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Thermal comfort and energy saving of a personalized PFCU air-conditioning system

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Abstract

This paper evaluates the performance of a personalized air-conditioning system, namely an innovative partition-type fan-coil unit (PFCU), against that of a central air-conditioning system, in terms of their thermal comfort provided and cooling energy consumed. For a cooling load given, it is found that the thermal comfort index (PMV) resulted from the personalized system is always lower than that from a central system. Also, the PMV-curve of the personalized system responds to the loads faster. The experimental results indicate that the personalized system, as compared to the central system, can shorten the operation time for the same level of thermal comfort required and save up to 45% of the energy consumed by the central system. As regards thermal comfort, the experiment with a thermal manikin substrates the PFCU design for its considerable reduction of the cold draft.

Keywords: Partition-type fan-coil unit (PFCU); Personalized air-conditioning system; Thermal comfort; Energy saving; Thermal comfort index/predicted mean vote (PMV)

1. Introduction

The designs of commercial and residential air-conditioning systems mostly adopt air ducts and ceiling diffiisers to distribute air into the room. There are some drawbacks to such traditional designs:

- The airflow may be blocked by the space partitions, cabinets, furniture, and the like, which make the air distribution uneven and, thus, cause discomfort to the occupants.
- The air-conditioning systems usually run according to the set-point temperature, irrespective of the number of occupants in the room. Should the actual number of occupants falls below the occupancy for which the air conditioning unit is designed, the considerable waste of energy may occur for the unnecessary runtime.
- Since the air outlets of the traditional air-conditioning units are located on the ceiling, the air distributed from them may carry the heat off the lighting fixtures, attics and walls, thereby, increase the cooling load considerably.

In these respects, the concept of personalized air-conditioning systems had emerged from the intelligent-building designs since the early 1990s. For the architecture then adopted the structure of raised floor [1], the air-conditioning systems could utilize the space between the floors and the slabs as air-ducts to deliver air. Such design idea had thus started to be popular. The original idea of personalized air system was introduced by the under-floor air-distribution systems (UFAD) and the task air-conditioning systems (T-AC), etc. The advantages of these designs provide the users the convenience to adjust the air outlets for the air quality that they prefer in their personal work environment.

Relative to the personalized air-conditioning systems that supply air by the fixed air outlets on the raised floors, there are other alternatives that place the outlets somewhere else, such as at the office desks or on the office space partitions. Such motivation led to another invention, namely, the desktop air-conditioning system (DAC). The design offers

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the users easier access and adjustment to the airflow and/or temperature of the supply air. Therefore, the concept of personalized system gradually takes their roots in the main stream of air-conditioning design [2–5]. In North America, Bauman et al. [6] had collaborated with a local bank in an experiment arranged in an office to evaluate a personal environmental module (PEM), a system possessing the functions of DAC. After installation and operation for some time, it is found that the performance of the workers was greatly improved by the personalized system.

In Europe, Zeng et al. [7] and Kaczmarczyk et al. [8] examined the performance of a personalized ventilation system (PVS) in regard to the air quality and thermal sensation. In their studies, two groups of people were exposed to the supply air subject to changes of temperatures in the presence of a personalized ventilation system and the conventional mixing ventilation system (namely, a central ventilation system), respectively. The experimental results revealed that, under the same amount of supply air, the personalized ventilation system is superior to the conventional mixing ventilation system, in respect to the comfort of air temperature and air current.

Recently in Asia, Chiang et al. [9,10] focused the studies upon the personalized air-conditioning systems in the aspect of energy conservation and the comfort of airflow distribution, using an innovative partition-type fan-coil unit (PFCU). This new design provided the users with greater flexibility and convenience of air-quality control relative to the systems adopting the air outlets installed on the floor or on the ceiling. Pan et al. [11] further materialized the PFCU concept by adding an air-change devise to verify the feasibility. The results showed that the rate of air change by the PFCU is 32% more efficient than that by the central air-conditioning system that adopted the ceiling air outlets.

The concept of personalized air-conditioning system can be effective in reducing the cooling load due to the stratification of its localized air distribution. Its supply air can be effectively separated from the room air at higher altitude, which is of higher temperature, and consequently eliminates the unnecessary space-cooling load. Moreover, the personalized air-conditioning system design demonstrates a ‘‘supply-on-demand concept’’, that is, the air conditioning is provided to the occupants based upon their request and actual presence in the personal work environment. The investigation by Nobe et al. [12] revealed that, due to the assignments, the probability that the office workers are absent from the seats is about 30–50%. In that respect, the traditional air-conditioning system designed to serve a large area may not be able to respond to such change. By contrast, the personalized air-conditioning system is able to detect the occupancy of the work environment and determine its instant on-off action of space cooling provided. Thus, it is the objective of this study to examine the advantages of the personalized system, quantitatively.

2. Experimental methods

A partition-type fan-coil unit (PFCU) incorporating the function of fan-coil unit and multiple-split air conditioner into a regular partition used in the office spaces is constructed. The PFCU is of a slim design having a depth of 5 cm and the components with it (such as: heat exchanger, fan, and fan motor) are slim-designed as well. Fig. 1(a) shows the profile of the PFCU system. Its upper portion is designated for air outlet and a control panel that holds an occupancy sensor and two thermometers that measure the temperature of supply air and return air, respectively. The lower portion is designated for air return. For comparison purpose, a central air-conditioning system is also constructed. The real-scale office environment is implemented in a controlled climate chamber. The PFCU is as described above and the central system is a large water-cooled fan-coil unit that supplies the cool air through the ceiling diffusers.

In setting up the personalized system, two adjacent office workstations are arranged. Each of the workstations is constructed by combining one PFCU with several regular partitions. The supply air of PFCU is distributed above the desk and returns below the desk. For setting up the central system, a large water-cooling fan-coil unit (with a maximum air-flow rate of 600 CFM) is installed in the plenum above

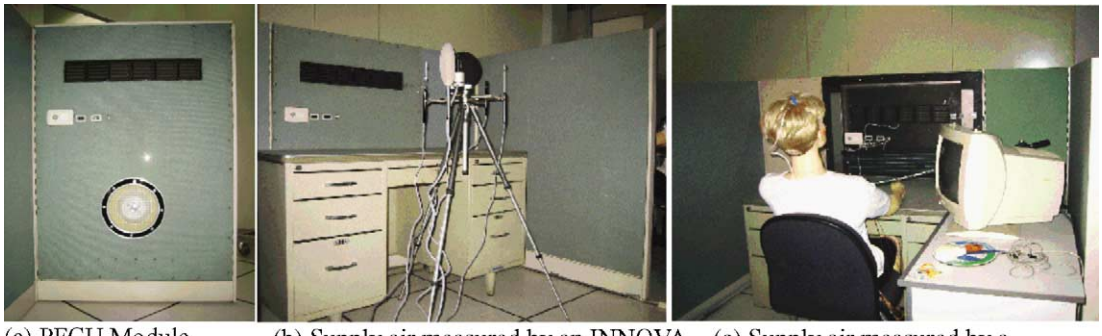

Fig. 1. Schematic of the innovative partition-type fan-coil unit (PFCU) installed in a controlled office environment.