Energy Proceedings
Vol 42, 2024
ISSN 2004-2965

Comparative Study on Thermal Performance of Novel Terminal Based on Flat Heat Pipes and Traditional Fan Coil and Floor Heating

Yifan Wu[1,3,5†], Hongli Sun[1,4,5†], Naini Zhao[1,5], Zixu Yang[1,3,5], Shuangdui Wu[3,5], Guangming Wang[2*], Wenyuan Wang[2], Borong Lin[3,5]

1 National Engineering Research Center of Building Technology, Beijing, 100029, China

2 China Energy Dadu River Shaping Power Generation Co., Ltd., No. 94, Jingyang Road, Shaping Town, Ebian Yi Autonomous County, Leshan City, Sichuan Province, 614300, China

3 Department of Building Science, Tsinghua University, Beijing 100084, China

4 College of Architecture and Environment, Sichuan University, Chengdu 610065, China
5 Key Laboratory of Eco Planning & Green Building, Ministry of Education, Tsinghua University, China
(*Corresponding Author: Email: gmwangsc@163.com)

ABSTRACT

Low heating load areas require intermittent heating to create a comfortable indoor environment quickly and efficiently, and the indoor thermal environment depends strongly on the choice of indoor terminal units. In this paper, the thermal performances of traditional fan coil and floor heating are analyzed. It shows that the radiant heat transfer shows good thermal comfort, while convective heat transfer shows higher intermittency. Therefore, adding switchable convective heating to radiant heating is an effective improving means. On this basis, a novel terminal based on flat heat pipes is proposed, which can switch flexibly between radiation and convection modes and its thermal performance is analyzed. Furthermore, a comparative experiment between the novel terminal based on flat heat pipes and traditional terminals is conducted. The results show that the effect of the switchable mode of the novel terminal is equivalent to the combined effect of the traditional terminals at the key points of heating capacity and temperature rise. In addition, this novel terminal can initially heat up the space within 20-40 minutes and then stabilize the room temperature in a comfortable range of 18-22 °C. In areas of low heating load, this novel terminal can replace two traditional terminals, thereby reducing system complexity and initial investment.

Keywords: energy conversion in buildings, heat pipe, heat pump, intermittent heating, low energy buildings

NONMENCLATURE

Abbreviations	
FHPs	Flat Heat Pipes
HTHEs	Harmonica Tube Heat Exchangers

1. INTRODUCTION

Climate change is caused by greenhouse gas emissions from buildings, transportation, industry, and other sectors of society, and is now become the greatest threat to humanity. The major component of a building's energy consumption that contributes to greenhouse gas emissions is space heating [1]. It has become imperative to conduct energy-saving studies for space heating applications to reduce greenhouse gas emissions.

The low heating load demand has a wide global scenario, such as the Yangtze River region of China, the southern part of Japan, the southeastern part of the United States, and other regions. Although the heating load of an individual unit in these areas is relatively small, the high population density in a wider region leads to a higher total cumulative heating load. Low heating load areas also have great potential for energy savings. Therefore, it is necessary to conduct thermal performance studies for low heating load demand scenarios.

Intermittent heating fulfills the demand for low heating load areas [2]. The aim of intermittent heating is to create a comfortable indoor environment quickly and efficiently. The thermal performance of heating systems and the resulting indoor environments depend strongly on the choice of indoor terminal units [3]. The existing heating terminals are based on convective and radiant heating. Due to the excellent thermal comfort, radiant heating terminals have been developed rapidly in recent years [4].

However, due to limited surface temperature and surface area, there are certain bottlenecks in the heating capacity of radiant heating terminals [5]. Compared to the radiant heating terminal, the convective heating terminal is an excellent means to achieve efficient and

This is a paper for 15th International Conference on Applied Energy (ICAE2023), Dec. 3-7, 2023, Doha, Qatar.

fast indoor environment creation. Since the convective heating terminal can achieve faster heating therefore it can be used in combination with the radiant heating terminal for the low heating load areas.

As for now, only a few relevant studies are available on the environmental characteristics of intermittent heating. Therefore, this paper proposes a novel terminal based on flat heat pipes for radiant and convective heating. Thermal performance of the traditional terminals and the novel terminal based on flat heat pipe was further compared.

2. MATERIAL AND METHODS

2.1 Design of the novel terminal

The novel heating terminal consists of harmonica tube heat exchangers (HTHEs), serrated fins, cross-flow fans, flat heat pipes (FHPs), and connecting piping. Fig. 1 shows the structural design of the novel terminal. As seen in Fig. 1, the HTHEs are connected to the outdoor unit and act as the condenser for the air source heat pump system to provide heat to the novel terminal. The FHPs and serrated fins are arranged in the front and rear of the HTHEs with silicon grease, respectively. After the heat is transferred from the HTHE to the fins and the bottom of FHPs, the novel terminal radiates heat liberated by the FHPs and convective heat using the cross-flow fans and the serrated fins.

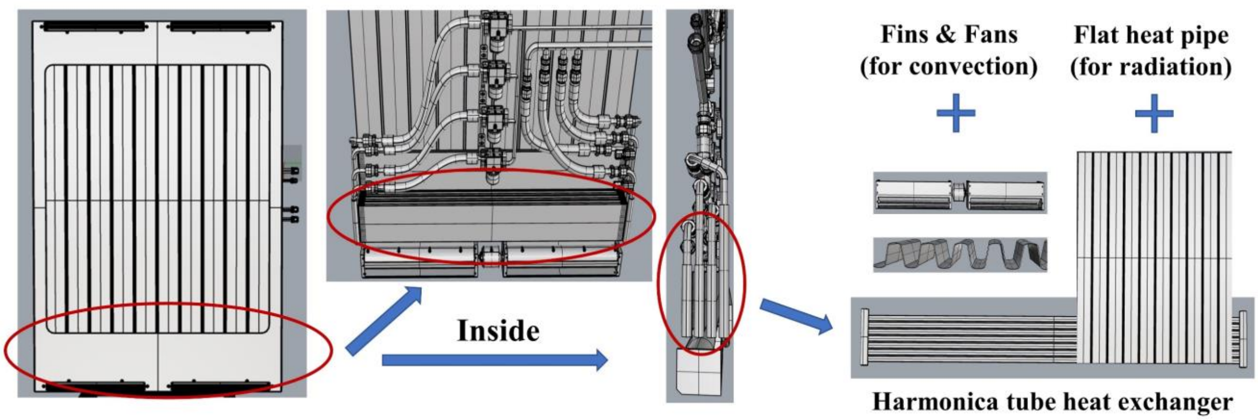

Fig. 1 Structure design of the novel terminal

The FHPs surface was coated with silicon grease to enhance the surface emissivity (~0.95) which improves the radiation heat transfer capacity of the terminal. FHPs were filled with a certain amount of acetone as the working fluid after being evacuated (50% vacuum degree), and the filling rate was approximately 20% based on engineering practices.

Thus, the novel terminal combines and switches between convection and radiation modes to adapt to different stages of thermal demand for intermittent heating under low heating loads, as shown in Fig. 2.

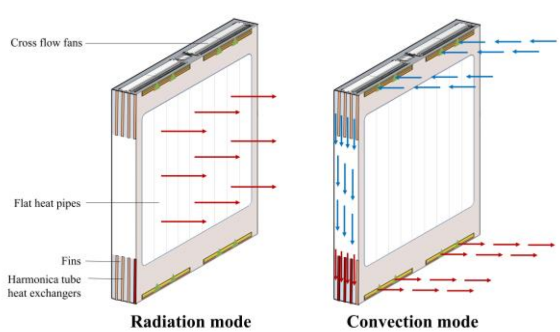

Fig. 2 Radiation and convection modes

2.2 Experimental system

The novel heating terminal is placed in a lab room, and traditional heating terminals including the floor heating and fan coil are placed in another lab room, as shown in Fig. 3 and Fig. 4.

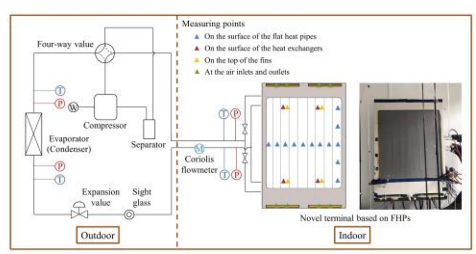

Fig. 3 Experimental laboratory room 1: Measuring points of the novel terminal

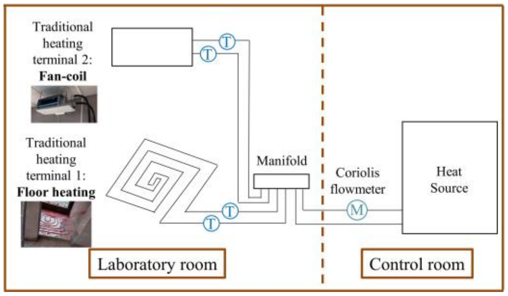

Fig. 4 Experimental laboratory room 2: Measuring points of the novel terminal

For traditional heating terminals, the fan coil provides heat energy by forced convection, while floor heating provides radiative energy. The novel terminal provides optimal heating through both convection and radiation modes similar to the traditional heating terminals. Experiments on the novel and traditional heating terminals were conducted simultaneously in the experimental laboratory rooms to record the heating capacity of the terminals and the rise in ambient temperature.

The temperature and pressure sensors were arranged at the inlet and outlet of the evaporator and condenser in the novel terminal, respectively, to obtain the enthalpy of the refrigerant. R134a was used as a refrigerant in the heat pump system. Similarly, for the traditional heating terminal, with the hot water tank as a heat source, a manifold was used to control the opening of the floor heating and the fan coil in the laboratory room. Temperature sensors were arranged at the inlet and outlet of each of the two traditional heating terminals. On this basis, Coriolis mass flowmeters were placed for both novel and traditional systems to obtain the flow rates of the refrigerant and hot water.

To examine the heating capacity of the terminal, the ambient temperature was controlled at 20.0 °C ± 1.0 °C to ensure the objectivity and accuracy of the experiment. The heat transfer characteristics of the novel terminal are evaluated by using the heating capacity Q_{nt}, as follows,

$$Q_{\mathrm{nt}} = G_{\mathrm{r}}(h_{\mathrm{ri}} - h_{\mathrm{ro}}) \times 1000/3600. \quad (1)$$

Where G_r is the flow rate of refrigerant [kg·h^{-1}]; h_{ri} and h_{ro} are the enthalpies of the refrigerant at the inlet and outlet of the novel terminal [kJ·kg^{-1}].

To evaluate the heat transfer characteristics of the fan coil and floor heating, heating capacity Q_t, is evaluated, as follows,

$$Q_{\mathrm{t}} = c_{\mathrm{w}} G_{\mathrm{w}}(T_{\mathrm{wi}} - T_{\mathrm{wo}})/3600. \quad (2)$$

Where c_w is the heat capacity of water [J·kg^{-1}K^{-1}]; G_w is the flow rate of hot water [kg·h^{-1}]; and T_{wi} and T_{wo} are the inlet and outlet water temperatures of the fan coil and floor heating [°C].

To examine the rise in ambient temperature, the initial indoor temperature in the experimental laboratory room was controlled to 10.0-12.0 °C while the outdoor temperature was 9.0-11.0 °C to ensure the objectivity and accuracy of the experimental results.

3. RESULTS

3.1 Thermal performance of traditional terminals

The thermal performance of traditional heating terminals represented by fan coil and floor heating has been discussed, as shown in Fig. 5 and Fig. 6. The inlet water temperature of the fan coil and floor heating has been controlled at 40 °C ± 1 °C based on practical application and experimental needs.

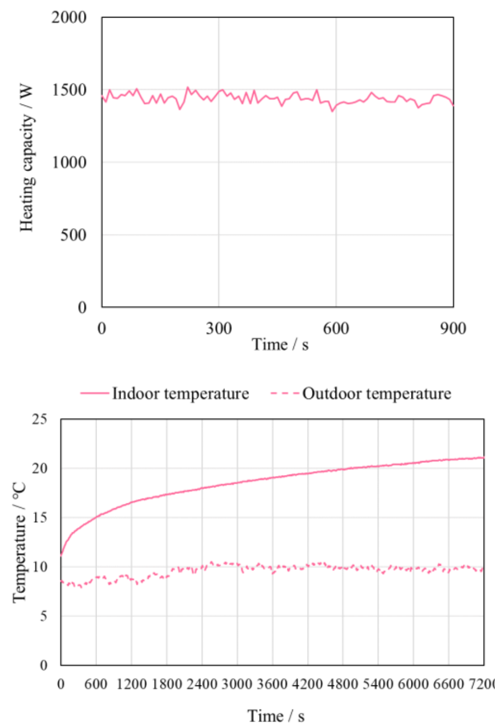

Fig. 5 Thermal performance of fan coil

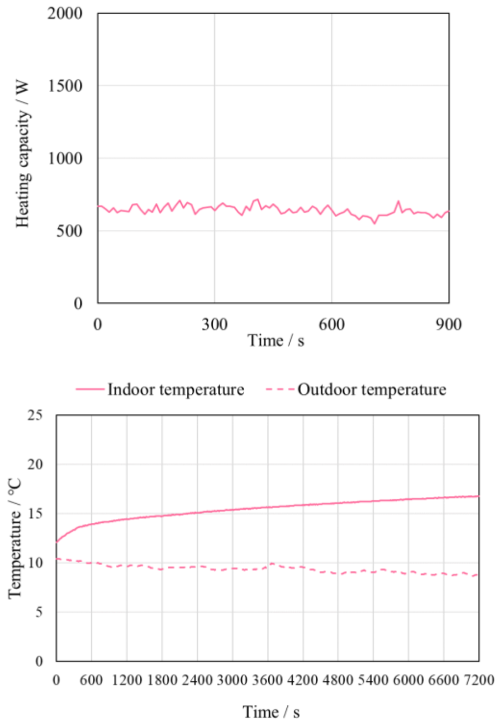

Fig. 6 Thermal performance of floor heating

Fig. 5 demonstrates the thermal performance of the fan coil with high airflow (340 m^3 h^{-1}), where the fan coil is able to provide a heating capacity of 1400-1500 W. The room temperature reaches 18 °C after nearly 40 minutes of heating. Fig. 6 shows the thermal performance of the floor heating, where the floor heating provides heat input in the range of 600-700 W, and the room is finally warmed up to 17 °C. It can be seen that the fan coil heats the room quickly, and the floor heating is stable and comfortable. For intermittent heating, the fan coil and floor heating should be arranged together in the room, just as the fan coil is used when starting and the floor heating is used when stable.

3.2 Thermal performance of the novel terminal

By combining the two basic heating modes of the traditional heating terminals, the novel terminal effectively provides heating by radiation mode and convection mode, as shown in Fig.7 and Fig. 8.

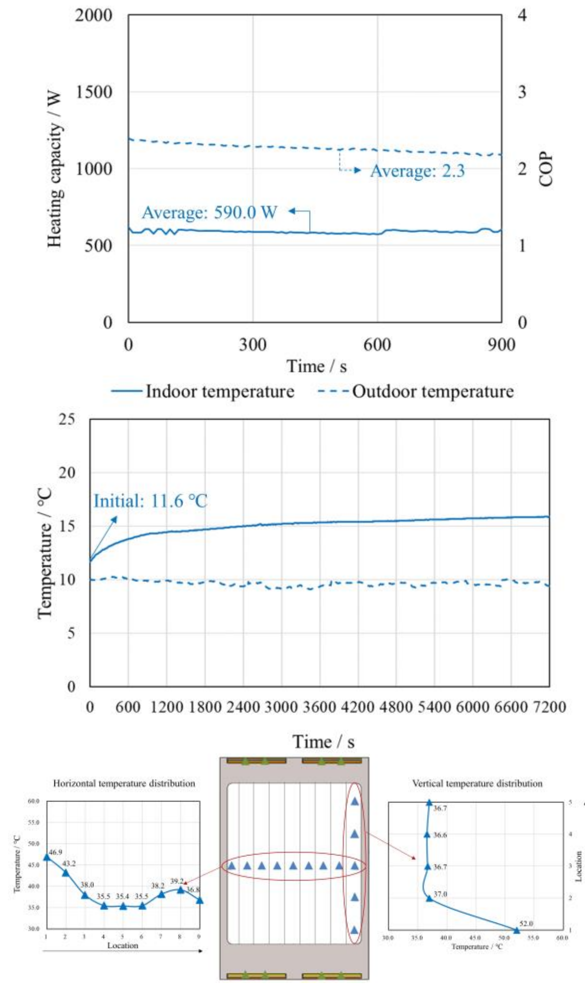

Fig. 7 Thermal performance of radiation mode

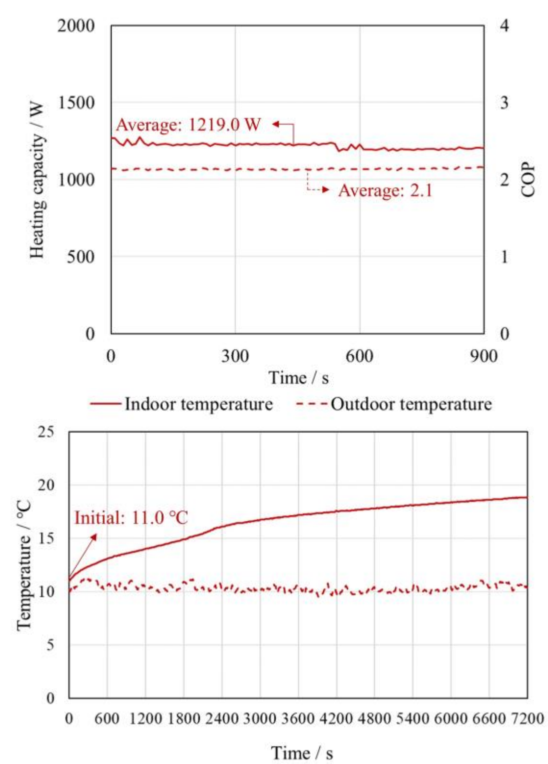

Fig. 8 Thermal performance of convection mode

The above analysis shows that both convection and radiation modes have certain advantages and disadvantages. Convective heating has the advantage of quick room heating in the beginning; the radiation mode provides uniform surface temperature without any requirement of draught during the stable period. The novel terminal can also switch between the convection and radiation mode to effectively match the intermittent heating demand in the low heating load area. Therefore, the novel terminal and the traditional terminals of the switchable heating will be further discussed.

4. DISCUSSION

Fig. 9 shows the comparative experimental data for the novel terminal and the traditional heating terminal. The experiments were conducted simultaneously in two identical experimental laboratory rooms. In one of the laboratory rooms with a traditional heating terminal, the fan coil heating was used initially and the floor heating was used in the stable period to provide good thermal performance for intermittent heating by the joint operation of the traditional heating terminals. However, in the other laboratory room with a novel terminal, the results showed that the combined effect of the traditional terminals could be achieved by using only the switchable mode of the novel terminal.

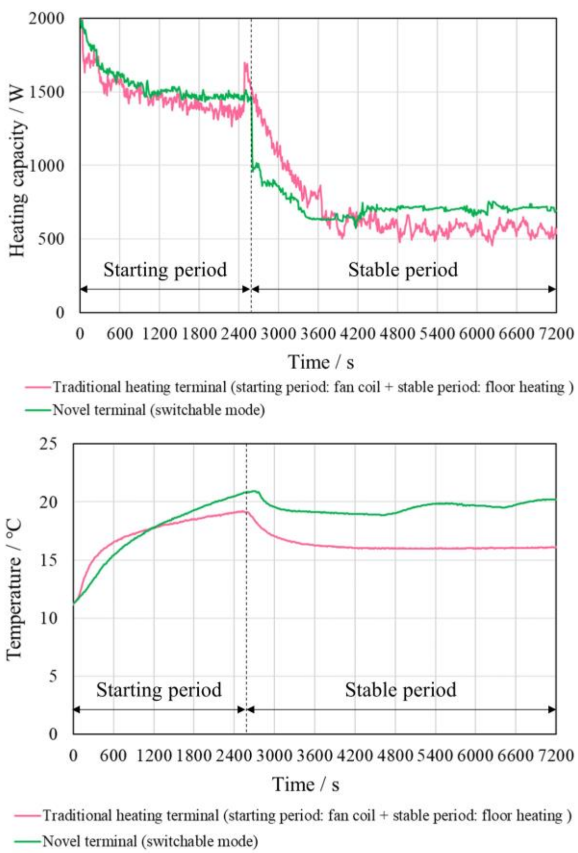

Fig. 9 The novel terminal versus the traditional terminal

As shown in Fig. 9, it can be stated that just one type of novel terminal can replace the combined use of two traditional heating terminals, reducing system complexity while lowering initial investment, and thus providing a good option for intermittent heating under low heating load areas. In addition, the flexible adjustment capability of the novel terminal can also better cope with heating load fluctuations, which is an additional advantage for intermittent heating.

5. CONCLUSIONS

This study explores the thermal performance of the traditional heating terminal and the novel terminal under intermittent heating in low heating load areas. Fan coil and floor heating were considered means of convective and radiant heating, however, only radiant or convective heating cannot fulfill the intermittent heating demand due to its limitations. Therefore, the combined convection and radiation traditional heating terminals were used. The strategy of using convective heating in the initial duration and radiant heating in the stable period was to maximize the advantages of respective modes of heating. Based on it, the novel terminal was found to provide a better way for intermittent heating with the help of switchable and combined convection and radiation modes.

ACKNOWLEDGEMENT

This research was supported by the Opening Funds of State Key Laboratory of Building Safety and Built Environment & National Engineering Research Center of Building Technology (BSBE2022-09), China Energy Dadu River Hydropower Development Co., Ltd. Science and Technology Fund (GJNY- DDH-2023-004), the National Natural Science Foundation of China (Grant No. 52130803 and 52108082), the New Cornerstone Science Foundation through the XPLORER PRIZE, Sichuan Province Innovative Talent Funding Project for Postdoctoral Fellows (BX202218), the Fundamental Research Funds for the Central Universities (YJ2021126) and the China Postdoctoral Science Foundation (2023M732479).

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

REFERENCE

[1] International Energy Agency [IEA]. Word energy balanced. 10.06, https://www.iea.org/; 2020.

[2] Wang X, Fang Y, Cai W, Ding C, Xie Y. Heating demand with heterogeneity in residential households in the hot summer and cold winter climate zone in China -A quantile regression approach. Energy 2022;247:123462.
[3] Kazanci OB, Olesen BW. IEA EBC Annex 59 - possibilities, limitations and capacities of indoor terminal units. Energy procedia - 6th international building physics conference, vol. 78; 2015. p. 2427-32. IBPC 2015.
[4] Rhee K, Kim KW. A 50 year review of basic and applied research in radiant heating and cooling systems for the built environment. Building and Environment 2015;91:166-90.
[5] Shinoda J, Kazanci OB, Tanabe S, Olesen BW. A review of the surface heat transfer coefficients of radiant heating and cooling systems. Building and Environment 2019;159:106156.