A Study on the Reduction Effect of Ventilation and Heating Load by Installing Air-based Solar System in the Detached Houses

Youngjin Choi*[1], Kozo Takase[2], Masayuki Mae[3], and Hyunwoo Roh[4]

1 The University of Tokyo
Hongo 7-3-1, Bunkyo-ku
Tokyo, Japan
**Corresponding author:choiyj11@gmail.com*

2 Tokyo University of Science
Yamazaki 2641, Noda
Chiba, Japan

3 The University of Tokyo
Hongo 7-3-1, Bunkyo-ku
Tokyo, Japan

4 OM solar
Murakushi -cho 4601, Hamamatsu
Shizuoka, Japan

ABSTRACT

Using solar heat energy has been paid attention to as effective natural energy use. In this study, we deal with air-based solar heat system, which is used for not only ventilation but heating and hot water supply by hot air.
In Japan, this system has been quite popular and installed into many buildings, but there is a few survey on the system by precise measurement. Then, we started the survey by building three huts with different specification and measure precise data of these in same weather condition. So we can analyse heat balance in these huts. Heat collection, thermal environment and heat storage are very important in the system. Especially, to use stored heat in night time is difficult because the solar heat is collected in the daytime only. The purpose of this research is to make some suggestion to improve the system by the measurement.

KEYWORDS

Air-based solar heat system, Experiment, Heat balance, Heat storage

1 INTRODUCTION

Using solar heat energy has been paid attention to as effective natural energy use. In this survey, we deal with air-based solar heat system, which is used for not only hot water supply but heating and ventilation by hot air. This system works as follows (shown in the Figure 1),

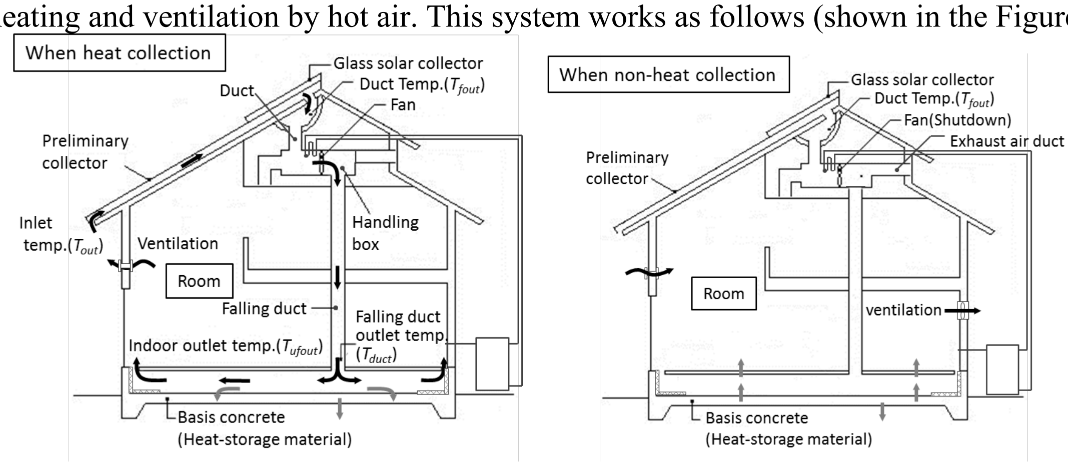


Figure 1: Conceptual diagram of the existing system

a) Heating outdoor air by solar collector on the whole roof.
b) Supply heat to water tank by antifreeze fluid which received heat by heat exchanger in the air handling box in the attic.
c) Blow hot air under the floor from the fan in the air handling box.
d) Store heat into the basis concrete under the floor by hot air.
e) Heating the whole room by supplying warm air from the under floor.

In this paper, we explain the system and the abstract of the measurement. The collector in air-based solar collect system is made up pre-heating collector of roof and glass collector for high temperature collection.

2 HEAT BALANCE AND THE POINTS OF IMPROVEMENT

2.1 Heat balance of the building with the system

The factors determining the performance of air-based collecting system, are the amount of collection, heat absorbing and radiating in the under floor, and heat loss by ventilation and heat flow-through. The performance of collector is calculated the difference of inlet (T_o) and outlet (T_{colout}) temperature and wind flow as shown in equation (1). The collection efficiency (η) is calculated by the ratio of solar radiation in the collector and the amount of collection (Q_{col}) as shown in equation (2).

$$Q_{col} = c\rho \cdot V \cdot (T_{colout} - T_o) \quad (1)$$

$$\eta = Q_{col}/(A_{col} \cdot I) \quad (2)$$

$$\rho = 353.25/(T_{colout} + 237.15) \quad (3)$$

In addition, the amount of collection of room temperature criteria, makes influence in the indoor heating load, is defined equation (4). In addition, the amount of collection of room temperature criteria, makes influence in the indoor heating load, is defined equation (4). As shown in equation (5), the absorbing heat into the heat storage material in the under floor is obtained from the difference of the temperature of under floor (T_{uf}) and the surface temperature of the heat storage material, and the convective heat transfer coefficient (α_c) of the heat storage surface.

$$Q_r = c\rho \cdot V \cdot (T_{colout} - T_r) \quad (4)$$

$$Q_{uf} = \alpha_c \cdot (T_{uf} - T_{hs}) \cdot A_{hs} = F_{hs} \cdot A_{hs} \quad (5)$$

As shown in Figure 2, the heated air moves to the under floor, and then occurs the heat absorbing into the heat storage material as basis concrete (Q_{uf}), heat flow to the room (Q_f), and air flow into the room. The heat balance in the under floor is shown in equation (6).

$$Q_{vd} = c\rho \cdot V \cdot (T_{duct} - T_{ufout}) = (c\rho \cdot Vol_{uf} \cdot \Delta T_{uf}) + Q_f + Q_{uf} \quad (6)$$

The heat from the floor surface into the room is used for room temperature rising, heat flow into the wall, ceiling, window (Q_{wall}, Q_{ceil}, Q_{win}), and the heat loss by ventilation (Q_v). The heat balance in the room in the absence of solar heat gain and internal heat generation is shown in equation (7).

$$Q_{vu} + Q_f = c\rho \cdot V \cdot (T_{ufout} - T_r) + Q_f \quad (7)$$
$$= (c\rho \cdot Vol_r \cdot \Delta T_r) + Q_{wall} + Q_{ceil} + Q_{win} + Q_v$$

If it is assumed that there is no heat loss in the falling duct and handling box, the outlet temperature of collector is same to duct temperature. As shown in equation (8), the amount of collection in the room temperature criteria is same to the sum of heat supply to the room (Q_{vu}) of equation (7) and heat supply to the under floor (Q_{vd}) of the equation (6).

$$Q_{vu} + Q_{vd} = c\rho \cdot V \cdot (T_{duct} - T_r) = Q_r \quad (8)$$

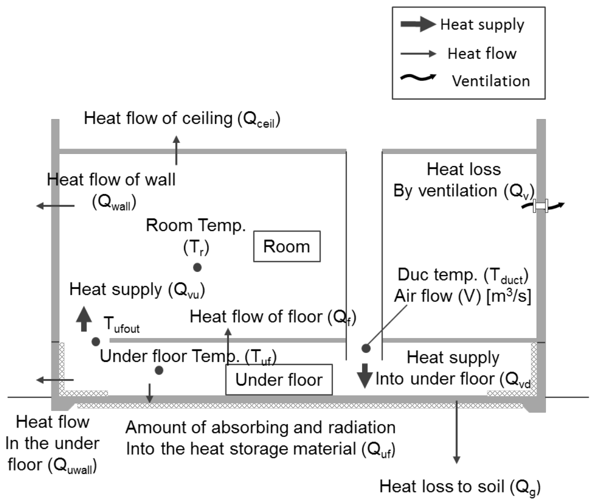


Figure 2: Definition of the heat flow

It is important to understand the heat balance in the building with this solar system in order to think about the improvement of the system. The heat balance diagram is shown in the Figure 3.

2.2 The points of improvement

There are four points for improvement as follows,
1) Increase the amount of solar heat collection.
2) Decrease the amount of heat loss from the basis concrete as the heat mass to the outdoor air and soil.
3) Increase the amount of heat absorption into the heat storage material.
4) Increase the amount of heat emission from the heat storage material.

In this study, as shown in Figure 4, (1) to improve the heat collection efficiency by improving the performance of collector and install the PV for electronic generation is target. The PV panel has same collection performance with existing pre-heat collector. And, (2) the method of insulation is considered for reducing heat loss to the outdoor and soil. The effective method of insulation is examined by measurement. (3) For increasing the heat absorbing and radiation of heat storage material by larger heat capacity, the water pack is installed as the additional heat storage material. (4) For increasing the heat radiation of heat storage material at the non-collection time, the forced air flow is adapted for increasing the convective heat transfer by changing the air of room and under floor. In the summer and intermediate season, the heated air is used for how water by heat exchange in the handling box.

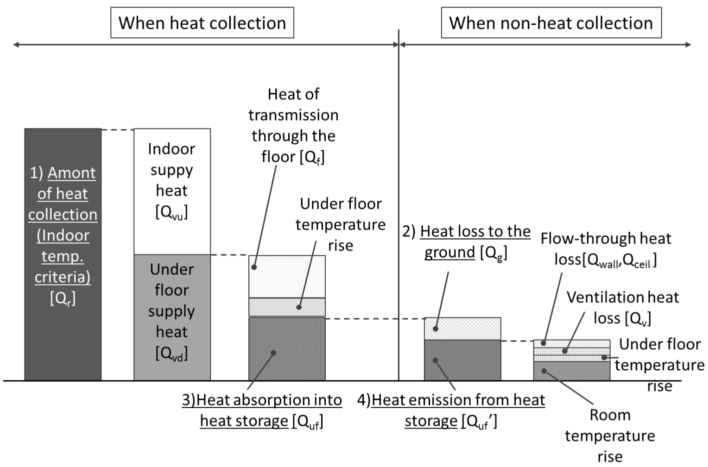


Figure 3: Heat balance of air-based solar system

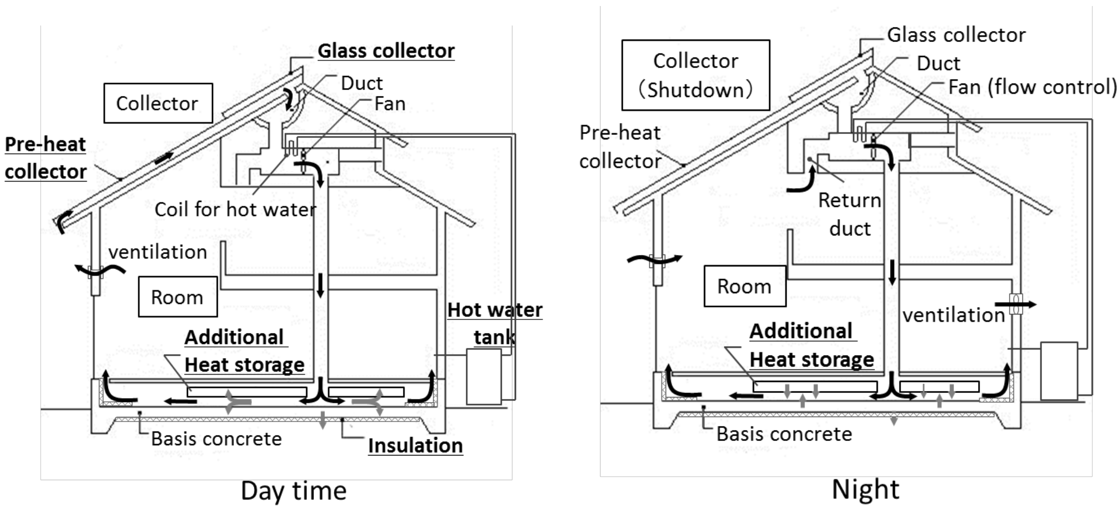


Figure 4: Improvement plan (system improvement is underlined)

3 SPECIFICATION OF HUTS AND MEASUREMENT

We built three huts in Hamamatsu City in Japan, of which size is same. These huts are equipped with well insulation which fills the energy saving standards in Japan. The specification is shown Table 1. Hut no.1 with the system and air conditioner has no insulation under the basis concrete. Hut no.2 with the system and air conditioner has insulation under the basis concrete. Hut no.3 doesn't have the solar heat system and equip only air conditioner. For example, we can compare the previous system with the improved system at the same time.

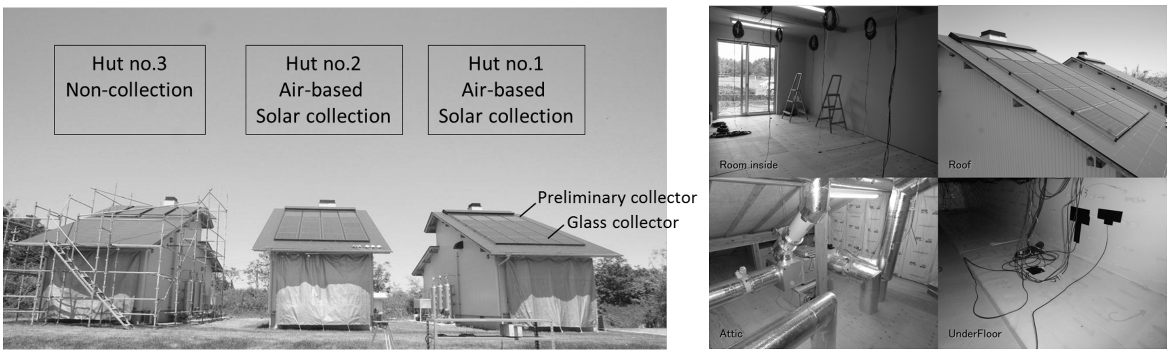
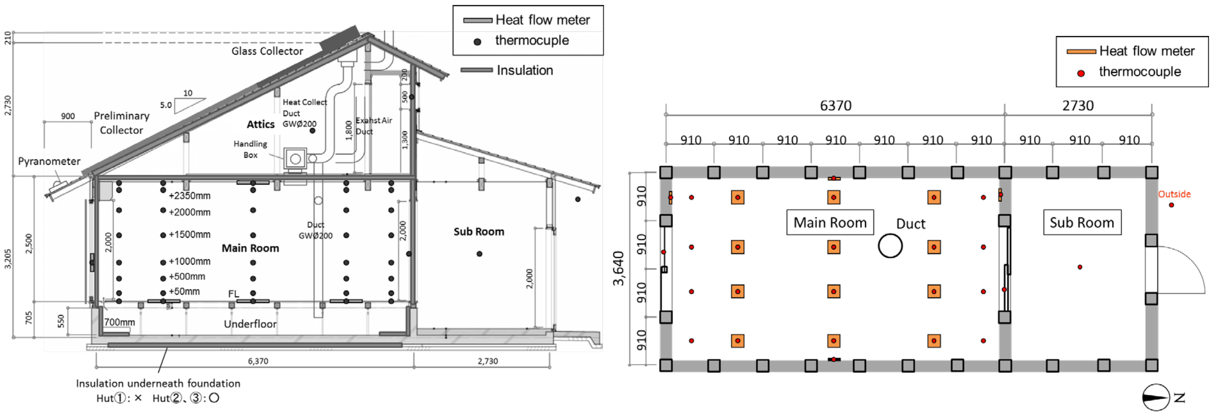


Figure 5: Overview of experiment huts

The measurement was set to analyse the heat balance in the whole huts. Especially, many thermocouples, heat flow sensors, mass flow maters and so on were set in the solar collector, duct space and under floor. The data was recorded every minute. We confirmed the measurement is very precise and grasp the heat balance in the real situation. Fig.6 and Fig.7 shows measurement point of building, collector, and under floor.

Table 1: Specification of experiment huts

Basis concrete	Walls: Width 150 * Height 600mm
	Plane: Thickness180*Width3, 790*Length6, 520mm
Walls (U-value：0.335W/m^{2}K)	Color steel plate, PB t=9.5mm, vent layer t=36mm, waterproof sheet, structural plywood t=9mm, High performanceGW16K 100mm, PB t=12.5mm
Floor	Structural plywood 28mm (thermal conductivity：0.13W/mK)
Ceiling (U-value：0.361W/m^{2}K)	Structural plywood t=28mm, phenolic foam t=80mm, Air layer 40mm, PB t=9.5mm
Roof (U-value：0.627W/m^{2}K)	Resin-based roofing t=0.42mm, Structural plywood t=12mm, GW32K t=50mm
South and North windows	Low-E(insulation)glass(3-A12-3, U-value：1.7W/m^{2}K)+aluminum multilayer・resin composite frame (Solar radiation through south window is shielded)
Insulation under basis concrete	extrusion method XPS 3-B t=50mm (hut no.2,3 only) (Thermal conductivity：0.03W/mK)
Insulation on basis concrete	Walls: extrusion method XPS 3-B t=50mm
	Outer periphery：extrusion method XPS 3-B t=50mm(Width：700mm)
Partition door between target and store room	Plywood t=3mm, GW32K t=25mm, Plywood t=3mm



(a) Section (b) Plan

Figure 6: Measurement point in the building

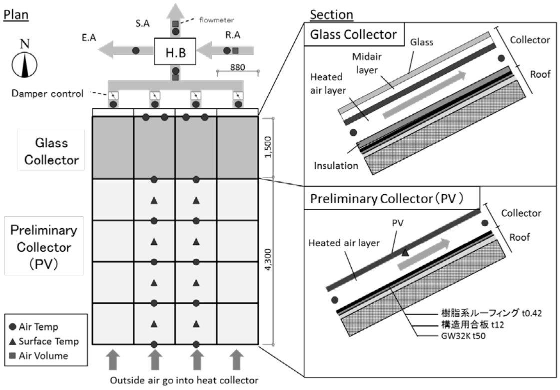


Figure 7: Measurement point of the collector

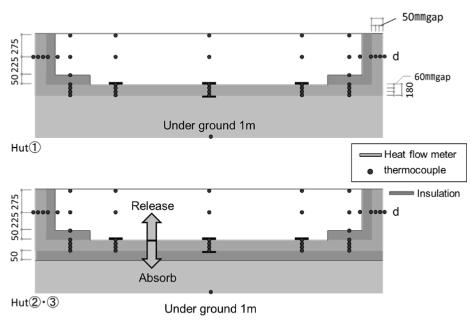


Figure 8: Measurement point of the under floor

4 EXPERIMENT OF HEATING IN WINTER

The purpose of these experiments is to analyse the efficiency of the improve methods. We judged the efficiency by the percentage of the amount of heat emission to the amount of heat absorption. The more the percentage (emission per absorption) is, it is consumed that the heating load will be reduced more.

Experiment 1): Confirmation of the amount of absorption and emission through the basis concrete between hut no.1 and no.2 in case of small solar collector
Experiment 2): Confirmation of the amount of absorption and emission through the basis concrete between hut no.1 and no.2 in case of large solar collector
Experiment 3): Confirmation of the amount of absorption and emission through the basis concrete and the additional heat storage, which was consisted of water in 40 packs (25 Litter per pack), between hut no.1 and no.2 in case of large solar collector
Experiment 4): Confirmation of the amount of absorption and emission through the additional heat storage. In hut no.1, there was water in 2000 PET bottles (0.5Litter per bottle). In hut no.2, there were water in 40 packs same as Experiment 3.

Table 2: Experiment conditions

	Heat Collection Area (Preliminary, Glass) [m^2]	Heat Storage	Experiment Period
Exp 1	7.0, 2.7	Basis concrete	29th Dec. 2012~6th Jan. 2013
Exp 2	14.0, 5.3	Basis concrete	7th Jan. 2013~14th Jan. 2013
Exp 3	14.0, 5.3	Basis concrete +water packs	29th Dec. 2012~6th Jan. 2013 (Hut1,2: Pre Experiment), 26th Dec. 2013~31st Mar. 2014(Hut2)
Exp 4	14.0, 5.3	Basis concrete +PET bottles	26th Dec. 2013~31st Mar. 2014

Insulation installation & Air conditioning

Experiment1, 2, 3:
Hut no.1-None, Hut no.2-possession under basis concrete
Air Conditioning from 6:00 to 23:00 (Set point = 20℃)
Auto-control Solar Collection（Handling Unit was stopped during night-time）

Experiment4:
Hut no.1- possession on basis concrete
Hut no.2- possession under and on basis concrete
Air Conditioning from 6:00 to 23:00 (Set point = 18℃)
Auto-control Solar Collection（Handling Unit was run during night-time）

4.1 Test Results

Experiment 1
If the solar collector doesn't get enough solar heat energy, the amount of absorption into the basis concrete is not sufficient, so the difference of the emission of heat between hut 1 and hut 2 was not appeared.
Clear days continued during the period. Collected Heat in hut 2 was about 10% less than in hut 1, Efficiency is about 15~20% (Figure 9).The reason of this difference may be caused by construction precision, the air-flow balance in the solar collector, and so on.
In hut 1, energy consumption for heating was over 1kW in the morning. It took a few hours to rise indoor temperature to 20 degree C. On the center part of concrete slab, peak value in

absorption was about 200W, in emission was about 170W. On the peripheral part of slab, heat emission was quite small (Figure 10).

Electricity consumption in hut2 was less than hut1, in spite of less collected heat. Underneath insulation of hut 2 gave good effect, but heat absorption and emission is small in both hut because of small collectors (Figure 11).

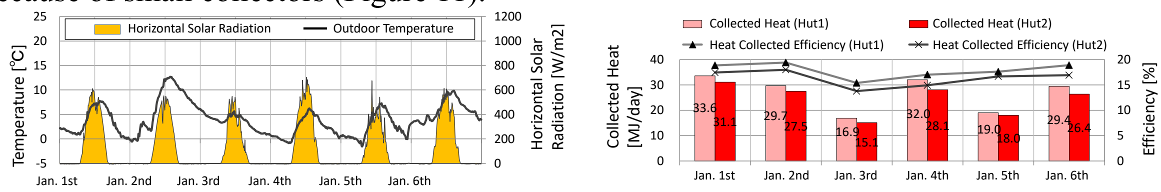


Figure 9: Weather & Collected Heat (Exp1)

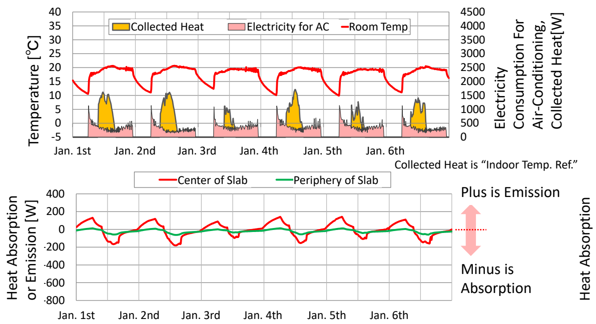


Figure 10: Result in hut 1 (Exp1)

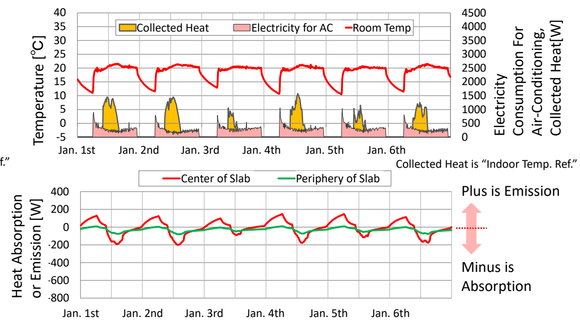


Figure 11: Result in hut 2 (Exp1)

Experiment 2

Collected Heat in hut 2 was about 15% less than in hut 1. Efficiency is about 17% in hut 1 and about 15% in hut 2 (Figure 12).

If the solar collector can get enough solar heat energy, the difference of the heat emission between hut 1 and hut 2 was appeared obviously. Although the amount of heat absorption into the basis concrete of hut 2 was less than hut 1, the amount of the heat emission of hut 2 was bigger than hut 1.

In hut 1, energy consumption for heating was over 1kW in the morning. It took a few hours to rise indoor temperature to 20 degree C. On the center part of concrete slab, peak value in absorption was about 600-750W, in emission was about 100W. On the peripheral part of slab, heat absorption was about 100W and emission was small (Figure 13).

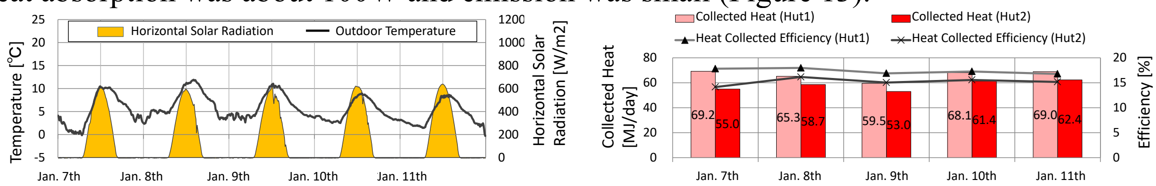


Figure 12: Weather & Collected Heat (Exp2)

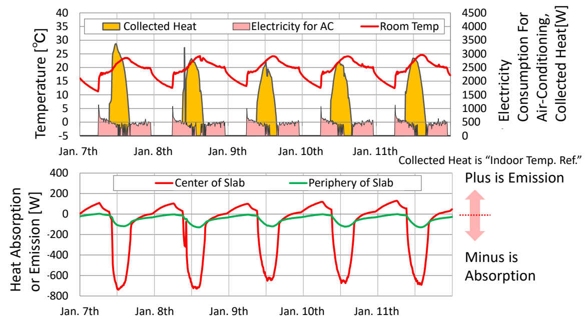


Figure 13: Result in hut 1 (Exp2)

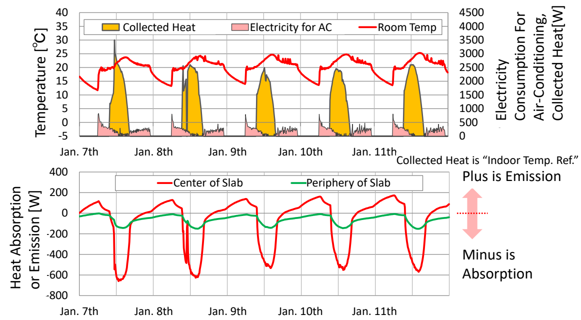


Figure 14: Result in hut 2 (Exp2)

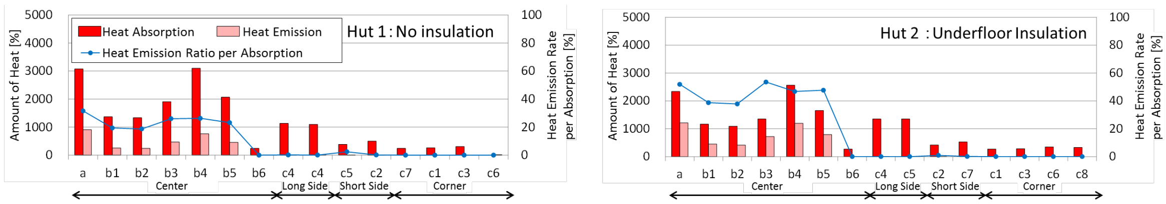


Figure 15: Heat emission per absorption of each heat flus sensors during the measurement period

Electricity consumption in hut2 was less than hut1 and indoor temperature rose in a short time. On the center part of concrete slab, peak value in absorption was about 500-600W, in emission was about 150W. On the peripheral part of slab, heat absorption was about 150W and emission was quite small (Figure 14).

In Hut2, absorption decreased but emission increased in comparison with Hut1. Heat emission ratio per absorption rose to about 50% in center part of slab (Figure 15). The percentage of total amount of emission per absorption was 17.6% in hut 1 and 29.4% in hut 2 during the period.

Experiment 3

Figure 16 shows the composition of water packs. In the case of setting water in packs in the underfloor space, the heat which water packs absorbed into wasn't extinguished as thermal loss into outdoor or soil. The amount of heat emission increased in night time. The percentage (emission per absorption) was 55.7% in hut 2.

Experiment 4

In the case of setting water in PET bottles in the underfloor space (Figure 18), the heat which PET bottle absorbed wasn't extinguished same as Experiment 3. Because the surface area of PET bottle is much larger than one of the water pack, the heat transfer was accelerated and the amount of heat emission highly increased in night time (Figure 18). The percentage (emission per absorption) was 47.0% in hut 1 and 25.7% in hut 2.

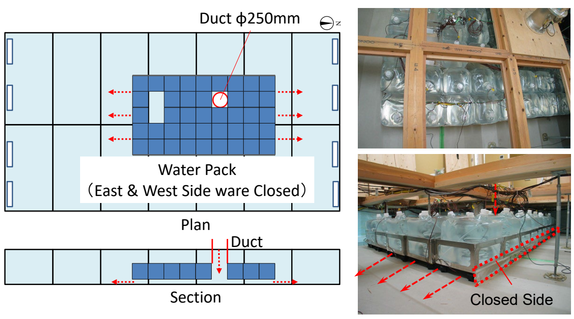


Figure 16: Composition of water packs in hut 2

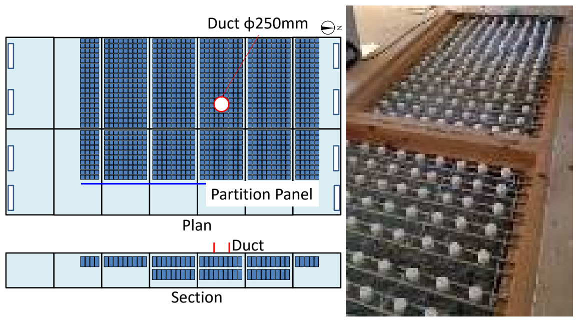


Figure 17: Composition of water PET bottles in hut 1

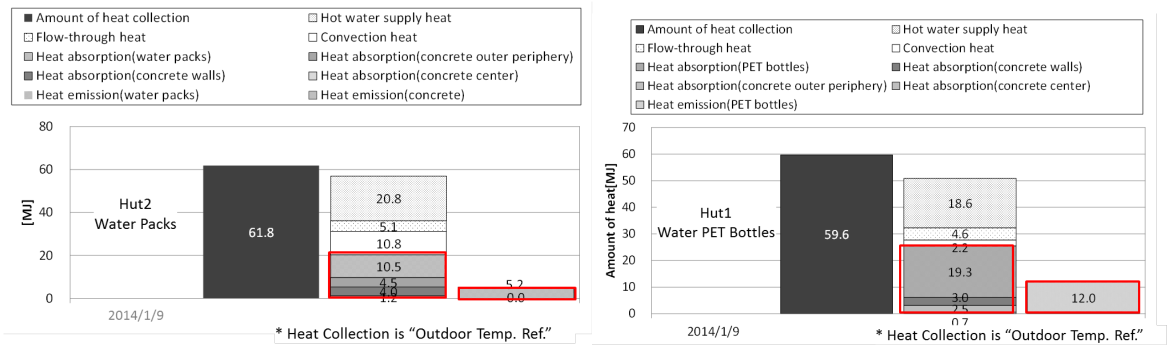
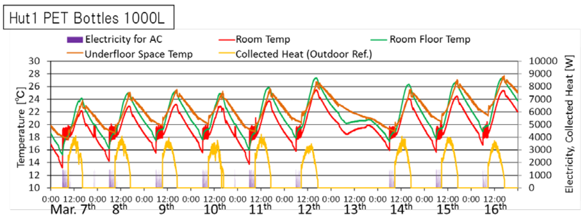


Figure 18: Heat balance in the underfloor in 1st Jan. 2014 (Experiment 3 & 4)

The amount of collected heat (outdoor temperature reference) in hut 1 and 2 were almost same. As shown in figure 19, Temperature of underfloor and floor in hut 2 was relatively higher than the temperature in hut 1, but room temperature of hut 1 was higher than hut2. As a result, the energy consumption for air-conditioning in hut 1 was lower than of hut 2. We confirm the result was caused by the fact that larger heat convection area of heat storage was preserved in hut 1 than hut 2, in spite of same volume of additional thermal storage.



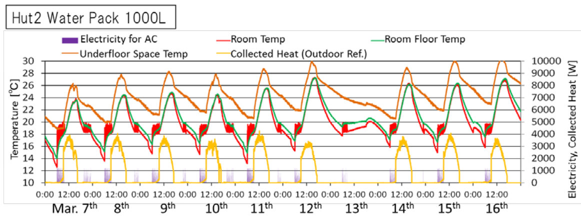


Figure 19: Temperature, collected heat & electricity used by air-conditioning (Experiment 3 & 4)

5 CONCLUSION

We confirmed the improve method of heat storage of the air-based solar system.

Experiment1 & 2:
There must be sufficient solar collector on the roof.
The insulation under the basement slab should be needed for night-time heat emission.
Reinforcement of insulation for the reduction of heat loss from peripheral part of basement should be needed.

Experiment 3 & 4:
Additional thermal mass is effective to increase heat emission in night time.
Especially, water in many PET bottles as thermal mass is effective to improve heat absorption and emission.

But the performance of the improvement system is not sure in the experiment. We'll show the amount of heating and hot-water load reduction by using simulation in the next study

6 ACKNOWLEDGMENT

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