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INSULATION OF TRADITIONAL INDIAN CLOTHING: ESTIMATION OF CLIMATE CHANGE IMPACT ON PRODUCTIVITY FROM PHS (PREDICTED HEAT STRAIN) MODEL

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Major databases on western clothing and their thermal properties are available, but information on non-western clothing is lacking. A recent ASHRAE project 1504-TRP, Extension of the Clothing Insulation Database for Standard 55 and ISO 7730 dealt with the issue. Simultaneously, a co-operation study at Indian workplaces allowed us to acquire some sets of the traditional clothes used at construction sites in Chennai area. The work was related to mapping of present work conditions in order to allow predictions and measures to be taken if the mean temperature of the work environment would rise. We selected ISO 7933 on predicted heat strain (PHS) as a tool to estimate productivity loss in physical work. PHS criteria are related to reaching safe body core temperature limit of 38 °C or excess water loss. 3 sets of clothing were investigated: 2 female sets of traditional clothes (churidar and saree) modified as used at construction site (added shirt and towel to protect traditional clothes and hair), and a male set commonly used at the construction sites. The clothing insulation and evaporative resistance were measured on thermal manikins. The climatic conditions were based on weather statistics, and metabolic heat production was based on field observations at work places and the ISO 8996:2004 tables (Ergonomics of the thermal environment — Determination of metabolic rate). For the future scenarios all basic parameters were left the same except the air temperature was increased by 2 °C. Adding the protective layer on female clothing did increase clothing insulation by 25-31 % and evaporative resistance by 10-18 % respectively. This affected the performance showing lower capacity to maintain work pace already under present climatic conditions. Further increase in mean air temperature may decrease the productivity by 30-80 % depending on the parameter that is observed (limited exposure time or lower work load), and on the earlier capacity to carry out the tasks. The present evaluation may have several limitations related to the PHS model's boundaries, and validation of the presented method application is needed.

Keywords: heat, physiological model, productivity loss, work clothing.

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INTRODUCTION

Human performance in heat has interested scientists for decades, and the contributing physiological factors have been studied extensively (Burse 1979, Smolander et al. 1987, Smolander et al. 1990, Weinman et al. 1967). Special attention has got exercise and military operations (Dill et al. 1973, Gisolfi and Copping 1974, Kamon et al. 1978, Nadel et al. 1980, Shapiro et al. 1981). One of the known researches who used the scientific methods to study and select workers for hot jobs and applied acclimatisation methods in mining industry was Wyndham (Wyndham 1962, Wyndham et al. 1954, Wyndham and Jacobs 1957 etc.). The aims of heat related studies have been to reduce heat induced disorders and to keep up productivity. Construction industry is strongly affected by weather. Both cold and heat do affect the productivity at the construction site (Koehn and Brown 1985, Mohamed and Srinavin 2002), and therefore, it is important to estimate climate effects on productivity for production planning (Shehata and El-Gohary 2011).

The climate change is affecting human health by increasing heat levels (IPCC 2007, 2014, World Bank 2012) and the potential impacts on occupational health and labor productivity was first referred to by Kjellstrom (2000) and in more detail in Kjellstrom et al. (2009). The increasing temperature of ocean surface water will create more evaporation resulting in higher absolute humidity of the atmosphere, affecting human thermal regulation due to reduced effectiveness of sweating (Dunne et al. 2013). When the ambient temperature reaches or exceeds the human core temperature of 37 °C, there are well documented physiological effects on the human body, posing risks to some organ systems and also making it progressively harder to work productively, especially in physically demanding work (Kjellstrom et al. 2009). In addition, other occupational health risks will increase as climate change progresses (Bennet and McMichael 2010). During the hottest month in the South-Indian afternoon; Wet-Bulb Globe Temperature (WBGT, ISO 7243:1989) levels are already high enough to cause major loss of hourly work capacity and this situation will become extreme for many jobs when facing future climate change. These trends will create longer periods of excessive heat exposure for people working outdoors or in non-cooled indoor factories and offices (Kjellstrom et al. 2013, Sett and Sahu 2014). Dunne et al. (2013) found under the highest scenario using Earth System Model (ESM2M) projections that by 2100, much of the tropics and mid-latitudes will experience months of extreme heat stress with a labour capacity reduction of about 40 % in peak months.

Various methods are used to estimate productivity loss in construction industry due to heat stress (Rowlinson et al. 2014). In earlier days temperature and humidity data was used (Koehn and Brown 1985) but with development of technology and models more sophisticated methods are used. Rational models or combinations of models should be preferable (Rowlinson et al. 2014). The personal properties/habits could be combined with thermal indexes, e.g. WBGT (ISO 7243:1989) for optimizing the work-rest schedules (Chan et al. 2012a, Chan et al. 2012b, Yi and Chan 2013). Including Predicted Mean Vote (PMV, ISO 7730:2005) into analysis allows human heat balance calculations in the predictions (Mohamed and Srinavin 2005, Srinavin and Mohamed 2003). However, PMV was not intended for evaluation of hot environments and some modifications, e.g.

extending the voting scales and combining it with WBGT is required. Predicted Heat Strain (PHS, ISO 7933:2004) is also based on human heat balance while it is intended to be used to evaluate human exposure to heat, making it a useful tool for performance predictions. Lately, PHS has been utilized for developing heat stress management guidelines for construction industry together with WBGT (Rowlinson and Jia 2013).

Human heat exchange with the environment is affected by clothing. Different clothing materials, body postures and motion velocities of the body all affect the insulation value of clothing ensembles. Comprehensive data on clothing insulation and evaporative resistance on western clothing are available, however, information on non-western clothing is lacking. A recent ASHRAE project 1504-TRP, Extension of the Clothing Insulation Database for Standard 55 and ISO 7730 dealt with the issue (Havenith et al. 2014). Simultaneously, an ongoing co-operation study at Indian workplaces (Venugopal et al. 2014) allowed us to acquire some sets of the traditional clothes used at construction sites in Chennai area. The study recorded present work conditions and the need for preventive measures. The results can also be used to improve the impact assessment models for workplace heat conditions in relation to climate change.

METHODS

Clothing

Three sets of clothing were investigated. Two female sets of traditional clothes "churidar" (X1) and "saree" (Y1) were modified as used at construction sites (added shirt and towel to protect traditional clothes and hair, X2 and Y2, respectively). A male clothing set (Z) commonly used at construction sites was also tested (see Figure 1). The clothing insulation was measured on thermal manikins in three laboratories and evaporative resistance was measured in one laboratory (Havenith et al. 2014).

Manikin tests at Lund University

Influence of postures and motion were studied at Lund University. The walking thermal manikin Tore is made of plastic with a metal frame inside to support the body parts and to simulate joints. Walking movements are created by pneumatic cylinders fixed to wrists and ankles. Tore is divided into 17 individually controlled zones: head, chest, back, stomach, buttocks, left and right upper arm, left and right lower arm, left and right hand, left and right thigh, left and right leg, and left and right foot. In addition, three air temperature sensors set at the heights of 0.1, 1.1 and 1.7 m were applied.

The air temperature in the chamber was set at 22.2 ± 0.1 °C. The mean radiant temperature was considered to be equal to the air temperature. The air velocity in the chamber was 0.21 ± 0.07 m/s. During walking the tests the recommendation of ISO 15831 (2004) were followed where the step length of 0.65 m at 45 double steps per minute would give an estimated walking velocity of 0.98 m/s.

The surface temperature of the manikin was kept at 34 °C. The temperatures and heat losses were recorded at 10 second intervals. Data from the last 10 minutes of the stable state was used for insulation calculation. Total insulation values were calculated according to the parallel method (ISO 15831:2004).

Each clothing ensemble was measured independently at least twice, i.e. the manikin was undressed and redressed between independent measurements. If the difference of the independent measurements was above 4 % an additional test was carried out.

Basis for predictions

We selected ISO 7933 on predicted heat strain (PHS) as a tool to estimate productivity loss in physical work related to reaching safe body core temperature limit of 38 °C. The calculation program version from 2013-08-23 was acquired from Prof. J. Malchaire.

The climatic conditions were based on weather statistics of Chennai area. The metabolic heat production was based on the field observations and the ISO 8996 tables. The basic conditions (Ta - air temperature, Tg - globe temperature, Tr - mean radiant temperature, RH - relative humidity, va - air velocity) were the following:

- activity 200 W, Ta=35 °C, Tg=38 °C, Tr=45.7 °C, RH=70 %, va=1.5 m/s in the shade;
- activity 200 W, Ta=35 °C, Tg=45 °C, Tr=67.3 °C, RH=70 %, va=1.5 m/s in the sun.

For the future scenarios all basic parameters were left the same except the air temperature was increased by 2 °C (keeping radiation level the same Tg also increased). The changed parameters were:

- Ta=37 °C, Tg=39.5 °C in the shade;
- Ta=37 °C, Tg=46.4 °C in the sun.

An acclimatized female (56 kg, 150 cm) and male (64 kg, 167 cm) were selected as reference persons according to the mean values that were measured at site. Productivity loss was based on time difference to reach critical body core temperature at the same activity, or lower continuous work pace (metabolic rate in Watts (W)) to keep core temperature below 38 °C under new climate conditions. In some analysis rest breaks of 30 minutes were included to lower the body core temperature in cool (27 °C) area, and total effective work time was compared to the total time available (480 minutes; 8 hours). This notion of "tolerance time" has been tested in a study by Zhao et al. (2009). Drinking water was considered to be freely available.

RESULTS AND DISCUSSION

Differences in clothing insulation

The female clothing without shirt and head cover created insulation conditions similar to male workwear (Figure 1). Female workwear with the shirt and towel on the head had considerably higher insulation than male workwear for standing and seated postures. During walking, female workwear ventilated better and insulation dropped closer to male clothing. The permeability index of the traditional female clothing was somewhat higher in comparison to male workwear, while adding a shirt on top of them reduced permeability to some extent. In the conditions where people already work close to their

heat tolerance capacity even small difference may cause considerable effect on productivity.

In hot conditions the clothing should allow for evaporation and enhanced ventilation. The traditional clothes are effective from this viewpoint. Any additional clothing layers do reduce the effect, diminish evaporation and thereby decrease body heat loss. Also, dehydration risk increases as the body increases sweat production in order to compensate for lower heat loss - unevaporated sweat is unnecessary water loss.

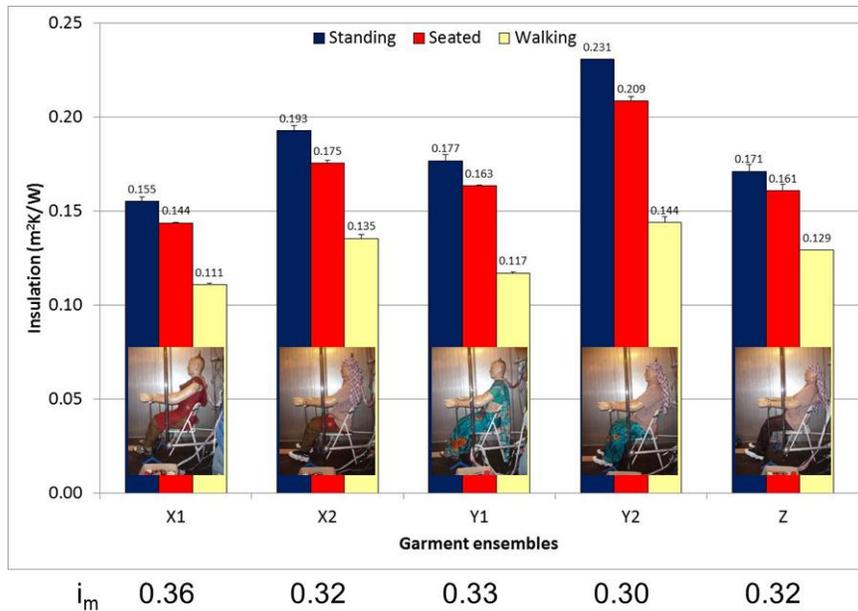


Figure 1. Workers' clothing from Chennai, India tested on thermal manikin Tore. i_m is clothing permeability index that depend on both insulation and evaporative resistance. The higher i_m value shows better thermal performance of the clothing.

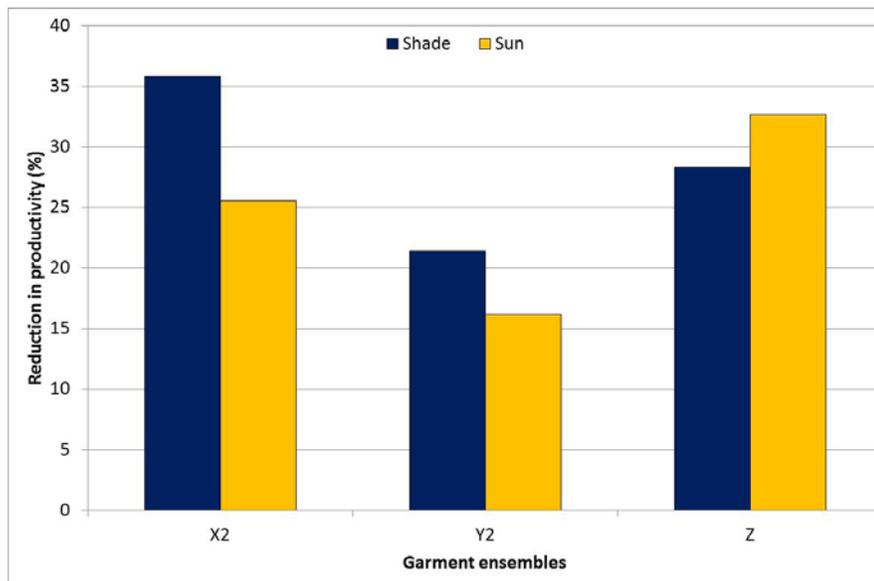


Figure 2. Predicted productivity reduction if the air temperature will be increased by 2 °C for workers in shade or exposed to solar radiation. If calculated body temperature reached 38 °C each time 30 minutes of rest was added to the work schedule.

Predictions of productivity loss

In clothing X1, Y1 and Z the workers could work in shade 8 hours at the defined load (200 W). The higher clothing insulation and evaporative resistance in modified female clothing (Figure 1) affected the results showing lower capacity to maintain work pace already under present climatic conditions (Figure 2 and Table 1). Further increase in

mean air temperature may decrease the productivity 30-80 % depending on the studied parameter (limited exposure time or lower work load), and on the previous capacity to carry out the tasks (Figure 2). If the capacity to carry out the tasks was already affected by the heat, e.g. in the sun, then the further percentage reduction was less than for work in the shade (Figure 2). However, in practice it means that workers already today need to reduce work during the hottest hours. In order to earn their living the length of the work day has to be prolonged (Kjellstrom 2009). This, in turn often leaves people with less time to take care of their homes and families, as distance between work and home may be long. Working in shade at described hot conditions assumed availability of drinking water at work places (Table 1). Exposure to sun and more extreme heat will create excess water loss, which may not easily be compensated except by rest and recovery in cool areas.

Table 1: Predicted productivity loss in shade if air temperature raises 2 °C. Icl is basic clothing insulation, i.e. insulation excluding air layer resistance and corrected for clothing area factor. Increased temperature, same activity considers keeping up the pace with the need for additional cooling breaks; increased temperature, reduced activity keeps on continuous work at lower pace/load.

Clothing	Basic condition			Increased temperature, same activity		Increased temperature, reduced activity	Productivity loss (%)	
	Icl (clo)	sweat (g/h)	time (min)	sweat (g/h)	time (min)	W	Time based	Load based
X2	0.75	700	480	710	56	88 (8 h)	36	93
Y2	1.06	660	84 (Y1->8h)	670	42	108 (84 min)	21	77
Z	0.60	620	480	760	80	106 (8 h)	28	78

CONCLUSIONS

Insulation

The female clothing without shirt and head cover had similar insulation to male workwear, while ventilation in female sets was better. Simultaneously, the female workwear with extra protective shirt had considerably higher insulation than male workwear for standing and seated postures. While walking the female workwear ventilated better and insulation became close to the male clothes, but did not perform better than male clothes. A new, affordable design of female workwear, that combines advantages of traditional clothes, fulfils traditional expectations and ensures protection requirements is needed. This could improve the heat stress situation for working women in hot places.

Productivity estimation

Productivity loss may be expected in most of the cases of this example. The loss would be between 16-36 % depending on working conditions and clothing. This fits with the estimations by Dunne et al. (2013) and comparison of brick workers walking velocities during winter and summer (20-39 %, Sett and Sahu 2014).

The clothing has a strong effect on productivity loss, especially, in the conditions that reach to the limits of human heat tolerance. In these conditions one garment piece may be one too much. In male workwear the relative productivity loss was the lowest. In female workwear (Y2) the productivity was already affected under present conditions, therefore, the relative loss was low.

Self-pacing has been shown to act as a protective mechanism against overheating of the body (Miller et al. 2011). If self-pacing is not possible then more frequent breaks are needed. Thus, productivity loss is reflected in time (more breaks) or lower pace or both. Availability of drinking water allows coping with heat and together with cool (<27 °C) recovery areas may be decisive for efficient work in the future.

Limitations

The present evaluation may have limitations related to better ventilation in traditional than in western clothes (Havenith et al. 2014) that the model is based on (Malchaire 2006). The work-rest schedule or planned work periods in cool areas may affect the results towards positive side, as well as availability of cooled recovery areas. Under outdoor conditions today, often only the shade may be provided while other ambient parameters stay the same as during the work, and the expectation of effectiveness of assumed 30 minute break may be too optimistic.

The human physiology based model PHS (predicted heat strain) was used here for the first time to estimate productivity loss during physical work in hot conditions. Therefore, validation of the presented method application is needed. Thermal discomfort itself can already cause distraction and reduction of productivity (Lan et al. 2011). The estimation of heat related reduction of mental performance under physical work would require different research methods.

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