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A novel air source heat pump powered bed-based space heating (ASHP-BBSH) system for improved indoor thermal environment

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Abstract

A novel air source heat pump powered bed-based space radiation heating (ASHP-BBSH) system is reported in this paper. This novel system combines the merits from a Chinese Kang, or a heated bed, widely used in northern rural China and a standard ASHP system, which can provide localized space heating via both convection and radiation to maintain a comfortable indoor thermal environment, at reduced energy use. In this novel bed-based system, a bed is heated and thus used as a radiator for providing space heating at both daytime and nighttime. In this paper, firstly, there is an introduction to the novel ASHP-BBSH system. Secondly, based on the experiment setup dimensions, a numerical model is built with a real size thermal manikin. Thirdly, the thermal environment generated by the ASHP-BBSH system is analysed by Fluent. The numerical results show that the ASHP system can achieve a uniform thermal environment and energy saving potential.

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Keywords: ASHP; radiant heating; thermal environment; CFD

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1. Introduction

Heating is necessary for regions with cold winter, providing adequate thermal comfort level to serve occupants. However, heating consumes a lot of energy, as much as 17GJ per household per year in China [1] and causes serious

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air pollution and environmental damage [2]. Therefore, it becomes highly necessary to develop novel heating systems, to reduce energy consumption while maintaining a suitable level of indoor thermal comfort.

Chinese Kang system provides both whole-space heating at daytime and localized heating at nighttime for a comfort environment in a bedroom, which can achieve a high thermal comfort level, quiet operation, energy saving potential, integration with building design, and so on. Chines Kang is commonly used in rural homes (about 85%) in northern China, which can be regarded as a bed-based radiant heating system [3]. Pan et al. [4] developed a novel bed-based task\ambient air conditioning (TAC) system with flexible air ducts and plenums installed in an experimental bedroom. Mao et al. made improvements on this bed-based TAC system, and based on this study, an improved bed based ductless TAC system was subsequently proposed [5, 6] to remove the bulky air ducts and supply air plenums. Du et al. developed and studied a bed-based system with a radiation panel hanged on top of the occupied zone both experimentally and numerically [7, 8]. The results showed that the novel radiant bed-based TAC system could effectively avoid the cold draft problem encountered when using the previously developed convective bed-based TAC system. However, there are few studies focusing on Chinese Kang as a bed-based TAC system

Besides the Kang system, air source heat pump (ASHP) is one of the most commonly used system for heating not only in China but also in many other countries. ASHP is a reliable system with low initial cost, simple maintenance and easy operation [9]. Since the Air source heat pumps (ASHPs) are environmentally friendly and reliable systems and are relatively easy and inexpensive to install, it is necessary to combine the merits of a conventional ASHP system and a Chinese Kang system to produce a novel air source heat pump powered bed-based space radiation heating (ASHP-BBSH) system.

2. Experimental setup

The experimental setup for the proposed prototype ASHP-BBSH system is purposely established. The refrigeration plant is shown in Fig. 1.

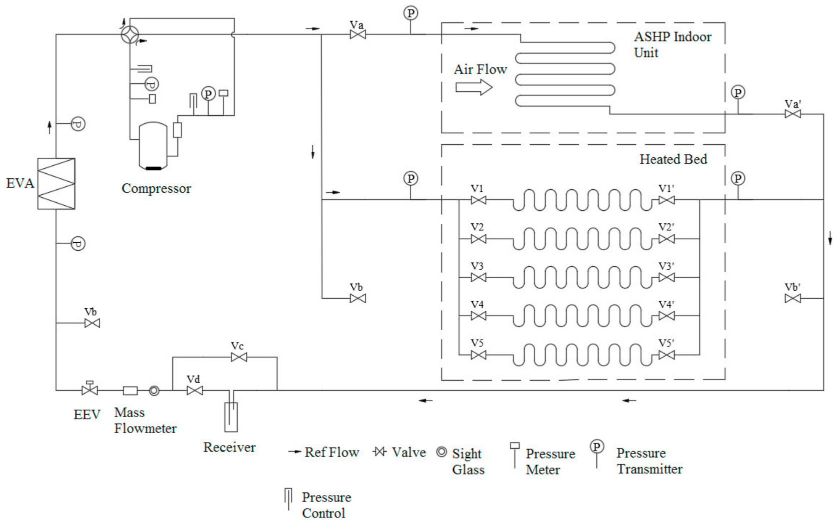

Fig. 1. Schematic diagram of the ASHP-BBSH refrigeration plant

As shown in Fig. 1, the major components in the ASHP-BBSH refrigeration plant include a variable speed rotary compressor, an electronic expansion valve, a high-efficiency tube-louver-finned direct expansion evaporator, a multi-circuit heated bed and indoor ASHP unit as condensers. The evaporator is placed inside a simulated outdoor environment room. The nominal output heating capacity from the direct expansion refrigeration plant is 2.5 kW. The compressor is driven by a converter control system. The electronic expansion valve consisted of a throttling needle valve, a step motor and a pulse generator, which could be manually or program controlled to regulate the refrigerant mass flow rate passing through it. An environmental friendly refrigerant, R410a is used as the working fluid in the ASHP-BBSH refrigeration plant, with a total charge of 1.4 kg.

The design of the heated bed coil is shown in Fig. 2. The vertical condenser is placed around the bed while the horizontal condenser is placed on top of the bed.

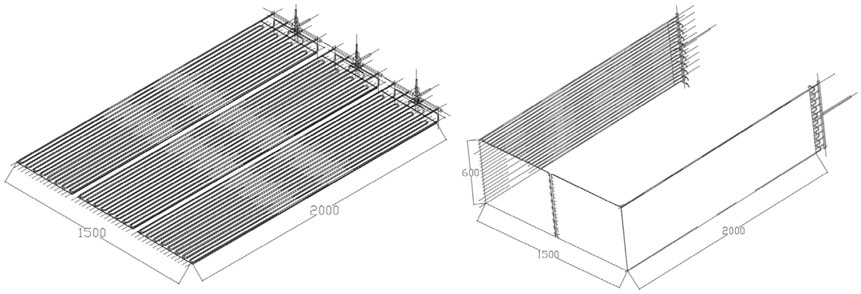

Fig. 2. The vertical condenser (left) and horizontal condenser (right) of the designed heated bed.

3. Indoor thermal environment with occupant analysis of the ASHP-BBSH system using CFD method

3.1. Model development and boundary conditions

In order to study the indoor thermal environment with occupant, a simulation model with an ASHP-BBSH system is built based on the experimental model built presented in Section 2, as shown in Fig. 3 and Fig. 4.. The size of the bedroom (W×D×H) is 2600 mm × 3700 mm × 3290 mm. On its external wall, there is an external window (1500 mm × 1000 mm). In this bedroom, a full-size heated bed (2000 mm × 1500mm × 900 mm) is placed in the central of the bedroom, satisfying the heating load radiatively and conductively. Besides that, there is an occupied zone with a thermal manikin lying in above the bed with a dimension of 2000 mm × 1500 mm ×600mm. An ASHP indoor unit is placed at 2500mm above the floor level on the wall adjacent to the manikin which provide the potential for a future work on the comparison study for the ASHP system and the Bed-based system. The boundary conditions for the CFD method including emissivity and thermal conditions are summarized in Table 1.

Table 1. Boundary conditions of the simulation bedroom

Boundary	External wall	External window	Floor	Other walls	Bed	Thermal manikin
Emissivity	0.9	0.94	0.3	0.07	0.9	0.98
Thermal conditions	Fixed temperature: 4 ℃	Fixed temperature: 4 ℃	Adiabatic	Adiabatic	Surface temperature: 43 ℃	Fixed skin temperature: 36.4 ℃

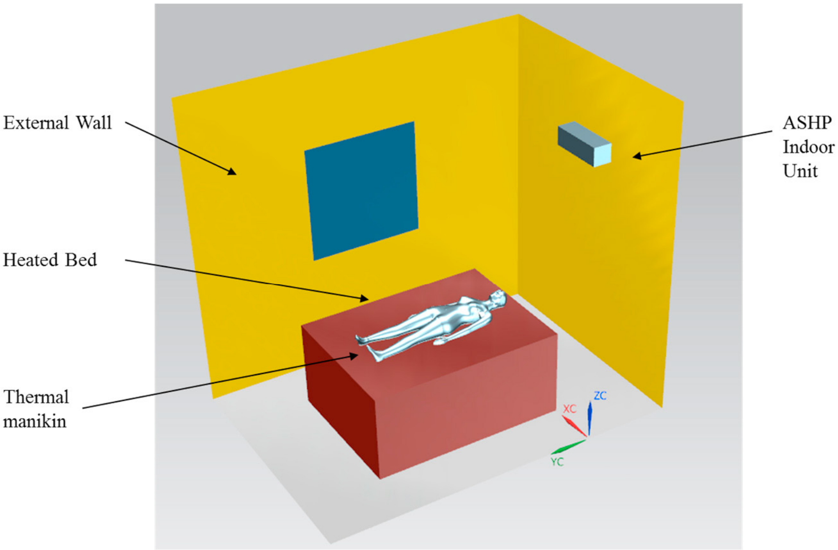

Fig. 3. The simulation bedroom layout under the ASHP-BBSH system

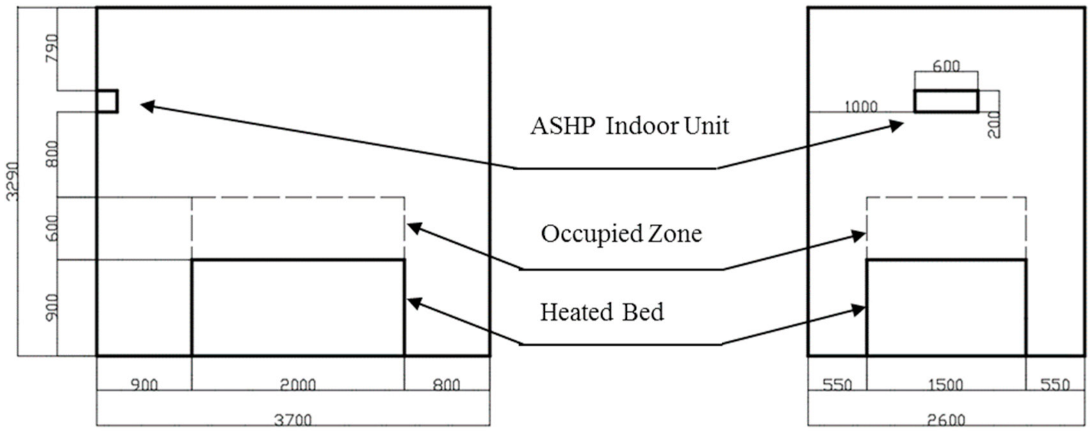

Fig. 4. Sectional View of the simulated bedroom under ASHP-BBSH system

3.2. Numerical results and analysis

3.2.1. Indoor air temperature

Fig. 5 shows the air temperature distributions in the simulation bedroom at cross section plane in x-direction and y-direction. Air temperature in the space under the height level of the heated bed ranged from 7 °C to 15 °C, while air temperature above the height level of the heated bed from 20 to 40 °C. Therefore, high level of indoor air temperature stratification could be expected in the occupied zone and the boundary line could be regarded as the height level of the heated bed. In the occupied zone, except part of the space close to outer surface near the thermal manikin, the air temperature is distributed very evenly, at approximately 23-26 °C. Otherwise, the air temperature difference between the occupied zone and unoccupied zone reached to 0.85 °C, which may suggest the good energy-saving performance using this ASHP-BBSH system. It is because that when higher air temperature is distributed in the unoccupied zone, more energy is consumed by unnecessarily compensating the heat in the unoccupied zone.

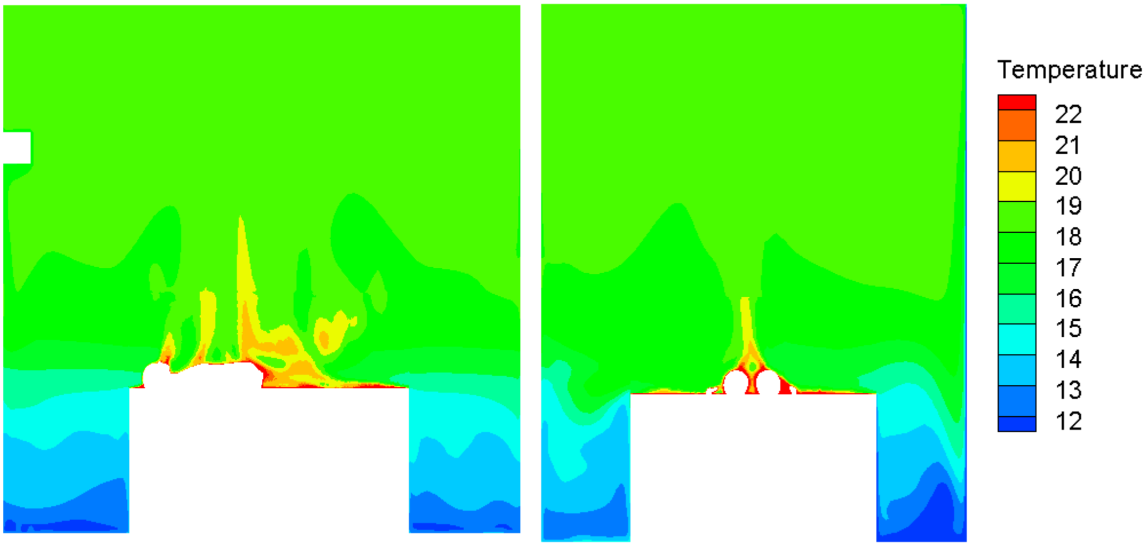

Fig. 5. Contour of air temperature in the simulation bedroom at cross section (ºC)

3.2.2. Air velocity

Fig. 6 shows the air velocity distributions at cross section plane in x-direction and y-direction in the simulation bedroom. As seen, averaged air velocity in the occupied zone is around 0.05m/s, which is lower than the air velocity level (0.3m/s) required for thermal comfort recommended by ASHARE Standard 55-2013 [10]. Even in the intensive heat transfer area, the space above the thermal manikin on bed, the air velocity do not exceed 0.2 m/s. Therefore, as compared with the convection-based system, the air velocity under the ASHP-BBSH system is lower and the problem of warm wind blowing feeling would not bother the occupants.

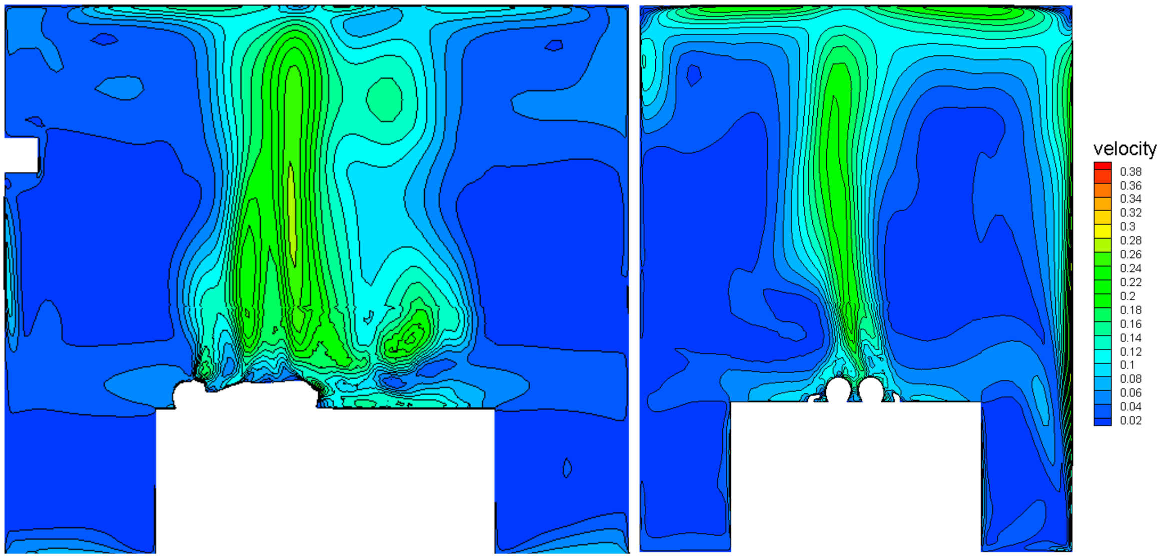

Fig. 6. Contour of air velocity in the simulation bedroom at cross section (m/s)

4. Conclusions

A novel air source heat pump powered bed-based space radiation heating (ASHP-BBSH) system is reported in this paper. To study the thermal comfort of the ASHP-BBSH system, a numerical study has been developed based on the experimental setup and the thermal environment is evaluated. First of all, simulation setup and research method are introduced. Numerical results of performance evaluation are secondly reported and analysed. The numerical results show that using the ASHP-BBSH system could provide a uniform and moderate thermal environment, which leads to a high thermal comfort level and an energy saving potential. It also shows that the air temperature in the occupied zone is 0.85ºC higher than that in the unoccupied zone. The air velocity inside the occupied zone remained below 0.14 m/s, which could satisfy the occupant with the demand of thermal comfort. Further study on the operational characteristics will be conducted in the future work.

Acknowledgements

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References

[1] Q. Zhang, Residential energy consumption in China and its comparison with Japan, Canada, and USA, Energy and Buildings, 36 (2004) 1217-1225.
[2] M. Ando, M. Tadano, S. Asanuma, K. Tamura, S. Matsushima, T. Watanabe, T. Kondo, S. Sakurai, R. Ji, C. Liang, Health effects of indoor fluoride pollution from coal burning in China, Environmental Health Perspectives, 106 (1998) 239.
[3] Y. Li, Z. Zhuang, J. Liu, Chinese kangs and building energy consumption, Science Bulletin, 54 (2009) 992-1002.
[4] D. Pan, M. Chan, L. Xia, X. Xu, S. Deng, Performance evaluation of a novel bed-based task/ambient conditioning (TAC) system, Energy and Buildings, 44 (2012) 54-62.
[5] N. Mao, D. Pan, M. Chan, S. Deng, Experimental and numerical studies on the performance evaluation of a bed-based task/ambient air conditioning (TAC) system, Applied energy, 136 (2014) 956-967.
[6] N. Mao, D. Pan, S. Deng, M. Chan, Thermal, ventilation and energy saving performance evaluations of a ductless bed-based task/ambient air conditioning (TAC) system, Energy and Buildings, 66 (2013) 297-305.
[7] J. Du, M. Chan, S. Deng, An experimental study on the performances of a radiation-based task/ambient air conditioning system applied to sleeping environments, Energy and Buildings, 139 (2017) 291-301.
[8] J. Du, M. Chan, D. Pan, S. Deng, A numerical study on the effects of design/operating parameters of the radiant panel in a radiation-based task air conditioning system on indoor thermal comfort and energy saving for a sleeping environment, Energy and Buildings, 151 (2017) 250-262.
[9] J. Dong, L. Zhang, S. Deng, B. Yang, S. Huang, An experimental study on a novel radiant-convective heating system based on air source heat pump, Energy and Buildings, 158 (2018) 812-821.
[10] A. Standard, Standard 55-2013, Thermal environmental conditions for human occupancy, (2013).