The Indonesian Journal of Occupational Safety and Health
2023, 12 (2): 292-303
p ISSN: 2301 8046, e ISSN: 2540 7872
http://doi.org10.20473/ijosh.v12i2.2023.292-303

ORIGINAL ARTICLE

Assessment of Occupational Heat Stress in A Selected Indonesian Steel Mill

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ABSTRACT

Introduction: Workers in the Indonesian steel manufacturing industry are subject to many heat stress risk factors, ranging from the equatorial climate to physically demanding work tasks which may result in heat- related illnesses and reduced worker productivity. Hence, a study was conducted at Steel Mill X to assess the level of heat stress among its workers, determine the association of related factors and to provide meaningful recommendations. **Methods:** This study uses a descriptive cross-sectional method to assess workers' heat risk level and its association with individual, occupational and heat stress symptoms. An online questionnaire was used to collect primary data yet WBGT monitoring data were provided by Steel Mill X as secondary data. **Results:** The heat stress risk level score ranged from 48 to 140 (M=89.8, SD=±31.0). 122 workers were in the very high-risk category (75.8%). Occupational factors which had a statistically significant association with heat stress risk category includes: work area, length of exposure, air movement, hot surfaces, confined space, clothing factors and WBGT; while heat stress-related symptoms which were associated include headache, fatigue, profuse sweating, extreme thirst and increased body temperature. The absence of significant association between individual factors and heat stress risk category eliminates it as a confounding factor, suggesting occupational factors was the main variable. **Conclusion:** Control measures such as improving the supply of drinking water and maintenance of cooling systems should be implemented as soon as possible to prevent heat stress among workers.

Keywords: heat stress assessment, manufacturing industry, occupational heat stress

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INTRODUCTION

Steel manufacturing is an internationally competitive industry. It is currently present in six continents (Europe, South America, North America, Asia, Australia and Africa); and in 2019, each continent had at least one country in the top 30 steel-producing countries (crude steel production) list, where Indonesia ranked 26th that same year (World Steel Association, 2020). Domestically, steel manufacturing is among the largest industries, where 5.2 million tons of crude steel was produced in 2017, which increased by 300 thousand tons the following year (World Steel Association, 2019). Indonesian steel mills generally utilise one of the five main types of metallurgical furnaces, which include the Blast Furnace, Refractory Furnace, Electric Furnace, Basic Oxygen Furnace and Rotary Kiln Incinerator. All five furnace types utilise extremely high temperatures (can reach above 1600°C) which pose significant risk to all workers involved, hence why it is crucial to control workers' exposure.

Workers who are exposed to extreme heat or work in hot environments may be at risk of heat stress (CDC, 2020a). Heat stress is the total amount of heat the body encounters, which occurs when the

Cite this as: Ridwan, F. Z., *et al*. (2023) 'Assessment of Occupational Heat Stress in A Selected Indonesian Steel Mill', *The Indonesian Journal of Occupational Safety and Health*, 12(2), pp. 292-303.

Received September 15, 2022; 1st revision July 04, 2023; 2nd revision July 25, 2023; Accepted August 31 2023; Published: August 2023. Published by Universitas Airlangga.

body cannot get rid of excess heat (CDC, 2020b). Continuous exposure to heat may cause heat-related illnesses, such as heat rashes and sunburn in mild cases and heat cramps, heat exhaustion (dizziness, nausea, etc.) and heat stroke in more severe cases, which could potentially result in death (CDC, 2022).

Heat stress is a multifactorial problem, derived from the environment (air temperature, relative humidity, etc), work activities, clothing, hydration, or lack thereof, level of acclimatization, training, health status, etc., all related factors must be addressed and analysed (Wang *et al*., 2023). To standardize the method for workplace heat stress assessments, many methods were developed, such as Hong Kong's Risk Assessment for the Prevention of Heat Stroke at Work, Health & Safety Executive (HSE) United Kingdom's Heat Stress Checklist, etc. Based on the assessment results, the employer can then create a system of controls to effectively reduce the level of heat stress among workers. For example, as a result of heat-related fatalities among foreign workers, Singaporean companies began to implement acclimatization systems to acclimatize said demographic to the local climate by limiting their exposure or providing them with extended rest times.

Humans' ability to regulate body heat is highly dependent on the temperature and humidity of the surrounding air, and heat stress will occur when it is too hot and humid. Unfortunately for the Indonesian steel manufacturers, the country where they reside is located in the tropical climatic zone of Southeast Asia (SEA), where the weather is hot and humid for most parts of the year (Phanprasit *et al*., 2021). In addition, Indonesian steel mills are mostly located within the urban parts of Java Island, which escalates the risk for heat stress as those who live in high-density areas with less green open spaces are more likely to experience heat stress (Arifwidodo and Chandrasiri, 2020).

This study aimed to assess the level of heat stress risk experienced by workers at Steel Mill X. The association between heat stress and risk factors such as individual and organizational; as well as syndrome were investigated in this study.

METHODS

This study uses the descriptive cross-sectional method to assess workers' heat stress symptoms. The goal of descriptive research is to describe a phenomenon and its characteristics. Secondary data (WBGT measurement data) was provided by Steel Mill X for the assessment of heat stress risk level. The data collection (questionnaire) of this study was performed for forty-five (45) days from the 16th of April until the 31st of May 2021. Convenience sampling was chosen for the questionnaire of this study as the study required workers to volunteer as participants. Data gathered from the questionnaire was analysed in conjunction with the secondary data to determine the status of occupational heat stress and to identify appropriate controls.

Participants were exclusively workers in the manufacturing division of the company. Those who did not meet this criterion were excluded from this study due to them being significantly less exposed to heat stress hazards which may decrease the validity of the findings. Participants must have had at least 1 year experience at Steel Mill X to reduce the chance of recency bias. Lastly, participants must be at least 18 years of age as younger individuals might face different physiological responses compared to fully-grown adults. There were 161 valid responses in this study from 171 total responses.

Pearson's Chi Square Test and Fisher's Exact Test was used for the categorical data analysis. The 'a' symbol denotes that the value was taken from Fisher's Exact Test instead of the Chi Square Test. The two-tailed p-value of was chosen to represent the statistical significance of a given test as the research hypotheses does not signify the direction of interaction or difference. A confidence level of 95% is chosen with a significance level (α) of 0.05. The * symbol was used to denote a significant level of <0.05.

RESULT

Individual Factors

Of the 161 responses, all were male above the age of 18 (n=161, 100%). The mean age of the workers is 29 years old (SD=±4.3), with the youngest worker being 21 years old and the oldest being 53 years old. The mean BMI of the workers is 23.5 with a maximum of 34.8 and a minimum of 16.7 (SD=±3.8). Most workers finished their education at Senior High School (n=109, 67.7%) (See Table 1).

Occupational Factors

The most common job position is the operator (n=94, 58.4%) and most workers are exposed to heat for 30 minutes to 2 hours (n=63, 42.9%) in a single workday. Majority of workers only perform moderate climbing, ascending and descending activities (n=88, 54.7%). The distance between most work areas and their respective nearest cool rest area is less than 50 metres (n=96, 59.6%) and the distance between most work areas and their respective nearest drinking water station is less than 30 metres (n=93, 57.8%). Most workers had not received training regarding heat stress (n=96, 59.6%). The air movement in most work areas are reported to be moderate (some wind) (n=100, 62.1%). Nearly all workers claim to be acclimatized to the workplace heat (n=158, 98.1%).

Most workers are exposed to surfaces that are burn on contact (n=79, 49.1%). All workers are subject to confined spaces (n=161, 100%). Most workers' task complexity is moderate (n=100, 62.1%). Most workers use a single layer of clothing (moderate) (n=97, 60.2%). All workers are required to use a half-face respiratory protection device (negative pressure) (n=161, 100%). Nearly all workers' metabolic work rate is categorized as heavy (n=140, 87.0%), excluding supervisors who are only required to perform light work (n=21, 13.0%). From the WBGT measurement data which was obtained during a HRA (hazard risk assessment) in 2020, a little above half of the workers (Plate Mill, Raw Material Handling and Sinter Plant) are exposed to a WBGT of more than 30°C (n=81, 50.3%) while the remaining 80 workers (Continuous Casting Plant, Coke Oven Plant, Refractory and Steel Making Plant) are exposed to a WBGT of 24°C to 27°C (49.7%).

Table 1. Sociodemographic Distribution

Characteristics	n	%
Age		
21-25	15	9.3
26-30	106	65.8
31-35	26	16.1
36+	14	8.7
BMI		
Underweight	14	8.7
Normal Weight	97	60.2
Overweight	41	25.5
Obese	9	5.6
Level of Education		
Junior High School	1	0.6
Senior High School	109	67.7
Diploma, Undergraduate Degree or Above	51	31.7

Table 2. Occupational Factors

Category	n	%
Work Area		
Coke Oven Plant	28	17.4
Continuous Casting Plant	26	16.1
Plate Mill	25	15.5
Raw Material Handling	29	18.0
Refractory	10	6.2
Sinter Plant	26	16.1
Steel Making Plant	17	10.6
Job Position		
Engineer	2	1.2
Foreman	23	14.3
Operator	94	58.4
Supervisor	21	13.0
Worker	21	13.0
Length of Employment		
1-5 Years	15	9.3
>5 Years	146	90.7
Additional Job		
No	154	95.7
Yes	7	4.3
Exposure Period (per day)		
<30 min	45	28.0
30 min - 2 hours	69	42.9
>2 hours	47	29.2
Climbing, Ascending, Descending		
None	15	9.3
Moderate	88	54.7
Significant	58	36
Distance from Cool Rest Area		
<50 Metres	96	59.6
50-100 Metres	33	20.5
>100 Metres	32	19.9
Distance from Drinking Water		
<30 Metres	93	57.8
30-50 Metres	34	21.1
>50 Metres	34	21.1
Training Received		
Yes	65	40.4
No	96	59.6

Heat Stress Risk Level Score

A score of less than 28 indicates low to moderate risk; 28 to 60 indicates moderate to high risk; and a score of more than 60 indicates high to very high risk (actions should be taken immediately). The mean score of heat stress risk level among the workers is 89.8 (SD=±31.0). The score of the workers ranged from between 48 to 140. As shown by Table 3, majority of workers had a score of more than 60, hence they are categorized as high to very high risk (n=122, 75.8%).

Advanced Table 2. Occupational Factors

Category	n	%
Air Movement		
Windy	36	22.4
Moderate	100	62.1
No Wind	25	15.5
Acclimatised		
Yes	158	98.1
No	3	1.9
Hot Surfaces		
Neutral on Contact	29	18.0
Hot on Contact	53	32.9
Burn on Contact	79	49.1
Confined Space		
Not Present	28	17.4
Present	133	82.6
Task Complexity		
Simple	0	0.0
Moderate	100	62.1
Complex	61	37.9
Clothing (permeable)		
Single Layer (light)	0	0
Single Layer (moderate)	97	60.2
Multiple Layers	64	39.8
Respiratory Protection		
None	0	0.0
Half-Face	161	100.0
Full-Face	0	0.0
Metabolic Work Rate		
Light	21	13.0
Heavy	140	87.0
WBGT		
<24°C	0	0.0
24°C - 27°C	80	49.7
27°C - 30°C	0	0.0
>30°C	81	50.3

Heat Stress-related Symptoms

The frequency of reported heat stress symptoms by the workers are illustrated in Table 4. Profuse sweating, extreme thirst and fatigue are the most prevalent out of the list (118, 105 and 97, respectively). Fainting and stomach cramps are very rarely chosen as the quantity of these responses are only single digit (1 and 2).

Association Between Variables

Based on the results illustrated in Table 5, there is no statistically significant association between Risk Score Category and individual factors of age and BMI. On the other hand, Table 6 shows that there is a statistically significant association between Risk Score Category and Work Area (x2=57.815, p=0.001). Exposure to Heat Stress has also shown to have a significant association with Risk Score Category (x2=18.582, p=0.001). The quantity of Air Movement in the Work Area also has a significant association with Risk Score Category (x2=7.326, p=0.023). Hot Surfaces in the Work Area (x2= 31.781, p=0.001), Presence of Work Activities in Confined Space (x2=10.472, p=0.001), Clothing Factors (x2=32.818, p=0.001); and Work Area WBGT Measurement (x2=50.362, p=0.001) all have a statistically significant association with Risk Score Category.

The results from Pearson's Chi Square Test on Table 7 shows that only 5 of the total symptoms/ illnesses have a statistically significant association with Risk Score Groups. These include Headache (x2=6.218, p=0.015); Fatigue (x2=6.669, p=0.014); Profuse Sweating (x2=13.531, p=0.001); Extreme Thirst (x2=9.896, p=0.003); and Increased Body Temperature (x2=5.896, p=0.022).

DISCUSSION

The entirety of the respondents was male as exposure towards health hazards such heat stress and physically-demanding work were deemed too dangerous for females. The entire age distribution of the respondents are within the working age population (15 to 64), however, even the oldest

Table 3. Heat Stress Risk Level Score

Score	n	%
28 – 60 (High Risk)	39	24.2
60+ (Very High Risk)	122	75.8

Table 4. Heat Stress-related Symptoms

Symptom/Injury	n	%
Headache		
No	86	53.4
Yes	75	46.6
Loss of Balance		
No	122	75.8
Yes	39	24.2
Tingling Sensation (hand)		
No	114	70.8
Yes	47	29.2
Blurred Vision		
No	123	76.4
Yes	38	23.6
Fainting		
No	159	98.8
Yes	2	1.2
Stomach Cramps		
No	157	97.5
Yes	4	2.5
Muscle Cramps		
No	135	83.9
Yes	26	16.1
Fatigue		
No	35	21.7
Yes	126	78.3
Nausea		
No	127	78.9
Yes	34	21.1
Loss of Appetite		
No	131	81.4
Yes	30	18.6
Profuse Sweating		
No	22	13.7
Yes	139	86.3
Extreme Thirst		
No	31	19.3
Yes	130	80.7
Anxiety		
No	127	78.9
Yes	34	21.1
Dark Urine		
No	128	79.5
Yes	33	20.5
Rashes		
No	136	84.5
Yes	25	15.5

Advanced Table 4. Heat Stress-related Symptoms

Symptom/Injury	n	%
Itchy Skin		
No	124	77.0
Yes	37	23.0
Dry Mouth		
No	89	55.3
Yes	72	44.7
Increased Body Temperature		
No	62	38.5
Yes	99	61.5
Collision		
No	128	79.5
Yes	33	20.5
Trips		
No	105	65.2
Yes	56	34.8
Minor Injuries		
No	110	68.3
Yes	51	31.7
Other Injuries		
No	143	88.8
Yes	18	11.2

respondent (53) is 11 years younger than that of the maximum age of the working age population and the youngest respondent (21) is 6 years above the minimum age (OECD, 2021). A vast majority of the workers are in the 26-30 age range, which may prove to be beneficial for the workers, as worsening physical performance has been observed as early as the fifth decade (Hall *et al*., 2017).

Workers were mostly high-school graduates and are married. The average BMI of the respondents is 23.5 (SD±3.7), which is relatively close to two other studies on foundry workers in Iran, where the mean BMI of their respondents is 24.2 (SD±3.9) and 26.14 (SD±3.6) (Choupani *et al*., 2018, Mohammadi *et al*., 2021). From a BMI point of view, according to Centers for Disease Control and Prevention, majority of the respondents belong to normal weight, which, in theory, should indicate that they are at less risk for many diseases and health conditions (CDC, 2022b). With regards to heat stress, having less body fat is theoretically advantageous since subcutaneous fat might serve as a barrier to heat loss and influence thermoregulatory abilities and individuals with a higher BMI tend to cool less rapidly and have to

Table 5. Association Between Individual Factors and Risk Score Category

Individual Factors	Risk Score Category		x2	P-value
	High	Very High		
Age			1.550a	0.661a
21-25	2 (1.2%)	13 (8.1%)		
26-30	25 (15.5%)	81 (50.3%)		
31-35	8 (5.0%)	18 (11.2%)		
36+	3 (1.9%)	11 (6.8%)		
Body Mass Index			2.894a	0.428a
Underweight	1 (0.6%)	13 (8.1%)		
Normal Weight	23 (14.3%)	74 (46.0%)		
Overweight	11 (6.8%)	30 (18.6%)		
Obese	3 (1.9%)	(3.7%)		

Table 6. Association Between Occupational Factors and Risk Score Category

Individual Factors	Risk Score Category		x2	P-value
	High	Very High		
Work Area			57.815	0.001*
COP	0 (0.0%)	28 (17.4%)		
CCP	0 (0.0%)	26 (16.1%)		
PM	12 (7.5%)	13 (8.1%)		
RMH	18 (11.2%)	11 (6.8%)		
Refractory	0 (0.0%)	10 (6.2%)		
Sinter Plant	8 (5.0%)	18 (11.2%)		
SMP	0 (0.0%)	17 (10.6%)		
Job Position			0.955a	0.945a
Engineer	0 (0.0%)	2 (1.5%)		
Foreman	6 (3.7%)	17 (10.6%)		
Operator	21 (13.0%)	73 (45.3%)		
Supervisor	6 (3.7%)	15 (9.3%)		
Worker	5 (3.1%)	16 (9.9%)		
Length of Employment			0.119	1.000a
1-5 Year(s)	3 (1.9%)	12 (7.5%)		
> 5 Years	35 (21.7%)	111 (68.9%)		
Additional Job			1.505	0.357a
Not Present	35 (21.7%)	119 (73.9%)		
Present	3 (1.9%)	4 (2.5%)		
Exposure Period (per day)			18.582	0.001*
<30 Minutes	21 (13.0%)	2 (14.9%)		
30 Minutes - 2 Hours	11 (6.8%)	58 (36.0%)		
>2 Hours	6 (3.7%)	41 (35.9%)		
Climbing, Ascending and Descending			1.072	0.578
None	4 (3.5%)	11 (11.5%)		
Moderate	18 (11.2%)	70 (43.5%)		
Significant	16 (9.9%)	42 (26.1%)		

Advanced Table 6. Association Between Occupational Factors and Risk Score Category

Individual Factors	Risk Score Category		x2	P-value
	High	Very High		
Distance to Nearest Cool Rest Area			4.484	0.105
<50 Metres	26 (16.1%)	70 (43.5%)		
50-100 Metres	9 (5.6%)	24 (14.9%)		
>100 Metres	3 (1.9%)	29 (18.0%)		
Distance to Nearest Drinking Water			2.315	0.297
<30 Metres	26 (16.1%)	67 (41.6%)		
30-50 Metres	6 (3.7%)	28 (17.4%)		
>50 Metres	6 (3.7%)	28 (17.4%)		
Training Received			3.105	0.090
Yes	20 (12.4%)	45 (28.0%)		
No	18 (11.2%)	78 (73.3%)		
Air Movement			7.326	0.023*
Windy	12 (7.5%)	24 (14.9%)		
Some Wind	25 (15.5%)	75 (46.6%)		
No Wind	1 (0.6%)	24 (14.9%)		
Acclimatised			0.944	1.000a
Yes	38 (23.6%)	120 (74.5%)		
No	0 (0%)	3 (1.9%)		
Hot Surfaces			31.78	0.001*
Contact Neutral	18 (11.2%)	11 (6.8%)		
Hot on Contact	12 (7.5%)	41 (25.5%)		
Burn on Contact	8 (5.0%)	71 (44.1%)		
Confined Space			10.47	0.001*
Not Present	0 (0.0%)	28 (17.4%)		
Present	38 (23.6%)	95 (59.0%)		
Task Complexity			0.841	0.445
Moderate	26 (16.1%)	74 (46.0%)		
Complex	12 (7.5%)	49 (30.4%)		
Clothing (permeable)			32.81	0.001*
Single Layer (moderate)	38 (23.6%)	59 (36.6%)		
Multiple Layers	0 (0.0%)	64 (39.8%)		
Respiratory Protection			-	-
Half-Face	38 (23.6%)	123 (76.4%)		
Metabolic Work Rate			0.331	0.585a
Light	6 (3.7%)	15 (9.3%)		
Heavy	32 (19.9%)	108 (67.1%)		
WBGT			50.36	0.001*
24°C - 27°C	38 (23.6%)	42 (26.1%)		
>30°C	0 (0.0%)	123 (76.4%)		

elevate their metabolism less significantly than lean individuals (Speakman, 2018).

2 of the 9 work areas (Blast Furnace & Facility Technology) could not join the study due to communication issues. This was a major, unexpected factor which led us to not be able to collect enough samples (161 instead of 252). The participants of this study were categorized according to their job position, Engineer, Foreman, Operator, Supervisor and Worker. An important thing to note is that there

Table 4. Heat Stress-related Symptoms

Symptom/Injury	n	%	x2	P-value
Headache			6.218	0.015*
No	27 (16.8%)	59 (36.6%)		
Yes	11 (6.8%)	64 (39.8%)		
Loss of Balance			1.928	0.198
No	32 (19.9%)	90 (55.9%)		
Yes	6 (3.7%)	33 (20.5%)		
Tingling Sensation (hand)			0.730	0.424
No	29 (18.0%)	85 (52.8%)		
Yes	9 (5.6%)	38 (23.6%)		
Blurred Vision			4.717	0.470
No	34 (21.1%)	89 (55.3%)		
Yes	4 (2.5%)	34 (21.1%)		
Fainting			0.626	1.000 a
No	38 (23.6%)	121 (75.2%)		
Yes	0 (0.0%)	2 (1.2%)		
Stomach Cramps			0.004	1.000 a
No	37 (23.0%)	120 (74.5%)		
Yes	1 (0.6%)	3 (1.9%)		
Muscle Cramps			0.329	0.626
No	33 (20.5%)	102 (63.4%)		
Yes	5 (3.1%)	21 (13.0%)		
Fatigue			6.669	0.014*
No	14 (8.7%)	21 (13.0%)		
Yes	24 (14.9%)	102 (63.4%)		
Nausea			1.892	0.184
No	33 (20.5%)	94 (58.4%)		
Yes	8 (3.1%)	29 (18.0%)		
Loss of Appetite			2.156	0.161
No	34 (21.1%)	97 (60.2%)		
Yes	4 (2.5%)	26 (16.1%)		
Profuse Sweating			13.531	0.001*
No	12 (7.5%)	10 (6.2%)		
Yes	26 (16.1%)	113 (70.2%)		
Extreme Thirst			9.896	0.003*
No	14 (8.7%)	17 (10.6%)		
Yes	24 (14.9%)	106 (65.8%)		
Anxiety			0.848	0.379
No	32 (19.9%)	95 (59.0%)		
Yes	6 (3.7%)	28 (17.4%)		
Dark Urine			3.034	0.107
No	34 (21.1%)	94 (58.4%)		
Yes	4 (2.5%)	29 (18.0%)		
Rashes			0.003	1.000
No	32 (19.9%)	104 (64.6%)		
Yes	6 (3.7%)	19 (11.8%)		

Advanced Table 4. Heat Stress-related Symptoms

Symptom/Injury	n	%	x2	P-value
Itchy Skin			0.014	1.000
No	29 (18.0%)	95 (59.0%)		
Yes	9 (5.6%)	28 (17.4%)		
Dry Skin			0.124	0.838
No	28 (17.4%)	87 (54.0%)		
Yes	10 (6.2%)	36 (22.4%)		
Dry Mouth			3.475	0.092
No	26 (16.1%)	63 (39.1%)		
Yes	12 (7.5%)	60 (37.3%)		
Increased Body Temperature			5.896	0.022*
No	21 (13.0%)	41 (25.5%)		
Yes	17 (10.6%)	82 (50.3%)		
Collision			0.132	0.821
No	31 (19.3%)	97 (60.2%)		
Yes	7 (4.3%)	26 (16.1%)		
Trips			0.747	0.440
No	27 (16.8%)	78 (48.4%)		
Yes	11 (6.8%)	45 (28.0%)		
Minor Injuries			0.001	1.000
No	26 (16.1%)	84 (52.2%)		
Yes	12 (7.5%)	39 (24.2%)		
Other Injuries			0.196	0.768a
No	33 (20.5%)	110 (68.3%)		
Yes	5 (3.1%)	13 (8.1%)		

were only 2 engineers who participated to join this study which made us not be able to draw any significant conclusions in terms of job position. On the bright side, the job position with the most responses in this study was the operator (58.4%) which should prove to be useful as workers, foremen and operators are those who are subject to the highest amount of exposure, respectively. Almost all respondents have worked at the company for more than 5 years (90.7%) and do not have an additional job (95.7%) which help strengthen the findings of this study since these may become confounding factors on their own.

Not all work areas are subject to a very high WBGT, these include the Plate Mill, Raw Material Handling and Sinter Plant. The WBGT is a well-known evaluation scale for prevention against hyperthermia, however, even though nearly half (49.7%) of the respondents are exposed to a WBGT of 24°C - 27°C, the number of workers who are categorized as having a very high risk score is still 75.8% (Takebayashi, 2018). Air movement was initially assumed to be very little to not present, however, the results indicate that most workers report moderate air movement (62.1%) with only 15.5% reporting little to no wind in their work area. Contrary to the air movement results from the questionnaire, in the suggestions section, 69.6% of workers have requested for cooling improvements in the workplace, such as ventilators, fans, air conditioning and more open areas.

In terms of distance to nearest cool area and distance to nearest drinking water, most results are positive (59.6% and 57.8%, respectively). Although there is no significant association between these two factors, from visual observation of the data, the larger the result is for the two variables, the more likely the worker will be in the very high risk category. Apart from the complaints about air movement and cooling in the workplace, water seems to also be a point of criticism towards the management. One worker stated that the company does not provide water stations in the work area and instead, workers there have to go to the nearby office to hydrate. Another complaint states that their work involves moving from place to place, ascending and descending 'towers', leading to difficulty in carrying their own water bottle. Overall, the controls put in place seem to be sufficient to most workers, however, an improvement would come a long way in reducing the risk of heat stress among workers.

Association Between Individual Factors and Risk Score Category

BMI is a huge proponent of heat stress, and it was thought that BMI would be associated with the risk score category of workers. A high BMI is associated with heat-related illnesses, however, in this study, BMI did not have a significant statistical association with which risk score category a worker belonged to. This may be due to 1) most workers of a certain work area being exposed to the same heat stress hazards and performing similar work activities, 2) the questionnaire being occupational factor-focused or 3) workers having similar BMI and only few outliers (Nutong *et al*., 2018).

The entire age distribution of our respondents are within the working age population, which is defined as those aged 15 to 64. A vast majority of the workers are in the 26-30 age range, which may prove to be beneficial for the workers, as physical performance worsens alongside increasing age decade. According to a recent study, worsening physical performance was observed as early as the fifth decade (Hall *et al*., 2017).

The fact that age and BMI do not have significant association with heat stress risk category indicates that our findings are exclusively associated with occupational factors without the results being skewed by confounding variables (individual factors).

Association Between Occupational Factors and Risk Score Category

There were many occupational factors which were identified to bare a statistically significant association with the risk score category of heat stress, namely work area, length of exposure, air movement, hot surfaces, confined space, clothing factors and WBGT measurement. It is important to note that work area determines the presence and magnitude of hot surfaces, the types of clothing worn in the work area and the WBGT as these 3 factors (as well as a couple of others) are uniform in each work area. Workers' length of exposure towards heat stress may also be influenced greatly by their work area. Air movement, on the other hand, is fairly subjective, with the overall aim of providing a thermally acceptable environment for human comfort and work that would in turn enable better work productivity and less thermal dissatisfaction (Hussin *et al*., 2013). Based on the responses, most workers reported moderate air movement, however, as previously mentioned, 69.9% of the workers requested that there should be improvements in the air movement of their workplace. On the contrary, there were some workers who expressed their satisfaction to the overall thermal environment in the workplace, with one worker even stating that his work area is too windy. It is important to keep in mind that a thermally acceptable environment is aimed to please the majority of workers and due to the subjective nature of this variable, there are bound to be a few individuals who are not.

Due to the nature of the workplace, hot surfaces, working in confined spaces and having to use thick work attire are part of the job description. One worker expressed his dislike for having denim as the chosen material for work clothing. Another worker expressed that there should be cooling vests to control workers' core body temperature (CBT) and to prevent hyperthermia. Though no other worker has suggested that there be cooling vests, this may be a good suggestion as other cooling strategies may induce some ergonomic problems to occupational workers (Chan *et al*., 2017).

For the WBGT measurement, this variable carries the most importance in determining the heat stress risk level score and is significantly associated with risk score category ($p=0.001$). Among various researches which have been conducted to investigate the performance of different heat stress indexes for estimation of thermal stress, Wet Bulb Globe Temperature (WBGT) index was found to be a suitable index to assess the climatic condition of the working environments (Falahati *et al*., 2012; Kakaei *et al*., 2019). In the study, the WBGT ranged from 24°C (RMH and PM) to 38°C (COP and Refractory) with a mean of 31.2 (SD±5.2). For reference, another study conducted on foundry workers had a mean WBGT of 33°C (SD±3.2) (Jafari *et al*., 2020). Based on the questionnaire, a WBGT of >30°C belongs to the group of the highest risk (4 points), however, this was to be expected from the beginning as the work processes and work activities include a plethora of heat stress hazards.

Association Between Heat Stress Symptoms and Risk Score Category

From the association tests, there were some symptoms which had statistically significant association with risk score group, including headache, fatigue, profuse sweating, extreme thirst and increased body temperature. Of the listed symptoms, some are signs of more chronic illnesses such as heat syncope, a condition which includes orthostatic symptoms or fainting occurring in a person who has not undergone heat acclimatization and who is exposed to a high environmental temperature (Bezruchka, 2008; Wang and Chiang, *et al*., 2009). On the contrary, the two individuals who has fainted in the past due to heat stress claim to have already been acclimatized to the workplace heat climate, which does not fit the previously stated definition.

Heat induced headache and fatigue may be caused by profuse sweating, which later develops into the sensation of extreme thirst and increased body temperature. When the body becomes dehydrated, i.e. from profuse sweating, it may trigger a headache due to narrowing blood vessels as the body loses water and electrolytes (Gutierrez, 2021). In addition, dehydration impairs thermoregulation, reducing both sweating and cutaneous vasodilation, leading to increased body temperature. On the other hand, the dehydration-induced hyperosmolality stimulates drinking behaviour, leading to the sensation of extreme thirst (Morimoto *et al*., 1998; Kavouras, 2013). When fluid and electrolyte losses exceed levels compatible with systemic function, there is a high chance that it will lead to fatigue (Flaminio & Rush, 1998; Xiang J, *et al*., 2014).

CONCLUSION

Based on the heat stress assessment at Steel Mill X, a vast majority of workers are categorized as very high risk (75.8%) and there were no workers of whom were categorized into the low-moderate risk category. As expected, WBGT was the biggest contributing factor which determined which risk category a worker from a specific area would be in, however, there were other occupational factors which were associated with risk score category, including Work Area, Length of Exposure, Air Movement, Hot Surfaces, Confined Space and Clothing Factors. In addition, headache, fatigue, profuse sweating, extreme thirst and increased body temperature were heat stress-induced symptoms which had a statistically significant association with risk score category. Improvements on the hydration systems by providing more drinking water near the work area and increasing the air movement are recommended. Ethical Clearance

ETHICAL CLEARANCE

Prior to conducting this study, JePEM-USM has given their ethical approval (JePEM Code: USM/JEPeM/21010085). All terms and conditions regarding how the information will be used, reproduced, and published has been displayed at the landing page in the Google Forms.

ACKNOWLEDGEMENTS

The main author would like to acknowledge HSE Team at Steel Mill X who has supported the author along the way.

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