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Performance of "ductless" personalized ventilation in conjunction with displacement ventilation: Impact of disturbances due to walking person(s)

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ABSTRACT

The performance of the novel "ductless" personalized ventilation in conjunction with displacement ventilation (DV) was compared with the performance of DV alone under realistic conditions involving disturbances due to walking of one or two persons. An office room with two workstations was arranged in a full-scale test room. Two thermal manikins were used as sedentary occupants at the workstations. Two pollution sources, namely exhaled air by one of the manikins and passive pollution on the table in front of the same manikin were simulated. The performance of the ventilation systems was evaluated with regard to the quality of inhaled air and thermal comfort of the seated "occupants". The walking person(s) caused mixing of the clean and cool air near the floor with the polluted and warmer air at higher levels and disturbed the displacement principle which resulted in a decrease of the inhaled air quality. The performance of the "ductless" PV under the tested conditions was better as opposed to DV alone. Thus in practice the "ductless" PV will be superior to DV alone as regards perceived quality of inhaled air. The location of a walking person was found to be important. Person(s) walking close to the displacement diffuser will cause greater disturbance.

1. Introduction

Personalized ventilation (PV) is a new principle of clean air distribution. It aims to supply clean air direct to the breathing zone of occupants and provides the possibility for individual control of the microenvironment at each workstation [1,2]. The occupants may control the flow rate, the direction and temperature of the supplied personalized air so as to achieve the preferred thermal comfort conditions at their workstations [3,4]. It is possible that some occupants may turn off the PV system. Therefore it is recommended in practice to use PV in conjunction with a background total volume ventilation system. Recently a novel "ductless" personalized ventilation system was introduced, which utilizes the clean and cool air supplied over the floor by the displacement ventilation (DV) principle [5]. The "ductless" PV sucks, transports and supplies the clean and cool air distributed over the floor area by the DV, to the breathing zone of the occupant. In this way, clean and cool air can be better utilized and the flexibility of desk layout is not affected. Previously, it has been shown that under steady-state conditions the "ductless" PV coupled with DV is able to provide clean and cool air to the breathing zone of seated occupant [5].

Displacement ventilation is in comparison with traditional mixing ventilation more sensitive to disturbances caused by physical activities of occupants [6] such as opening and closing a door, moving, walking, etc. Mattson and Sandberg [7] used a human simulator of cylindrical shape and Mattson et al. [8] a simulator of more human-like shape to study the impact of a moving person on the airflow pattern in rooms with DV. Bjørn et al. [9] used breathing thermal manikins in order to study the impact of movement on personal exposure to exhaled air. A real person was used in the study by Brohus et al. [6], in which the impact of several typical "movements" on the performance of DV was investigated. Mundt [10] studied particle re-suspension due to a walking person in a room with DV and their entrainment by thermal flows generated by heat sources (including occupants). Full-scale experiments combined with CFD simulation reported by Matsumoto et al. [11] revealed that the object's moving mode and speed significantly influence the temperature and contaminant distribution in the room. The findings of these studies reveal that movement of a person has a substantial impact on the air distribution in rooms with displacement ventilation and may lead to a decrease of its ventilation performance.

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The impact of walking person(s) in different walking scenarios on the performance of "ductless" PV in conjunction with displacement ventilation was studied with regard to concentration of pollution generated by active (heated) and passive (non-heated) pollution sources in the inhaled air. The effect of different walking scenarios on the heat loss from an occupant's body and temperature distribution were examined as well. Some of the results are presented in this paper.

2. Methods

The experiments were conducted in a full-scale test room ($4.8 \times 5.4 \times 2.6$ m^3) located in a laboratory hall. An office room with two workstations; each consisting of a table with "ductless" PV (Fig. 1), a breathing thermal manikin and typical office heat sources were arranged in the room. Prior to the experiments the whole room was sealed.

The "ductless" PV installed at each desk consisted of an air terminal device (ATD) mounted on a movable arm and a small axial fan incorporated in a short duct system (positions 1, 4 and 5 in Fig. 1). The treated outdoor air supplied to the room near the floor by the DV spread in a relatively thin layer over the floor. The "ductless" PV sucked the clean air direct from this layer at the locations of the desks (position 6 in Fig. 1) and transported it to the breathing zone of the manikins. The ATD used during the experiments, named round movable panel (RMP), is described in Ref. [12]. The movable arm, to which the RMP was attached, allowed for free positioning of the RMP. During the present experiments the RMPs were positioned in front (0.4 m) and slightly above the faces of the manikins. This positioning was most often preferred by people [3,4].

The workstations were positioned behind each other as shown in Fig. 2. A semicircular wall unit with a radius of planar projection of 0.25 m and a height of 1 m, installed on the floor and attached to the middle of one of the walls, was used to supply outdoor treated air. The unit was fitted with nozzles that ensured the spread of the air mainly along the adjacent wall. The air was exhausted from the room by a square unit installed in the middle of the ceiling area. The recirculation of exhaust air to the supply air was not utilized in order to increase sensitivity of the tracer gas measurements.

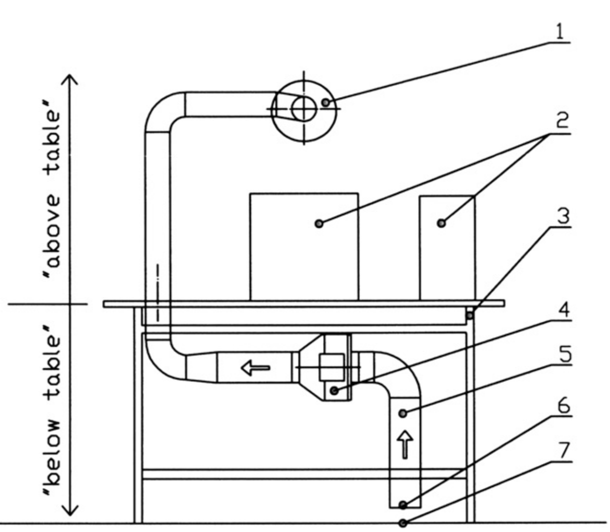

Fig. 1. "Ductless" PV system: (1) air terminal device, (2) heat sources, (3) table, (4) installed fan, (5) short duct system, (6) intake of "ductless" PV, (7) floor level.

2.1. Heat and contaminant sources

The total heat load generated in the room, i.e. the heat generated by the desk lights, the PC (tower plus monitor), the breathing thermal manikins and the six fluorescent lighting fixtures (6 W each) evenly distributed over the ceiling, was 22.6 W/m^2. The two breathing thermal manikins, each seated at one of the workstations on an upholstered office chair, were used to simulate two occupants. The manikins' bodies are shaped as a 1.7 m tall average size Scandinavian woman and are divided into several individually heated segments (17 or 23 segments). During the measurements the surface temperature of the manikins was controlled to be the same as the skin temperature of an average person in a state of thermal neutrality [13]. Since the experiments simulated summer conditions, the clothing insulation of the manikins together with upholstered office chair insulation, was 0.59 clo in total [14].

Pollution from two sources with different behaviors, namely warm exhaled air (active pollution) and passive (unheated) point pollution source on the table, was simulated by using a constant emission of tracer gases. One of the manikins (referred to in the following as a *polluting* manikin, seated at workstation WS1) was equipped with an artificial lung. The simulated breathing cycle consisted of 2.5 s inhalation, 2.5 s exhalation and 1.0 s pause. The breathing frequency was 10 cycles per minute and the pulmonary ventilation was 0.6 L per breath. The exhaled air was traced with a constant dose of 0.135 mL/s sulphur hexafluoride (SF_6). To ensure the density of air exhaled by people (1.144 kg/m^3) the air exhaled by the polluting manikin was heated. The air was exhaled from the nose of the polluting manikin and inhaled through the mouth. The pollution from the passive point pollution source in front of the polluting manikin was simulated by tracer gas Freon. This tracer gas was released from a small perforated ball to ensure a uniform dispersion. The second manikin was used in all experiments as an *exposed manikin* and was seated at workstation WS2 (Fig. 2).

2.2. Experimental conditions

The walking person(s) with natural body movement and wake behind their body generated more realistic disturbances in comparison with the regular and monotonous movement of the human simulators used in previous studies [7,9].

During all experiments 80 L/s of treated outdoor air at 20 °C was supplied to the room by the DV, aiming at an exhaust air temperature of 26 °C. The temperature in the tall hall was controlled to be 25 °C. Experiments with displacement ventilation only, i.e. the reference case (RF), and displacement ventilation together with the "ductless" PV at the two desks supplying each 15 L/s personalized air (PV_15_15) were performed. These are listed in Table 1. Three walking scenarios were simulated (Fig. 3): scenario 1 (W1_1P) – one person walking along the room between the displacement diffuser and the two workstations; scenario 2 (W2_1P) – one person walking along the room far from the displacement diffuser; scenario 3 (W_2P) – two persons walking at the same time along the room on the two sides of the workstations (the paths of scenarios 1 and 2). In order to avoid errors due to differences in the walking pattern and the behavior, the same person walked during the experiments of the three scenarios. In scenario 3 a second person joined the experiments.

2.3. Experimental procedure

The procedure applied during the experiments with the three walking scenarios was identical. After steady-state conditions were achieved, measurements were performed without a walking person. The results obtained are referred to in the following as