Safety and Health at Work 8 (2017) 99–104

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India

Manikandan Krishnamurthy, Paramesh Ramalingam, Kumaravel Perumal, Latha Perumal Kamalakannan, Jeremiah Chinnadurai, Rekha Shanmugam, Krishnan Srinivasan, Vidhya Venugopal*

Department of Environmental Health Engineering, Sri Ramachandra University, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 29 July 2015
Received in revised form
4 August 2016
Accepted 5 August 2016
Available online 3 November 2016

Keywords:
climate change
health risks
occupational heat stress
productivity loss
steel industry

ABSTRACT

Background: Workers laboring in steel industries in tropical settings with high ambient temperatures are subjected to thermally stressful environments that can create well-known risks of heat-related illnesses and limit workers' productivity.
Methods: A cross-sectional study undertaken in a steel industry in a city nicknamed "Steel City" in Southern India assessed thermal stress by wet bulb globe temperature (WBGT) and level of dehydration from urine color and urine specific gravity. A structured questionnaire captured self-reported heat-related health symptoms of workers.
Results: Some 90% WBGT measurements were higher than recommended threshold limit values (27.2−41.7°C) for heavy and moderate workloads and radiational heat from processes were very high in blooming-mill/coke-oven (67.6°C globe temperature). Widespread heat-related health concerns were prevalent among workers, including excessive sweating, fatigue, and tiredness reported by 50% workers. Productivity loss was significantly reported high in workers with direct heat exposures compared to those with indirect heat exposures ($\chi^2 = 26.1258$, degrees of freedom $= 1$, $p < 0.001$). Change in urine color was 7.4 times higher among workers exposed to WBGTs above threshold limit values (TLVs).
Conclusion: Preliminary evidence shows that high heat exposures and heavy workload adversely affect the workers' health and reduce their work capacities. Health and productivity risks in developing tropical country work settings can be further aggravated by the predicted temperature rise due to climate change, without appropriate interventions. Apart from industries enhancing welfare facilities and designing control interventions, further physiological studies with a seasonal approach and interventional studies are needed to strengthen evidence for developing comprehensive policies to protect workers employed in high heat industries.

1. Introduction

Heat is one of the physical hazards that can cause health problems in the workplace [1,2] and one of the most important and common occupational health problems in workplaces is inappropriate thermal conditions that can impact the health and productivities of workers [3–6]. Daily heat exposure during the hot season in tropical and subtropical parts of the world is a problem particularly for people working in jobs that cannot be, or are not cooled by air conditioning or other technical methods. Tropical climates with high ambient temperature and humidity may therefore pose higher heat-related occupational health and safety risks to the exposed population in low and middle income countries [4,5].

Climate change, as an environmental health-risk component is a newly recognized phenomenon, with global scope, operating over long time periods and affecting an unusually wide range of health outcomes [7]. Climate change is an added risk component due to the predicted rise in air temperatures and humidity as part of local climate change that shall further increase the existing occupational health risks due to heat exposures [8]. Several direct and indirect health impacts of global and local climate change have been documented or forecasted [9,10].

* Corresponding author. Department of Environmental Health Engineering, Sri Ramachandra University, No.1, Sri Ramachandra Nagar, Porur, Chennai, Tamil Nadu, India, 600116.
E-mail address: vvidhya@ehe.org.in (V. Venugopal).

2093-7911/$ – see front matter
http://dx.doi.org/10.1016/j.shaw.2016.08.005

People who carry out heavy physical labor as a part of their daily jobs (or household activities) are at particular risk, as the physical activity itself causes high internal heat production which must be released to avoid heat strain health symptoms, as it may lead to life-threatening "severe hyperpyrexia" (core body temperature > 40.6°C) [1]. When air temperature exceeds 37°C, evaporation of sweat becomes one of the primary mechanisms to cool the body that can be strongly impaired by high air humidity. This heat cannot easily be transferred from the body when the work environment is hot or when the air is humid and evaporation of sweat is inefficient [11], which creates health impacts and loss of work capacity among the exposed [1].

For workers to protect themselves from the heat, the simplest way is to slow down work and take more and longer breaks [1], but this reduces the daily work productivity of the workers and is also not possible in certain jobs [2]. The other mechanism is to cool themselves, but this is difficult to achieve in many Indian work settings by air conditioning or cooling systems. Asia is at particular risk, as confirmed by a health impact assessment for the World Health Organization [12]. India is a country with hot summer seasons and millions of poor workers are likely to be affected by excessive workplace heat [13], with consequent health risks, and reduced productivity and daily incomes [14,15]. The adverse impacts of heat on health and work capacity (and productivity) studied at an individual level [5,11,13,16,17] stands as evidence for this occupational health risk posed by the workers. With the predicted rise in temperature and anticipated economic loss due to the changing climate scenario in some geographical locations [18], it becomes imperative that attention be focused on conducting more such studies in the South Asian region of the globe [19].

The need to generate research evidence and implement sustainable intervention techniques to reduce workplace heat stress to prevent health and productivity risks for millions of poor working people employed in high heat environments is warranted. With this background, the present study was carried out by the investigators in a steel industry in India to understand the impacts of heat stress on the health and productivity of workers working in high heat industries, the results of which are presented in this manuscript.

2. Materials and methods

2.1. Plant and process description

The study was conducted in a steel industry located in a city nicknamed "Steel City" in Southern India, where the ambient temperatures are high (32.5 ~ 37.2°C) for about 6–7 months and humidities are high (47 ~ 55%) for about 4–5 months in a year [20]. The two large steel industries in the city are the highest employers in the region and the economy of the city is based around these industries. The working hours for the workers is 8 h/d with some workers doing overtime of 1–2 hours on random days during peak production. The steel manufacturing in the workplace involved the following two processes. The first process is the iron making process that involved chemically reducing and physically converting iron oxides in the blast furnace (BF) into liquid iron called "hot metal" with "liquid slag" and "liquid iron". This process is one of the biggest sources of radiation heat, where the hot molten metal is poured in to the channels. The liquid slag which is collected from the bottom of the furnace is very hot. Many workers were involved in transferring the molten slag into the disposal area and hence were exposed to radiant heat from the molten process heat. The next process is coke making, which involves the battery area where the coal was carbonized releasing process heat at 1,100°C in oxygen deficient environments in slot ovens. Here, again, very high process generated radiant heat was observed, especially during charging and discharging of coal and coke from the furnace. Radiant heat was also predominant in the cooling bed area where the coke was cooled for further processes. Coke making consisted of two processes, i.e., primary steel making and the secondary steel making process. In the primary steel making process, atmospheric oxygen is blown into an initial charge containing hot metal, preheated solid scrap, and fluxes in the energy optimizing furnace (EOF) where the slag is formed and carbon, silicon, and phosphorus are eliminated depending on the steel grade. Here, the workers had to manually supply oxygen continuously in to the furnace, as shown in Fig. 1. In the continuous casting mill (CCM), the molten steel from the EOF is solidified into a "semi-finished" billet, bloom, or slab for subsequent rolling in the finishing mills. The blooming mill, an intermediate link between the steel casting shops and the rolling shops, turns out the semi-finished product of blooms out of steel ingots of large cross sections and these are sent to bar and rod mills (BRM). In BRM, the final process of steel making, the "semi-finished" billet or bloom is size reduced to different dimensions based on the product requirements.

2.2. Methodology

Area heat stress was measured in 49 work locations throughout the industry where workers were exposed to heat. The quantitative heat measurements were conducted according to the protocols recommended by the National Institute for Occupational Safety and Health [21]. Locations for measurements were selected based on the initial walkthrough survey that was conducted before the start of the monitoring; these included indoor locations with and without exposures to process-generated heat exposure, and outdoor and semi outdoor locations. Since most of the workplace locations within the industry were not air conditioned, and therefore likely to be influenced by outside temperature and time of day/season, measurements were always made during the hottest part (10:00 AM–14:30 PM) of the day. For assessment of exposure to heat stress, the wet bulb globe temperature (WBGT) recommended by the American Conference of Governmental Industrial Hygienist (ACGIH) [22] USA, was used. The WBGT combines the effect of the four main thermal components in our environment, air temperature, humidity, air velocity, and radiation, as measured by the dry bulb, wet bulb, and globe temperatures [23]. Area heat stress was monitored using an area heat stress monitor, Model QuesTemp°34 (Quest Technologies, Oconomowoc, Wisconsin, USA) which has an accuracy level of ± 0.5°C between the range of 0°C and 120°C dry

Fig. 1. Worker wearing aluminum overall exposed to radiant heat from furnace.

bulb temperatures and ±5% between the range of 20% and 95% relative humidity (RH). The instruments were calibrated at the start and end of each measurement day. To measure the WBGT of a workplace, the QuesTemp°34 was mounted at a height of 3.5 feet (1.1 m) for standing individuals and 2 feet (0.6 m) for seated individuals using a tripod stand. It was also ensured that the QuesTemp°34 was placed away from any barriers that might block radiant heat or flow, and workers were then requested to stand away from the instrument to minimize variations in temperature and radiant heat. Continuous heat stress monitoring was done using a Lascar data logger that is capable of recording continuous temperature and humidity that may be downloaded into a computer for further analysis and WBGT calculations [23]. The necessary information on workload, clothing worn, worker's time-activity pattern, and acclimatization was collected on-site, to make appropriate adjustments to the measured WBGT value. The work category of the workers was based on the judgment by a trained industrial hygienist according to ACGIH guidelines, and observations were compared with the ACGIH screening limits [22]. The threshold limit value (TLV) was computed by taking spot readings throughout the work shift and by worker's observed workload, using a "clo" factor of 0.6 for summer work uniforms and 2.0 for aluminum overalls. This "clo" factor contributes to a WBGT correction factor of 0°C for summer uniforms and 2.0 for aluminum personal protective equipment (PPE).

Quantitative and qualitative data about the perceptions on heat exposure, health impacts, and productivity losses were collected by administering a standardized high occupational temperature health and productivity suppression (HOTHAPS) [24] questionnaire to 84 study participants. The mean age of the workers was 35 ± 8 years and only male participants were working in the study area. The average exposure to the participants was 7 years. Productivity loss due to heat stress was defined as loss in production, not achieving work targets, loss of work-days/work hours due to fatigue/exhaustion, sickness/hospitalization, and/or wages lost due to heat or heat-related illnesses. Workers with diabetes, hypertension, or who were under any medication were excluded from the study. Prior clearance from the Institutional Ethics Committee of Sri Ramachandra University, Tamilnadu, India and permission from the concerned supervisor of the work site was obtained for the study, and signed informed consent was obtained from the workers before administering the questionnaires. The questionnaire had sections that focused on the following information: demographic details, work profile, years and duration of heat exposures, any preexisting health conditions, perceived exposure to heat, and its impacts on health and productivity. An elaborate section on self-reported heat illnesses was administered and the symptoms of each illness were explained to the study participant by the interviewer. The questionnaire took about 20 minutes for each participant. To determine the dehydration status of the worker, urine samples were collected before they started to work and after 4 hours of their work, and the color of urine for dehydration was interpreted with a urine color chart [25]. Urinary specific gravity (USG) was measured via a standard urinometer and the safe limit of USG was considered as 1.010–1.020 [25,26].

All data analysis was done using Microsoft excel 2007 and R-statistical software (R Foundation for Statistical Computing, Vienna, Austria). Bivariate analysis was done for identifying associations using the Chi-square test. The odds ratio (OR) is presented as the measure of association, and the cutoff of 0.05 was used to interpret the significance of the *p* values for all analysis and 95% confidence intervals (CIs).

3. Results and discussion

The WBGT levels measured in 49 locations throughout the steel industry had 90% of values exceeding the recommended TLV limits during the study period (Table 1). The maximum WBGT recorded was 41.7°C in the coke oven area where the employees were exposed to high process generated radiant heat and the minimum WBGT of 27.2°C was recorded in the air conditioned/cooled control rooms during the study period.

It is apparent from Fig. 2 that the WBGT levels were high in all the process areas with a peak temperature (41.7°C) in the coke oven plant that was beyond human endurance for extended periods [1]. The high process-generated radiant heat was prevalent in almost all areas, especially in the furnace areas of the coke oven and BF, which is apparent from the high globe temperature reading (67.6°C). In the BF-II, CCM, EOF, blooming mill, coke oven, and the power plant, the mean WBGTs were above 30°C for all measurements taken by the quest temp monitor and the continuous measurements by lascar data loggers throughout the day, which indicates consistently high heat exposures for the workers engaged in these locations throughout the work shift. The workers in these areas are engaged in heavy work and such continuous exposures to high heat environments can potentially subject them to risks of adverse heat-related health illnesses. The perception of the workers about the health effects in Table 2 also shows that all the workers across the various locations in the industry experienced excessive thirst and sweating. Apart from the environmental heat imposed on the workers, high metabolic heat load is added for workers engaged in heavy physical work that involves intense arm and trunk work, carrying, pushing, and pulling heavy loads throughout their shifts, which categorizes them as being at a high risk as far as heat stress is concerned [22,23,27]. Employees in locations with furnaces and other slag handling processes have continuous exposure to high radiant heat, even during breaks, owing to the lack of cooler resting areas in those work locations. Additionally, heat load from PPE, aluminum aprons (Fig. 1), worn by

Table 1
Area heat stress measurements in steel industry for summer season (April 2014) using quest temp wet bulb globe temperature (WBGT) monitor ($n = 49$)

Plant location	Number of measurements above TLV	Dry bulb temp. (°C)			Wet bulb temp. (°C)			Globe temp. (°C)			WBGT (°C)		
		Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
BF ($n = 7$)	7	31.5	40.9	37.2 ± 3.0	25.2	28.5	27.3 ± 1.2	37.3	51.3	41.1 ± 5.1	28.9	34.6	31.4 ± 2.0
Blooming mill ($n = 7$)	7	37.3	46.6	40.7 ± 3.8	24.4	30.1	26.7 ± 1.9	38.1	60.6	47.7 ± 9.2	29.5	39.4	33.0 ± 3.9
BRM ($n = 5$)	5	30.5	39.0	33.2 ± 3.4	24.6	27.9	26.0 ± 1.4	34.9	44.8	38.4 ± 4.4	27.7	32.4	29.7 ± 2.2
CCM ($n = 7$)	7	38.9	45.9	42.4 ± 2.6	25.4	28.0	26.9 ± 1.1	44.7	64.1	51.5 ± 6.4	32.0	38.7	34.3 ± 2.5
Coke oven ($n = 5$)	5	33.7	42.3	37.3 ± 3.4	27.0	30.6	28.4 ± 1.6	38.6	67.6	53.2 ± 13.5	30.7	41.7	35.5 ± 5.1
EOF ($n = 10$)	10	30.1	41.6	35.2 ± 3.7	24.7	28.8	26.5 ± 1.4	34.8	53.4	42.1 ± 5.7	27.8	35.3	31.2 ± 2.7
Power plant-II ($n = 4$)	4	35.2	41.2	38.7 ± 2.6	24.2	26.9	25.6 ± 1.1	40.0	47.3	42.9 ± 3.2	28.9	32.3	30.8 ± 1.4
Sinter plant-II ($n = 4$)	3	34.3	37.6	35.6 ± 1.5	23.2	25.4	24.7 ± 0.7	35.3	39.1	37.2 ± 1.9	27.2	29.4	28.4 ± 1.1

BF, blast furnace; BRM, bar and rod mill; CCM, continuous casting mill; EOF, energy optimizing furnace; SD, standard deviation; TLV, threshold limit value.

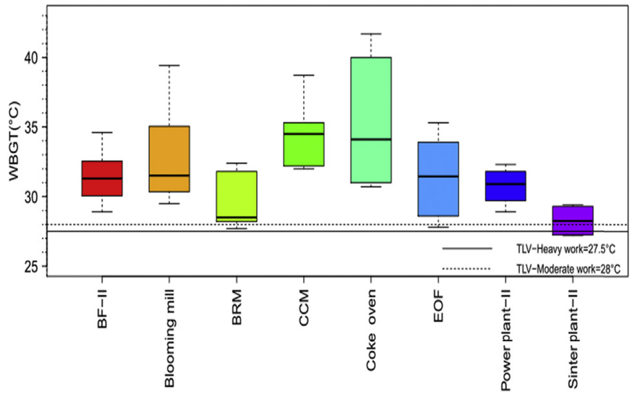

Fig. 2. Wet bulb globe temperature (WBGT) profile in different process units in steel industry in Southern India in April, 2014. BRM, bar and rod mill; CCM, continuous casting mill; EOF, energy optimizing furnace; TLV, threshold limit value.

the employees, is also imposed on the workers. High heat and poor working and welfare conditions at the workplace potentially make most of the employees vulnerable to the health risks of heat stress.

Of the 84 workers surveyed, 96% of them perceived that they experienced adverse heat-related health symptoms periodically, as shown in Table 2. It must be noted that about 79% of the workers who worked near direct heat in about 32% of the locations experienced high heat exposure, which was further aggravated by lack of ventilation in those locations. Among the workers, the odds of occurrence of heat-related illnesses was 9.0 times higher in workers exposed to WBGT above TLV as compared to those exposed to WBGT below TLV (OR = 9.0, 95% CI, 0.6746–108.5021, Z = 1.656, $p = 0.0977$). The workers had less flexibility to self-pace, owing to the fixed shift hours and tight production targets. Among the workers interviewed, 90% of them were nonsmokers and most of them did not consume alcohol on a regular basis. Therefore, the health issues could not be attributed to behavioral factors that may aggravate the heat-related health symptoms, such as smoking and alcoholism [28].

Nearly 82% of workers reported thermal discomfort in their work locations and about 61% reported heat exposure as a major problem during hot seasons, which is about 6–7 months in a year, with ambient temperatures ranging between 32.5°C and 37.2°C. About 86% workers reported excessive sweating and 77.2% of them reported tiredness/weakness, muscle/heat, and cramps, and 33% reported headache commonly in many work locations throughout the plant. About 17% in BFs and 20% in blooming mills suffered from heat rashes/prickly heat and 56% workers reported this condition in coke ovens where the WBGTs were the among the highest. Some 70% of workers reported change in urine color and volume, particularly in summer months, indicating progression towards dehydration or lack of periodic fluid consumption. Statistical analysis shows that the odds of change in urine color for the workers exposed to heat conditions above TLVs was 7.4 times more than those exposed below TLVs (OR =7.4, 95% CI 0. 0.7347 to 75.2332, Z = 1.699, $p = 0.0893$).

It is well known that heat stress reduces the workers' capacity to perform at full capacity [1], due to innate physiological reasons and physical inability to continue at the desired pace, which is in line with the workers reported perceptions about loss in productivity owing to heat stress at work in this study. From Fig. 3 it is apparent that about 27% ($n = 23$) of the workers reported that it took a longer time for them to complete the same tasks during summer as compared with cooler seasons, and 10.6% reported direct loss in productivity, including not achieving targets, due to heat. Out of the 23 workers who reported productivity losses, 21 workers were exposed to direct radiational heat during steel melting. Due to high heat and heavy workload, the workers were allowed to take rest by the management after the hot job was performed (work-rest regimen: 75% work, 25% rest, each hour) [22]. The perceptional study focused only on productivity losses due to heat fatigue and lost work capacity, and not the production outcomes. Among the study participants, statistical analysis showed that workers who were exposed to direct heat sources, including process generated radiant heat from furnaces, reported significantly high productivity losses compared to those who had indirect heat exposures ($\chi^2 = 26.1258$, degrees of freedom = 1, $p < 0.001$). Workers reported drinking high quantities of water because of excessive thirst, and rested in shades, a protective mechanism to reduce heat stress [29], did not help abate heat exposures in summer and early monsoon, due to the high ambient humidity that will impede sweat evaporation and would not help in evaporative cooling [30].

Workers in many hot areas such as coke ovens EOFs, BF-II, CCMs, and blooming mills, where there are high WBGT levels, had additional risks owing to the thick layers of clothing worn by them, and in coke oven, BF-II, and EOF areas (adjusted for "clo value" of 2.0 for 6 employees in this area) due to use of aluminum clothing for PPEs, as seen in Fig. 1, that further added to the heat stress for the workers. Although the workers perceptions regarding clothing was positive and they reported that the uniform protected their skin from high heat, about 69.2% admitted that the thick clothing was uncomfortable during summer. About a quarter of workers reported social impacts on their personal lives attributable to occupational heat stress, and the reasons quoted included time and resource spent in coping with heat, too tired to engage in social occasions, too fatigued to spend quality time with the family, and 22 workers reported that heat affected their social lives moderately.

It is evident from the results that exposure to high heat environments will impact the health and productivity of the workers unless efficient cooling methods are implemented, such as air conditioners, using fans, or wearing specially designed cooling clothes [31,32]. Although air conditioners are not the most environmentally friendly or permanent solution to the issue of heat

Table 2
Workers perceptions on impacts of heat stress on health for summer 2014 (in %)

Symptoms	BF (I & II) ($n = 17$)	Blooming mill ($n = 5$)	BRM ($n = 14$)	CCM ($n = 9$)	Coke oven ($n = 9$)	EOF ($n = 10$)	Power plant (I & II) ($n = 12$)	Sinter plant – II ($n = 8$)
Excessive sweating	88.2	100.0	78.6	77.8	100.0	90.0	91.7	62.5
Tiredness	88.2	100.0	78.6	44.4	100.0	90.0	91.7	25.0
Headache	5.9	40.0	–	–	44.4	40.0	33.3	–
Excessive thirst	100.0	100.0	92.9	88.9	100.0	90.0	100.0	100.0
Dizziness/fainting	5.9	20.0	7.1	–	33.3	10.0	8.3	–
Muscle cramps	11.8	20.0	7.1	–	55.6	40.0	16.7	–
Prickly heat & rashes	17.6	20.0	7.1	–	55.6	–	8.3	–

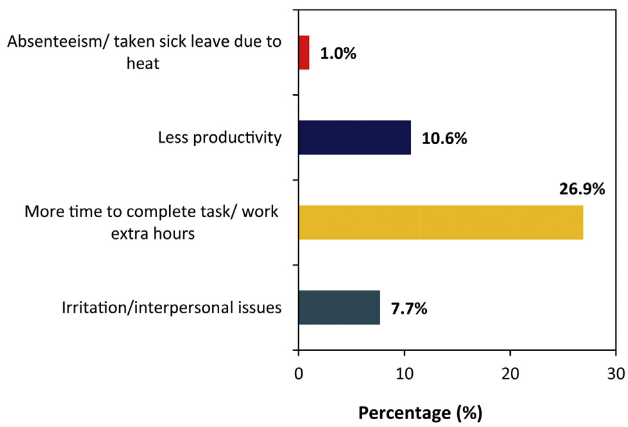

Fig. 3. Impacts on productivity.

stress [33], temporary relief from heat to cool the body becomes essential to protect workers from progression towards heat stroke [1]. Many work locations in the steel industry are such that air conditioning is not feasible owing to high heat processes/furnaces and requirement to wear work protective clothing, including aluminum vests and gloves, can further increase heat stress for the workers. Thus, the work conditions for many of these workers are not likely to improve with time without appropriate interventions, such as personal cooling or provision of cool rooms or cooling vests. The health and human performance risks associated with high heat exposure in workplaces have been well established through physiologic and ergonomic research in the past decades [35,36]. Another important and potentially negative outcome of working in hot environments and beyond physical capacity is the increase in accident rates at work [37,38]. Accident rates were not provided by the contractors/supervisors in this study and this additional data could potentially inform us of the indirect impacts of the effects of ambient temperatures and occupational heat stress on workers and business. With the predicted rise in temperatures due to climate change, the heat situation is expected to become further worse for workers, with consequent adverse health and productivity implications [18,39].

While addressing the problem of heat stress in the steel industry, the existing cultural and behavioral pattern of the different groups of workers must also be considered, as the success of any intervention depends on the acceptance from workers. A thorough understanding of the issue of occupational heat stress by the supervisors/managers, management support, and resource allocation for interventions such as engineering controls, administrative controls including job reallocation in cooler areas (to reduce down time of workers), appropriate provision of comfortable work environment and welfare conditions may lead to positive changes in the management of heat stress and improve the health and productivity issues arising due to heat at work.

As heat is usually perceived as a natural phenomenon and the risks of heat exposure are given less importance in tropical settings like India, the impacts of heat stress for workers, especially in high heat environments, on their health and productivities, must be viewed seriously. Given the extent of existing threats and the anticipated future threats to health and economic/productivity losses due to climate change [18], there is a need to take a precautionary approach in developing and designing management strategies that will benefit both the industry and the worker. The co-benefits of cooling interventions, a "win-win" for both the worker and industry, if well understood and implemented by the management may find acceptance by the workers that shall automatically propel the idea forward, as was done a few decades ago in South African mines where improvements in workers' productivity was achieved when reductions in WBGTs happened with cooling interventions, such as improved refrigeration procedures [40,41], and ventilation cooling [24,42]. Physiological responses and limits of the human body's adaptation and tolerance to temperature changes depends on the duration of and extent of exposure, a key component that must be considered in developing controls that may help the workers in managing the heat stress issue.

As previously discussed, if worker health is impaired, productivity, and subsequently economic losses shall destabilize the industry's human resource foundation that may have adverse implications on the business itself. Although the existing data on the adverse effects of high heat exposures on the health and productivities of the workers in high heat industries is limited, the onus now falls on the industry, policymakers, and the government to implement progressive policies that ensure worker safety and protection against heat stressors. Programs may be initiated by the industry that will seek to educate the workers on the dangers of working in hot environments, the appropriate precautions to take, and to recognize the signs and symptoms of potential heat illneses. It will also be wise for industries to invest in climate friendly adaptation techniques to tackle heat at work and be prepared to face the potential additional heat burden likely to be created by climate change. The industries must be proactive in having in-house preventive policies and interventions through a design of welfare mechanisms for workers and work locations with cooler resting places to reduce heat exposure at work. Involvement of government and workers unions in implementing programs, including health insurance, that protect individuals from risk of occupational heat stress may improve the occupational health in the country.

3.1. Limitations

The limitations to this study are that a convenience sampling method was adopted and had no control group to compare if the prevalence is different in a nonexposed group. Due to the relatively small size of the sample, caution should be exercised regarding the generalization of the results. With no other supportive clinical health data, more in-depth qualitative and quantitative research is needed to provide solid evidence of adverse impacts of workplace heat exposure. Despite these limitations, this study may add to current knowledge and feed into important preventive policy implications for millions of workers in developing countries with tropical climates.

4. Conclusions

Harsh and hot work appears to be related to health and productivity losses of workers engaged in manual work in steel industries that is supported by the workers perceptions and physiological measurements. Low- and middle-income countries are dependent on manual labor, and the health and the welfare of workers are of paramount importance for sustained industrial growth. However, workers in developing tropical country settings are likely at high risk of health burden of excessive occupational heat exposures due to lack of cooling provisions to protect them, especially with the expected temperature increases due to global climate change. Research concerning the current and future risks of impacts of occupational heat exposure is vital for developing comprehensive evidence-based policies for protecting current and future working populations from the adversities of heat stress.

Conflicts of interest

All authors have no conflicts of interest to declare.

Acknowledgments

The authors are grateful to the management of the steel industry for their kind co-operation that enabled us to pursue our research successfully. The authors also thank the Department of Science and Technology (DST) for funding this research [Grant number DST/CCP/(NET-2) PR-37/2012 (G)].

References

[1] Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity–an increasing challenge for low and middle-income countries during climate change. Glob Health Action 2009;2. DOI: 10.3402/gha.v2i0.2047.

[2] Venugopal V, Chinnadurai J, Vennila V, Ajith R, Lucas RAI, Kjellstrom T. The social implications of occupational heat stress on migrant workers engaged in public construction: A case study from South India. Constr Environ 2016;2:25–36.

[3] Venugopal V, Chinnadurai JS, Lucas RAI, Kjellstrom T. Occupational heat stress profiles in selected workplaces in India. Int J Environ Res Public Health 2015;13:89.

[4] Jendritzky G, Tinz B. The thermal environment of the human being on the global scale. Glob Health Action 2009;2. DOI: 10.3402/gha.v2i0.2005.

[5] Kjellstrom T, Climate change, direct heat exposure, health and well-being in low and middle-income. Countries. [cited 2015 Dec 23]. Available from: http://www.globalhealthaction.net/index.php/gha/article/view/1958/2182.

[6] Tawatsupa B, Lim LL, Kjellstrom T, Seubsman SA, Sleigh A, Thai Cohort Study Team. Association between occupational heat stress and kidney disease among 37 816 workers in the Thai Cohort Study (TCS). J Epidemiol 2012;22:251–60.

[7] Campbell-Lendrum D, Woodruff R, Prüss-Üstün A, Corvalán C. Quantifying the health impact at national and local levels. WHO environmental burden of disease series. Geneva: WHO publishers (WHO Environmental Burden of Disease); 2007. Report No. 14, pp (66).

[8] Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, Friel S, Groce N, Johnson A, Kett M, Lee M, Levy C, Maslin M, McCoy D, McGuire B, Montgomery H, Napier D, Pagel C, Patel J, de Oliveira JA, Redclift N, Rees H, Rogger D, Scott J, Stephenson J, Twigg J, Wolff J, Patterson C. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. Lancet 2009;373:1693–733.

[9] McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. Lancet 2006;367:859–69.

[10] McCarthy JJ. Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. UK: Cambridge University Press; 2001. p. 3–6.

[11] Parsons K. Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance. London: CRC Press; 2014. p. 47–8.

[12] Kjellstrom T, Lemke B, Otto M, Dear K. Global assessment of the health impacts of climate change: Occupational heat stress. [Internet]. 2014 [cited 2015 Dec 23]. World health Organization, Technical Report 2014:4. Available from: http://www.climatechip.org/sites/default/files/publications/TP2014_4_Occupational_Heat_Stress_WHO.pdf.

[13] Nag P, Nag A, Sekhar P, Pandit S. Vulnerability to heat stress: Scenario in western India. Ahmedabad: National Institute of Occupational Health; 2009. 56 p.

[14] Ayyappan R, Sankar S, Rajkumar P, Balakrishnan K. Work-related heat stress concerns in automotive industries: a case study from Chennai, India. Glob Health Action 2009;2:1–7. DOI: 10.3402/gha.v2i0.2060.

[15] Dash S, Kjellstrom T. Workplace heat stress in the context of rising temperature in India. Curr Sci 2011;101:496.

[16] McMichael AJ. Climate change and human health: risks and responses. World Health Organization; 2003. p. 1–40.

[17] Bridger R. Introduction to ergonomics. London: McGraw-Hill; 2008. p. 240–3.

[18] DARA. Climate vulnerability monitor 2012. A guide to the cold calculus of a hot planet. [Internet]. Barcelona: DARA International Foundation; Madrid. [cited 2015 Dec 23]. Available from: www.daraint.org.

[19] Hales S, Edwards S, Kovats R. Impacts on health of climate extremes. Climate change and health: risks and responses Geneva. World Health Organization; 2003. p. 79–102.

[20] ClimateSoft Ltd, Gannaway Merce [Internet]. [cited 2015 Dec 20]. Available from: www.ClimateCHIP.org.

[21] The National Institute for Occupational Safety and Health (NIOSH). Occupational Exposure to Hot Environment. U.S. Department of Health and Human Services; 1986, p. 86–113.

[22] American Conference of Governmental Industrial Hygienists (ACGIH). Threshold limit value for chemical substances and physical agents and biological exposure indices; 2010. p. 112–4.

[23] Lemke B, Kjellstrom T. Calculating workplace WBGT from meteorological data: a tool for climate change assessment. Ind Health 2012;50:267–78.

[24] Kjellstrom T, Gabrysch S, Lemke B, Dear K. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Glob Health Action 2009;2:1–7.

[25] Diem K. Documenta Geigy scientific tables. Manchester: Geigy Pharmaceutical Company Limited; 1962, p. 538–9.

[26] Armstrong LE, Soto JA, Hacker Jr FT, Casa DJ, Kavouras SA, Maresh CM. Urinary indices during dehydration, exercise, and rehydration. Int J Sport Nutr 1998;8:345–55.

[27] OSHA. OSHA technical manual: Heat stress. Washington (DC): Department of Labor; 1999. Directive Number: TED 01-00-015.

[28] Anbarasi K, Kathirvel G, Vani G, Jayaraman G, Devi CS. Cigarette smoking induces heat shock protein 70 kDa expression and apoptosis in rat brain: modulation by bacoside A. Neuroscience 2006;138:1127–35.

[29] Kjellstrom T, Kovats RS, Lloyd SJ, Holt T, Tol RS. The direct impact of climate change on regional labor productivity. Arch Environ Occup Health 2009;64:217–27.

[30] Larry Kenney W. Physiological responses to the thermal environment [Internet]. [cited 2015 Dec 20]. Available from: http://www.ilocis.org/documents/chpt42e.htm.

[31] Katsuura T, Tomioka K, Harada H, Iwanaga K, Kikuchi Y. Effects of cooling portions of the head on human thermoregulatory response. Appl Human Sci 1996;15:67–74.

[32] Kaufman JW, Fatkin LT. Assessment of advanced personal cooling systems for use with chemical protective outer garments: DTIC Document; 2001 [Abstract].

[33] Yu BF, Hu ZB, Liu M, Yang HL, Kong QX, Liu YH. Review of research on air-conditioning systems and indoor air quality control for human health. Int J Refrig 2009;32:3–20.

[35] Bhattacharya A, McGlothlin JD. Occupational ergonomics: theory and applications. New York: Marcel Dekker, INC; 1996.

[36] Lucas RA, Epstein Y, Kjellstrom T. Excessive occupational heat exposure: a significant ergonomic challenge and health risk for current and future workers. Extrem Physiol Med 2014;3:14.

[37] Kielblock A, Schutte P. Human heat stress: Basic principles, consequences and its management. Proceedings of the International Conference on Occupational Health and Safety in the Minerals Industry, Terrigal, NSW; 1993, p. 21–6.

[38] Knapik JJ, Canham-Chervak M, Hauret K, Laurin MJ, Hoedebecke E, Craig S, Montain SJ. Seasonal variations in injury rates during US Army Basic Combat Training. Ann Occup Hyg 2002;46:15–23.

[39] Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P, Dubash NK, Edenhofer O, Elgizouli I, Field CB, Forster P, Friedlingstein P, Fuglestvedt J, Gomez-Echeverri L, Hallegatte S, Hegerl G, Howden M, Jiang K, Jimenez Cisneroz B, Kattsov V, Lee H, Mach KJ, Marotzke J, Mastrandrea MD, Meyer L, Minx J, Mulugetta Y, O'Brien K, Oppenheimer M, Pereira JJ, Pichs-Madruga R, Plattner GK, Pörtner HO, Power SB, Preston B, Ravindranath NH, Reisinger A, Riahi K, Rusticucci M, Scholes R, Seyboth K, Sokona Y, Stavins R, Stocker TF, Tschakert P, van Vuuren D, van Ypserle JP. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2014. 151 pp.

[40] Pielke Sr RA. Climate vulnerability: understanding and addressing threats to essential resources. USA: Elsevier; 2013.

[41] Wyndham C. A survey of the causal factors in heat stroke and of their prevention in the gold mining industry. J South Afr Inst Min Metall 1994;94:165–88.

[42] Fisk WJ. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. Annu Rev Energ Environ 2000;25:537–66.