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The Impact of Workers Productivity under Simulated Environmental Factor by Taguchi Analysis

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Abstract

The objective of this study is to determine the dominance impact of environmental factors such as illuminance, humidity and temperature on worker productivity by Taguchi Method. A study was conducted under simulated environment factor which examined were the illuminance, humidity and temperature of the surrounding workstation area in the closed simulation lab. A set of representative data including the illuminance, humidity and temperature level and production rate were collected during the study. The production rate data were collected through observations and survey questionnaires while the illuminance, humidity and temperature level measured by valid apparatus and equipment. The Taguchi method was utilized to find the sequence of dominant factors that contributed to the productivity of the operator at that specified production workstation. The study reveals that the dominant factor that contributed to the productivity was temperature followed by illuminance and relative humidity.

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Keywords : Iluminance, Relative Humidity, Temperature, Productivity

1. Introduction

Manufacturing industry is one of the dominant industries that contribute to Malaysian economic growth.

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Most of the assembly line in manufacturing industries operates in manual or semi-automatic. Thus, the comfort of the working environment should be emphasized in order to improve the health and safety, performance and productivity. However, those studies carried out involving only one environmental factor and not on the effect of workers' performance on various combinations of environmental factors. This study aims to investigate the effect of the dominant environmental factors such as illuminance, relative humidity and temperature on workers' performance. The study was conducted in a closed simulation lab adapted based on a production line involving the installation of the components manually. 12 subjects were involved in this study responsible for installation works. The subjects divided into two groups that are 6 subjects used for data acquisition while the remaining six subjects used for confirming the results of the study. 6 subjects exposed to the nine sets of experiments while performing a light components assembly work. Productivity rates have been observed and recorded for every 10 minutes for 4 hours for each data set of environment parameters. The same experiment was repeated by the other six subjects. Next the data obtained were analyzed using the Taguchi Method in order to the interaction and dominance of environmental parameters on the performance. Taguchi Method results revealed that the dominant factor is the temperature, followed by the illuminance and relative humidity. It also shows that there is a positive impact on workers' performance at 24°C temperature, relative humidity at 40% and illuminance of 500 lux.

1.1. Illuminance, Relative Humidity & Temperature

Light is a simple part of the electromagnetic spectrum that enables human to see the objects of surrounding. Illuminance is one of the characteristic of light and it is a reflectance of light on subject to human to perform their visual activities. Illuminance (E) is a quantity that used for light incident on a surface and its standard unit is lux (lm/m2) with symbol *lx*. According to A. R. Ismail (2013), the measurement of illuminance is ratio of luminous flux (*lm*) to the area of illuminated surface (m^2). Several studies has been reveal that bad illuminance can affect the health of people such as causing visual discomfort, fatigue, eyestrain, migraine, and mood changes (HSE, 1997; Boyce, 2003; Hemphälä and Eklund, 2012). Besides that, Caballero-Arce et al. (2012) concluded that inadequate illuminance can also affect humans' alertness and circadian rhythms. Moreover, Juslén (2006) stated that good illuminance can be a positive impact on human performance because it improves the visual performance and visual comfort which affect the productivity indirectly.

Relative humidity (RH) is an amount of the moisture in the air, compared to the potential saturation level. In 2009, Ismail, A. R. et al. has been concluded that relative humidity can affects thermal comfort of human wellbeing as well as humidity can influence the heat transfer quantity from skin to environment. According to the Industry Code of Practice on Indoor Air Quality (2010), the suitable range for relative humidity is 40-70 %. Moreover, Atmaca and Yigit (2006) also stated that when the relative humidity is high, latent heat dissipation ability of the body decrease, where increasing in vapor pressure and sweat rate over the body also affecting the latent heat dissipation. The studied by Atmaca and Yigit (2006) stated that humidity may be one of the factors that cause discomfort to human with the reason of uncomfortably high level of skin wittedness or inhalation of humid and warm air. Moreover, Tsutsumi et al. (2007) have done a research on relative humidity with 4 conditions which are 30%, 40%, 50% and 70% relative humidity. He found that the subject who stayed at 70% will be more tired than others. In addition, the subjects in that study found that they felt discomfort while the relative humidity is less than 30% and more than 50%. Relative humidity is an element that will affects human performance. Therefore, relative humidity can't be ignored in determining which parameter will affect the human performance.

Temperature is a measure of the degree of heat intensity. According to Parsons (2003), temperature can be assumed as the average kinetic energy (heat) in a body at a molecular level. It is one kind of physical property of a subject which normally cause cold or hot to the subject. When the temperature increases, then

the temperature of subject is increasing too. Moreover, Parsons (2003) stated that environment temperature such as radiant temperature, humidity, and air velocity can raise intend to exist in body heat storage, and then body thermoregulation will try to give heat loss to achieve heat balance in the body. However, if the heat balance doesn't achieve, it can lead to heat illness such as heat stress. In addition, heat stress is a combination of internal body heat production from doing work and external heat exposure from the environment. Hot conditions will cause the human body under a lot of stress. Long term exposure to extreme hot working environment can lead to perspiration, heat cramps, or heat stroke as well as heat fatigue will be occurred while long term exposure to hot environment, which results in low performance capacity.

1.2. Taguchi Method and Productivity

In 1950 an engineer and a member of the Japanese introduced the method of statistical design of experiments known as the Taguchi method. Taguchi has defined the quality of the product as a function of time lost on the use of the product (Park, 1996). His method is a new experimental strategy which he has used a form of design of experiment (DOE), which has been modified and standardized. (Sahoo et al.2008). Taguchi method of experimental design is the way in which requires a fraction of the full factorial combination. It is also known as orthogonal arrangement which means a balanced design with equal weighting factor levels. As a result, each factor can be evaluated differently based on all factors. By the impact of one factor does not influence the assessment by other factors. Two main objectives are to ensure the Taguchi method to minimize the effects of noise and determine the optimum level of factors that can be controlled based on the concepts firmly. Productivity constructed from elements of production, performance, cost and results (Bain, 1982b) and can be define as a ratio of output and input as well as efficiency per effectiveness (Bain, 1982; Belcher 1987). Buehler and Krishna (1981) argues that productivity is the relationship between the output of goods or services or labor input of non-human resources in a production process which will take into consideration total number of hour's employee's work, the number of operating machines and so on. The concept of productivity is similar to that proposed by Samuelson and Nordhaus (1995) has shown the productivity is considered as output per unit of input. Olaoye (1985) explains that productivity can be defined as the relationship between the outputs produced basic resource inputs, especially labor and capital resources. Eatwell and Newman's (1991) view of input productivity is involved in the production process. According to Scott (1983), efficiency and effectiveness is actually a measure of the performance of a work which is also equivalent to productivity. Many researchers generally agree the word productivity is a concept that describes the relationship between input and output is produced. (Courbais and Temple, 1975; Gollop, 1979; Kurosawa, 1975; Pineda, 1990; Saari, 2006).

2. Methodology

2.1. Procedure

This study was carried out in a closed laboratory room area of approximately 17m^2 (4.91m x 3.53m) and arranged as a workstation similar to an assembly line production in the automotive components industry. It is equipped with air conditioning conditioner system located in the upper wall of the building facing the workstation. Lighting system used is direct illumination using three fluorescent lights from the roof that is designed to adjust brightness rate. Measurement devices should be installed as close as possible to the subject. Brightness measuring device must be contrary to the subject to ensure that the reading taken is the same rate of light received by the eyes of the subject. Studies conducted in the daytime (morning) for data acquisition process for 90 days. All factors being studied and the number of installed units recorded for intervals of 10

minutes for a work shift, ie for 4 hours. To get a reading accuracy of the data, repeated the same method which involves 6 different subjects but using the set of parameters of the same level or DOE. Hemler et al. (1997) also do intervals for 10 minutes also do their research. In addition, the subject will do the work as usual during the study being conducted and measuring equipment installation will not interfere with the movement of the subject to do the work. Conditions are as proposed by Clausen and Wyon (2005). In this study, the room temperature is controlled by the air conditioning system. For fitting fluorescent lights, rate of room brightness can be controlled using a dimmer connected to fluorescent lamps. Through dimmer, specific lighting levels can be achieved. Based on studies conducted by Juslen et al (2007e), fluorescent light (dimmer device equipped) mounted on the top of the subject so that the light source can illuminate the subject directly. In order to control the amount of water presence in the lab, the dehumidifier has been used indirectly and controlled at certain levels. Based on studies conducted by Tsutsumi et al (2007), humidity control device placed near the subject to control the relative humidity research room. Fluorescent lamp mounted on the position of the subject and Heavy Duty Light Meter tool that works to measure illuminance is placed perpendicular to the position of the subject in order to avoid reading errors. System air conditioning and humidity control devices installed in front of the subject, while Quest Thermal Environment Monitors tool that records temperature and humidity are placed to the left of research table.

2.2. Measurement and Parameter Control Method

There are some data that will be taken in the research process which temperature, relative humidity and illuminance. A tool that is used in observation of temperature is Thermal Environment Monitor Quest that considers the Wet Bulb Globe Temperature reading parameters. To measure the level of illuminance, the researchers used the device Quest Heavy Duty Light Meter and displays readings in choosing units of lux. This tool will be read manually with a time interval 10 minutes. Meanwhile, Quest-Thermal Environment device is also used to observe the environment humidity readings automatically in the interval of 10 minutes. For parameter control, room temperature and air velocity conditioner system is controlled by air conditioning and heating air-conditioning system at a temperature of 19^0C and 40^0C which mounted on the laboratory research. Meanwhile, in order to produce the range 200-1000 lux illuminance, fluorescent lighting OGX 254/T5 model with adjustable type was used. The humidity controller ED1838S model was used to control the room controller For this research, a controlled relative humidity range is 40% to 70%. Productivity for this study is to consider the value of the actual output with the target output. According to productivity ratio, data from Company X being gathered as target output (423 unit), item per shift (4 hour) and target output for 10 minutes (18 unit).

3. Result and Discussion

3.1. Experiment Parameters and Research Data

After observed and recorded, all data going through the process of analysis to obtain the relationship between parameters. Analysis was conducted using Taguchi method in which data generated by experiments in orthogonal layout for optimal reading. This study was designed to use the L_9 experiment and the productivity result was obtained as shown in Table 1.

Table 1. The results for the average productivity of workers who have been doing the job for four hours for each repetition.

No of Experiment	Ergonomic Factor			Productivity			Average Productivity (Unit)
	WBGT (^{o}C)	Relative Humidity (%)	Illuminance (Lux)	Repeated 1	Repeated 2	Repeated 3	
1	19	40	200	0.744	0.761	0.748	0.751
2	19	55	500	0.945	0.891	1.011	0.949
3	19	70	1000	0.725	0.721	0.711	0.719
4	24	40	500	1.235	1.238	1.229	1.234
5	24	55	1000	1.244	1.258	1.245	1.249
6	24	70	200	0.894	0.892	0.896	0.894
7	32	40	1000	0.791	0.792	0.796	0.793
8	32	55	500	0.738	0.743	0.742	0.741
9	32	70	200	0.791	0.809	0.797	0.799

3.2. Analysis of Variance (ANOVA)

Analysis of variance is designed to investigate parameters which will influence the nature of the performance. Using the F-Test, the average value for each parameter squared to be determined. The larger the F-Value obtained, the greater the impact of the performance properties which total employee productivity. Table 2 shows the results of analysis of variance.

Table 2. Analysis of Variance S/N Ratio for worker

Simbol	Factor	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
A	Temperature	2	17.975	17.9747	8.9873	72.46	0.014	67.00
B	Relative Humidity	2	3.7578	3.7578	1.8789	15.15	0.042	14.00
C	Illuminance	2	5.0391	5.0391	2.5196	20.31	0.047	18.00
Misc		2	0.2481	0.2481	0.1240			1.00
Total		8						100.00

In statistics, the F-Test can be used to obtain the parameters which have an impact on productivity. In the test-F, mean square (MS) for each parameter is determined. It also shows that the P-value obtained for the three environmental factors of ANOVA for S/N ratio is below the value of 0.05. Through analysis of the Taguchi Method, it is clear that the factors of temperature, humidity and illuminance significantly correlated with the rate of labor productivity. However, the dominant factor is temperature gave a significant difference compared with factors of moisture and lighting. In this case clearly shows that the temperature factors greatly influence the rate of labor productivity.

4. Conclusion

In conclusion, the results from the analysis of Taguchi method analysis of Signal-to-Noise Ratio (S / N) shows the temperature factor is the dominant factor affect the productivity followed by illuminance and relative humidity in which all the factors mentioned have a significant relationship with the rate of productivity employees. Taguchi analysis also shows the optimum level for the temperature factor is 24^{0}C, at

500 lux illumination and relative humidity at 40%. These findings are in line with previous studies explain that the parameters such as temperature rise in the workplace can affect productivity in the workplace (Croasmon, 2004; Lan et al., 2009; Tsutsumi et al., 2007; Niemela et al., 2002 ; Wolkoff & Kjǣgaard, 2007; Juslen, 2007; Bommel et al., 2002b).

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