DEVELOPMENT AND EVALUATION OF A NEW CENTRAL AIR-CONDITIONING SYSTEM USING UNDERFLOOR CHAMBERS FOR JAPANESE CONDOMINIUMS

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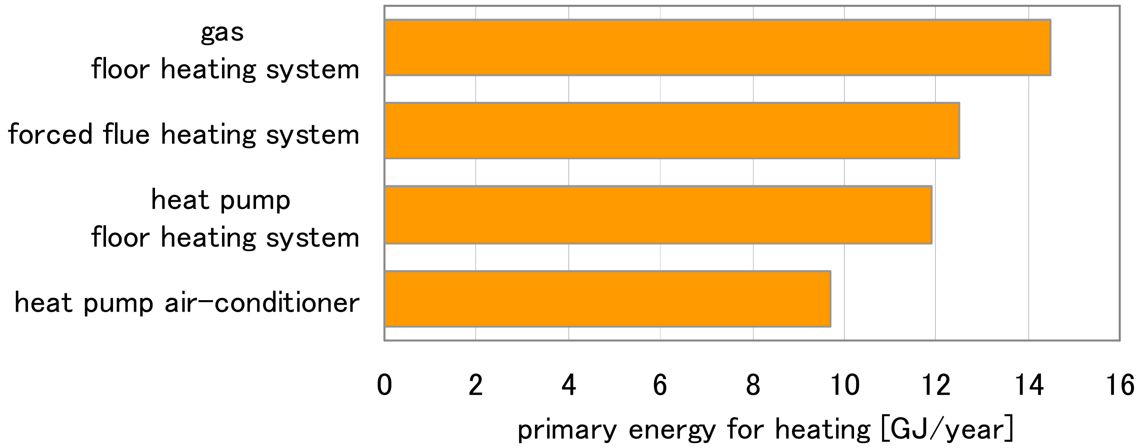
Abstract: A new type of central air-conditioning system for Japanese condominiums has been developed, tested and evaluated. This system is composed of a heat pump air-conditioner, a small ductwork and underfloor chambers, which are usually formed to prevent the floor impact sound and vibration, and which are thermally insulated well for this development.
The paper describes the measurements and evaluations that were made in both winter and summer. Room temperature was generally stable because of controlling supplied air volume. Floor surface temperature was about 2 ℃ higher than room air temperature in winter. On the other hand, it was about 1 ℃ colder than room air temperature in summer. These results suggest that this system should create thermal comfort and high energy efficiency in Japanese condominiums.

Key Words: underfloor chamber, central air-conditioning system, heat pump air-conditioner, condominium, comfortable indoor climate

1 INTRODUCTION

Heat pump air-conditioner is one of very popular heating equipments in Japanese condominium. Nevertheless people do not always use it, but sometimes use other heating equipments, such as portable kerosene stoves and electric heaters, when they want to heat rooms. The reason is that temperature of supply air (SA) is lower than that in other heating equipments. In addition, low level of thermal insulation in envelopes is a problem in Japanese housings, as it creates cold indoor climates.
The trial calculation of the primary energy for heating (JSBC 2009) is shown in Figure 1. Heat pump air-conditioners should be more often used even in winter from viewpoint of energy conservation, because they have higher energy efficiency than other heating equipments.
The authors attempted to improve air-conditioning system in condominiums. A new type of central air-conditioning system was designed, constructed and tested in a full-scale test dwelling unit.



Trial calculation in heat exchanger type ventilation system none, Ⅳb region, Q-value 2.7, and detached house.

Figure 1 TRIAL CALCULATION OF THE PRIMARY ENERGY FOR HEATING

2 DEVELOPMENT OF A FLOOR CHAMBER AIR-CONDITIONING SYSTEM

A new central air-conditioning system for Japanese condominium has been developed in order to achieve thermal comfort as well as energy conservation. Heat pump air-conditioner was adopted from view of energy conservation. Besides a central air-conditioning system was used to keep thermal comfort. High thermal insulation in envelope is needed to heat up a whole dwelling unit of condominium by a heat pump air-conditioner which has high energy efficiency. To create thermal comfort, vertical distributions of air temperature in rooms must be as uniform as possible in winter. If conditioned air is supplied to the underfloor space, much thermal radiation from the floor is expected as shown in a floor heating system.

Thus the new central air-conditioning system, which is illustrated in Figure 2, has been designed and constructed. The air-conditioning unit (indoor unit) was set up in the ceiling of the passage, and conditioned air was supplied to the underfloor space through the duct. By supplying the warm air to the underfloor space, the floor was heated slightly, and thermal radiation was emitted from the floor surface. Afterwards, conditioned air was blown to the room through the floor air outlet unit, and returned to the air-conditioner through the inlet in the ceiling of the passage.

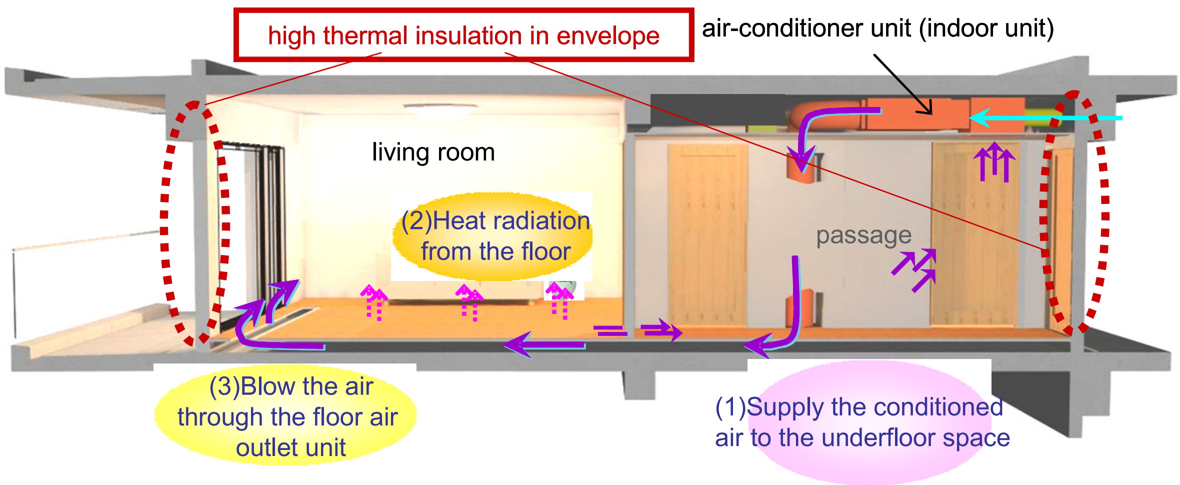


Figure 2 NEW CENTRAL AIR-CONDITIONING SYSTEM FOR JAPANESE CONDOMINIUMS

3 OUTLINE OF A TEST DWELLING UNIT AND THE AIR-CONDITIONER

The specifications of a full-scale test dwelling unit are shown in Table 1 and the plan is shown in Figure 3. The dwelling unit imitates the plan of a general condominium for families in Japan. The east, west, upper and lower sides of the dwelling unit face the buffer space. The envelopes of the buffer space are covered with the insulation material of 100 mm in thickness. The buffer space is designed to reduce heat loss through east, west, upper and lower sides of the dwelling unit. Temperature in the buffer room is controlled as equal to dwelling unit temperature.

Table 1 SPECIFICATIONS OF A TEST DWELLING UNIT

	SPECIFICATIONS
plan	general condominium for families in Japan(3LDK)
floor space	78 m²
size	wide 6,400 mm, depth 12,250 mm, height 2,500 mm (partry 2,150 mm)
window	living: wide 4,000 mm, height 2,000 mm room1,2: hight 1,000 mm *all windows are double glazing (5 mm + air 6 mm + 5 mm)

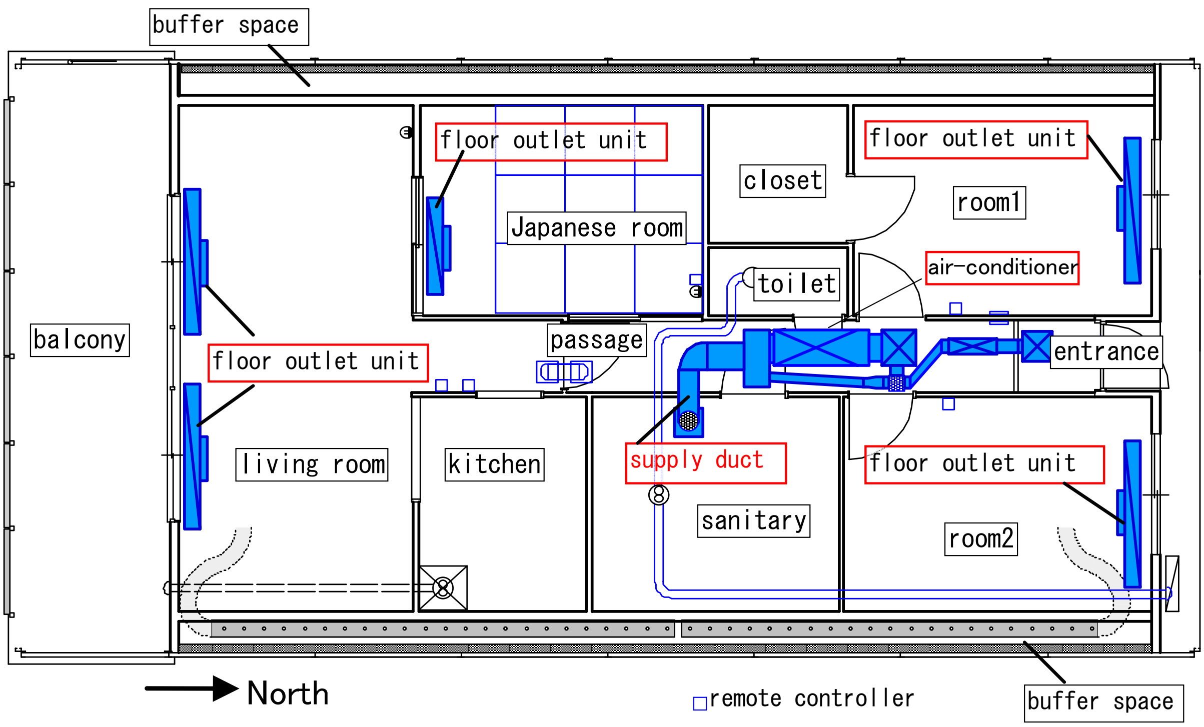


Figure 3 PLAN OF A FULL- SCALE TEST DWELLING UNIT

The specifications of air-conditioner are shown in Table 2. The heat pump air-conditioner (indoor unit) and ventilation system were set up in ceiling of the passage of the dwelling unit. Outdoor air was taken by a ventilation fan and was mixed with indoor air taken through the inlet. The mixed air was air-conditioned and then was supplied to the underfloor chamber through the duct in the center part of the dwelling unit.
In each room, air dampers were placed to the floor outlet units and remote controllers were installed. By controlling the SA volume of each room by the proper damper of the floor outlet unit, the room temperature is kept comfortable.

Table 2 SPECIFICATIONS OF HEAT PUMP AIR-CONDITIONER

	SPECIFICATIONS
cooing capacity	5 kW
heating capacity	5.6 kW
rated send air volume	750 m^3/h
rated electricity	1,700 W
voltage	200 V

4 MEASUREMENT OF THE ROOM AIR TEMPERATURE AND FLOOR SURFACE

To analyze the characteristic of air-conditioner's operation and thermal comfort in the rooms, air flow rate, electricity and various temperatures in Table 3 were measured in the dwelling test unit during 6days in winter when all rooms in the dwelling unit were set up at 22 ℃, and 6days in summer which were set up at 28 ℃.

Table 3 ITEMS OF THE MEASUREMENT

	MEASUREMENTITEMS
temperature	outside
	each room at height 1,100 mm (living room, Japanese room, room1, room2)
	floor surface (each room)
	supply air (supply duct, outlet of each room)
air volume	supply air (differencial pressure)
solor radiation	outside
electricity	air-conditioner

4.1 CHANGING OF THE TEMPERATURE IN WINTER MEASUREMENT

The changing of the room air temperature of each room and the floor surface temperature is shown in Figure 4. There were few days when the lowest temperature of the outside is below 0 ℃. The air-conditioner was operated, and the SA temperature in the outlet of each room rises to about 30 ℃ or more when the room air temperature fell to the designated temperature which was 22 ℃. The SA temperature in the outlet of each room moves up and down according to the heat load.

In the living room, the temperature of room air was higher than 22 ℃ in daytime, because of the solar radiation. The temperature of the other room was controlled approximately the designated temperature which was 22 ℃.

Comparing the temperature of the floor surface with the room air temperature, In the living room, the floor surface temperature was 2 ℃ higher at nighttime and it was more equal in daytime. The floor surface temperature was 1 ℃ higher than the room air temperature in the Japanese room and room1, 2 ℃ higher in the room2. It was confirmed that the temperature of the floor surface was slightly warm.

4.2 CHANGING OF THE TEMPERATURE IN SUMMER MESUREMENT

The changing of the room temperature of each room and the floor surface temperature is shown in Figure 5. The highest temperature of the outside in daytime is exceeded 30 ℃ on all 6 days and there were few days exceeded 35 ℃. The SA temperature of each room falls under 25 ℃ in daytime when the air-conditioner operated by the room air temperature rises. The SA temperature of each room moved up and down according to the heat load.
In the living room, the temperature of the room air was often exceeded 28 ℃ by the solar radiation. On the other hand, the temperature in Japanese room was lower than 28 ℃, because the minimum volume of SA for 24 h-ventilation was supplied to Japanese room, though. The temperature of other rooms were controlled at the designated temperature which was 28 ℃ or less.
Comparing the floor surface temperature with the room air temperature, the floor surface temperature was equal to or 1 ℃ colder than room air temperature. It was confirmed that the temperature of the surface was not too cold.

4.3 COMPARISON OF EACH ROOM TEMPERATURE IN WINTER AND SUMMER

The point of the comparison is that the temperature of each room SA is not same. This means that the temperature and air flow in the underfloor chamber was not uniformity.
And, there was a difference of the temperature of the floor surface, too. It is appeared that the temperature of the floor surface is related to the temperature in the underfloor chamber.
To create thermal comfort, it is necessary that the temperature of each room is uniformity as possible. To design this system for various condominiums, it is important that the temperature of the floor surface and room air in each room is estimated accurately in advance. It is our future tasks to build up the method to estimate the temperature in the room.

4.4 VERTICAL DISUTRIBUTION OF THE TEMPERATURE IN WINTER AND SUMMER

The vertical distribution of each room temperature in winter on 12/27 is shown in Figure 6. Excluding the period when the room is heated by the solar radiation, the temperature of the room air was from 20 ℃ to 23 ℃. In addition, the temperature of the floor surface was 2 ℃ higher than the room air temperature. The temperature distribution was small in height from 100 mm to 2,300 mm.
The vertical distribution of each room temperature in summer on 8/11 is shown in Figure 7. At 6:00, the air-conditioner was not operating because the room temperature was lower than the designated temperature which was 28 ℃, the all air temperature of the room at each height is about 26 ℃.
At 12:00, the air temperature was increased with the height of the measure point. The reason of the vertical distribution at 12:00 can be summarized in two points. First, the vertical distribution is tends to be enlarged by the solar radiation, because the cooling capacity in the living room is exceeded by the strong solar radiation. Second, blowing the SA from floor outlet unit is tends to be enlarged the distribution, because the SA is colder and heavier than the room air, and the SA remains in the bottom of the room.

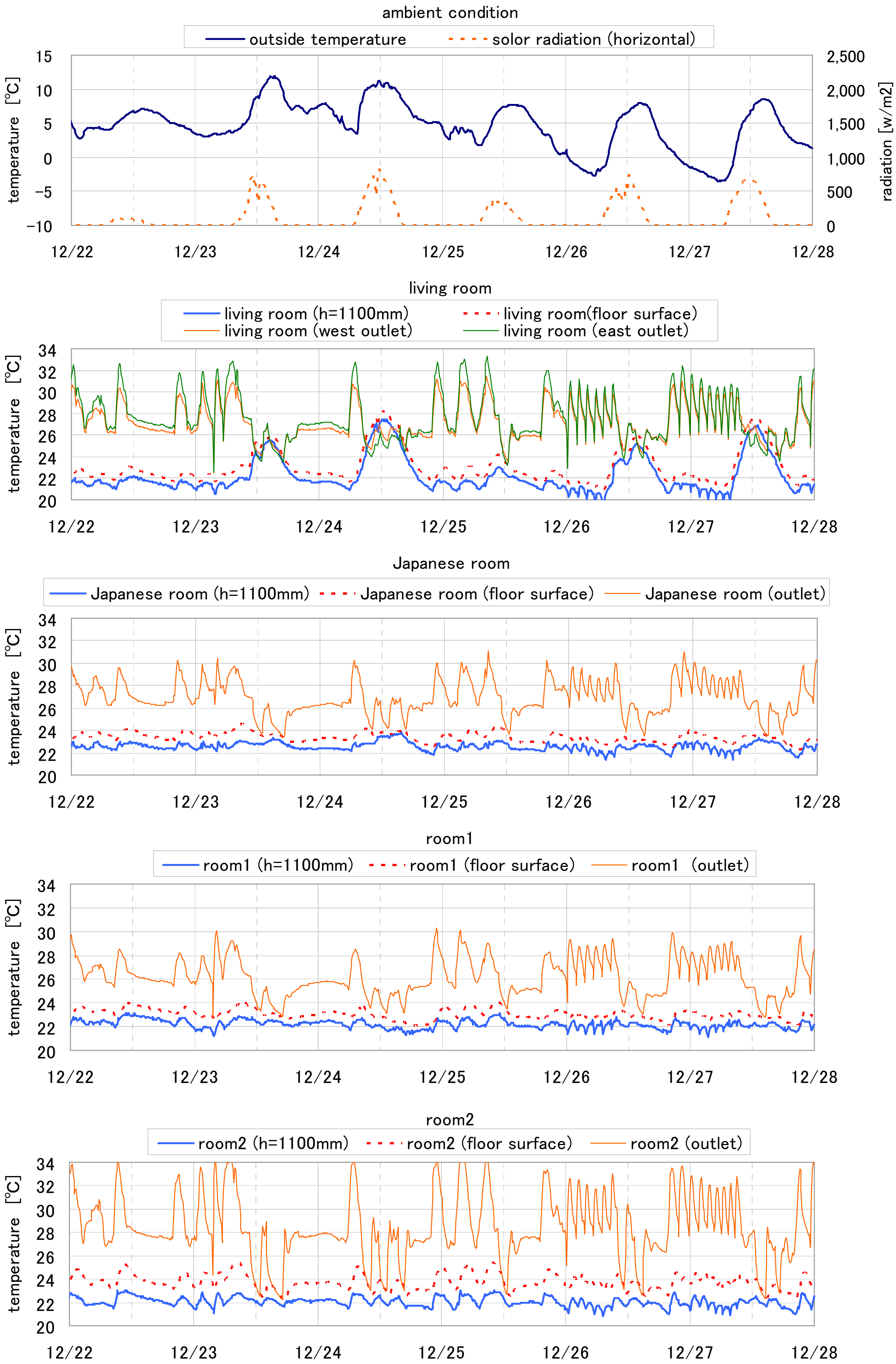


Figure 4 CHANGING OF THE TEMPERATURE IN WINTER

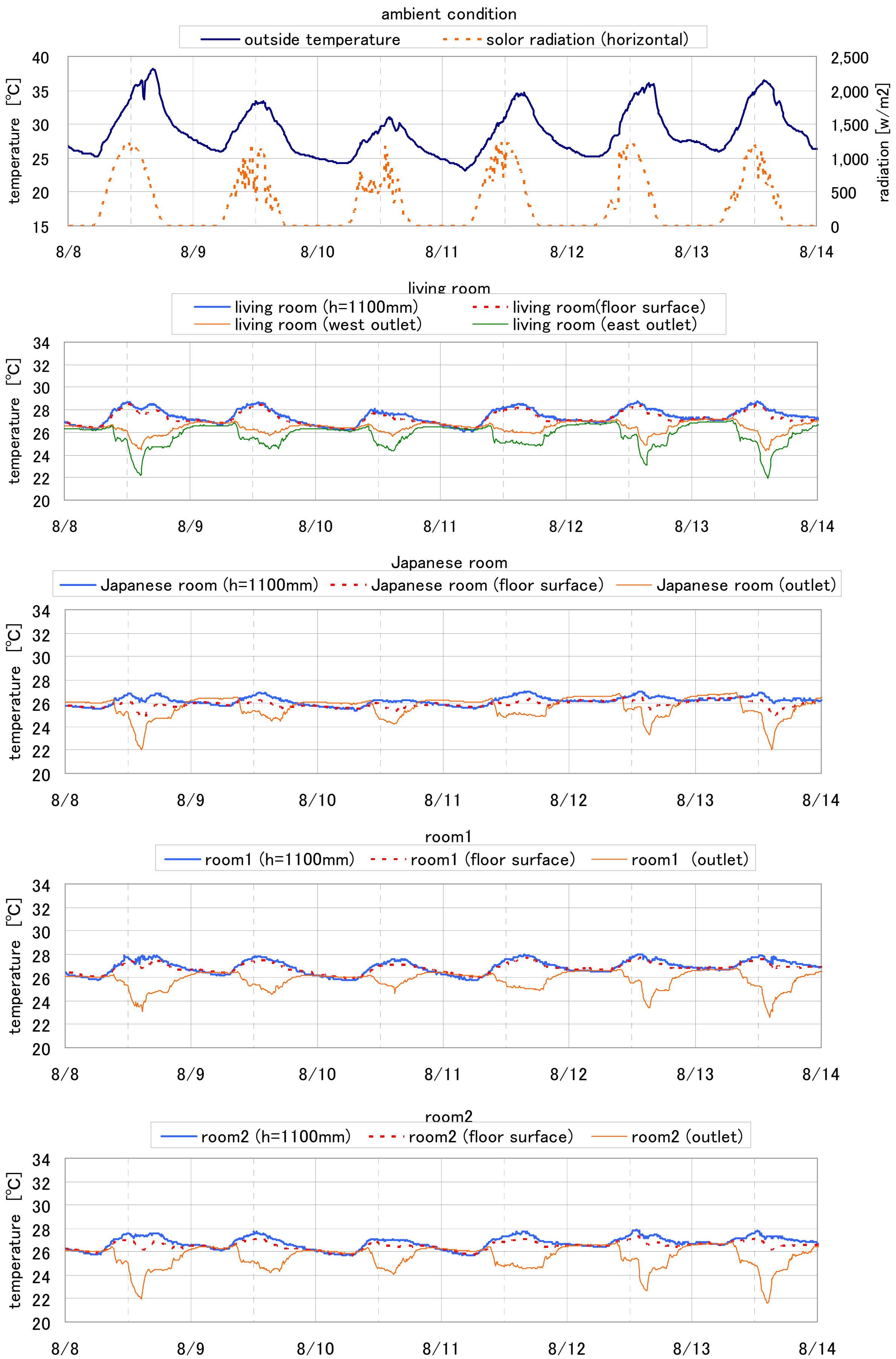


Figure 5 CHANGING OF THE TEMPERATURE IN SUMMER

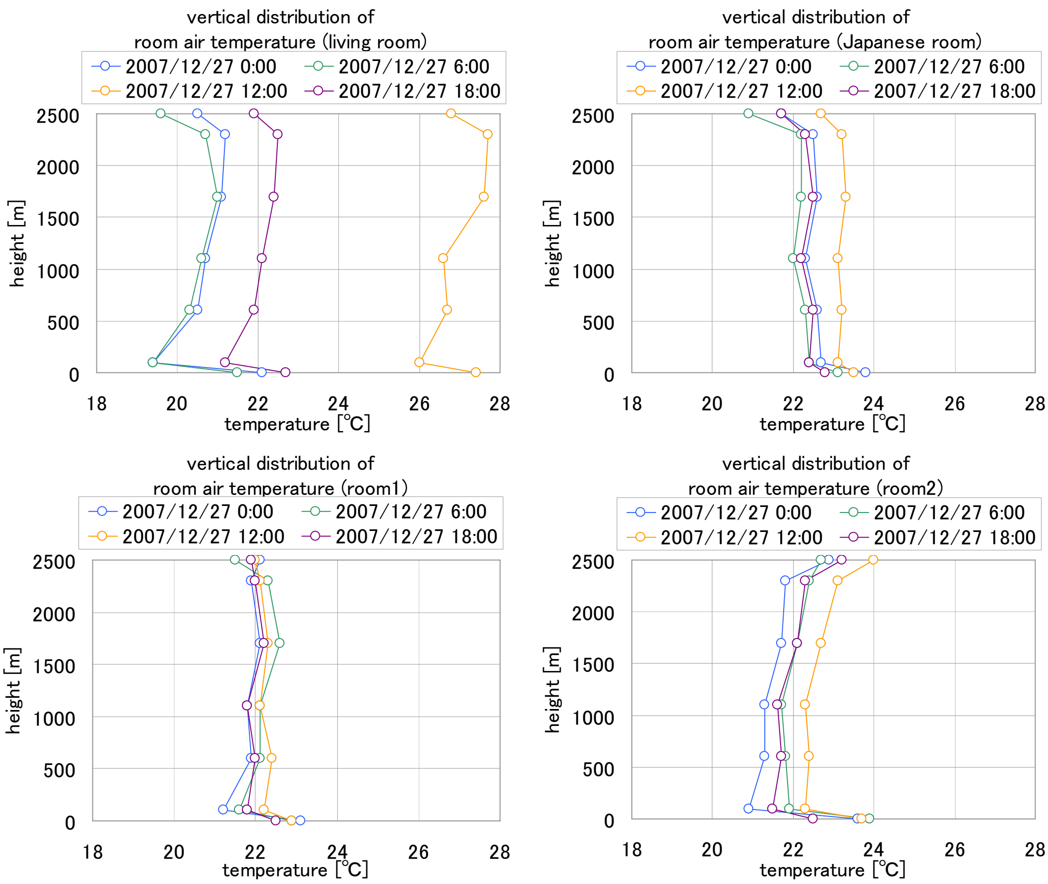


Figure 6 VERTICAL DISTRIBUTION OF ROOM AIR TEMPERATURE IN WINTER

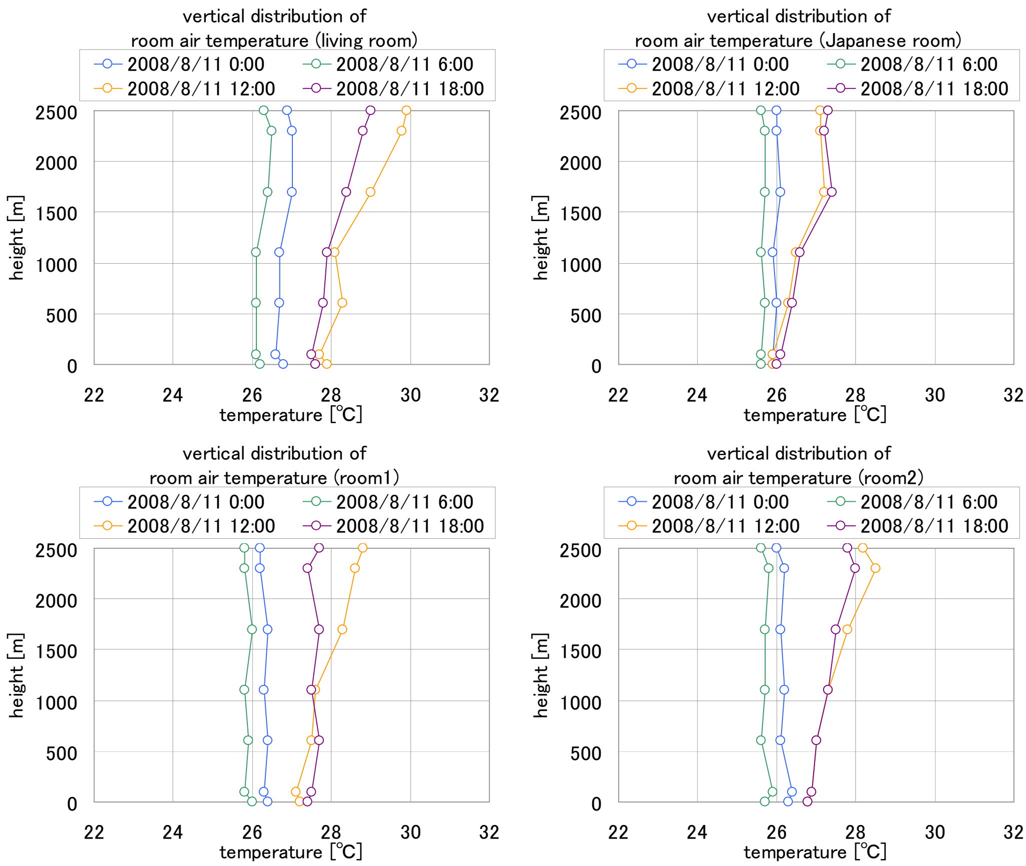


Figure 7 VERTICAL DISTRIBUTION OF ROOM AIR TEMPERATURE IN SUMMER

5 PERFORMANCE OF AIR-CONDITIONER OPERATION

The frequency and cumulative frequency of the air-conditioned heating value in winter and summer is shown in Figure 9.
The ratio that the air-conditioned heating value was 4 kW or less was about 80 %, while the rated capacity of the air-conditioner was 5.6 kW when it is heating. The mode of air-conditioned heating value was from 2 kW to 2.2 kW.
Moreover, the ratio that air-conditioned heating value was 1.6kW or less was more than 80 %, while the rated capacity of the air-conditioner was 5.0 kW when it is cooling. The mode of air-conditioned heating value is from 1.4 kW to 1.6 kW.
This result indicates a possibility that the capacity of the air-conditioner may be small.

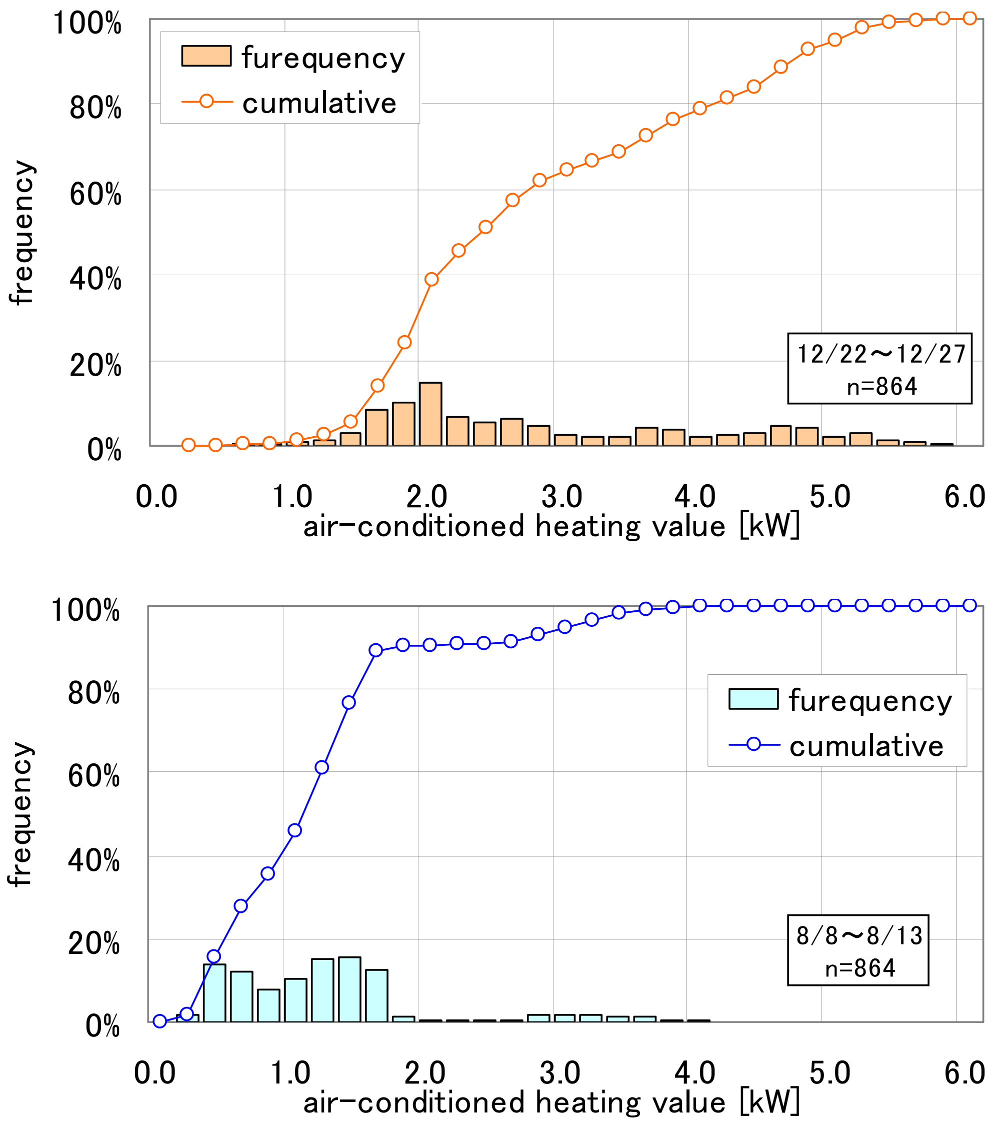


Figure 8 FREQUENCY DISTRIBUTION OF THE AIR-CONDITIONED HEATING VALUE IN WINTER AND SUMMER

6 CONCLUSIONS

The new central air-conditioning system that aimed to achieve the thermal comfort and energy conservation using the underfloor space as an air supply chamber for Japanese condominiums is developed. To evaluate the system, the full-scale dwelling test unit was constructed imitating general Japanese condominium for families. In addition air flow rate, electricity around the air-conditioner, the temperature distributions of the rooms were measured to analyze air-conditioner's operation and indoor thermal comfort, consequently the following have been concluded.

(1)This system can keep the room air temperature approximate to the designated temperature in winter and summer.
(2)The temperature of the floor surface was 2 ℃ higher in winter, and 1 ℃ colder in summer than room air. So thermal comfort is achieved in winter, and besides the temperature of floor surface is not too cold in summer.
(3)The air temperature of the room that was heated by solar radiation was higher than other rooms in winter and summer. In particular, the room temperature was higher than the designated temperature in summer.
(4) The temperatures of the SA are not same, because air flow in the underfloor chamber is not uniform.
(5) According to the result of the measurement, there is a possibility that the capacity of the air-conditioner may be a little small. There is a high performance air-conditioner that the COP is over than 6 in the small capacity air-conditioners for domestic use. If using the higher performance air-conditioner, more energy conservation can be achieved.

7 REFERENCES

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