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Field Study on the Performance of Intermittently Operated Radiant Floor Heating System in an Office

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Abstract

As a great energy and peak power savings potential system, radiant floor cooling system in the commercial building can additionally improve indoor thermal comfort. This study conducted a field study on the performance of the intermittently operated radiant floor heating system in a cold area. The results show that almost stable indoor air temperature with an approximately value of 18°C is monitored in an office room without larger internal heat source. Except that the northern window that has the relatively lower temperature about 13°C and floor that has the relatively higher temperature about 20°C, the temperature for the interior wall surfaces ranges from 16°C to 18°C. The vertical temperature difference is not remarkable with maximum difference about 0.6°C. The supply water temperature keep stable at 27°C which is sufficient to satisfy the indoor thermal environment when the outdoor air temperature ranges 0 to 10°C. The energy consumption of radiant floor heating system is summarized from Dec 21, 2015 to Jan 20, 2016, showing the heat pump consumed more than three-quarters of total energy consumption. However, due to the peak and valley power cost difference, the heat pump only operates during the time period of valley power and can benefit from this policy.

Keywords – radiant floor heating system; ground source heat pump; water storage tank; intermittent operating strategy; valley power and peak power

1. Introduction

In recent two decades, the radiant floor heating and cooling systems have been greatly investigated to provide the comfortable indoor environment and achieve the energy efficiency [1, 2]. Compared to the conventional air systems, the radiant floor heating/cooling system can maintain room air temperature be lower/higher, which leads to achieving the equivalent thermal comfort. There are a large amount of studies focusing on the experimental study [3, 4], numerical study [5-7] and on-site study [8-10], to in-depth exploration in indoor environment , thermal comfort, energy saving, indoor air quality, control strategy and so on.

Although the theory of building physic and engineering technology for the radiant floor heating system are developed, modified and improved characterized by lots of publications and applications, there are limited investigations regarding to explore the energy saving on the operation in the complete buildings in the extensive building types and climates, such as the field study after several years' operation, to greatly demonstrate its energy saving potential. Therefore, the objective of this study is to provide one case study in one commercial building in a clod area and on-site study on the performance in the intermittently operated radiant floor heating system with ground source heat pump, to present the better thermal comfort and energy saving potential, as well as to suggest possible further study trend related to the operating and controlling.

2. Descritpion of the field study on performance of the radiant floor heating system

2.1 Description of the Antaeus building

Antaeus dynamic energy-saving demonstration building is invested, developed and designed by Shandong Antaeus Engineering and Intelligent Co., Ltd. in November 2011, with a construction area of 5483m^2, one underground floor and 5 floors on the ground and mainly for office and research. Figure 1 shows the side view of Antaeus energy-saving demonstration building. In the cooling season, this building uses radiant floor cooling system to remove the indoor sensible heat load and employs the fresh air system to mainly dehumidify by considering the peak and valley power cost to storage energy in a water tank and provide the chilled water. In the heating season, this building adopts the price difference for peak and valley power to provide lower-temperature hot water for radiant heating system. Due to the short space, this paper only focus on the heating system and present the energy saving potential and better economy. Detail introduction for the cooling system will be provided in the following section.

2.2 Description of the radiant floor heating system

Figure 2 shows the system schematic diagram of the radiant floor heating system with ground source heat pump in winter. In winter, due to the policy of time-varying power price for the commercial building, it takes great attention to utilize the price difference to save energy. The lower temperature water is stored in the water storage tank by opening the heat pump from 23:00 at night to 7:00 in the morning, while the radiant floor circulating water pump continuously operates in the whole day to supply heat energy to the building. This system can shift the peak heating load, having a great energy-saving potential.

Fig. 1 Side view of the Antaeous energy-saving demonstration building

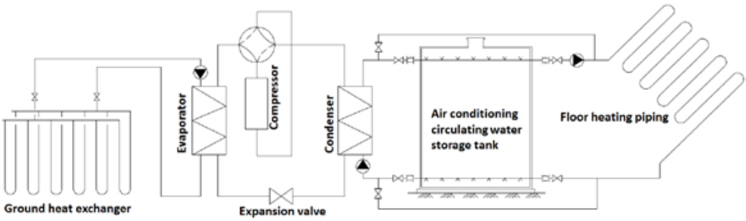

Fig. 2 System schematic diagram of the radiant floor heating system with ground source heat pump in winter

2.3 Introduction for the measurement of indoor thermal environemnt and system performance

In the field study, the air temperature is measured using the DS1922L temperature logger iButton sensors. This digital thermometer is a wireless temperature system with accuracy of ±0.5°C from -10°C to +65°C and with the precision of 0.0625°C [11]. Figure 3 shows the instruments for measured vertical temperature distribution. Note that the thermocouple sensors are used to compare the accuracy of iButton, resulting the relatively reliable results for iButton sensors. In addition, the infrared thermal camera is used to measure the temperature at the interior building walls, floors and ceiling surfaces, which has the measuring accuracy of ±2°C. Energy separate metering including about 74 ammeters is conducted in this building to meter the energy consumption for every elevator, plug, lighting, pump, fan, control equipment and so on June 2011 to now.

Fig. 3 Measured instruments for vertical temperature distribution

3. Performance analysis of the radiant floor heating system

3.1 Indoor thermal environemnt analysis

First, the comparison of indoor air and interior wall surfaces temperature in a size of $20m^2$ northern room in the fifth floor in Dec. 29, 2015 is illustrated in Figure 4. Note that there is not larger without larger internal heat source except for one person and one PC. It can be find in the day except that the northern window has the relatively lower temperature about 13°C and floor has the relatively higher temperature about 20 °C, the temperature for the interior wall surfaces ranges from 16°C to 18°C, resulting in the almost stable indoor air temperature with an approximately value of 18°C. In addition, from the morning to the afternoon, the variation for the wall surfaces keep almost steady state under the condition of accuracy of infrared thermal camera.

The same tests are carried out to measure the indoor thermal environment between 8:00pm to 5:30pm from Dec 29 to Dec 31, 2015. Table 1 shows summarization of measured minimum temperature, maximum temperature, average temperature and root mean square (RMS) for the indoor thermal environment, including the indoor air, outdoor air, floor, ceiling, interior walls, northern wall, northern window and averaged uncooled/heat surface temperature (AUST). Similar phenomena is found as mentioned above to present better indoor thermal comfort. The indoor air temperature is 18.1-19.7°C; the heated floor and unheated interior walls except for the northern wall are 19.2-21.5°C and 16.4-18.6°C, respectively;

the northern wall and ceiling are 15.7-17.1°C and 16.6-18.0°C, respectively. The lower northern window surface is recorded about 11.8 to 14.8°C. In summary, the comfortable indoor thermal environment is maintained during the winter season.

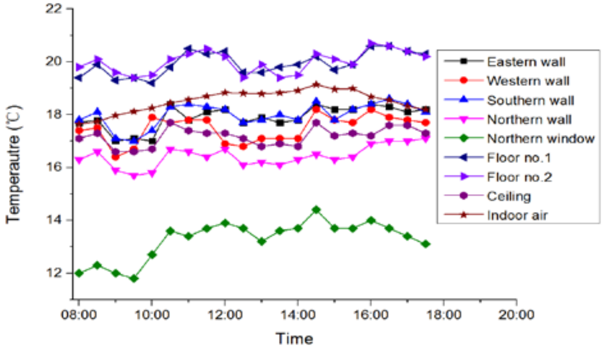

Fig. 4 Variation of indoor air and interior wall surfaces temperature in a northern room in the fifth floor in Dec. 29, 2015

Table 1. The summarization of measured minimum temperature, maximum temperature, average temperature and root mean square (RMS) for the indoor thermal environment in the fifth floor

	Min (°C)	Max (°C)	Ave (°C)	RMS
Indoor air	17.70	19.70	18.56	0.67
Outdoor air	0.50	10.70	6.31	2.33
Floor	19.20	21.50	19.96	0.42
Ceiling	16.60	18.00	17.21	0.39
Interior walls	16.40	18.60	17.79	0.50
Northern wall	15.70	17.10	16.43	0.55
Northern window	11.80	14.80	13.18	0.75
AUST	15.82	17.46	16.78	0.44

Note: The measured data came from 8:00pm to 5:30pm from Dec 29 to Dec 31, 2015. Interior walls does not include the northern wall.

The indoor vertical air temperature distribution is also studied as shown in Figure 5. The variation of indoor air temperature at the different height of 0.1m, 0.6m, 1.1m 1.7m and 2.3m from Dec. 29th, 2015 to Jan. 5th is recorded every 10 minutes. It was found that the vertical temperature difference is not remarkable with maximum difference about 0.6°C occurred in the day between the 0.1m height and 2.3m height. In most cases, the higher the measured location the higher the indoor air temperature, which attributes to the buoyancy effect of hot air.

In addition, it should be noted that, due to the longer holiday with more than two days in winter, the radiant floor heating system will close, such as the new year holiday from Jan 1st to Jan 3rd, 2016. The indoor air temperatures at the different heights are gradually decreasing from 19°C at 5pm in Dec 31 to 15.5°C at 9am in Jan 3th and mainly influenced by outdoor air temperature. The detailed variation and corresponding operation strategy is analyzed in the following subsection.

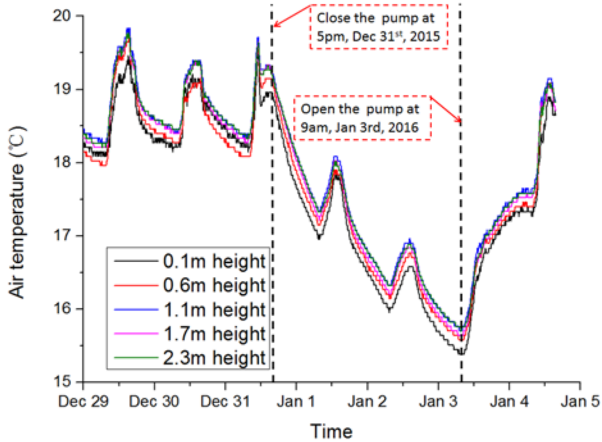

Fig. 5 Variation of indoor air temperature at the different height above the floor in a northern room in the fifth floor from Dec 29, 2015 to Jan 5, 2016

3.2 Energy consumption analysis

The radiant floor circulating water pump runs continuously except the longer holidays. Figure 6 shows the variation of heating capacity for radiant floor heating system and heat pump from Dec 29, 2015 to Jan 5, 2016. The instantaneous cooling capacity was calculated according to the value of flow rate and supply and return water temperature difference every 15 minutes. Note that the rapid change from about 160kW to 90kW for circulating water pump may only present the relatively larger flow rate change in short time, which in fact came from the influence of the sudden open with larger supply water temperature and lower return water temperature. Almost average 70kW heating capacity for radiant floor circulating water pump was monitored when the pump opens, while approximately average 85kW heating capacity for heat pump was recorded during the operation conditions.

By summarizing the energy consumption of radiant floor heating system from Dec 21, 2015 to Jan 20, 2016 as shown in Figure 7, the energy consumption for heat pump consumed more than three-quarters of total energy consumption. While the other equipment including radiant floor water pump, condenser circulating pump and evaporator circulating pump do not individually take more than 10% of total energy consumption.

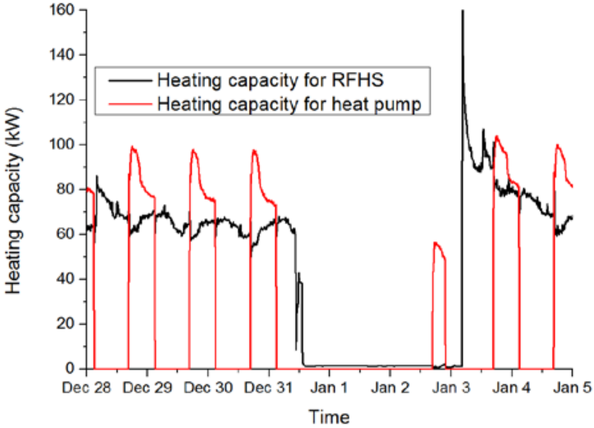

Fig. 6 Variation of heating capacity for radiant floor heating system and heat pump from Dec 29, 2015 to Jan 5, 2016

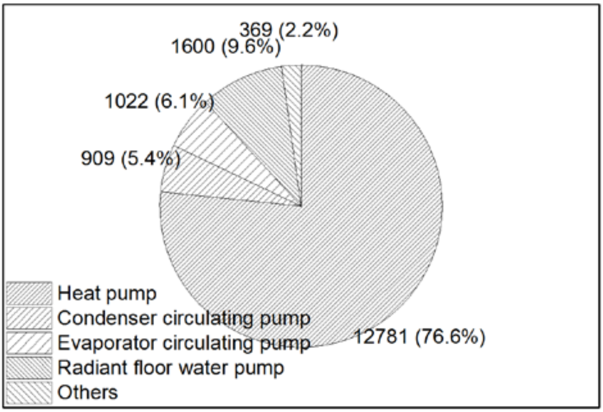

Fig. 7 Constitute for the energy consumption of radiant floor heating system from Dec 21, 2015 to Jan 20, 2016

It has to be pointed out that although the heat pump accounts for most of energy consumption, this system can benefit from the peak and valley power cost difference. Table 2 shows the time-of-use electricity price in Jinan city. It can find that the valley power price is only 0.327 Chinese Yuan per kWh from 23:00 to 7:00 that equals to 1/4 of the peak power price with 1.3078 Yuan/kWh. Therefore, by going through the power consumption and electricity bill for the radiant floor heating system from Dec 21th, 2015 to Jan 20th, 2016 as shown in Figure 8, we can find the advantage of water storage plays a significant role to reduce energy consumption, taking into account the peak and valley power price policy. Another analysis is also evaluated that employing peak and valley power policy instead of uniform flat power in the whole day, this integrated cooling system can save on average 30% of the total energy consumption.

Table 2. Time-of-use electricity price in Jinan city

Type	Period of power use	Price (Yuan/kWh)	Hours
Valley power	23:00~7:00, 21:00~23:00	0.3270	8
Flat power	7:00~8:30, 11:30~18:00	0.8174	8
Peak power	8:30~10:30, 18:00~19:00, 21:00~23:00	1.3078	5
Sharp power	10:30~11:30, 19:00~21:00	1.3896	3

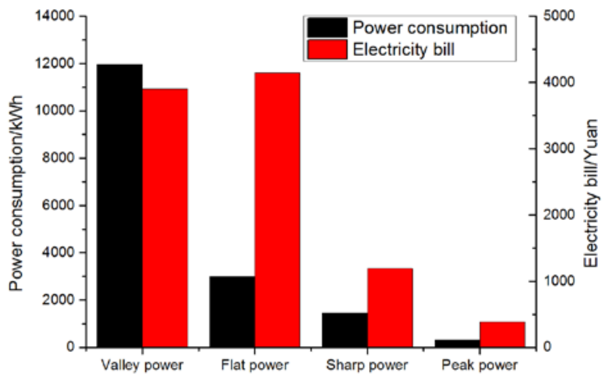

Fig. 8 Comparision of the power consumption and elecricity bill for the radiant floor heating system from Dec 21th, 2015 to Jan 20th, 2016

3.3 Operating control strategies analysis

As mentioned above, considering the peak and valley power cost difference, the heat pump only operates at night from 23:00 to 7:00, while the radiant floor water pump continuously runs the whole day, which can be found in Figure 9. The instantaneous power every 15minutes for southern heat pump, northern heat pump and radiant floor water pump from Dec 21, 2015 to Jan 20, 2016 are approximately 25kW, 23kW and 2.5kW, respectively.

In the New Year holiday (Jan 1 to Jan 3), the heat pump and water pump closed to save energy. In order to study the thermal inertia of building envelope, the variation of indoor air temperature, floor surface temperature, outdoor air temperature and supply water temperature from Dec 29, 2015 to Jan 5, 20 are monitored as shown in Figure 10. The results show that the supply water temperature keeps stable at 27°C when the system operates. Although the radiant floor water pump opens in advance at 9:00 in Jan 3rd, the indoor air temperature at 9:00 in Jan 4^{th} in the third floor did not reaches the level before the holiday. In addition, the floor surface temperature in the third floor and fourth floor varied significantly different after the holiday which probably attributes to distribution of water system. Further studies will be concentrate on the detailed analysis of stability of radiating floor water system.

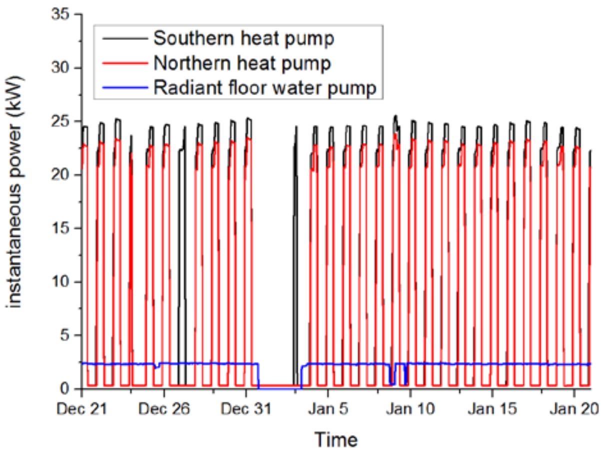

Fig. 9 Variation of instantaneous power for southern heat pump, northern heat pump and radiant floor water pump from Dec 21, 2015 to Jan 20, 2016

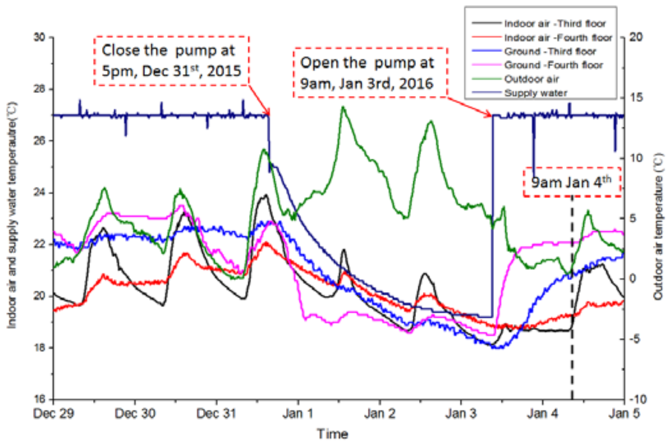

Fig. 10 Variation of indoor air temperature, floor surface temperature, outdoor air temperature and supply water temperature from Dec 29, 2015 to Jan 5, 2016

4. Conclusions

This study conducted a field study on the performance of the intermittently operated radiant floor heating system in a cold area. The main conclusion is presented as follows. First, the indoor environment without larger internal heat source is monitored from Dec. 29, 2015 to Jan 4, 2016. Except that the northern window that has the relatively lower temperature about 13°C and floor that has the relatively higher temperature about 20°C, the temperature for the interior wall surfaces ranges from 16°C to 18°C, resulting in the almost stable indoor air temperature with an approximately value of 18°C. The vertical temperature difference is not remarkable with maximum difference about 0.6°C occurred in the day between the 0.1m height and 2.3m height.

Second, by summarizing the energy consumption of radiant floor heating system from Dec. 21, 2015 to Jan. 20, 2016, the energy consumption for heat pump consumed more than three-quarters of total energy consumption. Although the heat pump accounts for most of energy consumption, this system can benefit from the peak and valley power cost difference. This system can shift the peak heating load, having a great energy-saving potential. By investigating the variation due to close of heat pump and water pump in the holiday (from Jan. 1 to Jan. 3), even the radiant floor water pump opens in advance at 9:00 in Jan. 3, the indoor air temperature at 9:00 in Jan 4 in the third floor did not reaches the level before the holiday, due to the larger thermal inertia of building envelope. Further studies will be concentrate on the detailed analysis of stability of radiating floor water system.

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References

[1] R. Hu, J.L. Niu, A review of the application of radiant cooling & heating systems in Mainland China, Energ Buildings, 52 (2012) 11-19.
[2] K.N. Rhee, K.W. Kim, A 50 year review of basic and applied research in radiant heating and cooling systems for the built environment, Build Environ, 91 (2015) 166-190.
[3] Y. Xia, X.-S. Zhang, Experimental research on a double-layer radiant floor system with phase change material under heating mode, Appl Therm Eng, 96 (2016) 600-606.
[4] G. Yu, Y. Yao, The Experimental Research on the Heating and Cooling Performance of Light Floor Radiant Panels, Procedia Engineering, 121 (2015) 1349-1355.
[5] H. Karabay, M. Arıcı, M. Sandık, A numerical investigation of fluid flow and heat transfer inside a room for floor heating and wall heating systems, Energ Buildings, 67 (2013) 471-478.

[6] D. Zhang, N. Cai, Z. Wang, Experimental and numerical analysis of lightweight radiant floor heating system, Energ Buildings, 61 (2013) 260-266.
[7] M. Zhao, T. Zhu, C. Wang, H. Chen, Y. Zhang, Numerical simulation on the thermal performance of hydraulic floor heating system with phase change materials, Appl Therm Eng, 93 (2016) 900-907.
[8] X. Wu, J. Zhao, B.W. Olesen, L. Fang, F. Wang, A new simplified model to calculate surface temperature and heat transfer of radiant floor heating and cooling systems, Energ Buildings, 105 (2015) 285-293.
[9] K. Zhao, X.-H. Liu, Y. Jiang, Cooling capacity prediction of radiant floors in large spaces of an airport, Sol Energy, 113 (2015) 221-235.
[10] K. Zhao, X.-H. Liu, Y. Jiang, Application of radiant floor cooling in large space buildings – A review, Renewable and Sustainable Energy Reviews, 55 (2016) 1083-1096.
[11] Maxim integrated, in, DS1922L/DS1922T datasheet. http://www.maximintegrated.com/en/products/comms/ibutton.html., 2013.