a building | 6.51 kW | 0.43 kW |
| Amount of radiation from an artificial solar | | 800 W/m2 (max.) |

Figure 2 shows the reduction model apparatus. And 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.

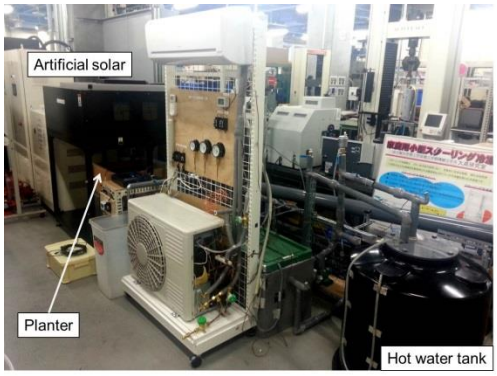



Fig. 2. Reduction model

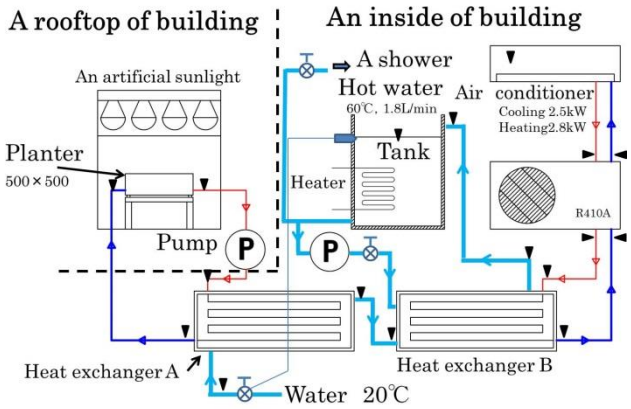



Fig. 3. Circuit diagram of reduction model

Figure 4 shows temperature change of water flowing to a planter as one of the reduction model apparatus operation check test. They become quasi-steady in about 60 minutes after a startup. These seem to be almost good performance. Figure 5 shows an example of experimental results of a reduction model apparatus in a summer mode as operation check. About 20% of value of solar radiation is provided as hot water supply in this condition.

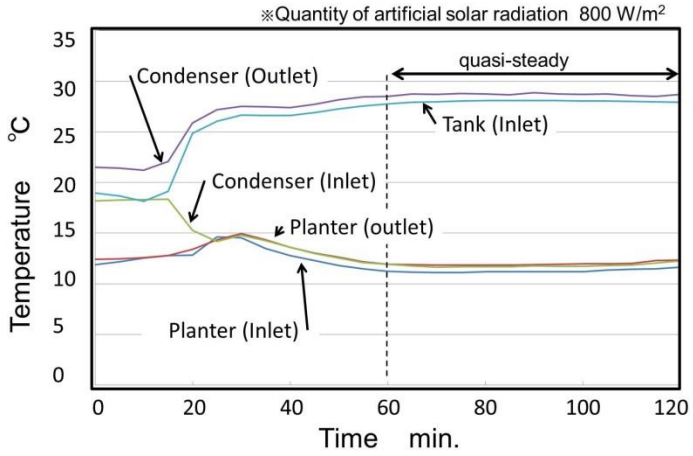


Fig. 4. Temperature change

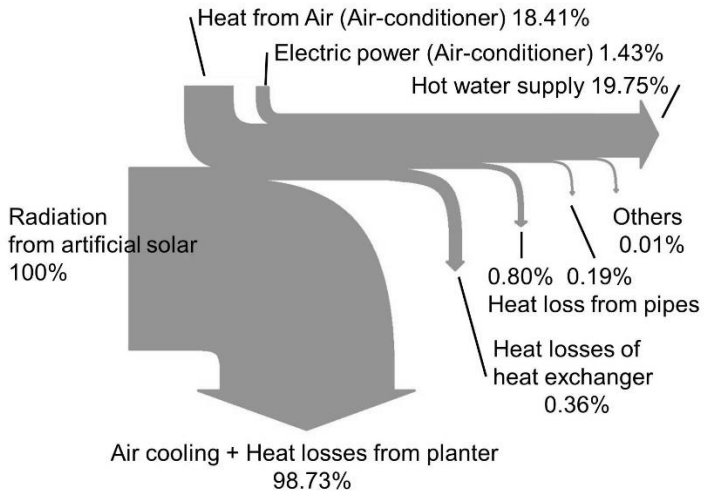



Fig. 5. Heat balance

## 4. Conclusion

Fundamental experiment was performed in which heat energy stored in the planter unit is recovered, revealing thermal storage properties of this model apparatus. Moreover, we perform a function usability test of this reduction model apparatus, and report the result because utility was confirmed in this apparatus. This system realizes about 20% hot water supply of solar radiation in the summer mode. These results demonstrate that the green roof building air-conditioning system is one of the promising candidates as a new building air-conditioning system.

## References

[1] T.Otaka, Study of a Green Roof Building Air-conditioning System with Thermal Energy Storage Unit using Light Weight Soil, Proc. The International Conference on Power Engineering-2009, (2009), pp.299-303
[2] H.Yokobayashi, D.Kim, T.Otaka, Basic Study on a Thermal Design of a Green Roof Planter –Thermal Properties of a Thermal Energy Storage Unit Using Light Weight Soil, Proc. Design Symposium 2012, (2013), pp.203-206
[3] T.Otaka, I. Kodama, M. Ota, Experimental Study on a Stirling Cycle Machine of 100W Design Capacity, Journal of Power and Energy Systems, Vol.2, No.3, (2008), pp.1027-1035
[4] T.Otaka, T.Odagiri, Fundermental Study on an Active-type Regenerator for a Small Sized Stirling Cycle Machine, Proc. The International Conference on Power Engineering-2013, (2013), Paper#192