STUDY OF AN INNOVATIVE PARTITION-TYPE PERSONAL MODULATION AIR-CONDITIONING SYSTEM

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ABSTRACT
This paper proposes a new personal air-conditioning system, which modifies a common partition used in offices to a partition-type fan-coil unit (PFCU) with inlets and outlets on its surfaces. Chilled water is supplied as the cooling energy, and is delivered to the partitions by pipelines incorporated into the structure. Hence, conventional air conditioning systems using ceiling-based air diffusers for open-plan offices may be dispatched into several small individual systems controlled by the occupants. Another advantage of the new system is that a raised floor system is not required, so the applicability to retrofit buildings is very convenient. In this study, the transient variations of room temperature distribution and the skin temperature of a thermal manikin were measured in a real-scale climatic chamber. The preliminary test results of a prototype system have shown that the PFCU system has many promising features and deserves further development.

INDEX TERMS
PFCU, Personal air-conditioning system, manikin, temperature distribution

INTRODUCTION
For decades, personally modulating of thermal environment has always been an interesting research topic in both industrial and academic sectors because of their benefits in increasing thermal comfort, improving indoor air quality and reducing energy consumption. Underfloor air distribution systems (UFAD) and task/ambient air-conditioning systems (TAC) are the well-known applications in this field. The rapid development of these systems was mainly due to the structural design of intelligent buildings (Caffrey, 1988). It provided the opportunity for new development of heating, ventilation and air-condition (HVAC) technologies. Especially, the raised floor system, a typical element of intelligent buildings, created an underfloor plenum to deliver conditioned air to the workspaces through the terminal devices on the floor or at the desktop. In comparison with the conventional ceiling-based air distribution systems, UFAD and TAC system have the benefits to allow the occupant to control the volume and the direction of the airflow to achieve more comfortable personal environment while several barriers do exist in widespread applications. The detailed reviews of these systems can be found in the literatures, such as Bauman and Webster (2001), Shute (1995), Heinemeier, Schiller and Benton (1990).

Using floor diffusers as the air terminal devices is the most common practice of UFAD system. The air supply units on the raised floor can be selectively allocated in the most crucial areas for improving thermal comfort or removing excessive cooling loads. They can also be moved to

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other places when the reconfiguration of buildings is needed. Thus, it provides flexibilities in terms of space and time. Nevertheless, there are still some concerns of the possible discomfort caused by draft and vertical temperature differences. The research efforts (Matsunawa, Lizuka, and Tanabe, 1995, Hanzawa and Nagasawa, 1990) have been introduced to improve the design of these air distribution devices for the satisfaction of occupants.

In order to give occupants more control capability over their personal environments, desktop air-conditioning (DAC) system has recently drawn great attention (Han et al., 2001, Cho, Kim and Zaheer-uddin, 2001, Lomonaco and Miller, 1997). DAC system supplies conditioned air from the desktop diffusers. In most cases, the supplied air is provided by an air duct connected to the underfloor plenum with or without the drive of a local fan. Hence, it belongs to one branch of the UFAD system, but it offers more benefits than the floor-based air distribution systems in terms of quicker response to personal need, higher ventilation efficiency and increasing productivity.

In this paper, we propose a new personal air-conditioning system, which can further decentralize a traditional ceiling-based fan-coil system into individual workspaces. This system changes the partition used in offices into a localized fan-coil unit with inlets and outlets on its surfaces. Room air, drawn in at the lower level by a small fan installed inside the partition, is cooled by an air-to-water heat exchanger and then discharged into the room from the outlets at the upper level. The air is mainly re-circulated within the workspace. If outside air is supplied to the partition through an air duct connected to the plenum, it can substitute portion of the circulated air in the workspace. Hence, the system is very suitable to accomplish the concepts of the personalized ventilation proposed by Melikov, Cermak and Mayer (2001), Fanger (2001), and Hiwatashi et al. (2000) and the dedicated outside air system by Mumma (2001) to improve the ventilation effectiveness and the indoor air quality.

Depending on the cooling demand of the workspace, several PFCU modules can be assembled together to divide the office space. The chilled water pipes or even the air ducts can be fitted in the partitions and joined with several PFCU modules. The chilled water pipes are then connected to a central chiller plant or several packaged chilling units. They can also be connected to a hot water supply system for heating purposes. It should be noted that, in this design, a raised floor system is not required, so its applicability to retrofit buildings is very convenient. It is especially attractive to the markets, as the economy no longer favors the growth of building constructions. The purpose of this paper is to justify the idea of this design. A prototype system has been built in our laboratory to examine the aforementioned benefits and to explore the potential problems for further improvements.

METHODS

In this study, a climatic chamber (about 4.6 x 3.7 x 2.7 cu. meters) was used to simulate a typical workspace as shown in Figure 1. The chamber has two exterior walls adjacent to a controlled exterior environment in 30℃ so to reflect the typical outdoor conditions in summer. The other two interior walls are adjacent to a walkway and a test room both without air-conditioning. The test chamber contains 480 points of T-type thermocouple forming a 3-D matrix to measure the room temperature.

The furniture arrangement in the test chamber is illustrated in Figure 2. Five partitions with different widths (but equal height of 1.4 m and thickness of 6 cm) were assembled to form an
individual workspace (2.4 m x 2.5 m) in the test chamber. Among these partitions, two of them were PFCU modules. Each contained a cooling coil and a cross-flow fan. The maximum air volume supplied by each module was approximately 60 L/s and it corresponded to an air speed of 1.0 m/s at the outlets that have the dimensions of 60 cm in width and 10 cm in height. The water with constant temperature of 7°C was supplied to the cooling coils through insulated polyethylene tubes inside the partitions.

**Figure 1.** Floor plan of the test chamber

**Figure 2.** Arrangement of workspace and PFCU system under tests

A thermal manikin consisting of 16 body parts was used to simulate a human body. It should be noted that the manikin only measures the sensible heat loss to the environment. The manikin sat on an office chair in front of a desk. The core temperature of the manikin was controlled to 36.5 °C and the transient skin temperature of each body part was measured. The manikin was dressed
as in Figure 2 and the Clo value of its garment was about 0.4. A personal computer was arranged next to the manikin to simulate an actual office set-up.

The test of PFCU modules was started from a uniform room temperature controlled at 30°C. In the test, a parallel air conditioning system for the base cooling of the entire test room was not considered, although some research works proposed the design concept. However, our paper is focused upon the transient response of local environment around the manikin.

RESULTS
In order to analyze the response time of the PFCU system, several extra points of temperature measurement were supplemented. These points were located at the inlets and outlets of the PFCU modules, the vicinity of the manikin and the outside of the partitioned zone. The measured results are plotted in Figure 3, accompanied with the transient variation of the mean skin temperature of the manikin. As the system was turned on, the air temperature at supply outlets decreased rapidly to around 19°C. The temperature of workspace around the manikin also approached to a comfort temperature of 26°C within 5 minutes. The mean skin temperature of the manikin reached its steady-state temperature within 20 minutes. The transient period of the PFCU system was comparatively shorter than the previous measurement (Hsu et al., 2000) for the traditional wall-mounted air conditioners, which took about 30 minutes to reach the stable mean skin temperature of the manikin.

![Figure 3](image-url)

**Figure 3.** Transient variation of the skin temperature of the manikin and some critical points

The steady-state temperature of each body part of the manikin is shown in Figure 4. The head and the hands had the lowest temperature due to cold air blowing directly on the bare surface of the manikin. The back and the hip had the highest skin temperature because the chair prevented heat dissipation from these portions. The largest temperature difference among these body parts was found to be around 2.5°C. Hence, the local discomfort resulted from the temperature difference was not significant for the tested system.
Figure 5 illustrates the temperature contours for the horizontal plane at the height of 1.1m (i.e., the workspace) and the vertical plane in which the manikin sat. The supply air discharged from the two PFCU modules can be clearly viewed in the figure and the two air streams merge at where the manikin located. In practice, an occupant can adjust the louvers of the outlets to change the direction of airflow upon personal preference. The figure also shows that the PFCU modules affect only the workspace enclosed by the partitions and cause little effect to the space outside the partitions. Therefore, the PFCU can be viewed as a personal device in an open-plan office to satisfy individual needs of occupants for air conditioning.

**Figure 4.** Steady-state skin temperature of each body part of the manikin

**Figure 5.** Temperature contours in test chamber

**CONCLUSIONS**

The paper illustrates a new personal air-conditioning system, which relies on a partition-type fan-coil unit for individual comfort control. The experimental results in a laboratory test chamber
have indicated that such a system provides two advantages: the fast response to occupant control and the flexibility of modulating the air supply conditions. Other benefits can also be expected if the system applies the proven technologies, such as: occupancy-based air-conditioning control, demand control ventilation, personal ventilation, off-hours cooling supply, etc. Although the preliminary results have shown the feasibility of this new system, some concerns relevant to technical and ethical issues still demand further studies in the future. These include the solutions of flexible piping, draining of condensate from cooling coil, and so on.

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REFERENCES