Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

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

Abdel karim Fahed *, Mehmet Ozkaymak, Siraj Ahmed

Energy Systems Engineering Department, Karabük Üniversity, Karabuk 78050, Turkiye

ARTICLE INFO

Article history:
Received 12 January 2018
Revised 25 April 2018
Accepted 7 May 2018
Available online xxxx

Keywords:
Heat load
Steel plant
Productivity
WBGT
HSI
PSI

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

* Corresponding author.
E-mail addresses: fahedkazan82@gmail.com (A.karim Fahed), mozkaymak@karabuk.edu.tr (M. Ozkaymak).

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.05.005
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

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 iron-making 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)