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Impact of Heat Exposure on Health and Productivity of among Aluminium Manufacturing Workers at Kuala Selangor, Selangor.

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ABSTRACT

Objective: The purpose of this study is to determine the relationship between heat stress index with the physiological changes and work productivity of aluminium manufacturing workers at Kuala Selangor, Selangor. **Method**: The study design was cross-sectional. A total of 112 fulltime male workers were selected as the study respondents. The workers' name list was obtained from the human resources department. The respondents were selected from the list name by simple random sampling. Variables measured were the environmental temperature (heat stress index), core body temperature, heart rate and blood pressure of the respondents. QUESTemp°34 WBGT Thermal Environment Monitor was used to measure the environmental temperature, while the body temperature was measured using OMRON Digital Body Temperature device. Blood pressure and heart rate were measured using OMRON T3 Blood Pressure and Heart Rate Monitor. Face to face interview using questionnaire was used to determine the respondents' socioeconomic background, employment information, health complaints and worker's coping mechanisms. **Result:** Heat stress index (WBGTin values) (°C) of respondents in the smelting department was significantly higher than workers in the powder coating and extrusion departments ($p<0.001$). The most commonly reported of heat-related symptoms, were heavy sweating and thirst. Majority of respondents stated that they took more time to complete task when exposed to the heat. Common coping mechanisms for the heat were to drink water and to get away from high temperature for a while. There was a significant correlation between heat stress index (WBGTin values) and work productivity of the respondents. However, physiological parameters such as body temperature, blood pressure, and heart rate have no significant correlation with the heat stress index (WBGTin values) in the workplace. **Conclusion**: This study showed the heat stress index (WBGT in value) at the smelting section was the highest compared to the other sections in the factory and the exposure to high temperature exceeded the ACGIH threshold limit value standard (27.5°C) for heavy workload.

Keywords: *heat exposure, environmental temperature, physiological changes, productivity*

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1. Introduction

Occupational heat stress commonly occurred among workers exposed to higher-than-normal ambient temperature which combined with the body heat generated from the jobs themselves (Tawasutpa et al, 2010). It is a common occupational health problem that could affect the workers' health and well-being particularly in tropical countries. Manufacturing, is one of the leading sector in the economic development, has the highest incidence of heat related illnesses.

Exposure to extreme heat can result in occupational illnesses and injuries. Heat can also increase the risk of injuries in workers as it may result in sweaty palms, fogged-up safety glasses, and dizziness. Burns may also occur as a result of accidental contact with hot surfaces or steam. The incidence of heat-related symptoms and disorders increases with the higher ambient temperatures. Muscle cramps, heat syncope, heat exhaustion, heat stroke, and other heat-related conditions have been reported among people working in outdoors, in hot indoor environments, and whose jobs require physical exertion. (Mirabelli et al, 2010)

The study aims to determine the association between heat exposure with related health symptoms and work productivity among aluminium manufacturing workers at Kuala Selangor, Selangor. These variables were shown in the conceptual framework (Figure 1)

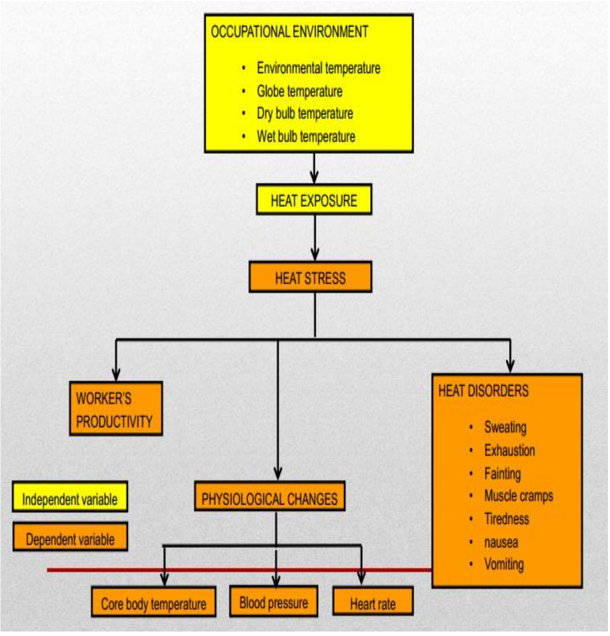

Figure 1. Conceptual Framework

2. Material and Method

This cross-sectional study was conducted in an aluminium manufacturing factory, Kuala Selangor which specialized in producing a wide range of aluminium profiles for a variety of applications, ranging from simple architecture needs to high precision electronic application.

Study population comprised 112 male workers from the three different sections namely smelting, extrusion, and powder coating sections. In smelting section, workers needed to handle and maintain the furnace with 500° C of temperature until all units of aluminium have melted. Workers in Extrusion Section handle press machine with high temperature to push the material through the die to shape. Meanwhile the workers in Powder Coating Section handle oven with high temperature of 80°C to coat the aluminium profile.

To eases the heat stress experienced by the workers at the workplace, the environmental parameters at the selected work sections were measured and the metabolic rate for different activities were determined. The metabolic rate was estimated based on American Conference of Governmental Industrial Hygienists method (ACGIH 2008).

Measurements of body temperature, blood pressure, and heart rate of the respondents were carried out before and after 8 working-hours. Four environmental parameters were also measured which included the environmental temperature (WBGTin values), globe temperature, wet temperature and dry bulb temperature, were recorded for 8 hours daily.

Workers who fulfil the study criteria were selected from the name list using simple random sampling method. The inclusion criteria such as male workers, age between 20-60 years, exposed to heat temperature while working, has been employed at the factory for not less than 3 months, and healthy without hypertension, heart disease, or other related disease that will increase body temperature. They should also be non-alcoholic.

Thermal Environmental Monitor (QUESTempo34 WBGT) was used to measure the heat stress index (WBGTin values) for the work areas. The body temperature was measured by using OMRON Digital Body Temperature Thermometer. Blood pressure and heart rate of the workers were measured using OMRON T3 Blood Pressure and Heart Rate Monitor. The readings of physiological changes of the respondents body temperature were taken twice; before their started their work (pre-) and after they finished their task (post-).

Work productivity were measure based on the workers' target number of aluminium product to be made and their work output were recorded by calculating the number of aluminium product made by each group in each section. An adopted questionnaire from Parsons (2003) was used to determine respondents background information, the workers' health complaints, and their coping mechanisms to exposure of heat. For quality control, all instruments were calibrated before use and a pre-test for the questionnaire was carried out before the study conducted.

3. Results

3.1 Respondents' background

More than half of the respondents were Malaysians and majority of the workers had primary education. The age range was between 20 to 60 years and the majority were between 20-30 years old. (Table 1). The respondents' prevalence of heat-related symptoms is shown in Table 2. Most frequent heat symptoms experienced were heavy sweating, thirst, and tiredness or weakness of the body due to the exposure to heat produced by the machines.

Table 1. Respondents' background information (N = 112)

Variables		N	%
Age	20-30	64	57.1
	31-40	36	32.1
	41-50	10	8.9
	51-60	2	1.8
Educational level	Illiterate	43	38.4
	Primary school	49	43.8
	Secondary school	19	17.0
	Polytechnic	1	0.9
Nationality	Malaysian	68	61.71
	Non-Malaysian	44	38.39

Table 2. Prevalence of heat-related symptoms of respondents (N = 112)

Variables	N	%
Heavy sweating	75	67
Thirst	72	64.3
Tiredness/weakness	60	53.6
Dizziness	59	52.7
Headache	38	33.9
Nausea	6	5.4
Vomiting	2	1.8
Fainting	2	1.8

3.2 Environment parameters (Heat Stress Index)

The reading of environmental parameters between 3 different sections is shown in Table 3. Heat stress index (WBGTin value) (°C) in the Smelting Section was the highest with mean of 32.81±0.258ºC as compared to Extrusion and Powder Coating Sections. However, Powder Coating Section stated the highest values of wet bulb (°C) and dry bulb (°C) among the three sections, which were 29.28±0.396ºC and 39.03±0.206ºC respectively. Globe bulb (°C) value for Extrusion Section was highest with mean of 40.03±0.231ºC as compared to Smelting and Powder Coating Sections.

Table 3. Heat stress index (WBGTin), wet bulb, dry bulb and globe bulb values between Smelting, Powder Coating, and Extrusion Sections (n = 20)

Variables	Sections	Mean	SD
WBGTin (°C)	Smelting	32.81	0.258
	Powder coating	31.87	0.137
	Extrusion	32.74	0.184
Wet bulb (°C)	Smelting	28.54	0.498
	Powder coating	29.28	0.396
	Extrusion	28.57	0.571
Dry bulb (°C)	Smelting	35.30	0.530
	Powder coating	39.03	0.230
	Extrusion	37.80	0.206
Globe bulb (°C)	Smelting	36.03	0.365
	Powder coating	39.94	0.223
	Extrusion	40.03	0.231

One-way ANOVA test was used to test if there is a difference in a measured heat stress index (WBGTin values) between the three sections; smelting, powder coating, and extrusion. Based from the test, mean heat stress index (WBGTin value) (°C) of smelting section was significantly higher to powder coating and extrusion sections, with means of 0.940 ($p<0.001$). Thus, WBGTin (°C) of Smelting Section was significantly higher than the Extrusion and Powder Coating Sections.

Table 4, shows the comparisons of the heat stress index (WBGTin values) (°C) in the 3 sections.

Table 4. Comparison of heat stress index (WBGTin values) (°C) between sections (n=20)

Variables	Mean	SD	t	F	p-value
Smelting	32.82	0.258	0.94		
Powder coating	31.88	0.137	0.07	137.57	<0.001***
Extrusion	32.75	0.184	0.87		

ANOVA test
**** *p is significant when <0.001*

3.3 Workload assessment and workload categories

Table 5 shows the workload categories and work-rest regime of the exposed workers while working in the 3 sections; Smelting, Powder Coating and Extrusion. All the workers in 3 sections differed in their workload categories. Workload categories were ranked based on the standard set by AGCIH (2008). Smelting Section workers had heavy work mean while workers in the Powder Coating Section had light work. Workers in Extrusion Section were having medium work. The work-rest regime for the workers in the aluminium manufacturing factory was 75% work and 25% rest per hour.

Table 5. Workload categories and work-rest regime of the workers

Work Area	Measured WBGT	Workload category	
Smelting	32.81	Standing	: 0.6
		Working with both arm	: 2.5
		Walking	: 2.0
		Basal metabolism	: 1.0
		Total	: 6.1 kcal x 60 min = 366 kcal/hour (Heavy)
Powder coating	31.87	Standing	: 0.6
		Hand work	: 0.4
		Basal metabolism	: 1.0
		Total	: 2.0 kcal x 60 min = 120 kcal/hour (Light)
Extrusion	32.74	Standing	: 0.6
		Walking	: 2.0
		Working with one arm	: 1.7
		Basal metabolism	: 1.0
		Total	: 5.3 kcal x 60 min = 318 kcal/hour (Moderate)

Work-rest regime, 75% work, 25% rest

3.4 Workers' coping mechanisms due to heat exposure

The coping mechanisms due to heat exposure were asked apart from the questionnaire interview to the respondents. The most common coping mechanism that they practiced was drinking water (91%) and take short rest (77%) from workplace to reduce the heat exposure. The workers too were asked on how the heat affects other aspects of their work. Respondents stated that exposure to heat made them took more time to complete task (83.0%), meanwhile 36.6% of them stated that heat exposure made them less productive. Table 6 below shows the prevalence of associated variables that affected the respondents' coping mechanism.

Table 6. The respondent's coping mechanism due to heat exposure. (N = 112)

Variable	N	%
Is the place you work is well-ventilated?	17	15.2
Are you comfortable with the workplace temperature?	15	13.4
How does heat affect other aspects of your work?		
- Absenteeism	14	12.5
- Less productivity	41	36.6
- Take more time to complete task	93	83.0
How do you limit heat exposure when needed?		
- Get away from machine for a while (stop work)	52	46.4
- Remove shirt	31	27.7
- Drink water	91	81.3
If you feeling unwell from heat exhaustion how do you cope with this?		
- Take rest	77	68.8
- Cool shower/bath	10	8.9
- Move to air-conditioned/cooler area	40	35.7
Do you spend more time to cope with heat?	33	29.5

3.5 Physiological parameters

Body core temperature, heart rate, and blood pressure were the three parameters that can show the physiological changes among the respondents exposed to heat. Table 7 shows the body temperature, systolic blood pressure, diastolic blood pressure, and heart rate showed a significant difference in body before and after working (p<0.001).

Table 7. Comparisons in physiological parameters among the workers before work (pre-) and after work (post-) (N=112)

	Before work (pre-)	After work (post-)		
	Median	Median		
Body Temperature (^{o}C)	35.70	36.50	-9.192	<0.001
Systolic blood Pressure (mmHg)	78.00	86.00	-6.087	<0.001
Diastolic Blood pressure (mmHg)	123.00	139.00	-9.185	<0.001
Heart (beat minutes) rate	74.00	85.00	-8.318	<0.001

3.6 Correlation between heat stress index (WBGTin values) with physiological parameters and work productivity of the workers

Result of the Spearman's Rho correlation test showed there was no significant correlations between heat stress index (WBGTin values) (^{o}C) with body temperature (p=0.403) and no significant correlation between heat stress index (WBGTin values) (^{o}C) with systolic blood pressure (p=0.055). Besides, the correlation between heat stress index (WBGTin values) (^{o}C) with diastolic blood pressure (p=0.211) and with heart rate (p=0.988) show no significant correlation respectively. However, there was a significant correlation between heat stress index (WBGTin values) with productivity of the workers (p=<0.001) as shown in Table 8

Table 8. Correlation between heat stress index (WBGTin values) with work productivity of the workers. (n = 20)

Variables		r	p
Heat stress Index (WBGTin values)	Work productivity	-0.691	<0.001***

Spearman's Rho correlation
*** *p is significant when <0.001*

3.7 Selected factors that influence the productivity of the workers

The selected factor that influences the productivity of the workers was determined by using general linear model. Among the variables that may influence the productivity were age, heat stress index (WBGTin values) of the workplace, heat-related symptoms reported by the respondents and their coping mechanisms to heat.

Table 9. The selected factor that influences the productivity of the workers.

Variables		t	p
Work productivity	Heat stress index (WBGTin values)	-94.59	<0.001***
	Heavy sweating	-2.470	0.015*
	Tiredness/ weakness	-2.640	0.010**
	Get away from machine for a while (stop work)	-2.288	0.024*

Multiple linear regression test, * *p is significant when* <0.05, ** *p is significant when* <0.01 , *** *p is significant when <0.001*

4.0 Discussion

All of the respondents were male and the age range between 20 – 60 years. Majority of the workers were young. Marszalek et al (2005) stated that older men had lower work ability in a hot environment compared to younger men. Older workers have less efficient sweat glands, thus this factor influenced the physiological effects on the workers. Majority of the respondents only had primary school education, in which explained that they have less knowledge in coping and managing extreme temperature in the workplace.

For the heat stress experienced by the respondents, 67% experienced heavy sweating. Heavy sweating occurred when the outside temperature rose and sweat glands produce perspiration that is carried to the skin's surface. (WHO, 2012) Another heat-related symptom with high prevalence was thirst (64.5%). this symptom was probably due to the insufficient water intake to replace those lost in sweat. Dehydration, as a result from thirst, depletion of electrolytes and sodium losses from sweat all accelerated in the hot environment, especially those who sweat profusely (Becker and Stewart, 2011).

For environmental parameters, the result showed that there were significant differences in environmental temperature between the 3 sections; Smelting, Powder Coating, and Extrusion Section. The mean of heat stress index (WBGTin value) (°C) at the Smelting Section was higher due to the presence of furnace and also heat during the pouring process of hot liquid aluminium from the furnace into the prepared metal mould. Singh et al (2010) stated that these two factors were the main source of the heat stress in the Smelting Section.

Based on the permissible heat exposure threshold limit value of ACGIH (2008), the Smelting Section was above the threshold of 27.5°C for heavy work task, meanwhile Extrusion and Powder Coating Sections were below the heat exposure of 29.0°C and 31.0°C for moderate and light work. These have been described as the threshold limit values based on the assumption that nearly all acclimatized, fully clothed workers with adequate water and salt intake should be able to function effectively under the given working conditions without exceeding a deep body core temperature of 38°C of normal human body.

Some of the respondents took some adaptive measures to reduce the risk of heat stress. A very high percentage (81.3%) of respondents reported that they drank water in order to reduce the body heat. The factory management also provided water dispenser for their employees. The respondents stated that they took a 10 –15 minutes of break during the working shift, in order to avoid prolong exposure to heat (68.8%). It appeared that some of the respondents have insufficient levels of adaptive behaviors. These could be related to their level of knowledge and education as people who have heard on heat stress were more likely to practice adaptive behaviors than those who have not and eventually displayed a fairly good understanding that extreme heat could cause serious health problems. (Dao et al, 2013)

The study showed significant difference in all physiological parameters of the respondents, which include body temperature, systolic blood pressure, diastolic blood pressure, and heart rate; before and after working in extreme heat. These are due to the increasing core body temperature among the workers who were exposed to heat at the workplace for a long period of time. Continuous physical activity by the workers during performing their task caused more heat produced by the body and increasing the core body temperature. Vangelova et al (2006) which found the systolic and diastolic blood pressure of the industrial workers exposed to heat increased as the temperature of the workplace increased. This was due to the heat gained and stored in the body. This situation of heat gain caused the heart to work a lot harder to pump blood to periphery for heat loss, which eventually increased the blood pressure.

Goh et al (2004) stated that the changes in the heart rate before and after work was due to the increase in metabolic rate on the physiology of the workers and increased the oxygen use. Therefore, the heart would pump stronger to supply blood all over the body. The increasing heart rate would eventually balance the body heat regulation, due to extreme temperature.

There was also significant correlation between heat stress index (WBGTin values) (^{o}C) with work productivity of the workers. According to Kjellstrom et al (2009), high level of direct heat exposure to workers would affect their ability to continuously carry out work. When the body exceeded the level of thermal equilibrium, it would eventually affect the workers by which they would need to take a rest or took some time off for the body to cope with the heat. Through these, their productivity would decrease when they slow down to cool their bodies and to complete their tasks.

A few selected factors have been identified which influenced the work productivity of the respondents. The selected factors were heat stress index (WBGTin values) (^{o}C), symptom of heat-related illness such as heavy sweating and tiredness or weakness, and slow down or stop work as heat coping mechanisms. From the study, it showed that there was a significant correlation between heat stress index (WBGTin values) (^{o}C) and work productivity. When the body thermal equilibrium exceeded, the workers would slow down their body physical activity, and their productivity would decrease. According to Nag et al (2012), these serious heat effects were inevitably affect the work productivity when the workers slowed down their work pace in order to cool down their bodies. The workers too might have to get away for a while from the hot workplace.

5.0 Conclusion

In conclusion, workers at smelting section were exposed to high temperature which exceeded the ACGIH threshold limit value standard (27.5^{o}C) for heavy workload. There was a significant difference in body temperature, systolic blood pressure, diastolic blood pressure, and workers' heart rate before and after 8 working-hours when exposed to extreme heat. In addition, there was a significant correlation between heat stress index (WBGTin values) and work productivity of respondents exposed to heat. However, no significant correlations between the heats stress index (WBGTin values) with the physiological parameters such as body temperature, blood pressure, and heart rate among the respondents during the 8 hour work.

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