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Effective draft temperature for evaluating the performance of stratum ventilation

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ABSTRACT

With its reliability and simplicity, effective draft temperature (EDT) has been a popular tool for the practice engineers to evaluate and/or predict the performance of mixing ventilation. In this study, experimental measurements are conducted in a large environmental chamber under stratum ventilation. A computational fluid dynamics (CFD) model, which is previously validated extensively, is further validated with the experimental data generated in the current study. Simulations are also carried out using the validated model. Data generated by means of experiment and of simulation are used to formulate effective draft temperature for stratum ventilation (EDTS). Similar to its counterpart for mixing ventilation, the new effective draft temperature for stratum ventilation (EDTS) is also found to be reliable and straightforward in evaluation of the performance in thermal comfort of stratum ventilation. The effective draft temperature for stratum ventilation (EDTS) has the potential to be applied easily by practice engineers in air distribution design of stratum ventilation.

1. Introduction

Minimizing the energy consumption by air conditioning systems would help to reduce carbon emission. Proactive actions in this regard have been taken by several governments in East Asia. Guidelines for various elevated room temperatures in summer have been issued, e.g. 25.5 °C for Hong Kong, 26 °C for the Chinese Mainland, 27 °C in the "Office of President" in Taipei, 26 to 28 °C for the Republic of Korea, more radically, 28 °C for Japan [1]. Similar trend even occurs in the United States [2]. Elevating room temperature also could achieve thermal comfort. The new ANSI/ASHRAE Standard 55-2010 offers new provisions that allow increased air movement to broadly offset the need to cool the air in warm conditions [3]. To accommodate the elevated room temperatures, stratum ventilation was proposed for small to medium rooms [4,5]. This ventilation method is realized by positioning supply terminal(s) at the side-walls or columns slightly above the height of occupants. Although the supply air temperature for stratum ventilation is higher than that of conventional ventilations, the distance between the occupants and the air terminal is shorter. The RNG k-ϵ turbulent model can be used to predict the flow field created by stratum ventilation [1,6]. Tian et al. showed that stratum ventilation was able to achieve good thermal comfort measured by PMV and PPD [7]. Tian et al. investigated the diffusion of CO_2, formaldehyde and toluene under stratum ventilation experimentally and numerically [8]. The results demonstrated the flow pattern formed by stratum ventilation was able to provide good IAQ in the breathing zone. Tian et al. found that the particle concentrations under stratum ventilation of the entire room, and of the breathing zone in particular, are less than those under displacement ventilation [9]. Typical configurations of an office, a classroom and a retail shop in Hong Kong were investigated [10]. Compared with mixing ventilation and displacement ventilation, the year-round energy consumption of stratum ventilation was found to be substantially lower. The thermal neutral temperature under stratum ventilation was found to be approximately 2.5 °C higher than that under mixing ventilation and 2.0 °C higher than that under displacement ventilation respectively [11]. This result indicated that stratum ventilation could provide satisfactory thermal comfort level to rooms of temperature up to 27 °C. Tian et al. investigated air speed, temperature and CO_2 concentration of a stratum ventilated office experimentally and found that: (1) the CO_2 concentration in the occupied zone is typically lower than that in the upper zone; (2) in the occupied zone, the air speed generally increases with height, whereas the temperature gradient is reverse with the lowest value at the head level [12]. The cooling effect (temperature and air movement) of the conditioned airflow is also strongest at the head level; (3) ventilation effectiveness of all the four cases studied is greater than 1.4, which shows that the air distribution of stratum ventilation is efficient. Although several aspects of stratum ventilation have been investigated, there still is insufficient knowledge on how to evaluate the performance of

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Fig. 1. Experiments in environmental Chamber.

stratum ventilation. The aim of this study therefore is to find a simple formula characterizing thermal comfort condition in a stratum ventilated room for the easy use of the design engineers.

2. Methodology

2.1. Effective draft temperature (EDT)

For stratum ventilation, non-isothermal air streams enter a room at head level. A horizontal air layer is formed with some entrainment of surrounding air. Compared with conventional ventilation methods, the age of the air layer is younger. A greater amount of fresh air is brought into the breathing zone/head level. The range of air speed approaching the occupant(s) is from 0.3 to 0.8 m/s to break the boundary layer around an occupant and to minimize risks of draft. In the occupied zone, the vertical temperature gradient is reverse and modest with the lowest point at the head level. On one hand, for the occupied zone in a stratum ventilated room, the largest variations of air velocity and temperature occur at the head level because the supply air jets are at this level [12]. It is obvious that the higher the non-uniformity, the more difficult to achieve universal thermal comfort. The head-level plane is therefore the most difficult position to achieve thermal comfort condition under normal circumstances. If the thermal comfort requirements are satisfied at the head-level plane, so does in the entire occupied zone. On the other hand, variations in air velocity and temperature are significantly higher than variations in the other parameters that affect thermal comfort, such as mean radiant temperature, relative humidity, etc. It is therefore clear that thermal comfort in a room can be achieved if the variations of air velocity and temperature at head level are restricted within a certain range. To evaluate the uniformity of air velocity and temperature, Koestel and Tuve [13] and Reinmann et al. [14] studied the effect of air motion on comfort and defined draft as any localized feeling of coolness or warmth of any portion of the body due to both air movement and air temperature, with humidity and radiation considered constant. To define the effective draft temperature θ_{ed} (difference in temperature between any point in the occupied zone and the control condition), the investigators used the following equation originally proposed by Rydberg and Norback [15] and later modified by Straub and co-workers [16,17] in discussion of the paper by Koestel and Tuve [13]:

$$\theta_{ed} = (t_x - t_c) - 8(v_x - 0.15) \tag{1}$$

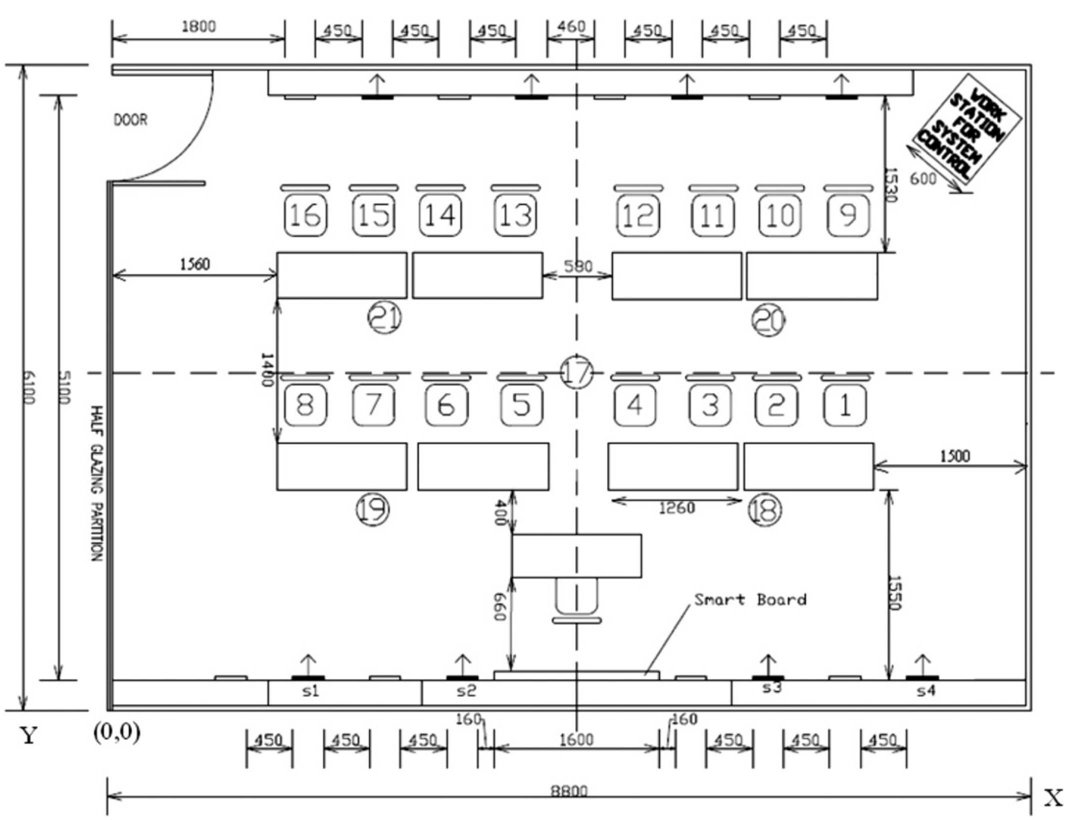

Fig. 2. Measuring positions at 1.1 m level.