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Experimental evaluation of subjective thermal perceptions for sewing activity

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ABSTRACT

From field monitoring, it has been observed that in readymade garments (RMG) production spaces, thousands of workers have been worked day long and might have probability of different thermal perceptions. As thermal comfort is the crucial phenomenon for workers, for the reduction of excessive indoor heat, using HVAC cooling strategies are the most critical segments in energy consumption. This paper describes an experimental study about assessment of different indoor environmental steps to evaluate the acceptable adaptive thermal comfort range for the workers considering typical summer climate in tropics. Tests were carried out in a climate chamber designed to represent typical RMG factory worker's (sewing) working station and analyses were carried out under pre-conditioned air temperature, wind speed, and relative humidity. During the experiments, all subjects wore typical summer clothing and needed to answer questionnaires according to ASHRAE comfort scale. This current study only focused on tropic's different summer temperature and humidity steps to explore the adaptive comfort range. Finally, this research was specified that indoor temperature range 25–26 °C and humidity 60 ± 5% with significant air movement (0.25–0.30 ms^{-1}) indicated the acceptable in combination and 25.6 °C represented the best fitted condition for the sewing activity.

1. Introduction

From the previous field observations, it has been observed that in RMG production spaces, the poor thermal indoor environment was one of the most concerns affecting issue regarding the health safety of workers and indoor energy consumptions [1–3]. Nowadays, it is widely recognized that indoor environments getting warmer day by day because of the rapid climate change [4,5]. As a result, due to excessive indoor AT than the worker's normal body t_{sk}, it impacts not only on the body which creates the serious health hazards of workers but also its effects on their productivity [2,5]. This creates crucial phenomenon regarding health and productivity for the hot humid tropical climate region because of hot environment (summer) in this region remains more than normal range half of the year and outdoor AT range becomes excessively higher than the comfortable range [1,2,6,7]. Although, there are very few local comfort ranges according to international code and compliance for RMG factory activities but according to WBGT and PHS criteria [2], the acceptable comfort range and effects of various indoor environmental conditions could be different from the normal indoor comfort range which are identical essential for the reduction of the energy consumption [1]. Hence, factory workers have a probability of different thermal preferences and perceptions than other communities [2] [5]. Meanwhile, the use of energy for HVAC and cooling become one of the major sectors in energy consumption in various parts of the world [5,8,9]. The main objective in this research is to explore the effects of different indoor temperature and humidity steps on health and comfort to evaluate the desirable adaptive comfort [10–13] range for the workers by way of using laboratory climate chamber experiment that could be maintained with free running RMG factory building's production space basically in sewing section in hot humid tropical climatic conditions. These comfort standards are required to assistance factory designers to provide a comfort and low energy indoor environment for the workers who stay almost all day long in the production spaces for the country's economic development [1–4].

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Nomenclature

AT	Air temperature (°C)
BMI	body mass index
BP	blood pressure (mmHg)
CDF	cumulative density functionCumulative density function
DBT	Dry bulb temperature (°C)
h	Height (m)
HR	Heart rate (bpm)
HF	Heat factor
HVAC	Heating, ventilation and air conditioning
I_{cl}	Clothing value (clo)
m	Body weight (kg)
M	Metabolic rate ($W m^{-2}$)
PHS	Predicted heat strain
RH	Relative humidity (%)
RMG	Ready-made garments
SD	Standard deviation
t_{sk}	Skin temperature (°C)
t_{skcr}	Critical body skin temperature (°C)
t_{skn}	Body skin temperature of thermal neutral state
T_g	Globe temperature (°C)
WS	Wind speed ($m s^{-1}$)
WBGT	Wet bulb globe temperature (°C)
WBT	Wet bulb temperature (°C)

2. Research methodology

2.1. Experimental conditions

The whole analysis has been formulated by way of using laboratory climate chamber (Height 220 cm, Width 260 cm and Length 425 cm) which consists of air-conditioning and mechanical ventilation systems and capable of controlling the AT and WS rates by adjusting the AT and RH to achieve the required room conditions. For the experiment, the temperature in climate chamber was set at different indoor conditions (18/24/26/28/30 °C) to represent the typical AT levels generally found in air conditioned and naturally ventilated indoor thermal environments in tropical summer [1,6]. Here, It has been analyzed three kinds of RH steps condition within the ranges of (phase 1–5 = RH 60 ± 5%, phase 6 = RH 40 ± 5% and phase 7 = RH 80 ± 5%). WS was kept under 0.18 0.25 ms^{-1} and mean radiant temperature was close to AT during the experiments. The physical parameters of the climate chamber are described in Fig. 1 and Table 1.

2.2. Subjects

Six subjects (Table 2) have been participated in this climate chamber experiments voluntarily and most of them are students, so that it can compare the difference of comfort perceptions accurately. It may be noted here that they (subjects) were not familiar with the specific task (sewing), so that they were learning the tasks for 2 weeks before the experiments for acclimatize their activity level. The subjects continuously performed sewing activity of RMG factory and the estimated metabolic rate (M) was approximately 1.63 met according to ISO-EN 7730 [14]. All subjects were healthy, non-obese, non-smokers, not taking any medication and abstained from alcoholic beverages at least 24 h before of their experiments. The subjects wore standardized typical summer clothing (I_{cl}) for sewing activity, consisting of a normal full pant, T-shirt, underpants, socks, mask and shoes (sandal) and Clo-value was determined 0.53–0.6 clo according to ISO-EN 9920 [9,15]. It may be noted here that, subjects were not informed before about the actual exposed conditions of the chamber during their experiments for more accuracy.

Table 1
Experimental condition of climate chamber.

Conditions	Indoor AT (°C)	Indoor RH (%)	Air velocity (ms^{-1})
Phase 1	18.0 ± 0.5	60.0 ± 5	0.23 ± 0.1
Phase 2	24.0 ± 0.5	60.0 ± 5	0.23 ± 0.1
Phase 3	26.0 ± 0.5	60.0 ± 5	0.23 ± 0.1
Phase 4	28.0 ± 0.5	60.0 ± 5	0.23 ± 0.1
Phase 5	30.0 ± 0.5	60.0 ± 5	0.23 ± 0.1
Phase 6	25.0 ± 0.5	40.0 ± 5	0.23 ± 0.1
Phase 7	25.0 ± 0.5	80.0 ± 5	0.23 ± 0.1

2.3. Physical measurement

AT and RH data loggers (T & D, TR72WF) were used to measure AT and RH at 0.6–1.1 m height from the floor level. WS was recorded at 1.1 m height (range 0.1–50.0 ms^{-1}) by an anemometer (Kanomax 6114 Anemometer). The DBT and WBT were recorded from 0.6 m height using 'Aspiratory Psychrometers, Assmann'. Psychological measurements including self-reported symptoms, such as (i) Thermal sensation (7 points ASHRAE thermal sensation scale) [16] (ii) Humidity feelings (iii) Sweating feeling (iv) Clothing wet feeling (v) Thirsty feeling (vi) Airflow feeling (vii) Comfortable feeling (viii) Clothing adhesion degree (ix) Tightness feeling (x) Site specific thermal sensation (head, stomach, forearm, thigh, lower leg, hand, foot and back) (xi) Exercise intensity were performed by direct questionnaires (Fig. 2). Among many human physiological indexes, skin temperature (t_{sk}) (8 sensors thermistor and tympanic thermometer) and heart rate (HR) (Polar FT60) were measured (every 1 min interval). Subject's t_{sk} were measured on 8 body parts [17] (foot, shin, thigh, abdomen, back of hand, forearm, forehead and shoulder; over trapezius in interscapular region) in Fig. 3(a) and t_{sk} (mean) was calculated according to the following equation 1 (modified and lab validated) [18].

$$t_{sk}(\text{mean}) = (0.07 \times \text{Forehead}) + (0.175 \times \text{Abdomen}) + (0.175 \times \text{Shoulder}) + (0.19 \times \text{Thigh}) + (0.14 \times \text{Forearm}) + (0.05 \times \text{Backofhand}) + (0.07 \times \text{Foot}) + (0.13 \times \text{Shin}) \quad (1)$$

For the research purpose, subject's BP (mmHg) (A & D Telehealth Blood Pressure Digital Monitor), height, h (cm) and body weight, m (kg) (electronic TCS-JL18) were measured. Here, Fig. 3(a–c) described the overall scenario (8 points body sensors and HR measurement, instrumentals list and clothing's, experimental steps) of climate chamber experimental procedure for this research.

2.4. Experimental procedures

At the beginning of each experiment, subject needed to take rest outside of the climate chamber for 15 min (for adaptation and preparation time) with pre-defined clothing (summer type) in the fixed room temperature and measured m, h and BP just before entering into the chamber for the experiment. Before each experiment, the climate chamber was pre-conditioned to prescribe AT and RH according to Table 1. The entire duration of each phase experiment was 1 h (60 min) for each time and every subject individually needed to perform sewing activity for 7 pre-conditioned indoor thermal environments. At the beginning of the experiment, subject answered questionnaires (Fig. 2) and subject asked to continue this survey within 1 min in every 9 min interval. Meanwhile, AT, WBT, RH, and WS were measured by loggers separately in the