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Perceptible airflow fluctuation frequency and human thermal response

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ABSTRACT

In the past 60–70 years, a lot of thermal comfort studies have examined the effects of air movement on human comfort. Previous research has shown that besides air velocity and turbulence intensity, airflow fluctuation frequency is also important for the perception of thermal environment. In the current study, a dynamic air supply terminal was used to generate sinusoidally varying airflows with different fluctuation frequencies. Subjective climate chamber experiments were carried out at both 28 °C and 30 °C, and the results showed that the perceptible range of fluctuation frequency was between approximately 0.2 and 1.5 Hz. The subjective thermal response results indicated that airflows of 0.5 and 1.0 Hz had a stronger cooling effect on subjects. The air velocity fluctuating frequency identified in the present study confirmed previous findings and was around 0.5 Hz. The results also indicated that proper application of airflow fluctuation frequency could offset the 2 °C temperature increase from 28 °C to 30 °C. So when the air velocity is limited and cannot be elevated, airflow fluctuation frequency can be considered as another control factor to offset increased temperature in warm environment.

1. Introduction

Most HVAC systems are designed to provide a uniform and constant environment within the occupied zone in order to attain an average overall thermal sensation for all occupants that is approximately neutral. However, a lot of energy is required to maintain a steady air-conditioned environment in the occupants' comfortable zone. Appropriate airflows can provide suitable stimuli to eliminate fatigue effectively. In addition, effective utilization of airflows can allow the indoor set temperature to be increased, resulting in cooling energy savings [1]. At high heat loads, air movement can increase the cooling effect and maintain thermal comfort at elevated temperatures, as recommended in the present standard (ASHRAE 55 2004, ISO 7730 2005 and EN 15251 2007 [2–4]). Previous study has shown that the power input of the fan is a critical factor for achieving energy saving at elevated room temperature [5]. So by reasonably using airflow and fan systems, the amount of energy required to cool a building can be reduced compared to general air conditioning systems [6].

In the past 60–70 years, numerous thermal comfort studies have examined the effects of air movement on human comfort [7]. Many airflow studies have focused on air velocity; the main goal of these studies has been to determine possible air velocity values that will improve human thermal comfort in different temperatures [8–13]. As a basic airflow parameter, turbulence intensity has also drawn much attention and the impact of turbulence intensity on people's thermal sensation and comfort has been studied [14–16]. A function of predicted percentage of people dissatisfied due to airflow draft (DR) was put forward considering the effect of turbulence intensity [14] and it is included in the present standard [2]. Airflow direction is also well documented and the influence of airflow direction on the comfort level as well as the convective heat transfer coefficients was discussed [17–20] in previous work.

In addition to air velocity, turbulence intensity and airflow direction, another airflow characteristic, fluctuation frequency, is also important for the perception of thermal environment. Numerous studies have examined the effect of fluctuation frequency on human thermal response. Fanger and Pedersen carried out a series of subjective experiments under cool and moderate conditions, and their results showed that maximum discomfort was experienced when the air velocity fluctuated at frequencies between 0.3 and 0.5 Hz [21]. This result was confirmed by Zhou and Melikov [22,23], who found that frequencies in the range of 0.2–0.6 Hz were the most uncomfortable. Tanabe and Kimura [24] examined various forms of fluctuating air movements in the range of 27–31 °C; they concluded that sine waves with cycles of 10, 30, and 60 s produced significantly cooler thermal sensations at a given mean speed than constant or step-changed wind speeds. They also found that the differences among

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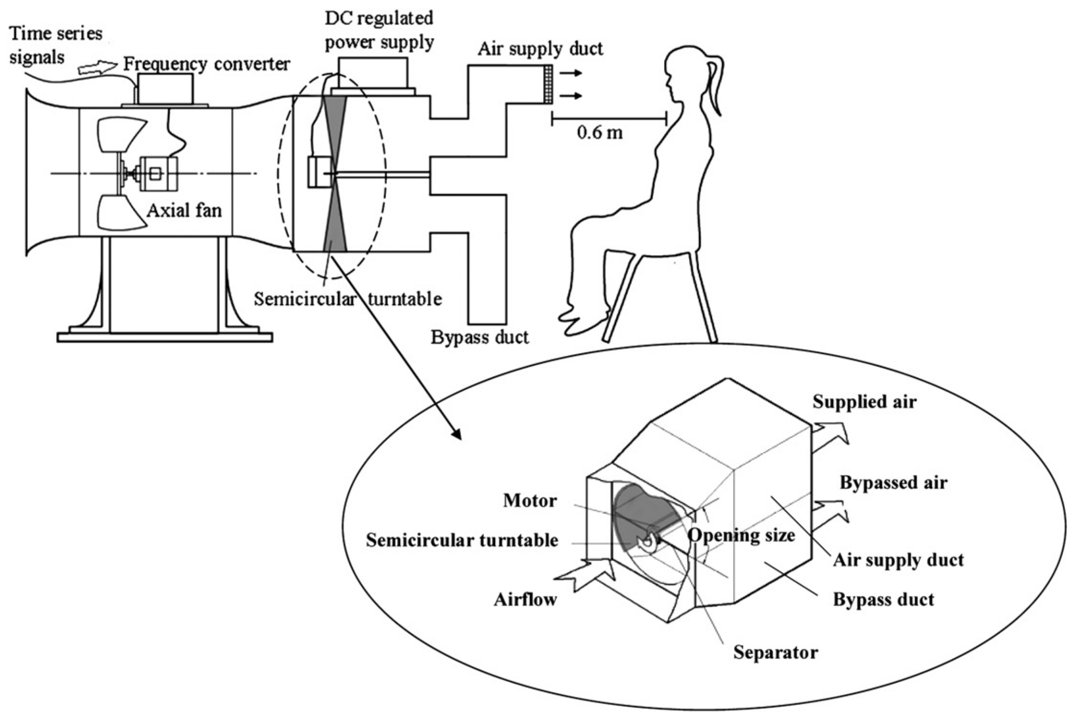

Fig. 1. Dynamic air supply terminal.

subjects' thermal sensation votes for airflows of 0.0167, 0.033, and 0.1 Hz were not significant. Arens [25] conducted a study in which occupants' thermal responses were measured in personally controlled environments; it was found that a cooling mode with a power spectrum peaking between 0.7 and 1.0 Hz was more effective than a mode with peaking frequencies between 0.2 and 0.4 Hz. Through a series of subjective climate chamber experiments in warm environments, Xia [26] found no significant differences among the thermal sensation votes for airflows of 0.057 Hz, 0.08 Hz, 0.113 Hz, and 0.182 Hz. 80% of subjects reported that frequencies between 0.3 and 0.5 Hz were comfortable, meaning that airflows with frequencies between 0.3 and 0.5 Hz had the best cooling effect.

The goal of the current study was to find the range of frequencies that have a significant effect on human thermal response based on whether the fluctuation frequencies are perceptible. Climate chamber experiments were conducted and the effect of perceptible fluctuation frequency on subjects' thermal responses was examined. The results of this study were also compared to previous research.

2. Methods

2.1. Measurements

In the experiments, the air velocity was measured using a hot wire anemometer with a hot wire diameter of approximately 20 μm. The sampling frequency was 10 Hz, meaning that the anemometer recorded 10 air velocity values every second. Its precision was ±(5% V+0.02) m/s, where V is the actual velocity. A PMV and PPD indices meter (AM-101, Kyoto Electronics Manufacturing Co. Ltd., Japan), with which air temperature, mean radiant temperature (MRT), airflow velocity, and relative humidity could be measured, was used to measure air temperature and relative humidity. Its precision for temperature measurement was ±0.5 °C (15–35 °C), and for relative humidity measurement, its precision was ±3% (20–80% RH).

2.2. Dynamic air supply terminal

A dynamic air supply terminal was used to generate sinusoidal airflows with different fluctuation frequencies (Fig. 1). This device

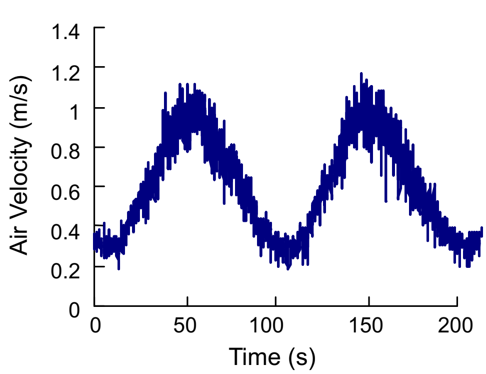

Fig. 2. Measured air velocity diagram of airflows at 0.01 Hz.

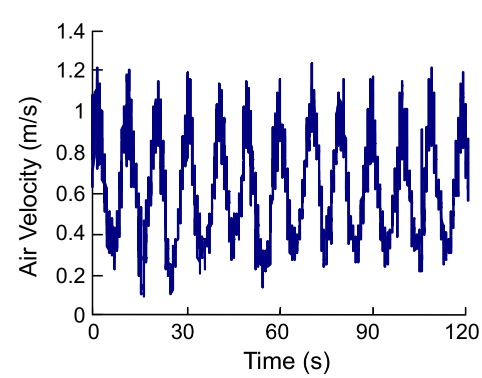

Fig. 3. Measured air velocity diagram of airflows at 0.1 Hz.