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Rethinking Workplace Thermal Comfort in Climate Change Context

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Abstract: **In the coming decades, global warming is likely to adversely change indoor thermal comfort without interventions. Select workplaces were assessed for indoor thermal comfort, workers' health impacts with future projections for indoor thermal conditions. Wet Bulb Globe Temperature (WBGT) monitor was used to measure heat exposures and validated questionnaires captured workers perceptions on thermal discomfort. Average seasonal WBGT levels ranged between 30°C-33°C and ~66% of workers were working above safe limits. Workers (56%) who perceived thermal discomfort had significantly higher odds of reporting heat-related health symptoms (Adj.OR: 8.0;p-value=<0.0001). Passive cooling and climate smart workplaces can improve thermal comfort with energy-saving co-benefits.**

Keywords: **Climate Change; Occupational Health; Passive Cooling; Thermal Comfort**

I. INTRODUCTION

The frequency of hot days and heat waves are predicted to increase globally and in India under climate change (IPCC, 2014, Angeles-Malaspina et al., 2018) with negative effects on thermal comfort in indoor work places. 'Thermal comfort', a term used to describe a satisfactory, stress-free thermal environment in buildings and is a socially determined notion defined by norms and expectations (Chappells & Shove, 2005) which keeps changing with time, place and season between workplaces. Some of the key factors that influence are shown in Figure 1.

In climate vulnerable regions and low-resource settings, 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. Recent evidence indicates overheating of buildings leading to indoor discomfort with high-heat stress and adverse health implications (Venugopal et al., 2015, Venugopal et al., 2016, 2017 & 2019, Krishnamurthy et al., 2017). With view of the 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) and energy consumption (Aebischer et al., 2007).

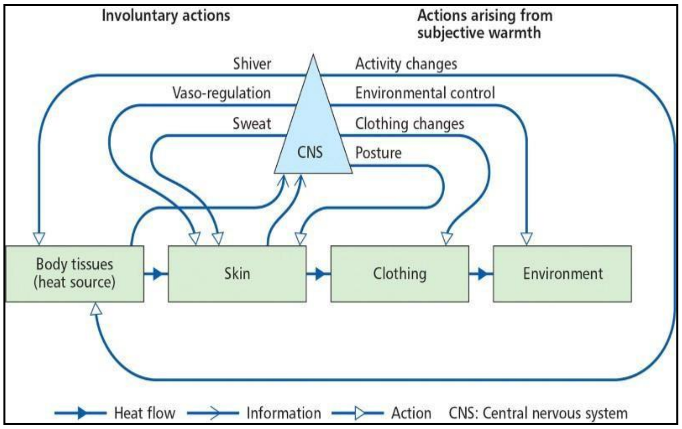

Figure 1. Thermal Regulatory System

Source: Nicol and Humphreys (1973) and subsequently used in CIBSE (2013)

Over 60% workers are likely to be affected in India (Venugopal et al., 2015 & 2016, Krishnamurthy et al., 2017) and the need to provide cooling interventions increases (Holmes and Hacker, 2007). Health effects of thermal discomfort with high baseline temperatures in workplaces remain a critical research gap.

With this background, the present study was aimed to fill this gap and provide some sustainable solutions for improving thermal comfort, health and productivity in occupational settings with co-benefits of reduced energy consumption.

II. MATERIALS & METHODOLOGY

Study Design

The study used a cross-sectional study design to assess heat stress, thermal comfort of workers for two seasons "summer" and "winter" in 6 occupational sectors, categorized into high (Steel Industry & Auto Parts Industry), medium (Heath care center AC and Non AC) and low-heat generating (garment exports with AC and Non AC) sectors, in Tamilnadu. The study was conducted with four objectives I) profiling the indoor heat stress in the selected workplaces II) understanding the workers' perceptions on indoor thermal comfort and its health impacts III) projecting the rise in indoor heat stress in the climate change scenario IV) suggest recommendations using passive cooling technologies for improved thermal comfort. Prior ethical clearance from the Institutional Ethics Committee (IEC) and permission from the concerned industries was obtained for the study. A walk-through audit in all workplaces to identify sampling locations for heat monitoring and to make observations about the workplace ventilation and existing cooling provisions was conducted. Both qualitative and quantitative data were collected on different days when work was in progress.

Profiling of indoor heat stress was done using Wet Bulb Globe Temperature (WBGT) 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 (DBT) and 5% Relative Humidity (RH) between 20% and 95% RH. Globally, the WBGT index is the most commonly used heat index for heat stress assessments (Alimohamadi et al., 2015). Workers' perceived thermal comfort data was recorded using a questionnaire adapted from (ASHRAE, 2004) that also included 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.

Indoor WBGT was calculated by assuming the Globe Temperature (GT) and Relative Humidity (RH) to be same as the measured value from the WBGT monitor.

To the DBT obtained from the WBGT monitor, the respective rise in temperature of four RCP scenarios projected by IPCC 2014 was added (Lemke and Kjellstrom, 2012). Using these projected DBT and RH, the Wet Bulb Temperature (WBT) was calculated using (5.396998+ (0.525968*WB) + (0.06927*GT) multivariate logistic regression equation. Then the respective indoor WBGT was calculated using the standard formula (0.7WB+0.3GB) and the WBGT was projected for the four RCP scenarios using the Climate CHIP software (ClimateCHIP, 2016).

Detailed literature review was done for identifying passive cooling technologies 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.

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 (COR) with a 0.05 cut off was used to interpret the significance of the p-values and multivariate logistic regression analysis using stepwise method was done for controlling possible confounders. The Adjusted OR (AOR) thus calculated are presented with the corresponding p-values and 95% CIs.

III. RESULT AND DISCUSSION

Study Population

A total of 741 workers interviewed from various workplaces (high-heat industry N=441, medium-heat industry N=170 and low-heat industry N=130), 73% (n=559) were males and 27% (n=202) were females. The interview was based on the Workers mean age was 37 years and ~70% workers (n=540) were literate. 79% workers were non-smokers, 20% consumed alcohol and ~30% had pre-existing medical conditions such as diabetes or hypertension.

Heat Stress Profile

The WBGT profile in Figure 2 shows that the measured summer average WBGTs in the high, medium and low-heat industries were above the limits of Threshold Limit Value (TLV) in most workplaces with maximum WBGTs being recorded in the work locations where employees were working near furnaces and dryers. During summer 94% workers were at the risk of heat stress as per as per ACGIH guidelines 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) and around the world (Lucas et al., 2014, Venugopal et al., 2015, Lundgren et al., 2014). The evidence suggests that occupational heat-protection and mitigation requires more attention and action in many regions of the world.

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 observed between workers' perceived thermal discomfort and season (X^2=73.047; p-value=<0.0001) was also directly related to the exposure to the level of heat (high, medium or low) at workplaces (X^2=1.718; p-value = <0.0001). The workers who had heat exposures had 12-times higher risk of perceiving thermal discomfort compared to workers who had no heat exposures (OR=12.46; 95% CI-8.140- 19.058; p-value =< 0.00001) as shown in Table 2 indicating a definite relationship between heat exposures and indoor thermal discomfort. In addition to the workers' perceived discomfort, the reported heat-related health symptoms such as excessive thirst, muscular cramp, head ache, prickly heat, dehydration, tiredness/weakness/dizziness collected was also observed in 80% of the occupational groups in a previous study (Nag et al., in 2009).

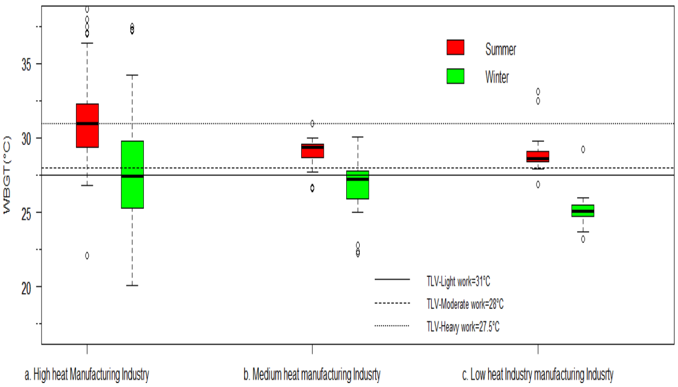

Figure 2 Wet Bulb Globe Temperature (WBGT) profiles across various workplaces during summer and winter seasons

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)

A significant association between the workers' perceived thermal discomfort and self-reported heat strain symptoms (X^2=1.70; p-value=<0.0001) indicates that the exposed workers had 11-times higher odds of heat-related health symptoms (OR=11.13; 95% CI-7.464-16.603; p-value =<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-value=<0.00001) and self-reported health symptoms (Adj. OR=8.4; 95% CI-4.796-14.073; p-value =< 0.00001). From these results and previous Indian – based research (Nag et al., 2009, Indraganti, 2011, Venugopal et al., 2016), it is clear that indoor thermal discomfort has a significant role to play on workers' health.

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 Ratio^1, 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: ^{1}Adjusted for age, gender, education, alcohol and smoking, years of exposure, *Significant association

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 and higher energy consumption risks, 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 indoor WBGTs in workplaces 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 (Figure 3).

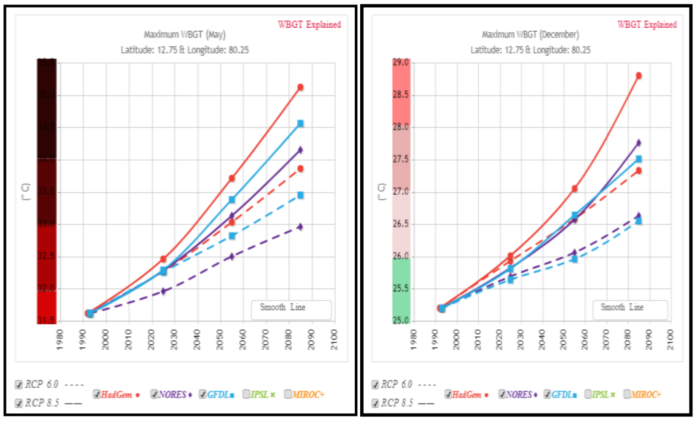

Figure 3 Projections of WBGT for Chennai: RCP scenarios 6:0 & 8.5 for summer (a) and winter (b) (Source: Climate CHIP.org)

To tackle the thermal discomfort and avert workers' health and productivity losses, a rise in energy consumption towards providing cooling interventions is inadvertent, especially in summer. 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 across India during summer months and workers suffer due to heat stress who will have to continue working with or without cooling interventions (Venugopal et al., 2015).

Passive Methods for Improve Thermal Comfort at Workplaces

A literature review attempt made to find alternative sustainable solutions and a range of materials that have the properties for passive cooling techniques, identified 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 to improve thermal comfort. Particularly, Vacuum Insulation Panel (VIPs) (Pacheco-Torgal et al., 2015), Phase Change Materials (PCMs) (Nguyen et al., 2013), Aerated Autoclaved concrete/Autoclaved Cellular concrete (ACC) (Kurama et al., 2009) & polymer skin (Kumar and P Singh, 2013), Rubber added brick (Makaka and Yesilata, 2008) with good thermal properties have the 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), cooling paints and tiles (Singh et al., 2018), and different glazing systems are also preferred options to help reduce the heat load off the building (Singh et al., 2008). 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). Improved envelope and passive designs such as natural ventilation (Cardinale et al., 2003), radiant cooling systems (Hui and Leung, 2012), roof-top gardening (NRDC, 2013), architectural designs and modifications (ITC, 2016), 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, louvers and internal movable shades (Synefra, 2009) 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.

IV. CONCLUSION

The study findings clearly show that (1) workers in India are subjected to heat stress, thermal discomfort and heat-related illness in poor ventilated occupational irrespective of the season which is predicted to increase in the future. Passive cooling technologies could be effective and sustainable solution to avert occupational health and high-energy risks in the changing climate scenario.

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