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Research on control methods of roof radiant cooling system

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Abstract

Taking the capillary ceiling radiation air conditioning system in radiation cooling Laboratory of comprehensive experimental building in Shandong Jianzhu University as an example, research the two different control methods which are room temperature control and water temperature control. The roof cooling model was established by using TRNSYS simulation software, two typical summer days were selected to explore the stability of the room temperature and the supply and return water temperature, research the comfort of human body and system energy consumption under two control methods. The results show that the indoor temperature of the two control methods can be stable at the design temperature of 27℃ under outdoor high temperature environment in summer. When the maximum outdoor temperature does not exceed 30℃, the temperature stability of the room temperature control method is better, the comfort of the two control methods can meet the requirements, but the water temperature control method is more comfortable. The room temperature control method is 20% ~ 25% energy saving than the water temperature control method in the two typical selected days, and is 40.5% energy saving in the whole cooling season.

*Keywords:*Roof radiant cooling system; control method; TRNSYS, system energy consumption

1. Introduction

As a fast cooling mode in recent years, radiant cooling system has the advantages of high comfort and less indoor space[1].Its end equipment are arranged indoor and use radiation model to cool indoor. Combined with

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displacement ventilation[2], it creates comfortable and healthy working environment for indoor environment[3]. At present, domestic research mainly focuses on the internal heat transfer, cooling performance and condensation prevention of radiant panels. There are few studies on the regulating performance of radiant cooling system[4], and reasonable control strategy can solve the problem of radiation cooling system easy condensation, poor cooling capacity, hot inertia and other issues[5]. In this paper, take cooling experiment station of the first domestic radiation building assembly type, passive, ultra low energy consumption building as an example, based on TRNSYS software, the system model of the roof radiant cooling system based on air cooled heat pump unit was established to explore the influence of different control strategies on indoor temperature and cooling capacity. According to the PMV-PPD index, the comfort of people under different control strategies is studied. Finally, the energy consumption of the system is analyzed, and the results can be used as reference to improve the regulating performance of the radiant cooling system.

2. A survey of radiation cooling laboratory

2.1. Construction profiles

The comprehensive experimental building in Shandong Jianzhu University was built in Mar. 2017, consists of 6 floors, with a construction area of 9679.1m^2, a building height of 23.96m, cold load index is 39W/m^2, and heat load index is 14.5W/m^2.The Radiation Cooling Laboratory is located on the northeast side of the 6th floor, with an area of 46.5m^2 and a height of 3.7m. The walls of the East, South and North are exterior wall, the heat transfer coefficient of exterior wall and roof is 0.17W/(m^2.K), the west is inner wall, the coefficient of heat transfer is 1.02W/(m^2.K), and the heat transfer coefficient of the ground is 0.57W/(m^2.K). Internal disturbance setting value is: the number of laboratory is 5 people, according to the per capita construction area of 10m^2/ d to estimate; lighting power density value is 9W/m^2; electrical equipment power density is 15.0W/m^2.

2.2. Radiation roof structure

Radiant cooling laboratory, using prefabricated radiant ceiling cooling system at the end, the capillary metal of common prefabricated module instead of the plastic coil system, through the capillary internal heat exchange system and metal diffusion plate forming cold radiation surface, for the elimination of indoor sensible heat cooling load. Radiation ceiling module with light steel keel fixed, radiation ceiling module structure shown in Figure 1.

The capillary in radiant roof is made of PP-R with a size of 4.3 × 0.8mm (outer diameter × wall thickness), and the distance between tubes is 20mm. The metal ceiling module adopts 10 pieces of 1200 × 600mm (L × W) and 10 pieces of 1800 × 600mm (L × W) porous metal plates. The radiation end of this structure is low in thermal inertia, rapid cooling, large output of cold volume per unit area, high heat exchange efficiency[6], integrated decoration and environmental regulation functions.

2.3. Radiation roof structure

Radiation cooling experimental system is shown in Figure 2.

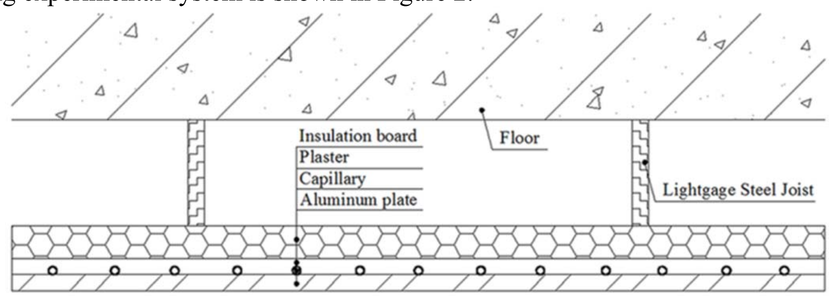

Fig.1.Schematic diagram of the structure of the radiation ceiling module.

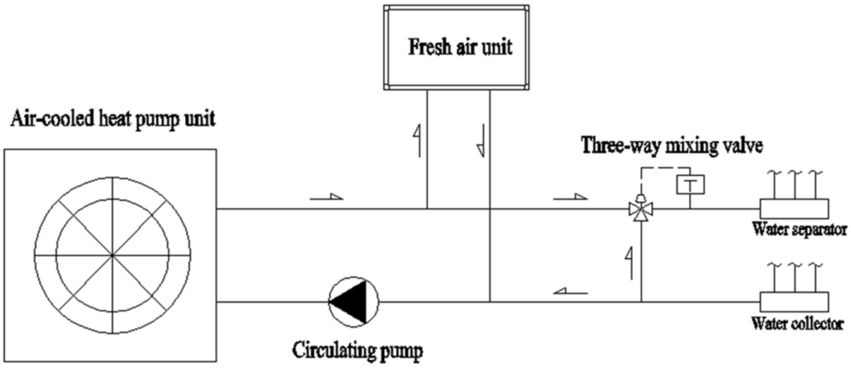

Fig. 2.Flow chart of the system.

Air conditioning system cold source is air-cooled heat pump unit, in summer, the heat pump unit produces 7℃ of chilled water, after entering the new air unit, heating up to 12℃[7]. In order to avoid condensation, the capillary about 20℃ backwater and 12℃ water supply in the three-way mixing valve in accordance with a certain percentage Mixed, mixed to 16℃~18℃[8], and then sent to the end of the capillary heat exchange.

3. Modeling system construction

Based on Figure 2， the TRNSYS simulation model of air source heat pump-roof radiant cooling air conditioning system is constructed, for the characteristics of air source heat pump-roof radiant cooling air conditioning system, the system should include air-cooled heat pump unit, fresh air unit, water pump, water distributor, water collector, PID controller, etc. The TRNSYS simulation model of air source heat pump ceiling radiant cooling air conditioning system is established, as is shown in Figure 3.

There are two ways to control the radiation cooling in this paper: (1)Room temperature control: The temperature of the water supply does not change with the outdoor air parameters. When the indoor temperature is lower than 26.5℃ or the water supply temperature is lower than the dew point temperature+1℃, the formula in the calculator is used: xinhao=min{ge(shiwen,26.5),ge(gongshuiwendu,ludianwendu+1)}.Provide the signal for the stop of the pump, and close the cooling pipe of the radiation. When the room temperature is higher than 26.5℃, and the water supply temperature is higher than the dew point temperature +1℃, the water pump starts operation; (2) Water temperature control: Set the capillary water supply temperature to dew point temperature+1℃[9], through the Type33e module to calculate the dew point temperature of the room, when the outdoor air parameters or indoor load changes caused by indoor dew point temperature changes, the corresponding water supply temperature changes. The PID controller is used to adjust the flow of the water feeder to the water collector -1, which changes the mixing ratio of the three-way valve, thus changing the water supply temperature of the capillary tube.

4. Simulation results and analysis

4.1. Temperature analysis

According to the TRNSYS simulation model set up earlier, the influence of two kinds of radiant cooling control methods on the room temperature and cooling capacity was simulated. The two typical summer days of the simulation are June 18 (4063h ~ 4077h) and some period of July 24 (4927h ~ 4941h). Figure 4 (a) and (b) show the temperature profiles of the two control methods, which are room temperature control and water temperature control, at a certain time period (4063h ~ 4077h) in June.

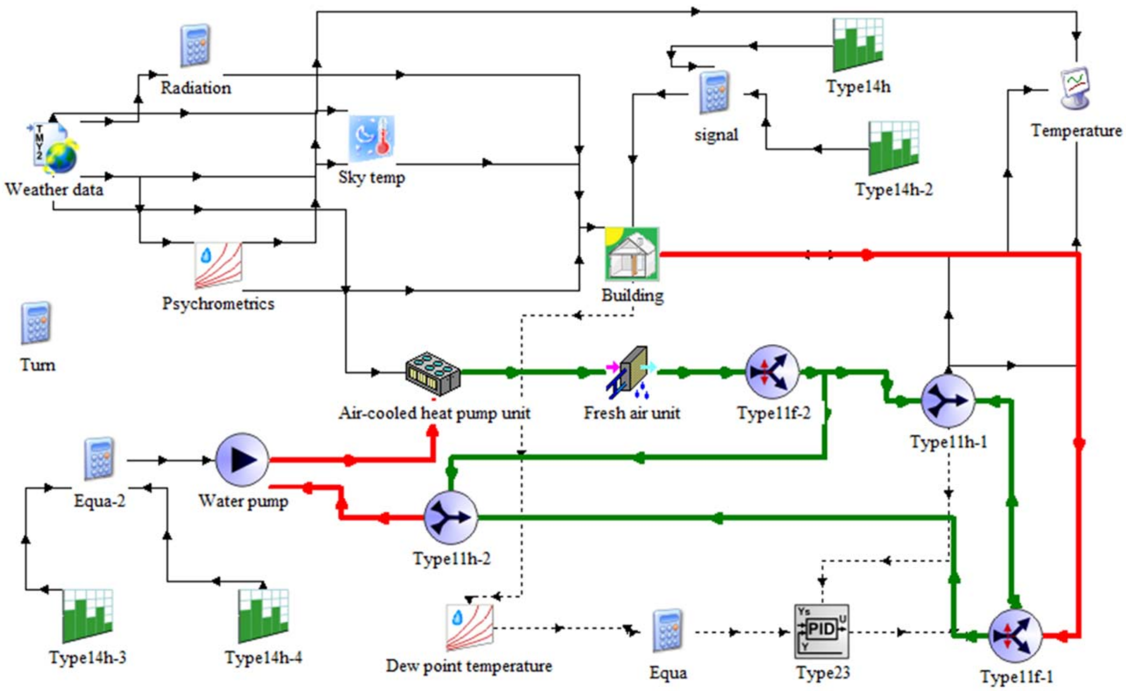

Fig.3.TRNSYS simulation model of air source heat pump ceiling radiant cooling airconditioning system.

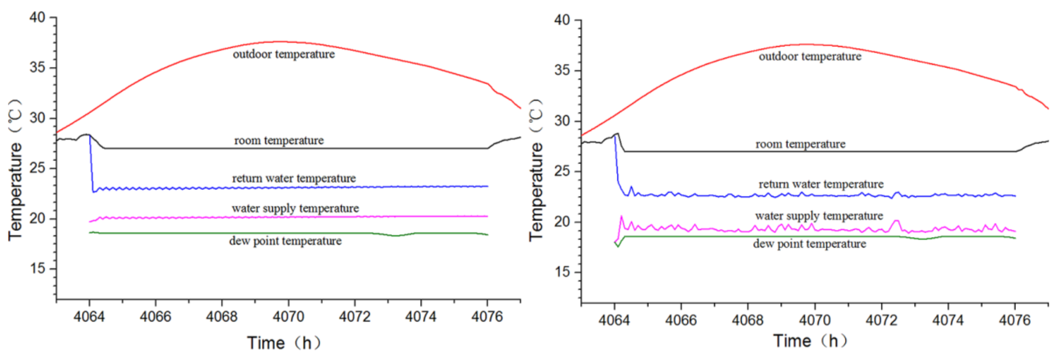

Fig.4.(a) Temperature curve by room temperature control; (b) Temperature curve by water temperature control.

As you can see from the graphs，In the 4064 hour，the radiant cooling system starts to run. Adopting room temperature control method and water temperature control method,room temperature is steadily in 27℃ after the radiation system starts up to 24min and 16min respectively, that means at this moment, thehysteretic quality of room temperature control is greater than that of water temperature control. As the outdoor temperature gradually rises, room temperature control method is better for the stability of water supply and return temperature,the water supply temperature keeps in 21℃and the return water temperature keeps in23.2℃.Bycontrast, the disadvantages of PID controller's volatility are revealed through adopting water temperature control method, the water supply temperature has changed greatly(between 19.1℃~ 20.2℃),however, because water temperature control method is based on flow control, the room temperature did not fluctuate. Adopting room temperature control method, the supply and return water temperature difference is 3.1℃,but adopting water temperature control method, the supply and return water temperature difference is 3.7℃ or so, therefore the use of room temperature control is more conducive to the cooling method of small temperature difference but big traffic, when Indoor cooling load is same .

Figure5 (a) and (b) respectively indicate that the temperature curves of the two control methods are controlled by room temperature control and water temperature control at a time in July 24 (4063h ~ 4077h).

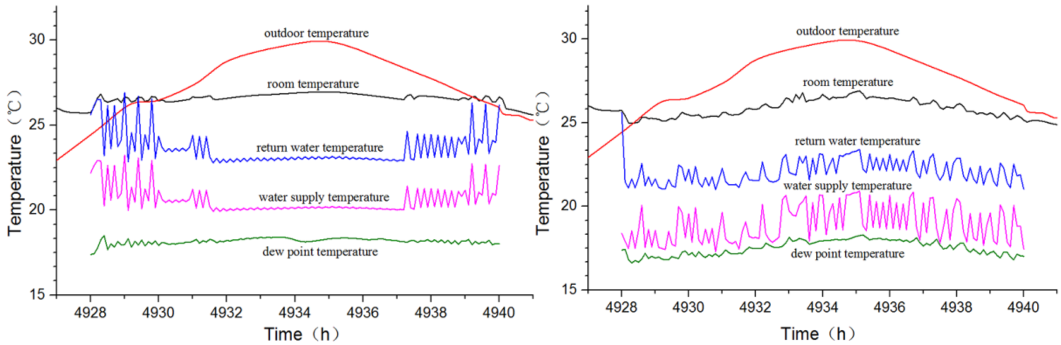

Fig.5.(a) Temperature curve by room temperature control; (b) Temperature curve by water temperature control.

As you can see from the graph, the radiant cooling system starts to run in 4928 hour. Adopting room temperature control method , after the room temperature goes through the initial shock, the final stable between 26.6℃~ 26.9℃, while adopting water temperature control method ,room temperature rises as outdoor temperatures rise, from the initial 25℃ shaking rise to 27℃.Adopting room temperature control method , in the radiation cooling system for two hours(4028h～4030h),if the room temperature is lower than 26.5℃,pump will be out of operation, and room temperature will decrease, which will cause the pumps reciprocating start-stop and lead to the initial water supply temperature fluctuates greatly. After 4030 hour, room temperature is above 26.5℃,and the pump has been working, The water supply temperature is more stable. For the water temperature control, the disadvantages of PID controller's shock and jump will lead to the water temperature fluctuation greatly.

4.2. Comfort analysis

Figures 6 (a) and (b) represent the variations of PMV and PPD over time in two control methods during the period of June 18 (4064h ~ 4076h) and the periods in July 24 (4928h ~ 4940h).

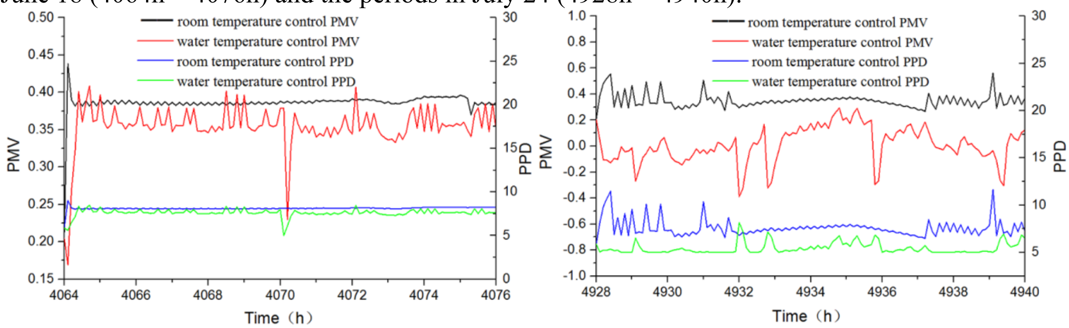

Fig. 6.(a) The PMV and PPD of June; (b) The PMV and PPD of July.

In Figure 6 (a) can be seen during in June 18 (4064h~4076h), when the outdoor temperature is high, the indoor temperature maintained at 27℃, and the PMV of two control methods mostly between 0.35~0.4, PPD is about 7.5%; In Figure 6 (b) can be seen during in July 24 (4928h~4940h), when the maximum outdoor temperature does not exceed 30℃,the PMV is between 0.3~0.5, and the PPD is between 7%~10% under room temperature control method; the PMV is between -0.4~0.3, and the maximum of PPD is about 5%, which exceeds 7% at some time under the water temperature control method.

In these two periods, PMV and PPD indicators meet the ISO7730[10]recommended value, but no matter on the PMV index or PPD index the thermal comfort of water temperature control method are better than the room temperature control method.

4.3. Energy consumption analysis

Figure 7 (a) (b) show that the energy consumption of the two control methods in June 18 (4064h~4076h)，Figure 8 (a) (b) show that the energy consumption of the two control methods in a certain period of time (4928h ~ 4940h) in July. Figure 9 (a) (b) shows that the energy consumption of the two control modes during the cooling season (3240h ~ 6192h). Among them, the other energy consumption consist of the pump energy consumption and the new wind machine.

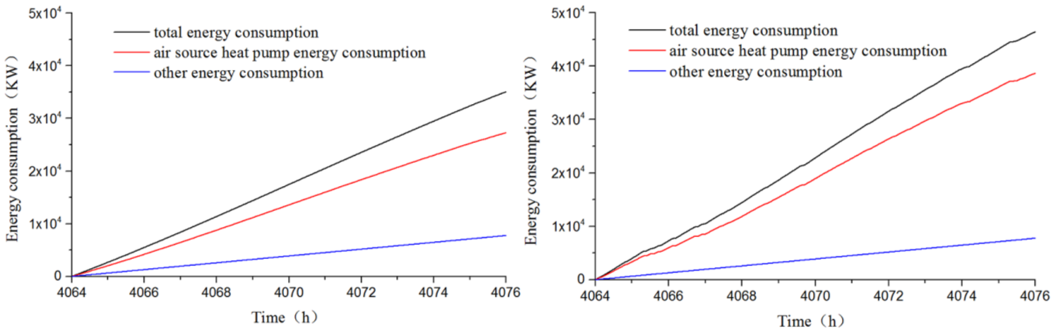

Fig.7.(a) Energy consumption of room temperature control in June18; (b) Energy consumption of water temperature control in June 18.

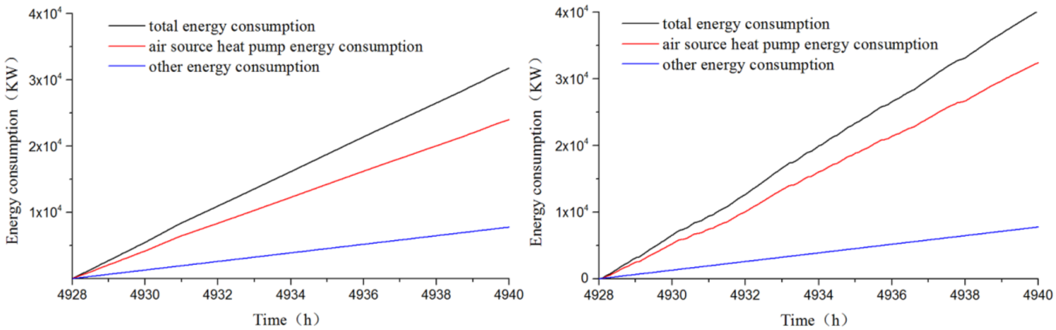

Fig.8. (a) Energy consumption of room temperature control in July24; (b) Energy consumption of water temperature control in July 24

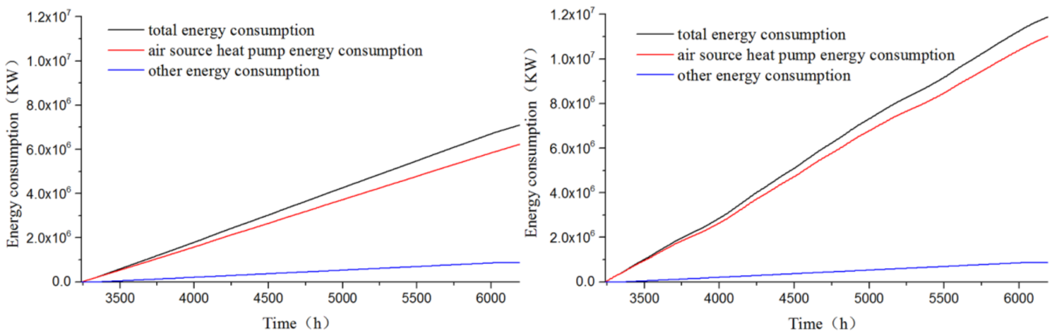

Fig. 9.(a) Energy consumption of room temperature control in cooling season; (b) Energy consumption of water temperature control in cooling season.

5. Conclusion

Through analyzing the temperature, comfort level and energy consumption of the two control methods of the roof radiant cooling system, the conclusions are as followed:

Adopting room temperature control method, the stability of room temperature and water supply and return temperature are better than adopting water temperature control method, and it is more conducive to the use of the cooling method of small temperature difference but big traffic.

Adopting water temperature control method, indoor temperature can reach the control temperature more quickly, when outdoor temperature is high.

Both control methods meet the requirements of PMV and PPD, the comfort level of water temperature control method is better than room temperature control method.

In two typical days, compared with water temperature control method, room temperature control method can save energy 20%~25%, and it can save energy 40.5% in the total refrigeration season, adopting room temperature control method is more energy efficient.

Acknowledgement

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