Conference Paper

Thermal Environment Analysis for Good Manufacturing Place

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Abstract

One of the rubber company in North Sumatra producing crumb rubber has an alarmingly hot work station that is a drying station that uses a machine dryer. This station has a rate of up to 35.5°C air temperature exceeding the national threshold. These conditions will result in heat stress on workers because of high room temperature so that the heat loss is reduced. This causes a decrease in productivity of up to 33 percent of non-productive time of a total of eight hours of work. The purpose of this study was to analyse the heat exposure that is happening on the production floor at the drying station in order to find solutions to reduce heat exposure at the workstation. The method used to analyse the workload is Brouha method and % CVL, while to analyse heat exposure Wet Ball Temperature Index (WBGT) and Heat Stress Index (HSI) were used. Results obtained from workload calculation are that the work is categorized in heavy work load and needed repair. Results of the analysis of heat stress showed that HSI values at work stations is 94.86 percent and WBGT value is 29.21°C where both values have exceeded the threshold value and indicate a need for improvement. It is found that there is an inverse relationship between workers' productivity and their WBGT threshold. The productivity will increase when the WBGT threshold is lesser. Chosen alternative improvement is done through the installation of turbines ventilator that can lower the temperature of the room below 29.21°C. This temperature is already below the recommended national threshold. This result showed that the improved condition can create a good manufacturing place in thermal condition.

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1. Introduction

Temperature is one factor to be considered in the work environment. In addition to causing the decreased of productivity [1], it is also causing discomfort in working, and can further cause disruption of the health of the workers [2]. This disruption occurs because the temperature of the room can affect the heat balance of the workers' body. To balance body's heat, human body performs heat production and heat release (heat loss). The production of human's body heat is required for the metabolism process, but the production of this heat will be offset by the release of heat to maintain the heat balance in the body [3]. Environmental temperatures greatly affect this equilibrium condition. If the environment temperature is less than or exceeds the threshold, then the body will also be affected because the heat release activities were also disrupted. If the environment temperature is too high, then the accumulation of heat in the body will be more while the release of heat emitted is not proportional to the heat production. This will cause excessive pressure to the human body that can cause dehydration, heat cramps, heat stroke and even death if not treated promptly [4].

The production environment is a place that cannot be avoided from exposure to heat. But the longer the duration of worker's exposure to heat can be arranged so as to prevent accidents. To know the duration of this can be done by analysing the critical limit of heat exposure. The critical limitation is influenced by four factors: the indoor air temperature, relative humidity, wind speed and average radiation temperature. There are two additional factors of personal information of workers that are workers metabolic heat and type of clothing used by workers.

The location of this recent research is in a privately owned crumb rubber company in North Sumatra Province. The company has been producing crumb rubber that already uses dryer machine operated by five workers in the drying process. The company's production floor is in the form of a closed room with a roof made of aluminium alloy that makes the heat trapped in the room. Dryer machine is used to dry out, which means these engines emit high heat for drying shredded rubber for further processing. According to the research, these engines are the highest heat source on the production floor with a temperature of 140^{o}C. At such temperatures, the human body's release of heat that occurs will be very little because the room temperature is too high. Based on interviews with workers, they recognize that the high heat conditions make them secrete excessive sweating, dehydration, and there have even been cases of heat cramps and heat stroke. During this time, workers overcome this condition by going out of the production site up to 8–10 times per day for 5–10 minutes to avoid heat. This shows that there is a minimum of 40 minutes and a maximum of 100 minutes of idle time for each worker per day. The ratio of working hours is seven hours and one hour of rest with 40–100 minutes of idle time. This shows that in a single work shift, there is 21–33 percent of non-productive time per employee. This condition must be detrimental to the productivity of the company.

The threshold values for room temperature according to SNI 16-7063-2004 work valued at 25.9°C, but temperatures in the drying work station reached 35.5°C. Temperature values exceeding this threshold is an indication that further research is required about the heat conditions on the production floor drying part to find a solution. The approach taken in this study is to use the parameter Heat Stress Index (HSI) and the Wet Ball Temperature Index (WBGT).

2. Methods

In this study, there were five people working in the drying station who acted as research subjects (total sampling). Stages of research procedures in analysing the thermal environmental conditions are as follows:

1. Finding the personal data of workers including gender, age, height, weight, and physiological data of workers that is pulse using thermal questionnaire.

2. Determine the workers' energy consumption using physiological methods that include:

   (a) Direct assessments; using pulse data to determine the category of the workload with Brouha standards. Category workload Brouha based heart rate calculation:

   Light (2.5 to 5.0 calories/minute) = 60–100 heartbeats per minute

   Medium (5.0 to 7.5 calories/minute) = 100–125 heartbeats per minute

   Weight (7.5 to 10 calories/minute) = 125–150 heartbeats per minute

   Very Heavy (10.0 to 12.5 calories/minute) = 150–175 heartbeats per minute

   (b) Indirect assessment; using % Cardiovascular Load (% CVL) calculations that is a calculation to determine the classification of the workload by increased pulse rate of work compared with the maximum pulse rate. The formula to calculate % CVL is [5]:

$$\%CVL = \frac{100 \times (working\ pulse - resting\ pulse)}{maximum\ pulse - resting\ pulse}. \quad (1)$$

   %CVL of calculation will be compared with the classification that has been set as follows:

   < 30% = No fatigue occurred

< 30–60% = Required repairs

< 60–80% = Work in a short time

< 80–100% = Needs immediate action

> 100% = Not allowed to work

3. Measuring determinants of HSI and WBGT is:

   (a) Temperature (T) and humidity (RH) by using the tool *4in1 Environment Meter.*

   (b) Air velocity (V) and the radiation temperature (T_r) by using Anemometer.

   (c) Wet temperature, dry temperature, and the temperature are measured using a ball *QuesTemp.*

   (d) Worker's heat sensation information and the kind of clothes used by workers with thermal questionnaire.

   Measurements were made over two days in a row once every 60 minutes for 8 hours at a height of 0.1 m, 0.6 m, 1.1 m, 1.7 m, and 2.5 m with work sampling method. The volume of the drying station room is 630 m^3 with a length of 15 m, a width of 6 m, and a height of 7 m. There are five measurement points that are the location of workers around the machine dryer. These measurements were performed according to the standards of ASHRAE 55-2004 [6].

4. HSI is used to measure the amount of heat pressure in a closed room to the condition of the body heat. Measuring the value of HSI is done by using the formula:

$$\text{HSI} = (\text{Ereq}/\text{Emax}) \times 100\%, \tag{2}$$

   where:

   Ereq = The release of heat required = (W/m2) = MRC

   Emax = The maximum heat release (W/m2)

   = 7.0 vo.6 (56-pa) clothed

   = 11.7 vo.6 (56-pa) conditions without clothes

5. ISSB used to assess the level of workplace climate. Measurement of ISSB done using the formula:

$$\text{WBGT} = 0.7\ \text{Tnwb} + 0.1\ \text{Tg} + 0.2\ \text{Ta}, \tag{3}$$

   where:

   Tnwb = Wet temperature

Tg = Globe temperature

Ta = Dry temperature

6. After the HSI and ISSB values are found, the analysis is done to determine the right solution for repairing the hot working environment.

7. Comparison of conditions before and after improvements was made to see if the improvements do give results that can improve worker productivity.

3. Results

3.1. Physiological calculation results

Calculation is performed to measure physiological workload categories based on the energy consumption required. In this study, two types of physiological calculations, that is, a direct way (Brouha) and an indirect way using % CVL were used.

Direct calculation is calculated using heart rate data to determine the energy consumption per unit of time defined by Brouha. Based on the energy needed to do this job the category of the workload of each employee can be specified (see Table 1).

Table 1: Value energy consumption.

Worker	WP (Bpm)	Energy Consumption (Kcal/min)	Energy Consumption (Kcal/h)	Category Workload
1	127	6.4552	387.3130	Heavy
2	124	6.1701	370.2087	Heavy
3	127	6.5036	390.2132	Heavy
4	125	6.3116	378.6972	Heavy
5	120	5.8483	350.8975	Heavy
WP = Work Pulse				

Table 1 shows that the categories of workload of all worker at the factory was included in heavy categories. Indirect calculation is calculated using % CVL that calculates the category of workers based on the formula (1). The results of % CVL value are shown in Table 2.

Results of physiological calculation show that jobs in the drying station are a heavy workload and needed repair. The study of the effect of heat on the heat balance of the body will not be discussed here because it had ever been done before in [10].

Table 2: Results calculation% CVL.

Worker	Gender	Age (Year)	RP (Bpm)	WP (Bpm)	PMax	% CVL	Information
1	Male	52	79	127	168	53.63	Improvements needed
2	Male	45	76	124	175	47.97	Improvements needed
3	Male	44	79	127	176	49.48	Improvements needed
4	Male	39	75	125	181	47.16	Improvements needed
5	Male	40	70	120	180	45.45	Improvements needed
RP = Rest Pulse; WP = Work Pulse; Pmax = Pulse Max.							

3.2. Heat exposure calculation results

Calculation of heat exposure is done by two methods: Heat Stress Index (HSI) and the Wet Ball Globe Temperature (WBGT). Results of measurement data required for the calculation of these two methods are shown in Table 3.

Table 3: Parameter working environment measurement results.

Parameter	Measurement results
The average air temperature	35.8°C
The average air humidity	59.9%
Average wind speed	0.39 m/s
The average thermal sensation	Hot

Based on Table 3, it can be concluded that working conditions need to be improved. Indoor air temperature has exceeded the limit recommended by the national standard that is 18–30°C, and the workers also complaint that the working place is hot and expected more comfortable working place.

HSI result of the calculation using the formula (2) shows that the average HSI is 94.86%. In [7], this index value indicates that the work station heat stress is very disturbing and harmful to health.

WBGT calculation results made by considering radiation because there are vents that allow sunlight into the room. The average WBGT value obtained was 29.21°C. Existing WBGT value is perceived by each worker, adjusted for their work clothing which is categorized as a summer uniform correction values obtained amounted to 0 [8]. This indicates that the average WBGT value obtained is not affected by the work uniform.

The proportion of work–idle ratio based on SNI16-7063-2004 standard has a weakness where the value of the proportion of work–idle was only limited to paired work–idle at a sampling activity, not necessarily the exact worth of the proportion. Therefore, equation is created to determine the WBGT threshold value appropriately, according to the proportion of work–idle. Because of the workload, all operators are categorized as heavy, then the line equation for workers is defined as:

$$y = 10,667x3 - 15,2x2 - 1,6667x + 31.2.$$

Based on the equation, a threshold value of each worker can be obtained. In Figure 2, the chart shows a comparison between the Threshold Limit Value WBGT and the percentage of work.

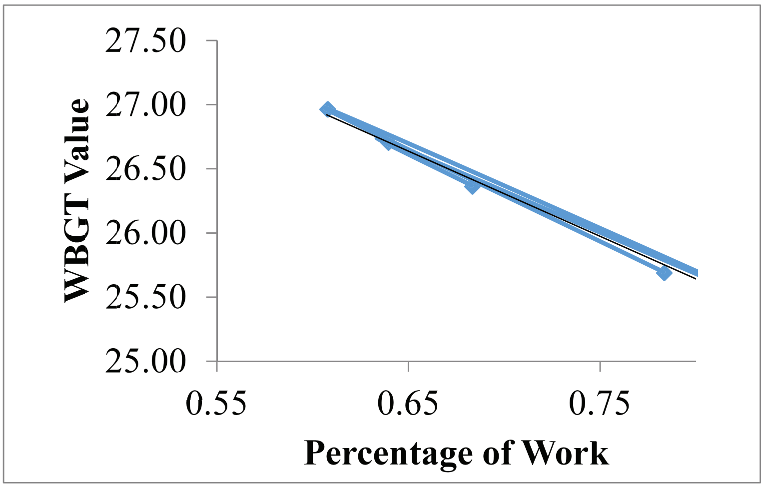

Figure 1: Relationship between percentage of work and WBGT threshold values.

The graph in Figure 1 illustrates that there is an increase in the work percentage along with decrease in WBGT threshold value. The average WBGT value (29.21°C) is above the WBGT threshold value for all workers. This showed that the working conditions are not in accordance with the conditions of the worker's body.

3.3. Improvement

An improvement proposed in this study is the installation of turbine ventilators that utilize the natural properties of the wind that moves from high pressure to low pressure. The nature of this tool makes the turbine ventilators become more economical because it does not use electricity. A similar solution has been done in previous study [9] with the result of significant improvements to the reduction of the working room heat as shown in Figure 2.

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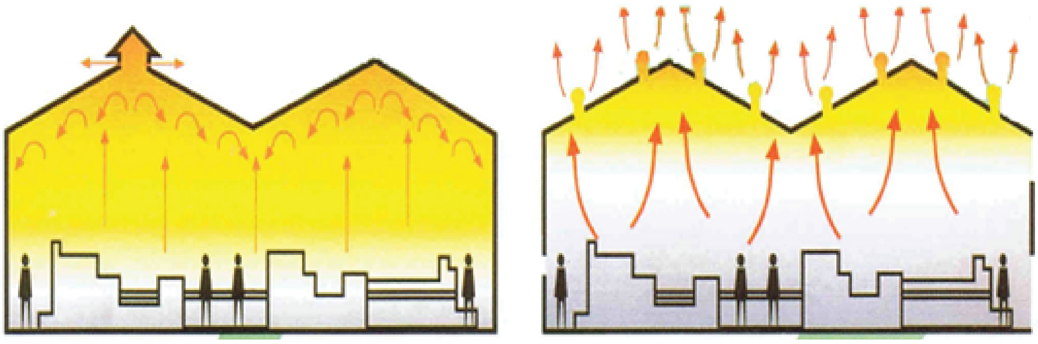

Figure 2: How to work turbine ventilator. Source: Turbine Ventilator Bandung, 2015.

If the selected turbine type is of L-45, then the amount required is 2 units with the following calculation:

$$\text{Total Turbine} = \frac{\text{Room Volume}}{\text{Sucking Capacity} \times \text{Circulation Time}}$$
$$= \frac{765\ \text{m}^3}{42{,}39\ \text{m}^3/\text{minute} \times 10\text{minute}}$$
$$= 2\text{units}.$$

The turbine installation can reduce the air temperature to 27.46°C and HSI value becomes 64.17 percent.

4. Discussion

The installation of turbines results in a decrease in air temperature in the room and that value has been below the national threshold value. However, based on the value of HSI obtained, the value of 64.17 percent still indicates that the effects of exposure to heat for 8 hours would pose a threat to the health, and adjustment is indispensable to guard the health of workers. One way suggested by [11] is by providing provision of water and salt consumption regularly and periodically to maintain the balance of the worker's body. Such cases are very frequently found in Indonesia, but there is no strict regulation to monitoring this problem. Therefore, a better government monitoring system is needed to create more good manufacturing place, especially in terms of thermal condition.

5. Conclucions

Heat exposure value at the drying station exceeded the recommended threshold in terms of temperature, HSI, WBGT, and the perception of workers. Excessive heat exposure is very harmful to human health and therefore improvement is necessary to the working environment. This study recommends the installation of two units of turbine ventilator to reduce the hot air trapped in the room. Based on calculations, installation of this turbine can reduce heat to below the threshold and became safer for workers. This did not include a simulation study on the perceptions of workers heat after the repair, and therefore further research can use the data provided in this study for further research.

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