Sains Malaysiana 42(12)(2013): 1815–1818

Effect of Temperature, Humidity and Illuminance Towards Worker's Performance in Automotive Industry

(Kesan Suhu, Kelembapan, Pencahayaan Terhadap Prestasi Pekerja Dalam Industri Automotif)

MOHD YUSRI MOHD YUSOF, BABA MD. DEROS* & AHMAD RASDAN ISMAIL

ABSTRACT

Working environmental conditions in automotive industry are very challenging to the human workers. Meanwhile, products quality is very much dependent on workers' health, safety and comfort in their working environment. Environmental factors, such as temperature, illuminance and humidity levels have significant effect on workers' performance at the production line. In this experiment, temperature, humidity, illuminance levels and productivity rate were observed in a control room. An automotive manufacturing firm production line was chosen to be simulated in the control room to observe the temperature, relative humidity, illuminance and worker's productivity rate. The experimental data collected was analyzed using Response Surface Method (RSM). RSM is an analysis technique, which combined statistical systems and mathematical methods. It can be applied for research and development, reform and optimize a process, which involves several design variables. As a result, the combined effect of temperature, illuminance and humidity toward productivity can be clearly seen. Optimum environmental factor cannot be predicted using first order RSM analysis because it gives low reliability for obtaining the optimum level. Thus, a second order RSM analysis was generated for obtaining the optimum level of environmental factors.

Keywords: Environmental; humidity; illuminance; response surface method; temperature

ABSTRAK

Keadaan persekitaran tempat kerja dalam industri automotif sangat mencabar para pekerja. Sementara itu, kualiti produk sangat bergantung kepada keselamatan, kesihatan dan keselesaan pekerja di persekitaran tempat kerja mereka. Faktor persekitaran seperti suhu, pencahayaan dan tahap kelembapan mempunyai kesan yang signifikan ke atas prestasi pekerja di bahagian pengeluaran. Dalam eksperimen ini, pengaruh suhu, kelembapan, pencahayaan dan kadar produktiviti telah diperhatikan di dalam sebuah bilik uji kaji terkawal. Satu bahagian pengeluaran firma pembuatan automotif telah dipilih untuk disimulasikan bagi memerhatikan pengaruh suhu, kelembapan relatif, pencahayaan dan kadar produktiviti pekerja. Data eksperimen yang dikumpul telah dianalisis dengan menggunakan Kaedah Tindak balas Permukaan (RSM). RSM merupakan teknik analisis yang menggabungkan sistem statistik dan kaedah matematik. Ia boleh digunakan bagi tujuan penyelidikan dan pembangunan, penggubalan dan proses pengoptimuman yang melibatkan pelbagai pemboleh ubah. Hasilnya, kesan gabungan suhu, pencahayaan dan kelembapan ke arah produktiviti dapat diperlihatkan dengan jelas. Faktor persekitaran yang optimum tidak boleh diramalkan dengan menggunakan analisis RSM tertib pertama kerana ia memberikan tahap keboleharapan yang rendah untuk mendapatkan tahap optimum. Oleh itu, analisis RSM tertib kedua perlu dijana untuk mendapatkan tahap optimum faktor persekitaran.

Kata kunci: Kaedah tindak balas permukaan; kelembapan; pencahayaan; persekitaran; suhu

INTRODUCTION

Automotive industry is an important industry to the Malaysian economy. Contribution of this sector to the economy is large and is closely related to the manufacturing and service sectors. Manpower remains a vital resource that contributes to productivity. Higher productivity means more output is gained with the same input source. In general, work quality, management and working conditions are identifiable factors that capable of increasing workers' productivity (Prokopenko 1987). In this study, the authors have investigated environmental factors, such as illuminance, relative humidity and WBGT influence towards workers' productivity. These factors contribute significantly towards safety, health and performance in the workplace and daily life (Dul & Weerdmeester 2008). According to Dua (1994), lower emotional health is manifested in the form of psychological distress, depression and anxiety; whereas, lower physical health is manifested as heart disease, insomnia, headaches and infections. In other words, these environmental factors can affect the comfort level of production operators to perform their jobs. Ettner and Grzywacz (2001) associated the work environments with perceived effects of work on health. Therefore, in this paper, the authors conducted a study to determine the

relationship between the effects of these environmental factors on the productivity of workers. Application of Response Surface Method (RSM) through MINITAB software was used to obtain the environment parameters that will optimize the productivity of workers. According to Myers et al. (2009), RSM is an empirical model that can be used to obtain the relationship between various parameters and find the desired parameter of interest. This is a successive strategy to build and optimize empirical model.

METHODS

SUBJECT SELECTION

A total of 6 adults from both genders were used as subjects, which is in-line with Goldman (2005) suggestion that states the minimum number of subjects for a study that involve human performance is 6 persons. All subjects were volunteers, they were paid for taking part in the experiments. Subjects' physical characteristics, such as age, height, weight and sex were recorded for analysis. Subjects do not have any experience in this task and they were trained for a week before performing the actual study. They performed their tasks and considered to be undergoing the same physical effects.

EQUIPMENT

Temperature readings in this study were measured based on Wet Bulb Globe Temperature (WBGT). This WBGT was measured using QuestTemp^{0}36 as shown in Figure 1. In addition, this equipment was also used to measure relative humidity level in the study. Meanwhile, illuminance level was measured by using Heavy Duty Light Meter as shown in Figure 2. The three environmental factors readings were recorded at every 10 min interval.

TESTING CHAMBER

The study was conducted in an environmentally controlled room with an area of about 17 m^2. The room is equipped with an air-conditioning system, variable lighting control switch and dehumidifier to control the environmental factors such as WBGT, illuminance and relative humidity. Placement of the parameter control equipment are shown in Figure 3.

EXPERIMENTAL DETAILS

Six subjects performed the assembly work to assemble contact springs to the body switch followed by wire harness. They performed their tasks and are assumed to be exposed with the same physical effects. The study was run

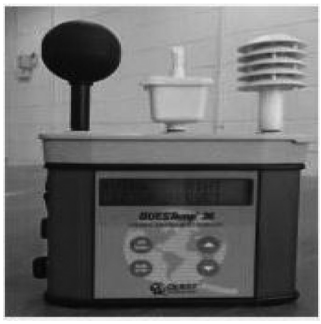

FIGURE 1. QuestTemp°36

FIGURE 2. Heavy duty light meter

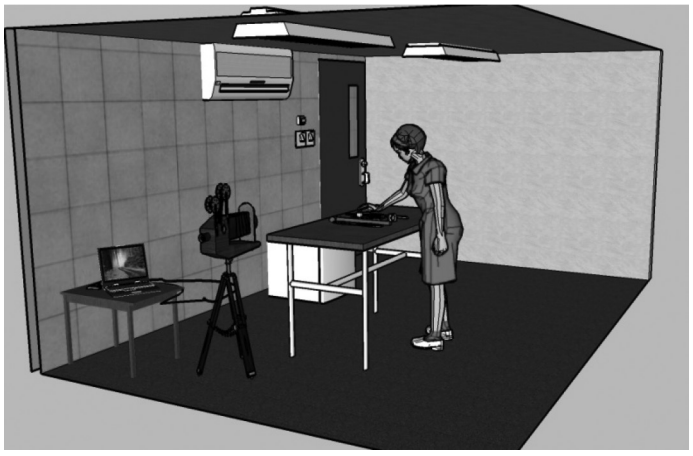

FIGURE 3. Plan of study location

during the day for 45 days from January to March 2011. All environmental factors and number of completed units were recorded at 10 min time interval for a day work shift, which is 4 h to ensure that all the parameters are controlled in a certain range. Measuring equipment were placed at a certain distance without affecting the operation of assembly work. The measuring equipment were calibrated, prior to starting the data collection process. The target time for a completed unit is 1.8 min. Productivity of workers is the ratio of actual output to targeted output. Therefore, in this experiment productivity was calculated using (1).

$$\text{Productivity} = \frac{\text{Actual output}}{18}. \quad (1)$$

DATA ANALYSIS

Data were analyzed using first order analysis of RSM via MINITAB software in order to study the relationship of each factor towards worker's productivity. Further optimization of environmental factors were carried out through MINITAB to determine the optimum environmental factors that can produce productivity of 1.0.

Results and Discussion

All coefficients in the model is then converted into a mathematical equation in real terms as shown in (2):

$$y = 1.224 - 0.008035x_1 - 00.002427x_2 + 0.0001902x_3 \quad (2)$$

where y is the productivity, x_1 is WBGT (°C), x_2 is relative humidity (%) and x_3 is lighting level (lux).

From Table 1, it was found that coefficient of illuminance (p=0.000), coefficient of WBGT (p=0.001) and coefficient of relative humidity (p=0.023) showed to have a significant effect on the worker's productivity. This indicates that any changes in WBGT value, relative humidity or illuminance will cause significance changes in the workers' productivity in the first order analysis. Meanwhile, if viewed in terms of coefficient of regression, R^2, which is 57%. This value indicates the extent to which the validity of the built model with existing model in determining the dependent variable. Given the value of R^2 is quite low at 0.57; therefore the model validity is still questionable and thus not really suitable to be adopted. Moreover, the value of coefficient of Lack of Fit is 0.000. The value of Lack of Fit suggests that there is huge gap between the real productivity and analyzed productivity. Therefore, the result of the first order analysis can be doubted. Since this is a preliminary study, so the analysis must proceed to the development of second order model for more accurate findings.

Table 2 shows the predicted regression coefficients second order model. From Table 2, it was found that coefficient of illuminance (p=0.000), coefficient of WBGT (p=0.000) and coefficient of relative humidity (p=0.000) showed to have a significant effect on the worker's productivity. This indicates that any changes in WBGT value, relative humidity or illuminance will cause significance changes in the workers' productivity in the second order analysis at 95% confidence interval towards productivity value. Meanwhile, if viewed in terms of coefficient of regression, R^2, which is 96%. This value indicates high validity of the built model with existing model in determining the dependent variable. Given the value of R^2 is approaching towards 1; therefore this model can be accepted and adopted to generate study plot and optimization. In this study, the value of coefficient of Lack of Fit is 0.151 and shows the model is not significant for Lack of Fit factor. The value of Lack of Fit suggests that there is small gap between the real productivity and analyzed productivity. Therefore, the result of the second order analysis can be accepted.

All coefficients in the validated model were then converted into a mathematical equation in real terms as shown in (3):

$$y = 1.961908 + 0.00573566x_1 - 0.0203483x_2 - 5.58281e^{-4}x_3 - 2.6557e^{-4} + 7.4446e^{-5} + 1.51106e^{-7} \quad (3)$$

where y is the productivity, x_1 is WBGT (°C), x_2 is relative humidity (%) and x_3 is lighting level (lux).

OPTIMIZATION OF ENVIRONMENTAL FACTORS

The objective of optimization process was to find out the factors combination set that fulfil the requirement of each studied factor. The environmental factors optimization process was performed using the MINITAB software to find out the productivity value that equal to 1.0.

TABLE 1. Predicted regression coefficients for first order model

Term	Coefficient	SE Coefficient	T	P
Constant	0.9995	0.006937	144.086	0.000
WBGT	-0.0522	0.009499	-5.498	0.000
Relative humidity	-0.0364	0.009499	-3.833	0.000
Illuminance	0.0761	0.009499	8.012	0.000
S=0.0658092	R-Sq = 57.55%	Lack of Fit = 0.000		

TABLE 2. Predicted regression coefficients for second order quadratic model

Term	Coefficient	SE Coefficient	T	P
Constant	0.9837	0.0049	201.038	0.000
WBGT	-0.0522	0.0029	-17.431	0.000
Relative humidity	-0.0364	0.0029	-12.152	0.000
Illuminance	0.0761	0.0029	25.398	0.000
S=0.020759	R-Sq = 96.09%	Lack of Fit = 0.151		

Productivity value that equal to 1.0 occurs when the real productivity is the same with the targeted productivity. In this study, the optimal value of productivity can be achieved by combining WBGT 24.9°C, relative humidity 47% and illuminance 478.51 lux, however, it need to be noted that the relationship is weak. The WBGT comfort level is between 24 and 27°C and this is in-line with the ISO7730:2005 study results. Tsutsumi et al. (2007) recommended the comfort level for humidity is in the range of 40 to 50%. According to Juslén et al. (2007), the minimum requirement for illuminance in an assembly line for electrical industry is 500 lux. So, the illuminance level of 441.51 lux is inadequate for an electrical component assembly line at an automotive industry.

CONCLUSION

The paper main objective was to study the effects of environmental factors (WBGT, relative humidity and illuminance) towards the workers' productivity at the assembly production line in an automotive industry was achieved through the research. A mathematical model was developed to relate the relationship of each factor on the worker's productivity. Environmental factors that can provide optimal productivity value of 1.0 are: WBGT 24.9^0C, relative humidity 47% and illuminance 478.51 lux. In conclusion, it was empirically shown that environmental factor such as: WBGT, relative humidity and illuminance have significant impact on workers' productivity.

ACKNOWLEDGEMENTS

The authors would like to thank Universiti Kebangsaan Malaysia under UKM-GUP-2011-039 for their support in providing a research grant for a project Design of an Ergonomics Car Driver's Seat Using Malaysian Anthropometrics Data. We also thank the research assistants and the Metal Industries Company for their assistance and cooperations given to the authors in conducting this study.

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Mohd Yusri Mohd Yusof & Baba Md. Deros
Department of Mechanical and Materials Engineering
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia
43600 Bangi, Selangor
Malaysia

Ahmad Rasdan Ismail
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
26600 Pekan, Pahang
Malaysia

*Corresponding author; email: hjbaba@eng.ukm.my

Received: 2 April 2012
Accepted: 18 June 2012