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Experimental and simulated energy performance of a personalized ventilation system with individual airflow control in a hot and humid climate

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ABSTRACT

This paper presents the energy performance of a personalized ventilation (PV) system with individual control of airflow rate in a hot and humid climate. A set of experiments with 46 tropically acclimatized subjects were conducted with ambient temperatures of 23 and 26 °C and PV air temperatures of 20, 23 and 26 °C. It has been found that as the ambient temperature is increased, subjects prefer higher PV airflow rates. While the higher ambient temperature reduces the cooling load, this is partly offset by the increased ventilation load. Therefore, it is not straightforward to quantify the energy savings accurately. In this work, an EnergyPlus simulation model was developed and validated by measurement data. The model was normalized to take into account the effects of the variations of outdoor conditions and the number of occupants. It was then applied to evaluate the energy performance of the PV system. The results show that when the PV air temperature is kept at 20 °C, the energy consumption at an ambient temperature of 23 °C is 10.8% higher than that at 26 °C. The best results are obtained when the PV air temperature is 20 °C and the ambient temperature is 26 °C. It is therefore concluded that increasing the ambient temperature has good potential to reduce energy consumption, whereas increasing the PV temperature does not bring appreciable benefits.

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1. Introduction

A personalized ventilation (PV) system supplies outdoor air close to the breathing zone of each occupant and has several advantages over conventional ventilation systems. Compared with mixing ventilation (MV) and displacement ventilation (DV), PV system has the potential to maintain a healthier environment at each workstation [1,2]. PV can improve the inhaled air quality and occupants' thermal comfort, and decrease sick building syndrome (SBS) symptoms [3–10]. PV in conjunction with MV or DV decreases the risk of airborne transmission of infectious agents and is superior to MV or DV alone [11,12]. With individually controlled microenvironment, PV has the potential to satisfy more occupants [13,14].

Limited studies have been performed on the energy performance of PV system. Yang et al. [15] indicated that ceiling mounted PV with MV system can realize better cooling effect and also decrease the total energy consumption when compared with MV alone and MV plus desk fan system. Cruceanu et al. [16] showed through simulation that PV could reduce the energy consumption by about 60% when compared with MV alone. Schiavon et al. [17,18] showed by means of energy simulation that PV has the potential for energy savings in both cold and tropical climates compared to MV alone when proper control strategies are applied. Through simulations with EnergyPlus, Schiavon et al. [19] studied the potential saving of cooling energy by increasing air speed. Seem and Braun [20] used simulations to compare the energy use characteristics of systems incorporating personal environmental control with conventional designs. Pan et al. [21] evaluated the performance of a personalized air-conditioning system, namely a partition-type fan-coil unit, in comparison with a central air-conditioning system, in terms of thermal comfort and cooling energy. Computational fluid dynamics (CFD) simulations were performed in many studies [22–27] to analyze the airflow, thermal, and/or CO_2 concentration fields around occupants as well as the energy saving potential

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when PV systems were used. However, these studies are done either by simulations alone or using experiments without subjects. The impact of large differences in behavior and preferences among occupants [3] on energy performance of PV system has not been studied.

Even though the energy saving potential of personalized ventilation (PV) is well recognized [28], adequate attention has not been paid to accurate energy modeling of PV systems taking into account the differences in personal preferences and behavioral characteristics of occupants. In this study, a set of experiments was conducted in a hot and humid climate to evaluate the energy performance of an individually controlled PV system. The system was equipped with individual control of airflow rate and hence referred to as PV-ICA (PV with Individual Control of Airflow) in this paper. Most of the subjects could achieve acceptable thermal comfort by adjusting the airflow rates [29,30]. The focus of this paper is on the energy saving potential of the PV-ICA system.

2. Methods

2.1. Experimental facilities

This study was conducted in the Field Environmental Chamber (FEC) of the National University of Singapore (NUS). The floor plan of the FEC is shown in Fig. 1. There are 13 workstations equipped with a computer and a desk-mounted PV air terminal device (ATD), and three openings which supply PV air to the room contributing to the ambient outdoor air supply. Fig. 2 shows the schematic diagram of the air distribution system. The FEC is served by two dedicated systems: an ambient air handling unit (AHU) with 100% recirculated air that is supplied through ceiling outlets and a PV AHU with 100% outdoor air that is supplied through the PV ATDs. Both systems are linked to a common Building Automation System (BAS). Fig. 3 shows the system diagram of the PV AHU in the BAS including the location of the sensors. The PV AHU includes a heat pipe for sensible heat recovery, and an electrical heater to control the PV supply air temperature. All the parameters required for computing energy consumption on the air side were recorded through the BAS at 1 min intervals, including supply air flow rates, fan speed, air pressures, supply and return air temperatures and RH, outdoor air temperature and RH, and chilled water supply and return temperatures. Users were able to control the airflow rate through PV ATDs at individual workstations using a software interface [31]. The flow was regulated by operating a motorized damper installed in the supply duct. In addition, users could change the direction of flow by turning the diffusers horizontally and vertically. All the changes were automatically recorded in the control system.

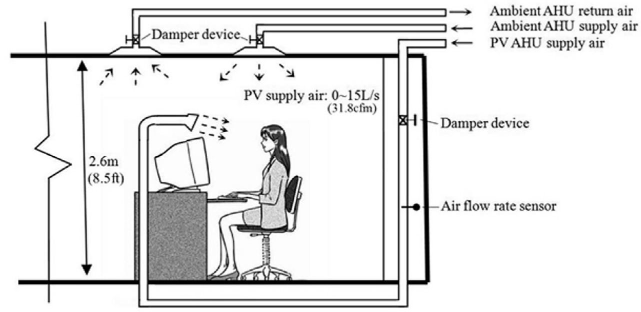

Fig. 2. Air distribution system in the FEC.

2.2. Experimental conditions

The subjective study consisted of 15 sessions of 2-h duration in the FEC. About 13 subjects participated in each session. During each session, environmental parameters such as ambient air

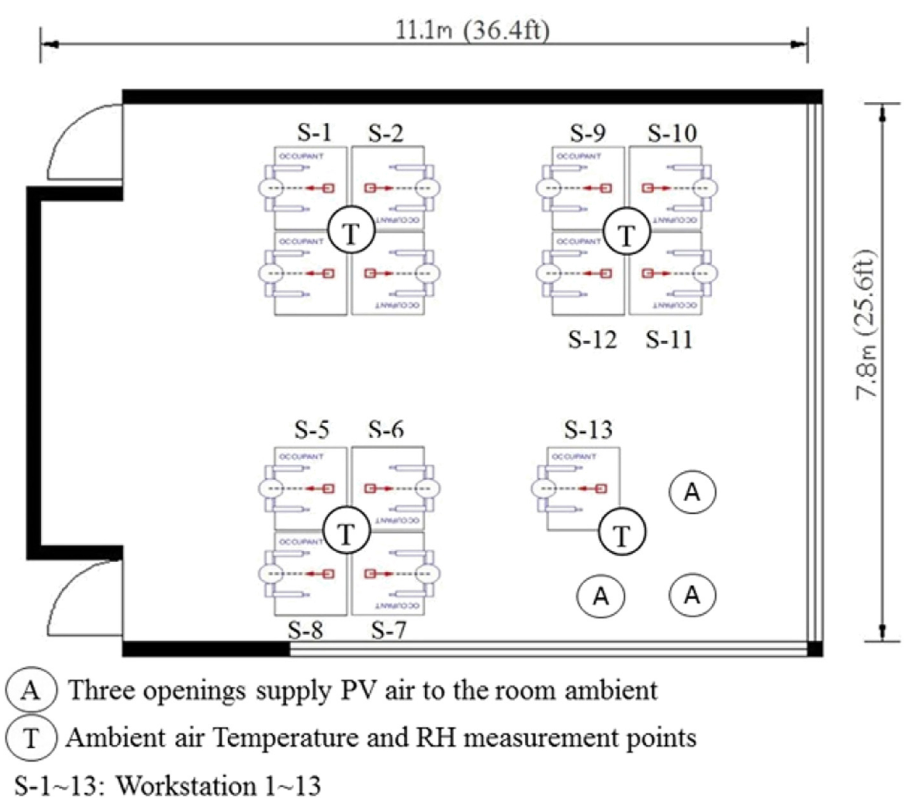

Fig. 1. Schematic of the Field Environmental Chamber.