Poll Res. 39 (2) : 481-488 (2020)

ISSN 0257–8050

THERMAL DISCOMFORT AND HEALTH SYMPTOMS IN INDIAN OCCUPATIONAL SETTINGS IN THE CLIMATE CHANGE SCENARIO

P.K. LATHA[1], VIDHYA VENUGOPAL*[2], R.K. ELANGOVAN[3], M. NEELAMEGAM[4] AND S. REKHA[5]

[1]*AMET University, Chennai, India*
[2]*Sri Ramachandra Institute of Higher Education and Research, Chennai, India*
[3]*Factory Advice Service and Labour Institutes, Mumbai,*
[4]*Easwari Engineering College, Chennai, India*
[5]*Sri Ramachandra Institute of Higher Education and Research, Chennai, India*

(Received 3 January, 2020; accepted 5 March, 2020)

ABSTRACT

Heat stress, a common risk at workplaces in hot climates, is likely to be enhanced in the changing climate with consequent increase in energy demands for cooling. The study assessed the thermal comfort and energy demands in workplaces with an aim to provide sustainable solutions for improved health and reduced energy consumption via use of building materials. Data on indoor-heat stress, workers' thermal comfort, excess energy consumed for cooling were collected from select workplaces. Wet Bulb Globe Temperature exceeded safe limits for 66% and thermal discomfort for 56 % workers who had higher odds of self-reported health symptoms (Adj. OR=8). An increase in energy demand corresponding to heat level in the industry was observed. Use of vacuum insulation panel, phase change materials, aerated autoclaved concrete & polymer skin incorporated in the building envelope and passive envelop design has been proven to largely improve thermal comfort as a passive sustainable solution in the rising temperature scenario.

KEY WORDS: Occupational health, Climate change, Energy demand, Sustainable, Thermal Comfort

INTRODUCTION

Globally there is a significant increase in daily average temperatures per decade and climate change scenarios are projecting high probability of more frequent heat waves (IPCC, 2014; Gershunov *et al.,* 2013; Angeles-Malaspina *et al.,* 2018). In climate vulnerable regions, most of the residential buildings still rely on natural ventilation for cooling and thermal discomfort can be significant in terms of adverse health, well-being and energy consumption. There is recent evidence of overheating of buildings leading to indoor discomfort with high heat stress and adverse health implications (Venugopal *et al.,* 2015; Ayyappan *et al.,* 2009; Venugopal *et al.,* 2016, Venugopal *et al.,* 2017; Krishnamurthy *et al.,* 2017; Pogacar, 2018; Venugopal *et al.,* 2019). In the context of climate change, and in the view of predictions made by Intergovernmental Panel on Climate Change (IPCC), the rise in temperatures across the globe is further expected to adversely affect the thermal comfort in the work places, health of the workers (Kjellstrom *et al.,* 2009; Venugopal *et al.,* 2019; India Climate Dialogue, 2019; Pogacar, 2018) and energy consumption (Aebischer *et al.,* 2007). Rise in temperature is likely to subject nearly 60% of the working populations in India to thermal discomfort in their workplaces (Venugopal *et al.,* 2015; Krishnamurthy *et al.,* 2017; Venugopal *et al.,* 2016) and the need to provide cooling interventions increases (Holmes and Hacker, 2007).

Buildings are responsible for around 35% of India's total energy consumption, and this is increasing by 8% annually (Rawal *et al.,* 2012). HVAC (Heating, Ventilation and Air Conditioning) systems account for 31% of the energy used by commercial buildings and air conditioner purchases in India are currently growing at 20% per year, with about half of these purchases attributed to the industrial sectors (McNeil and Letschert, 2008). Average energy use per unit area due to operation of HVAC systems in air conditioned buildings in India currently lies in the range of 120e290 kW h/m^2/year. If not improved, total energy usage for providing AC in buildings is expected to grow to 1547 TW h in 2030 (Rawal *et al.*, 2012). A study showed recently that the energy used for space heating and cooling can be expected to increase in India by 85% from 2005 levels to 2050 if the buildings continue to be operated and built as they are done today (Sivak, 2009). Hence with this background the present study is aimed to provide some sustainable solutions based on review using building material to improve the thermal comfort level in occupational settings for improved health & safety outcomes with co-benefits of reduced energy consumption.

MATERIALS AND METHODOLOGY

Study Design

The study used a cross-sectional study design to assess heat stress, thermal comfort of workers and energy consumption towards cooling for two seasons, "summer" and "winter", in 6 occupational sectors from 2-cities of Tamilnadu. The occupational sectors were classified according to the existing cooling provisions such as use of air conditioner and/or use of mechanical devices/fans to provide thermal comfort. The sectors were categorized as high, medium and low heat industry (based on the heat-generating processes) only for the purpose of estimating the energy consumption pattern with regard to cooling. The study was conducted with five objectives I) profiling the indoor heat stress in the selected workplaces II) understanding the workers' perceptions on indoor thermal comfort III) estimating the excess energy consumed and cost incurred to provide cooling interventions IV) projecting the rise in indoor heat stress in the climate change scenario and finally to provide V) a sustainable solution by use of passive building materials to improve thermal comfort.

Prior ethical clearance from the Institutional Ethics Committee (IEC) and permission from the concerned industry was obtained for the study. The risks and benefits of participating in the study were explained to the workers and signed informed consent was obtained. A walk-through audit was done in each workplace to identify sampling locations for heat monitoring and to make observations about the workplace ventilation and existing cooling provisions. Both qualitative and quantitative data were collected on different days when work was in progress.

Profiling indoor heat stress and workers' perception

Profiling the indoor heat stress in the occupational sectors was done using the quantitative data on heat stress exposure via measurements of the Wet Bulb Globe Temperature (WBGT) using a portable heat stress monitor, (QuesTemp 34; QUEST Technologies, Oconomowoc, WI, USA), which has an accuracy level of 0.5 °C between 0 °C and 120 °C of dry bulb temperature and ° 5% relative humidity (RH) between 20% and 95% RH. Globally, the WBGT index is the most commonly used heat index in heat stress assessments (Crowe *et al.*, 2010; Alimohamadi *et al.*, 2015, Parsons, 2014). Thermal comfort data were recorded using a questionnaire adapted from (ASHRAE, 2004). The questionnaire had workers demographic details like age, gender, education status and other details like type of work as per (ACGIH, 2018), workers' exposure to heat, health impacts, impacts of clothing, coping mechanisms and thermal responses like indoor humidity & ventilation status.

Energy consumption and costs incurred for providing cooling systems

Monthly data on energy consumption in the industries was collected from the high, medium and low heat industries with and without air conditioners to compare the energy consumption pattern. The current energy consumed and cost incurred for it was collected from the respective occupational sectors for 3 years (2015- 2017) from their records. The selection of industries in each category was based on similar manufacturing processes but one industry with and another without cooling provision. The energy consumption and the cost incurred were estimated based on the number of units of electricity used seasonally.

Projections of future indoor heat stress and suggested sustainable solutions using building material.

Indoor WBGT was calculated by assuming the Globe Temperature (GT) and Relative Humidity (RH) to be same as the measured value and to the measured Dry Bulb Temperature (DBT) which was obtained from the portable heat stress monitor, respective rise in temperature of four RCP scenarios projected by IPCC 2014 (IPCC, 2014) was added. Using these projected DBT and RH, the projected Wet Bulb Temperature (WBT) was calculated using (5.396998+ (0.525968*WB) + (0.06927*GT) multivariate logistic regression equation. The respective indoor WBGT indoor was calculated using the formula (0.7WB+0.3GB) and the WBGT was projected for four RCP scenarios projected by IPCC 2014 using Climate CHIP software (Climate CHIP, 2016).

Detailed literature review was done for identifying building materials based on their thermal properties that could be used to improve the indoor thermal comfort with a co-benefit of reduced energy consumption in workplaces which could provide a sustainable solution to cool workplaces with or without the availability of electricity.

Data Analysis

All data analysis was done using Microsoft Excel 2007 and SPSS software. Bivariate analysis was done for identifying associations using chi square test. The crude Odds Ratios (OR) is presented as the measure of association, the cutoff of 0.05 was used to interpret the significance of the p-values for all analysis. Multivariate logistic regression analysis using stepwise method was done for controlling possible confounders. The adjusted ORs thus calculated are presented with the corresponding p-values and 95% CIs.

RESULTS AND DISCUSSION

Study Population

A total of 741 workers (high heat industry N=441, Medium Heat industry N=170 and low heat industry N=130) were interviewed, of whom 73% (n = 559) were males and 27% (n = 202) were females. The mean age of the study population was 37 years and approximately 70% of the workers (n = 540) had some basic level of education. 79% of the study populations were non-smokers, 20% of the population consumed alcohol and about 30% had some pre-existing medical condition such as diabetes or hypertension.

Heat Stress profile

The WBGT profile in Fig.1 showed that the measured average WBGT in the high heat, medium heat and low heat industry were 31°C, 30 °C and 29 °C during summer and maximum WBGTs were quantified in the places where employees were working near furnaces and dryers. During winter the average WBGT was 28.2°C, 27°C and 25 °C respectively (Fig. 1). It was clearly seen that in summer 94 % were at the risk of heat stress as per the Threshold Limit Value (TLV) as per ACGIH guidelines (ASHRAE, 2004) compared to only 37% in winter. High occupational heat stress profiles that exceed recommended TLVs have also been demonstrated in other studies conducted in India (Nag *et al.*, 2009; Ayyappan *et al.*, 2009) and around the world (Lucas *et al.*, 2014; Venugopal *et al.*, 2015; Lundgren *et al.*, 2014; Krishnamurthy *et al.*, 2017).

From such evidence it is suggested that occupational heat-protection and mitigation requires more attention and action in many regions of the world.

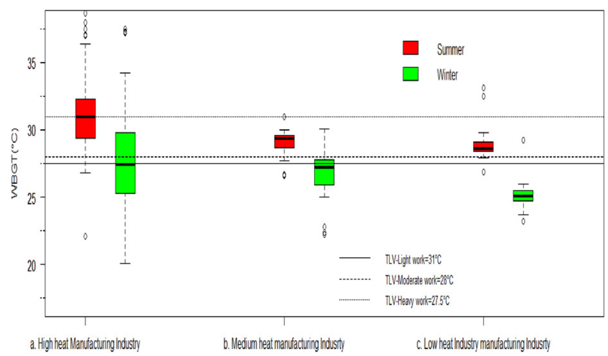

Fig. 1. Wet Bulb Globe Temperature (WBGT) profiles across various workplaces during summer and winter seasons

Workers perception on thermal comfort

Workers perceived higher thermal discomfort in summer (69 %, N=250) compared to winter (45%, N=170) as shown in Table 1. A significant association was observed between workers perceptions of thermal discomfort and season (X^2=73.047; p = <0.0001) and was also directly related to the exposure to the level of heat (high, medium or low) at workplaces (X2=1.718; p = <0.0001). The workers who perceived thermal discomfort had 12-times higher risk of exposures to heat stress compared to workers who did not perceive thermal discomfort (OR=12.46; 95% CI-8.140- 19.058; p=< 0.00001) as shown in Table 2. This proves that exposures to heat and indoor thermal discomfort are directly related. In addition to the workers perception on thermal comfort, their perception of heat-related health symptoms such as

excessive thirst, muscular cramp, head ache, prickly heat, dehydration, tiredness/weakness/dizziness collected and which showed results similar to a study conducted by Nag *et al.*, in 2009 who reported that 80% of the occupational groups in India are exposed to higher indoor temperatures reported excessive sweat, thirst, tachycardia and dryness of mouth, 70% reported feeling of elevated body temperatures (hot flashes) and 33% reported reduced urination and itchy skin.

Thermal discomfort shall also impair a person's ability to do physical and mental work (Aries *et al.*, 2010) which was also observed in our study. A significant association between the workers' perceived thermal discomfort and self-reported heat stress symptoms (X2=1.70; p = <0.0001) was observed and the exposed workers had 11-times higher odds of heat-related health symptoms (OR=11.13; 95% CI-7.464-16.603; p=< 0.00001) even after adjusting for potential confounders like age, gender, water consumption, pre-existing medical conditions, education status and (OR=8.4 ; 95% CI-4.499-15.657; p=< 0.00001) and self-reported health symptoms (Adj. OR=8.4; 95% CI-4.796-14.073; p=< 0.00001). From these results and previous Indian –based research (Nag *et al.*, 2009; Indraganti, 2011; Mishra and Ramgopal, 2014; Venugopal *et al.*, 2016) it is clear that indoor thermal discomfort has a significant role to play on workers health.

Estimating the excess energy consumption and cost used for air conditioner

In summer, the average ambient temperature in high-heat, medium-heat and low-heat manufacturing industries were 33.8 °C, 33.3 °C and 31.9 °C respectively. Similarly in winter, the ambient temperature in high, medium and low heat manufacturing industries were 31.5 °C, 30.1 °C and 28.9 °C (Table 3). In summer, the average indoor WBGT (without process generated heat), in the occupational settings were found to be much higher than in winter as can be seen in the (Table 3). In high-heat industries, an unusual low WBGT in winter was due to production shut down in few work areas during the assessment period. The average excess energy consumed for use of air conditioner for improving thermal comfort in the industries in summer compared to winter was 76890 units, 13326 units and 230 units in high-heat, medium-heat and low-heat manufacturing industries respectively. The clearly shows that energy consumption for cooling is based on indoor heat generating processes and also largely

Table 1. Perceptions of workers on Indoor thermal comfort

No.	Self-reported observations (ASHRAE 2004)	Summer (Total N=361) % (N)	Winter (Total N=380) % (N)
1	Thermal discomfort	69 (250)	45 (170)
2	High indoor humidity	42 (150)	53 (201)
3	Need mechanical ventilation	84 (304)	74 (281)
4	Coping mechanisms to avert heat	25 (91)	11(42)
5	Self-reported heat stress/thermal discomfort symptoms	83 (299)	68 (258)

Table 2. Association between workers perception on thermal comfort and study variables

			Risk Estimate	
Sl. No	Study variables	Chi-square, p-value	Crude Odds Ratio, 95 %CI	Adjusted Odds Ratio1, 95 %CI
1	WBGT	1.718, p= <0.0001*,	12.455, 8.140-19.058	8.393,4.499-15.65
2	Season	73.047, p= <0.0001*,	5.720, 3.722-8.790	0.75,4.499-15.65
3	Self reported thermal discomfort symptoms	1.706, p= <0.0001*	11.132,7.464-16.603	8.369, 4.796-14.073

Note: 1Adjusted for age, gender, education, alcohol and smoking, years of exposure
*Significant association

dependent on ambient temperature which is in concurrence with other global studies (Aebischer *et al.,* 2007; Thomas *et al.,* 2010).

Projections of future indoor heat stress in the changing climate change scenario

To substantiate the hypothesis that rise in ambient temperature due to climate change has an impact on the indoor WBGT with consequent occupational health risks and higher energy consumption, projections for future rise in indoor WBGT in the selected workplaces was done using Climate CHIP software in the various RCP scenarios predicted by IPCC, 2014). Projections show a rise in WBGTs in Chennai area and the decadal rise is projected to be 0.38°C for the month of May (i.e. Chennai workplaces could be up to 3 °C higher in 2100) with consequent higher indoor temperature and increased thermal discomfort for the workers in the coming decades. To tackle the thermal discomfort and avert workers' health and productivity losses, rise in energy consumption towards providing cooling interventions is inadvertent, especially in summer. It must also be noted that the increasing energy demands if misaligned with the energy production will force energy cuts and selective supply based on priorities (Ahn and Graczyk, 2012) like many workplaces in Tamilnadu during summer months (Abrar, 2016) and workers suffer due to heat stress who continue working with or without cooling interventions during summer months (Venugopal *et al.,* 2015).

Suggested sustainable solution to improve thermal comfort at workplaces

Building materials

With this predicted rise in WBGTs in the coming decades and rapidly increasing energy demands to tackle the heat, there is an urgent need to address the alarming issue especially in tropical settings via preventive approaches that are feasible and sustainable. A literature review attempt was made to find alternative sustainable solutions and a range of

Table 3. Heat stress and energy consumption pattern in the selected occupational sectors for summer and winter for the years 2015-2017

Type of industry	High-heat			Medium-heat			Low-heat		
Year	2015	2016	2017	2015	2016	2017	2015	2016	2017
Location		Salem			Chennai			Chennai	
SEASON-SUMMER									
Ambient dry bulb temperature °C	31.2	35.3	34.9	31.7	34.2	34.1	30.9	31.6	33.4
RH (%)*	64.0	56.0	58.0	56.0	48.0	48.1	60.0	46.0	51.1
WBGT °C	28.2	30.7	30.6	27.7	28.6	28.6	27.5	26.8	28.3
Energy consumption for cooling (Mev)	8.40*	8.51*	1.14#	1.14#	1.06#	9.45*	2.13@	3.50$	4.54$
Amount spent for cooling in INR (in lakhs).	38.2	41.50	37.5	39.7	37.1	32.1	0.06	0.1	0.12
SEASON-WINTER									
Ambient dry bulb temperature °C	31.7	30.8	32.2	31.0	30.3	31.5	28.9	28.8	29.2
RH (%)	45.8	45.0	49.0	44.4	51.9	47.0	52.9	54.0	53.1
WBGT °C	26.7	25.8	27.0	26.0	25.6	26.6	25.0	25.4	24.7
Energy consumption for cooling (Mev)	8.67*	8.00#	8.76*	1.03#	1.03#	8.32*	1.79$	3.48$	3.35$
Amount spent for cooling in INR (lakhs).	35.6	37.6	33.5	35.7	35.9	28.8	0.05	0.1	0.09

NOTE 1 MeV = $4.4504902416667 \times 10^{-20}$ kWh and MeV= Mega-electron Volt, * Energy consumption for cooling $\times 10^{+24}$ Mev, # Energy consumption for cooling $\times 10^{+25}$ Mev, @ Energy consumption for cooling $\times 10^{+23}$ Mev, $ Energy consumption for cooling $\times 10^{+22}$ Mev.

Add

materials that have the properties for passive cooling techniques may be used to help achieve thermal comfort. It is apparent that materials with lower thermal conductivity, thermal diffusivity and absorptivity may be suitable as envelopes for building, especially work-spaces that are occupied primarily during the day. The review particularly identified certain materials such as Vacuum Insulation Panel (VIPs) (Pacheco-Torgal *et al.*, 2015; Alotaibi and Riffat, 2014); Phase Change Materials (PCMs) (Nguyen *et al.*, 2013), Aerated Autoclaved concrete/Autoclaved Cellular concrete (ACC) (Kurama *et al.*, 2009; Stuckes and Simpson, 1985) and polymer skin (Kumar and Singh, 2013), Rubber added brick (Turgut and Yesilata, 2008) with good thermal properties and with a potential to be incorporated in different parts of the building envelope to enhance thermal comfort (Latha *et al.*, 2015). Light colored external surfaces, window treatments (Kumar and Kaushik, 2005) and different glazing systems are also identified as preferred options to help reduce the heat load off the building (Singh *et al.*, 2008; Klems *et al.*, 1995; Chaiyapinunta, 2009). Sustainable building materials with good thermal performance suitable for tropical countries are available locally and detailed review of their thermal properties has been done (Latha *et al.*, 2015).

Building materials and designs to improve thermal comfort: Improved envelope and passive designs such as natural ventilation (Cardinale *et al.*, 2003), radiant cooling systems (Memon *et al.*, 2008; Hui and Leung, 2012), use of electronic controls to improve thermal comfort inside buildings (Álvarez *et al.*, 2018), roof top gardening (NRDC, 2013), architectural designs and modifications (ITC, 2016), cooling paints and tiles (Singh *et al.*, 2018), enveloping with a second skin with an air gap providing isolation of the façade from the structure (Synefra, 2009), use of cavity walls (Reilly and Kinnane, 2017), sail-shaped, semi-opaque shades (Singh *et al.*, 2018), louvers and internal movable shades (Synefra, 2009), optimize lighting design, deep shading and recessed fenestration with aesthetic jaalis (Singh *et al.*, 2018) and passive down-draft evaporative cooling system (Paanchal and Mehta, 2017) are select few passive technologies that are successfully tested and could improve thermal comfort within the building envelope.

CONCLUSION

Indoor thermal discomfort is one of the silent causes of morbidities and mortalities worldwide and will continue to increase in severity with the rise in global temperatures due to climate change. The study has assessed the indoor thermal comfort condition, workers' perceptions on thermal discomfort, its impacts on their health and productivity, and a survey of the energy used for cooling intervention in 6-occupationalsectors located in Tamilnadu, India and an attempt to project the future thermal discomfort level for various RCP scenarios predicted by IPCC that the workers are likely to experience in the wake of climate change. The study findings are (1) workers in India are subjected to heat stress and thermal discomfort in their workplaces irrespective of the season which is predicted to increase in the future (2) energy demand for indoor cooling is high now and will continue to increase based on projections of the future rise in WBGTs in the workplaces (3) interventions for improved indoor thermal comfort including identifying sustainable building materials with low thermal conductivity, high heat capacity, thermal mass and resistance, solar reflectivity, thermal emissivity and passive envelop design could reduce heat transferability into the buildings. The current study provides preliminary evidence to emphasize that thermal discomfort and energy demand is an alarming issue in tropical settings like India with consequent occupational health and productivity risks. Further studies are warranted to identify building materials that are appropriate for use in high, medium and low heat occupations to improve the thermal comfort and energy in the climate change scenario.

ACKNOWLEDGEMENT

This study was carried out as a part of DST project. The authors are grateful to the management and the workers of the occupational sectors for their kind co-operation that enabled the author to pursue the research successfully. The authors also highly acknowledge and thank the Department of Environmental Health Engineering, Sri Ramachandra Institute of Higher Education and Research, Chennai for providing this platform for carrying out the work. Authors also appreciate the support extended by Rekha, Manikandan and Kumaravel of EHE Department, SRIHER for their support.

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