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Prediction and comparison of monthly indoor heat stress (WBGT and PHS) for RMG production spaces in Dhaka, Bangladesh

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ABSTRACT

In recent years, due to lack of considerations of indoor thermal condition as well as increasing global temperature has led to rapid increase of heatstroke patients at workplaces. In such context predicting overheated environment is becoming an imperative for the industry. From field monitoring, it was observed that production spaces in Readymade Garments (RMG) were adversely impacted by excessively hot indoor environments, and yet thousands of workers toiling away their days doing production work-in these spaces. Such excessive indoor temperatures, much higher than the worker's normal body temperature, have an adverse impact on physiological conditions potentially leading health risks. In this study, whole year heat stress prediction for RMG workers has been analyzed by simulations using Energy Plus© and Open Studio©. Field monitoring of local RMG factories was conducted with data loggers for in-situ assessment. Wet Bulb Globe Temperature (WBGT) and Predicted Heat Strain (PHS) model criteria for the factory workers were examined. It was found that WBGT and PHS reached higher than comfortable levels between the months of May-August. The level of PHS was observed to reach values up to 53–60% higher than the average meteorological values, and the rest of the conditions remained moderate.

1. Introduction

According to the Bangladesh Garments Manufactures and Exporters Association (BGMEA) (Bangladesh Garment Manufacturers and Exporters Association, 2015), more than 4 million workers, mostly women, were working in the approximately 5,600 RMG factories in Bangladesh during the year 2013-14. In production spaces, a poor thermal indoor environment is one of the conditions affecting the health of workers (Khan et al., 2011). In fact, the health and efficiency of workers have been influenced by the stress resulting from exposure to hot environments since ancient times (Bernard and Mark Hanna, 1988; Malchaire, 2006; Chowdhury, Ahmed, & Hamada, 2015; Promliphonkul and Chutarat, 2010). From field monitoring, it was observed that in production spaces of many purpose-built RMG factories, the indoor thermal condition like air temperature (AT) °C, relative humidity (RH) % and air velocity (V) ms^{-1} for the workers had not been properly maintained (Chowdhury et al., 2015). On the other hand, skin temperature (t_{sk}) and core temperature (t_{cr}) (Bernard and Mark Hanna, 1988; Malchaire, 2006; Parsons, 2006; Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain ISO/FDIS 7933:2004 (E), 2016) of the workers were greatly affected by hot indoor environment, resulting in serious health hazards for the factory workers. This study attempts to explore the whole year wet bulb globe temperature (WBGT) °C and predicted heat strain (PHS) criteria of workers for local RMG factories in Dhaka, Bangladesh. The whole prediction has been formulated by way of field environmental monitoring (for simulated model validation) and a series of parametric studies which aim to predict indoor heat stress of the factory workers under the local climate consideration (Promliphonkul and Chutarat, 2010; Chowdhury and Alam, 2011; Crawley et al., 2001; Fumo, Mago, & Luck, 2010;Al-Zubaydi, 2013). The primary purpose of this study is to evaluate the approximate environmental safety of garment workers (ASHRAE, 2013; Promotions of social and environmental standards in the industry, giz in Bangladesh, 2013) in the case of hot indoor environment. This study is focused mainly on the

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Nomenclature

a	area (m^2)
AMY	actual meteorological year
AT	air temperature (°C)
BMD	Bangladesh Meteorological Department
BMI	body mass index
BNBC	Bangladesh National Building Code
CDF	cumulative density function
C_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
E	saturation vapor pressure
EP	energy plus
EPW	energy plus weather data
h	height (m)
HR	heart rate (bpm)
HR_n	equilibrium heart rate (bpm)
I_{cl}	clothing value (clo)
k	conductivity ($wm^{-1}\,K^{-1}$)
k_b	rate of increase in body temperature (°C)
$k_{b/c,HR}$	heart rate increase (bpm/K)
m	mass (kg)
M	metabolic rate (Wm^{-2})
MRT	mean radiant temperature (°C)
ND	normal distribution
OSH	occupational health and safety
OT	operative temperature (°C)
PHS	predicted heat strain
Q	amount of heat (J)
R	thermal resistance ($m^2\,kW^{-1}$)
RCC	reinforce concrete
RH	relative humidity (%)
RMG	ready-made garments
SD	standard deviation
ΔT	temperature difference (°C)
TMY	typical meteorological year
T_a	air temperature (°C)
t_{crn}	permanent body temperature, which is proportional to the work intensity (°C)
t_{cr}	core temperature (°C)
T_{dc}	dew point (°C)
T_g	globe temperature (°C)
T_{nwb}	natural wet bulb temperature (°C)
t_{sk}	skin temperature (°C)
t_{skp}	upper limit skin temperature (°C)
T_w	wet bulb temperature (°C)
V	air velocity (ms^{-1})
w	depth (m)
WBGT	wet bulb globe temperature (°C)
x	length (m)

indoor thermal heat stress (WBGT and PHS) of the factory workers according to the established criteria and formulation.

2. Research methodology

This study deals with the indoor thermal conditions of the RMG factory with special reference to tropical hot-humid climate like Dhaka, Bangladesh. The values of AT, RH and V were measured by the data logger (HOBO Weather Station Pro 30) (Nga and Cheng, 2012; Singha et al., 2010) at 5 min intervals for specific week-long durations. These measurements provided the basic environmental statistics for the indoor thermal performance level of existing production spaces. Then a comparison was conducted before the core simulation and parametric studies for validation, which was carried out by developing a three dimensional parametric modeling by Energy Plus integrated with Open Studio Plug-in (Promliphonkul and Chutarat, 2010; Chowdhury and Alam, 2011; Crawley et al., 2001; Fumo et al., 2010; Al-Zubaydi, 2013). To improve the accuracy of the simulated factory model, the basic fundamental factory functions and mechanisms (for sewing section) of the surveyed factory (Y) (Table 1) were considered in this analysis. This enabled to easily validate the simulation results between the existing and predicted conditions. Finally, a series of analytical simulation studies were evaluated for the prediction of whole year WBGT and PHS criteria for the workers according to its established formulations (Parsons, 2006; Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain ISO/FDIS 7933:2004 (E), 2016) under the local climatic conditions as profiled in the weather data (EPW) for Dhaka city (Dhaka (SWERA), 2014) and data from the Meteorological Office (BMD) Dhaka, Bangladesh (Meteorological Office Dhaka, Bangladesh, 2014). It may be noted here that the study was sensitive to the parameters of indoor AT, RH, and V and also limited to the worker's age, gender, size, sweating efficiency (Bernard and Mark Hanna, 1988; Malchaire, 2006; Parsons, 2006; Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain ISO/FDIS 7933:2004 (E), 2016). Simulated model was only validated with respect to its basic purposes, like constructions – scheduling details (lighting, equipments, clothing, occupancy and infiltration) and according to users feedback by questionnaire assessments from filed monitoring. Hence, for this indoor heat stress prediction, detail estimation of all building operational impacts of the factory users was not the focus point and will be an area for the future investigation (Lemke and Kjellstrom, 2012; Moran et al., 2001; Sarbu and Adam, 2014; Fiorito, 2014; Zhang and de Dear, 2015).

The overall structure of the research work has been illustrated in Fig. 1.

Table 1
Selected RMG factories for experimental survey.

Selection Criteria	Y
Production lines	Sewing (8) (variable)
Floor height (h)	3.8–6.1 m (depends on production types)
Orientation	North–South
Floor depth (w)	41.5 m
Floor area (a)	4650 m^2
Workers (Nos.)	2609 (maximum in sewing section)
Number of Floor	6
Floor Shape	Rectangular
Construction	Local type (brick exterior wall with concrete slab)
Openings	Simple (3 mm glass window with 15-18% openings)
Ventilation	Natural (mainly) and mixed system (exhaust & cooler)
Window height	1.35 m
Opening time	9.00 am.–6.00 pm. (normal)
Location	Dhaka, Bangladesh

Source: Environmental monitoring, here, Y = N. Fashion Ltd., Local RMG Factory, Dhaka, Bangladesh.

3. Field monitoring and scheduling

3.1. *Factory selection criteria and monitoring*

Environmental field monitoring of local RMG factories by data logger (Fig. 2, Appendix A) was conducted from Nov. 2009 to March 2010 and different periods in 2013–14 on the basis of the selections made against previously set criteria (Bangladesh Garment Manufacturers and Exporters Association, 2015; Chowdhury et al., 2015; ASHRAE, 2013; Bangladesh National Building Codes (BNBC), 2006; Bangladesh Knitwear Manufactures and Exporters Association (BKMEA), 2013). This enabled a com-