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Full Length Article

Impacts of heat exposure on workers' health and performance at steel plant in Turkey

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ABSTRACT

Workers of Iron and steel plants are exposed to extreme environmental heat that causes discomfort and limits their performance. This study investigates the influence of heat load on workers' health and activity in Kardemir Steel Factory in Karabük-Turkey using several heat stress indices. Combined field measurements and questionnaires were carried out over a period from June to August 2016. A total number of 100 workers regularly working in the steel plant from five different workplaces were selected. The wet bulb globe temperature (WBGT), the physiological strain (PSI), and the heat stress (HSI) indices were calculated. Workers' productivity level was evaluated by analyzing the relationships between work capacities and different WBGT levels against work intensities' curves and by using the predicted mean vote (PMV)-productivity model. The highest values of WBGT were recorded in August, notably within the blast furnace area and continuous casting unit with mean values of 31.32 ± 0.8 °C and 31.34 ± 0.74 °C respectively, while the maximum HSI was calculated at the rolling mills unit with a value of 137.83% ±18.45. About 86% of participants complained of thermal discomfort during summer as a result of heat waves, dirt and gas emissions. Strong correlations were found between PSI and WBGT indices with core body temperature ($r = 0.725$ and $r = 0.721$ respectively) as well as the rate of heartbeat ($r = 0.648$ and $r = 0.517$). These are considered as the most applicable indices for evaluating heat load impact on workers' health and performance.

1. Introduction

Heat exposure has a great impact on workers' health and productivity in many industrial workplaces, especially steel industry where excessive heat exposure is a major occupational problem. The relationship between occupational heat exposure and productivity has already been studied [1,2]. There are different environmental factors that significantly impact worker performance and health in iron and steel manufacturing plants, however, the radiant heat from the furnaces and coke ovens is the fundamental factor due to thermal stress, especially amid hot summer days [3]. Moreover, the increasing heat exposure due to climate change is likewise creating occupational health risks and debasing the ability of workers to be productive to their full potential [4].

A group of researchers carried out a study to assess the impact of heat load of the workplace environment among the workers in ceramic and iron industries, and then compared results. Common symptoms for both industries included higher body temperature, sweating, excessive thirst, insomnia, fatigue and muscular discomfort. However, insomnia, sweating, kidney stones, muscular discomfort, and decreased amount of urine were more prevalent among the workers of ceramics [5]. Thus, stress from heat, humidity, welding fumes, metal dust and gas emissions increases strain is are reflected on the workers' physical and psychological state, negatively affecting their productivity and performance [6,7]. Heat stress occurs at lower temperatures and humidity in workers wearing protective gear because they diminish the cooling impact of the evaporation that occurs naturally [8]. Thus, ensuring the health status of the workers who are constantly exposed to hot thermal environments and internal heat created through physical work leading to dangerous health issues such as heat exhaustion or stroke is of prior importance [9].

In recent years, the assessment of thermal stress, excessive noise, and poor illumination have been obtained through both laboratory and field studies using different methods, the most common being that of Taguchi and Delphi [10,11]. Some researchers have provided empirical proof from the manufacturing and agriculture sectors that increasing heat stress has an adverse impact

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on workers' productivity by reducing their working capabilities, especially in developing countries [12]. The relationship between WBGT and productivity was demonstrated in a cross-sectional sample of agricultural workers by using linear mixed effects models, and it was found that increases in WBGT are correlated with reductions in productivity [13].

Other studies used thermo-physiological modelling as the premise to estimate productivity loss due to heat exposure in workplaces [14]. Because of the importance of laborers' wellbeing, quality of work, and production capacity, workers ought to implement and conform to all the guidelines and safety procedures in their working environment to reinforce performance and productivity [15].

There are many industrial areas around the world with poor air quality due to coal combustion methods in their industrial processes. For instance, Turkey is one of the most industrialized area with high PM_{10} (particulate matter with an equivalent aerodynamic diameter of 10 μm or less) concentration ranging from 102.3 μg/m^3 during winter to 59.9 μg/m^3 during summer [16]. There are many risks associated with different aspects of iron and steel industry, such as emissions resulting from blast furnaces, large quantities of gas produced by converters and coke ovens, and dust and fumes resulting from the process of iron and steel manufacturing, all of them having a direct impact on the workers' health and safety.

Oxides of sulphur, nitrogen and carbon are major air pollutants, with severe effects on workers' health status. Using a retrospective cross-sectional study, Rafiei et al. [17], showed a direct effect of indoor air pollution on increased risk of cardiovascular diseases, chest tightness, and cough in beam rolling mills factory in Iran. When the concentration of these pollutants increases beyond a certain level, it may lead to human health problems, especially those related to breathing. According to Liu et al. [18], higher concentrations of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in air at the steel plant zone are associated with respiratory symptoms and cardiovascular diseases.

In order to obtain realistic results of the impact of environmental stress on workers' physical state, the three most relevant indices were calculated, namely WBGT, HSI and PSI. The Wet Bulb Global Temperature (WBGT) index takes into account the effect of air temperature, humidity, air velocity, and radiation. It has been suggested as a standard heat stress index based on ISO 7243 [19], and recommended by many researchers [20,21].

Heat Stress Index (HSI) is the proportion of evaporation required to keep the body's heat balance (E_{req}) to the maximum evaporation that can occur in in the environment (E_{max}). Its value is expressed as a percentage [22]. The last index used in this study is the Physiological Strain Index (PSI) introduced by Moran et al. [23], which is used to measure the physiological response to hot environmental conditions. To calculate the PSI index measurement of heart rate and deep body temperature is required.

In this study the WBGT, PSI, and HSI indices were utilized to empirically assess the impact of heat stress on health status and productivity decline among Kardemir Iron and Steel Factory workers in Karabük-Turkey during the hot months. To our knowledge, it is the first study of this nature in the locality and the information compiled can be the first step in reforming the working conditions in order to improve the lives of thousands of workers at the plant.

2. Material and methods

2.1. Area of study

The Kardemir iron and steel plant is located in Karabük city in the black sea region of Turkey (41°11′55″N 32°37′35″E). It is the sole manufacturer of rails not only for Turkey, but the surrounding region as well. The plant has 2600 employees working on a weekly rotation with a three-shift system of 8-h a day, 5-days a week. The climate characteristics of the region are warm and dry summers, and rainy cold winters. During summer, August is the hottest month with an average temperature of 38 °C, while the average temperature in June is 28.2 °C at the plant zone.

The manufacturing process of iron and steel is based on the blast furnace (B.F) and basic oxygen furnace (B.O.F). Five workplaces that contribute the highest sources of radiant heat during steel manufacturing process were identified in four workstations (Fig. 1). They are the coke ovens and blast furnace from the ironmaking unit, basic oxygen furnace from steelmaking unit, reheat furnace from continuous casting unit and the production of billets from the rolling unit. Twenty workers from each unit were selected for the survey.

2.2. Sampling and survey

Subjects' surveys and instrumental measurements were finished simultaneously in all five workplaces during the hot season from June to August of 2016. A total of one hundred male workers (20 per station) who were exposed to heat in different workstations were selected based primarily on work region, type of work and health status (not suffering from any cardiovascular, breathing or infectious diseases), as well as those who were not under any medication during the survey.

The questionnaire was designed with the help of experts from the college of technology, Karabük University. It took between 20 and 30 min to fill in the background information, occupational information and 15 closed-ended question related to thermal workplace conditions, such as thermal sensations humidity, and air quality. There were also questions concerning the form of work, amount of daily water intake, rest periods, and activity level during the working hours. There was also one open-ended question included in the questionnaire about improvements that the workers would like to have. The questionnaire was conducted only once and all the questions were in Turkish language, which is spoken by all the employees. In addition, there was also a short interview to provide more explanations about the purpose of the survey and the value of information given by each worker. They were encouraged to express their opinions freely. Due to time constraints, the questionnaires were filled mostly during the lunch break between 12:30 and 13:30.

The work shift of the participants ran from 09:00 am to 17:00. All the concerned individuals were factory personnel and they were wearing light-weight blue cotton uniforms, helmet, and protection footwear throughout summer season. For more effective protection, blast furnace workers were wearing aluminum clothing for PPEs and they were standing at distances of 1.5–2.0 m away from the furnace. During winter, extra layers of clothing was supplied for insulation in cold climate conditions for all the personnel working outside (coke plant). The standards of ISO 9920 [24], were used to estimate the average clothing value which was rounded to 0.8 clo.

2.3. Measurement of environmental variables

Measurements were taken at 9:00 a.m., 12:00 a.m. (midday), and 16:00p.m. once a month through the three months study. Measuring locations were selected as close as possible to the worker's activity site without interfering with their job. Environmental parameters of dry air temperature (T_a), globe temperature (T_g), mean radiant temperature (MRT), relative humidity (RH), air movement (V_a), and wet bulb globe temperature ($WBGT$) were measured at the required places with a handheld WBGT monitor (Extech HT30), and a multi-functional measuring instrument (Testo435-4)

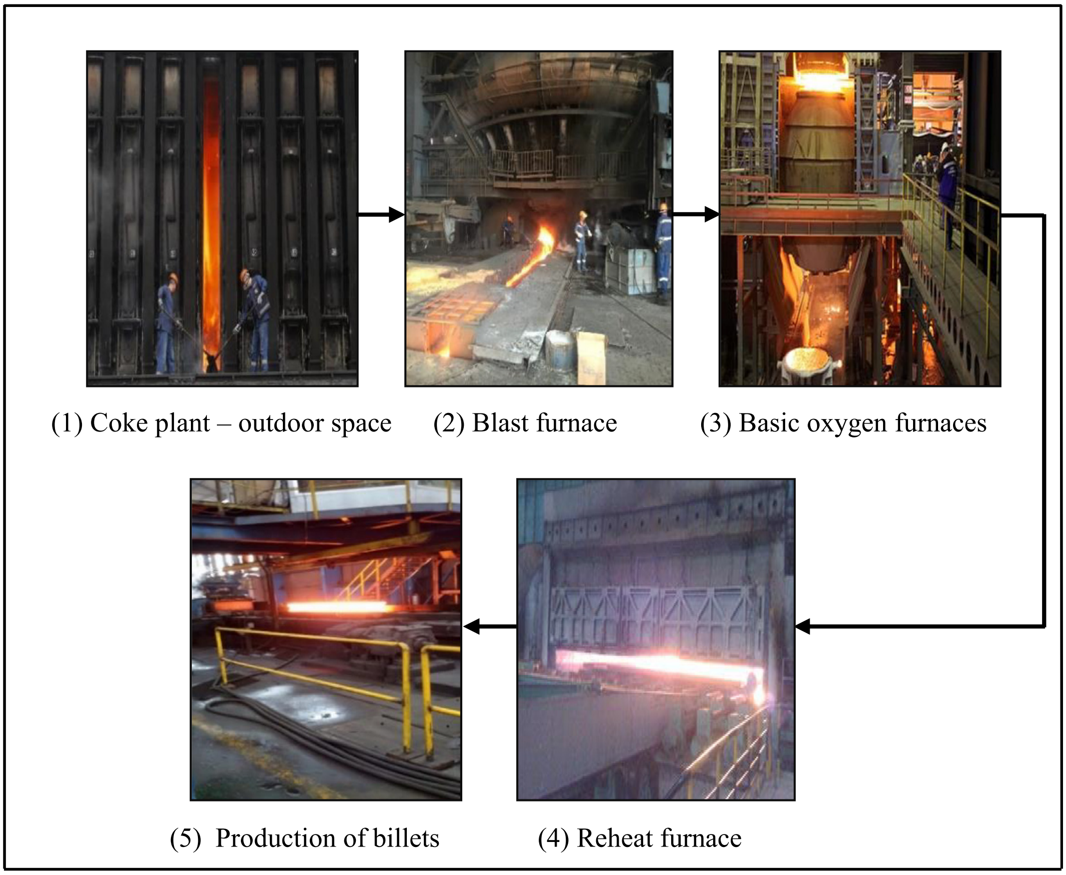

Fig. 1. The selected workplaces for measurements and survey.

which consists of an instrument kit with classical wired probes as well as wireless probes which could be operated from distance as far as 20 m supported by a 1.1 m high tripod was used.

2.4. Measurement of physiological parameters

Measuring physiological parameters (the core body temperature and pulse rate) were performed while the employees were in standing position in rest room located 30 m away from the workplace in each unit. Apart from the workers of coke oven located outdoors and blast furnace located indoors, their body temperature and heart rate were measured in the course of work in standing position.

Measurements of heart rate and core temperature were performed half an hour before work, 2 h after starting work, and one hour after lunch break. All measurements were performed with Omron M2 monitor. This instrument measures blood pressure (Systolic & Diastolic) and pulse rate simultaneously. For measurement of core body temperature, Braun ear ThermoScan was used to estimate core body temperature by measuring the temperature in the ear canal by waiting for a minimum of two minutes before taking readings. The instruments were calibrated before and after measurements. Data were manually recorded, then the mean values were calculated. Metabolic rates (M) was calculated from the worker's heart rate, age, and body weight by using the methods provided in ISO 8996 [25]. The equations used in the calculation of the Heat Stress Index (HSI) are:

$$\boldsymbol{HSI} = \frac{\boldsymbol{E_{req}}}{\boldsymbol{E_{max}}} \times 100 \quad (1)$$

$$\boldsymbol{E_{req}} = \boldsymbol{M} - \boldsymbol{R} - \boldsymbol{C} \quad (2)$$

$$\boldsymbol{R} = 4.4(35 - \boldsymbol{MRT})\boldsymbol{V}^{0.6} \quad (3)$$

$$\boldsymbol{C} = 4.6\boldsymbol{V}^{0.6}(35 - \boldsymbol{T_a}) \quad (4)$$

$$\boldsymbol{E_{max}} = 7\boldsymbol{V}^{0.6}(56 - \boldsymbol{P_a}) \quad (5)$$

where M stands for Metabolic rate in (w/m^2), R for Energy exchanged by radiation (w/m^2), C for Energy exchanged by convection (w/m^2), MRT for Mean radiant temperature (°C) T_a for Workplace dry temperature (°C), V for Air velocity (m/s), and P_a for Pressure of water vapor in the air (mb).

PSI index was calculated by the following equation:

$$\boldsymbol{PSI} = 5(\boldsymbol{T_{re,t}} - \boldsymbol{T_{re,0}})(39.5 - \boldsymbol{T_{re,0}})^{-1} + 5(\boldsymbol{HR_t} - \boldsymbol{HR_0})(180 - \boldsymbol{HR_0})^{-1} \quad (6)$$

where $T_{re,o}$ and $T_{re,t}$ indicate the rectal temperatures at rest and during work, however in this study inner ear canal temperature was used in its stead [26]. HR_0 and HR_t show the heart rate at rest and work respectively. HR_0, and $T_{re,o}$ were obtained in the standing position 30 min before work in the resting room. HR_t and $T_{re,t}$ were obtained 2 h after starting the work. This index has a numerical range between 0 and 10, where 0 represents no strain and 10 very strenuous physiological conditions, within the limits of the following values: $36.5 \le T_{re} \le 39.5$ °C and $60 \le HR \le 180$ beats/min.

2.5. Air quality

In order to examine air emissions in the steel plant area and to assess the effects of pollutants on workers' health inside the existing work surroundings, concentrations of air pollutants were continuously measured and collected in Kardemir plant in the course of 12 months in 2016 by Turkish air quality stations through a network of monitoring stations across the country [27]. The monitoring network involves daily measurements of environmental parameters and air pollutants in a number of locations in the country. Table 2 shows a comparison between the World Health Organization (WHO) emission limits for the concentration values of $\boldsymbol{PM}_{10}$, $\boldsymbol{NO}_2$, $\boldsymbol{SO}_2$, and $\boldsymbol{NO_x}$, with the values measured in Kardemir plant.

2.6. Productivity impacts

The present study is focused only on productivity losses due to heat exposure in the thermal working environment. The survey results of 100 workers, who were asked to rate the impact of heat exposure on their activity levels are shown in Fig. 3. The productivity loss was estimated based on two previous researchers' methods. The first is a measure of the relationship between employees' ability, extreme WBGT level and work intensities as detailed by Kjellstrom et al. [28], and represented in a graph based on the ISO 7243 for acclimatized persons. These theoretical results were then compared with the survey results. Fig. 2 demonstrates that different work intensities are related to different work capacities for different WBGT indices: 200 Watts indicates light work such as office work; 300 Watts indicates moderate work such as that in the manufacturing industry; and 400 Watts suggests heavy work such as construction work. The second method is based on the theory that productivity can be predicted as a function of the predicted mean vote (PMV) index in the construction industry by means of a polynomial regression analysis resulting in three different mathematical regression models for predicting productivity for light, moderate and heavy tasks [29]. PMV was selected due to its capability to integrate the effects of thermal environment variables, the nature of the job task being performed, and the clothing ensembles worn by workers, and provide a single value as a thermal index. The PMV index was originally developed by Fanger [30], and is currently adopted by the International Standards Organization (ISO, 1995a) [31]. For determining the conditions for thermal comfort. Eq. (7) represents the productivity percentage for heavy workload.

$$\boldsymbol{P_H} = 83 + 21.64\boldsymbol{PMV} - 9.53(\boldsymbol{PMV})^2 + 0.91(\boldsymbol{PMV})^3 \quad (7)$$

where $\boldsymbol{P_H}$ stands for productivity value for heavy workload.

2.7. Data analysis

The collected data from the questionnaire and physical measurements were analyzed using Statistical Package for Social Science (SPSS) software version 20. The means and standard deviations of the outcomes were calculated separately for workers in each workplace. Differences in the outcome variables between groups were tested using the Kruskal-Wallis and Chi-square tests. Pearson correlation analysis was used to determine the correlation between physiological parameters and heat stress indices, where the significance level for all analysis was set to be 0.01 at 95% confidence. Cronbach's alpha analysis was used to represent the internal consistency and reliability of all the constituents of the survey.

3. Results

3.1. Study sample

The average age of the employees was 37.54 ± 5.86, and the majority ranged from 33 to 43 years old. The mean work experience was 9.79 ± 5.76 years, and there was no significant relationship between workers experience and their workplaces (p = 0.345). Finally, 70% of the workers were non-smokers.

The inner consistency reliability of the questionnaire predicted by way of Cronbach Alpha coefficient (α) was 0.681, which is considered an acceptable value, after removing the variables related to the laborers' position during work (standing, walking, or both). Table 1 summarizes the participants' characteristics. Fig. 3 illustrates the percentage of steel workers wearing a personal protective equipment (PPE) while working.

3.2. Heat stress profile

Results from the survey showed that the majority of workers complained of thermal discomfort in their workplaces, where the ambient temperatures ranged from 34 to 40.9 °C throughout hot summer days. 44% of the participants mentioned that they were feeling very hot, followed by 52% who were feeling hot, and finally 4% who were feeling warm. Heat rashes are the most common problem in the selected workplaces, which in most cases disappear when the affected worker returns to the cool resting room. There was no significant distinction of thermal discomfort level experienced by employees working in different workplaces (p = 0.647).

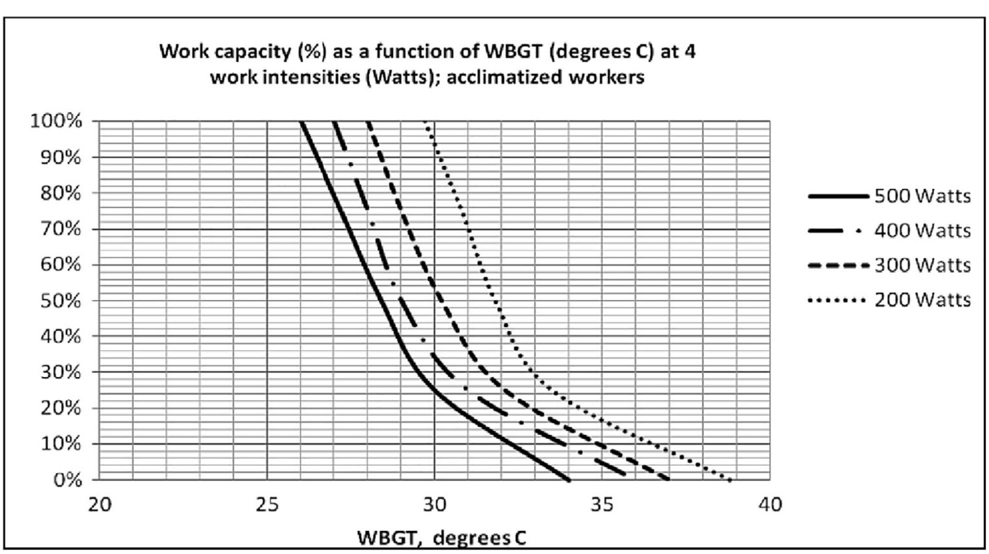

Fig. 2. Relationship between productivity loss (%) and WBGT (°C) for 4 work intensities (Watt) (Source, Kjellstrom et al., 2009).

Table 1
Workers characteristics. (No. of workers = 100 male).

Variables	Min.	Max.	Mean	S.D
Age (years)	25	51	37.54	5.86
Height (cm)	168	188	178.9	5.67
Body mass (kg)	75	88	80.3	4.4
Work experience (years)	1	21	9.79	5.76

Fig. 4 shows the distribution of survey's participants' thermal sensation for all workstations.

Principle results from the predicted heat stress and strain indices showed that the mean values of WBGT, PSI and HSI across the steel plant were 30.89 ± 1.1 °C, 3.15 ± 0.64 and 118.5 ± 18.61%, respectively during the month of August. High levels of heat stress were observed close to furnaces and hot rolling area. The minimum WBGT, HSI and PSI were found in the outdoor coke ovens area with values of 29.87 ± 1.26 °C, 92.13% ±2.82, and 2.22 ± 0.15 respectively (Table 2). Based on the total anticipated scores of PSI, the heat strain ranged from none/little to low in all units. The results confirmed that the mean WBGT values in the five workplaces exceed the threshold limit value (TVLs) of 28 °C WBGT recommended by American Conference of Governmental Industrial Hygienists (ACGIH) in summer time [32]. According to the ACGIH screening criteria (WBGT in °C) for 8 h work five days a week with conventional breaks for a job involving heavy work (Table 3), one-hour shift should be split into 30 min of work and 30 min resting in coke ovens and rolling mills areas, and 25% work and 75% rest for workers in furnaces areas.

The predicted values of HSI at workplace air velocity of less than 1 m/s were compared with the measured WBGT on the same conditions and were not compatible with each other. This is due to the low accuracy of HSI in environments of such low wind velocity, meaning that this index is not appropriate for all workplace thermal conditions. According to the results of Hajizadeh et al. [33], values of HSI index are too exaggerated; when the airflow rate is equal or close to zero, the estimations are higher than the real values. Consequently, the HSI index can be used under certain circumstances as a supplement index of WBGT. Their study showed that the WBGT and HSI had the highest correlation with other physiological parameters among the other heat stress indices during heavy work activities in hot and dry climates, which is in line with our results.

The optimum index was selected primarily based on the correlation coefficient between the various indices with each other as well as with physiological parameters in the exposed samples. However, in a steel industry, the indices of HSI, WBGT, ET and CET did not have a significant relationship with deep and oral tem-

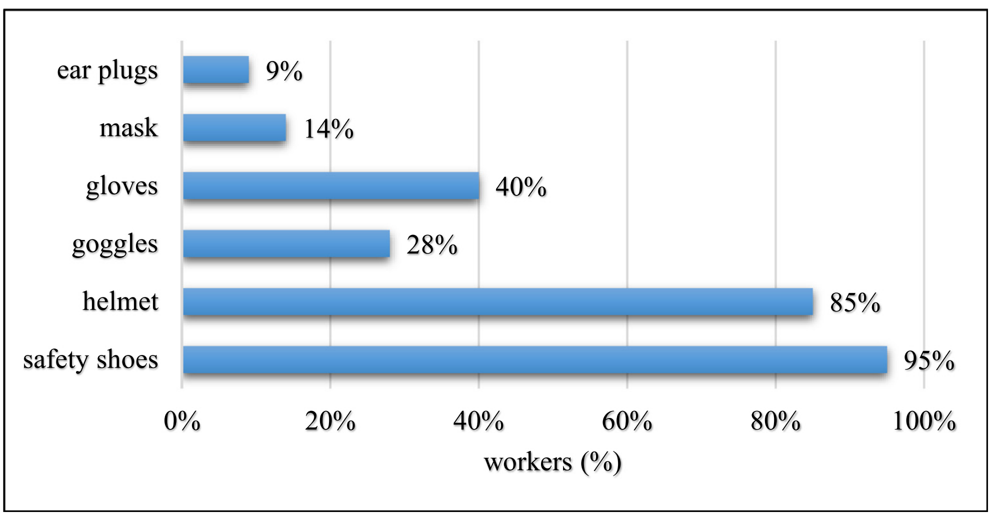

Fig. 3. Workers wearing P.P.E from survey.

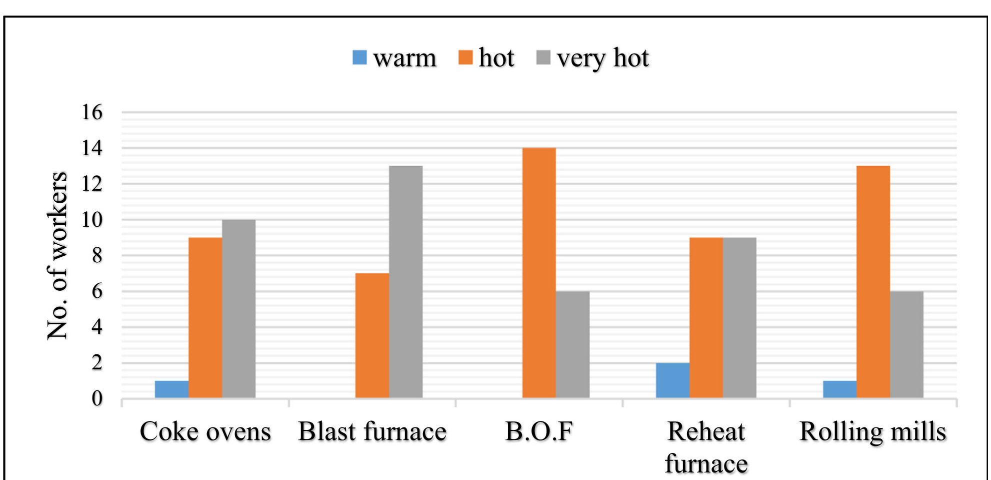

Fig. 4. Thermal sensation votes from survey.

Table 2
Heat stress indices, environmental and physiological measurements, (Mean ± S.D).

Parameter	Coke ovens	B.F	B.O.F	Reheat furnace	Rolling mills
T_a (°C)	37.6 ± 3.14	39.7 ± 2.61	38.2 ± 2.42	38.1 ± 1.33	37.5 ± 1.82
T_g (°C)	42.7 ± 4.12	46.5 ± 4.32	44.2 ± 3.34	45.1 ± 4.71	42.4 ± 2.43
T_{mrt} (°C)	58.2 ± 1.24	62.5 ± 1.1	57.7 ± 1.63	57.2 ± 1.4	50.6 ± 1.7
RH (%)	33 ± 5.16	35 ± 3.74	35 ± 3.91	40 ± 2.61	40 ± 3.46
V_a (m/s)	2.3 ± 0.45	1.6 ± 0.31	1.4 ± 0.67	0.9 ± 0.34	0.8 ± 0.44
HR (bpm)	92.3 ± 4.32	104.2 ± 7.7	98.1 ± 10.5	102.8 ± 8.0	102.2 ± 6.7
T_{core} (°C)	37.32 ± 0.38	37.95 ± 0.11	37.71 ± 0.34	37.46 ± 0.42	37.35 ± 0.46
WBGT (°C)	29.87 ± 1.26	31.32 ± 0.8	31.25 ± 0.75	31.34 ± 0.74	30.68 ± 1.14
HSI (%)	92.13 ± 2.82	118.6 ± 9.45	109.8 ± 4.9	134.3 ± 19.42	137.83 ± 18.45
PSI	2.22 ± 0.15	4.02 ± 0.32	3.30 ± 0.18	3.13 ± 0.31	3.1 ± 0.40

Table 3
ACGIH Screening Criteria for Heat Stress Exposure (WBGT values in °C) for 8 h work day five days per week with conventional breaks.

Work demand	Percentage of work in a cycle of work and recovery in an hour			
	75–100%	50–75%	25–50%	0–25%
Light	31.0	31.0	32.0	32.5
Moderate	28.0	29.0	30.0	31.5
Heavy	–	27.5	29.0	30.5
Very heavy	–	–	28.0	30.0

peratures [34]. Further, Golbabaei et al. [35], examined the relations between the thermal stress indices to develop an optimal index based on physiological parameters in petrochemical industry. According to them, the best index correlating with heart rate was WBGT, so it was chosen as the optimal index for hot and humid surroundings.

3.3. Physiological changes measurements

The physiological changes of pulse rate and body core temperature were measured, and the mean values of the entire sample were 99.93 ± 8.39 beats per minute and 37.56 ± 0.42 °C, respectively. Pearson correlation showed a strong positive correlation (r = .648) between WBGT and PSI index, as well as between WBGT and core body temperature (r = .725) as shown in Table 4. From the heart rate data, the average values ranged between 92 and 104 beats per minute (bpm). An average heart rate is normally between 60 bpm and 100 bpm. OSHA Technical Manual, 1999 [36], recommends that if the heart rate exceeds 110 bpm, the next period of work shift should be shortened by one third and the rest period should be preserved. Most respondents thought that the rest periods and lunch break are short and must be increased during summer season. When it comes to workers movements and position during work shift, more than half of them reported walking and standing, and 40% said they were walking, standing, and sitting, depending on the needs of the process.

The average water intake reported during work shift for each worker was 0.67 ± 0.64 L, which is not enough to replace the sweating rate and avoid health risks. Body water loss was measured by weighing the worker on a scale at the start and end of work shift. Although the worker's weight loss did not exceed 1.5% of total body weight, workers were encouraged to increase fluid intake during work in order to prevent dehydration.

3.4. Heat and air pollution-related health impacts

About 85% of individuals complained of heat exposure and pollution because of dust and gas emissions, including particulate matter, sulphur oxides, and carbon monoxides, which originate mostly from air emissions in blast and basic oxygen furnaces.

According to Table 5, the average annual concentrations of $\boldsymbol{PM_{10}}$ was greater than WHO limits. $\boldsymbol{SO_2}$ and $\boldsymbol{NO_x}$ concentrations were below the daily, and annual standards in line with WHO limits in the evaluation of 2016, while $\boldsymbol{NO_2}$ concentrations exceeded by about 25%. Therefore ventilation, air cooling, fans, shielding, and insulation are important controls used to reduce heat stress and air pollution in hot workplaces.

Around 30% of workers complained of health and social problems resulting from occupational heat stress and air contamination. Their complains included weakness, excessive sweating, headache, a large percentage of hearing loss, lack of ventilation and, too fatigued to spend quality time with the family after finishing work. As per 2016 daily data recorded from the Occupational Health and Safety Department in Kardemir steel plant, there were no injuries and accidents. There were no reported heat illness cases during the night and very few during the day shifts.

3.5. Productivity

Almost two-thirds of the workers stated their activities were excessive during the first half of work shift before lunch break and they thought their productivity loss was approximately 30% in the remaining hours of the shift. 17% claimed their activity levels were high during all hours of work and 19% reported their performance increased 2 h after starting work (Fig. 5). The Kruskal-Wallis analysis confirmed that there were statistically significant differences in workers overall performance levels before ($x^2(2) = 8.100$, p = .017), and after lunch breaks ($x^2(2) = 12.316$, p = .002) among all units. In contrast, ANOVA analysis indicated that there was no significant relationship between workers experience and their activity levels before (p = 0.345) and after lunch (p = 0.711). The Percent productivity loss ranged from 61 to 76%. According to the Fig. 5, there was a significant difference in productivity level of workers estimated from the survey and the ones obtained from the WBGT vs. productivity loss curve (Fig. 2). The results may vary due to studies performed in different types of industries and countries. Moreover, the ISO standard used for plotting the WBGT vs. productivity loss curve assumes that workers take rest in the same environment when they work, but workers in Kardemir plant tend to take rest in cooler rest rooms. In contrast, performance loss values from the survey results in Fig. 3 are in line with the calculated values from Eq. (7) for PMV-productivity model, ranging from 20 to 30% productivity losses for a heavy workload.

Table 4
Summary of correlation results.

Variables		T_{core} (°C)	HR (bpm)	WBGT (°C)	HSI (%)	PSI
T_{core} (°C)	*r*	1	.605**	.721**	.334	.725**
	P-value		.000	.000	.071	.000
HR (bpm)	*r*	.605**	1	.517**	.678**	.648**
	P-value	.000		.003	.000	.000
WBGT (°C)	*r*	.721**	.517**	1	.465**	.623**
	P-value	.000	.003		.010	.000
HSI (%)	*r*	.334	.678**	.465**	1	.535**
	P-value	.071	.000	.010		.002
PSI	*r*	.725**	.648**	.623**	.535**	1
	P-value	.000	.000	.000	.002	

** Correlation is significant at the 0.01 level (2-tailed).

Table 5
Comparison of (WHO) emission limits for the concentration values of PM_{10}, NO_2, SO_2, and NO_x, with the estimated values in Kardemir steel plant.

Pollutant	Annual average concentration (μg/m^3)	
	Limit value (WHO)	Recorded value
PM_{10}	20	86
NO_2	40	50
SO_2	20 (daily average)	17 (daily average)
NO_x	25	24

4. Discussion

The present study shows that furnace workers are exposed to more heat stress than others (WBGT = 31.25, 31.32, and 31.34 °C) which is consist with the study of Haji Azimi et al. [37]. Intervention can be done in order to reduce radiant heat around the furnaces by using a heat absorbing system in the furnace body and installing reflective barriers. Omid Giahi et al. [38], confirmed that heat control at the heat source can be considered as a first solution for reducing radiant heat of blast furnaces by installing reflective aluminum barrier in the main workstation of steel industry. Their results showed that WBGT indexes decreased by 3.9 °C.

The correlation between heat stress indices and physiological parameters of heart rate and core temperature indicated a significant relationship between them. HSI showed a higher correlation than the other indices with heart rate. However, WBGT and PSI indices indicated a significant relationship with core body temperature. Moreover, a relatively weak correlation was observed between the HSI and core body temperature.

The findings of a study by Habibi et al. [39], confirmed our results and showed that the WBGT had a direct significant correlation with the physiological variables of heart rate, oral temperature, and PSI.

The results showed significant correlation between PSI, WBGT, and HSI. Thus, PSI index showed more correlation than others. In Dehghan et al. study [40], the deep body temperature parameter had a much higher correlation with a HSI than the WBGT index. In addition, PSI was more strongly correlated with the HSI than the WBGT index; they are all consistent with the results of our study.

On the other hand, Heidari et al. [41], studied workers who were experiencing high heat stress and found the highest correlation between aural temperature and WBGT, an observation not in agreement with the results of the present study.

To validate the indices, the considered index should have a strong meaningful relationship with physiological parameters. In this study, the optimum index was chosen by studying the correlation coefficient between the various indices with each other as well as with physiological parameters. However, this study showed that the WBGT and PSI indices had the highest correlation with physiological parameters as compared to the HSI index.

According to Fig. 5, there was a significant difference in productivity levels of workers estimated from the survey and the ones obtained from the WBGT vs. productivity loss curve (Fig. 2). The results may vary for studies done in different types of industries and countries. Moreover, the ISO standard used for plotting the WBGT vs. productivity loss curve assumes that workers take rest in the same environment where they work, but in reality workers in Kardemir plant tend to take rest in a cooler rest room.

In contrast, values of performance loss from the survey results (Fig. 3) are in line with the calculated values from Eq. (7) for PMV-productivity model, ranging from 20 to 30% productivity loss during heavy workload. Thus, the workers' productivity loss estimated in this study is not an accurate value, but an approximation.

In a study conducted by Langkulsen et al. [42], the impact of climate change on occupational health and productivity in Thailand

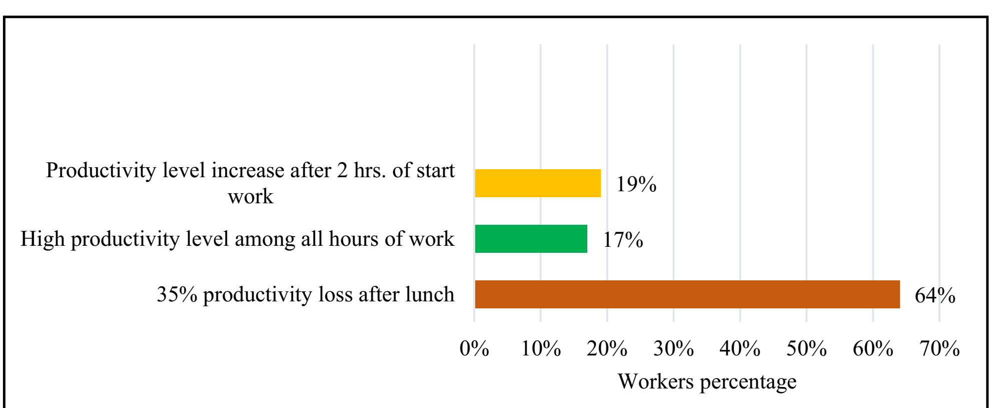

Fig. 5. Workers' productivity percentage from the survey.

was assessed. They found the range of production loss to be from 10 to 66.7%, which is significantly different from that of the present study probably due to different levels of heat exposure, socio-economic differences, as well as different nutritional status and culture.

According to the results of air pollutants in Kardemir plant, PM_{10} was 4 times greater than

WHO limits in a year. These results confirm the outcomes found for PM_{10} concentration exceeding the limits set by WHO in the districts around Kardemir [43]. The major reason for this condition is that the plant is surrounded by mountains and hills and the wind speed is not high enough to transport the pollution away from the plant atmosphere. Therefore, using respiratory protective devices to reduce or eliminate hazardous exposures to PM_{10} is an urgent measure.

5. Conclusion

The results from this study revealed that thermal working conditions and air pollution have a considerable impact on workers' health and performance. The results demonstrate that WBGT and PSI are the foremost applicable indices for assessment of heat stress within the Kardemir steel plant. It is worthwhile to note that the present study was conducted in hot and dry summer season, during which a profound effect on the cardiovascular response, reactivity, and subjective fatigue symptoms of workers merits concern. Therefore, to enhance the efficiency of the workers, health and safety should be considered as a matter of urgent attention in the plant, and workers should be under constant medical supervision.

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