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Heat Stress and Noise Exposure Levels in a Manufacturing Plant

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ABSTRACT

This paper analyses skilled workers' heat stress and noise exposure levels at a pressure vessel manufacturing plant. Measurements were conducted at three partially enclosed workspaces of the plant where hot work and metal fabrications were conducted using a multi-function thermal environment data logger and a sound level recorder. A survey was developed to obtain the field workers' perceptions of their immediate heat and noise environments. The findings suggested that the heat and noise conditions were generally acceptable. The calculated mean Wet-bulb Globe Temperature (WBGT) indicated that there was only minimal risk of heat stress for the workers. It was also identified that the noise intensities in the sections studied were within the permissible exposure limit for an 8-hour duration specified in the Department of Occupational Safety and Health (DOSH) guideline. Besides, questionnaire survey results showed that the thermal and noise conditions at the workplace were acceptable. The workers perceived their work environment as warm with sensible air movement, moderately humid, free from heat and noise-related injuries, and able to have clear conversations with their co-workers while working.

Keywords: Heat stress, manufacturing plant, noise exposure, Wet-bulb Globe Temperature (WBGT), workplace

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INTRODUCTION

A safe, comfortable, and healthy workplace environment plays an important role in ensuring the good productivity of the employees. The impacts of undesirable workplace conditions, which led to poor work performance, have been documented (Srinivasan et al., 2016; Edem et al., 2017). Since workers are the most valuable assets of an organisation, improving their workplace's physical comfort is essential to ensure a satisfactory productivity level (Andrew, 2011). Besides, the need for the workers to understand the occupational safety and health (OSH) requirements and their participation in formulating preventive measures to create a safer working environment have been highlighted (Gravel et al., 2011). Heat stress is defined in the guideline as the overall heat exposed to a worker from the combination of metabolic heat and thermal parameters - air temperature, air velocity, humidity, radiant heat from machinery or building materials, and clothes worn by the workers. Therefore, these factors are considered in heat stress evaluations at workplaces. The Wet Bulb Globe Temperature (WBGT) index is widely used in heat stress analysis. This index considers the main thermal parameters such as dry bulb, natural wet bulb, and globe temperature. In Malaysia, a workplace heat stress management guideline was introduced in 2016, and important information such as environmental factors, assessment requirements, and preventive measures for heat stress are presented (DOSH, 2016). Heat stress is assessed using the WBGT index, and the values obtained are compared with the action limit, and threshold value limit reference values stated in the American Conference of Governmental Industrial Hygienists guideline (ACGIH, 2015 as cited in DOSH 2016). The international standard ISO 7243 prescribes a specific duration of rest time for employees, depending on the work intensity and the WBGT level, to prevent the core body temperature from exceeding 38ºC (Parsons, 2006).

Heat-related illnesses could happen if the human body fails to control its temperature, and the symptoms include heat cramps, heat exhaustion, heat syncope, and a more life-threatening heatstroke (Parsons, 2014). It was evident that workers exposed to excessive heat and conducting manual labour in extremely hot environments may be at risk of heat stress and other occupational injuries (Xiang et al., 2014; Yang et al., 2017). It usually happens in industries with high-temperature equipment use and the associated processes, such as manufacturing, construction, mining, utility, agriculture, and others (Andrew, 2011). According to Rabeiy (2019), heat disorders were experienced by several bakery workers, and appropriate control measures were suggested. It was reported by the Bureau of Labour (2017) that exposure to environmental heat had resulted in 37 work-related mortalities and 2830 cases of non-life-threatening heat-related injuries and diseases in 2015 alone. A study of occupational heat stress in workplaces found that 60% of the workforce had experienced a loss in work productivity due to the air temperature level. Approximately 20% were also more vulnerable to heat illness during the hotter month (Venugopal et al., 2015). Climate change was found as a factor that intensified heat stress, where a study conducted in an automotive parts manufacturing plant revealed that a high percentage of the workers were not satisfied with the temperature of the workplace where headache and exhaustion were among the occupational illnesses reported (Pogačar et al., 2018). Berry et al. (2010) summarised the effects of climate change on mental health. They concluded that heat exposure at work might cause psychological distress among workers due to the loss of work capacity, income and disruption in social activity.

A heat stress assessment of a metal workshop found that the heat stress condition was aggravated by the protective clothing worn during work (Bernard, 1999). Therefore, personalised monitoring using sensor technology was proposed to evaluate heat stress as this method was less invasive and could record workers' effort intensity (Pancardo et al., 2015). Furthermore, to reduce such thermal stress, introducing a liquid cooling garment was useful in lowering the temperature and relative humidity under the workers' clothing (Bartkowiak et al., 2014). In the tropics, Tawatsupa et al. (2013) analysed the environmental heat exposure of Thai workers. The findings showed that 18% of the survey respondents were exposed to uncomfortable high temperatures while working, and men were more likely to experience heat stress than women. Besides, some workers in the hot-humid region expressed dissatisfaction with the workplace thermal environment, drinking water and sanitation facilities provided but were compelled to tolerate such harsh working conditions because of economic vulnerability (Dutta et al., 2015).

Besides the thermal conditions, undesirable noise level (NL) has been recognised as an occupational hazard for various industries in developing and modern countries (Edelson et al., 2009; Mohammed & Rabeea, 2021). Noise annoyance and related issues in buildings were found to affect the emotions and productivity of the occupants (Lusk et al., 2009; Aalto et al., 2017). According to Manivasagam (2019), Malaysia's occupational noise-related hearing disorders cases have increased significantly in the past decades and contributed to more than 60% of the total occupational diseases recorded. More than 80% of the incidents were reported from the manufacturing sector. To assist businesses in Malaysia in complying with the Occupational Safety and Health (Noise Exposure) Regulations 2019 (DOSH, 2019b), the industry code of practice to manage occupational noise exposure and hearing conservation has been introduced by DOSH (2019a). This code of practice specifies the practical procedures to analyse and control the noise level in workplaces. For instance, noise dose (ND) and noise exposure level (NEL) is required for noise risk assessment in all workplaces, and research should be conducted to reduce emission whenever necessary.

Building acoustic studies have been conducted worldwide. The outcome of an online survey showed that a large proportion of the respondents stated that their workplaces' noise level had negatively affected their workability (Oseland & Hodsman, 2018). Nelson et al. (2005) concluded that workplace noise is responsible for 16% of adults' disabling hearing loss, which is more apparent in developing nations. The noise level of two commonly used machines in a factory was studied by Tomozei et al. (2012), and the noise transmission reduction trend from the noise sources to the outdoors was documented. A noise exposure study in a Danish factory found that the sound level was higher than the permissible level, and negative perceptions were recorded due to machinery use (Berry et al., 2010). This finding echoed Sriopas et al. (2017), where the NEL in a tropical factory exceeded 86 dBA, contributing to the high prevalence of auditory problems. Similarly, the noise level in an Indian manufactory was higher than the permitted noise limits, mainly because of the machines' sound (Krishnamurthy et al., 2017). The importance of the management's role in creating a healthy occupational surrounding was highlighted by Bockstael et al. (2013). Bell et al. (2015) compared the noise control performance in different manufacturing companies. They highlighted that corporations categorised as "high performers" had better knowledge of noise-related issues, were more aware of the newest engineering or administrative methods in noise reduction, and the management was more supportive of noise control initiatives.

Some studies analysed both heat stress and noise exposure simultaneously. For example, Meegahapola and Prabodanie (2018) studied a rubber compound factory's temperature, noise, and lighting conditions. The findings demonstrated that the two former parameters significantly influenced workers' productivity. This study has also recommended using the WBGT index to predict the heat stress condition instead of merely considering the air temperature. The noise level, thermal exposure and workplace safety practices of casting and forging units were assessed using calibrated meters by Singh et al. (2010). The study outcomes showed that WBGT and NL were high compared to the limits specified in the guidelines. In another study, ND was the main factor in causing noise-induced temporary threshold shift (TTS), and such hearing fatigue was enhanced with the heavy workload and heat stress (Chen et al., 2007).

Since the concurrent studies of heat and noise conditions in factories in hot and humid climates have yet to be extensively conducted, more work is needed. Hence, this case study aims to analyse a manufacturing plant's heat stress and noise conditions in an equatorial country. The main objectives are to measure the air temperature, relative humidity, air velocity and globe temperature to calculate WBGT and the noise level for ND and NEL analysis. First, a field survey consisting of physical measurements and questionnaire surveys was conducted at the plant's fan-assisted and naturally aired working areas. The results were then compared to the previous studies and the acceptable ranges recommended in relevant standards and guidelines.

Case Study Location

The research team selected a plant that manufactures pressure vessels for heat stress and noise exposure analysis because hot works like welding, brazing, grinding and fabrication of steel materials were conducted within the premises. The production area was estimated to house around 30 field staff. This particular workspace was divided into three main sections - Section A was assigned as the mechanical fitting place where different pressure vessel parts were assembled, and Section B was allocated for cutting and welding jobs. At the same time, the drilling, grinding and fabrication works were mostly carried out in Section C. As this area was partially enclosed where outdoor air was used as the means for ventilation, portable industrial fans were used to enhance air movement within the work sections.

METHODS

A pilot walkthrough survey was conducted about a month before the actual assessment to identify the locations where data collection was to be held. Upon obtaining the factory management's consent, a field study covering physical condition measurement and subjective evaluation was conducted from 0900 to 1700 h at the plant's three work sections. The research team measured heat and noise parameters concurrently, and care was taken not to interrupt the employees' work.

Heat Stress and Noise Level Measurements

A digital climate measuring instrument was used to measure the heat stress parameters. The device is connected with three sensor probes, measuring air temperature, relative humidity, and air velocity levels. These thermal parameter readings were then used to calculate the WBGT index. Following the DOSH guideline (2016), the instrument was positioned at about 1.1m above floor level, as the workers mostly stood while performing their duties. The noise level inside the factory was recorded using a sound level meter, which complied with the IEC61672-1 Class 2 standard and met the noise measuring equipment requirement of DOSH (2019a) for the sound level meter. The meter was placed near the locations where mechanical work was conducted to ensure accuracy. Both meters provide real-time data for the ease of environmental monitoring and come with data logging functions that allow continuous measurements. The heat and noise data were collected at 1-minute intervals throughout the survey.

Calculation of WBGT, ND and NEL

This work calculated the WBGT values of all three locations studied using the measured heat stress data. As the workplace was only partially enclosed and the influence of solar radiation was considered, Equation 1 was used for the calculation of WBGT:

$$WBGT = 0.7\ T_{wb} + 0.2\ T_g + 0.1\ T_{db}\ ^{o}C \quad (1)$$

where T_{wb} = wet-bulb temperature, T_g = globe temperature and T_{db} = dry-bulb temperature

The workers' exposure to work-related noise was analysed using the daily noise exposure level (NEL) method (DOSH, 2019a). The ND of the workers was calculated using Equation 2:

$$ND = 100 \text{ x } (T_e/8) \text{ x } 10^{\ (L-85)\ /\ 10}\ \% \quad (2)$$

where T_e = effective duration of work and L = measured noise level.

The NEL of the workers was estimated using Equation 3:

$$NEL = NL_{eq} + 10\ Log_{10}\ (T_e/\ T_o)\ dBA \quad (3)$$

where NL_{eq} = 8-hour A-weighted equivalent continuous noise level, T_e = effective duration of work and T_o = 8 hour.

Workers' Perception Survey

The questionnaire survey aimed to identify the workers' perceptions of their thermal and noise environments. The questionnaire covered perceptions on heat and noise exposures, clothing acclimatisation, symptoms of potential health impacts, possible productivity losses due to extreme conditions and employee acceptance. The survey form has four sections, as shown in Table 1. All the questions posed in the survey form were developed by referring to the sample checklists and questionnaires published in the Heat Stress Management at Workplace (DOSH, 2016) and the Industry Code of Practice for Management of Occupational Noise Exposure and Hearing Conservation 2019 (DOSH, 2019a). Some questions were modified to suit the factory environment. Part C of the survey form used the DOSH subjective scores to acquire the descriptions of the workers' immediate thermal and noise environments.

Table 1

Contents of the questionnaire

Questionnaire Part	Content	Question type
Part A	Employee personal details	Multiple choice
Part B	Identification of potential hazards in the workplace	Dichotomous and multiple choice
Part C	Heat stress and noise level perceptions of the staff using DOSH subjective scores and checklists	Likert scale and Dichotomous
Part D	Employee's acceptability of the current workplace environment	Dichotomous and open-ended

RESULTS

Heat Stress and Thermal-Related Parameters

Fan-assisted natural ventilation was the main mode for thermal comfort and fresh air provisions in the manufacturing sections. As presented in Table 2, the air temperature measured at all three workplaces ranged from 26.9 to 35.7ºC. The relative humidity (RH) levels ranged from 44.3–83.6%, while the air velocity was recorded from 0.01–2.45 m/s. The global temperature influenced by solar radiation was measured to be within the range of 27.4–36.9ºC. Therefore, the WBGT index was calculated using the measured heat stress parameters to be within 25.2 to 29.8ºC with a total mean value of 27.7ºC, and the highest mean WBGT value was obtained in Section A. Since the clothing types were standard work clothes, no clothing-adjustment factor was added to the WBGT index (DOSH, 2016).

Table 2

Locations under study and heat stress parameters

Heat stress parameters/location		Section A	Section B	Section C
Air temperature (ºC)	Range	26.9–35.7	28.6–33.9	31.7–33.8
	Mean	32.1	31.7	32.6
Air velocity (m/s)	Range	0.02–1.40	0.01–2.45	0.03–1.44
	Mean	0.24	0.27	0.37
Relative humidity (%)	Range	44.3–83.6	52.9–71.0	49.5–57.2
	Mean	60.3	62.1	53.5
Globe temperature (ºC)	Range	27.4–36.9	29.3–34.3	32.6–34.5
	Mean	33.1	32.3	33.3
WBGT(ºC)	Range	25.2–29.8	26.2–28.3	27.1–28.5
	Mean	27.8	27.3	27.7

Noise Level

The plant's noise level ranged from 40.4 to 111.4 dBA during working hours (Table 3). The background noise was below 45 dBA. As mechanical fitting works requiring hammering and joining heavy materials were conducted in Section A, the average noise level in this area was the highest among all work sections. Unlike the thermal environment, the noise level in such workplaces was more challenging to predict as it depended mainly on the duration and intensity of work. From the results obtained, the NL was below the 85 dBA threshold limit specified by DOSH (2019a) for more than 80% of the work time and the maximum dBA was only recorded for a brief period. This finding shows that the workplace was acoustically safe for the workers. Based on an 8-hour exposure period to the mean noise level, the mean NEL was calculated as 74.1 dBA, while the ND of the workers was within 6.3 to 9.3%.

Table 3
Noise level at different work sections

Location	Minimum noise level (dBA) (background)	Maximum noise level (dBA)	ND (%)	NEL
Section A	41.5	100.2	9.3	74.7
Section B	40.4	100.4	6.3	73.0
Section C	43.0	111.4	7.9	74.0
	Mean			74.1

Questionnaire and Observation Findings

Twenty-five skilled workers responded to the questionnaire survey. All the survey participants were male and were full-time employees of the company. The participants were mostly physically fit and free from acute diseases during the survey, and their metabolic rate was estimated at 180 W because the work intensity was light. For safety and practical reasons, 16 employees (64%) engaged in hot work, such as welders and steel cutters, were seen wearing a cotton coverall with a safety jacket and other personal protective equipment (PPE). The rest of the field staff wore lighter clothes and company uniforms to safely and comfortably perform their tasks. More than 65% of the survey respondents found the workplace air temperature acceptable during working hours. Besides, 80% of them opined that the plant area's humidity level was comfortable. Although most were satisfied with the thermal environment, the workers' perception skewed towards the warmer side of the scale as 76% and 24% of the welders termed their working environment "warm" and "hot," respectively. No vote was placed on the cooler side (-1 to 1) and the extreme "very hot" categories of the heat sensation scale. The same goes for the staff with lighter clothing levels, of which 34% felt "hot" while working. However, the perception of radiant heat was mostly placed on the central categories (1 to 3), where 84% of the workers felt a heat source, but there was no risk of contact burns.

Higher airflow rates are recommended for non-air-conditioned spaces in hot and humid regions to increase the neutral temperature (Toe & Kubota, 2013). Ventilation fans can increase airflow rates to maintain the core body temperature (Ravanelli et al., 2015). 56% of workers with cotton coveralls and jackets rated the air velocity as "still air at the warm environment," while the rest of them voted for "warm air at low speed" (19%) and "still air in a hot environment" (25%). Similar outcomes were obtained from their lighter-clothed co-workers, where 75% of them found low air movement in their workplace. The air humidity condition was identified to be "very humid and very dry" by 92% of the test subjects. This result agreed well with the physical measurement outcomes, where the relative humidity was between 44.3 and 88.3%. It should be noted that the time and locations where the plant's staff were invited to participate could have influenced their perceptions. The mean scores for each heat stress question using scale points are presented in Table 4. It can be observed that the workers generally considered their workspace as warm with sensible air movement, moderately humid and safe from contracting heat-related injuries.

The noise level perceptions among the staff were acquired during the field survey. For brevity, only the important data are presented in this paper. About 70% of the workers voted that their hearing ability was not affected by the noise level in their workplace, and they did not experience any dizziness due to noise. Furthermore, most of them had not experienced loud enough noise to make their hearing "muffled" for a moment. As for the question about using industrial equipment for work, less than 30% of the respondents stated that they used powered tools or machinery for more than half an hour each day. The survey results also demonstrated that more than 80% of the workers wore hearing protective equipment, such as earplugs and earmuffs provided by the company when using these tools. Besides, 75% opined that there was no need to raise their voice while communicating with their work colleagues.

Table 4

Mean scores for heat stress survey questions

Questions	Scale points/ Option	Mean Score/ Percentage
How do you feel about your workplace's air temperature?	-1 (cool) to 4 (very hot)	2.24
How is the air movement at your workplace?	-3 (cool air at high speed) to 5 (very hot air at high speed)	1.76

Table 4 *(Continue)*

Questions	Scale points/ Option	Mean Score/ Percentage
How do you perceive the radiant heat condition?	-1 (cold object) to 6 (workers are not permitted to work without PPE)	1.60
How would you describe the humidity level?	0 (Air is dry) to 6 (Air is too humid)	2.04

DISCUSSION

Heat stress and elevated noise exposure at workplaces pose a significant challenge to occupational safety and health, impair the workers' general comfort, and lower their productivity (Meegahapola & Prabodanie, 2018). The heat stress measurements showed that the mean air velocity and relative humidity levels were within the acceptable ranges recommended in DOSH (2016). The plant's owner implemented a good workplace management system where all workers had periodic rest breaks besides mealtime to ensure they got enough rest during work. Referring to the DOSH's screening action limit (AL) and threshold limit value (TLV), the workers' risk of excessive exposure to heat stress was minimal. These findings contradicted the work of Singh et al. (2010), where high heat stress and noise levels in casting and forging units were found. It has indirectly suggested that the work sections in the plant were well-planned and organised.

The survey results showed that most employees found their thermal environment acceptable. As for air movement perception, one of the possible factors that made the respondents felt low air movement in the factory was their clothing type. The working locations that were equipment and material intensive may have contributed to this perception. As stationary pedestal fans were used to induce airflow, the workers' sensation of air movement would be affected if they moved around their work area without first adjusting the pedestal fans' blow direction. There were instances where the welders had to move to the other end of the work section, where airflow was slightly restricted to complete their welding task.

Since the studied workplace was partially enclosed and naturally ventilated, the Threshold Limit Value (TLV) for WBGT set by ISO 7243 is 28ºC. Based on the results obtained from field measurement, the highest WBGT readings (29.8ºC, 28.3ºC and 28.5ºC) at the work sections were mostly calculated during lunch break (1300 to 1400 h) when the ambient air temperature was high. The mean WBGTs were lower than the stipulated TLV value. Therefore, it has been suggested that the workforce was not exposed to high temperatures that may lead to heat stress while performing their tasks. In comparison, the WBGT values for this work were much lower than that of the earlier studies, where a heat stress analysis in a steel factory found that the WBGT was more than 35ºC owing to the influence of radiation heat (Krishnamurthy et al., 2017). It was evident in Section B where most questionnaire participants claimed that the surrounding temperature was warm but found their surrounding temperature level acceptable. Among the reasons for this was that workers working for an extended period in a warm environment are usually acclimatised to the thermal environment and may tolerate the workplace temperature (Joubert & Bates, 2008). Considering this, it can be assumed that the respondents of this study were already fully acclimatised to the workplace environment as they had been long-term employees of the company. It should be noted that this study did not consider personalised evaluations of heat stress levels, and the field data were analysed based on each selected location and the calculated mean scores for heat stress survey questions.

The measured sound intensities showed that the NEL did not exceed the permissible level of 85 dBA for an 8-hour exposure period stipulated in the Noise Exposure Regulation 2019. The daily ND was also far below the prescribed limit of 100%. The main reason for this was that the activities which generated high noise levels were only carried out for a brief moment during the time when this study was conducted. The highest NL was recorded when hammering work and the use of heavy machinery were carried out simultaneously, and this only occurred for a very short period of time. It was further identified that although machines and tools were used, the effect on background NL was not as high as expected, possibly because of the large openings at the plant's perimeter that dissipated the noise generated from work. It is in line with the workers' power tools and machinery use durations, where most did not use these industrial devices for more than half an hour a day. From the questionnaire survey, most respondents did not experience any noise or hearing impairment while working. It can be attributed to the low mean noise level in the plant and the use of personal auditory protectors when engaging with work that produced loud noise.

CONCLUSION

This study systematically measured and analysed a manufacturing plant's heat stress and noise levels. The field-measured data showed that the heat stress and noise exposure levels were generally below the stipulated limits of the guidelines, which suggested that the locations under study were safe and comfortable for the workers. It is in good agreement with the questionnaire survey outcomes. In future studies, other occupational safety and health requirements, such as light level and air quality, can be considered to make the research findings more comprehensive. Furthermore, since this study only focused on the heat and noise conditions of a hot and humid country's manufacturing plant, the workers' heat and noise exposure may differ from that of other places or industries that warrant further research in these areas.

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