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The Development of the Bed-Based Task/Ambient Air Conditioning System Applied to Sleeping Environments

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Abstract

Task/ambient air conditioning (TAC) system is an excellent air conditioning method due to good performance in thermal comfort, indoor air quality and energy saving. For a sleeping environment, since a sleeper is usually immobile and occupied a small space, TAC systems can be regarded as the best air conditioning method. Nowadays, some bed-based TAC systems have been proposed and its operation performances on energy use, thermal comfort and indoor air quality were experimentally and numerically studied. In this study, the previous studies on these bed-based TAC systems are reviewed and its advantages and disadvantages are summarized.

Keywords: Task/ambient air conditioning; Bed-based; Sleeping environments;

1. Introduction

Due to the increased expectations on human thermal comfort, air-conditioning (A/C) becomes a necessary provision in people's daily life. Not only in office buildings at daytime, is maintaining a suitable indoor thermal environment in residential buildings at nighttime also needed. Therefore, energy use for air conditioning sleeping environments is

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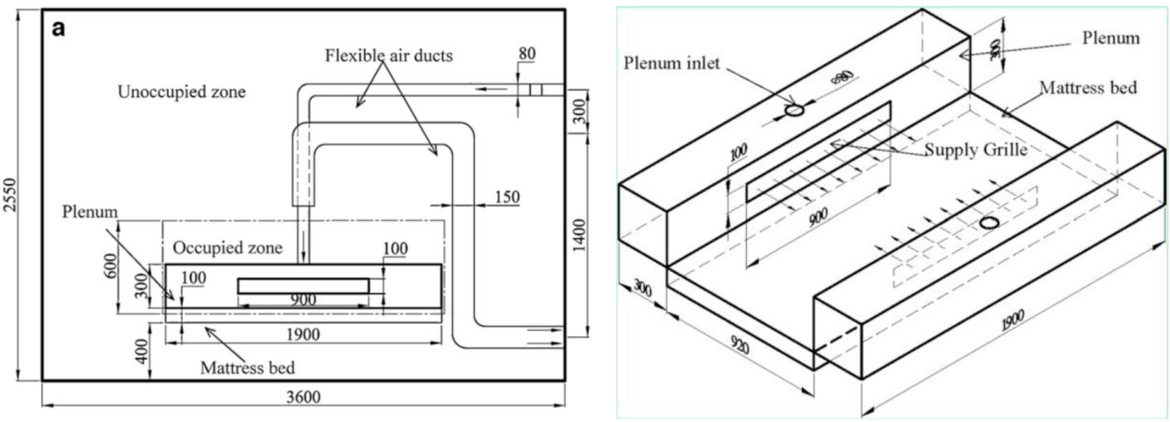
increasing yearly[1] and contributes significantly to the total annual electricity use in residential buildings, which has been clarified by an analysis on residential energy use in Hong Kong [2]. With such an increasing trend, it is highly necessary to develop novel air conditioning technology, so as to reduce energy consumption for A/C while still maintaining a suitable level of indoor thermal comfort.

In recent years, task\ambient air conditioning (TAC) systems has attracted many research attentions due to its excellent performances in thermal comfort, indoor air quality (IAQ) and energy saving, which allows thermal conditions in small, localized zones to be individually controlled by occupants. On the other hand, during sleeping time, the sleepers are usually immobile and occupy a relatively small space, therefore, TAC systems can be regarded as the best air conditioning method applied to sleeping environments to reduce A/C consumption. In the recent years, some bed-based TAC systems have been proposed to study its performances in thermal comfort and energy saving. From the perspective of heat transfer method, these bed-based TAC systems can be divided into two types: convection-based and radiation-based. In addition, some systems are designed for cooling a sleeping environment while other for heating. In this study, these bed-based TAC systems will be reviewed and summarized.

2. The convection-based TAC (C-TAC) systems

To save energy use for air conditioning a sleeping environment, Pan et al [3] proposed a bed-based TAC system with plenum and air ducts, as seen in Fig. 1. In Fig. 1(a), the flexible air ducts were used to link the novel bed-based TAC system to both the supply inlet and return outlet. In Fig. 1 (b), two supply air plenums were symmetrically placed on both sides of a mattress bed to ensure a uniform supply air distribution, and two supply grilles, with $\pm 90^{o}$ adjustable outlet vanes, were each installed on one side of the supply air plenums. The experimental results show that PMV values when using the bed-based TAC system at 50 L/s supply air flow rate were very close to those when using the full-volume air conditioning (FAC) system at 100 L/s supply air flow rate. This implied that the supply air flow rate could be reduced for energy saving when using the novel bed-based TAC system, while maintaining the same level of indoor thermal comfort in the occupied zone as if the FAC system was used. Furthermore, by theoretical analysis, the energy saving potential when using the bed-based TAC system in an actual bedroom with envelope loads can be significantly larger than that in the experimental bedroom without envelope loads.



(a) (b)

Fig. 1. The convection-based TAC system with plenum and air ducts: (a) Experimental setup (b) Plenum.

Later on, Mao et al. [4-6] made some improvements based on Pan et al.'s bed-based TAC system. As seen in Fig. 2(b), they removed the bulky supply air plenums and flexible air ducts, which may cause inconvenience to users, and only installed a supply air outlet near a sleeping person and a return air inlet on the wall in the bedroom to circulate indoor air and remove indoor cooling load. The results demonstrated that a higher supply air temperature of 21 ºC at the TAC setting and a lower supply air temperature of 19 ºC at the FAC setting would result in a similar averaged air temperature in the occupied zone, indicating a great energy saving potential when using the bed-based TAC system.

However, since the vent supplying air with a high velocity and a low temperature had to be close to occupants, the cold drafts (evaluated by *DR*, defined in Eq. (1)) could hardly be avoided when using a convection-based TAC system for a sleeping environment.

$$\begin{cases} DR = (34 - t_a)(v - 0.05)^{0.62}(0.37vT_u + 3.14) \\ v = 0.05 \text{ m/s, when } v \le 0.05 \text{ m/s} \\ DR = 100\%, \text{ when } DR > 100\% \end{cases} \tag{1}$$

It can be seen in Fig. 3, among the 12 measurement positions in an occupied zone when using the ductless TAC system, the values of draft risk in 8 of the 12 positions were higher than 20% and even that in 4 out of the 8 positions reached 40%, which were far higher than the permissible value of 20% as suggested by ASHRAE Standard 55.

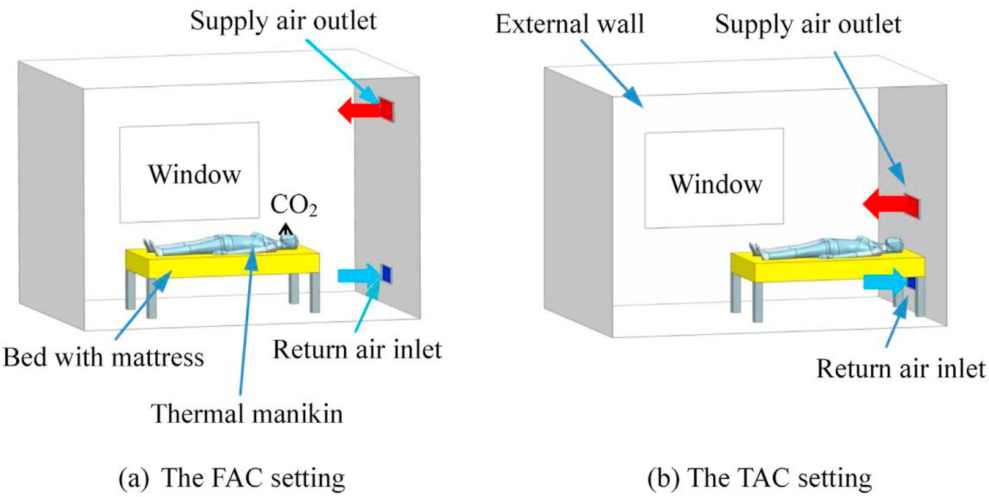


Fig. 2. The convection-based ductless TAC system.

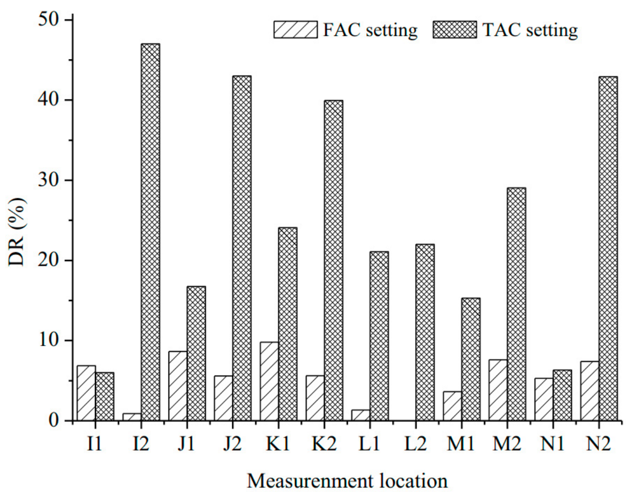


Fig. 3. Values of draft risk at each measurement point in the occupied zone at two experimental settings.

3. The radiation-based TAC (R-TAC) systems

3.1. The radiation-based TAC system for cooling a sleeping environment

Since the above TAC systems for sleeping environments used predominantly the convection-based method to cool an occupied zone, the cold-draft problem is difficult to be solved when using the convection-based TAC system. Furthermore, draft can not only cause thermal discomfort, but also result in temporary illness or even chronic diseases for occupants. To address this issue, a radiation-based TAC system applied to sleeping environments was proposed by Du et al. [7, 8], as seen in Fig. 4. A radiant panel was placed above the thermal manikin to provide cooling in the bedroom, and the ventilation system, made of supply vent and return vent, were only used to provide fresh air in the bedroom. The results showed that, except the air temperature difference between the occupied zone and the unoccupied zone, mean radiant temperature in the occupied zone were also 0.9-1.3 ºC lower than that in the unoccupied zone. Furthermore, draft risk values when using the radiation-based TAC system were very lower than those when using the convection-based TAC system (see Fig. 5).

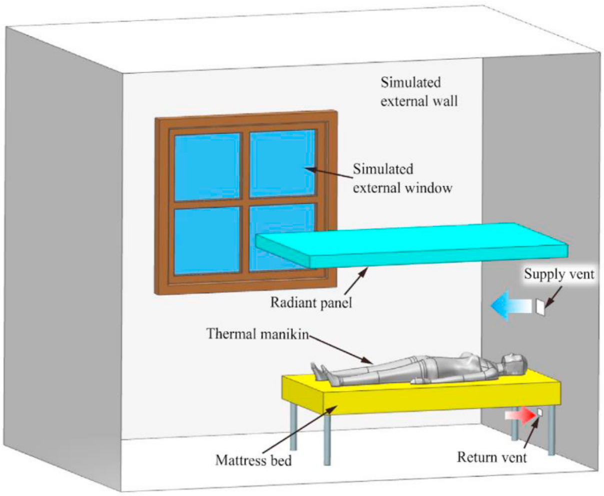
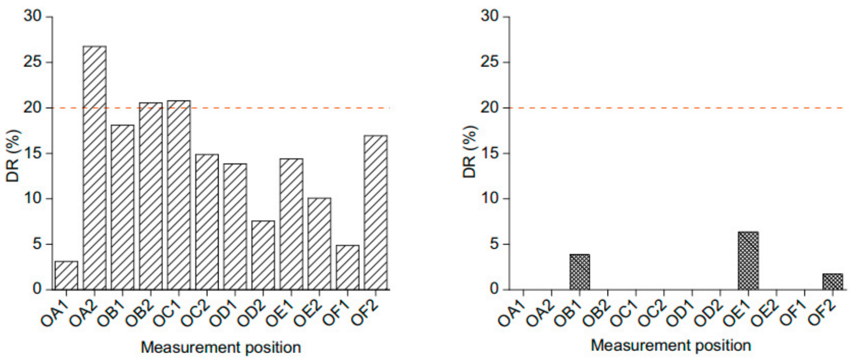


Fig. 4. The radiation-based TAC system for cooling.



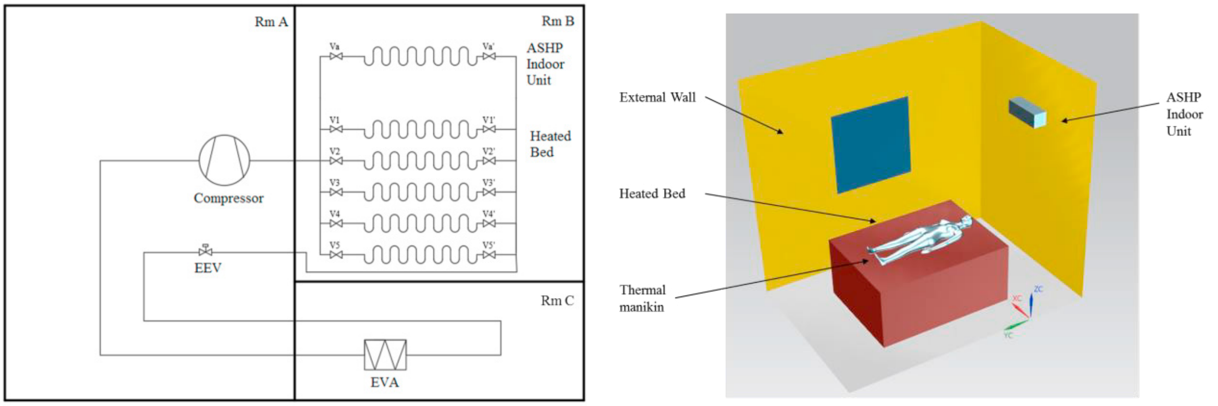
(a) t_s=23ºC, Q_s=50 L/s, for the C-TAC system in a previous study [13]

(b) t_{rp}=17ºC, t_s=23ºC, Q_s=7.5 L/s, for the R-TAC system in the current study (Case 2.2)

Fig. 5. Comparison of draft risk values at each measurement position between when using the C-TAC system and R-TAC system.

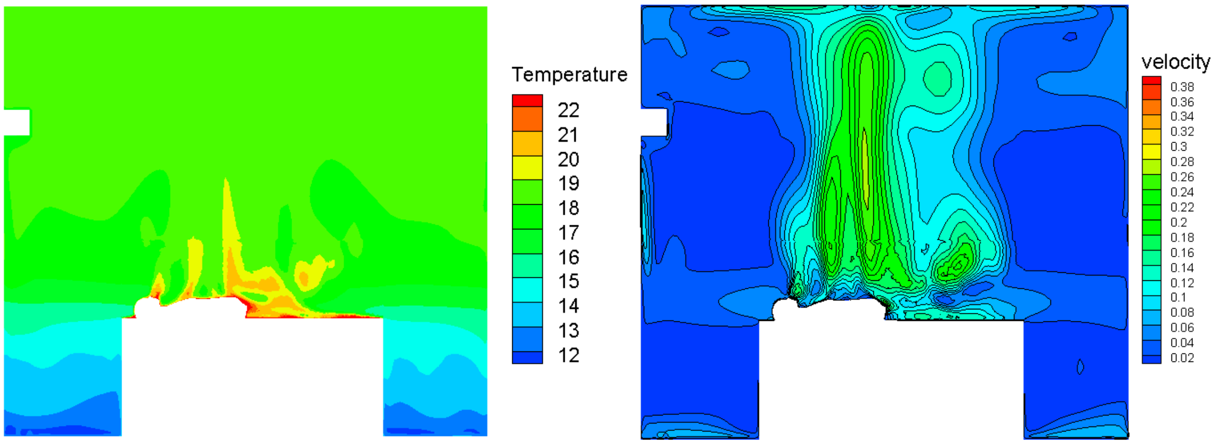
3.2. The radiation-based TAC system for heating a sleeping environment

When it comes to heating a sleeping environment, it is better to place the radiant panel under the sleepers, being the upper surface of the bed mattress, to reduce heat loss and improve energy use efficiency, like Chinese Kang or electric blanket. However, using Chinese Kang may lead to serious air pollution due to biomass burning as the heat source [9], while using electric blanket is not energy-economical due to high-level electricity used. Therefore, Fang et al. [10] proposed a novel radiation-based heating system powered by air source heat pump (ASHP) applied to sleeping environments, which can be seen in Fig. 6. The simulation results demonstrated that indoor air temperature in the occupied zone was 0.85ºC higher than that in the unoccupied zone and air velocity in the occupied remained a low level when using this system (see Fig. 7). In the future, the energy saving and thermal comfort performances when using the radiation-based heating TAC system will be experimentally optimized, and the simulation results verified.



(a) (b)

Fig. 6. The radiation-based TAC system power by ASHP: (a) Experimental setup (b) 3D view in the bedroom.



(a) (b)

Fig. 7. Simulation results: (a) Air temperature field (b) Air velocity field.

4. Conclusions

In this study, the structure, energy and thermal comfort performances on four types of bed-based TAC system were reviewed, as summarized in Table 1. All the bed-based TAC systems have great potential on energy saving, since only a small space is needed to be air conditioned. Although cold draft problem is severe when using the convection-based TAC systems, overall thermal comfort level is acceptable and using a proper supply air temperature, flow rate and a proper supply vane angle may help ease off the issue. Therefore, in general, good thermal comfort in a sleeping environment when using bed-based TAC systems can be achieved. Finally, for the first three bed-based TAC systems, indoor air quality in the occupied zone is better due to the available fresh air from supply vents. In the future, the bed-based TAC system should be optimized to further improve its performances on energy saving, thermal comfort and IAQ, and its structure should also be improved to make it more user-friendly.

Table 1. Four types of bed-based TAC system.

Author	Heat exchange method	Structure feature	Purpose	Pros	Cons
Pan et al. [3]	Convection	Air plenums, flexible air ducts, supply & return vents	Cooling	Energy saving	Bulky air ducts and plenums, Cold drafts
Mao et al. [4, 5]	Convection	Supply & return vents	Cooling	Energy saving, good IAQ	Cold drafts
Du et al. [7, 8]	Radiation	Radiant panel, supply & return vents	Cooling	Energy saving, good IAQ and thermal comfort	Bulky radiant panel
Fang et al. [10]	Radiation	Heating bed powered by air source heat pump	Heating	Energy saving, good thermal comfort, friendly to environment	High initial cost, large bed area

Acknowledgements

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