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Effects of temperature and supply airflow rate on thermal comfort in a stratum-ventilated room

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ABSTRACT

Providing an appropriate thermal comfort level is crucial for the technical feasibility of stratum ventilation at elevated room temperatures. This paper presents a subjective study of thermal comfort in a stratum-ventilated environmental chamber. Overall thermal sensation (OTS), local thermal sensation (LTS) of body segments, overall thermal comfort (OTC) and draft were investigated. The objectives of this study were twofold: to evaluate the effect of room temperature on thermal comfort (Test Series 1) and to assess the effect of supply airflow rate and supply air temperature on thermal comfort (Test Series 2). Test Series 1 revealed that the room temperature had a great impact on the OTS, LTS, OTC and draft. Under 10 air change per hour (ACH), a room temperature of 27 °C provided neutral OTS, satisfactory OTC and low draft risk. However, at room temperatures of 24 and 29 °C, the percentages of subjects feeling comfortable were obviously less than 80%. Test Series 2 showed that at the room temperature of 27 °C, increasing the supply airflow rate from 7 ACH to 17 ACH only exhibited a small influence on the thermal sensation and draft, indicating a preference for air movement. More than 80% subjects felt comfortable at 27 °C. However, to minimize draft complaints, the supply air temperature should not be below 20 °C. These results show that stratum ventilation provides a thermally comfortable environment, so that people can have the feeling of "cool head and warm feet", with low draft risk at a room temperature up to 27 °C.

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1. Introduction

Elevating the indoor air temperatures in air-conditioned buildings may lead to energy savings and thus a reduction of CO_2 emission [1–3]. Guidelines for various elevated room temperatures in summer have been issued by several governments in East Asia, such as 25.5 °C for Hong Kong [4], 26 °C for the Chinese Mainland [5], 26–28 °C for the Republic of Korea [6] and 27 °C for Taiwan [7]. The present standards allow elevated air speed to offset the impact of increased room temperatures on occupants' comfort [8,9]. To accommodate the warm indoor conditions, stratum ventilation, an air distribution solution, was proposed for small-to medium-sized rooms [10,11]. It supplied cool fresh air directly to occupants' head level (i.e. the breathing zone) by positioning supply air terminal(s) at the side walls or columns slightly above the height of the occupants. Thus, compared with mixing ventilation and/or displacement ventilation, stratum ventilation can provide air of younger age to the breathing zone [12], and therefore, it can lower the inhaled contaminant concentration [13,14], the risk of pathogen inhalation [15,16] and the year-round energy consumption substantially [17].

Providing the appropriate comfort level is essential for the technical feasibility of stratum ventilation at elevated room temperatures. It is thus important to evaluate the thermal comfort performance of stratum ventilation. Tian et al. [18] measured the detailed distributions of air velocity and temperature in a stratum-ventilated office. Based on the measured data, the calculated thermal comfort indices including the PMV (predicted mean vote), PPD (predicted percentage dissatisfied) and PD (percentage dissatisfied due to draft) satisfied the comfort requirements prescribed in ASHRAE 55-2013 [8] and ISO 7730-2005 [9]. This indicated that stratum ventilation provided a satisfactory thermal comfort level. Similar results were also obtained by CFD (computational fluid dynamics) simulations in an office [19], a classroom [20,21] and a workshop [22].

There exist a number of factors which may affect the comfort performance of stratum ventilation, e.g. air terminal layout [23], air terminal type [24], supply air temperature [18,25] and supply

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airflow rate [26]. In a previous simulation study, two supply temperature levels (19 °C and 21 °C) were employed to investigate their impact on thermal comfort [25]. Results showed that when the supply air temperature was increased from 19 °C to 21 °C, the thermal comfort level quantified by PMV, PPD and PD was improved. Actually, the study presented the combined effect of room temperature and supply air temperature rather than supply air temperature alone, because under an identical indoor cooling load and supply airflow rate, supply air temperature and room temperature were coupled. Cheng and Lin [26] assessed the influence of supply airflow rate on thermal comfort under different supply air temperatures in a stratum-ventilated classroom with multiple thermal manikins. Results indicated that at relatively low supply temperatures (e.g. 18 °C), increasing supply airflow rate significantly deteriorated thermal comfort whereas the elevation of supply airflow rate did not lead to draft at relatively higher supply temperatures (e.g. 23 °C).

Although these studies had been carried out to evaluate the thermal comfort of stratum ventilation, most of them adopted thermal comfort indices based on objective measurements and numerical simulations. Additionally, they mainly focused on investigating overall thermal sensation (OTS) with little attention to local thermal sensation (LTS) of body segments; however, the suitable level of LTS of the body segments is also important for thermal comfort [27,28]. As a new air distribution method, the knowledge about stratum ventilation is therefore still limited. There is a need to assess the effect of room temperature, supply airflow rate and supply air temperature on thermal comfort under stratum ventilation using human subjective experiments.

The specific objectives of the present study are to:

1. evaluate the impact of room temperature on the OTS, LTS of body segments, overall thermal comfort (OTC) and draft;
2. study the OTS, LTS of body segments, OTC and draft under various supply airflow rates; and
3. assess the effect of supply air temperature on the OTS, LTS of body segments and draft.

2. Experimental methodology

2.1. Experimental facilities and setup

The experiments were conducted in an environmental chamber with the dimensions of 8.8 m (L) × 6.1 m (W) × 2.4 m (H), as shown in Fig. 1. The left wall comprised a half glazing partition. This

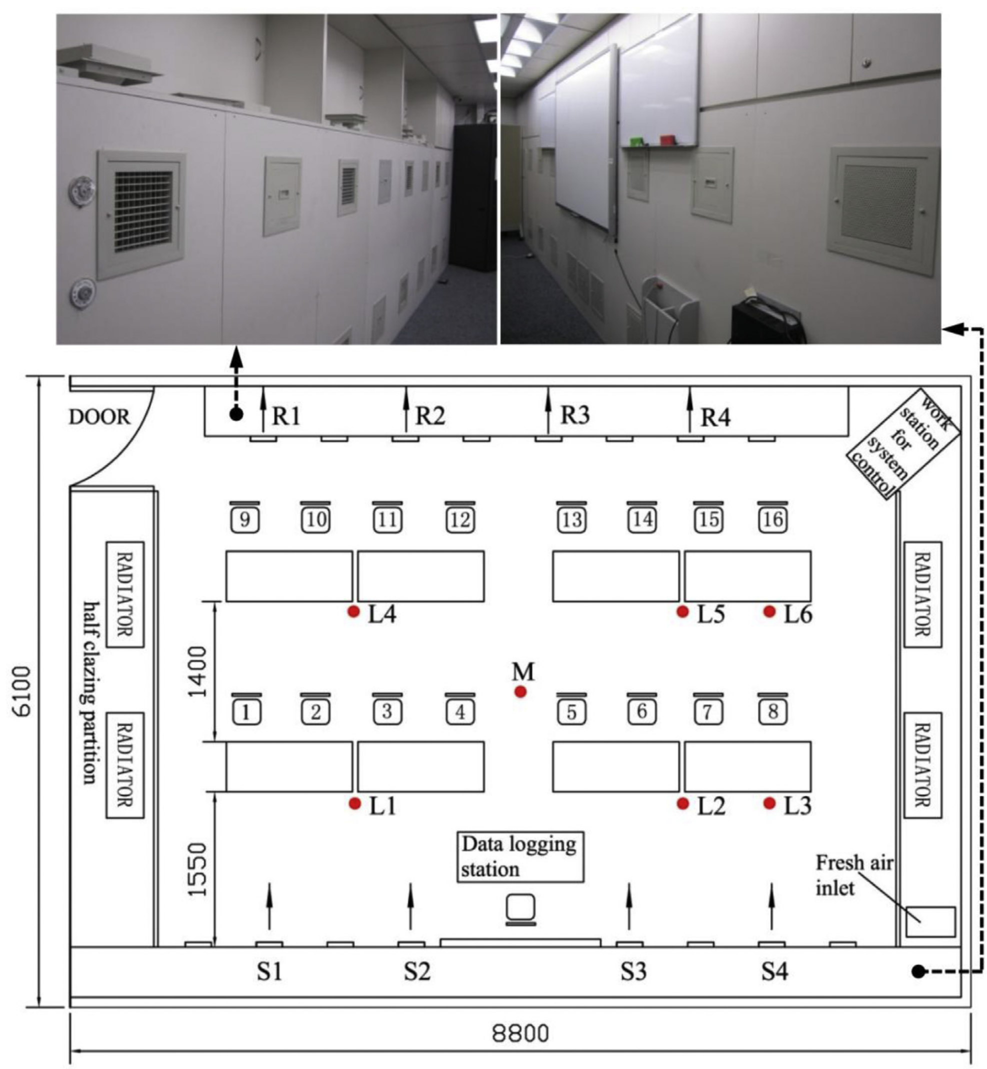

Fig. 1. Setup of experiments and layout of sampling plumb lines (mm).

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