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Thermal Storage Radiation Air-conditioning System from the Concrete Slab that uses Underground Heat and Solar Heat Directly

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Abstract

We proposed the system that uses the renewable energy by bringing water from the pipes and piles under the soil, and solar collectors on the roof, into the concrete floor and ceiling slab directly without any other heat sources. To lay the pipes under the soil, rolled pipes are set as they are, to reduce construction time greatly. Piles are recycled by using the pile with the shuttlecock on the head of the pile. Concerning the solar collector, we developed the simple one, which can be used even when repairing the building. The cost is verified through an actual design and construction of the building, and it aims at the establishment of the best design and the construction technique.

Moreover, the performance of the system is evaluated by the measurement of the building. COP (coefficient of performance) of this system is around 10 in cooling season summer, because this system does not have any heat sources, but also pumps which supplies the water from soil and solar collector to the concrete slab optimized by inverter. The amount of the CO_2 exhaust reduction is about 4.0 kg-CO_2/m^2 by measurement from July 19 to August 22, 2014. It becomes about 8.1 kg-CO_2/m^2/year. Concerning the energy reduction rate of the air-conditioning system, about 20% energy conservation is achieved.

Keywords – natural ventilation; cross ventilation; hybrid ventilation;

1. Introduction

The technique for using underground heat and solar heat for air-conditioning is very effective for the CO_2 exhaust reduction. When solar heat and underground heat are used for cooling and heating, another heat source such as heat pump and boiler, will be often used to supply steady cold and hot water for HVAC system. However the initial cost of the equipment is not cheap. In addition, when underground heat is used, it is necessary to lay the pipes or piles under the soil, and it leads to high initial cost, which disturbs the widespread of these kinds of system.

Then, we proposed the system that uses the renewable energy by bringing water from the pipes and piles under the soil, and solar collectors on the roof, into the concrete floor and ceiling slab directly without any other heat sources. To lay the pipes under the soil, rolled pipes are set as they are, to reduce construction time greatly. Piles are recycled by using the pile with the shuttlecock on the head of the pile. Concerning the solar collector, we developed the simple one, which can be used even when repairing the building. The cost is verified through an actual design and construction of the building, and it aims at the establishment of the best design and the construction technique. Moreover, the performance of the system is evaluated by the measurement of the existing building.

2. Outline of the System

Figure 1 shows the outline of the system. This system is introduced in the new building in our university. It uses the renewable energy by bringing water from the pipes and piles under the soil, and solar collectors on the roof. The water goes into pipes laid in the concrete floor and ceiling slab directly without any other heat sources. It is a radiation air conditioning system using thermal storage of the building frame. There are a lot of radiation air conditioning systems that use the ceiling panel. This system does not use any ceiling or floor panel, to reduce the initial cost and use the thermal storage effect of the concrete slab. The piping longevity equal with the building can be expected because the piping laid uses thin metal layer sandwiched by reinforced polyethylene which has high heat resistance, causticity and processability.

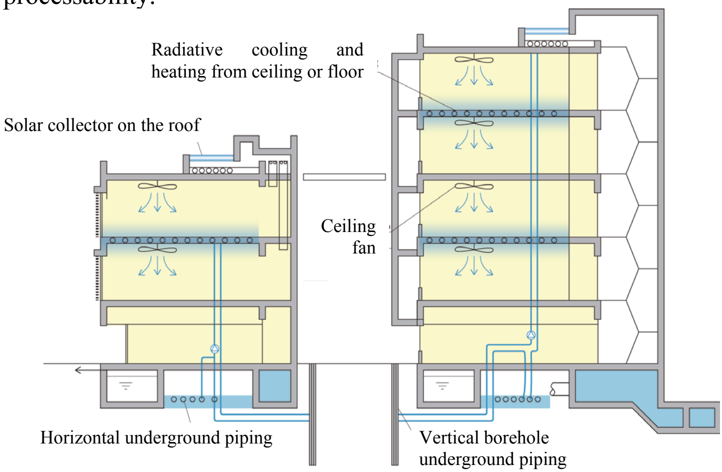


Fig. 1 Outline of the system using underground heat and solar heat directly

2.1 Outline of the air-conditioning system from the concrete slab

To verify the heat flow both from ceiling and floor, the room on one floor has heat transmission from floor, and the room on another floor has different heat transmission from ceiling, as shown in Figure 1. Figure 2 shows the situation of piping laid in the concrete slab. In winter, underground water is used for the preheating of outer air for ventilation using the air processing air-conditioning system.

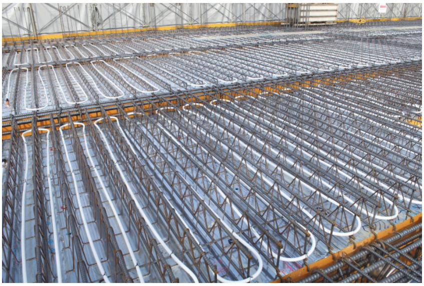


Fig. 2 The piping laid in the concrete slab

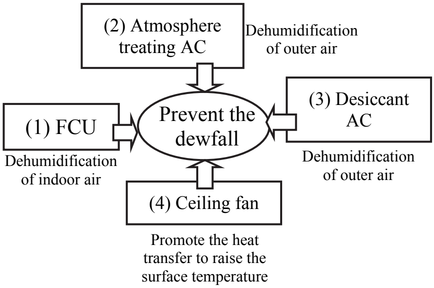
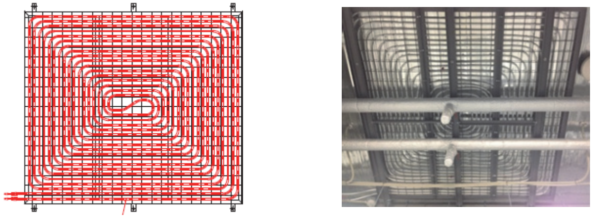


Fig. 3 Options for dehumidification

The temperature of the water from underground is around 18 - 20 °C all the year round, it is a little higher than dew point temperature of the indoor air, therefore the system using underground heat for cooling directly does not lead to dewfall through the year. However, in Japan, we have very hot and humid summer, therefore some options were examined for dehumidification. Figure 3 shows 4 options. 1st is the FCU set in all rooms in this building by controlling the target indoor air temperature, because their supply temperature are not controllable. 2nd is the atmosphere treating air-conditioning system introducing outside air for ventilation by controlling the supply temperature and dehumidification performance. 3rd is the desiccant air conditioners. We use 2 types of the unit. One is the packaged type using heat pump, and the other is unit type which uses hot water from solar collector for regenerator of absorbent, and cold water from underground for cooling. 4th is the ceiling fan promoting the airflow near ceiling and floor. The ceiling fan is set up in the room, promotes the convective heat transfer from the concrete slab, and the dew condensation will be prevented.

For the renovation, the verification of the exposed piping system for cooling and heating under the ceiling was also done (Figures 4).



Figs. 4 Exposed piping system under the ceiling

2.2 Outline of the system using the underground heat

The vertical borehole and the horizontal piping laid underground are used. Concerning the borehole, piles are recycled by using the pile with the shuttlecock on the head of the pile. The depth of the borehole is 36 m, and 9 boreholes were constructed.

In the normal construction borehole technique, various machine parts such as the boring machine, pumps, water tanks, and the digging rejection soil are needed. The price of the steel recycle pile is high though it generates low noise, low vibration, and no remainder soil, because it digs using the shuttlecock by rotating. The method developed this time inserts the polyethylene piping after it digs, and leaves the polyethylene piping, then pulls out the steel pile by reverse-rotation. It is thought that cost becomes only construction expense, and can be constructed cheaper than the normal method, because the steel pile with the wing is repeatedly used.

The normal technique was executed for the comparative verification. The depth of it is 100 m, and 3 boreholes were constructed.

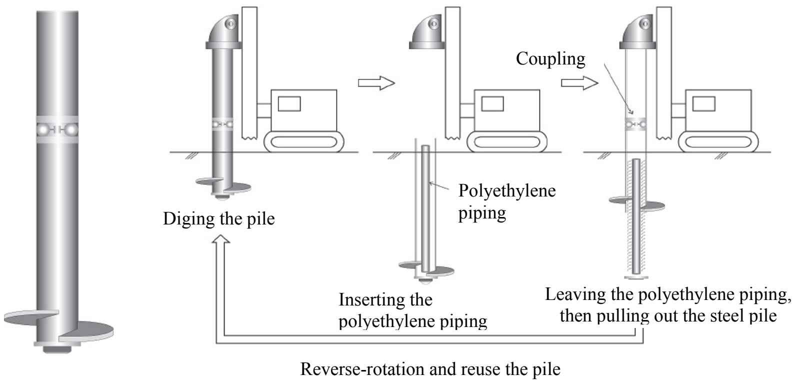


Fig. 5 Borehole, piles are recycled by using the pile with the shuttlecock

To lay the pipes under the building, rolled pipes are set as they are, to reduce construction time greatly. In this technique, polyethylene piping is set by sideways moving as it is and fixed with insulation lock mutually. In normal technique, the polyethylene piping that had been carried by the scroll was enlarged, and fixed to the wire mesh after the wire mesh is constructed for piping of the horizontal laying underground (Figures 6). Time and cost to set wire mesh will be also decreased. The normal technique was also executed for the comparative verification.

(1) Rolled pipes are set as they are

(2) Normal pipes set

Figs. 6 Horizontal piping laid underground

2.3 Outline of the system using the solar heat

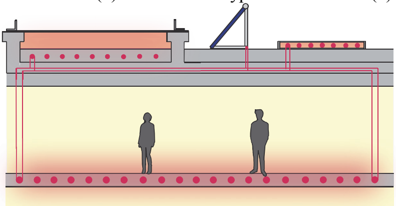
Concerning the solar collector, we developed the simple one, which can be used even when repairing the building. The cost is verified through an actual design and construction of the building, and it aims at the establishment of the best design and the construction technique.

One example is the laying the polyethylene piping in a rooftop suppression concrete layer to get solar heat (Figure 7 (1)). Rooftop suppression concrete exists in many building, therefore it need little extra cost to set in a new building. This solar collector is covered with the transparent polycarbonate board.

For the existing buildings, simple solar collector unit which is composed of the polyethylene piping and the transparent polycarbonate board, was putted on the rooftop (Figure 7 (3)).

To keep high temperature, for heating and regenerating absorbent for desiccant air conditioning unit, vacuum tube type solar collector is set for verification (Figure 7 (2)).

(1) Piping in a rooftop concrete (2) Vacuum tube type collector (3) Collector for exiting building

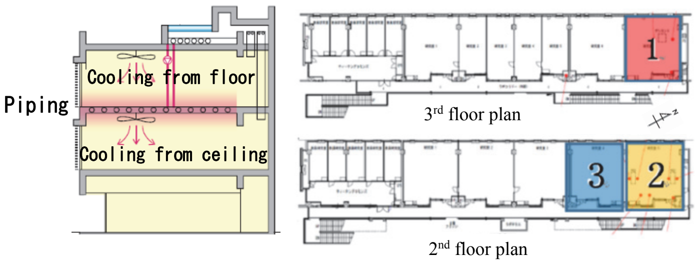


Figs. 7 Solar collectors

3. Evaluation of performance of cooling using the undergrond heat in summer

3.1 Outline of the field experiment

Measurement period is July 23rd - August 14th, 2014. The system was turned on at 9:00, and turned off at 17:00. The measurement was executed in three rooms on the 2nd floor and the 3rd floor, which are used for laboratory rooms in the university (Figures 8). The surface temperature on ceilings, floors, walls and windows, globe temperatures, and the vertical temperature distribution were measured in each laboratory. Laboratory 1 has the floor side cooling by the ground heat and 2 has the ceiling side. The indoor environment and cooling effect which are caused by the location of the cooling were compared with the result of these laboratories. Laboratory 3 has the exposed piping system under the ceiling. By comparing laboratories 2 and 3, the effectiveness of the exposed piping system is verified.



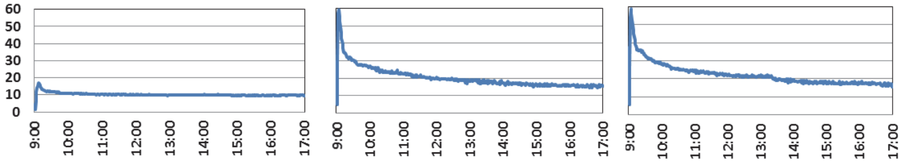
Figs. 8 Laboratories for measurement

Table 1 Cases analysed in cooling condition using the undergrond heat in summer

Case No.	Case 0	Case 1	Case 2	Case 3	Case 4	Case 5
Flow quantity inside the piping (L/min)	0.0	1.5	5.0	6.0	5.0	5.0
Dehumidification method	FCU	FCU	FCU	FCU	Atmosphere treating AC	Packaged Desiccant AC

3.2 Field experiment results

Figures 9 show the supplied cold heat to the concrete slab of the laboratory from the ground by the water. It was derived by using the data of the temperature difference between inflow and outflow of the concrete slab, and the flow quantity. The supplied heat of Case 1 was smaller than that of Case 2 and 3. It was caused by the slowness of the flow in the pipe of Case 1. Especially at the beginning of the operation, in Case 1, cold heat was not supplied comparing other cases. In Case 1, Reynolds number is not big enough, therefore there is a possibility that is the laminar pipe flow. Keeping the flowing quantity more than a certain amount is important.

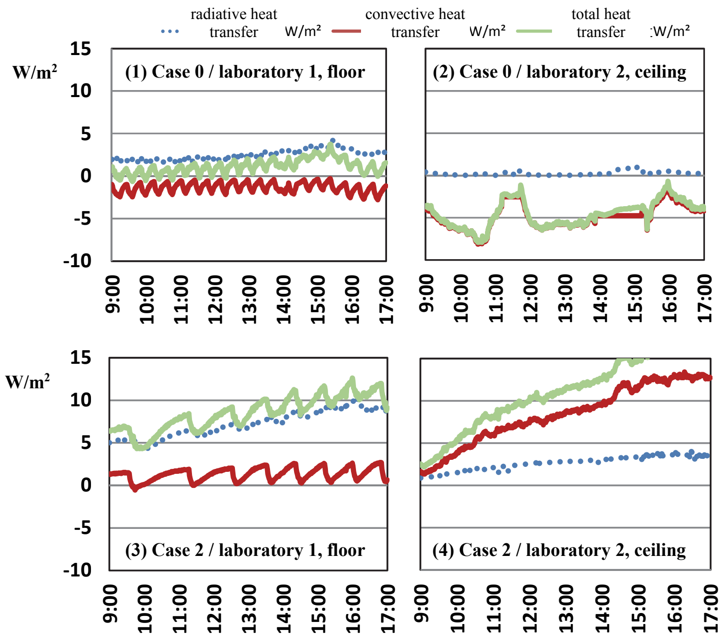


(1) Case 1 (Flow quantity:1.5L/min)   (2) Case 2 (5.0L/min)   (3) Case 3 (6.0L/min)

Figs. 9 Supplied cold heat to the concrete slab

The results of amount of radiative and convective heat transfer from the surface of ceiling or floor in Case 0 and 2 are shown in Figures 10. In Case 2 / laboratory 1, the vertical temperature distribution was generated, and the cool air stayed near the floor, the radiative heat transfer from floor was large, and the convective heat transfer was small. On the other hand, in Case 2 / laboratory 2, because warm air stayed near ceiling and the emissivity of the ceiling metal surface (galvanized sheet iron finish) is low, convective heat transfer was larger than radiative heat transfer. In Case 2, about half of the supplied cold heat from water was transferred to the indoor space. The storage cold heat was transferred in the delay. In Case0 / laboratory 1 there was little heat transfer from floor, and in Case0 / laboratory 2, it was cooled on the surface of the ceiling. It was caused by the warm temperature near ceiling.

Though the results were omitted, in the Case 2 / laboratory 3, which has the exposed piping system under the ceiling, the convective heat transfer was promoted, because there was less conductive heat transfer to the ceiling.



Figs. 10 Radiative and convective heat transfer from the surface of ceiling or floor

COP (coefficient of performance) was calculated from the amount of power consumption of the pump and the supplied cold heat to the concrete slab (Table 2). Generally, COP becomes lower as flowing quantity grows. It is thought that an enough result was confirmed. As for Case 3, supplied cold heat was smaller than assumption, and it leads to low COP. It is thought that the low outside temperature in Case 3 caused low cooling effectiveness.

Enough cooling effect and high COP can be achieved by doing the control that supplies necessary flowing quantity, though it verified this time with flowing quantity was constant.

Table 2 Result of the COP

Case No.	Case 1	Case 2	Case 3
power consumption of the pump (kWh)	2.7	9.0	14.0
supplied cold heat to the concrete slab (MJ)	23.4	51.7	47.4
COP	12.1	8.0	4.6

The amount of the latent heat and sensible heat processing of each dehumidification method system was also derived. Though the processing heat by FCU was a little larger than that by other system, in accordance with the difference of the amount of supply (FCU : 900 m^3/h, and atmosphere treating AC : 600 m^3/h, packaged desiccant AC : 500 m^3/h), there was not large difference between these system and the dewfall was not generated.

4. Evaluation of performance of heating using the solar heat in winter

4.1 Outline of the field experiment

Measurement period is November 15th - December 31th, 2015. The system was turned on at 9:00, and turned off at 17:00. The measurement was executed in two rooms on the 2nd floor (laboratory 2) and the 3rd floor (laboratory 1) (Figures 8). Because the capacity of the solar collecting equipment is relatively small, the flow quantity could not be enlarged.

Table 3 Cases analysed in heating condition using the solar heat in winter

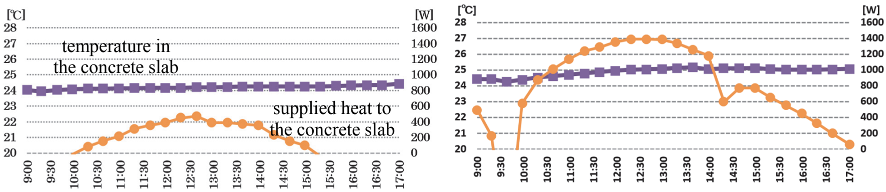
Case No.	Case 1	Case 2	Case 3	Case 4	Case 5
Flow quantity inside the piping (L/min)	2.8	0.8	0.8	1.5	1.5
Solar collecting system	(3) *	(2) *	(2) + (3)*	(1) *	(3) *

* (1) Piping in rooftop concrete, (2) Vacuum tube type, (3) Piping on rooftop (see Figures 7)

4.2 Field experiment results

The results of temperature in the concrete slab and supplied heat to the concrete slab of the room from the solar collector by the water of Case 1 (piping on rooftop), and Case 3 (piping on rooftop with vacuum tube type) are shown in Figures 11. Temperature in the slab rises in both cases. Supplied heat to the slab of Case 2 became larger than that of Cases 1.

Other performance verifications are being executed now.



Case 1 Case 3

Fig. 11 Temperature in the concrete slab and supplied heat to the concrete slab

5. Evaluation of other performance

5.1 Performance of the proposed vertical borehole system

The proposed system does not need stock space for water and mud which are needed by normal system, therefore construction necessity area of proposed system became 80% as the one of normal system. And construction cost of proposed system became 70% as the one of normal system by reusing pile etc. The performance of collecting underground heat of the proposed system is about 30~40 W/m and roughly equal as the one of normal system.

5.2 Performance of the proposed solar heat collecting system

The performance of collecting solar heat on the roof system is about 40~100 W/m^2, which is about 20~30 % as the one of vacuum type solar collector.

6. Conclusion

In this study, we proposed the thermal storage radiation air-conditioning system from the concrete slab that uses underground heat and solar heat directly without any other heat sources that was able to be used at a low price and for the long term. Though room has been left for the improvement e.g. the control method of the amount of the suppling water by the pump, the stable performance of the solar collector etc., the proposed system can achieve relatively high performance. The examination of practical use is scheduled to be attempted in the future.