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Simulation Study on Comparison of Thermal Comfort during Heating with All-Air System and Radiant Floor System

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***Abstract*—**Radiant heating systems work fundamentally differently from air systems by taking advantage of both radiant and convective heat transfer to remove space heating load. There are rare studies on differences of heating systems between all-air system and radiant floor system. This paper uses the method of simulation based on state-space to calculate the indoor temperature and wall temperature of each system and shows how the dynamic heat transfer in rooms conditioned by a radiant system is different from an air system. Then this paper analyses the changes of indoor temperature of these two systems, finding out the differences between all-air heating system and radiant floor heating system to help the designer choose a more suitable heating system.

***Keywords*—**Radiant floor, all-air system, thermal comfort, simulation, heating system.

I. Introduction

In recent years, there has been an increase in interest and growth in radiant cooling and heating systems, as they have be proven to be energy efficient compared to all-air systems [1], [2]. The people in the hot summer and cold winter zone prefer to use intermittent energy-using mode [3]. In this mode, the start and stop of the system will cause the difference of the indoor thermal environment of the two systems. Reference [4] is studying the differences between radiant cooling and all-air cooling systems at the start and stop under cooling conditions, analyzing from the parameters of wall temperature response speed and indoor air temperature response speed. There is still very little comparison between the two on the heating system. Studying the difference in indoor thermal processes between the radiant system and the all-air system during heating can help designers design a more suitable heating system and help the users choose a more energy-efficient start-stop time. Therefore, in this paper, the differences between the radiant floor and the all-air systems in the heating system are investigated from comparisons of the parameters of wall temperature response speed and indoor air temperature response speed.

II. Modeling

A. Method of Modeling

The building simulation model mainly adopts the following methods: differential method, reaction coefficient method, harmonic reaction method and state space method. Among them, the difference method can deal with various complex enclosures, but the calculation is large and the stability is affected by the initial value and the difference step size.

Both the reaction coefficient method and the harmonic reaction method first determine the thermal characteristic coefficient of the room envelope structure, and then establish a heat balance solution.

The harmonic response method needs to simplify all the thermal disturbances to make the periodic harmonic function, and there are certain difficulties in engineering application. The reaction coefficient method needs to use the inverse transformation to find the reaction coefficient, and the rooting process is more complicated.

The state space method is a spatially discrete time continuous method. The influence of the thermal disturbance on the indoor air temperature is converted into a series of heat transfer characteristic parameters, and the room temperature and load calculation are performed on this basis. It only needs to solve the heat transfer characteristic coefficient once, avoiding the repeated calculation of the heat transfer characteristics of the system, the calculation amount is small, and the calculation result is stable. Moreover, the state space method calculates the thermal characteristic coefficient in units of rooms, and the integrity is strong, and the speed is faster in the multi-room simultaneous solution [5].

Based on the above analysis of the advantages and disadvantages of various modeling methods, this paper adopts the state space method to model, which can reflect the temperature changes of each node more quickly and directly with MATLAB software.

B. Model Condition Settings

This article builds a room (3 m*4 m*3 m) with a 1.5 m*1.5 m window on the south wall, as shown in Fig. 1.

Among them, the walls were set in two different materials: the east wall and the west wall are set as the first material; the south wall and the north wall are the second material. Each layer of material is listed in order from outdoor to indoor as shown in Fig. 2.

The material composition and parameters of each enclosure are shown in Table I.

C. Heating Setting

According to the intermittent mode of operation in Table II, the radiant and full air systems provide 1500 W of heat input

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during heating system operation.

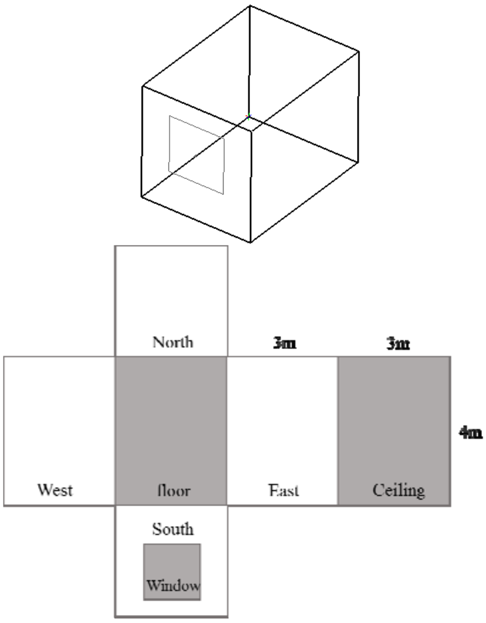

Fig. 1 Simulate room size parameter settings

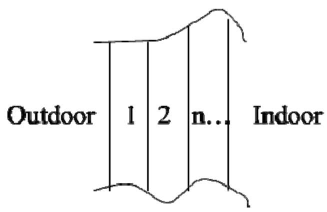

Fig. 2 Wall Material Arrangement Order

According to engineering experience, when the radiant floor heating system is installed, the water side provides 38 °C hot water. The heat transfer coefficients of each enclosure and indoor air are shown in Table III.

The outer surface of the floor in the radiation system is in contact with the hot water pipe, and the heat transfer coefficient is set to 1000 W/(m^2•K). In the all-air system, since the floor insulation performance is good, the heat transfer coefficient is set to 0 W/(m^2•K), which can be regarded as floor insulation. The number of bleed air changes is set to 1.2 times per hour.

III. Result

A. Indoor Air Temperature

Fig. 3 is a comparison of the changes in room temperature of two systems over a day. From the figure, we can see that the indoor air temperature response of the all-air system is almost instantaneous when the system is turned on, while the indoor air temperature of the radiant floor system is slowly rising, and the rising speed gradually decreases with the opening time.

TABLE I
The Material Composition and Parameters of Each Enclosure

Envelope	Order	Material	Thickness (mm)	Thermal Conductivity W/(m.K)	Heat Capacity kJ/(kg.K)	Density kg/m^3
Type 1 Wall	1	Cement mortar	20	0.93	1.05	1800
	2	Autoclaved aerated concrete block	240	0.14	1.05	500
	3	Cement mortar	20	0.93	1.05	1800
Type 2 Wall	1	Autoclaved aerated concrete block	240	0.14	1.05	500
	2	Polyurethane insulation board	50	0.024	1.38	45
Ceiling	1	Sand stone	30	0.23	0.92	600
	2	RC	120	1.74	0.92	2500
	3	Polyurethane insulation board	50	0.024	1.38	45
Floor	1	Mortar concrete	100	1.5	0.97	2344
Window	1	Glass	12	3.4	0.85	1530

TABLE II
Intermittent Energy-Using Mode

Season	Heating Demand Time	Heating Duration
Winter	20:00-8:00	·12.15-2.15

TABLE III
Heat Transfer Coefficient of Each Enclosure

	Walls	Ceiling	Floor	Window
h_i	2.5	2.5	4.14	2.5
h_o	23	23	1000(RF) / 0(AA)	23
h_r			5.5 [6][7]	
Unit			W/(m^2·K)	

h_i - Convective heat transfer coefficient between the air indoor and the envelope; h_o - Convective heat transfer coefficient between the air outdoor and the envelope; h_r - Radiant heat transfer coefficient between the air outdoor and the envelope.

When the system is shut down (removing the heat source), the air temperature in the all-air system drops immediately, while in radiant floor system it drops slowly. And the lowest air temperature in radiant floor system is higher than it in the all-air system. At the same time, the maximum temperature of the all-air system is greater than that of the radiant floor heating system, so that if the same temperature is reached in this indirect mode, the full air system will consume less energy than the radiant floor heating system.

Since the indoor air temperature response time of the radiant floor is long, the user can turn on the radiant floor system 1 hour in advance, and shut down the system one hour earlier to adjust the peak electricity and save energy.

B. Envelope Temperature

Figs. 4-7 show the difference in wall temperature between different types of walls in the two systems as the system starts and stops (RF refers to radiant floor system, AA refers to all-air system).

It can be seen from Figs. 4-7 that the trend of temperature changes of various types of retaining walls is similar. When the system is turned on, the indoor wall temperature response in the all-air system is faster and higher than that of the radiant floor system, and its growth rate gradually decreases with the increase of the starting time. After two hours, the temperature of the enclosure of the all-air system becomes lower than radiant floor system.

When the system is shut down, the instantaneous rate of wall temperature reduction of the enclosure of the all-air system is higher than that of the radiant floor system.

The maximum temperature and minimum temperature of the wall of the radiant floor system are higher than the all-air system. In the radiant floor system, the envelope structure stores more heat.

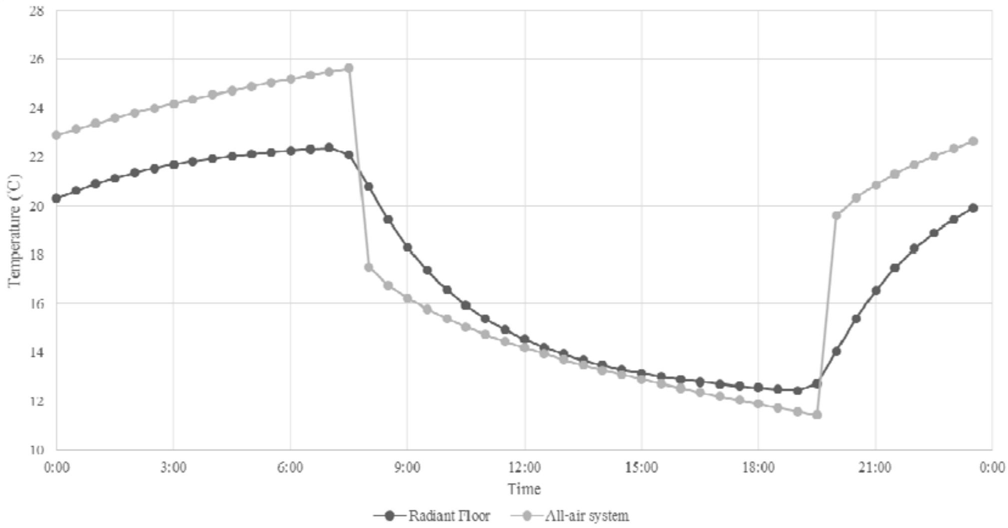

Fig. 3 Indoor Air Temperature of RF and AA System

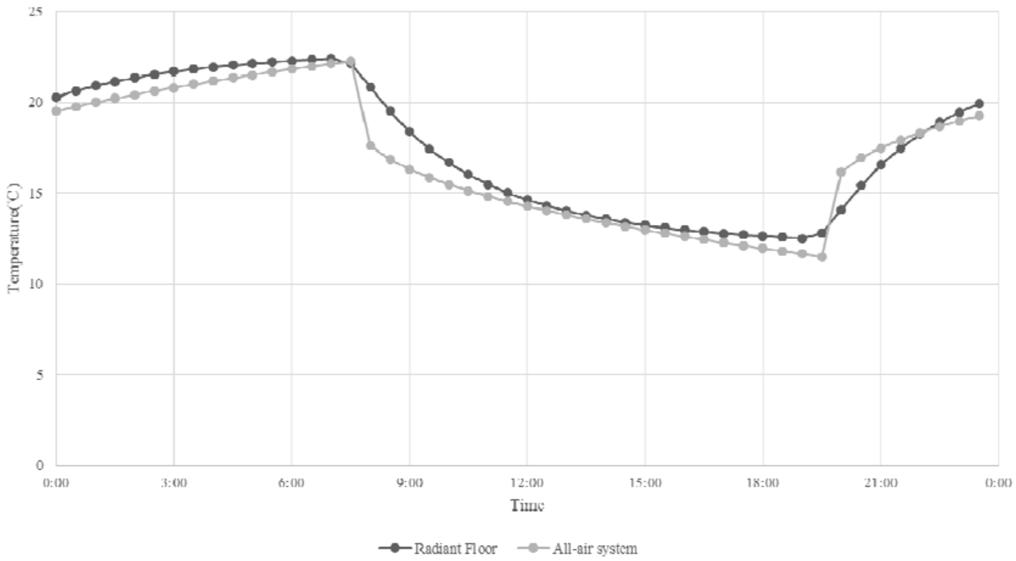

Fig. 4 Type 1 Wall Temperature of RF and AA System

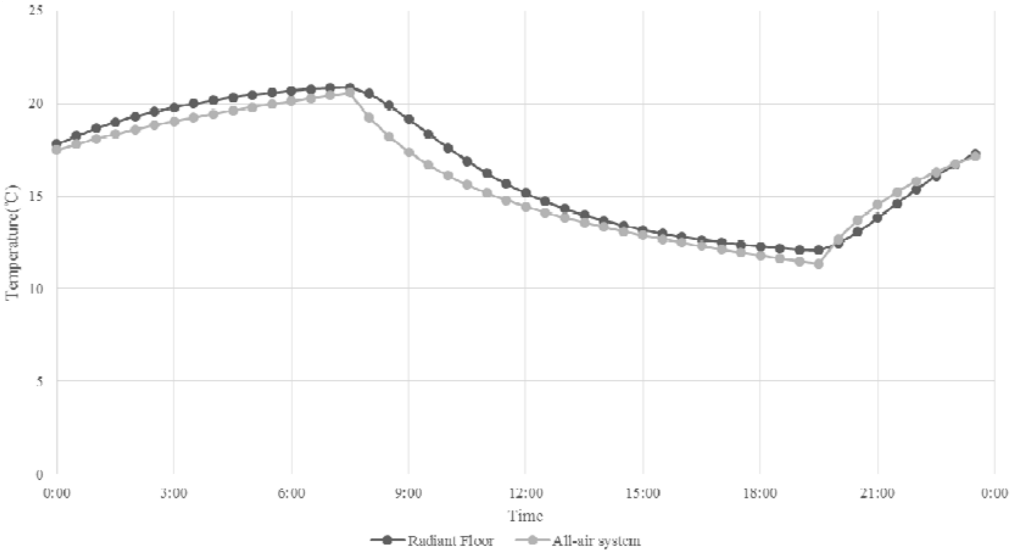

Fig. 5 Type 2 Wall Temperature of RF and AA System

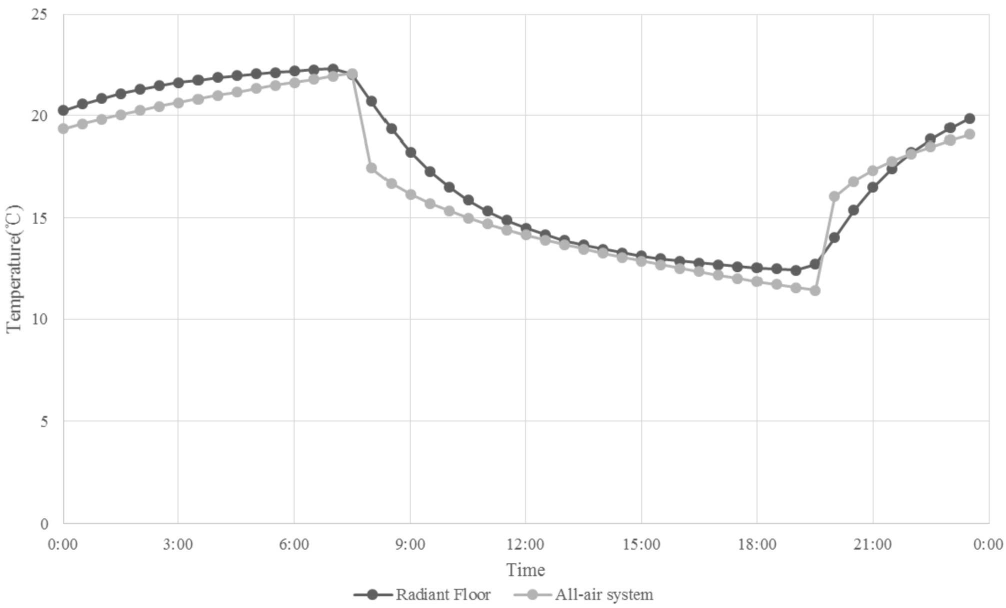

Fig. 6 Ceiling Temperature of RF and AA System

From Fig. 7, we can see that the temperature of the windows in these two systems is nearly same though the trends of the temperature are different, because the thickness of the window is so small that the glass has almost no heat storage capacity. It shows that when the heat capacity of the enclosure is small, the difference between these two systems is small.

As can be seen from Figs. 4, 5, different wall materials and insulation structure can cause differences in wall temperature response trends. Especially in the all-air system, the better the wall insulation performance, the slower the temperature response rate of the wall surface, as shown in Fig. 9, compared with the difference in indoor wall temperature between Type 1 and Type 2 walls in the whole air system. It can be seen that the wall temperature response rate and the maximum temperature of the type 1 wall are higher than the type 2 wall.

It can be seen from Fig. 8 that when the system is opened or closed, the temperature change of the inner wall surface of the inner heat preservation is slower than the temperature of the inner wall surface of the sandwich heat preservation.

C. Heating Load Removal Rate

Fig. 10 shows comparison of the percentage increase in total heating load removed and the percentage of energy stored in the radiation and air system during heater turn-on. In the radiant floor, the amount of cooling is 49%, and the heat storage capacity of the enclosure is 51%. In the whole air system, the cooling capacity is 54% and the heat storage is 46%. It can be seen that the radiant floor heating system has a heat storage capacity of 10.9% higher than that of the all-air system, and the heat is continuously released after the system is turned off, which can regulate the electric load.

IV. Conclusion

In this paper, the state space method is used to simulate and compare the difference of indoor thermal environment between radiant floor and all-air heating system when intermittent energy is used, and the reasons for the difference of indoor thermal environment are analyzed. The main conclusions are as:

1. The indoor air temperature response rate of the all-air system is greater than that of the radiation system;
2. In the case of the same indoor set temperature, the all-air system will consume less heat in the intermittent energy mode.
3. The heat storage of radiant floor is 10.9% larger than the all-air system, which has the effect of regulating electric load.

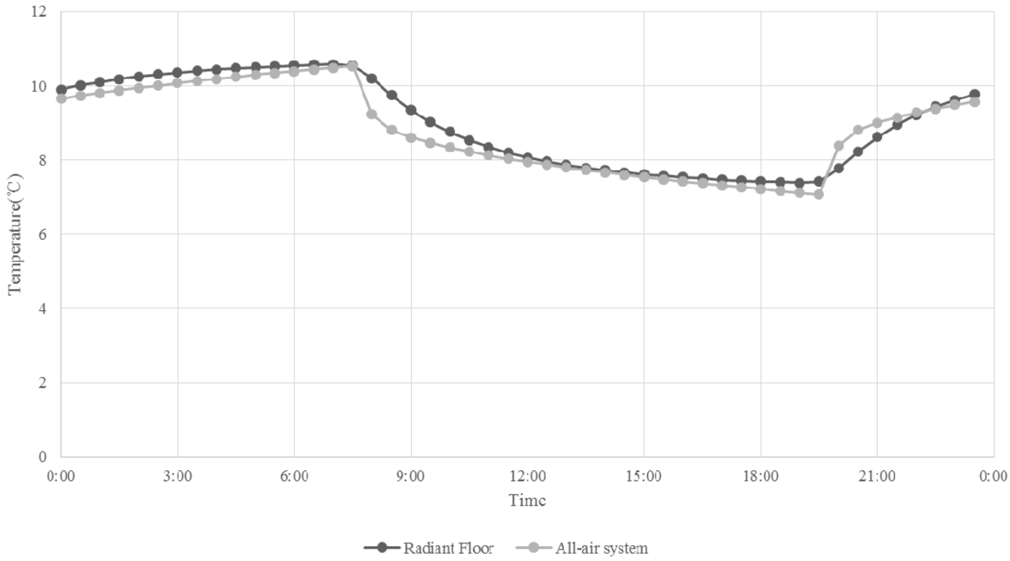

Fig. 7 Window Temperature of RF and AA System

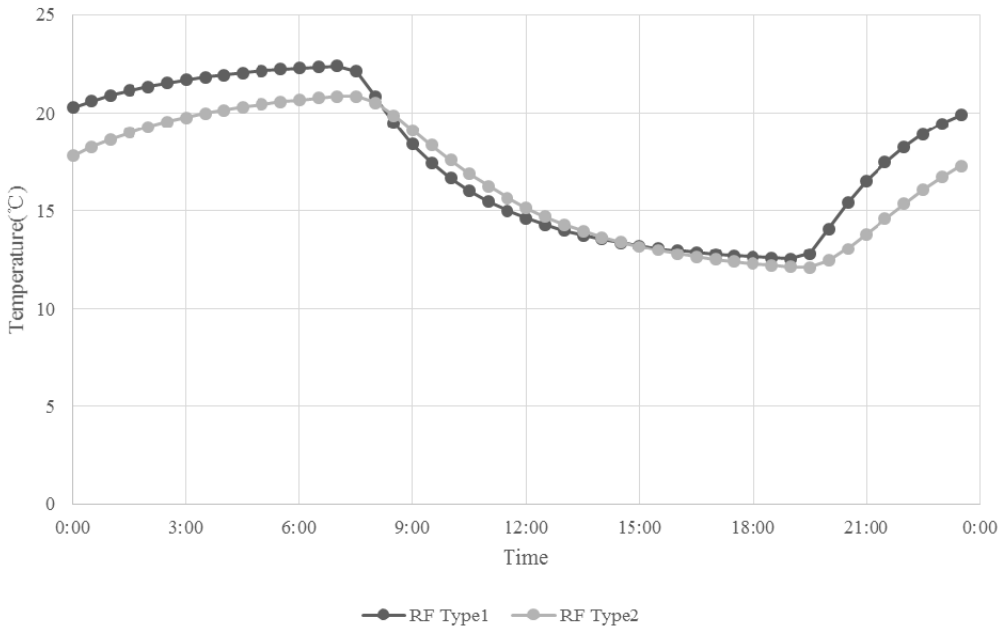

Fig. 8 Temperature of Type 1 and Type 2 Wall in RF System

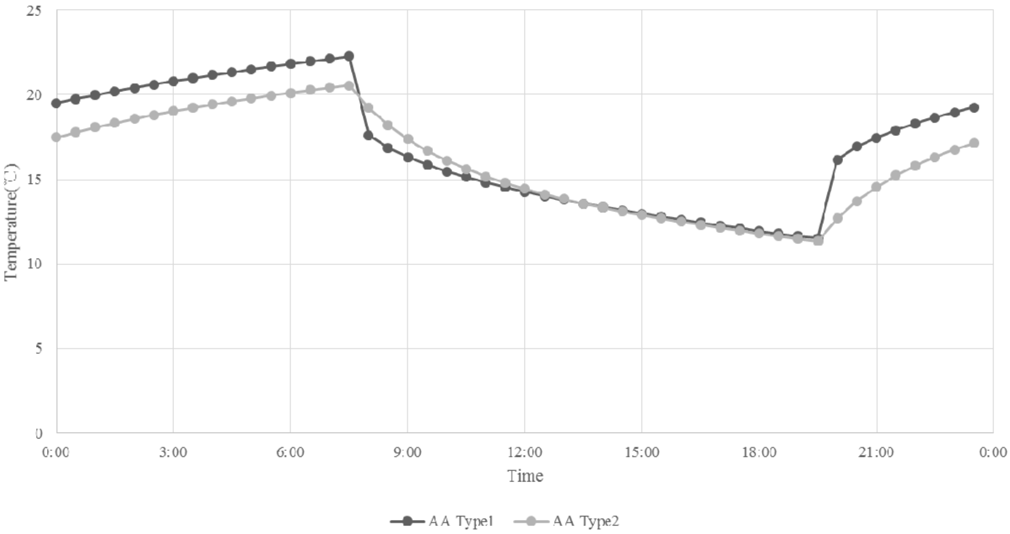

Fig. 9 Temperature of Type 1 and Type 2 Wall in AA System

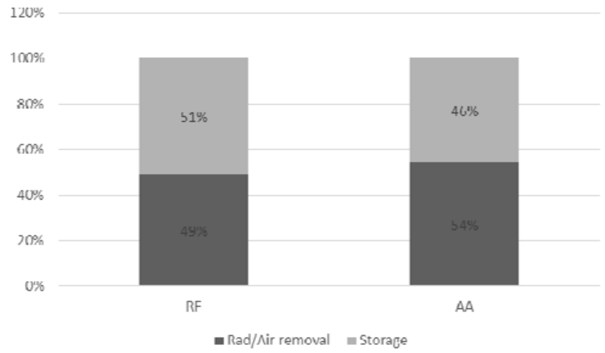

Fig. 10 Percentage of the Heating Load Removal in Heating Source

4. Different insulation constructions will affect the wall temperature of the enclosure and affect the indoor air temperature. In the all-air system, the wall temperature difference of the different wall insulation structures is particularly obvious. Strengthening the insulation of the wall under the conditions of the all-air heating system contributes to the stability of the wall temperature and the indoor temperature.
5. When the system is opened or closed, the temperature change of the inner wall surface of the inner heat preservation is slower than the temperature of the inner wall surface of the sandwich heat preservation.
6. The smaller the heat capacity of the wall, the smaller the difference between the radiant floor and the indoor thermal environment of the all-air heating system.

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