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Thermal insulation of clothing ensembles for Chinese textile workers in the cotton textile workshop

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ABSTRACT

To assess the thermal insulation of clothing ensembles in a real cotton textile workshop environment, air velocity and walking speed were adopted to correct the static value of the basic insulation. Approximately 41 workers were chosen as the subjects to assess the static value of the thermal insulation and derive the dynamic value of the thermal insulation in the actual cotton textile workshop. Comparative analyses were performed between the data obtained in both static and real world conditions. Results showed that the dynamic value of basic insulation/total insulation was significantly lower than the static value, with basic insulation lowering 0.07 clo and total insulation lowering 0.29 clo. Due to the change in the thermal insulation, the thermal environment deteriorated at a low operative temperature ($< 32\ ^{\circ}C$) and improved at a high operative temperature ($> 32\ ^{\circ}C$) in real world conditions when compared to static conditions.

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1. Introduction

Thermal insulation is one of the most important parameters in the thermal models adopted by the ASHRAE 55 [1], ISO 7730 [2], and ISO 7933 [3]. However, most thermal studies [1–4] are primarily focused on the thermal insulation in the static conditions. The static insulation for these standards [1–3] was measured at the air velocity around 0.1–0.15 m/s [5]. In real world situations, when the air velocity and walking speed exceed the limit of the static conditions, the heat transfer from the skin surface to the clothing is significantly increased [6], which results in changes in the thermal insulation and thermal comfort [7] in the actual situations.

The textile industry is characterized by its poor workshop environments [8] and low wages [9], which has resulted in labor shortages in recent years in China. However, the textile industry is an important industry in the national economy to meet growing domestic and international market demands. According to Ref. [10], the Chinese textile industry employs more than 10 million workers. The total value of exports from the Chinese textile industry was 2209.6 billion USD in 2013, accounting for over 35% of the world's export market. Therefore, it is necessary to research the thermal characteristic experienced by the textile workers and the corresponding thermal environment of the Chinese textile workshops, which was investigated by the authors in 2014 [8]. But the former research of the authors was based on the thermal insulation in the static conditions. In the actual cotton textile workshop, the thermal sensation of the worker may be affected by considering the thermal insulation change between the static and real world conditions. This work aims to assess the thermal insulation of the typical clothing ensembles for workers in the cotton textile workshop by performing comparative analyses

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between the results obtained in static and real world conditions.

2. Theories

Basic insulation for an ensemble (I_{cl}) can be estimated based on a summation of the insulation of individual garments using the following empirical equation [5]:

$$I_{cl} = 0.161 + 0.835 \sum I_{clu} \tag{1}$$

where I_{clu} is the basic insulation of the individual garment.

The static value of total insulation (I_T) from the body surface to the environment can be determined by the following equation:

$$I_T = I_{cl} + \frac{I_a}{f_{cl}} \tag{2}$$

where I_a is the static air insulation around the outer clothing. The static value of I_a in most studies was estimated as 0.7 clo in the static conditions. The clothing area factor f_{cl} is estimated from the following equation [5,6]:

$$f_{cl} = 1.00 + 0.28 \times I_{cl} \tag{3}$$

Once the basic insulation was determined, the static value of total insulation can be obtained by Eqs. (2) and (3).

Total insulation and basic insulation are defined for standardized (static, standing body) conditions. In the actual cotton textile workshop, air movement was present and movement of the worker was given as the constant, the air insulation in the dynamic conditions was different to the total insulation and basic insulation typically used in standardized conditions. The dynamic value of air insulation ($I_{a,r}$) can be corrected by the static value of the air velocity and the walking speed [5,11,12].

$$I_{a,r} = e^{\left[-0.533\times(v_{ar}-0.15)+0.069\times(v_{ar}-0.15)^2-0.462v_W+0.201v_W{}^2\right]}.I_a \tag{4}$$

where v_{ar} is the relative air velocity, in m/s;v_w is the walking speed, in m/s;I_a is the reference value for air insulation (=0.7 clo).

The dynamic value of the total insulation ($I_{T,r}$) can be corrected by the following equations [13].

$$I_{T,r} = \begin{cases} I_{T,r,dressed} & 0.6\,clo < I_{cl,r} < 1.4\,clo \\ I_{a,r} & I_{cl,r} = 0\,clo \\ \left[(0.6 - I_{cl,r})I_{a,r} + I_{cl,r} \times I_{T,r,dressed}\right]/0.6 & 0\,clo < I_{cl,r} \le 0.6\,clo \end{cases} \tag{5}$$

where

$$I_{T,r,dressed} = e^{\left[-0.281\times(v_{ar}-0.15)+0.044\times(v_{ar}-0.15)^2-0.492v_W+0.176v_W{}^2\right]}.I_T \tag{6}$$

The dynamic value of the basic insulation is determined by the following equation [13].

$$I_{cl,r} = I_{T,r} - \frac{I_{a,r}}{f_{cl}} \tag{7}$$

$I_{cl,r}$ is the basic insulation in an actual situation, and can be solved iteratively using Eqs. (4)–(7).

3. Experiment

This experiment was conducted in the cotton textile workshops of Zhengzhou Hongye Textile Co., Ltd., one of the largest textile corporations in China. Participants included 23 female workers and 19 male workers, with 39 workers wearing the most typical clothing ensembles [14]. The most typical clothing ensemble for the female worker includes: short-sleeve shirt, shorts, sandals, bra and panties, half-slip and cap. While the most typical clothing ensemble for the male worker includes: short-sleeve shirt, shorts, briefs and sandals. According to Eqs. (1)–(3) and ISO 9920, the basic insulation values of the most typical clothing ensemble for the female worker and the male worker were 0.48 clo and 0.39 respectively. While the static total insulation values of the most typical clothing ensembles for the female worker and male worker were 1.10 clo and 1.02 clo, respectively. The selected workers all had years of work experience to ensure thermal adapt to the cotton textile workshop.

Thermal environment parameters were measured to derive the dynamic value of the thermal insulation and Predicted Mean Vote (PMV). The PMV is the standard method used for predicting thermal comfort and can be deduced by two personal variables (activity level and basic insulation) and four physical variables (velocity, temperature, humidity, and

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