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Improved performance of displacement ventilation by a pipe-embedded window

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ABSTRACT

The air distribution in displacement ventilation (DV) mainly depends on the heat sources in the room. The solar radiation and cold window are strong heat source or heat sink in summer and winter. A pipe-embedded window (PEW) has been developed to address the heat gain/loss through the window. In this study, the performance of the system based on DV and radiant ceiling was compared with that based on DV and PEW. A room with two workstations and two thermal manikins was adopted in the experiment. The impact of human bioeffluents and passive contaminant sources were studied. The results show that the warm window and floor in summer and cold window in winter damaged the normal air distribution of DV. The vertical temperature gradient was weakened and the ventilation effectiveness was close to that of mixing ventilation. The normalized contamination concentration was almost 1 in both workstations in different conditions. On the contrary, the PEW was able to keep the nature of DV and eliminate the negative effect from window. The bioeffluents and heat was efficiently removed by the DV flow. The exhaust air temperature in PEW system was higher in summer and lower in winter compared with radiant ceiling system.

1. Introduction

One of the main goals of heating, ventilation and air-conditioning (HVAC) systems is to maintain a healthy Indoor Air Quality (IAQ). The buoyancy-driven ventilation is considered as a promising approach to remove indoor contaminants and excess heat [1]. And the displacement ventilation (DV) is one of the most popular systems that obey this principle [2].

DV has been developed for several decades, and it is becoming increasingly popular in North America and Europe, especially in Scandinavian countries [3]. Compared with the conventional all-air system, the main advantage of DV is the ability of improving IAQ in the occupied zone where the warm air is rising through the stratified air rather than being mixed. The warm air is usually associated with the contaminant sources such as occupant's exhalation and odors [4]. Thus the polluted air can be removed through the extract air directly instead of transferring in the room. However, as concerns the passive pollution sources, they are independent of the heat sources and their transportation under the DV airflow is mainly affected by their locations. Sometimes, the contaminants at lower level can be raised by the occupant plume to the breathing zone and increase the personal exposure risk [5]. The airflow pattern and contamination distribution under DV are much more complicated than the simple mixing and dilution modes. It is crucial to apply DV in a proper way.

There are already extensive investigations on the impact factors of DV performance. The main factors include the location and intensity of heat sources, the room partitioning, the parameters of supply air, the human activities and the thermal plume around windows and walls [6]. Overall, the turbulence of occupied zone under DV is relatively low, and the ventilation effectiveness of DV may be easily destroyed by strong heat sources. Schmeling [7] investigated the effect of sensible heat release on ventilation efficiency and thermal comfort in DV. The results showed that the heat removal efficiency (HRE) decreased with increasing mean cabin temperature during human subject tests. Maier [8] researched the thermal comfort of different displacement ventilation systems and found that DV could provide comfortable climate situation in the aircraft passenger cabin with low air velocities. Mundt [9] conducted tracer gas measurements in a room with DV and found that the pollutants distribution is very sensitive to disturbances. Park and Holland [10] performed simulations and the results showed that the convective heat sources had significant influence on the flow and temperature fields in DV systems. If the DV system cannot accord with the heat sources or contaminant sources in the room, its performance is even worse than that of mixing ventilation [11].

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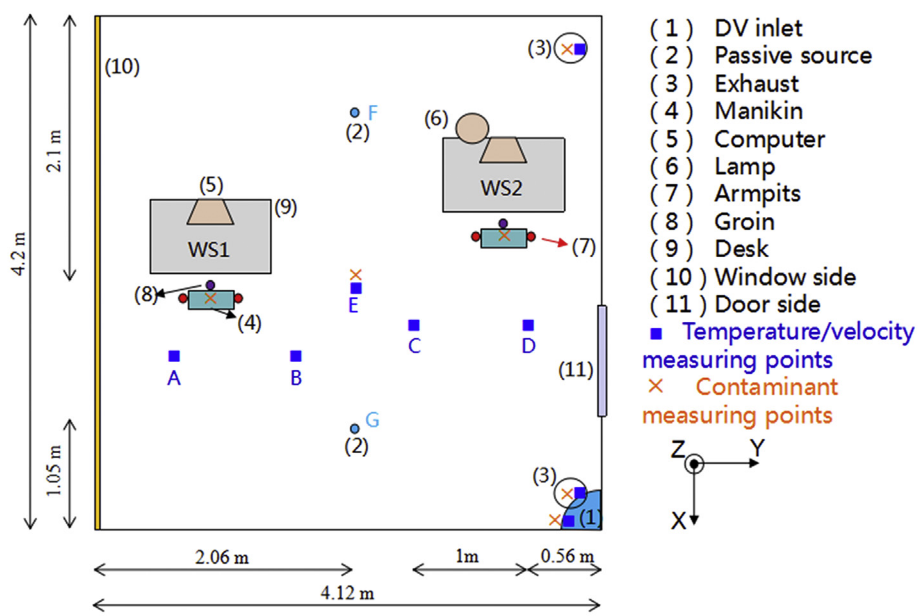
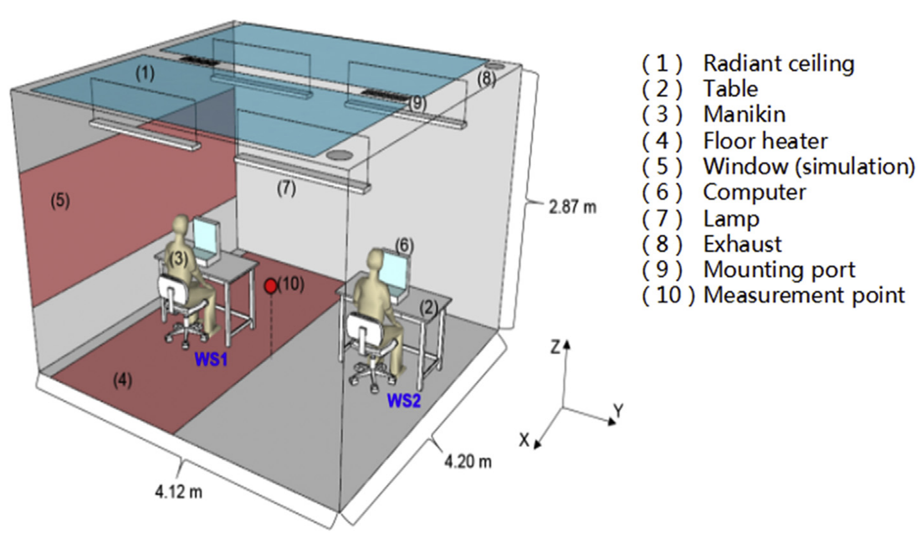
Nomenclature

C_x	concentration at the measuring point
C_s	concentration at the supply diffuser
C_e	average concentration at the exhaust diffusers
DR	draft rate
DSF	double skin façade
DV	displacement ventilation
DVCC	DV combined with chilled ceiling
DVCW	DV combined with cooling window
DVHC	DV combined with hot ceiling
DVHW	DV combined with hot window
HVAC	heating, ventilation and air-conditioning
IAQ	Indoor Air Quality
PEW	pipe-embedded window
WS	workstation
ε	normalized contamination concentration

A window is no doubt an important and intense heat source in a room. In summer, a window and the floor near the window are warmed up by the solar radiation. In winter, the surface temperature of window is much lower than the room temperature. These may influence or even destroy the normal air pattern and the ventilation effectiveness of DV systems [12]. To address the negative effects of windows, innovative solutions have been studied. Passive techniques such as the double skin façade were proposed to improve the shading in summer and insulation in winter [13]. In addition, the integration of passive techniques and active techniques has been investigated to improve the thermal



(a) Plan view of the simulated room



(b) Perspective view of the simulated room

Fig. 1. Plan and perspective view of the simulated room.