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Experimental Study on the Combined Heating of Phase-Change Water Tank and Different Terminal Cooling Equipment

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Experimental Study on the Combined Heating of Phase-Change Water Tank and Different Terminal Cooling Equipment

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Abstract—In this paper, we set up a solar energy-phase change heat storage system and experimental study on the matching of the phase-change tank and three different terminal cooling equipment. Among them, phase-change water tank is used as heat source, meanwhile, radiator, heater and capillary as terminal cooling equipment. When radiator the terminal is radiator, the indoor temperature is difficult to meet the heating temperature requirements. When the terminal is heater, the indoor temperature can meet the requirements of heating temperature. However, the longitudinal distribution and lateral distribution of indoor air temperature are unevenly distributed and affect the thermal comfort of human body. When the terminal is capillary tube, the indoor temperature maintain at a high temperature and the temperature is satisfied with the thermal comfort of human body. Therefore, the capillary tube as the terminal cooling equipment is more advantageous of matching with the phase-change tank.

1. Introduction

Phase change material has the advantages of high heat storage density, small heat storage device, small change of temperature in the process of phase change and large latent heat, and the phase change temperature can be determined according to the needs of the system. Because of these advantages, it realizes the transfer and utilization of solar energy in time and space, so as to improve the utilization efficiency of energy. At present, the research on phase change heat storage materials is extensive in the world. Fath[1] conducted an experimental study on the casing type phase change heat storage device filled with phase change materials in the annular gap, and analyzed the influence of factors such as the geometric structure of the heat storage device on the accumulated heat storage and heat transfer rate. Nagano[2] et al. experimentally studied the heat storage and release process of a vertical tubular phase change heat storage device equipped with a phase change material inside the tube, and the results showed that the heat storage capacity of the phase change material could reach 2~2.5 times that of the sensible heat storage with water as the heat storage medium. Bansal NK and Buddhi DC[3] established the coupled heat transfer model of the phase change heat storage device and the solar collector, and concluded that the direct coupling of the phase change material and the solar collector had better heat transfer performance. Although the research on solar energy phase change heat storage technology started late in China, the research progress is rapid and many remarkable achievements have been made in recent years. Li Huixing[4] built an air source heat pump and phase change water tank heating system, and studied the heat storage and release performance of the phase change heat storage system. Wang Xi[5] optimized the size of the phase change heat storage unit by designing a kind of cylindrical stacked bed phase change water tank. Liang Fei[6] et al. built a heat storage system with solar energy as the main heat source and electric heating as the auxiliary heat source. They tested the temperature variation of the immersion phase change tank under two different heat storage conditions of solar energy and electric heating, and obtained the heat storage temperature variation characteristics of the phase change tank. The heat storage performance of phase change water tank during the heat storage process is also analyzed.

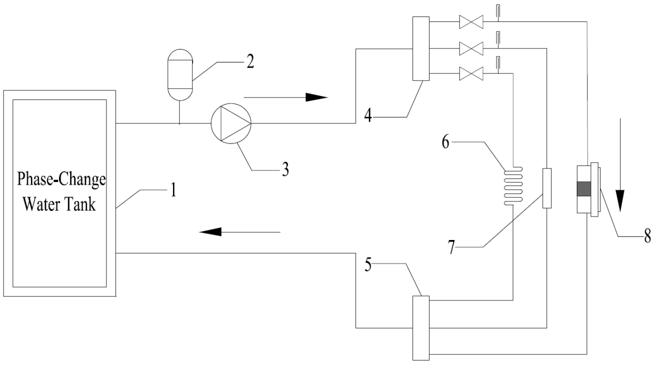
In summary, there have been extensive studies on the use of phase-change materials in the field of heat storage and solar heating systems, but there is almost no research on the matching between phase-change water tank and terminal cooling equipment for joint heating. Phase change water tank can not maintain a constant water supply temperature as a finite heat source and the design of the end cooling equipment has the requirements of water supply temperature. Therefore, there will be a matching problem when the end cooling equipment and phase change water tank are combined for heating. In order to make better use of the heat stored by the phase-change water tank and ensure the heating effect, a solar-phase change heat storage heating system was built in this paper. The matching property of the joint heating between the phase-change water tank and the terminal heat dissipation equipment was studied, and the optimal terminal heat dissipation equipment matching the solar-phase change heat storage heating system was selected.

2. Experimental system and measuring points

2.1 Experimental system

The system used in this experiment is the phase-change heating subsystem of the solar-phase change heat storage heating system, as shown in Fig.1. The system is mainly composed of phase change water tank, circulating water pump, constant pressure tank and end cooling equipment (including capillary, radiator and heater). The system is provided by the constant pressure tank to ensure the stability of the pressure of the system. The high temperature water from the phase-change tank is powered by the circulating water pump and enters the room. The cooling water returns to the phase-change tank after heat exchange with the phase-change material and enters the next exothermic heating cycle.

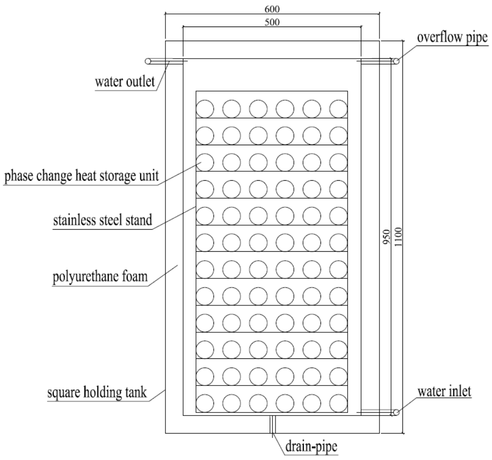
The heating room is 3.4m long from east to west and 3.0m wide from north to south. The total indoor area is about 10.2m^2. For the end heat dissipation equipment, the radiator is installed in the middle line of the north wall by the north wall, the heater is installed in the middle line of the south wall by the south wall, and the capillary is tiled in the whole room. Different end cooling devices are switched by the opening and closing of corresponding valves.



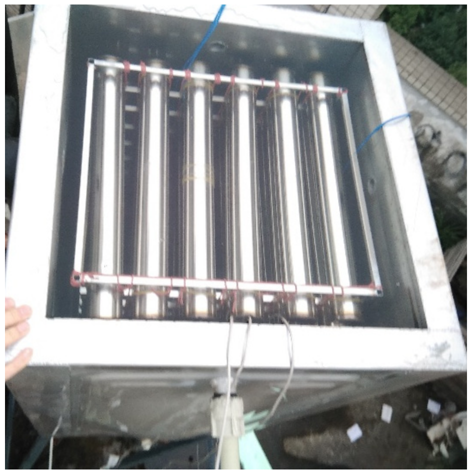
Which, 1-Phase change water tank, 2-Constant pressure tank, 3-Water pump, 4-Water separator, 5-Water collector, 6-Capillary tube, 7-Radiator, 8-Heater.

Fig.1 Diagram of phase change heating system

In this experiment, the phase change water tank was used as the heat source for heating operation. PCM-50 phase change material was selected as the heat storage material for the phase change water tank. The phase change temperature was 50℃, and the enthalpy value of phase change was 260.11kJ/kg. The phase change water tank is composed of phase change heat storage unit, stainless steel fixed bracket and square insulation water tank. The structure is shown in Fig.2. Among them, there are 72 phase change heat storage units. Stainless steel cylinder is used as the packaging shell, the diameter is 50mm, the length is 450mm, the single cylinder can encapsulate the phase change material 0.685kg, the total mass of encapsulating the phase change material is 49.32kg. The phase change heat storage unit is fixed by the customized stainless steel bracket with 12 layers in total. Each layer is fixed with 6 groups of phase change heat storage units. The distance between the heat storage units is 25mm. The design size of the water tank is 500mm×500mm×1000mm, and the effective volume is 235.8L.



(a) Profile of phase change tank

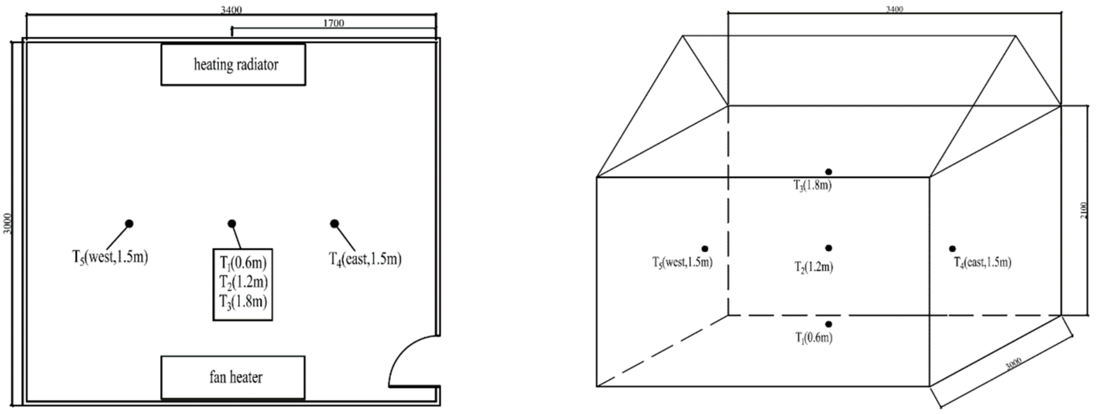


(b) Field diagram of phase change tank

Fig.2 Phase change water tank

2.2 Arrangement of experimental measuring points

In the heating experiment, in order to show the indoor temperature change of the heating room, a total of 5 temperature measuring points were arranged in the heating room, as shown in Fig.3 and Fig.4. In order to study the longitudinal difference of indoor temperature distribution, three temperature measuring points T_1, T_2 and T_3 were placed on a vertical line at 0.6m, 1.2m and 1.8m from the ground, respectively. In order to study the horizontal difference of indoor temperature distribution, three temperature measuring points, T_4, T_2 and T_5, are arranged on the central line of the east and west walls. The distance between the measuring points is 0.85m and the distance from the ground is 1.2m. The city (Chengdu) in this experiment belongs to the hot summer and cold winter area. According to the "Energy Saving Design Standard for Residential Buildings in Hot Summer and Cold Winter Areas", the design temperature of indoor thermal environment for heating in winter is set at 16~18℃ for bedrooms and living rooms. Therefore, the heating effect was evaluated at room temperature 16℃ and 18℃ in this paper. In the heating process, the multi-channel temperature heat flow tester is used to record the temperature changes of all temperature measuring points.



a) Layout plan of indoor temperature measuring points

b) Stereo diagram of indoor temperature measuring points

Fig.3 Arrangements of indoor temperature measurement points in the heating room

3. Experimental study on heating of phase change water tank combined with different terminal cooling equipment

3.1 Experimental study on phase change water tank and radiator heating

The outdoor average temperature is 9.2℃ and the indoor initial temperature 12.5℃ while phase change water tank combined with radiator heating period. The change of room temperature of phase change water tank combined with radiator heating is shown in Fig.4. It can be seen that: (1) when the radiator is used as the end radiator, the indoor temperature is difficult to reach the minimum heating temperature (16℃). The reason is that the heat resistance of the cast iron radiator is larger, and the water supply temperature is higher. The phase change water tank is a limited heat storage source, and the water temperature is higher in the water tank at the beginning of heating. It can still meet the requirements of radiator water supply and can achieve the requirements of indoor heat supply. But it can not meet the radiator water supply temperature requirements and provide little or no heat for the indoor heat with the heat supply tank water temperature is falling which results in a slow rise in indoor temperature or even no longer heating. (2) when the radiator is used as the end heat dissipation equipment, the room temperature heating reaches 16℃ after 151 minutes, and only lasts for 19 minutes, and the indoor temperature can not reach 18℃.

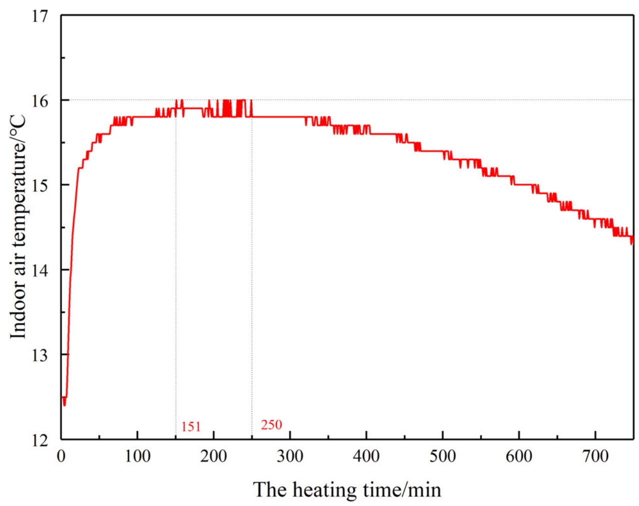


Fig.4 phase change water tank combined with radiator heating indoor temperature

After experimental analysis, phase change water tank combined with radiator heating, heat loss in the pipeline and can not be effectively transported to the room. It can not meet the temperature requirements of cast iron radiator water supply and indoor temperature is difficult to meet the heating requirements. Therefore, when the phase change water tank is used as a heat source for heating, it is not appropriate to use cast iron radiator as the end heat dissipation equipment.

3.2 Experimental study on phase change water tank combined with heater

The average outdoor temperature is 9.5℃ and the initial indoor temperature is 12.5℃ during the heating period of phase change water tank and heater. The average temperature variation in the heating room of the phase-change water tank combined with the heating fan is shown in Fig.5. It can be seen that: when the heater is used as the terminal heat dissipation equipment, the indoor temperature rises faster. After 7 minutes of heating, the indoor average temperature rises from 12.5℃ to 16℃. After 9 minutes, the temperature reaches 18℃. In addition, the heater is used as the terminal heat dissipation equipment to maintain the indoor average temperature above 16℃ for about 888 minutes (about 14.8h), and the indoor average temperature above 18℃ for about 587 minutes (about 9.8h).

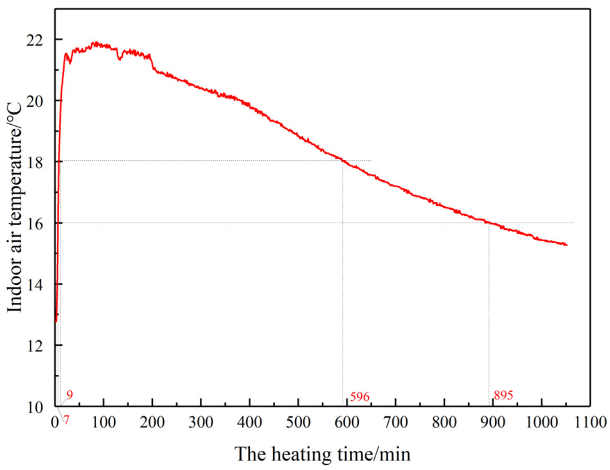


Fig.5 phase change water tank combined with heater indoor temperature

The existence of the heater will have an impact on the indoor air distribution in the reason of the heat transfer process between the heater and the room belongs to the mechanical forced convection heat transfer. In order to study whether heating by air heater affects indoor temperature distribution, longitudinal and transverse measurements of indoor temperature were also carried out during the experiment of phase change water tank combined with air heater heating. The measurement points T_1(0.6m), T_2(1.2m) and T_3(1.8m) reflect the longitudinal distribution of indoor temperature. The longitudinal distribution of room temperature is shown in Fig.6. Measurement points T_4(east), T_2(middle) and T_5(west) reflect the horizontal distribution of indoor temperature, and the horizontal distribution of room temperature is shown in Fig.7.

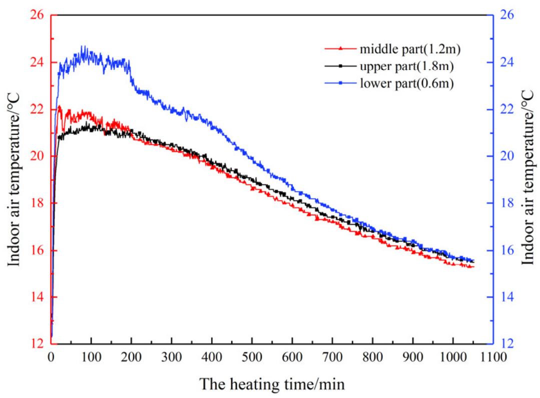


Fig.6 Longitudinal distribution of room temperature

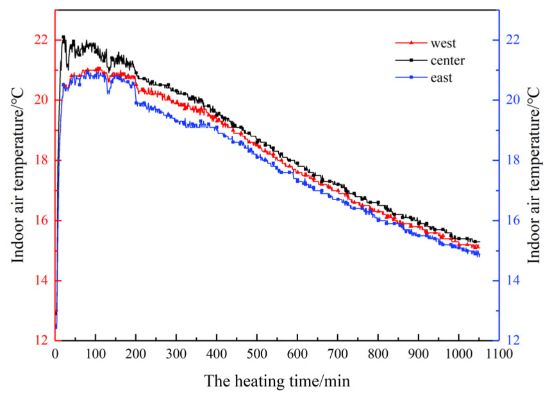


Fig.7 Transverse distribution of room temperature

As can be seen from Fig.6 and Fig.7, the phase change water tank combined with the heater can achieve a higher indoor temperature and maintain a longer time, but the indoor horizontal and longitudinal temperature distribution is uneven. In terms of longitudinal temperature distribution: due to the downward direction of the air outlet of the heater in this experiment, the indoor lower air temperature rises faster and is much higher than the upper and middle air temperature. The average temperature difference is about 1.2℃, and the maximum temperature difference is as high as 3.6℃. Moreover, the uneven distribution of longitudinal temperature in the middle period before heating is obvious. The temperature in the upper and middle layers of the room is relatively close, but there is still a temperature difference of 0~1.6℃. In terms of horizontal temperature distribution, the air temperature in the center of the room near the air outlet of the heater is greater than the air temperature on the east and west sides of the room. In the whole heating period, the average temperature difference between the center and the air on the east and west sides is about 0.6℃, and the maximum temperature difference is 2.1℃. Similar to the longitudinal temperature distribution, the uneven distribution of transverse temperature is more obvious in the middle period before heating.

Through the analysis of the heating experiment of phase change water tank combined with heater, it can be seen that the indoor air can reach a higher temperature by using the heater as the terminal cooling equipment, which can meet the heating temperature requirements. However, the indoor air temperature distributes unevenly in longitudinal and transverse directions, which affects the thermal comfort of human body. Therefore, the heating fan combined with phase change water tank is not suitable for places with high requirements for comfort, but it can be used for plants and workshops with low requirements for comfort.

3.3 Experimental study of phase change water tank combined with capillary heating

During the phase change water tank combined with capillary heating, the indoor initial temperature was measured at 11.5℃ and the outdoor average temperature was 8.1℃. The variation of indoor average air temperature is shown in Fig.8. It can be seen that: (1) the highest indoor temperature is higher, about 20℃, when phase change water tank is used as a heat source,. (2) when the heating is above 33 minutes, the indoor temperature rises to the minimum heating temperature of 16℃. After 640 minutes, the indoor temperature drops to below 16℃, a total of 607 minutes, about 10.12h. (3) when the heating time exceeds 55 minutes, the indoor temperature rose to 18℃. After 418 minutes, the indoor temperature slowly dropped to below 18℃, the room temperature maintained above 18℃ for 363 minutes, about 6.05 h.

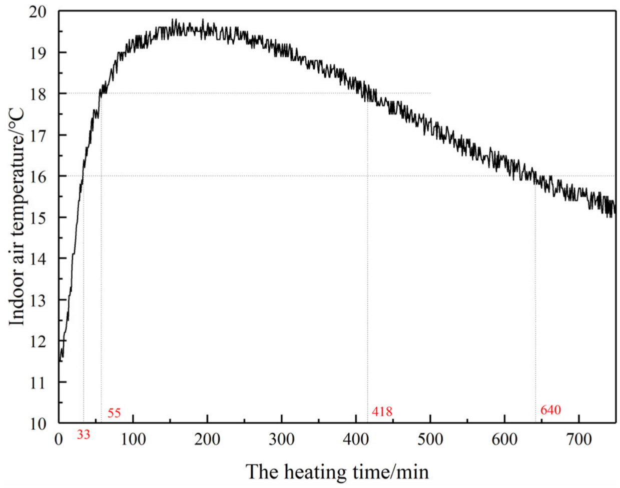


Fig.8 Average indoor temperature of phase-change water tank heating

As the terminal heat dissipation equipment of phase-change water tank heating system, capillary can make the indoor temperature reach the minimum indoor heating temperature (16℃), and the time is short. The time of maintaining the indoor temperature at 16℃ can reach 607 minutes (about 10.12h), and the time of maintaining the indoor temperature at 18℃ is about 363 minutes (6.05 h). In addition, because the capillary tube is laid in the whole room, the heat is transferred from the bottom to the top, and the horizontal distribution of indoor temperature is more uniform. Through the measurement and analysis of the longitudinal temperature, it can be seen that the indoor longitudinal average temperature difference is 0.23℃ and the maximum temperature difference is 0.8℃ during the heating period when the capillary is used as the terminal heat dissipation device of the phase-change water tank heating system. The longitudinal distribution of indoor temperature is also relatively uniform.

To sum up, as the terminal heat dissipation equipment of the phase-change water tank heating system, capillary can not only ensure the indoor temperature to maintain a high temperature, but also make the indoor temperature distribution uniform, and meet the thermal comfort of human body. Therefore, in the solar phase change heat storage heating system, the phase change heat storage tank and capillary matching have more advantages.

4. Conclusion

In the operation process of the solar phase change heat storage heating system, the following conclusions can be drawn by comparing the phase change water tank and ordinary water tank heating and studying the matching of different end radiators used in the solar phase change heat storage heating system:

(1) when the radiator is used as the end heat dissipation equipment, the heat loss is in the pipeline and can not be effectively transported to the room. It can not meet the water supply temperature requirements of cast iron radiator, and the indoor temperature is difficult to meet the heating temperature requirements. Therefore, when the phase change water tank is used as a heat source for heating, it is not suitable to use cast iron radiator as the end heat dissipation equipment for heating.

(2) when the heater is used as the end heat dissipation equipment, the indoor air can reach a higher temperature, which can meet the heating temperature requirements. However, the indoor air temperature distributes unevenly in longitudinal and transverse directions, which affects the thermal comfort of human body. Therefore, the heating fan combined with phase change water tank is not suitable for places with high requirements for comfort, but it can be used for plants and workshops with low requirements for comfort.

(3) When the capillary is used as the terminal heat dissipation device, the indoor temperature is maintained at a higher temperature and the indoor temperature is evenly distributed to meet the

thermal comfort of human body. Therefore, the phase change heat storage tank and capillary matching has more advantages.

Acknowledgments
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