The thermal environment effect on the comfort of electronic factory worker

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Abstract. In this paper, thermal comfort issues of the operators working on one of the electronics companies in the evaporator area are observed. The objective of this study is to reduce Percentage of Dissatisfied (PD) of operators in an effort to improve the work productivity. PD is predicted using CBE Thermal Comfort Tool by measuring the thermal variables around the evaporator area and by calculating the Heat Stress Index (HSI). The operator productivity is analyzed by Wet Bulb Globe Thermometer (WBGT) Work-Rest Chart. The PD of operators before and after improvement is compared. The results showed that the average temperature around the operators area at evaporator station is high with average WBGT of 33.6°C. HSI value is 51.95 indicating that the effect of 8-h exposure is severe strain with work impact is health threat for unit operators and acclimatization is necessary. The PD value is 96% indicating that almost all operators feel uncomfortable at work. These indicate that the thermal environment should be improved. The proposed improvement is by installing water cooled and sprayed into the evaporator area. This installation is able to reduce HSI and PD by more 70% and more 60%, respectively. These findings indicate that improving the thermal environment will be able to improve working comfort which will further affect the level of work productivity.

1. Introduction
Environmental conditions prevailing in the workplace are closely related to the operator's ability to allow the time allowed for his work [9]. The work comfort of the operator is supported by indoor environments that meet comfortable conditions both in terms of environmental conditions and energy consumption and ergonomics [4]. Thermal comfort is a condition in which the mind expresses satisfaction from the thermal environmental conditions [8]. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [2].

Discomfort will result in functional changes in organs in the human body. The excessive work environment heat conditions will lead to fatigue, sleepiness, reduce stability and increase the number of work errors. This will lower the creative power of the human body to produce less heat. One way to create a comfortable workplace environment is to minimize heat stress. Parameters that need to be assessed for determining heat stress include air temperature, air velocity, air humidity, and heat production from metabolic processes. According Suarbawa [5] the longer exposed to heat the smaller
the productivity level of the operator in doing the work. Heat Stress in the work environment negatively impacts the productivity of operators exposed to heat exposure [11]. Therefore it is very necessary analysis of heat stress in the workplace which is very useful to know the level of worker productivity.

A research in India found that having a thermally comfortable workplace could improve the health and productivity of the workers. In order to achieve that condition, there are several confounders such as cost investment, management cooperation, worker behavior, etc. The subjects of this study are workforces from various field of work in India. The result suggested that heat stress could cause local to global-level impact of economic losses. Therefore, there is a need to consider the importance to protect the health and productivity of the workers. [13]

Research conducted in one of the major mosques in Sarawak [9], Malaysia is to improve thermal comfort of pilgrims when performing praying. The cause of thermal comfort problem is the lack of natural ventilation and mechanical ventilation so that the air exchange is not regulated well. To reduce this heat exposure, the improvements done is to install the insulation of the roof made of asbestos so as to reduce the heat and the addition of mechanical ventilator in the form of turbine ventilator as much as 2 units and the addition of natural ventilation on each side of the mosque building.

Another research conducted in one of the industrial companies in Slovakia found that the average person spend 8 hours of work in every day. During work, the operator feels the heat generated by the factory machine. The heat generated by the engine resulting in thermal stress is also called thermo-hygric microclimate. The research results can be seen the high air temperature and WBGT value reaching 40°C indicates the operator is exposed to thermal stress. This thermal stress measurement index can be seen from the high WBGT value that exceeds 280°C. Improvements made are air vents and cooling systems. Air ventilation serves to regulate air humidity and other conditions industrial work environment.

In this study, the thermal comfort issues was investigated at one station at the Business Unit Air Conditioner (BU AC) at an electronics company in Jakarta. Floor production on the BU AC is a closed room, so the condition of the production floor is considerably hot. The heat source comes from solar radiation and operating machinery. A list of machine that generate heat is shown in Table 1.

| Station | Machine Name & Process       | Temperature (°C) |
|---------|------------------------------|------------------|
| Painting| Dry off and Baking Oven      | 100              |
| Evacond | Dry of Oven                  | 175              |
|         | Brazing                      | 480 – 820        |

One work station that has an excessive thermal working environment is the evaporator station in the Evacond line. At this station, there is an oven operating at a temperature of 175°C and there is a brazing process that has operating temperature at the end of silphos of 480°C. Due to oven engines and brazing processes in the same workplace cause heat radiation resulting in discomfort to the operator. Based on preliminary studies conducted on the operators by using the operator comfort level questionnaire, it is found that of 82% operators feel uncomfortable. Based on the result of interview, the effect of thermal working environment condition found that there are operators fell unconscious due to uncomfortable working environment, resulting in decreasing productivity and production target is not reached which can be seen in Table 2.
Table 2. Number of Production at Evaporator Station

| Days | Actual Production (kg) | Plan (kg) |
|------|------------------------|----------|
| 1    | 1492                   | 1600     |
| 2    | 1527                   | 1600     |
| 3    | 1540                   | 1600     |
| 4    | 1465                   | 1600     |
| 5    | 1496                   | 1600     |

The average thermal working temperature temperature mixed with the radiation at the evaporator station is 35°C, whereas according to SNI 16-7063-2004, the recommended threshold value in the working environment is 26.7 °C. Based on these comparisons, it is necessary to conduct further research on the condition of evaporator stations to find alternative solutions to the problems that occur. One alternative solution to problem solving is done through the calculation of Heat Stress Index. The heat stress index defined as the relation of the amount of evaporation (or perspiration) required as related to the maximum ability of the average person to perspire (or evaporate fluids from the body in order to cool him or herself). When the heat stress index is high, humans can experience heat stress, which can lead to particularly dangerous conditions in which people can actually die from their body being too warm and unable to cool itself properly. Severe dehydration and even death can result from overexposure when the heat stress index is high.

Understanding the heat stress index and having a portable meter to measure it while you are outdoors is the key to preventing these types of deaths and overexposure. Knowing the heat stress index can help to prevent fatigue, heat cramps, exhaustion and in some cases, even death. In addition to careful monitoring of the heat stress index, staying hydrated and taking frequent breaks in the shade or in a cooler indoor area can help to prevent injuries and fatalities related to the sun. Look for signs of heat emergencies in yourself and in others when working or training outdoors during times when the heat stress index is high. Excessive flushing of the skin, dizziness, confusion and fainting are all signs that a person needs to seek immediately shade and hydration.

The PMV/PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot (+3). Fanger’s equations are used to calculate the Predicted Mean Vote (PMV) of a large group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation.[3] Zero is the ideal value, representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits (-0.5<PMV<+0.5).[1] Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied. Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions could be precisely controlled.

ASHRAE Standard 55-2010 uses the PMV model to set the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied.[1] The CBE Thermal Comfort Tool for ASHRAE 55 allows users to input the six comfort parameters to determine whether a certain combination complies with ASHRAE 55. The results are displayed on a psychrometric or a temperature-relative humidity chart and indicate the ranges of temperature and relative humidity that will be comfortable with the given the values input for the remaining four parameters.[12]

The Wet Bulb Globe Temperature (WBGT) is a measure of the heat stress in direct sunlight, which takes into account: temperature, humidity, wind speed, sun angle and cloud cover (solar radiation).
This differs from the heat index, which takes into consideration temperature and humidity and is calculated for shady areas.

2. Method

2.1. Observation procedure

In this study, 11-subjects are participated as the subject. Thermal comfort issues were investigated at station Business Unit Air Conditioner (BU AC) with the following procedure:

1. Identification of the machine that the engine generates the greatest heat
   There are several machines in BU AC workstation. This step is done to analyze which machine produces most heat in the room. This step aims to minimize the focus of the research to get the best result with the limited resource available.

2. Identification thermal sensation of operators working around the machine
   This step means to confirm further if the machine really disturb the workers thermally. Workers opinions are collected and summarized to get the conclusion.

3. Measure the thermal conditions around heat-affected workers during work as shown in Figure 1.
   To conduct this step, there are 11 measurements point that are the position of the workers. The measurements for each point are done uniformly. The altitude is at 1.1 meter for HSI and WBGT.

![Figure 1. Measurement Points at Evaporator Station](image)

4. Calculate HSI using the following formula [Stanton Niebel];
   \[
   HSI = \left( \frac{E_{req}}{E_{max}} \right) \times 100\% 
   \]
   where:
   \[E_{req} = \text{Required Evaporation (W/m}^2\text{)} = M-R-C\]
   \[E_{max} = \text{Maximum Evaporation (W/m}^2\text{)}\]
   \[= 7.0 v0.6 \text{ (56-pa)} \quad \text{clothed condition}\]
   \[= 11.7 v0.6 \text{ (56-pa)} \quad \text{unclothed condition}\]

5. Calculate the WBGT using the following formulation.
   For indoors or outdoors without direct sun exposure:
   \[
   \text{WBGT} = 0.7 \times \text{Temp}_{\text{wet bulb}} + 0.3 \times \text{Temp}_{\text{globe}}
   \]
   where:
   \(\text{Temp}_{\text{wet bulb}}\) natural wet bulb temperature measured by using a thermometer whose bulb is covered with wet cotton cloth and is cooled by the natural air movement
   \(\text{Temp}_{\text{globe}}\) temperature measured using a black globe thermometer
Temp<sub>air temperature</sub> measured using a conventional thermometer
All temperatures are to be expressed in °C

6. The operator productivity is analyzed by Wet Bulb Globe Thermometer (WBGT) Work-Rest Chart as shown in Figure 2.

![Wet Bulb Globe Temperature Category Work/Rest and Water Intake Chart](image1)

**Figure 2. WBGT Work Rest Chart**

7. Analyze all the thermal condition and improve the condition of evaporator area by engineering control.
This step will analyze the findings about the room’s thermal condition and provide a solution to improve the condition. In this study, there will be a suggestion on what installation can be used to reduce the heat and regulate the air better.

8. Compared the PD value between before and after engineering control using the CBE Thermal Comfort Tool as shown in Figure 3.
After improvement is given, simulation of the condition before and after improvement need to be done. This step aims to show the difference in the thermal condition made after the improvement, if it is better or worse than before.

![CBE Thermal Comfort Tool](image2)

**Figure 3. CBE Thermal Comfort Tool**
2.2. Observation equipments
The observation equipments that are used in the research shown in the Table 3.

Table 3. Observation Equipments

| No | Equipment       | Function                        | Specification                                                                 |
|----|-----------------|---------------------------------|-------------------------------------------------------------------------------|
| 1  | 4 in 1 Environment Meter | Measure temperature, humidity, lighting intensity, noise | • Dimension: 251,0 x 63,8 x 40 mm  
• Accessories : 9V Baterai  
• Temperature : -20°C - 750°C / -4°F - 1400°F  
• Humidity : RH 35% - 95% RH with resolution of RH 0,1%  
• Noise : 35dB – 100dB with resolution of 0,1dB  
• Lighting : 3,5 LCD monitor with Lux unit |
| 2  | Questemp        | Measure dry bulb, wet bulb, globe bulb | • Dimension : 23,5 cm x 8,3 cm, 7,5 cm  
• Weight : 1.2 kg  
• Accessories : 9V alkaline: 140 hour  
• Sensor type : Temp: 1000 ohm platinum RTD  
• Accuracy : Temp : +/- 0,5°C to 0°C dan 100°C |
| 3  | Anemometer      | Measure velocity speed, temperature | • Merk : Krisbow KW06-562  
• Dimension : 16.3 x 4.5 x 3.4 cm  
• Weight : 210 gr  
• Air velocity : 0.6 – 30 m/s resolution of 0.01  
• Temperature : -10 – 60°C resolution of 0.1°C |
| 4  | Oximeter        | Measure heart rate, percentages of O₂ in human body | • Dimension : 5.8 x 3 x 3 cm  
• Weight : 75 gr  
• Display : LED  
• SpO₂ : 1% - 100% Resolusi : 1%  
• Heart rate : 30 bpm – 250 bpm Resolution of 1 bpm; Accessories : 1.5 V alkaline |

3. Results and Discussions
In this session, the results will be discussed in accordance with observation procedure that has been mentioned in sub-section 2.1.

3.1. Identification of the machine that the engine generates the greatest heat
Based on Table 1 it can be seen that heat was generated around the evaporator station on line of evacond. There are 2-machines as a heat generator in that area that is Dry of Oven and Brazing machine. Heat is radiated around the operator's operating room by radiation from heat sources having temperatures ranging from 170 to 820°C. This temperature provides heat radiation around the workspace and affect the working conditions of operators. As Venugoval [13] said that heat stress in the work environment negatively impacts the productivity of operators exposed to heat exposure.

3.2. Identification thermal sensation of operators working around the machine
The heat effect of the radiation of both machines resulted in 11-operators having a thermal sensation that almost entirely felt a warm sensation at before working and reach to hot sensation at after working as shown Figure 4. This is because in addition to the radiation effects caused by both machines there is heat generated by the process of operator metabolism due to work activities.
3.3. Measure the thermal conditions around heat-affected operators during work

The measurement points can be seen in Figure 1 at the altitude of 1.1 meter. Thermal condition at the evaporator station are shown in Table 4.

**Table 4. Thermal Condition Around the Evaporator Station**

| Operator | Temp. at 1.1 m (°C) | Velocity, $V_a$ (m/s) | Humidity, % RH |
|----------|---------------------|-----------------------|---------------|
| 1        | 34.5                | 0.9                   | 52.3          |
| 2        | 34.9                | 0.2                   | 51.6          |
| 3        | 35.1                | 0.8                   | 59.2          |
| 4        | 35.1                | 0.8                   | 51.7          |
| 5        | 35.1                | 0.9                   | 52.0          |
| 6        | 34.9                | 1.4                   | 52.7          |
| 7        | 34.7                | 1.3                   | 53.2          |
| 8        | 34.6                | 0.6                   | 54.2          |
| 9        | 34.4                | 0.8                   | 56.0          |
| 10       | 34.4                | 1.6                   | 52.9          |
| 11       | 34.8                | 1.8                   | 52.1          |
| Average  | 35.0                | 1.0                   | 53.5          |

Table 4 shows that the average thermal working temperature at the evaporator station is high around 35°C, whereas according to SNI 16-7063-2004, the recommended threshold value in the working environment is 26.7 °C. Supported by low wind speed conditions and humidity conditions that are not too humid, increasingly lead to workspaces that do not support operators to work optimally. Therefore the production target can not be achieved in accordance with the plan as shown in Table 2.

3.4. Calculating the HSI

HSI is calculated using the formulation 1 [10]. The HSI of all operators shown in Table 5.

**Table 5. Recapitulation of Calculation of Heat Stress Index (HSI)**

| Operator | $t_i$ (°C) | $M$ (Wm$^{-2}$) | $R$ (Wm$^{-2}$) | $C$ (Wm$^{-2}$) | $P_a$ (Kpa) | $E_{req}$ (Wm$^{-2}$) | $E_{max}$ (Wm$^{-2}$) | HSI  |
|----------|-----------|----------------|---------------|----------------|------------|----------------------|----------------------|-----|
| 1        | 36.34     | 165            | -5.91         | 2.23           | 2.86       | 168.68               | 351.87               | 47.94 |
| 2        | 35.97     | 165            | -4.28         | 0.11           | 2.90       | 169.17               | 152.43               | 110.98 |
| 3        | 36.57     | 165            | -6.93         | -0.81          | 3.37       | 172.74               | 315.21               | 54.80 |
| 4        | 36.25     | 165            | -5.49         | -0.59          | 2.93       | 171.08               | 321.35               | 53.24 |
| 5        | 36.77     | 165            | -7.79         | -0.47          | 2.94       | 173.27               | 338.10               | 51.25 |
| 6        | 36.48     | 165            | -6.50         | 0.61           | 2.95       | 170.89               | 454.26               | 37.62 |
| 7        | 36.42     | 165            | -6.25         | 1.34           | 2.95       | 169.91               | 431.35               | 39.39 |
| 8        | 35.62     | 165            | -2.72         | 1.47           | 2.98       | 166.25               | 272.54               | 61.00 |

Figure 4. Thermal Sensation of the Operators
Table 5. Recapitulation of Calculation of Heat Stress Index (HSI) (Continued)

| Operator | t (°C) | M (W/m²)  | R (W/m²)  | C (W/m²)  | Pa (Kpa) | Ereq (W/m²) | Emax (W/m²) | HSI |
|----------|--------|-----------|-----------|-----------|---------|-------------|-------------|-----|
| 9        | 35.63  | 165       | -2.78     | 2.33      | 3.05    | 165.45      | 333.77      | 49.57 |
| 10       | 36.10  | 165       | -4.86     | 3.88      | 2.87    | 165.98      | 488.21      | 34.00 |
| 11       | 36.51  | 165       | -6.63     | 1.52      | 2.90    | 170.11      | 536.96      | 31.68 |
| **Average** |        |           |           |           |         | **51.95**   |             |     |

The HSI value is around 52 and based on the HSI category contained in the Neville Stanton book for the HSI value obtained the effect of 8-h exposure in the form of severe strain with work impact on the health threat for unit workers and acclimatization is needed.

3.5. Calculating the WBGT

WBGT is calculated using formulation 2. The WBGT values of 11 operators are calculated using data from wet bulb, dry bulb and globe bulb temperature as shown in Table 6.

Table 6. Recapitulation of WBGT value

| Operator | Wet Bulb | Dry Bulb | Globe | WBGT |
|----------|----------|----------|-------|------|
| 1        | 32.8     | 34.0     | 35.1  | 33.2 |
| 2        | 33.3     | 34.5     | 35.5  | 33.7 |
| 3        | 33.5     | 34.6     | 35.7  | 33.9 |
| 4        | 33.8     | 34.5     | 35.5  | 34.1 |
| 5        | 33.4     | 34.5     | 35.7  | 33.8 |
| 6        | 33.6     | 34.4     | 35.3  | 33.9 |
| 7        | 33.3     | 34.2     | 35.2  | 33.7 |
| 8        | 32.9     | 34.0     | 35.0  | 33.3 |
| 9        | 33.0     | 34.0     | 34.8  | 33.4 |
| 10       | 32.8     | 33.8     | 34.8  | 33.2 |
| 11       | 33.3     | 34.2     | 35.2  | 33.6 |
| **Average** | 33.2     | 34.3     | 35.3  | 33.6 |

The operators do brazing work on this station which is categorized as a moderate work. According to Table 6 it is shown that the average WBGT value of the operators is 33.6°C. This indicates that the workspace of the operator is exposed to heat. This means that regulation is required to regulate the operators working time allowed to work in the room.

3.6. The operators’ productivity

Wet Bulb Globe Thermometer (WBGT) Work-Rest Chart analyzes operators’ productivity. Based on Figure 3, we can see that the heat risk category for the WBGT value of 33.6 °C or at 93 °C at moderate work is extreme. The table shows the value of Work/Rest at unacclimated condition should be **avoided** while at acclimated condition is should be 20 minute for work and 40 minutes for rest. This shows the comparison between working time and rest versus 1 to 2. This indicates the working conditions at the evaporator station are uncomfortable which resulted in the operator requiring a rest time greater than the working time. This certainly affects the productivity of work.

3.7. Improvement

After the problems are address, then the solution of the problems are carried out. From the findings of points 3.1 to 3.6 it can be indicated that the thermal conditions of the evaporator stations in the BU AC of electronic companies are uncomfortable and have an impact on the productivity of the operators. Therefore the working environment must be improved in engineering. It is suggest that the proposed improvement can create more comfortable working environment and improve operator performance.
The physical condition of evaporator station building currently has a length of 20.6 m and width of 13 m with a wall height of 10 m. Meanwhile, the height from the floor to the top of the roof is 12 meters. Thus the volume of the room is 2678 m$^3$. In fact, the ventilation needed to remove heat from the workspace is inadequate. Then the proposed thermal repair will be performed on the ventilation design using direct evaporative air cooler. This design was chosen because of its energy-efficient usage. The working system of air cooler can be seen in Figure 5 and its specifications can be seen in Table 7.

![Figure 5. How the Air Cooler Works](image)

**Figure 5. How the Air Cooler Works**

**Table 7. Specification of Air Cooler**

| Picture | Specification |
|---------|---------------|
| Air Flow | 2150(m$^3$/h) |
| Exterior Size | 650x550x890mm |
| Weight | 25kg |
| Power Supply | 220 V/380V, 50Hz/60Hz |
| Power Consumption | 240 watt |
| Applicable Area | 43m$^2$ |
| Auto Fan Type | Axial |
| Available Air Discharge | Down/Up/side |

Figure 5 shows that the mechanism of new construction of the air cooler will deliver the cool air to evaporator station in the BU AC. Then, the hot air in the station will expels out of the room. Removing the hot air from those station will reduce the heat exposure to the operator and it causes the HSI value to decrease. Also the percentage of PD value that predicted by the CBE Thermal Comfort Tool was reduced to 34%. The same problem also investigated in [5] and [9] where the thermal issue is found in the workstation. The suggestion given is to use air vents and cooler to reduce the heat. Therefore, this research findings shows that the thermal environment at the evaporator room in BU AC were affected to the comfortable level of the factory worker indicating by HSI and PD values.

### 3.8. Comparing the PD value between before and after engineering control

The addition of 1 unit water cooler the value of HSI decreases to 13.61. Conducting a water cooler installation causes the HSI category to change from “heavy heat” to “mild heat pressure” so that there is assume only a small impact on physical work. The comparison of operators' discomfort before and after improvements is calculated using CBE Thermal Comfort Tool seen in Figure 6 and Figure 7.
The proposed installation is able to reduce HSI from 51.95 to 13.6 and Predicted PD is reduced from 96% to 34%. In other words, the HSI at before and after improvements is decreased around 70% and the predicted PD is also decreased around 60%. These findings indicate that improving the thermal environment will be able to improve working comfort which will further affect the level of work productivity.

4. Conclusions
This study examines the thermal comfort issue in working station Business Unit Air Conditioner (BU AC) at an electronics company in Jakarta. The thermal working environment conditions in the room observed are not meeting the standards of SNI 16-7063-2004. Stress due to thermal working environment called Heat Stress accepted operator is above acceptable standard. This indicates that the evaporator work station is under heavy heat exposure. The result of improvement study on thermal working environment condition by constructing the air cooler that can decrease heat stress level and Percentage of Dissatisfied (PD) more than 50%.

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