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Thermal environment in the cotton textile workshop

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ABSTRACT

Workers with years of work experience and students with rarely entering into the cotton textile workshop were chosen as subjects to investigate the thermal environment in the cotton textile workshop. Questionnaires have been applied to obtain actual thermal sensation and personal information. In this period, thermal comfort parameters were measured to derive the predicted mean vote (PMV). The adaptive predicted mean vote (aPMV) model and the extended predicted mean vote (ePMV) model were also introduced to compare with the actual mean vote (AMV) and the PMV. Compared with the PMV model and the ePMV model, the aPMV model is more suitable to describe the actual thermal environment in the cotton textile workshop. According to the actual thermal environment and thermal acceptability (TA) survey, the aPMV range for the worker in the cotton textile workshop was recommended to find the environment thermally acceptable to textile worker, which was applied to a graphic of acceptable zone for the cotton textile workshop. The acceptable zone is defined by the combinations of the key factors for thermal sensation, thermal adaptation and technological requirement, so it is suitable to be applied to the cotton textile workshop.

1. Introduction

Indoor thermal environment is caused by many environment factors and has been the subject of extensive studies for the past few decades [1]. Several methods, including the rational approach, the adaptive approach and the wet bulb globe temperature (WBGT) index, have been proposed to estimate the thermal environment in different environments. The rational approach which uses data from climate chamber studies is original approach and remains the choice by most researchers [2]. The predicted mean vote (PMV) model is one of the most typical rational approaches and has become the standard method of predicting thermal comfort for occupants by ASHRAE 55 [3] and ISO 7730 [4]. However, the PMV model ignores the psychological dimensions of adaptation, social and cultural aspects of an occupant, which is otherwise so prominent in building different from climate chamber [5]. Brager et al. found that the PMV overestimated actual neutral temperature by up to 2.1 °C and underestimated it by up to 3.4 °C [6]. Humphreys concluded that the PMV model was more accurate in laboratory studies which used sedentary activities and light clothing, but the discrepancy between the PMV and the actual mean vote increased for heavier clothing and higher activity level [7]. Becker et al. reached similar conclusions [8]. So it is now widely accepted that the previously used the PMV model fail to provide the participating humans with so-called "experiential realism" in determining thermal comfort [9].

Different to the rational approach, the adaptive approach derives from field studies, having the purpose of analyzing the real acceptability of the thermal environment, which strongly depends on the past thermal history, cultural and technical practices [10]. In general, people naturally adapt and may also make various adjustments to themselves and their surroundings to reduce discomfort and physiological strain [11]. These adjustments are attributed to three different processes: behavioral adjustment, physiological acclimatization and psychological habituation [6]. One's past and current thermal experiences can directly affect one's thermal response and cognitive assessment of acceptability [2]. Now field study on adaptive approach includes office [12], resident [13], classroom [14], patient rooms [15], outdoor [16], vehicle [17] etc. Several researchers have reviewed the field studies on thermal comfort [1,2,6,11,18–20]. Brager et al. provided direct evidence for behavioral adaptation and psychological adaptation [6]. However, only limited documentation and information on such changes are available [10].

The WGBT index is a composite temperature used to estimate the effect of temperature, humidity and solar radiation on humans, which is regarded as the most accepted index representing the heat stress to which an individual is exposed in an industrial

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environment [21]. But the WGBT index should be regarded as an exploratory method, with the drawback of being longer and more difficult to undertake [22]. The most serious limitation of the WBGT index is that environments at a given level of the index are more stressful when the evaporation of sweat is restricted (by high humidity, such as the cotton textile workshop) than when evaporation is free [23]. Thus it is encouraged immediately to define a new index or method instead of the WGBT index to be used in an industrial environment [22]. In fact, although there are relevant national standards on the WBGT index such as GB/T 4200-2008 [24] and GB/T 17244-1998 [25] in China, the WBGT index is seldom used in Chinese textile workshop due to relative complexity and relative inaccuracy [26].

As an important livelihood industry to meet growing domestic and international market demand, the textile industry plays an irreplaceable role in the Chinese economy. According to Ref. [27], Chinese textile industry employs more than 10 million people. However, the cotton textile workshop is characterized with the feature of high temperature in the workshop. The temperature of the cotton textile workshop often maintains above 27 °C of the year. According to Chinese national standard "Code for design of cotton spinning and weaving factory" (GB 50481-2009) [28], summer temperature of the cotton textile workshop can be above 30 °C. For example, summer temperature of the spinning workshop (the most typical cotton textile workshop) should range from 30 to 32 °C, much exceeding the acceptable operative temperature range from 23 °C and 26 °C by ISO 7730 [4]. In fact, the temperature of the cotton textile workshop may often be higher than 32 °C, especially in the summer. Obviously, higher temperature of the cotton textile workshop can save energy consumption and capitalized cost, but results in deteriorating working condition and poor thermal comfort.

Another feature of the cotton textile workshop is low occupant density and high equipment power density. Due to most highly automated manufacturers in general used in the cotton textile mill, a few front-line workers are hired and a lot of machines are used in the workshop with large area. Low occupant density with hundreds of square meters per worker and high equipment power density with hundreds of watts per square meter in the cotton textile workshop make the workshop environment different to the environment of classroom, hospital ward, residence or other public building. Furthermore, the poor environment with hot and humid environment in the cotton textile workshop results in special thermal adaptation for most textile workers, which makes the thermal research on the cotton textile workshop different to that on other types of building. So mechanically applying the field study on classroom, hospital ward and other public building to the cotton textile workshop is unreasonable. There are a large number of cotton textile enterprises in the world, thus it is necessary to research the thermal environment in the cotton textile workshop.

The purpose of this paper is to investigate the thermal environment in the cotton textile workshop, seeking for a suitable model to describe the thermal environment in the cotton textile workshop. Since many papers [1–3,6–8,18,19,29] claimed that one's past and current thermal experiences can directly affect one's thermal response and cognitive assessment of acceptability, workers with years of work experience and students with rarely entering in the workshop were chosen to analyze the connection between their actual thermal sensation and thermal environment. Comparison of the PMV model, the Adaptive predicted mean vote (aPMV) model and the extended predicted mean vote (ePMV) model shows that the aPMV model is more suitable to describe actual thermal environment in the cotton textile workshop. Thus the aPMV range for the worker in the cotton textile workshop was recommended to find the environment thermally acceptable to textile worker. To serve the engineering practice, a graphic of acceptable zone for the cotton textile workshop was created by the recommended aPMV range, which is believed to be potentially valuable for the health of workers and the design of air conditioning system for the cotton textile workshop.

2. Subjects and methods

2.1. Subjects

A field research was conducted in the cotton textile workshops of Zhengzhou Hongye Textile Co., Ltd, located in the central Henan Province (the central part of China, the most populous province with over 103 million people). The corporation is one of the largest textile corporations in Henan Province, and its main business includes design, production and sale of cotton textiles and knitwear. Textile main production area of this corporation covers over 10,000 m^2, including a large number of spinning frames, rowing frames, drawing frames, etc.

Experiments were conducted from August 7 to 12, 2014 in the cotton textile workshops including two relatively closed workshops (see Fig. 1), one is the spinning workshop with area of

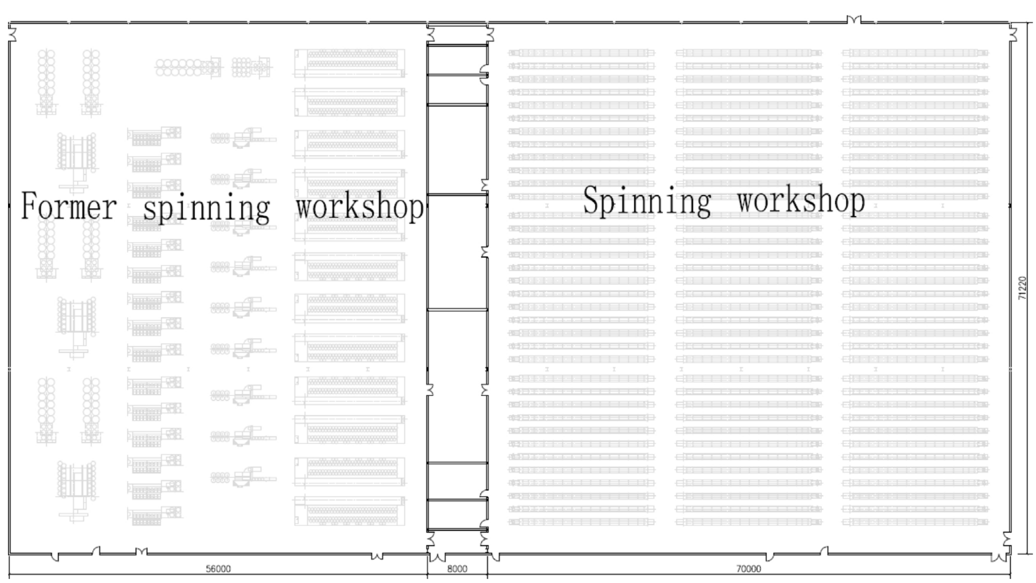

Fig. 1. Scheme of the cotton textile workshop.