SIMULATION STUDY ON THE HEAT STORAGE SYSTEMS COMBINED WITH AIR COLLECTORS

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1. Introduction

Air heating solar collectors are advantageous to be used for space heating. It is also suitable to use in solar buildings with both solar collectors and PV modules, since PV modules can be used as the preliminary heating collector. However it is necessary to consider the device for the thermal storage. In this study, several heat storage methods combined with air heating solar collectors are compared as the integrated thermal storage system expecting the thermal storage and the rediative floor heating.

2. Simulation models

The simulation model house is a detached house of wooden construction in Takasaki (36.32 degrees N, 139.0 degrees E), Japan. Fig.1. shows the floor plan of this house. The house structure is a one-story with a loft. The total floor area is 90 m^2. The house is provided with good insulation as shown in Tab.1.

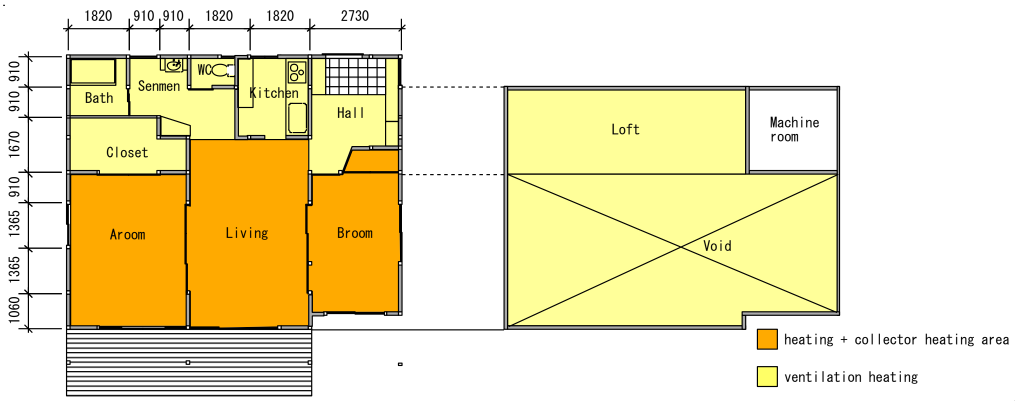
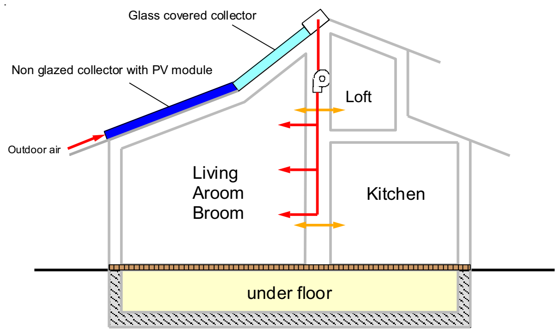


Fig.1. Floor plan of the simulation model house

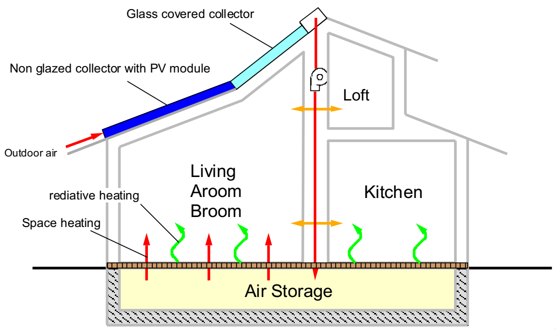
Tab.1. Case of simulation

Case	Outside wall	Heat storage system	Glass cover collector area	Preliminary collector with PV modules area	Total area
Case1	wood	wooden floor (none)	16m^2	32m^2	48m^2
Case2		heat storage with underfloor space(wooden floor + concrete foundation)			
Case3		wooden floor + pabble bed heat storage using underfloor space			
Case4		wooden floor + bottled water heat storage using underfloor space			
Case5		concrete hollow core slab			
Case6		concrete slab on ground			
Case7	concrete				
Case8	wood	wooden floor (none)	24m^2	24m^2	
Case9		heat storage with underfloor space(wooden floor + concrete foundation)			
Case10		wooden floor + pabble bed heat storage using underfloor space			
Case11		wooden floor + bottled water heat storage using underfloor space			
Case12		concrete hollow core slab			
Case13		roof			
Case14	concrete				

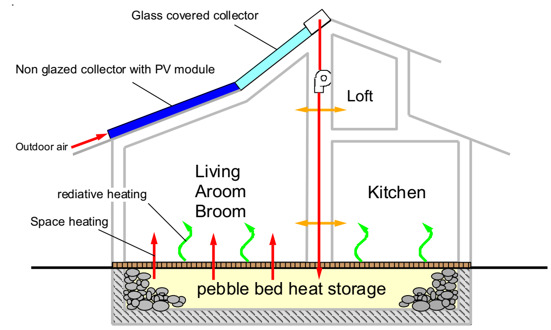
Building thermal insulation	
Roof	glass wool 200mm + phenol foam 60mm
Outside wall	wood : glass wool 100mm + phenol foam 35mm
	concrete : glass wool 100mm + phenol foam 35mm (concrete 150mm)
Floor and underfloor	Wood : polystyrene foam 100mm (concrete 120mm)
	concrete : polystyrene foam 30mm (concrete 350mm)
Windows	Low-e, donble pane U=2.08 W/m^{2}K



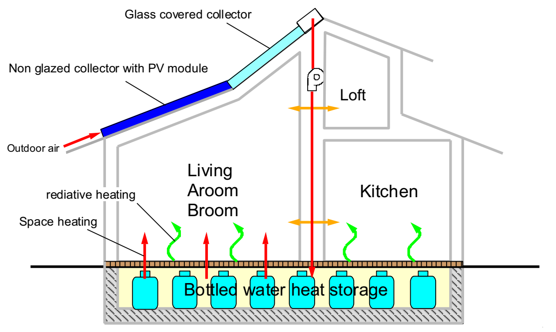
a) Without heat storage (Case 1, Case 8)



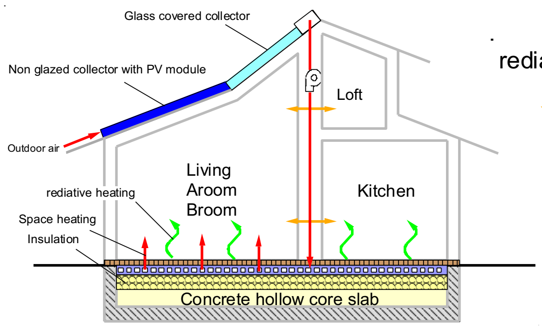
b) heat storage with the underfloor space (Case 2, Case 9)



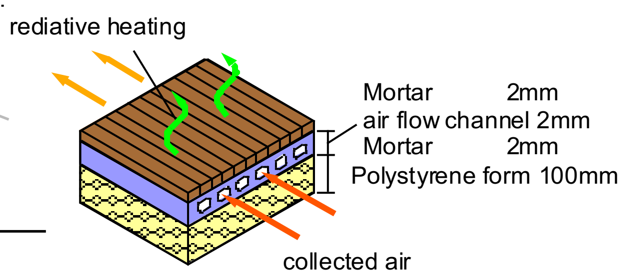
c) Wooden floor + Pebble bed heat storage (Case 3, Case 10)



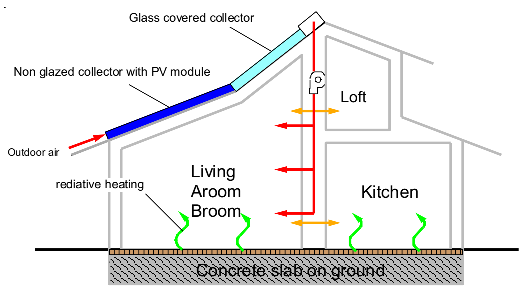
d) Wooden floor + bottled water heat storage (Case 4, Case 11)



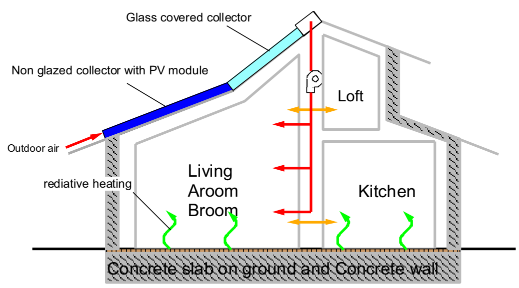
e) Concrete hollow core slab (Case 5, Case12)



Detail of Concrete hollow core slab



f) Concrete slab on ground (Case 6, Case13)



g) Concrete slab on ground and concrete wall

Fig.2. Simulation model of the solar house

Table.2. Detail of heat storage system

			Pebble bed	Bottled water	Concrete hollow core slab
Heat storage volume	V	m^3	20	20	3
Void fraction	–	–	0.47	0.85	–
Number of heat storage elements	n	–	10,365,188	1,500	–
Surface area	A	m^2	5088	150	–
Equivalent diameter	D	m	0.0125	0.1560	–
Heat transfer coefficient	α	W/m^2K	17.7	2.0	18.5
Temperature effectiveness	eff	–	1.000	0.846	–
Heat capacity	Hcap	KJ/K	12,879	12,540	3,321

The south roof of this house is provided with the PV modules also used for the preliminary heating collector and the glass covered collector. The total collector area is $48m^2$, while the areas of preliminary collector and glass covered collector are arranged from Case 1 to Case 14 as shown Table.1. The simulation is carried out not only for the heat storage systems but also the whole space heating systems including the solar collectors. Two types of building structure are assumed. One is a wooden structure house and the other is a concrete structure with the wooden roof. A wooden house needs the thermal storage system to increase the thermal capacity for the solar heating system. The heat storage system using a floor slab or an underfloor space is expected for the radiation heating from the floor. Seven heat storage systems shown in Fig.2 are examind using the simulation. The all systems are combined with the air heating collector. Fig.2 shows the schematic diagrams of the solar collecter and heat storage systems. Table.2 shows the details of heat srotage systems.

Using the simulation tool, EESLISM (M. Udagawa, M. Satoh, 1999), the simulation study was carried for 14 cases. The whole solar house simulation was carried out to evaluate the heating load and the room thermal environment. The system performance of the thermal storage was evaluated for the reduction in the seasonal auxiliary space heating load and also in the peak load which is related to the capacity of the auxiliary heating system.

This simulation period is from November to March. Calculation interval is 1 hour. In this study, the collected hot air was used to only space heating. Tabs.3 and 4 show the simulation schedule. The used wheather date is the Expanded AMeDAS date (AIJ, 2005) for Maebashi(about 4km apart from Takasaki). Three rooms provided with the air conditioners for the auxiliary heating are Living, Aroom and Broom, but all rooms excepted for the machine room are heated by the hot air from adjacent spaces. The underfloor space is used for the heat storage, the bottled water or the pebbles as shown in Fig.2 and Tab.2.

Table.3. Detail of air colecter

Collector area	Case1-7	Glass covered collector : $16m^2$ Preliminary collector with PV module : $32m^2$
	Case8-14	Glass covered collector : $24m^2$ Preliminary collector with PV module : $24m^2$
Collector tilted angle		Glass covered collector : 38^o Preliminary collector with PV module : 21^o
Collector azimuth angke		South
Start collecting temperature		Collecter surface 40^oC
Air flow rate		$570m^3/h$
Solar heating space		Living, Aroom, Broom

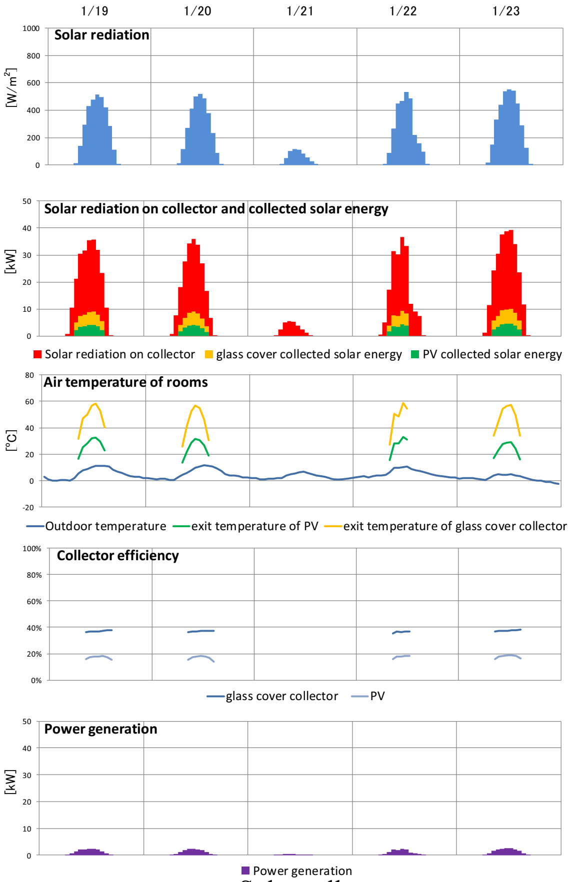
Table.4. Simulation schedule

Weather date		Expanded AMeDAS (Maebashi)
Simulation period		Jan.-Mar. Nov.-Dec.
Calculation interval		1 hour
Room set point		Operating temperature 18^oC
Space heating control time	Living	6:00 - 14:00 17:00 - 23:00
	Aroom	6:00 - 7:00 19:00 - 23:00
	Broom	6:00 - 7:00 19:00 - 23:00

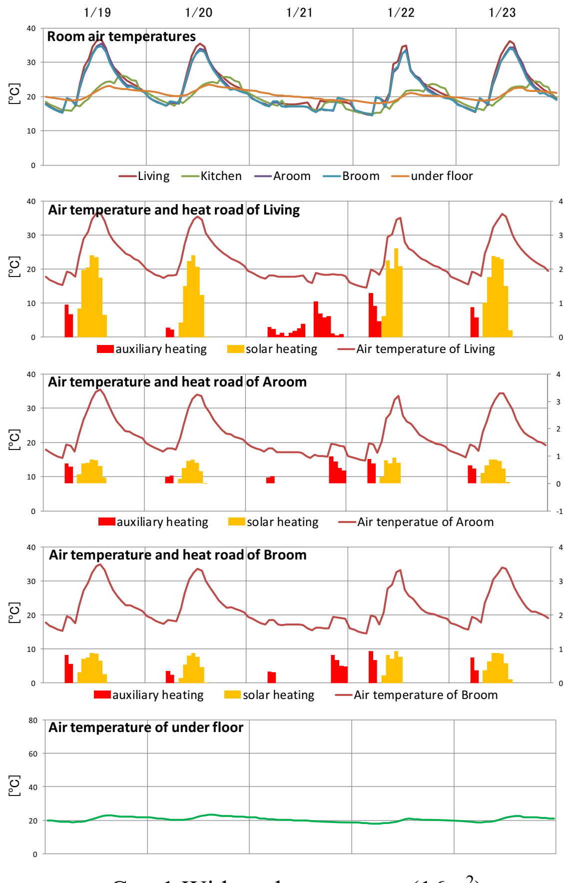
3. Simulation results

Figs. 3 and 4 show the hourly simulation results for Cases 1 to 7 (glass covered collector area is 16 m^2) on the typical days in winter. The typical days were from 19th to 23rd, January that is composed of four fine days and a cloudy day. The maximum collected solar energy was about 10kW and the power generation was 2.5kW. Case 1 without heat storage, the Living room air temperature rose to 35 degrees C in the daytime. But it fell to 17 degrees C in the night. Therefore, the temperature fluctuate was about 20 degrees C in a day. However, Cases 2 to 5 using the underfloor heat storage, the Living room air temperatures rose in the daytime were suppressed, and the descent of the temperature were slow at night-time. Especially, in Case 5 with the concrete hollow core slab, the Living room air temperature was 19 degrees C in the night. In Cases 6 and 7, the Living room air temperature were 34 degrees C in the daytime, because collected air is blown to the room directly. But auxiliary heating loads were nothing even in the cloudy day, so there is enough heat storage capacity for Cases 6 to 7.

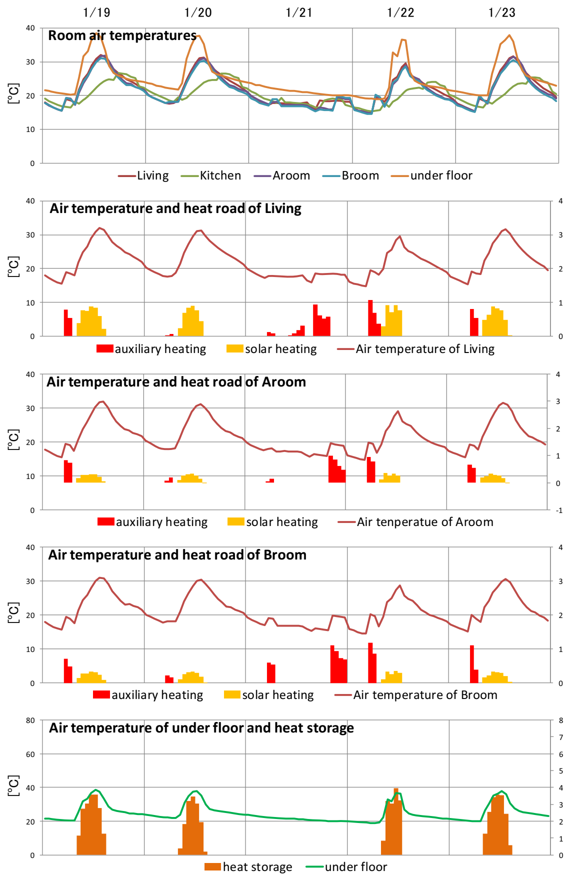
Figs. 5 and 6 show the hourly simulation results on same day for Cases 8 to 14 (glass coverd collector area is



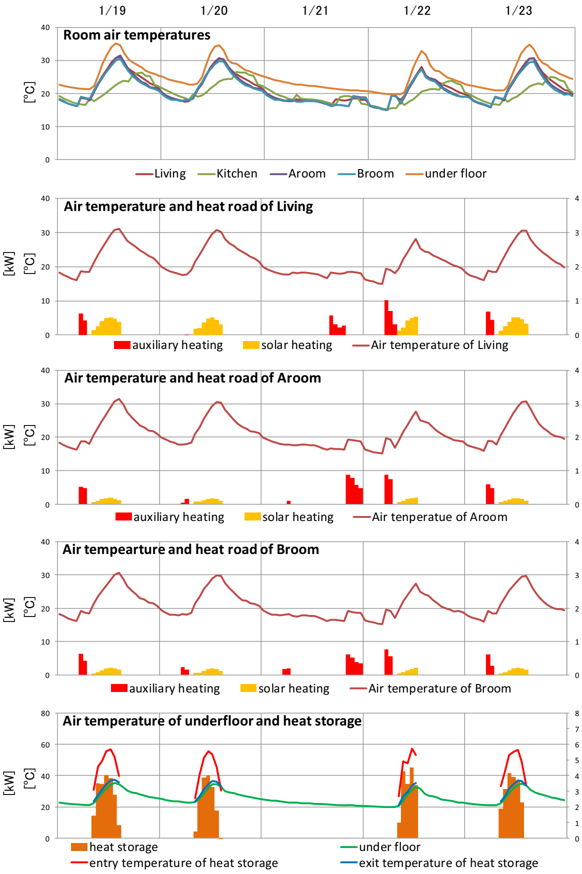
Solar collector



Case1 Without heat storage (16m^2)

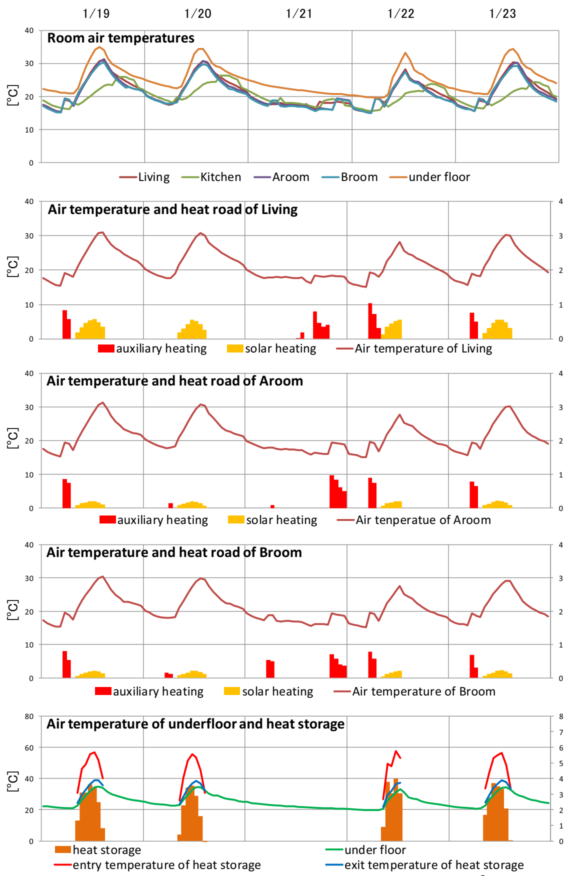


Case2 heat storage with underfloor space (16m^2)

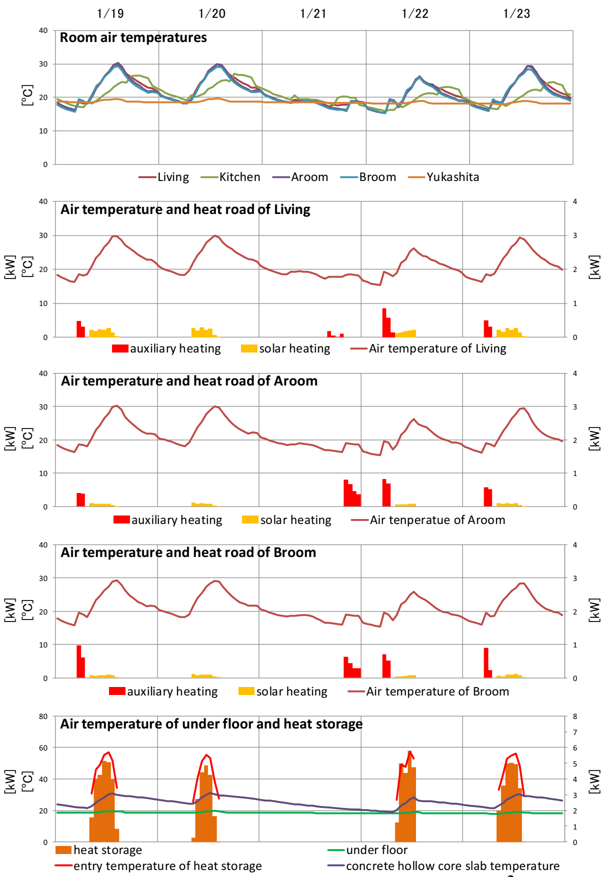


Case3 pebble bed heat storage (16m^2)

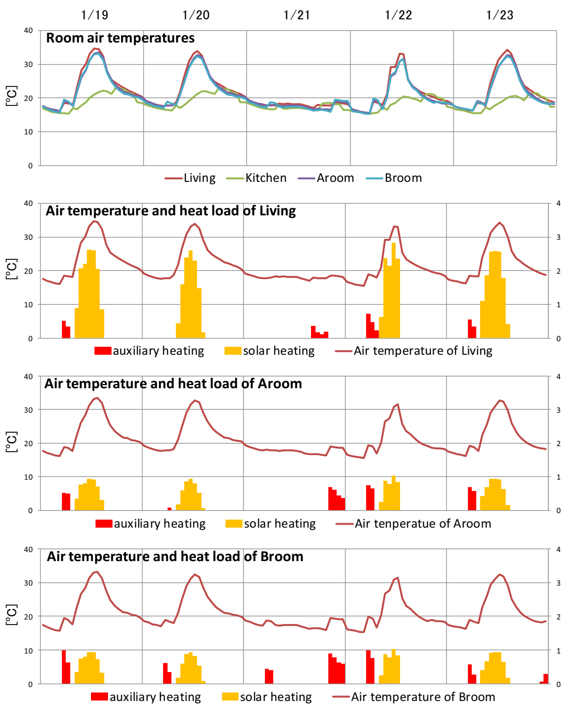
Fig.3. simulation results (Glass collector area 16m^2 1/19~1/23)



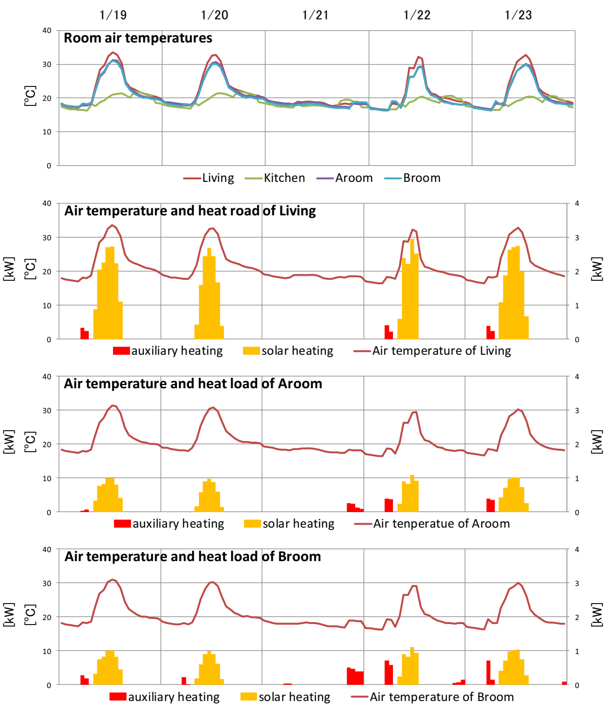
Case4 bottled water heat storage (16m^2)



Case5 Concrete hollow core slab (16m^2)

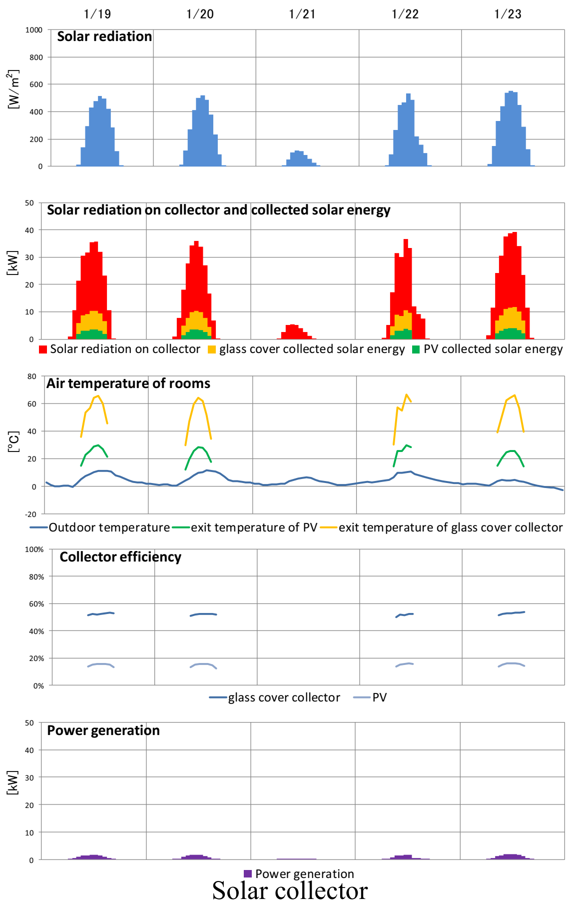


Case6 Concrete slab on ground (16m^2)

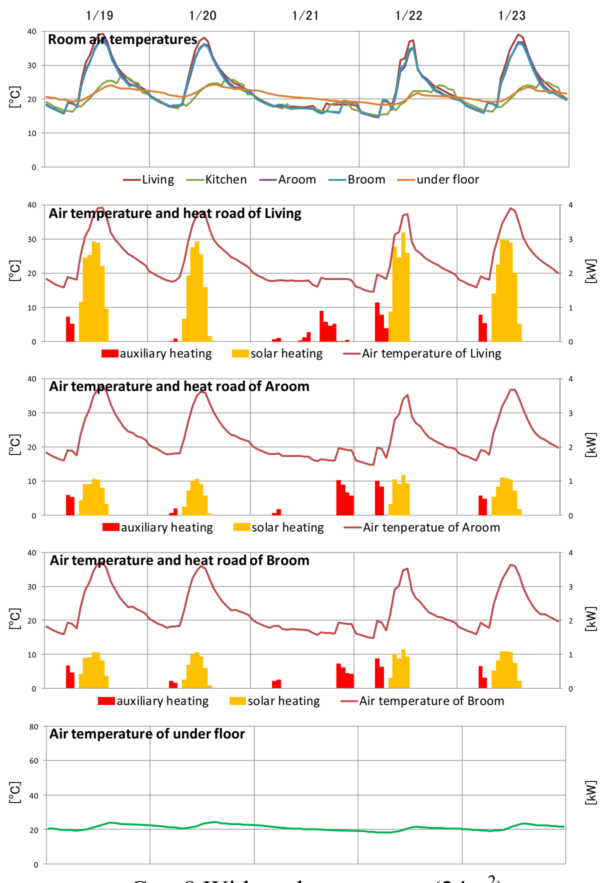


Case7 Concrete slab and wall (16m^2)

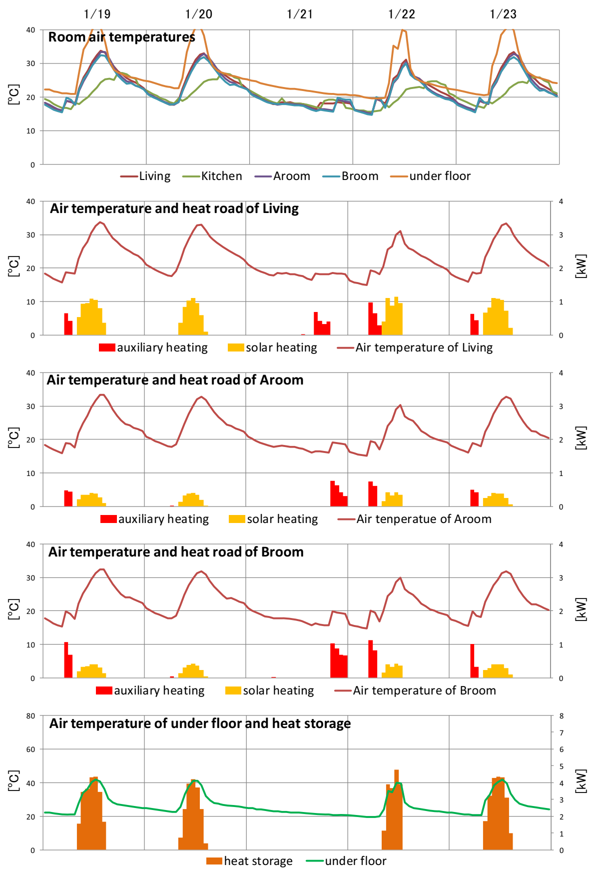
Fig.4. simulation results (Glass collector area 16m^2 1/19~1/23)



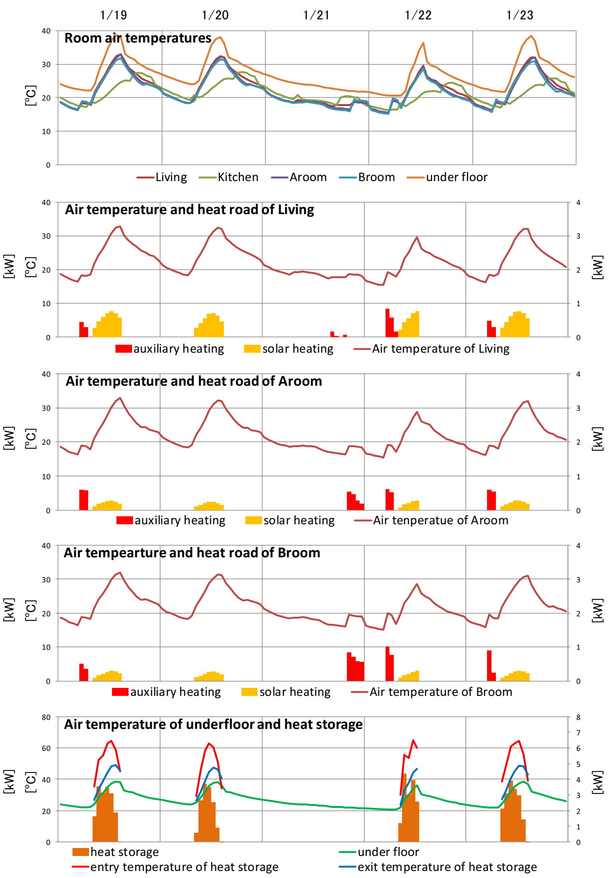
Solar collector



Case8 Without heat storage ($24m^2$)

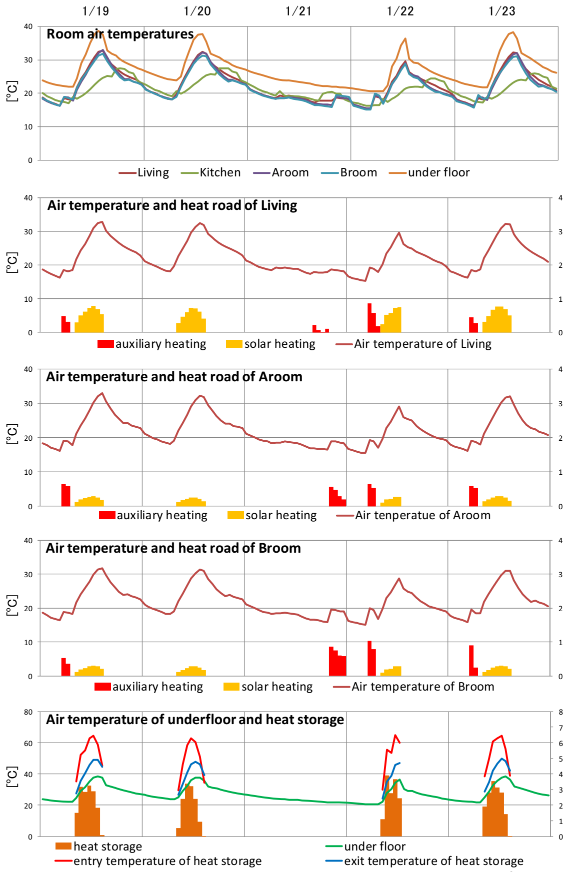


Case9 heat storage with underfloor space ($24m^2$)

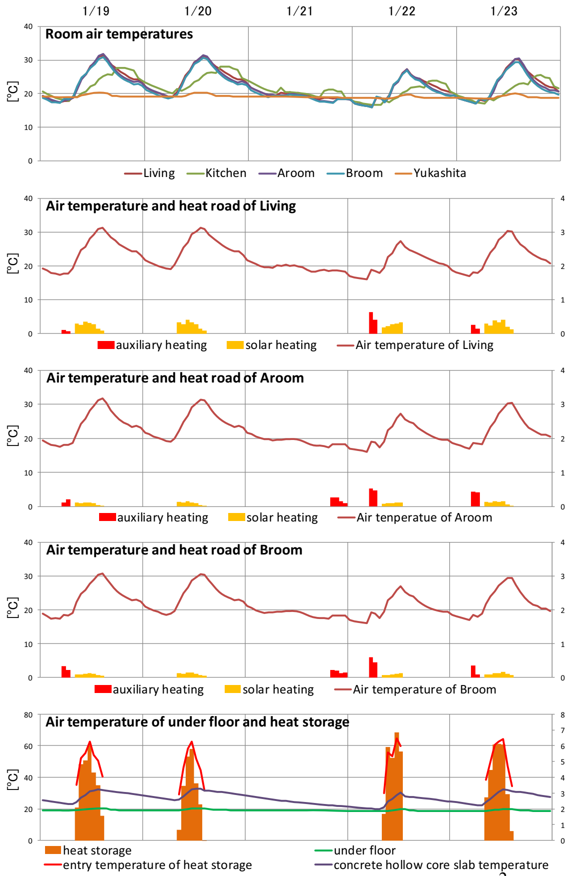


Case10 pebble bed heat storage ($24m^2$)

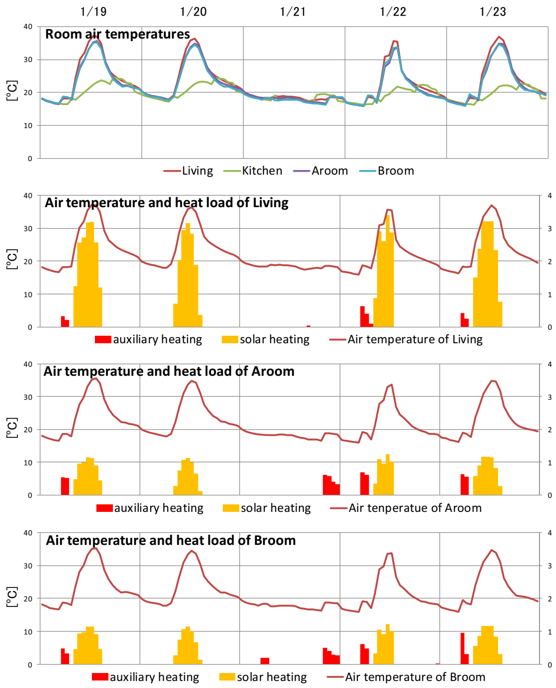
Fig.5. simulation results (Glass collector area $24m^2$ 1/19~1/23)



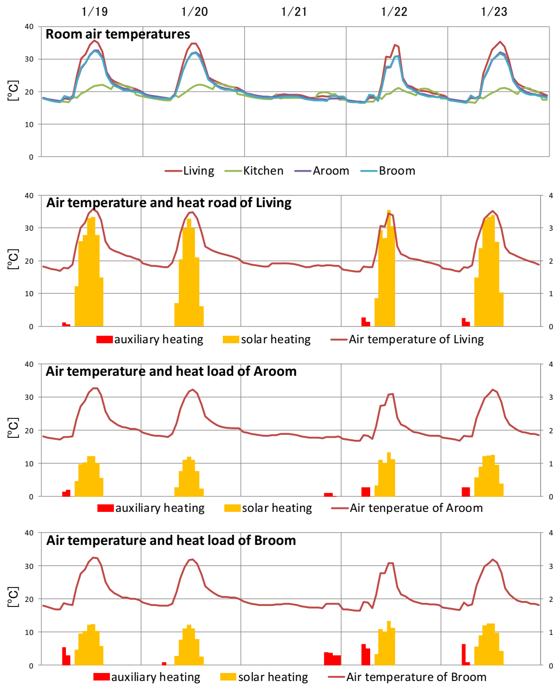
Case11 bottled water heat storage (24m^2)



Case12 Concrete hollow core slab (24m^2)



Case13 Concrete slab on ground (24m^2)



Case14 Concrete slab and wall (24m^2)

Fig.6. simulation results (Glass collector area 24m^2 1/19~1/23)

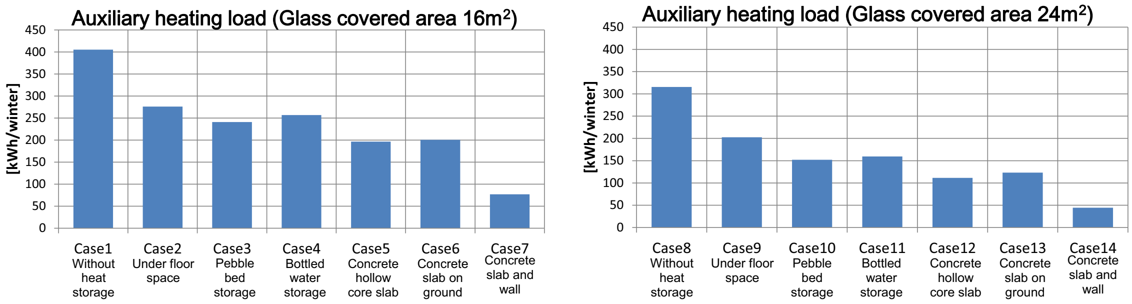


Fig.7. Auxiliary heating load (November - March)

Table.6. Auxiliary heating load and reduction efficiency (November - March)

	$16m^2$			$24m^2$		
	Case	Heating load [kWh/winter]	Reduction against Case 1	Case	Heating load [kWh/winter]	Reduction against Case 8
Without heat storage	Case1	405.2	-	Case8	315.6	-
Thermal storage with under floor space	Case2	276	31.9%	Case9	202.6	35.8%
Wooden floor + Pebble bed thermal storage using under floor space	Case3	240.8	40.6%	Case10	152.2	51.8%
Wooden floor + Bottled watert hermal storage using under floor space	Case4	256.6	36.7%	Case11	159.5	49.5%
Concrete hollow core slab	Case5	196.5	51.5%	Case12	111.4	64.7%
Concrete slab on gound	Case6	200.6	50.5%	Case13	123.1	61.0%
Concrete slab and wall	Case7	76.9	81.0%	Case14	44.4	85.9%

$24m^2$). The maximum collected solar energy was about 12kW and the power generation was 2 kW. For Case 8, without heat storage, the Living room air temperature rose to 40 degrees C in the day, and it fell to 18 degrees. It was the same as Case 2 in the night. Therefore, the temperatures fluctuate was about 22 degrees C in the day. But in Cases 9 to 12 using the underfloor heat storage, the Living room air temperatures rose in the daytime were suppressed, and the descent of the temperatures were slow at the night-time. Therefore, the temperature fluctuate was about 10 degrees C in the day and the auxialiary load was 10kW or less. Especially, in Case 12 with the concrete hollow core slab, the living temperature was about 20 degrees C in the night. The auxiliary heating load of Living was nothing even in cloudy day. In Cases 13 and 14, the Living room air temperatures rose about 35 degrees C, but it was small that the auxiliary heating loads of Living and Aroom in all day.

Fig.7 shows the auxiliary heating load in the winter, and Tab.6 shows the auxiliary heating load and the reduction against the case without heat storage, Case 1 for Cases 2 to 7 and Case 8 for Cases 9 to 14, respectively. In Cases 2 to 7 (Glass covered collecter area is $16m^2$), the auxiliary heating loads were reduced comparing to Case 1 (without heat storage system). The reductions of auxiliary heating loads were 31.9% for Case 2 (the underfloor with heat storage), 40.6% for Case 3 (the pebble bed heat storage), 36.7% for Case 4 (the bottled water heat storage), 51.5% for Case 5 (concrete hollow core slab), and 50.5% for Case 6 (concrete slab on ground). Therefore, the reduction of Case 5 was larger than than that of Case 6, because the heat transfer coefficient of Case 5 was larger than that of Case 6. The best one was Case7 (concrete slab on ground and concrete wall) with the large thermal capacities of the outside wall. The auxiliary heating load of 81% was reduced against Case 1.

In Cases 9 to 14 (Glass covered collector area is $24m^2$), it is possible to reduce the auxiliary heating load comparing to Case 8 (without heat storage system). The reductions of auxiliary heating loads were 35.8% for Case 9 (the underfloor with heat storage), 51.8% for Case 10 (the pebble bed heat storage), 49.5% for Case11 (the bottled water heat storage), 64.7% for Case12 (concrete hollow core slab), and 61.0% for Case 13 (concrete slab on ground). Therefore, the reduction of Case 12 was larger than that of Case6 too. The best one is Case 14 (concrete slab on ground and concrete wall) with the large thermal capacities of the outside wall. The auxiliary heating load of 86% was reduced against Case 8.

4. Conclusion

The whole building simulation study was carried out for 14 cases of heat storage systems combined with the air collectors.

1) In the wooden house, it is possible to reduce the auxiliary heating load by the heat storage systems using the floor slab or the underfloor space. The auxiliary heating load of 30% - 60% were reduced against the case without heat storage.
2) Using the concrete outside wall structure the maximum reduction of the auxiliary heating load was 86% against the case without heat storage.
3) The floor heating system using the hollow core slab which could directly heat the room by convection and radiction from the floor surface reduced the auxiliary heating load of 64.7% against the case without the heat storage.
4) For the wooden house using the devices for the thermal storage, it can achieve smaller the temperature fluctuate during the day than the house using the concrete outside walls without the heat storage devices. The thermal storage devices using the floor slab or the underfloor spaces are effective to increase the heat capacity for the wooden house.

5. References

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