GROUND SOURCE HEAT PUMP SYSTEM FOR NET ZERO ENERGY HOUSE

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Abstract: Authors designed a passive low energy house integrated with a ground source heat pump (GSHP). Firstly we measured the total energy flow through a year and demonstrated the high potential of this low energy house. Secondly we mentioned the automatic control of temperature and humidity of the ventilation system. An earth tube, which is tube for heating supply air and buried in the ground, helped to reduce the heat loss of the ventilation, and Wakkanai Siliceous Shale (WSS), which was a porous material, helped to control humidity. Thirdly we changed the operation pattern of GSHP for Space Heating (SH) and evaluated the room environment and the running cost. Lastly, we developed a radiative floor heating simulator. It had advantage for the calculation of the house with the large thermal capacity. We demonstrated one of the most efficient controls of SH in pursuit of the comfort and the low energy for the condition of the measurement house.

Key Words: Ground Source Heat Pump System, Low energy house, Ventilation, Computer simulation tool

1 INTRODUCTION

To stop global warming, the low energy action becomes active not only in the industrial domain but in the household domain. On the other hand, the demand for the comfort becomes high and complicated, and the uniform and comfortable temperature environment is required. The objective of this research is to suggest one of the ideal comfortable house models with low energy systems and to show the new way to go for the northern region houses in Japan.

Authors designed and constructed a passive low energy house installed with a ground source heat pump system for the space heating and the domestic hot water (DHW) in November, 2007, and have continued system measurement for a year since January, 2008. This house has high insulation and large heat capacity by using much concrete.

This report is the second one in a series of the research. In this report, first we show the energy flow of this house and consider how much energy consumption this house can save. Next, we changed the operation pattern of the GSHP for SH, i.e. the water temperature and the operation duration, and compared the variation of the room temperature and the heat pump coefficient of performance (COP). Third, we developed a simulation program which predicted the room temperature and the heat pump COP, and considered the optimization control of the low temperature radiant heating.

2 MEASUREMENT RESULTS

2.1 Energy flow

Fig.1 shows the energy flow of this house. As a result, power consumption was 11.5kWh/(m^2・ year) for SH, 6.5kWh/(m^2・ year) for DHW, and 1.1 kWh/(m^2・ year) for the ventilation, so the total power consumption of the thermal system was 19.1 kWh/(m^2・ year). When this result was compared with that of a conventional house in Japanese cold region, i.e. coefficient of heat loss was 1.6W/(m^2・ K)and heat source was an oil boiler, we could see 71% reduction of annual CO2 emissions and 53% reduction of primary energy consumption. Moreover, we are predicting this house has more potential to reduce the power consumption, because it was the first year of this house, the concrete was not dry enough and was in low temperature, and the solar collector began to start from June 11th, 2008.

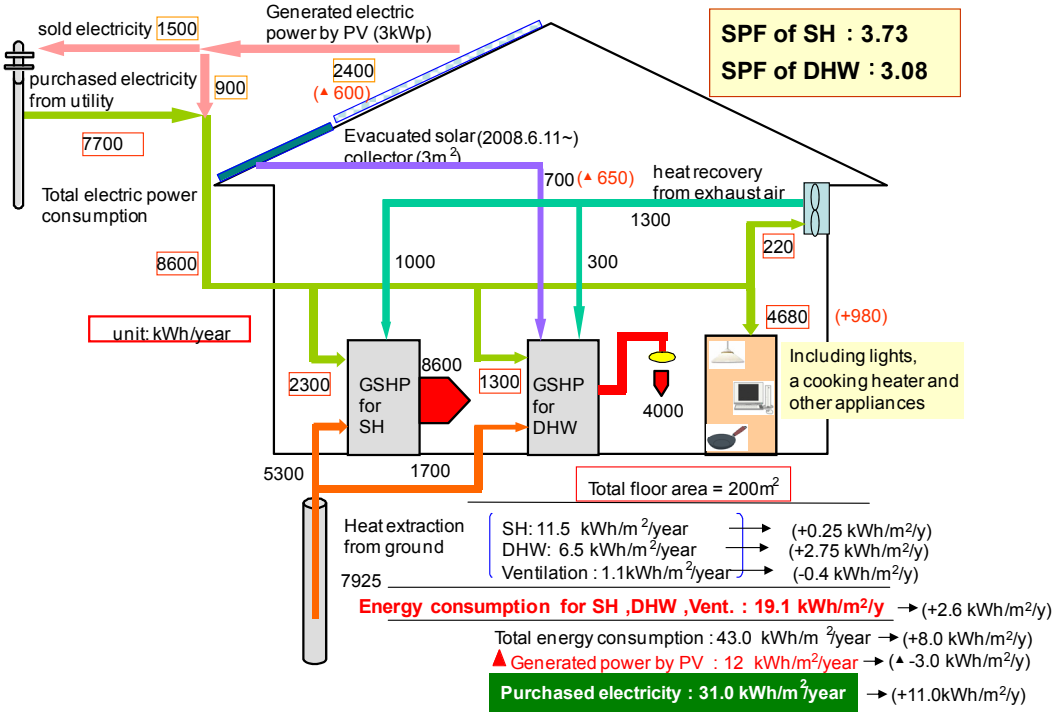


Figure 1: Annual energy flow of the house

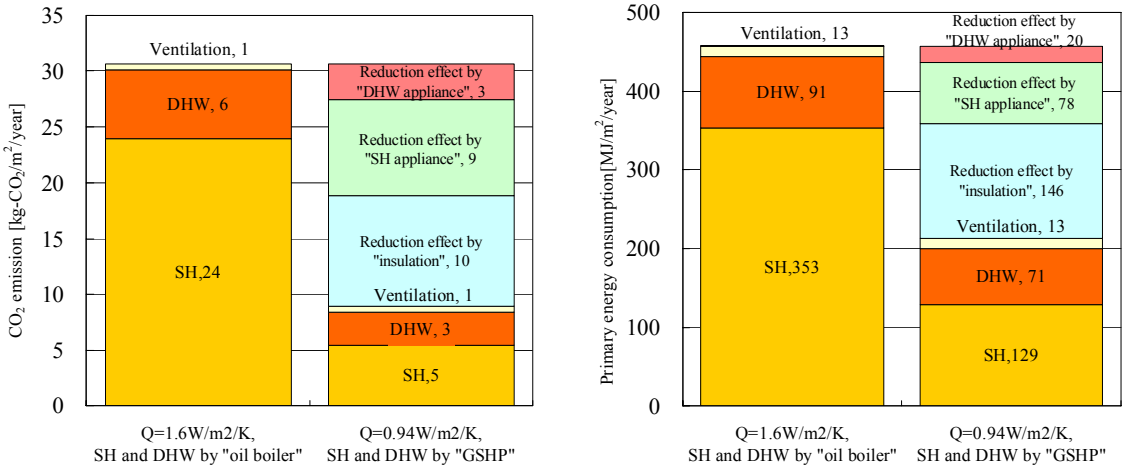


Figure 2: Annual CO_2 emission **Figure 3: Annual primary energy consumption**

2.2 Annual variation of temperature and humidity

We expect an automatic control to be operated on the ventilation system about the temperature and the humidity by using a 40m long earth tube and "Wakkanai siliceous shale" which filled up in an underfloor pit. Fig.4 shows the annual variation of temperature and humidity at the inside rooms and at the each place in the ventilation system. You can see a cooling effect in summer season and see a heating effect in winter season through the earth tube. Fig.5 and Fig.6 show the details of summer and winter. In July, earth tube outlet temperature was 5 degrees below the outside temperature on average, so it means we obtained 0.25kW cooling. On the other hand, in early winter we obtained 0.25kW heating inside the earth tube and if you include the machine exhaust heat, finally we obtained 0.6kW heating.

Then, Fig.7 and Fig.8 show the variation of the absolute humidity of summer and winter. In summer, when the outdoor absolute humidity was high, we could see a dehumidification effect after through the underfloor pit especially on the day when the humidity was high. On the other hand, in winter, when the outdoor absolute humidity was low, we were able to obtain 0.17kg-H2O/kg-Air of moisture taking on average. From these phenomena, we can know that Wakkanai siliceous shale releases its moisture stored in summer at the condition of the low humidity.

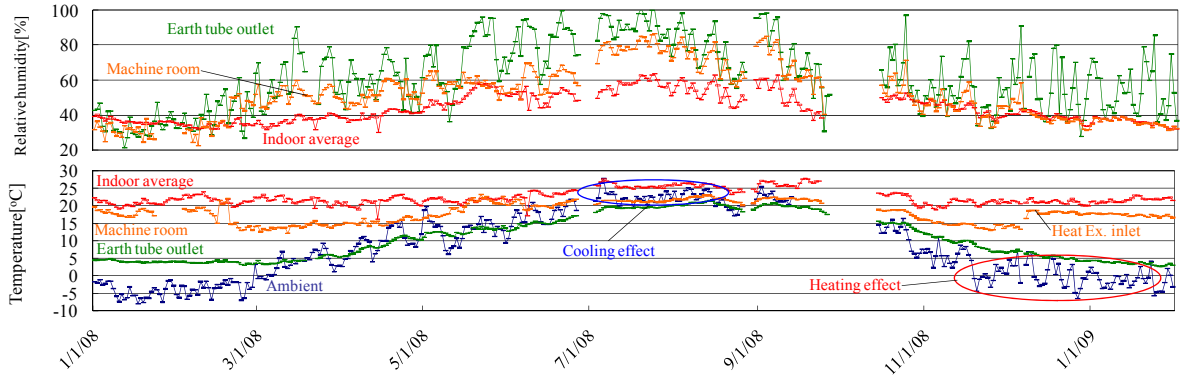


Figure 4: Annual variation of temperature and humidity

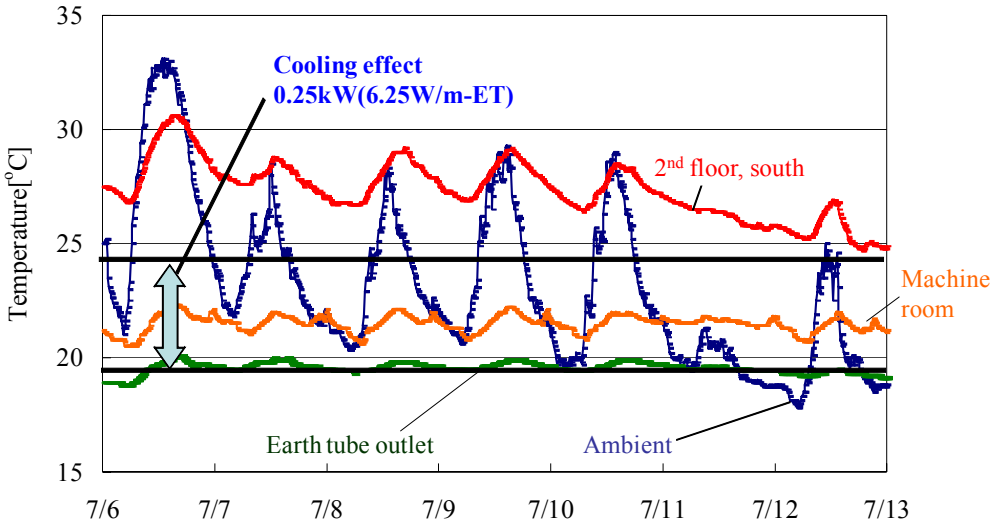


Figure 5: Cooling effect of the cool tube

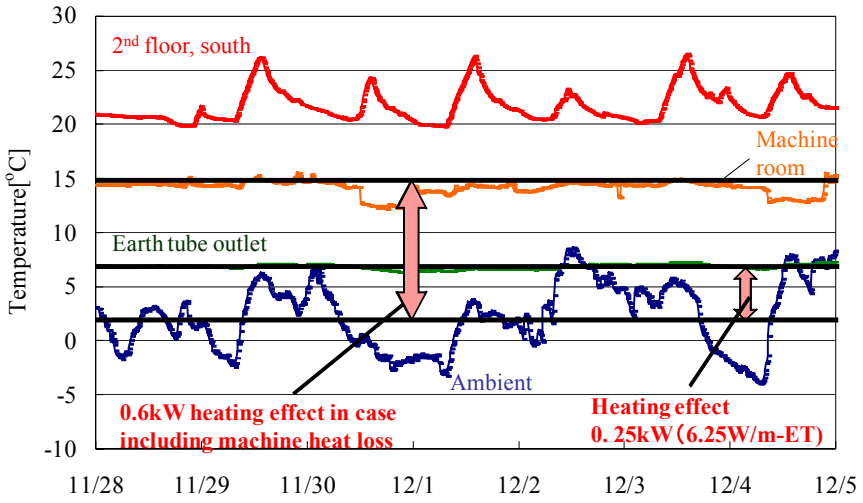


Figure 6: Heating effect of the earth tube

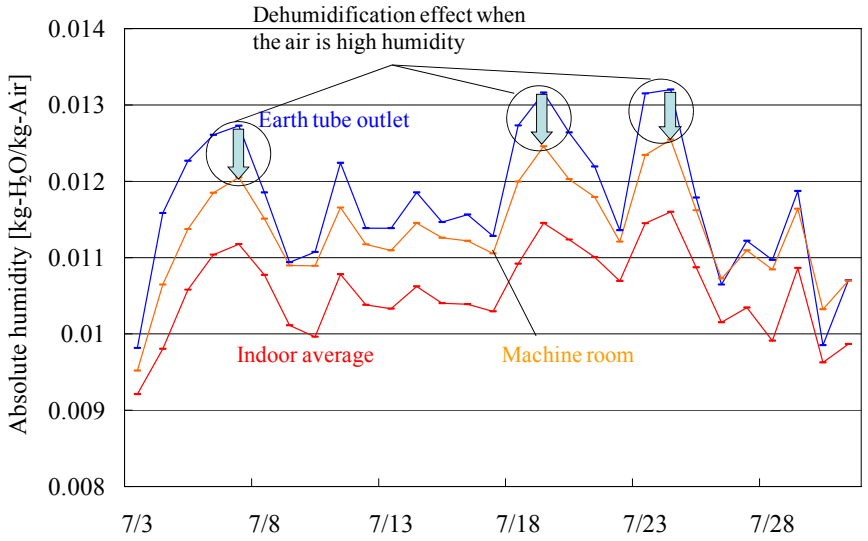


Figure 7: Dehumidification effect of WSS

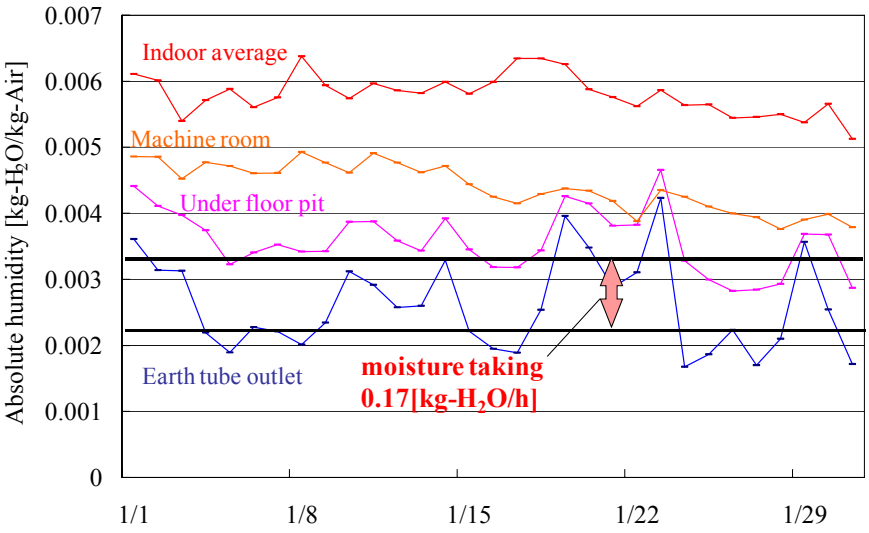


Figure 8: Moisture taking effect of WSS

3 THE LOW TEMPERATURE RADIATIVE FLOOR HEATING ON THE LARGE HEAT CAPACITY HOUSE

In a Japanese conventional house made of woods, it was general that heaters were at each room and operated intermittently. However, thus system caused temperature irregularity from the point of view of time and space. In this point, we gave the house a large heat capacity by using much concrete inside the house. So we could store the solar heat during the daytime and the space heating heat during the nighttime. The effective usage of this system's characteristics brings the dweller low energy and comfortable space.
The authors considered the heat capacity, the partial load characteristic of heat pump, and the cheapness of the nighttime electricity, and tried three patterns of the operation below.

(1)intermittent, 10 hours per day, T_{2out} 32ºC (22:00 ~ 8:00)

(2)intermittent, 14 hours per day, T_{2out} 30ºC (22:00 ~ 12:00)

(3)continuous, 24 hours per day, T_{2out} 28ºC

$$SCOP\ [-]=Q_2/(E_{HP}+E_{cp}) \quad (1)$$

Q_2: Space Heating output [kWh]

E_{HP}: Compressor power consumption [kWh]

E_{cp}: Pump power consumption [kWh]

(1) Intermittent , 10 hours per day, T_{2out} 32ºC (22:00 ~ 8:00)

Fig.9 and Table 1 show the data of the typical day when the system was operated under the condition of "10 hours per day, T_{2out} 32ºC". The average output of the heat pump was 9.4kW. Even though the average outdoor temperature was 0.1 ºC and the solar radiation was low, the room temperature was kept almost constant through a day and it didn't go down below 20 ºC. From this fact, we understand that the stored heat during the night was emitted during the day on an average. Because the whole operation was in the nighttime, the running cost was inexpensive. However, SCOP was the lowest, 3.8, among the three patterns due to the high output.

(2) Intermittent , 14 hours per day, T_{2out} 30ºC (22:00 ~ 12:00)

Fig.10 and Table 2 show the data of the typical day when the system was operated under the condition of "14 hours per day, T_{2out} 30ºC ". The average output of the heat pump was 6.3kW. The average outdoor temperature was 2.7 ºC and the average indoor temperature was 21.8 ºC. So we could get almost the same condition compared with the former operation.
This method has strong points about both of the cost and SCOP, because the 70% of the total output is in the nighttime and the output is lower than the former.

(3) Continuous, 24 hours per day, T_{2out} 28ºC

Fig.11 and Table 3 show the data of the typical day when the system was operated under the condition of "24 hours per day, T_{2out} 28ºC". The average output of the heat pump was 4.4kW. The average outdoor temperature was 2.1 ºC and the average indoor temperature was 22.3. This operation showed the highest efficiency because of the low output, but it was the most expensive due to the daytime operation.

Table 1: Summary of the operation (1)

Date	T_{2out} setting	Operation duration	Outdoor Temp.	Indoor Temp.	Energy consumption	Heating output	SCOP	Running cost
	°C	Hours	°C	°C	kWh	kWh	-	Yen/day
10th.Jan	32	10	0.1	21.0	24.7	94.4	3.8	214

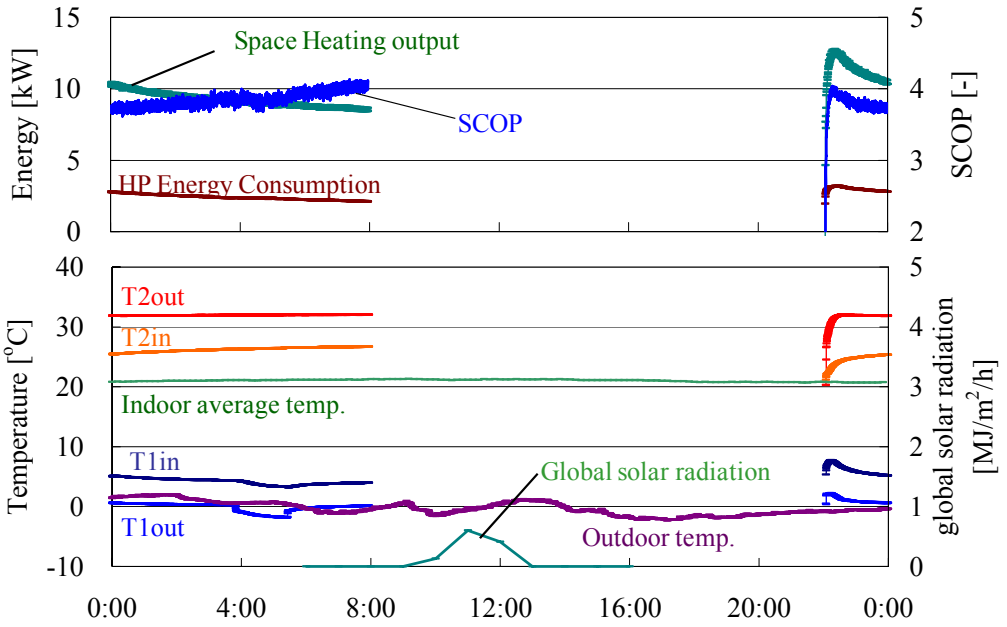


Figure 9: Intermittent, 10 hours, T_{2out}:32 °C

Table 2: Summary of the operation (2)

Date	T_{2out} setting	Operation duration	Outdoor Temp.	Indoor Temp.	Energy consumption	Heating output	SCOP	Running cost
	°C	Hours	°C	°C	kWh	kWh	-	Yen/day
19th.Jan	30	14	2.7	21.8	20.3	87.8	4.3	254

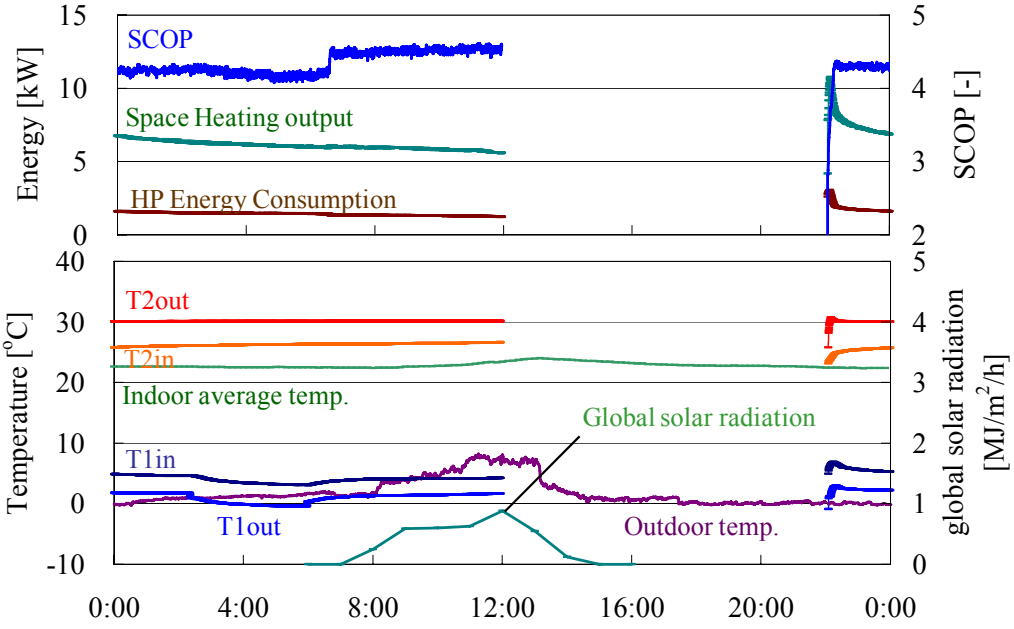


Figure 10: Intermittent, 14 hours, T_{2out}:30 °C

Table 3: Summary of the operation (3)

Date	T_{2out} setting	Operation duration	Outdoor Temp.	Indoor Temp.	Energy consumption	Heating output	SCOP	Running cost	
	°C	Hours	°C	°C	kWh	kWh	-	Yen/day	
29th.Jan	28	24	2.1	22.3	22.4	104.9	4.7	196	425

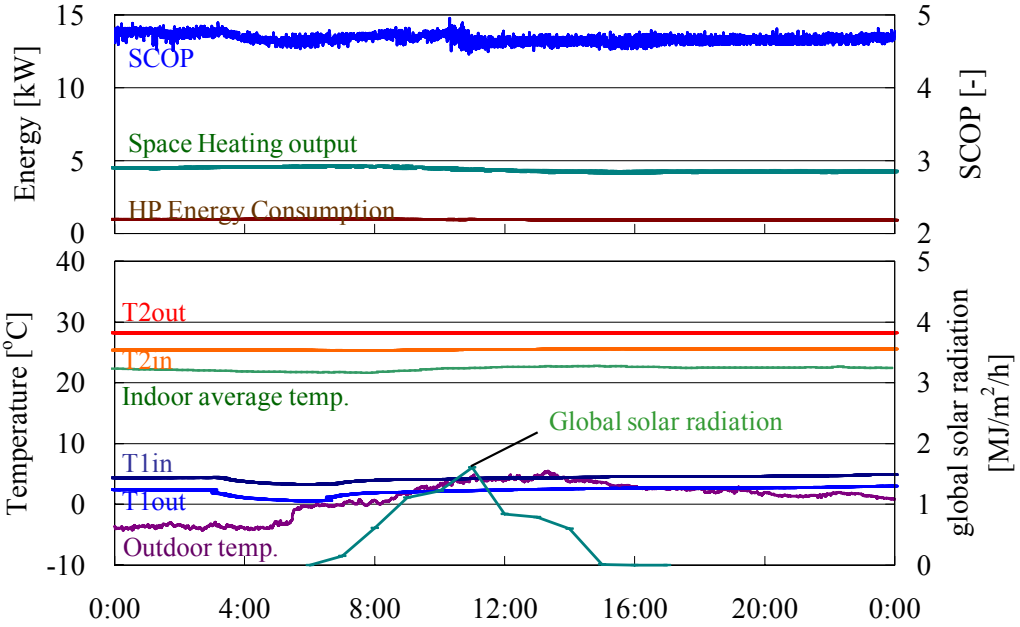


Figure 11: Continuous, 24 hours, T_{2out}:28 °C

As a summary of these operations, we can say that the room temperature won't rise at night if you operate the heat pump with high power in the nighttime and keep almost the same temperature through the daytime in the large heat capacity house. It means there is possibility of the reduction of the running cost and we can grow the market of GSHP systems in Japan.

4 DEVELOPEMENT OF THE RADIATIVE FLOOR HEATING SIMULATOR

4.1 Concept of the simulator

Authors made a prediction simulator to decide the best suited way of the heat pump operation. The simulator consisted of the 4 parts: building, floor, heat source, and ground. From the measurement, we showed the constant and comfortable temperature environment either by the intermittent or by the continuous operation. However, there is a big difference on the SCOP and the running cost. And it is difficult to control the system changing the water temperature from the heat pump and the operation time according to ambient climate condition. Therefore, we developed the radiative floor heating simulator into which we input climate condition, the building condition, and the heat pump characteristic, and considered the optimal system and the control method which realize both the comfort and the low cost.

4.2 Discovery of the minimum T_{2out}

We set the limitation temperature range between 19 ºC and 27 ºC and counted the time under or over the range. The building condition was the same as the measurement house and the heating period was set from 1st November to 30th April. Table4 shows the results of the intermittent 10 hours operation. When the T_{2out} was less than 30ºC, there were times when the room temperature was under 19ºC. Therefore, required T_{2out} temperature was 31 ºC to keep the room temperature over 19ºC. Next, table 5 shows the results of the 24 hours continuous operation. In this case, the required T_{2out} temperature was 27 ºC to keep the room temperature over 19 ºC. COP was higher than intermittent operation because of the low output, but SPF dropped greatly due to the increase of the delivery energy. Also, the long operation in the daytime causes the increment of the running cost and the value was the 2.5 times as much as the intermittent 10 hour operation.

4.3 Introduction of the floor temperature sensor

In the former section, we showed that 27 ºC was required to keep the ideal room temperature. However, the output of the heat pump was very low almost all the time and it causes increment of cost. Then, we set the temperature sensors under the floor and introduced the optimal control by using them. The sensors were set at the center of pitch like Fig.12. Table 6 shows the result. From this result, the most effectual operation was 'the set temperature: 23 ºC and the sensor depth: 25mm'. In this case, the room temperature was kept between 19 ºC and 27 ºC except 3 hours, and the power consumption was reduced 17% and the running cost was reduced 37%. Therefore, the floor temperature sensors can draw the potential of a big heat capacity house, from the point of view of the comfort and a cost.

Table 4: Simulation results of the intermittent for 10 hours

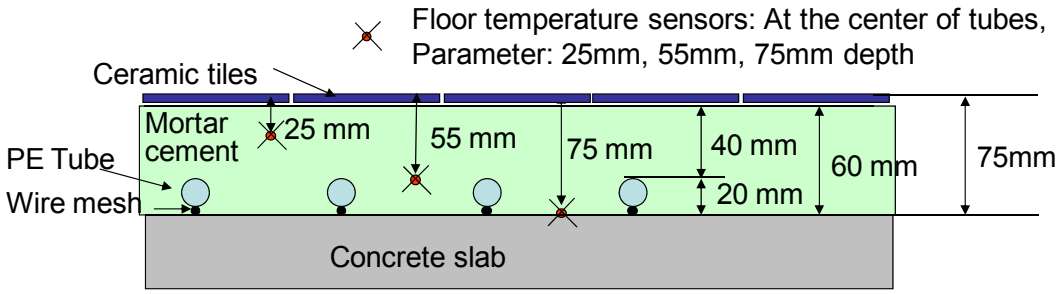
T_{2out}	Tr_min	Tr_ave	Tr_max	Tr<19ºC	Tr>27ºC	T_{1in}_ave	T_{2out}_ave	Pw_HP	Q_{1g}	Q_{2out}	COP	SPF	Cost
℃	℃	℃	℃	h	h	℃	℃	kWh	kWh	kWh	–	–	JPY
28	17.4	21.4	27.1	283	1	1.7	28.0	2344	8138	10066	5.22	4.29	20274
29	18.0	22.1	27.8	88	7	1.2	29.0	2540	8456	10580	4.98	4.16	21974
30	18.7	22.8	28.5	15	26	0.8	30.0	2761	8751	11096	4.73	4.02	23887
31	19.4	23.5	29.2	0	74	0.4	31.0	3004	9025	11613	4.49	3.87	25988
32	19.4	24.2	29.9	0	204	0.0	32.0	3270	9276	12129	4.25	3.71	28283

Table 5: Simulation results of the continuous for 24 hours

T_{2out}	Tr_min	Tr_ave	Tr_max	Tr<19ºC	Tr>27ºC	Pw_HP (0-24)	Pw_HP (22-8)	Pw_HP (8-13, 18-22)	Pw_Hp (13-18)	Q_{2out}	COP	SPF	Cost
℃	℃	℃	℃	h	h	kWh	kWh	kWh	kWh	kWh	–	–	JPY
26	18.6	21.7	27.1	19	1	2882	1240	981	661	10521	5.59	3.65	54955
27	19.3	22.5	27.9	0	7	3002	1290	1020	692	11118	5.55	3.70	57297
28	19.4	23.3	28.7	0	40	3126	1343	1061	722	11715	5.51	3.75	59665

Table 6: Simulation results of the continuous for 24 hours with control by floor temperature

Set Temp.	Sensor depth	Tr_min	Tr_ave	Tr_max	Tr<19ºC	Tr<24ºC	Ope. hours	Pw_hp (0-24)	Pw_hp (22-8)	Pw_hp (8-13,18-22)	Pw_hp (13-18)	Pw_pmp	Q_{2out}	COP	SPF	Cost
℃	mm	℃	℃	℃	h	h	h	kWh	kWh	kWh	kWh	kWh	kWh	–	–	JPY
23	25	18.9	21.2	26.4	3	0	2237	2504	1655	632	217	515	10164	5.11	4.06	36320
23	55	18.8	21.1	26.2	14	0	2165	2514	1706	699	110	498	10153	5.04	4.04	35048
24	25	19.2	21.6	26.5	0	0	2520	2556	1349	860	347	580	10477	5.30	4.10	43230
24	55	19.1	21.5	26.5	0	0	2419	2550	1329	895	326	556	10420	5.23	4.09	43250
25	25	19.3	22.3	27.3	0	2	3638	2859	1382	1021	455	837	11028	5.45	3.86	50768
25	55	19.3	22.2	27.2	0	2	3478	2850	1406	1012	432	800	11093	5.41	3.89	50024



Section of the floor

Figure 12: The image of the underfloor

5 CONCLUSIONS

1) Authors constructed a passive low energy house with a GSHP system and measured the total annual energy flow. As a result, the power consumption for SH, DHW, and the ventilation was 19.1kWh/(m^2・ year). It also demonstrated that the annual primary energy consumption was reduced 53% compared with the conventional Japanese insulated house.

2) Thermal environment inside the room was also measured for a year. The room temperature was kept in the range from 20 ºC to 27 ºC through a year. Then we confirmed the heating and cooling effect with the earth tube, and the dehumidification and the humidification effect with WSS.

3) The operation condition of GSHP for space heating was changed in three patterns. In the high insulation and big thermal capacity house, it was possible to keep the room temperature through a day only by operating for 10 hours in the nighttime at low cost.

4) We developed the radiative floor heating simulator and compared the amount of power consumption and the running cost in many cases of the operation. As a result, required T_{2out} temperature was 31 ºC to keep the room temperature in the range from 19 ºC to 27 ºC for intermittent 10 hours operation. However, by using floor temperature sensors, we can obtain more comfortable environment and less cost operation.

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