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Assessment of Thermal Comfort at Manual Car Body Assembly Workstation

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Abstract**—**The objective of this study is to determine the thermal comfort among worker at Malaysian automotive industry. One critical manual assembly workstation had been chosen as a subject for the study. The human subjects for the study constitute operators at Body Assembly Station of the factory. The environment examined was the Relative Humidity (%), Airflow (m/s), Air Temperature (^{o}C) and Radiant Temperature (^{o}C) of the surrounding workstation area. The environmental factors were measured using Babuc apparatus, which is capable to measure simultaneously those mentioned environmental factors. The time series data of fluctuating level of factors were plotted to identify the significant changes of factors. Then thermal comfort of the workers were assessed by using ISO Standard 7730 Thermal sensation scale by using Predicted Mean Vote (PMV). Further Predicted percentage dissatisfied (PPD) is used to estimate the thermal comfort satisfaction of the occupant. Finally the PPD versus PMV were plotted to present the thermal comfort scenario of workers involved in related workstation. The result of PMV at the related industry is between 1.8 and 2.3, where PPD at that building is between 60% to 84%. The survey result indicated that the temperature more influenced comfort to the occupants.

Keywords**—**Thermal, Comfort, Temperature, PPD, PMV.

I. Introduction

THE ventilation of building is used to maintain indoor air quality and thermal comfort. In order to attain these objectives, airflow rate should be controlled.

The minimal airflow rate is determined by indoor air quality requirements so that the maximal concentration for every pollutant is lower than the maximum admitted. Thermal comfort is influenced by air parameters (temperature, humidity, velocity and turbulence) and surface temperatures (walls, windows) but also by the type of human activity and clothing.

Thermal comfort has a great influence on the productivity and satisfaction of indoor building occupants [15]. Thermal comfort is very difficult to define. This is because we need to take into account a range of environmental and personal factors when deciding on the temperatures and ventilation that will make feel comfortable. The best that we can realistically hope to achieve is a thermal environment which satisfies the majority of people in the workplace, or put more simply, 'reasonable comfort' [9].

Thermal comfort can be defined as that condition of mind which expresses satisfaction with the thermal environment [15]. The reference to 'mind' indicates that it is essentially a subjective term; however, there has been extensive research in this area and a number of indices exist which can be used to assess environments for thermal comfort [7]. Fanger (1970) suggested three conditions for comfort; these are that the body is in heat balance and that the mean skin temperature and sweat rate are within limits required for comfort. Conditions required for heat balance can be derived from a heat balance equation. Mean skin temperatures and sweat rates that are acceptable for comfort have been derived from empirical investigation [11].

Predicted mean vote (PMV) is a parameter for assessing thermal comfort in an occupied zone based on the conditions of metabolic rate, clothing, air speed besides temperature and humidity. PMV values refer the ASHRAE thermal sensation scale [3] that ranges from –3 to 3 as follows: 3=hot, 2=warm, 1=slightly warm, 0=neutral, –1=slightly cool, –2=cool, –3=cold. Fig. 1 summarizes the overall process of using the six variables associated with thermal comfort sensation to evaluate the PMV [1]. The general comfort equation developed by Fanger [11] to describe the conditions under which a large group of people will feel in thermal neutrality is too complex and cannot be used in real time applications.

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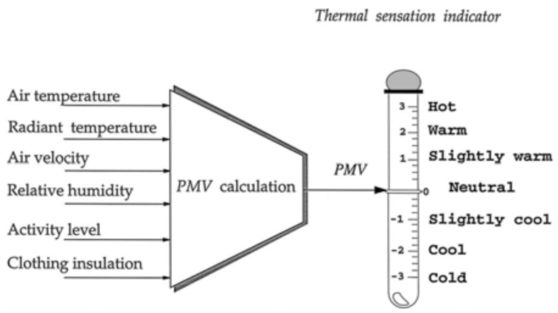

Fig. 1 PMV and thermal sensation

$$PMV = (0.028 + 0.3033e^{-0.036M}) \{(M – W) – 3.05[5.733 – 0.000699(M – W) – Pa] – 0.42[(M – W) – 58.15] – 0.0173 M (5.867 – Pa) – 0.0014M (34 – T_a) – 3.96x10^{-8} fcl [(T_{cl} + 273)^4 – (T_{mrt} + 273)^4] – fcl.hc(T_{cl} – T_a)\} \quad (1)$$

Where:

$$T_{cl} = 35.7 – 0.028(M – W) – 0.155 I_{cl} [3.96x10^{-3} fcl[(T_{cl} + 273)^4 – (T_{mrt} + 273)^4] – fcl.hc(T_{cl} – T_a) \quad (2)$$

$$h_c = \begin{cases} 2.38(T_{cl}-T_a)^{0.25} \; for \, 2.38(T_{cl}+T_a)^{0.25} \geq 121\sqrt{V_{air}} \\ 121\sqrt{V_{air}} \; for \, 2.38(T_{cl}-T_a)^{0.25} \leq 121\sqrt{V_{air}} \end{cases} \quad (3)$$

The parameters are defined as follows:

- PMV: predicted mean vote.
- M: metabolism (W/m^2)
- W: external work, equal to zero for most activity (W/m^2)
- I_{cl}: thermal resistance of clothing (Clo)
- fcl: ratio of body’s surface area when fully clothed to body’s surface area when nude.
- T_a : air temperature (^{o}C)
- T_{mrt} : mean radiant temperature (^{o}C)
- V_{air}: relative air velocity (m/s)
- Pa: partial water vapour pressure (Pa)
- h_c: convectional heat transfer coefficient (W/m^2 K)
- T_{cl}: surface temperature of clothing (^{o}C)

Furthermore, the equation for PPD is given by equation (4).

$$PPD = 100 – 95 \exp (- 0.03353 PMV^4 + 0.2179 PMV^2) \quad (4)$$

Predicted percentage dissatisfied (PPD) is used to estimate the thermal comfort satisfaction of the occupant. It is considered that satisfying 80% of occupant is good; that is, PPD less than 20% is good [19].

Without ventilation, a building’s occupants will first be troubled by adours and other possible contaminants and heat [5]. When we discuss about heat, actually automatically discuss about thermal comfort building’s occupant. In most cases, buildings are erected to protect their occupants from the external environment (e.g. extreme temperatures, wind, rain, radiation etc.) and to provide them with a good indoor environment. Proton Factory is using natural ventilation. This ventilation is different with mechanical ventilation. Three objectives of natural ventilation are indoor air quality, thermal comfort and energy savings [5].

The good building design characteristic, including both the engineering and non engineering disciplines, might be summarized as follow [17]:

- Meets the purpose and needs of the building’s owners/managers and occupants,
- Meets the requirements of health, safety and environmental impact as prescribed by codes and recommend by consensus standards,
- Achieves good indoor environment quality which in turn encompasses high quality in the following dimensions: thermal comfort, indoor air quality, acoustical comfort, visual comfort,
- Creates the intended emotional impact on the building’s occupants and beholders.

Improving workers’ productivity, occupational health and safety are major concerns of industry, especially in developing countries. However, these industries are featured with improper workplace design, ill-structured jobs, mismatch between workers’ abilities and job demands, adverse environment, poor human-machine system design and inappropriate management programs [14]. Light, noise, air quality and the thermal environment were considered factors that would influence the acceptability and performance on the occupants of premises [12]. [6] stated that lower emotional health is manifested as psychological distress, depression and anxiety, whereas lower physical health is manifested as heart disease, insomnia, headaches, and infections. These health problems could lead to organizational symptoms such as job dissatisfaction, absenteeism, and poor work quality. Irritated, sore eyes and throat, hoarseness, stuffy congested nose, excessive mental fatigue, headache and unusual tiredness were all signs of the negative workplace environmental conditions [3].

Fig. 2 Babuc Equipment

Previous research done by [8] showed that the work environments were associated with perceived effects of work on health. This research used a national sample of 2048 workers who were asked to rate the impact of their respective jobs job on their physical and mental health. Regression analyses proved that the workers’ responses were significantly correlated with health outcomes. In addition to this, Shikdar et al. pointed out that there was high correlation between performance indicators and health, facilities, and environmental attributes [12]. In other words, companies with higher health, facilities, and environmental problems could face more performance related problems such as low productivity, and high absenteeism. Employees with complaints of discomfort and dissatisfaction at work could have their productivity affected, result of their inability to perform their work properly [10].

Increased attention had focused on the relationship between the work environment and productivity since the 1990s. Laboratory and field studies showed that the physical and chemical factors in the work environment could have a notable impact on the health and performance of the occupants, and consequently on the productivity. Workplace environmental conditions, such as humidity, indoor air quality, and acoustics have significant relationships with workers' satisfaction and performance [2], [4], [8]. Indoors air quality could have a direct impact on health problems and leads to uncomfortable workplace environments [7], [13], [18].

A. Data of Thermal Comfort Study

At all 12 workers participated with this station. The age is between 19 and 39 years. The average is 28 years. 50% are married with children, 50% are not. 41.5% are in their job for 10 years and more, 17 for 2 to 5 years and the other 41.5% for two years and less. 75% finished school with SPM and one with SPMV, Majlis Latihan Vokasional Kebangsaan (MLVK) or vocational school. The type of employment is 58% permanent and 42% on contract.

II. Methodology

A. Equipments

The measurement was carried out on one day at assembly line of Malaysian car manufacturer. The type of ventilated in that place is Mechanical ventilated building. These buildings usually have a central fan or local fans that provide the ventilation air. Each day the measurement devices were set up at different locations. By this approach, information of a wide range of different influences to the workers at the different stations in the plant should be collected. The basic device for the measurements was the Babuc A multi-data inquisition unit as a shown in Fig. 2. This instrument was used to obtain value air temperature, air humidity, mean radiant temperature, relative air velocity, activity level (heat production in the body), thermal resistance of the clothing (clo – value). To have a wide range of date, measurements were done at one day. Beginning with the start of the dayshift at 8.00 am the daily measurements continued until the end of the dayshift at 5.30 pm.

The station to assemble the first body part was located at the very beginning of the assembly belt. The whole station was based on a platform, about one meter above the zero level in the plant. Beside this platform was a conveyer, which mechanical parts and actuators were located below. To operate on the same level with the conveyer, the surrounding workplaces hat to be raised. On the conveyer and on four separate stations the parts for the lower front end of the car are assembled. At the first station the front floor panel is mounted. On the following two stations several other small parts are added and the whole part is welded together. The fourth station is not used for the actual model. It is just used as a buffer. Between the stations, the parts are moved with small cranes, mounted under the ceiling. Simultaneously the front end of the car is assembled on the conveyer. It is assembled in three steps, parallel to the floor panel. After finishing on step the conveyer moves the front end to the next station. At the fourth station the front end and the floor panel are joined together on the conveyer. The complete front section is then picked up by a different transport system and taken to the next stations. The workers on the separate stations take the precasted plates from containers close to their station. Whenever a container is empty, it is replaced by a new one. The parts are put on special tables. On the table the parts are fixed in their position by. Several profiles on the table work as a stencil for the final part. Hydraulic powered claps fix the parts on the table. The clamps are operated by the workers from a console close to the table, which also contains the switch for the current, used to weld the parts together. Once the parts are clamped, the current is switched on. With large spot welding tool the parts are connected. The tools are very heavy. To facilitate the operation of the tool, they are mounted under the ceiling on a rope. The rope is spooled in a winch, which is adjusted to the weight of the tools. Moving the tool up causes the rope to wind up, easy pulling causes it to unwind. Thus the operation of the heavy tools is possible with very less muscle power. To open and close the claws of the tools, pushing a button is enough. The tools are air powered. When the claw is closed and the button remains pushed, after a few seconds the current flows. Depending of the location of the weld spots two different tool were used at each station. When a part was finished it was grabbed with a crane. The crane was guided under the ceiling in a rail and the winch was air powered. Again the operation was quite easy. To each station belonged one crane, operated by the same workers, operating the spot welding tools. The final crane places the finished floor panel on the conveyer, where it is connected to the front panel by welding too. Fig. 3 below showed the workflow at the Body Assembly Station.

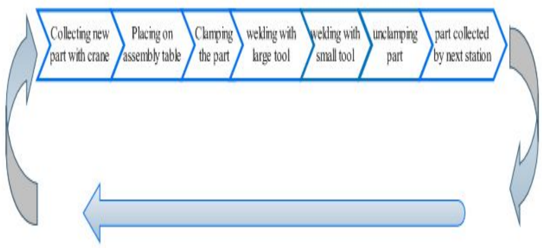

Fig. 3 Workflow at the Body Assembly

B. Analysis and Results on Thermal Comfort Study

In this section the collected and analysed data are discussed based on the Table I. Thermal comfort are examined, with six primary factors to most affect the thermal comfort are air temperature, humidity, air velocity, mean radiant temperature, clothing level and metabolic rate. Predicted Mean Vote (PMV) is one way to quantify the comfort achieved in a space. As PMV moves away from zero in direction, the Predicted Percentage of Dissatisfied (PPD) people increases. In respect of subjective thermal votes the workstation under survey are inappropriate. The scale for sensation vote towards thermal comfort is shown in Table I.

TABLE I
SCALE FOR SENSATION VOTE TOWARDS THERMAL COMFORT

	Air Temperature	Relative Humidity	Air Velocity
-3	Cool	Very Humid	Very Strong
-2	Cold	Humid	Strong
-1	Slightly Cool	Slightly Humid	Slightly Strong
0	Neutral	Neutral	Neutral
1	Slightly Warm	Slightly Dry	Slightly Weak
2	Warm	Dry	Weak
3	Hot	Very Dry	Very Weak

The Body Assembly Station was located again close to on gate at the side of the plant as illustrated in Fig. 4. The influence of the outside environment is again stronger. The day started sunny and dry. The PMV index in Body Assembly Station between 1.76 to 2.1. Meanwhile, the PPD is around 65% to 81%. So, 19% are likely to be satisfied by the worker. At this station, the workers had to wear long sleeves.

The metabolic rate was also 116 W/m² although the clothes value was 1.1 clo. So, as a conclusion, this station is not comfort. This is because the thermal sensation is warm. Although, the weather outside humid and also cause of raining but cause of the location this station is center. Far away from gate and windows, so this station less air flows.

Between the start of the measurement at 11:20 am and 12:30 pm the temperature dropped significant from highs of 28.5 degrees and more to lows of 26 °C as illustrated in Fig. 5. From 12:30 pm on the temperatures leveled off to an almost constant behavior. The values ranged around 26 °C. Like the weather outside the temperatures at this station did not change much until the end of the measurements. The temperature is mainly kept in this range by a lot of fans, mounted around the station. The location close to a gate would have caused higher temperatures without fans. The maximum measured temperature was early in the morning measured with 28.7 °C. The rest of the day the temperatures ranged around 26 °C.

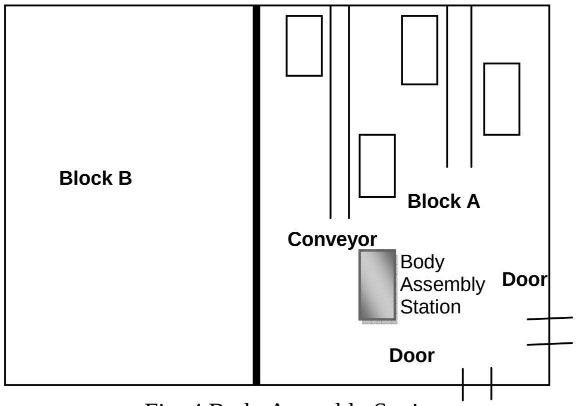

Fig. 4 Body Assembly Station

Starting at 11:20 am the humidity rose from about 55% to values ranging around 70% as show as in Fig. 6. Until 4:00 pm it kept this range and then started to decrease a little to 65% relative humidity. The jump in the beginning between 11:20 am and 12:30 pm is correlating with the change in temperature and illuminance. The values of 70% relative humidity are normal for the tropical climate, but have to be considered as high. The recommended values between 50% and 60% relative humidity are overridden. The personal impression confirms with this fact.

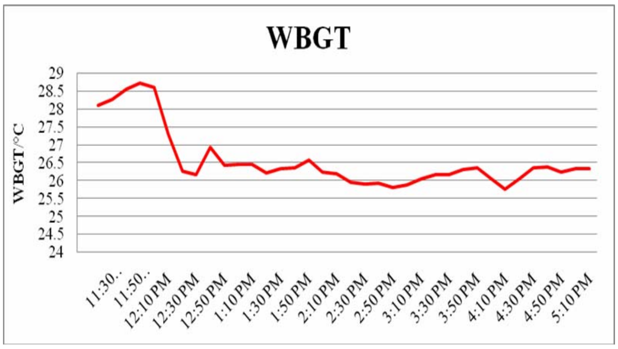

Fig. 5 WBGT measured at the body assembly station

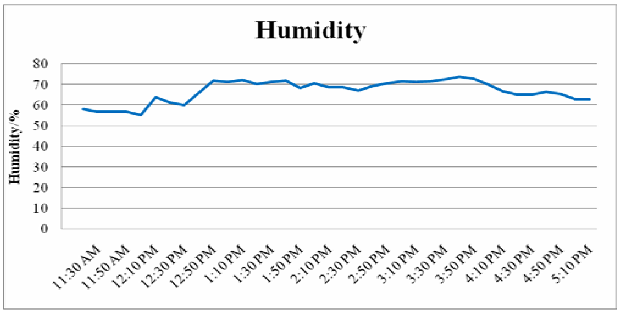

Fig. 6 Relative humidity measured at the body assembly station

III. Discussion

The Body assembly was at the very beginning of the assembly belt. The location was close to a gate, which had again a huge influence to the environmental factors. Whenever the outside climate changed, a change could be seen immediately at this station. The measured temperature was in the beginning very high, but cooled down significant to values around 26 °C. At this day the temperatures were not that exhausting, but the workers have to wear shirts with long sleeves and protection clothes to cover them from the spraying sparks. On hot and sunny days the temperature can easily be much higher at this station. The tires receiving and first stamping station were located similar. The measured data from this station show the possibility of very high temperatures close to gates or loading ramps. The humidity was also very high, again caused by the location. The survey approved the measured data. Although the temperature level at this specific day was not so high, the workers feel much affected of the temperature. The heavier clothes might be a reason for stronger impression of the temperature and on others days the temperature might be much higher. The humidity is, compared to other stations more affecting. The reason might be the stronger influence of the outside environment.

IV. Conclusion

The thermal comfort of a factory worker depends on there being an average skin temperature (resulting from the combination of climate, clothing and metabolic heat production). The purpose of heating or cooling enclosures to be occupied by human being is to provide thermal comfort. A given system will be judged by the occupants according to its ability to satisfy this demand and it is therefore obvious that a rational calculation of heating and air – conditioning systems must begin with the conditions for comfort.

The activity level and the thermal resistance of clothing are determined, depending on the purpose for which the space will be used, and the comfort equation gives all combinations of the environmental variables which will create optimal thermal comfort. Therefore there are many possibilities for satisfying the comfort demand. However, for a given room, the environmental system chosen, the thermal properties of the room and the outdoor conditions will jointly establish certain dependence between the variables. Clearly it is important to ensure that the level of dissatisfaction with the thermal environment is kept to minimum, preferably to no more than 5% of the people populating a building.

This research added one step which is the survey process. The survey indicates a lot about the personal impression of the workers. Compared to the measured data, many of impressions match with the actual parameters. The temperature seems to be the most disturbing factors.

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