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ORIGINAL ARTICLE

The Impact of Heat Stress on Physiological Health in Industrial Workers: A Mixed-Methods Study

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ABSTRACT

Introduction: The discrepancy between actual heat stress and workers' perception results in a mitigation failure, potentially leading to fatality. This study aimed to investigate workplace heat stress, workers' workload, and personnel's heat strain in steel mills under extreme temperature conditions. **Methods:** The study used a mixed-methods design and was conducted across three steel mills in East Java, Indonesia. An analysis of heat-stress data included heat-stress symptoms derived from physiological and environmental factors, while the personal perception assessment was based on comprehensive interview sessions. These quantitative results, obtained from 119 operators, were compared with workers' personal thermal perceptions using a mixed-methods approach. Phase 1 quantitative method consisted of onsite data collection, walkthrough inspection, questionnaire distribution, workplace monitoring, personal assessment, and statistical analysis. Phase 2, as a qualitative stage, consisted of in-depth interviews and focused group discussions with 15 participants. **Results:** The wet-bulb globe temperature measurements confirm significant heat stress in all mills. Workers' physiological responses remained within acceptable limits according to ACGIH criteria. However, a noticeable discrepancy was found between the quantitative data and workers' perceptions, highlighting the need for greater awareness and training on heat-stress hazards. **Conclusion:** The alignment between qualitative and quantitative findings underscores the importance of integrating both approaches to develop effective mitigation strategies. This study contributes to understanding occupational heat stress in high-risk environments and emphasizes the need to incorporate worker perceptions into health and safety protocols.

Keywords: Heat Stress, Mixed Method Analysis, Steel Mills, Thermal Perception

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INTRODUCTION

Heat stress is a common workplace health hazard, whether outdoor or indoor, particularly in industries that involve extreme thermal processing, such as steel mills, cement plants, and ceramics. In the long run, heat stress, which can originate from both internal and external factors, can lead to fatigue and stress in the body, skin irritation, excessive sweating, heat stroke, respiratory illness, increased blood pressure and heart rate, which can lead to cardiovascular disease (Patwary *et al.*, 2022). On the other hand, internal factors which determine the heat stress level imposed on the body comprise core body temperature, acclimatization, natural heat tolerance, and metabolism-generated heat of the body, which depends on the workload of the workers; the external ones may include the ambient and radiant temperature, velocity of air (air movement), and air humidity. Extremely

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hot workplaces can reduce workers' productivity, increase the risk of worker accidents, and increase the risk of heat-related disorders (Hassan *et al.*, 2017). When men experience a high index of heat stress, they feel heat strain, leading to a condition in which they are unable to survive because they are too warm and cannot cool themselves properly. Overexposure to a high index of heat stress will lead to severe dehydration and even fatality (Kjellstrom, Lemke and Otto, 2017).

Furthermore, the adverse impacts of heat stress in workplace settings are exacerbated by rising air temperatures driven by global warming, which is causing climate change. Given the harmful consequences of heat stress, workers at risk must take preventive measures to mitigate its impacts. In this sense, it needs to raise workers' awareness regarding the hazards of heat stress through training and education. Workers' perceptions and thermal responses to a hot environment are crucial to occupational health and safety. Heat stress is not only associated with physiological responses but also with workers' thermal perception (Meng *et al.*, 2022). However, heat stress-related risks can be mitigated to some extent according to what personnel perceive and the extent to which their understanding can be adopted, while not many workers are currently fully aware of the hazards of heat stress

Recently, Meng *et al.* (2022) conducted a study on heat stress and compared it with workers' perceptions in industrial plants in China. They found that acclimatized workers felt comfortable when exposed to heat stress, whereas unacclimatized workers did not. Thus, acclimatization is essential when working in a heat-stress environment. Aside from the workplace setting, external factors can contribute to heat stress, including thermal environment parameters such as air temperature and velocity, relative humidity (RH), and thermal radiation (Meng *et al.*, 2022).

In a study on heat stress conducted in Malaysia, Nizam *et al.* (2023) examined the impacts of heat stress on a construction site. Based on their statistical analysis, the respondents at the workplace were exposed to heat stress, consistent with their perceptions of high air and radiant temperatures. They also admitted that they were not comfortable holding any surface area, felt a dry throat, and experienced profuse sweating. Nevertheless, they did not perceive any adverse effects of heat stress on their work performance. While they performed their tasks, they showed no signs of heat stress, no heavy breathing, and felt motivated and even eager to work overtime. Thus, workplace heat stress is often underestimated due to a lack of knowledge about the hazard. Bonafede *et al.* (2022) conducted a cross-sectional online questionnaire on workers' perceptions. They found that all. They regarded heat stress as a contributing factor, yet about 83% of them were not warned about the hazards in their workplace. They concluded that workers needed to improve their perceptions of heat stress to preserve their health and productivity.

However, the actual hazard of workplace heat stress and workers' perceptions of its adverse effects may differ in many cases. Workers' perceptions of the harmful effects of heat stress are often influenced by the degree of acclimatization, workers' level of knowledge, and other factors. Although it is essential, the role of psychological perception is only little understood (Li *et al.*, 2024). Workers' perceptions of heat stress could be further explored through a study that employs content analysis to detect the presence of particular utterances, topics, or concepts in provided qualitative data (i.e., text). With content analysis, one can quantify and analyze the presence, meanings, and relationships of specific words, topics, or concepts. Content analysis consists of two general forms, i.e., conceptual analysis and relational analysis. While conceptual analysis detects the existence and frequency of concepts in a text, relational analysis, on the other hand, is further developed through the examination of the contextual relationships in specific texts.

Mixed-method research, combining qualitative and quantitative results, makes a significant contribution to understanding the complexity of social science phenomena (Nunfam, 2021). This method, unlike qualitative or quantitative methods, gathers information, assesses it, and integrates both qualitative and quantitative results to understand the phenomenon under study comprehensively. For instance, a study conducted by Nunfam (2021) investigated the social impacts of workplace heat stress on mining workers in Ghana, Africa. Furthermore, Milando *et al.* (2022) employed a mixed-methods approach to assess personal heat exposure, sleep patterns, and physical activity, along with thermal-adaptation strategies, among Boston's urban residents in Massachusetts, US. They used quantitative data on personal heat exposure, sleep patterns, activity, and body temperature, while qualitative data on personal perceptions informed heat adaptation strategies and intervention programs. More specifically, Tetzlaff *et al.* (2024) employed content analysis in their mixed-methods study of heat-related messages during the 2021 heat dome in Canada. They identified opportunities to improve health communication during extreme heat events.

Heat the human body experiences is not able to be described with a single parameter. Instead, it relates to various factors. There are also influences of some factors associated with personal health status, dietary habits, age groups, and gender groups (Matzarakis & Santos, 2022). Some studies investigated heat stress levels and personal perceptions using a mixed-methods approach; for instance, Hass (2019) conducted one among the population in Knoxville, Tennessee, USA. He used Kruskal-Wallis tests to assess individual thermal perception and found that perception influenced respondents' climate adaptation and acclimatization, thereby reducing the adverse effects of a heat-related environment.

Most previous studies on social phenomena are conducted using either qualitative or quantitative research methods, while only a few use a mixed-methods approach (Nunfam, 2021). In addition, the previous studies on heat stress in workplace settings have been extensively carried out in Indonesia, such as those conducted by Handayani, Hernawati and Ningtyias (2021), Nurhartonosuro *et al.* (2023), Siami and Ramadhani (2019); however, there is still inadequate research on heat stress assessment and workers' perception, in particular in Indonesia, conducted using a mixed method. Given this circumstance, the authors must conduct a study investigating the impacts of heat stress on steel mill workers and comparing these impacts with workers' perceptions and understanding, using mixed methods. In this study, the qualitative method used content analysis to assess respondents' perceptions and understanding of heat stress, its impacts, and mitigations. Meanwhile, quantitative analysis was conducted to investigate environmental factors, physiological changes, and workers' thermal comfort. Finally, quantitative analysis and qualitative data were compared to provide further insight into more effective mitigation of heat stress.

METHODS

This study design aimed to develop a more complete, corroborated understanding of heat stress by combining the strengths of quantitative and qualitative methods. It was conducted onsite at three steel mills in East Java, Indonesia: Surabaya, Sidoarjo, and Gresik. The data were collected during the summer, from April to May 2021 (2 months). The targeted respondents were the operators of indoor industries with exposure to high temperatures, WBGT indoor >29.5 °C, as proposed by ACGIH (2004), with the agreement of the respective steel mill management.

This study comprises two (2) phases, as shown in the figure above. Phase 1 (quantitative stage) consisted of four (4) stages: onsite data collection among operators from the selected study population; walkthrough inspection; distribution of questionnaires; workplace monitoring and personal assessment; and, finally, statistical analysis. The study involved 119 operators out of 220 workers in total from the three mills, determined using the Slovin formula. The respondents were selected upon meeting the criteria as follows: Indonesian male, aged between 18 – 55 years old, works as an operator that involved directly with heat exposure, employed not less than 3 months (considering sufficient period of acclimatization at workplace), operators who had exposed to high temperature (29.5°C), and being able to speak and read Indonesia language. Meanwhile, Phase 2, i.e., the qualitative stage, consisted of in-depth interviews, questionnaire distribution, and focused group discussions. In the FGD, since the respondents were considered homogeneous in terms of workplace characteristics,

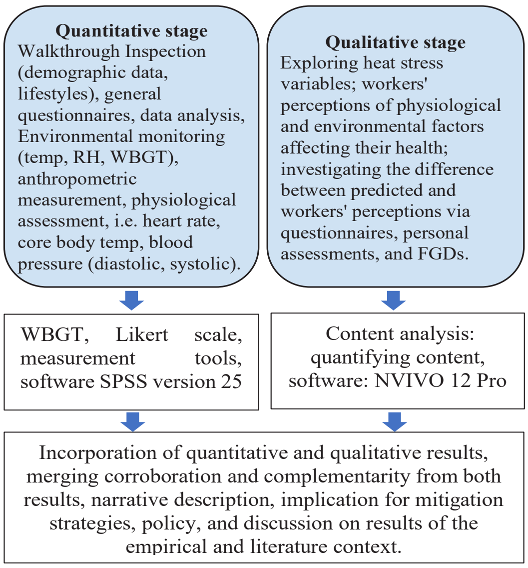

Figure 1. Research Framework

we determined the number of respondents to be 5 per cent, for a total of 15 participants, using practical feasibility as the rule of thumb. Universiti Putra Malaysia's Ethics Committee approved the ethics of this research with reference number UPM/TNCPI/RMC/JKEUPM/1.4.18.2 (JKEUPM).

After the data were separately analyzed, the results were merged and compared during the overall interpretation, and the findings were explicitly linked.

Environmental Monitoring

A walk-through inspection was conducted to provide an overview of the current condition and situation, and to investigate heat exposure, workers' workload, and workplace practices. Environmental monitoring was carried out using a QuesTemp 34 Thermal Environmental Monitor, including natural wet bulb temperature (NWB), dry bulb temperature (DB), globe temperature (GB), and relative humidity (RH). The average of WBGT values is determined using the following equation (Zare *et al.*, 2019; Lemke & Kjellstrom, 2012):

$$WBGT = 0.7\,T_{nw} + 0.2T_g + 0.1T_a$$

Where Tnw is natural wet temperature, Tg is radiation temperature, and Ta is dry temperature.

Personal Assessment

A personal assessment was conducted for anthropometric measurements, metabolic workload, physiological measurements, and a comfort perception checklist. Prior to the study, the questionnaires were validated by the supervisory committee for face validity, content validity, construct and criterion validity, reliability, and pilot testing. The questionnaires covered the workers' perception of the thermal environment, their demographic data, lifestyles, etc. The average metabolic rates were determined based on the workload adapted from ACGIH (2004), and the TLV for the WBGT index was determined based on ACGIH (2004). Physiological measurements included core body temperature, heart rate, and blood pressure, with a clothing adjustment factor incorporated. The metabolic workload of the workers was determined via visual inspection, aided by video recording and measured using the time-weighted average (TWA) below:

$$M_{TWA} = \frac{\sum(M_i \times t_i)}{\sum t_i}$$

Where: Mi refers to the metabolic rate of activity ti denotes the time spent in activity i.

Meanwhile, the thermal comfort perception was guided using questionnaires adopted from ASHRAE (Biswas and Hamada, 2018) thermal sensation scale (2010), (Biswas and Hamada, 2018), which divides into several scales, i.e., 'very comfortable' (0 – 12), 'less comfortable' (13 – 23), 'discomfort' (24 – 34), and 'severe discomfort' (35 – 45). All the data from Phase 1 were analyzed using IBM Statistical Package for Social Science (SPSS) version 25.

Word Count (Content Analysis)

To determine the perceptions of steel mill workers regarding physiological and environmental factors that affect their heat-stress-related health, qualitative data analysis was conducted using content analysis to identify the presence of particular words, topics, or concepts within the provided qualitative data (e.g., narrative texts). In conceptual analysis, a concept was selected for examination, involving quantifying and counting its presence and the occurrence of selected terms in the data, whether explicit or implicit. All the data (word counts or content analysis) were analyzed using NVivo 12 Pro.

RESULT

Socio-demographic of the Respondents

Based on data analysis, the three companies under the study had the respondents' age range between 22 and 56 years old, with most of the respondents being older (46 – 55), accounting for 39.5%, while the age group of 19 – 25 was the minority group. The mean age was 43.03 years with a standard deviation of 10.09. The average working hours are 7.97 per day, with most respondents working 5 to 8 hours per day (84.87%). Furthermore, most respondents have overtime work (68.1%), with the highest frequency being 1–3 times a month (48.7%).

Environmental Factors of the Three Mills

Environmental factors, including WBGT measurements, were carried out at three steel mills with different numbers of tests: Steel Mill A, 44 tests; Steel Mill B, 30 tests; and Steel Mill C, 90 tests. Not all the locations where workers were working were tested to determine whether they were the same. Thus, the exact location was assumed to have similar WBGT, humidity and room temperature values. Therefore, the number of tests was not equal to the number of respondents (workers). The measurement results of environmental factors are presented in Table 1 below.

The range of temperature was 29.96 °C – 34.6 °C (Steel Mill A), with an average of 32.64 °C, 31.05 °C – 38.52 °C (Steel Mill B), with an average of 34.57 °C, and 28.54 °C – 33.98 °C (Steel Mill C), with an average of 30.82 °C. Overall, the average temperature was 31.99 °C, with the lowest at Steel Mill C (28.54 °C) and the highest at Steel Mill B (38.52 °C). The highest humidity was at Steel Mill C, then Steel Mill A, and the lowest was at Steel Mill B. Overall, the average humidity for all plants was 54.10%; the lowest was at Steel Mill B, 48.9%, and the highest was at Steel Mill C, 58.03%. Meanwhile, humidex was measured 45 times (Steel Mill A), 29 times (Steel Mill B), and 90 times (Steel Mill C). Overall, the average humidex index was 46.16, with the lowest index at Steel Mill C (38.00) and the highest at Steel Mill B (67.00).

Table 1. Environmental factors of the three mills

	No.		$WBGT_{in}$ (°C)				RH (%)				Humidex (%)			
Mill	Sample	Test	Min	Max	Ave.	Std. dev	Min	Max	Ave	Std. dev	Mean	Std. dev	Min	Max
SM A	49	44	29.96	34.6	32.6	1.78	45	62	52.2	4.4	46.8	3.04	41.0	52.1
SM B	20	30	31.05	38.52	34.04	1.76	30.6	67	48.90	11.18	48.20	6.82	41.00	67.00
SM C	50	90	28.54	33.98	30.82	1.66	43.8	68	58.03	7.61	45.20	6.14	38.00	58.00
Total	119	164	28.54	47.92	31.99	2.47	30.6	68	54.10	8.04	46.16	5.69	38.00	67.00

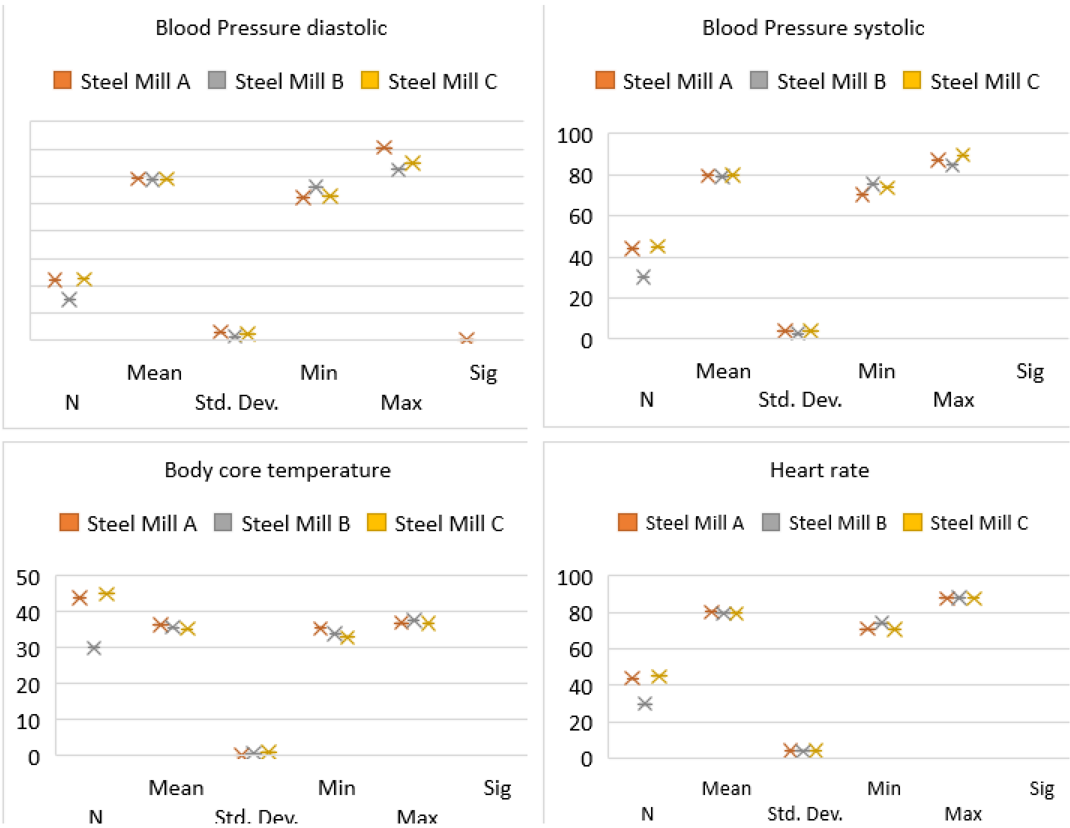

Figure 2. Physiological changes among the three mills

The Physiological Aspects Measurement

Physiological parameters were measured by monitoring changes in three physical indicators: body core temperature, blood pressure, and heart rate. From the figure above (Fig. 2), no significant differences were found in blood pressure or heart rate. In addition, there is no significant difference between these mills because they are in the same industry with the same environmental conditions.

Metabolic Workload Comparison at Different Workplaces

Based on the study results (Table 2), we observe that the highest average workload is Steel Mill A (306.02), followed by Steel Mill B (249.00), while the lowest is Steel Mill C (291.20). The results of the comparison test showed that the workload differences among the three mills (significance value $0.048 < 0.05$) were significant.

The Workers' Thermal Comfort Perception

The findings of this study reveal that most workers in the surveyed steel mills are exposed to hot working conditions for durations of 1 to 3 hours, with exposure rates reaching 94% in some mills. A significant proportion of the workers identified heat, noise, and dust as primary workplace hazards, leading to universal usage of personal protective equipment (PPE) (ASHRAE, 2010). Despite these measures, workers' perceived thermal comfort was predominantly low: 82.35% reported discomfort and 17.65% severe discomfort. Notably, the discomfort was more pronounced in environments with minimal ventilation from fans and no advanced cooling systems, such as air conditioning.

Table 2 shows the distribution of respondents' perceptions of the perceived hot conditions in the work environment. Of the 119 respondents, most of them felt uncomfortable (82.35%), while the remaining 17.65% felt very uncomfortable. Of the 98 respondents who felt uncomfortable, 43 were from Steel Mill A; 42 were from Steel Mill C, and 13 were from Steel Mill B. Of the 21 respondents who felt very uncomfortable, eight came from Steel Mill C, seven were from Steel Mill B, and six were from Steel Mill A.

Heat stress-related symptoms

In addition to the reported discomfort, Table 3 below identifies a range of heat-stress-related symptoms among the workers. The average Acute Heat Symptoms Score (AHSS) was relatively low, at 0.189, suggesting that many respondents did not experience severe symptoms. However, a closer examination revealed that 39.5% of workers fell into the low AHSS category, 15.97% into the moderate category, and 4.2% into the severe category.

Figure 3 showed that most reported symptoms included heavy sweating (54.62%), fatigue (45.38%), and severe thirst (38.66%). These symptoms were particularly prevalent among workers at Steel Mill B, where high fatigue and excessive sweating were observed. The data also showed that a smaller

Table 2. Comparison results of workload and thermal perception of heat stress among three mill workers

Mills	Workers' workload						Perception (frequency	
	N	Mean	Std. dev	Min.	Max.	Sig	Discomfort	Severe discomfort
SM A	49	306.02	72.77	115.00	415.00	0.05	43(36.1%)	6(5.04%)
SM B	20	249.00	120.24	115.00	415.00		13(10.9%)	7(5.88%)
SM C	50	291.20	89.37	115.00	415.00		42(35.3%)	8(6.72%)
Total	119	290.21	90.50	115.00	415.00		100%	

Table 3. Index of acute heat symptoms score (AHSS)

Score	Symptom category	n (%)	Mean	St. dev
1.00	Very High	0 (0)	0.189	0.209
0.71 – 0.86	High	5 (4.2)		
0.43 – 0.57	Moderate	19 (15.96)		
0.14 – 0.29	Low	47 (39.5)		
0.00	No Symptoms	48 (40.34)		

subset of workers experienced more severe health issues, such as muscle cramps, seizures, and loss of consciousness, underscoring the serious nature of the heat stress they face. These findings suggest that while the overall physiological impact of heat stress may not reach critical levels across the entire workforce, a significant proportion of workers are at risk of more severe heat-related health issues. The variation in symptom severity across mills further underscores the need for tailored interventions that address the specific conditions of each work environment. Overall, this study underscores the importance of implementing more effective heat mitigation strategies, including advanced cooling systems and enhanced PPE, to improve thermal comfort and health outcomes for workers in high-temperature industrial settings. The integration of workers' perceptions into occupational health protocols is also crucial, as it provides valuable insights into the adequacy of current interventions and the areas where improvements are most needed.

Content analysis

Content analysis is used to identify the presence of specific words, topics, or concepts in provided qualitative data, such as texts. With this method, one can analyze and quantify the existence, relationships, and meanings of certain words, topics, or concepts. The content analysis consists of two general types, i.e., relational and conceptual analysis. While relational analysis further develops conceptual analysis by examining the relationships

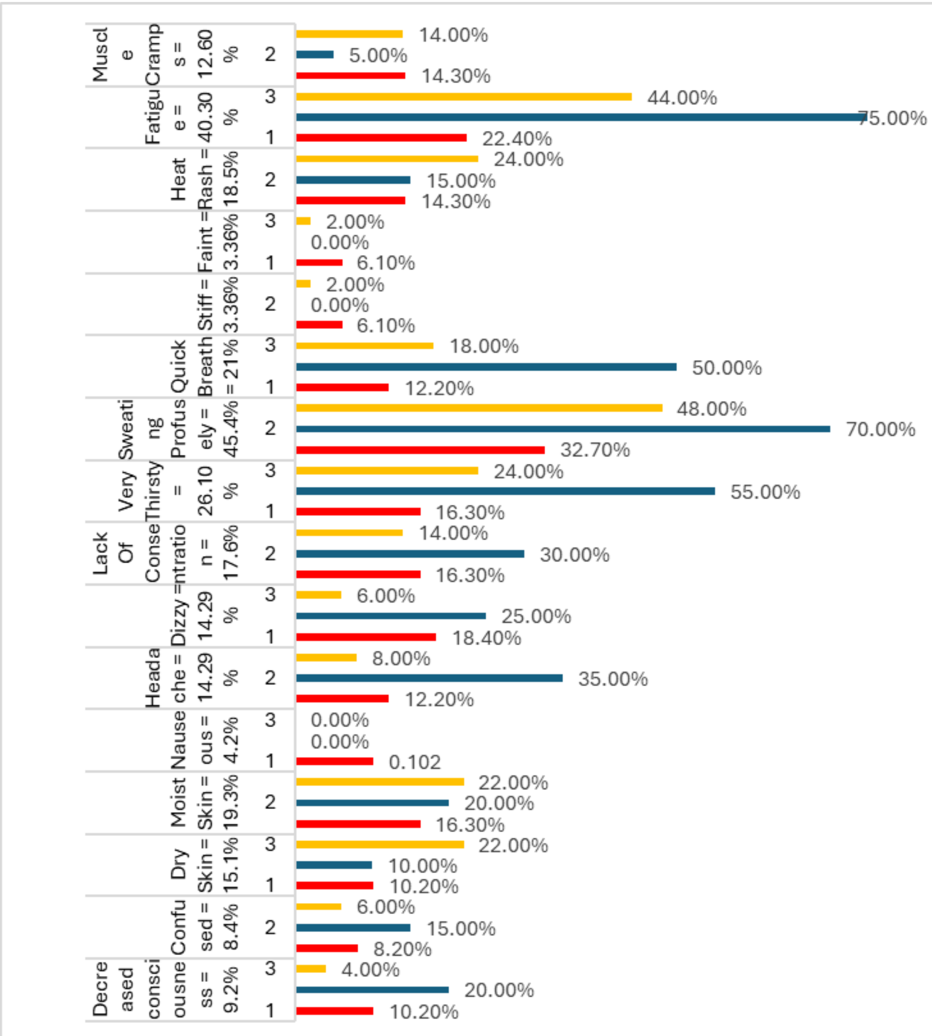

Figure 3. Heat stress-related symptoms

Table 4. Content analysis of 15 in-depth interview sessions

Word	Length	Count	(%)
Blood	5	249	005
Pressure	8	239	004
Temperature	11	182	003
Health	6	154	003
Symptoms	8	117	002
Related	7	100	002
Work	4	99	002
Interviewer	11	90	002
Room	4	86	002
Heat	4	77	001
Informant	9	75	001
Please	6	68	001
Workers	7	68	001
Explain	7	66	001
Occupational	12	61	001
Stress	6	61	001
Workspace	9	61	001
Body	4	56	001
Understand	10	55	001
Cause	5	49	001
Environment	11	40	001
Perception	10	40	001
Also	4	39	001
High	4	36	001
Steel	5	34	001
Range	5	32	001
Efforts	7	31	001
Interview	9	30	001
Improvement	7	29	001
Comfortable	11	28	001
According	9	27	001
Factory	7	26	000
Familiar	8	26	000
Heart	5	26	000
Normal	6	26	000
Causal	6	25	000
Relationship	12	25	000
Term	4	25	000
Good	4	24	000
Opinion	7	24	000
Working	7	24	000
Optimum	7	23	000
Healthy	7	22	000
Failure	7	21	000
Later	5	21	000
Temperatures	12	21	000
Understanding	13	21	000
Condition	9	20	000
Reducing	8	20	000
Time	4	20	000

among concepts within a text, conceptual analysis determines the presence and frequency of concepts in a text. In conceptual analysis, a concept is selected to examine, whereas the analysis covers quantification and counting its presence. Its main objective is to determine whether selected terms occur in the data. It is sometimes easy to detect when the terms are explicit, but at other times they may be implicit. We gathered the qualitative data from 15 informants (5 informants per company) through in-depth interviews. In this study, the content analysis was based on 15 informants, as shown in Table 4.

During the in-depth interview in this study, blood pressure was considered related to heart rate. It was considered that most respondents' educational level was elementary school to senior high school, so they were more familiar with blood pressure terminology than with heart rate terminology. Therefore, in the content analysis, the word "blood pressure" is the most frequent.

Analysis of the quantitative and qualitative comparison

To investigate whether differences exist among the three mills in workplace actual heat stress, heat-stress-related symptoms, workers' perceptions, and physiological changes, quantitative and qualitative data analyses, along with their comparisons, are presented in the table below (Table 4). The

Table 5. The comparison of quantitative and qualitative data analysis

Quantitative data analysis	Qualitative data analysis	Note
Heat stress is indicated with heat stress-related symptoms	Heat stress is associated with heat stress-related symptoms	In line
The symptoms related to heat stress were predicted by WBGT, body core temperature, and heart rate significantly.	Room temperature (WBGT), body core temperature, blood pressure in association with heart rate were perceived to be associated with the symptoms related to heat stress	In line
The health-related symptoms were manifested by 16 symptoms in detail (positive and significant)	The heat stress-related symptoms were not described in detail	Differ

physiological factors (body core temperature, blood pressure, and heart rate) and the environmental factor (Wet Bulb Global Temperature – Room Temperature) were positively and significantly associated with heat stress-related symptoms. The qualitative data also confirmed these results, as the respondents (15 informants) perceived during the interviews.

The physiological factors, such as heart rate and core body temperature, as well as environmental factors (WBGT– room temperature), were significantly proven as positive predictors of the symptoms related to heat stress. Furthermore, qualitative data from 15 respondents (working at three steel mills in East Java) confirmed this phenomenon.

DISCUSSION

Environmental Factors

The range of temperature was 29.96 °C – 34.58 °C (Steel Mill A), with an average of 32.64 °C, 31.05 °C – 47.92 °C (Steel Mill B), with an average of 34.57 °C, and 28.54 °C – 33.98 °C (Steel Mill C), with an average of 30.82 oC. The overall average temperature was 31.99 °C, which is considered high and causes thermal discomfort for workers. Meanwhile, the average humidity was 54.10%, which is at an acceptable level. According to the ACGIH standard, the recommended range of RH for thermal comfort is 30%- 60%, with the best range 40%-60%. In comparison, the previous study conducted at steel mills during winter in a subtropical country, i.e., Iran (Sartang, A. *et al.*, 2017), reported WBGT values ranging from 26.63 to 27.40 °C. The minimum value for this parameter is reasonable and much lower than the value reported in this study, as it was conducted in subtropical regions. Moreover, a previous study by Krishnamurthy *et al.* (2017) found that 90% of WBGT measurements in Southern India, in a similar workplace setting of steel processing mills, ranged from 27.2 to 41.7 °C, much higher than those in this study. However, Hasan *et al.* (2014) reported indoor temperatures of 26.5°C to 30.6°C in the same industry in Malaysia, which exceeded the TLV/ ACGIH temperature standard of 28 °C.

A relationship exists among WBGT, relative humidity (RH), and environmental temperature. For instance, a study by Houmsi *et al.* (2023) in Peninsular Malaysia found that higher relative humidity reduced evaporative cooling potential, thereby elevating WBGT values. It means that when relative humidity is high, the body's ability to dissipate heat through perspiration is reduced, leading to greater heat stress. However, they asserted that relative humidity had a lesser impact on WBGT than air temperature and solar radiation, with its influence ranging from 0% to +5%. In contrast, temperature has the most significant influence on WBGT among environmental parameters and meteorological variables, such as RH, solar radiation, zenith angle, and wind speed.

Physiological Patterns

The physiological indicators of respondents at work increase compared to before work and return to baseline after finishing work (when resting). Even after work, the average physiological score is lower than before work. For instance, physiological conditions before, during, and after work show the lowest blood pressure (diastolic) before work: 105 (Steel Mill A), the highest: 130 (Steel Mill C), and an average of 117.2. Overall, no significant difference in body core temperature was found in this study. This might be due to acclimatization, since all respondents in this study had been working at the workplace for> 3 months. However, this finding differs from those of Mishra *et al.* (2019), who observed that workers' core body temperatures rose from 37 ± 0.44 °C before work to 39 ± 0.34 °C after two hours, indicating a statistically significant increase. In another study, Palupi *et al.* (2018) examined the effects of heat stress in an automotive factory. They found physiological changes in core body temperature, yet it remained below 38 °C, which is still within the permissible range according to ACGIH. These findings suggest that under certain conditions, i.e., proper workers' acclimatization, steel mill workers may maintain their stable core body temperature throughout their work shifts.

The average Acute Heat Symptoms Score (AHSS) was relatively low, at 0.189, suggesting that many respondents did not experience severe symptoms. However, a closer examination revealed that 39.5% of workers fell into the low AHSS category, while 15.97% exhibited moderate symptoms, and 4.2% experienced severe symptoms (Kjellstrom, Lemke and Otto, 2017). The data also showed that a smaller subset of workers experienced more severe health issues, such as muscle cramps, seizures, and loss of consciousness, underscoring the serious nature of the heat stress they face (Meng *et al.*, 2022).

The lack of advanced environmental controls in these mills exacerbates the workers' exposure to extreme temperatures, highlighting a critical area for intervention (Hassan *et al.*, 2017).

Most notably, the discomfort was more pronounced in environments with minimal ventilation from fans and no advanced cooling systems, such as air conditioning (Bonafede *et al.*, 2022). For instance, this situation is valid when no artificial air circulation, mechanical air movement, or air dehumidifier is present at the workplace.

Workers' Workload and Thermal Perception

As previously described, workers' workload was determined through visual inspection aided with video recording based on their job patterns, i.e., sitting, standing, walking, etc. It was found that most activities at Mill A were conducted manually by workers based on the TWA value, resulting in a higher workload than at other mills.

Furthermore, regarding thermal comfort, most respondents felt uncomfortable, and the rest felt very uncomfortable. This result shows that workers' thermal perception aligns with the environmental workplace, exceeding the thermal comfort threshold based on the ACGIH value.

The integration of workers' perceptions into occupational health protocols is also crucial, as it provides valuable insights into the adequacy of current interventions and the areas where improvements are most needed (Li *et al.*, 2024). In this study, blood pressure is perceived in association with heart rate during this in-depth interview. It was considered that the majority of respondents' educational level is elementary school to senior high school, so they are more familiar with blood pressure terminology than with heart rate terminology. So, in the content analysis, blood pressure is the most frequent word. This result is in line with the research conducted by Noviyanti, Utami, and Mawarni (2023), who found that a hot work environment was associated with hypertension (high blood pressure), along with acclimatization, age of the worker, and nutrient status. Similarly, Houmsi *et al.* (2023) found that high ambient air temperature was positively correlated with blood pressure, suggesting that hourly ambient temperature is inversely correlated with ambulatory blood pressure. As temperature increases, blood pressure tends to decrease. It is because elevated temperatures lead to vasodilation and increased sweating, which may result in dehydration.

Some respondents felt discomfort while working because only fans were provided to create artificial airflow. Meanwhile, PPE and other controls, such as air conditioning, were not provided due to the extreme temperature within the room. Analysis of the thermal comfort data indicates that the environmental controls in place are insufficient to mitigate heat stress among workers. This is particularly concerning given the high levels of discomfort reported, which were most prevalent in Steel Mill A and C. The lack of advanced environmental controls in these mills exacerbates the workers' exposure to extreme temperatures, highlighting a critical area for intervention. Most respondents (42.9%) perceive heat, noise, and dust as the main hazards in their work, so all respondents (100%) use personal protective equipment (PPE). According to ASHRAE, thermal comfort is the subjective state of mind that expresses satisfaction with the thermal environment. Individual efforts can mitigate the adverse consequences of extreme heat (Li *et al.*, 2024), but personal perceptions influence these efforts.

Heat stress-related symptoms

Based on the results, the value of AHSS is relatively low, indicating that most workers did not experience heat-stress-related symptoms, despite discomfort in their thermal perception due to the high WBGT value. All respondents involved in this study were acclimatized prior to exposure to a high-temperature workplace. Acclimatization enhances thermoregulatory mechanisms and heat tolerance (Pryor *et al.*, 2019), thereby improving the body's adaptability to a hot workplace environment and reducing the risk of heat stress for workers. This study finding aligns with the previous study conducted by Sankar *et al.* (2024). Heat-stress intervention via acclimatization by providing water, rest, and shade (WRS) effectively reduced the risk of heat stress among outdoor workers.

Heat Stress-related Symptoms Predictive Index

To assess the correlation between heat stress-related symptoms as a predictive index of heat stress, we used the Kolmogorov-Smirnov one-sample test for normality, with a p-value of 0.13 > 0.05, indicating the data in the regression model are normally distributed. Meanwhile, the Durbin-

Watson statistic (D) was close to 2, indicating no autocorrelation. Furthermore, the results of the multicollinearity test showed that all independent variables had tolerance values> 0.1 and VIF values < 10, indicating that the independent variables are not highly correlated. Finally, the heteroscedasticity test using the Glejser test indicates that all independent variables have an insignificant effect on the absolute residual values (sig. > 0.05). After we analyzed the variables in the regression model, we found the formula as follows:

Heat stress-related symptoms = (-77.074) + (0.360 x WBGT) + (0.919 x core body temperature) + (0.474 x heat rate)

Where correlation coefficient (R) and coefficient of determination (R2) denote 78.4% and 61.4%, respectively.

Content Analysis

Based on qualitative data analysis, 14 informants were familiar with the terminology of heat stress and health–related symptoms. Heat stress is associated with heat-related symptoms. This finding is in line with the quantitative results, which show that heat-stress-related symptoms have a positive relationship with heat-stress-related physiological changes. Based on qualitative data analysis, 15 informants were familiar with the terminology of blood pressure in association with heart rate, which confirms that this finding aligns with the quantitative results, revealing that the predictive index of heat-stress-related symptoms shows a positive relationship with the symptoms of heat stress.

Based on qualitative data analysis, 15 respondents were familiar with the association between blood pressure and heart rate. This result aligns with the quantitative results, indicating that room temperature (body temperature and WBGT) has a positive relationship with the heat-related symptoms predictive index. Based on qualitative data analysis, 15 informants were familiar with the terminology that blood pressure was associated with heart rate, room temperature, and heat-stress-related health risks. Furthermore, this finding aligns with the results of the quantitative analysis, which indicate that heart rate (i.e., blood pressure) and room temperature (WBGT – body rate) are closely related to heat-stress-related symptoms.

Based on qualitative data analysis, 15 respondents working at the steel mills were familiar with efforts to improve occupational health. This finding is part of the recommendations on the efforts to improve occupational health as perceived by respondents. In the context of heat-stress mitigation, perception and knowledge are essential for implementing corrective measures and preventive actions.

Analysis of the quantitative and qualitative comparison

Based on qualitative data analysis, 15 informants were familiar with efforts to improve occupational health. This finding is part of the recommendations on the efforts to improve occupational health as perceived by respondents. In the context of heat-stress mitigation, perception and knowledge are essential for implementing corrective measures and preventive actions. This is evident in the study by Lohrey *et al.* (2021), conducted in Hanoi, Vietnam, in 2018. They found that disseminating educational materials was essential to improving workers' knowledge.

CONCLUSION

The study's results highlight the discrepancy between workers' perceptions of thermal discomfort and physiological measurements. Although substantial heat stress, as indicated by WBGT values, is present, the workers' physiological responses remain within acceptable limits. The qualitative data reveal a gap between workers' subjective experiences and actual heat stress, underscoring the importance of enhancing workers' awareness and implementing training on heat-related hazards. The study results indicate that current occupational health measures might prevent severe physiological consequences; yet, it is crucial to improve training, education and communication on heat stress and its adverse effects on health to inform workers' perceptions of actual work-related risks. These efforts are important for developing more effective, tailored mitigation strategies to address the adverse risks of high-temperature workplaces to workers. This study also highlights the importance of integrating qualitative and quantitative data to gain deeper insights into occupational health issues.

Future research is expected to explore the effects of workers' perceptions on heat stress management and extend these results to other industries with high-risk workplace environments. Policy makers and industrial leaders should incorporate workers' thermal perception into workplace heat-stress mitigation measures.

CONFLICT OF INTEREST

The authors acknowledge that no known personal relationships or competing financial interests could have influenced the study reported in this paper. The funders did not have a role in the design of the study, in data collection, analyses, or data interpretation, in the writing of the manuscript, or in the decision to publish the results.

AUTHORS' CONTRIBUTION

IM: conceptualization, summarizing, writing original draft, SBMdT: conceptualization, supervision, writing review & editing, DHMSN: conceptualization, supervision, writing, summarizing, KK: conceptualization, supervision, NYG: supervision and resources provision, GPA: supervision, conceptualization

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