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Research article

Evaluation of occupational exposure to heat stress and working practices in the small and mid-sized manufacturing industries of Lahore, Pakistan

Muhammad Salman Butt[1*], Kalev Kuklane[2], Javeria Saleem[3], Rubeena Zakar[3], Gul Mehar Javaid Bukhari[4], Muhammad Ishaq[5]

[1] Department of Public Health, University of the Punjab
[2] Institute for Safety (IFV), NL-2701 AC Zoetermeer, The Netherlands
[3] Department of Public Health, University of the Punjab
[4] Department of Community Medicine, Federal Medical and Dental College Islamabad
[5] Department of Sociology, University of the Punjab

* Email: sames_butt@hotmail.com

ABSTRACT

Background: Climate change is evident around the globe causing heat stress as an emerging public health problem for people working in tropical and subtropical areas. Occupational heat stress can impact the health and productivity of small and mid-sized enterprise workers.
Objective: This study aimed to profile the indoor thermal environmental conditions and modify the working practices by recommending the work/rest cycle according to the international organization for standardization 7243.
Study Design: This cross-sectional study design included eight industrial (Iron spare parts manufacturing) small and mid-size enterprises in Lahore, Pakistan. The indoor thermal environment, including globe temperature, natural wet bulb temperature, ambient temperature, relative humidity, and air velocity, were recorded during summer to measure the wet bulb globe temperature (WBGT). Quest heat stress meter (model 2500), modified Testo loggers (177-T4), and EL-USB-2-LCD data loggers were placed at different working stations to measure these thermal environmental parameters. A self-administered questionnaire was used to measure the workers' demographic characteristics and working practices. The International Organization for Standardization 7243 reference was used to estimate and recommend the work/rest cycle.
Results: 138 workers aged 28.59 ± 10.46 years participated in this study. Continuous work of 8.8 ± 1.5 hours per day with a conventional resting period of 30-60 minutes was recorded on a typical working day. The indoor wet bulb globe temperature ranged from 26.8°C to 36.4°C. The workers were registered for low (72.5%), moderate (18.1%), and high (9.4%) metabolic rates according to the International Organization for Standardization 7243 reference values.
Conclusion: A high wet bulb globe temperature was recorded in the selected small and mid-sized enterprises making these workers vulnerable to heat stress and related illnesses. Work/rest cycle evaluation suggested that the workers were required to improve their cool-down time by avoiding continuous exposure to high temperatures and reducing the metabolic rate.

Keywords: WBGT, environmental factors, occupational health, ISO 7243

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1. INTRODUCTION

Evidence on climate change and its health hazards on the general population is well understood in the literature [1], but its relationship with occupational health has not been well established [2]. Human performance is affected by thermal environmental conditions [3]. Workers involved in various construction, manufacturing industries, and agricultural settings are vulnerable to stressful environmental situations due to rapid climate change [4]. Frequent exposure of the workers to such conditions can directly affect heat exhaustion, kidney diseases, and heart or lung diseases [5], as well as indirect effects through impaired mental functions, lethargy, and dehydration [6]. This is especially important for workers with high physical activity under hot environmental conditions [4].

Heat stress is a public health problem for people working in densely populated tropical and subtropical areas of the world [7]. Regional and global occupational heat exposure assessments in occupational settings have recently been started [8]. Serious health consequences related to heat stress have been demonstrated in Central America and South-East Asia [9,10]. Agricultural, industrial manufacturing, and construction workers are potentially vulnerable to adverse climatic conditions [11]. The effects of climate change are also evident in Pakistan and the heat index (HI) has estimated an average increase of 3^{o}C for summer in the last 47 years [12].

Many heat stress indexes have been used in occupational settings to estimate the thermal environment and workload level [13]. Wet Bulb Globe Temperature (WBGT) is normally used in domestic, sports, agricultural, and industrial settings to evaluate heat stress [14]. International Organization for Standardization (ISO) Technical committees 159 Ergonomics prepared the specifications relating to the methods of measurements for physical parameters characterizing thermal environment. This standard also establishes the recommendations for maximum thermal exposure values and method practices and measurements for efficient calculations of WBGT [14]. WBGT index has been adopted at national (e.g., UK, Japan, China, Australia, and the USA) and regional levels as a standard to prevent heat stress and related illnesses [15].

Workers in agriculture (45%), industrial manufacturing (13.7%), and construction (7%) settings are potentially vulnerable to adverse climatic conditions in Pakistan [11]. This study aimed to profile small and mid-sized enterprises' indoor thermal environmental conditions and modify the working practices by recommending the work/rest cycle according to the International Organization for Standardization ISO 7243 reference values.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This cross-sectional study design included eight industrial (iron spare parts manufacturing) small and mid-size enterprises in Lahore, Pakistan.

2.2 Study Population and Sampling Technique

Iron spare parts manufacturing industries with less than 250 employees were considered small and mid-size enterprises in this study. A list of small and mid-size enterprises was obtained from the Lahore Chamber of commerce. A total of 17 industries were shortlisted for telephonic contact based on their accessibility and good market reputation. Written consent was obtained by the industry owners from the eight small and mid-size enterprise companies. The consented industries were scheduled for a working day to measure indoor thermal environment and working practices data. The demographic data and working practices were measured from 138 workers available on the day of data collection. Male workers of all age groups with no pre-existing disability and comorbidity were selected for this study using a purposive sampling technique.

2.3 Data Collection Procedure

2.3.1 Thermal parameters measurements

The indoor thermal environmental parameters, including globe temperature (T_g), ambient temperature (T_a), natural wet bulb temperature (T_{nw}), relative humidity (RH), and air velocity (v_a), were recorded during the summer season to calculate the wet bulb globe temperature (WBGT) using the following equation;

$$WBGT = 0.7\, T_{nw} + 0.2\, T_g \quad \textbf{Equation 1}$$

These thermal parameters were recorded for six hours (10:00 to 16:00) using the quest heat stress meter (model 2500), modified Testo loggers (177-T4), and EL-USB-2-LCD data logger. These instruments were calibrated against Bruel & Kjaer procedure under controlled environmental conditions of the climatic chamber at Lund University. Devices were placed on an aluminum tripod stand adjusted at the height of 100 cm from the ground. The globe temperature (T_g) was measured at the height of 120 cm from the ground surface to minimize the radiant heat effect, as shown in **Figure 1.**

Figure 1. The placement of the equipment to measure the thermal environmental parameters. **(a)** Sensor to measure the globe temperature T_g, **(b)** Sensor to measure the wet bulb temperature T_{nw}, **(c)** Sensor to measure the ambient temperature T_a, **(d)** EL-USB-2-LCD data logger.

These thermal parameters were recorded every 10 seconds on a typical working day and were placed close to the working stations after consultation with the field supervisor of the SMEs. Four Testo loggers (177-T4) with three Type T thermocouple wire sensors (accuracy of ± 0.5 °C) were used in this study. Thermocouple sensors 'a' were used to measure the T_g by connecting it with a standard 5 cm black globe. Thermocouple sensors 'b' was used to measure the $T_{nw,}$ and thermocouple sensor 'c' was used to measure T_a shielded in an aluminum foil paper to prevent direct exposure to sunlight. Relative humidity (RH), dew point, and air temperature (T_a) for every 10 seconds were recorded by four EL-USB-2-LCD Lascar data loggers with LCD (**Figure 1**).

Swema air (model 300-SWA03) with an omnidirectional sensor (accuracy of ± 0.02 m/s) was used to measure three minutes of averaged ambient air velocity (va). The va was measured for the morning, noon, and afternoon sessions by placing the Swema air sensor close to the selected working stations.

2.3.2 Working practices measurements

The workers present on the day of data collection were briefed on the study objectives and were requested to volunteer for data collection. A total of 138 workers gave verbal informed consent and participated in this study. A self-administered questionnaire was used to measure the demographic data, working practices, and estimation of metabolic energy.

ISO 7243 reference table was used to estimate the metabolic energy produced for different working postures. The ISO 7243 classifies the metabolic rate into five different classes based on the mean skin surface area of 1.8 m^2. It considers the metabolic rate both in watt/square meter (W/m^2) and watt (W) only as shown in **Table 1**. This classification was used to determine the mean metabolic rate for the workers by estimating the metabolic activity level.

Table 1. Classification of metabolic rate levels according to ISO 7243 [14].

Class	Metabolic rate (W/m^2)	Metabolic rate (W)	Example
0 (Resting)	65	117	Resting
1 (Low metabolic rate)	100	180	Light manual work
2 (Moderate metabolic rate)	165	297	Sustained hand and arm work
3 (High metabolic rate)	230	414	Intense arm and trunk work
4 (Very high metabolic rate)	290	522	Very intense activity at a fast to maximum pace

The researcher observed the elementary activity of the workers, and a subjective response was also recorded to confirm the class ranging from resting to very high metabolic rate on a typical working day. The ISO 7243 reference curve was used to determine the work/rest cycles of the acclimatized workers by comparing the measured metabolic rate with the calculated WBGT.

2.4 Data Analysis

The data were entered in an excel file for data cleaning and mean value calculations for the morning (10:00-12:00), noon (12:00-14:00), and afternoon (14:00-16:00) workday segments. The data were further processed using the SPSS v 23 and GraphPad Prism v 9.0 to prepare participants' summary statistics (means and proportion by variable categories and factories). The environmental parameters measured by the instruments were comprised to measure the indoor WBGT index (Mean ± S.D) on a working day for the selected sites. All explanatory variables (age, smoking, education, work experience, posture, and resting hours) were considered potential confounders to estimate the association with thermal stress.

2.5 Ethical Considerations

This study was conducted according to the Helsinki declaration of 2008 and assures the participants' life, health, privacy, and dignity.

3. RESULTS

A total of 138 workers aged 28.59 ± 10.46 years had working hours of 8.84 ± 1.51 hours with a resting time of 61.74 ± 10.10 mins on a typical working day participated in this study. Most of the workers (64.5%) were young (17-30 years) and had eight working hours (57.2%). Some workers reported higher working hours of 8-10 hours (35.5%) and even more significant than 10 hours (7.2%) on a typical working day. Workers had a conventional resting duration of 30-60 minutes (84.8%) and had standing as the most frequent working posture (47.8%), as shown in **Table 2**.

Table 2. Demographic characteristics of the workers.

N = 138	Categories	N(%)
Age group (yr) (Mean ± S.D) 28.59 ± 10.46	17-30	89 (64.5)
	30-45	36 (26.1)
	> 45	13 (9.4)
Work experience (yr) (Mean ± S.D) 12.56 ± 9.74	< 5	42 (30.4)
	6-15	56 (40.6)
	>15	40 (29.0)
Working hours/day (hr) (Mean ± S.D) 8.84 ± 1.51	8	79 (57.2)
	8-10	49 (35.5)
	> 10	10 (7.2)
Resting hour during work (min) (Mean±S.D) 61.74 ± 10.1	< 60	17 (12.3)
	50-60	117 (84.8)
	60-120	4 (2.9)
Smoking	Yes	38 (27.5)
	No	100 (72.5)
Education	Illiterate	60 (43.5)
	Primary	70 (50.7)
	Graduate	8 (5.8)
Working posture	Sitting	57 (41.3)
	Standing	66 (47.8)
	Walking	15 (10.9)
Subjective exertion level	Mild	9 (6.5)
	Moderate	121 (87.7)
	High	8 (5.8)

The indoor environmental conditions varied in different SME settings due to small rooms, multiple working stations, impaired ventilation with no air conditioning, and non-compliance to the international labor organization (ILO) ergonomics standards. The parameters for measuring the WBGT are presented in (**Figure 2 (a-d)**), reflecting the variation during the day of data collection from the selected SME settings. The averaged globe temperature (T_g) was recorded (mean ± SD) at 34.4 °C ± 3.5 °C and ranged between 29.2 °C – 40 °C (**Figure 2a**). The ambient air temperature showed similar readings as that of (T_a) 34.5 °C ± 3.5 °C as the data was recorded indoors to protect the globe from direct solar radiation effect (**Figure 2b**). The nature wet bulb temperature (T_{nw}) showed an average value of 12.9 °C ± 2.3 °C and ranged between 9.5 °C – 16.7 °C for the selected SMEs from morning to afternoon, as shown in **Figure 2c**.

The WBGT (indoor) ranged from 26.8°C to 36.4°C in the selected SMEs. The average WBGT (indoor) for all these SMEs was 28.9 °C ± 2.3 °C. The WBGT ranged between 26.2 °C – 30.9 °C (morning), 26.4 °C – 31.6 °C (noon), and 26.6 °C – 36.4 °C (afternoon), as shown in **Figure. 2d**.

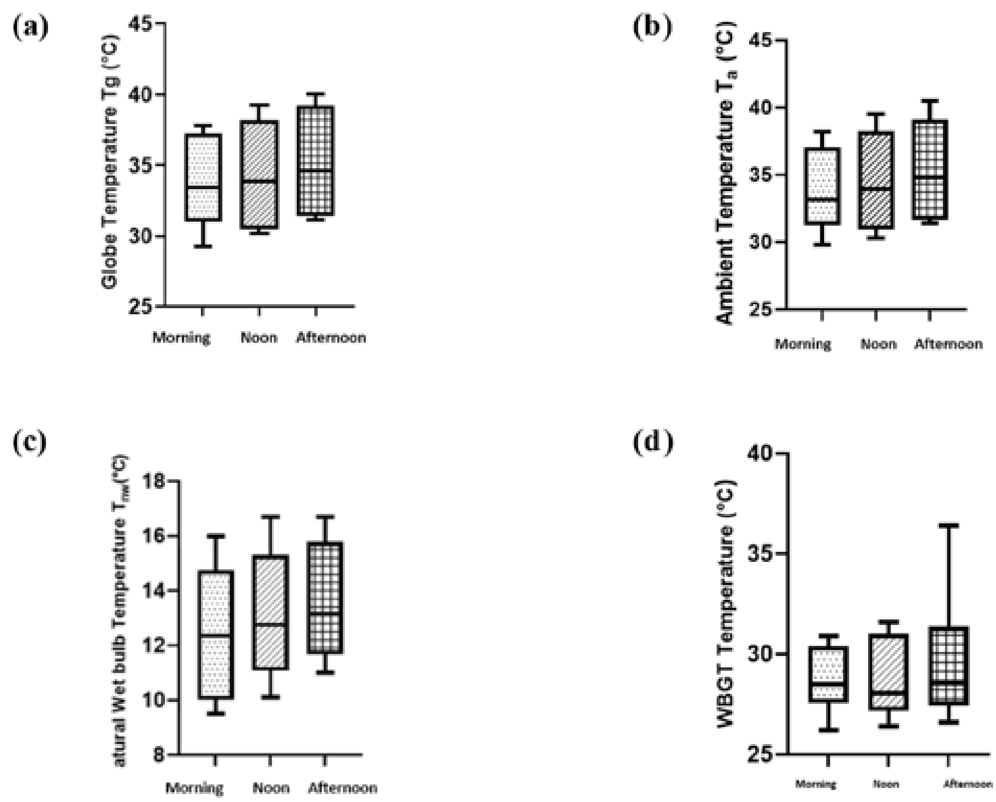

Figure 2 (a-d). The thermal environmental parameters to calculate the averaged (a) Globe, (b) Ambient, (c) Actual wet bulb, and (d) WBGT temperatures for morning, noon and afternoon working hours.

The metabolic rates and the measured WBGT were compared with the reference values suggested in the ISO 7243, as shown in **Table 3**.

Table 3. Comparison of WBGT reference values corresponding to a given situation.

	Wet Bulb Globe Temperature		**Measured class**				**Recommended allocation of work in a work/rest cycle**
Reference class	Reference limit value of WBGT for a heat acclimatized person °C	Measured WBGT at SMEs	1 Low metabolic rate N (%)	2 Moderate metabolic rate N (%)	3 High metabolic rate N (%)	Total N (%)	
1 Low metabolic rate	30	26-28 °C	9 (6.5)	60 (43.5)	31 (22.5)	100 (72.5)	75-100 %
2 Moderate metabolic rate	28	29-32 °C	-	22 (15.9)	3 (2.2)	25 (18.1)	50-75%
3 High metabolic rate	No sensible air movement 25	32-34 °C	-	10 (7.2)	3 (26.8)	13 (9.4)	25-50%

Recommended work allocation was made based on the recommended work/rest cycle, assuming an 8-hours workday in a 6-days working week with conventional breaks for 30-60 minutes. The work/rest cycle recommendations for the selected workplaces thought that workers exposed to these conditions were adequately hydrated, not taking medication, wearing lightweight clothing, and generally in good health.

4. DISCUSSION

Thermal stress in SMEs is one of the vulnerability factors causing the workers to experience potential injuries and long-term health disabilities. At some workplaces, the ventilation was limited and had air velocity (va) of 0.1 m/s. The ambient indoor air temperature (T_a) was recorded as high as 40.5 °C. Under such a working environment, it becomes difficult for the workers to get facilitated by the natural cooling effects of evaporation and breathing. Electric power failures and no air conditioners further complicated the situation for the workers during the summer season. Previous studies have reported that such environmental conditions make the occupational group vulnerable to experiencing acute and chronic health-related problems. Heat cramps, lethargy, breathing disorders, and renal disorders were the commonly reported health problems encountered by the workers as a result of continuous exposure to high temperature [8,16].

Workers in the SMEs were not facilitated with any preventive measures from thermal stress and were bound to work with the same work/rest cycle throughout the year. These SMEs had limited financial resources and governmental support to install air conditioning systems to mitigate the adverse effect of hot environmental conditions on the workers. Previous studies have suggested adjusting the high-temperature exposure time, reducing the physical workload, improving workers' tolerance by acclimatization, health and safety training, and providing air-cooled garments [17,18] including air temperature (Ta. The scarce financial resources and limited support from the local government make it difficult for these SMEs to adopt these modification strategies.

Workers in these SMEs were found illiterate (43.5%) or had primary education (50.7%) with no vocational training, making it difficult for them to switch jobs. These workers had no workplace health and safety education or training by the competent authorities to educate them. Such circumstances bound them to work under these environmental conditions with no or limited workplace safety. Electricity power cuts adversely affect the working environments, and these workers had no choice other than to use the daylight and manual force to perform their assigned duties.

According to ISO 7243, the nature of work, duration of physical activity, and thermal conditions are the decisive factors in determining the work/rest cycle for the workers to prevent them from heat stress and related illnesses. Workers had moderate to high metabolic physical activities. The perceived metabolic activity level differed from ISO 7243 calculated values, and the workers reported a moderate level of metabolic activity. This variation can be because most of the workers in the selected SMEs were young (17-30 years). Similarly, other explanatory variables can also be the potential confounding factors in measuring the work/rest cycle.

With the increase in WBGT or the metabolic activity level, the cool-down time for these workers should be enhanced to avoid heat stress and related illnesses [14,19]which is based upon the wet bulb globe temperature index (WBGT. The measured WBGT (indoor) ranged from 26.8°C to 36.4°C in the observed SMEs, as shown in **Figure 2d.** A comparison of the metabolic activities and measured WBGT was made in **Table 3**, recommending work/rest cycles for different categories. For a high metabolic rate of 230 W/m^2, the recommended work allocation in a work/rest cycle is 25-50% at a WBGT greater than 32 °C. The indoor averaged air velocity was 0.67 ± 0.32 m/s which was insufficient to keep the rooms and workers ventilated for heat dissipation by the convection processes.

Resting in an air-conditioned or well-ventilated room at an average room temperature of 27 °C will reduce the metabolic rate and the workers' skin and core body temperature. Phase change materials, including ice, frozen gel, and salt wax, can also be used in the worker's vest and clothing as a passive cooling system [20]mass, and covering area. The objective of this study was to investigate if the cooling effects of the temperature gradient observed on a thermal manikin could be validated on human subjects in extreme heat. The subjects wore cooling vests with PCMs at two melting temperatures (24 and 28°C. Adequate water and glucose intake can also help avoid severe dehydration and hypoglycemia. Some culturally accepted methods, including siesta can also prove to be effective in reducing the health risk. It is also essential for future research to make an economic comparison of productivity loss due to heat stress and the installation of air conditioners or other protective systems in such workplace areas [21].

This study had limitations in that the data was collected from the workers present on the day of data collection, which can lead to a bias toward healthy workers' effects. Some additional physical environmental factors were not considered in this paper, such as air pollution, vibration, noise, and illumination level at the workplace, which can also affect the thermal perceptions of the workers. These physical environmental factors can exacerbate the thermal effects and affect the workers' subjective response to heat stress.

5. CONCLUSION AND RESEARCH IMPLICATIONS

A high wet bulb globe temperature and non-compliance to the international organization for standardization 7243 recommendations were recorded in the selected small and mid-sized enterprises making these workers vulnerable to heat stress and related illnesses. Work/rest cycle evaluation suggested that the workers required to improve their cool-down time by avoiding continuous exposure to high temperatures and reducing the metabolic rate.

This research addressed the workplace environment and the challenges faced by the workers. Continuous exposure to heat stress and the exertional workload was common in the selected SMEs, requiring policies and strategies to mitigate the adverse effects of heat stress. This research will educate the employers of small and mid-sized manufacturing and realize the importance of thermal environmental conditions and their negative effects on human health. This research will also facilitate the policymakers to adopt international standards, including ISO 7243, to develop strategies specifically for improving SMEs' environmental conditions and reducing the associated occupational hazards.

Table of abbreviations

ISO	International Organization for Standardization
RH	Relative Humidity
S. D	Standard Deviation
SME	Small and Mid-Size Enterprises
SPSS	Statistical Package for the Social Sciences
SWA	Swema Air
T_a	Ambient Temperature
T_g	Globe Temperature
T_{nw}	Natural Wet Bulb Temperature
va	Air Velocity
WBGT	Wet Bulb Globe Temperature

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