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Assessment of Environmental Factors Ergonomics and Thermal Comfort: A Study at Discrete Manual Automotive Assembly Line

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Abstract

The aims of study were to investigate the effects of ergonomics and thermal comfort during the cycle of process works in workplace. The selected workplace was handling the restoration of trouble report. The environment examined was the radiant temperature (^oC), humidity (%), wind speed (m/s), air temperature (^oC), illuminance (lux), sound (dB) and CO_2 (ppm) of the surrounding workstation area. The environmental factors were measured using thermal comfort 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 the thermal comfort of the workers was assessed by using ISO Standard 7730 and 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 PMV were plotted to present the thermal comfort scenario of workers involved in related workstation. The thermal comfort assessment of this workplace which is hot following by thermal sensation and likely to be dissatisfied by the occupant. The result indicated that the activity level and clothing more influenced comfort to the occupants. The workstation must be minor improvement to improve productivity.

Keywords: Thermal comfort, Environmental factors, PMV, PPD.

1. Introduction

The purpose of the study is to appreciate the ergonomics role and to measure thermal comfort in industrial environment and in everyday life. This is also to make realize that ergonomics is a wide subject that consists of product design, material handling, environment, physiology and psychology and also thermal comfort is one of items influence our future. Thermal comfort is recognized as a key parameter for a healthy and productive workplace [1]. Unhealthy buildings have

been seen associated with the high prevalence of several symptoms: headaches, dry eyes or throat, itchy or watery eyes, sneezing, blocked and stuffy nose, runny nose and dry or irritated skin [2]. Malaysia has one of the fastest growing building industries worldwide, where the corresponding energy demand would significantly increase in the next coming years [3], so if thermal comfort we take of granted, productivity in industries decrease. These findings further support the idea by A.R. Ismail et al [4]. They find the productivity was one of the most important factors affecting the overall performance to any organization, from small enterprises to entire nations.

There are quite a number of similar studies being conducted overseas and locally where most of the references are found. Most of the studies are on the design of products, workplace quality and working environment including the ergonomics of workstation.

The anthropometrics data for a specific population is needed in order to optimize and help the researchers on the dimensioning aspect. With the Malaysian anthropometrics data to be published, more research on this field can be executed and accuracy can be achieved.

It is also understood that ergonomics contributes towards employee's health and safety in the workplace and profitability of the company.

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 [5]. 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' [6].

Thermal comfort can be defined as that condition of mind which expresses satisfaction with the thermal environment [7]. 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 [8]. 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 [9].

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 [7] that ranges from –3 to 3 as follows: 3 = hot, 2 = warm, 1 = slightly

warm, 0 = neutral, –1 = slightly cool, –2 = cool, –3 = cold. Figure 1 summarizes the overall process of using the six variables associated with thermal comfort sensation to evaluate the PMV [10]. The general comfort equation developed by Fanger [9] 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.

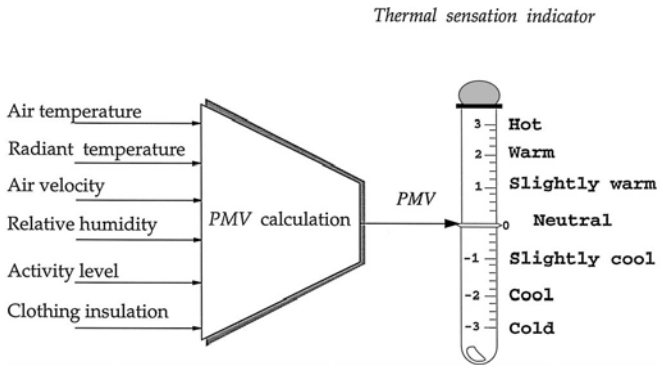


Figure 1: PMV and Thermal Sensation.

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 [11].

Without ventilation, a building's occupants will first be troubled by adours and other possible contaminants and heat [12]. 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 [12].

The good building design characteristic, including both the engineering and non engineering disciplines, might be summarized as follow [13]:

- 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 [15]. [16] 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 [17].

Previous research done by [18] 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 [15]. 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 [19].

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 [18], [20], [21]. Indoor air quality could have a direct impact on health problems and leads to uncomfortable workplace environments [22], [23], [24].

Thermal comfort surveys in tropical countries near to the equator have been actively assessed by researchers since 1949 [25–27]. The importance of comfort generally in a building design has been widely translated into several comfort types [28, 29] of which the most influential and most studied is thermal comfort. Naturally ventilated buildings designs can perform efficiently in hot climate countries, like Malaysia because of their low evaporation rate, long hours of sunshine, high relative humidity, and very overcast cloud cover [30]. In Malaysia, thermal comfort assessments on naturally ventilated building have been conducted in low cost housings, traditional Malay houses, terraced houses, walk-up flats [31, 32], and class-rooms but none have been conducted in high-rise domestic buildings. Malaysia is a maritime country close to the equator. It has abundant sunshine but it is rare to have a full day with a completely clear sky. The average sunshine is around 6 h. The daily range of temperature in Malaysia is from a low of 24^{o}C up to 38^{o}C with the lowest temperature usually recorded during the night. Relative

humidity can be as low as 42% to as high as 94%. Malaysia's annual evaporation rate is about 4–5 mm per day depending on the cloud cover and air temperature (Malaysian Meteorological Department, 2007, unpublished data). Because of its hot and humid climate, cooler days are often recorded with low evaporation rate, high relative humidity value, cloudier sky (7 oktas), and wet while warmer days are usually the opposite. As a country that is progressing towards an energy consumption conscious target, buildings are designed to enable natural ventilation. However, a naturally ventilated building cannot give a thermally comfortable environment in Malaysia. At the very least a ceiling fan needs to be installed to lessen the heat gain indoors [28].

2. Methodology

Workstation overview: The study was done at the sub-assembly line. This production line acts as a feeder to the main assembly line where most of the sub assembly of the engine done and pulled by the main line for other major assembly process. A simple Figure 2 below shows the process flow in relation with the main assembly line and the layout of engine sub assembly line.

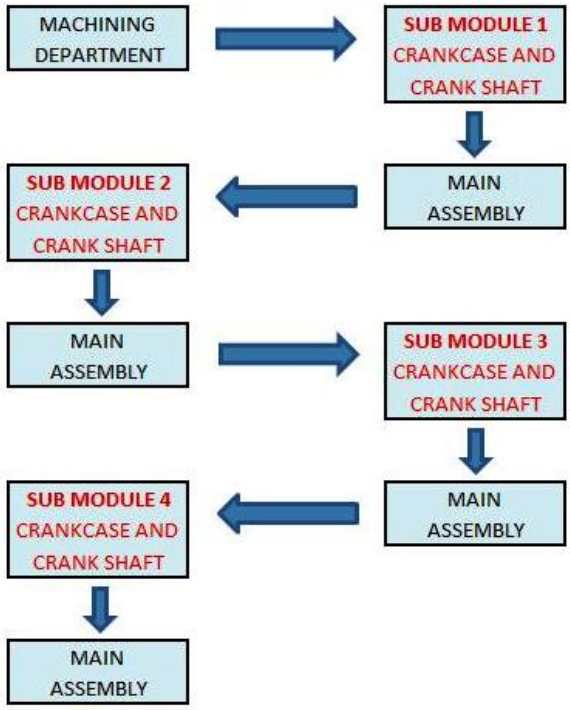


Figure 2: The Process Flow of Engine Assembly.

From the Figure 3, layout, the 'x' mark was the area where the study had been conducted. The subjects are from every sub-assembly module. Actual data and data from Malaysian population anthropometric had been used throughout the discussion. Figure 4 presented the workstation design and subjects. The anthropometric data in every subject also was described in Figure 4. The workstation design in Figure 4 was illustrated at the layout in Figure 3. It can be seen from the Figure 4 that the workstation design reported top view and front view. The circle one shows the study was conducted.

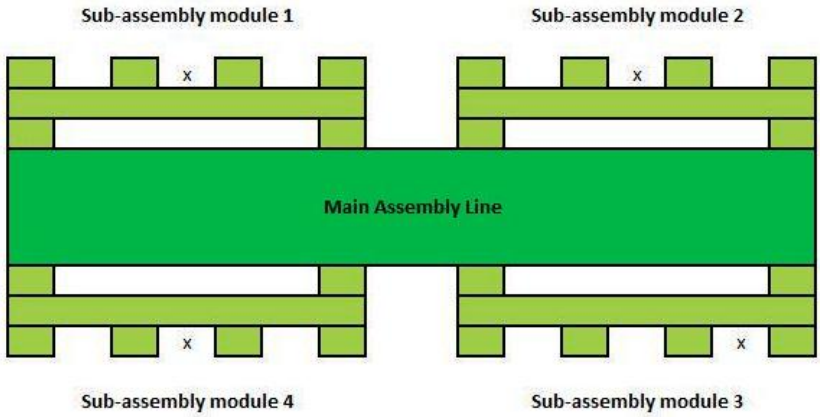


Figure 3: The Layout of the Assembly Process.

Workstation Design and Subjects:

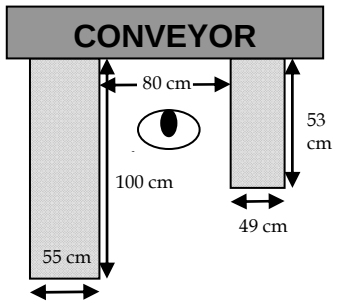
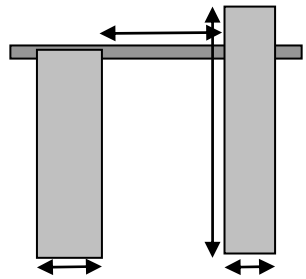
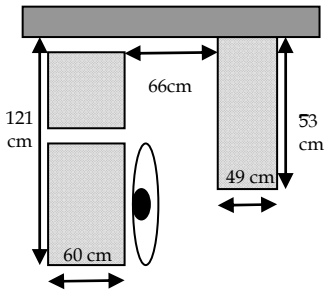
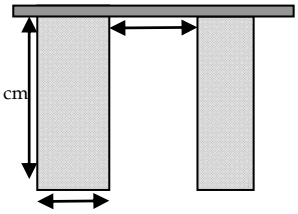
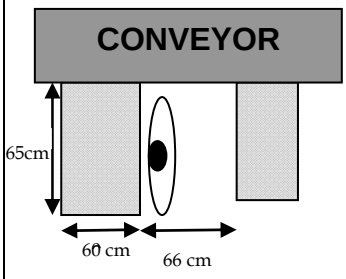
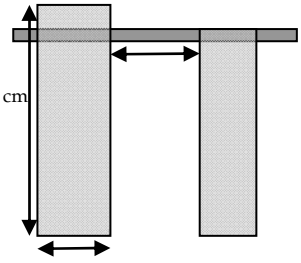
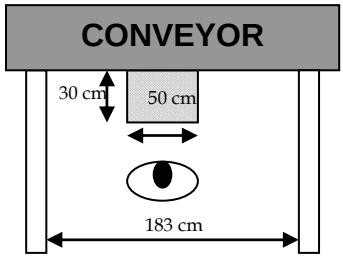
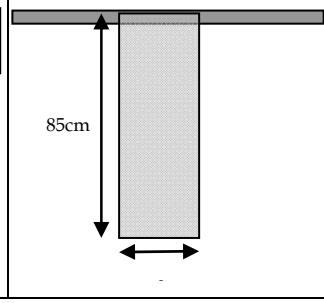
Top View	Front View	Anthropometrics Data
		Gender : Male Age : 26 years Weight : 53 kg Stature : 166 cm Forearm Length : 45cm Elbow Height : 98cm Waist height : 93 cm
		Gender : Male Age : 28 years Weight : 58 kg Stature : 162 cm Forearm Length : 44 cm Elbow Height : 96 cm Waist height : 91cm
		Gender : Male Age : 33 years Weight : 58 kg Stature : 163 cm Forearm Length : 44 cm Elbow Height : 96 cm Waist height : 91 cm
		Gender : Male Age : 26 years Weight : 63 kg Stature : 170 cm Forearm Length : 46 cm Elbow Height : 100 cm Waist height : 95 cm

Figure 4: Workstation Design and Dimension.

Working Shedule: The working schedule for the company in Sub-Assembly Line is from Monday to Friday. Staffs clock-in at 7.50 am and start working from 8.00 am to 5.30 pm. The company provides 65 minutes in total for breaks, where 15 minutes for morning break, 35 minutes for lunch and 15 minutes for evening break.

Experiment Set-up: From the Figure 5 below we can see that the layout environmental monitoring station location. This figure indicates that the manufactures saiz was 31640 mm^2x6700 mm^2. The red shape shows the Evironmental Monitoring Station was located. This figure below illustrates the green color was walkways area. The grey color presents the production area. Besides workstation ergonomics, an environmental ergonomics studies had also been established at the line. The study is to recognize any environmental attributes that will affect the staffs. The measurement of lighting, air and temperature had been taken by the Environmental Monitoring Equipment as presents in Figure 6 that is comprised of eight sensors. The station had been stationed nearest possible to the workstation to acquire best results. The writer had also determined the nearest source of natural light. It can be seen from the Figure 7, Figure (a) reported the nearest natural light source on the left side of the station while Figure (b) shown the nearest natural light source on the right side of the station. These door become source of lightning in this manufacturing.

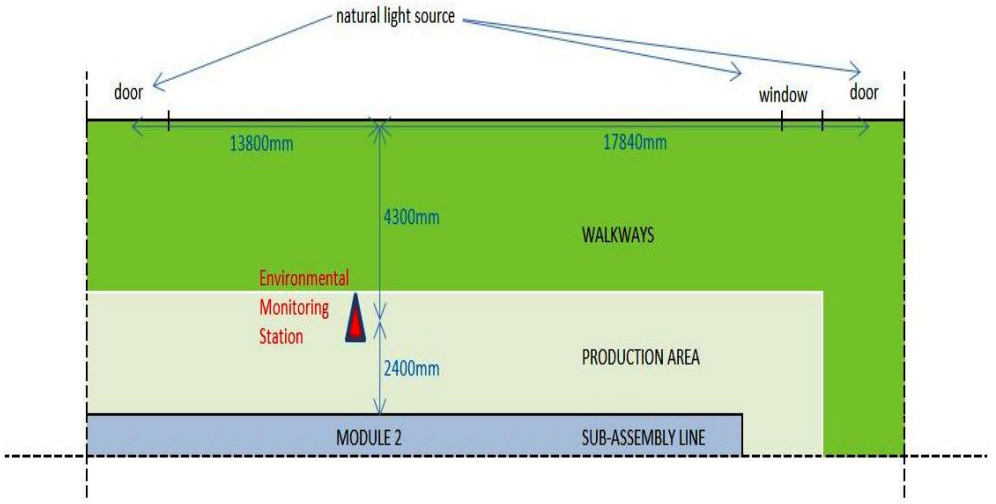


Figure 5: Layout Environmental Monitoring Station Location.

Figure 6: Environmental Monitoring Equipment and the Location Measurement.

(a) (b)

Figure 7: (a) The nearest natural light source on the left side of the station, (b) The nearest natural light source on the right side of the station.

3. Result And Discussion

Table 1 presents the results obtained from the measurement in Sub-Assembly Line Station. There are 6 figures in Table 1. The PMV index in this station between 2.1 to 2.9 are presented in Figure (a). Meanwhile, the PPD is around 81.1% to 98.6%. The metabolic rate was 93 W/m² (light industry) although the clothes value was 0.9 clo. So, as a conclusion, this station is not comfort. This is because the thermal sensation is warm and almost hot.

The affect of environmental to the workers should be considered as standards had been introduced. The environmental monitoring station had been

collecting online data for 6 hours and 30 minutes. The overall pattern of the result shows a normal and harmless condition of environment. At the end of the data, we can see in Figure (f) and (b), some variation in terms of illuminance and radiant temperature. This is due to heavy rain and changes in lighting. The natural light source had been closed and replaced by ceiling lighting that is obviously better. From the Graph Humidity in Figure (b), ANSI recommended 30% to 60% as acceptable. By referring in the official portal of Malaysian Meteorological Department, based on the Humidity Sensor stationed at Petaling Jaya, the range of Humidity is between 78% and 98%. The data showing more than 50% of Humidity. During the study, we experienced a lot of body sweating, especially at morning time and before rain started at the end of study. Air temperature line in Figure (b) shows the constant temperature during measurement. The reading shows a constant reading and slightly rising before raining. The recommendation from ASHRAE is between 19^{o}C and 26^{o}C. The actual result showed that the working area is out of comfort in terms of room temperature.

The outdoor air is needed to dilute pollutant inside the working area. CO_2 are of exhaled breath. As shown in Figure (e), CO_2 measurement is to indicate of whether sufficient quantities of outdoor air are being introduced to an occupied space. American Society of Heating, Refrigerating and Air Conditioning Engineers Inc (ASHRAE) recommended that the CO_2 level should be below 700 ppm. Form the measurement, the highest reading was 600 ppm where the amount of CO_2 is at comfort level. The effects of excessive CO2 are nausea, dizziness and can cause occupant to faint.

Figure (c) illustrated the wind speed graph in measurement day. The value depicts air movement in area under study. Wind speed contributes to effective temperature (ET). Wind speed helps promotes improvement of relative humidity through convection and radiation. ASHRAE recommends 0.2 m/s; where slow air movement contributes to a comfortable working environment. A fluctuation in the data is caused by the effect of oscillated wall fan provided to each of line operators. We perceived that the wall fans are provided to reduce the sweating experienced by them.

Figure (d) provides the sound measured. The reading shows that the operators are only allowed to be exposed to 32 hours. Observation showed that all operators are to use ear plug all time during work.

The light source of the assembly line is the natural light source and pendarflour lamp placed along the assembly line. Data collected in the line as shown in Figure (f) that the illuminance level is too low for the job. Based on the recommended interior illumination level proposed by Illuminating Engineering Society of North America, the activities and illumination level lies between category C and D where 150 to 350 lux are needed for comfort. The best level is recorded during raining when all doors are shut and the ceiling light is turned ON. This results to better illumination level for both production floor and the walkways.

For the work study purpose, we had chosen two subjects; male and female to determine the activity metabolic rate for their job. It is the calories needed to perform the job for every single day. The calories will be then converted into energy (kj).

Subject 1

Gender: Male

Age: 28 years old

Weight: 58kg

Activity	Time	ER	Weight Factor	Total
Resting (seated)	45mins	1.5kcal/min	58/72	54.375kcal
Walking @ 3km/hr	20 mins	2.8kcal/min	58/72	45.111kcal
Assembly work @ standing	505mins	3.1kcal/min	58/72	1261.097kcal
			AMR	1360.583kcal

Subject 2

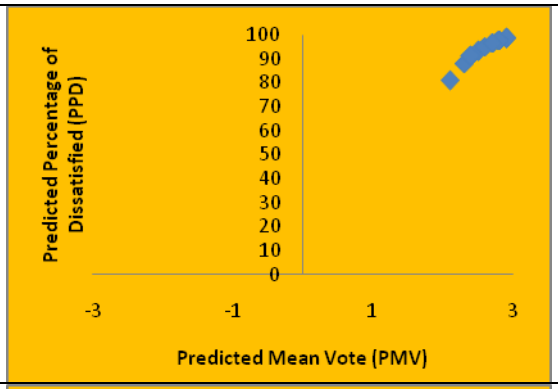
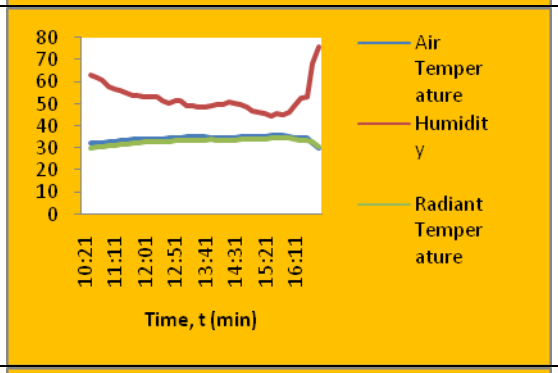
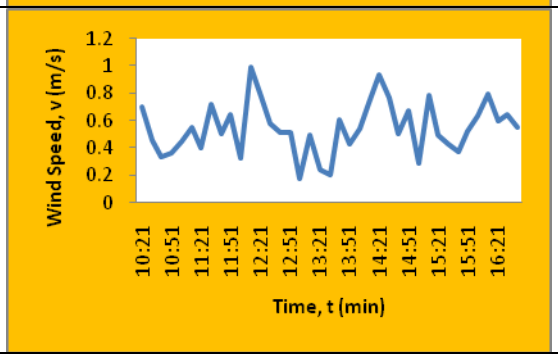
Gender: Female

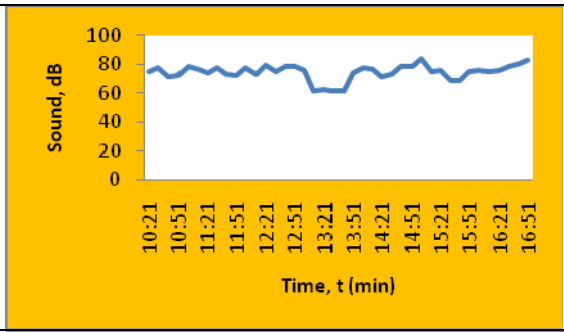
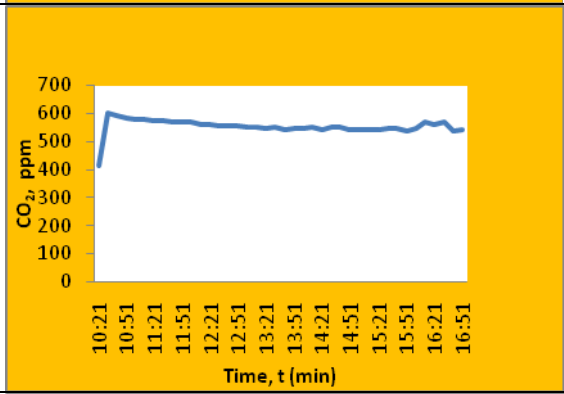
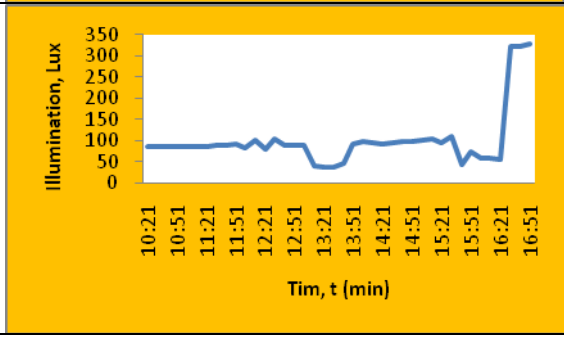
Age: 22 years old

Weight: 45kg

Activity	Time	ER	Weight Factor	Total
Resting (seated)	45mins	1.5kcal/min	45/72	42.188kcal
Walking @ 3km/hr	20 mins	2.8kcal/min	45/72	35kcal
Assembly work @ standing	505mins	3.1kcal/min	45/72	978.438kcal
			AMR	1055.626kcal

Table 1: Parameters Environmental Factors Measured

Figure	Title
	PPD as a function of PMV measured at the engine sub assembly line station
	Humidity, radiant temperature and air temperature measured at the engine sub assembly line station
	Wind speed measured at the the engine sub assembly line station

	Sound measured at the the engine sub assembly line station
	CO_2 measured at the the engine sub assembly line station
	Illuminance measured at the the engine sub assembly line station

4. Conclusion

From the study that had been done, the workstation needed some minor improvement. Most modifications had to be done to the height of the work surface. With respect to the suggestions in the earlier chapter, height adjustment is based on the type of work done by the operator whether it is precision, light or heavy work. The height suggested is based on the mean elbow height of Malaysian population. Introducing a height adjustable work desk is also appreciated. This is to allow any operators with different body size to work comfortably.

Working while standing had been proven to maintain productivity. Through interviews, subjects are complaining of sore feet. Be it the safety shoes or

excessive standing are to be blame. We also perceived that other CTD symptoms remain silence due to their young age.

In term of the environmental factors, the product area can be considered good considering the CO_2 level. Exploiting the natural source of light is also appreciated. Besides energy saving, sunlight can minimize the effect of shadow. The results showed that the illumination level is not adequate at the sensors. The effect of ceiling light and the pendarflour lighting is better even in the absence of sunlight.

Time study had shown that the highest productivity occurs after lunch meal. The contributing factors are work while standing, hot sun, calories burning and faster heart beat also contribute to improves focus.

Good energy source is vital to perform better in work. We would like to suggest a 7 to 8 inches banana to be included in their lunch meal. This size of banana can provide 438 kj and it is low in carbohydrate. Bananas had been introduced to the sportsman because the energy from bananas is burn slowly at a constant rate.

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