

Impact of Environment Ergonomics on the Productivity of Office Workers.

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Abstract: The effect of office indoor room temperature and illumination has an influence on the performance and productivity of office workers. A computerized neurobehavioral test (NBT) has been proposed for the evaluation of office workers' performance. Environmental factors such as indoor temperature and indoor workstation illumination have been investigated at three levels. A field lab to emulate an office has been created. In controlled condition of environmental factors, the neurobehavioral test has been conducted with ten volunteers. The response time and the number of errors in each test have been recorded. A randomized block factorial design was used to analyze the responses of office worker's productivity. The results revealed that the independent and interaction effect of temperature and illumination have significant effect on the office workers' productivity. The effect of indoor room temperature has more influences than the effect of illumination. Similarly block effect of both the responses (Reaction time, Errors) also significant on the productivity of office workers. The optimum level of indoor room temperature (21°C) and illumination (1000lux) have improved the performance and productivity of office workers.

Key words: Office environment, Productivity, Indoor room temperature, Illumination, Performance.

INTRODUCTION

An office is a place where professional duties and administrative work is carried out in the organization building. The work depends on the type of business, but it will usually include using computers, communicating with others by e-mail, telephone or fax, keeping records and files etc., in hard and soft format. Features of an office such as people, building space, equipment, furniture and the environment, must fit together well for workers to feel healthy and comfortable and to be able to work efficiently and productively. More than 50% of the world's population currently works in some form of office.

Mostly the developing countries like India and China are having more population. They are working with machines and majority of them are from computer related sector. In the Information Technology (IT) and Information Technology Enable Services (ITES), workers are dependent on the computers. More IT and ITES sectors are increasing in India. The study on performance, health and wellbeing of office workers productivity is an essential to improve it. Indoor environmental quality has an important role to play in office worker's performance, health and wellbeing. The effect of environmental factors brings down the health and efficiency of office workers. The primary objectives of this study are to improve productivity and performance. Any study on these environmental factors can potentially benefit millions of people around the world. Hence an attempt has been made to carry out a study on the performance of office workers by considering the indoor office environment.

Literature Review:

An essential requirement of office worker's productivity improvement is indoor environmental quality. The indoor room temperature and illumination are the most important vital factors that affect the performance of office workers. Li Lan., Pawel Wargocki., Zhiwei Lian., (2011) stated that the thermal discomfort caused by elevated air temperature had affected the performance of office workers. The performance decreased when the thermal condition in the indoor room was deviated from the neutral conditions. While comparing with neutral condition, the performance decreased at the slightly cool or slightly warm environment condition. Roelofsen P. (2002) explained the office workers spend 90% of the time in indoor environment. Indoor room environment has direct relation with the office worker's health and wellbeing. 10 % of office worker's performance may be increased by achieving the best indoor environmental quality. Li Lan, Z.W. Lian, L. Pan, Q. Ye, (2009) studied the office workers had more negative emotions and had to use more effort to maintain performance under slightly warm or slightly cool environment conditions. Environmental factors have imperative role to play in the effectiveness of office workers. There have been no standard procedures to evaluate office worker's performance. Li Lan, Z.W. Lian, (2009) was proposed neurobehavioral approach to evaluate the effect of office indoor room temperature on the office worker's performance.

Niemela et.al., investigated the performance of call center workers has less performance, when the temperature was above 25°C. Performance has been reduced to 2.4% per degree temperature increase between

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21.9⁰C to 28.5⁰C. Similarly call center worker’s Performance was reduced 5 – 7 % while the indoor room temperature exceeds 25⁰C. Federspiel, C., Liu ,G., Lahiff, M., (2002) measured the productivity of call center workers in the US. Within the comfort zone, varying the room temperature had no significant effect on performance of the workers. Indoor room temperature at more than 25.4⁰C was affected the performance of office worker. During the high indoor room temperature, the lower work performance was shown by the office worker.

Charles, R., Reardon, J.T., Magee, R.J, (2005) stated that indoor air quality and thermal comfort are most important factors for the worker’s performance, satisfaction and wellbeing. Poor office environmental conditions can affect the worker’s visual discomfort and thermal discomfort. This may affect the health and wellbeing of workers. Very low and very high indoor room temperature and humidity can dissatisfy the workers and also create health problems. Air conditioned office aim to provide a thermally accepted environment for office worker’s comfort and health (Kosonen, R., Tan, F., 2004). Henri, J., Marius, W., Tenner, A., (2007) clearly explained that proper lighting was an important factor that influence on the productivity. The effect of increased or decreased illumination affects the productivity, psychological and biological effect of workers. The employees preferred high illumination rather than low.

Pilcher, J.J., Eric, N., Caroline, B., (2002) stated that very hot and cold temperature conditions had effect on the performance of workers. These room temperatures have negative impact on a wide range of cognitive related task. In cold condition [10⁰C] the workers performance had decreased at an average of 13.91%. Similarly in hot condition [32.22⁰C], the performance had reduced at an average of 14.88%. Hiroshi et.al. (2006) has reported that the higher illumination has significant effect on the task performance of office workers productivity. More than 9% performance improvement was achieved in higher illumination. Parsons., K.C., (2000) has stated that the study of workers response on environmental factors has an important role to play in office Performance. The thermal response of the body has consequences for the workers health, comfort and efficiency. As heat stress increases there would be an effect on mental performance. Similarly the effect of cold on human performance also has significant effect. Young S. Lee., Denise A.Guerin., (2010) explained that the indoor air quality enhance worker’s job performance in enclosed private offices. Good indoor air quality and light have more significance on the productivity of office workers.

Environmental factors have more related influence on productivity of office workers. Good working environment is an essential requirement for the office workers. Indoor room temperature, illumination are the factors which is affecting the indoor environmental quality (IEQ) of an office. If IEQ affected in the office, the response of office workers will also be affected. This leads to the negative performance of office worker. So the productivity of office workers also decreased. The relation between indoor environmental factors on productivity of office worker is shown in the fig1.

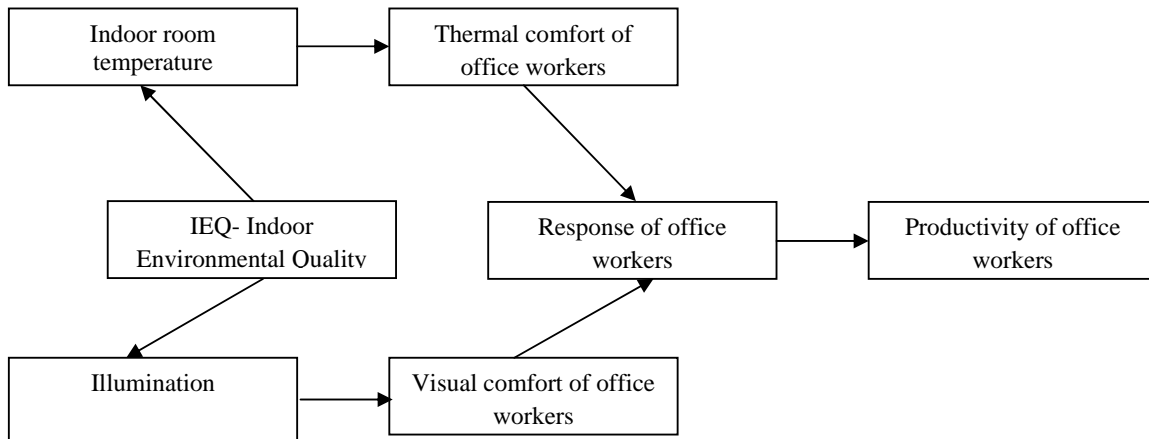


Fig. 1: Relation between Indoor Environment factors on productivity.

Earlier researchers had given enough contribution to physical factor and work place design that affecting performance and productivity of office workers. The study on indoor room temperature on the performance of workers has been studied by researchers. Similarly the effect of illumination also studied already. The combined effect of environmental factors such as temperature and illumination on the productivity of office workers has to be studied. Hence indoor room temperature, illumination have been investigated in this paper.

Methodology:

A field lab to emulate an office has been created. The experiment was carried out in the field lab (L × W × H= 13 × 9 × 5 m) which has a controlled condition of indoor office environment. Ten voluntary participants (10 men) sat in the ergonomically designed VDT workstations (fig 2). Each workstation had a table, a chair, and a personal computer of equal configuration (Intel Pentium(R) dual CPU, E2200 @ 2.20 GHz processor 1 GB RAM). USB optical mouse and multimedia keyboard was connected with USB2.0 of the personal computer. The workstation specifications are set based on height of the individual volunteer.

For example a person with 157 cm height requires the following specifications:

The mean distance between eye to screen was 60 cm.

Seat (revolving and height adjustable) height from the floor was 38cm.

Sitting eye height from floor was 110cm. Sitting elbow height was 59cm.

Angle of LCD monitor was 10° - 20°.

Necessary software had been installed before the commencement of the training. The field lab room temperature has been controlled by air conditioner. Temperature may be adjusted from 17°C to 28°C using the controls available in the air conditioner. Illumination has been controlled by regulator for focus mercury lamps and adjusting number of fluorescent lamp using on /off switch. By this way illumination may be adjusted from 500 lux to 1000 lux. The illumination level was tested at the workstation's keyboard.

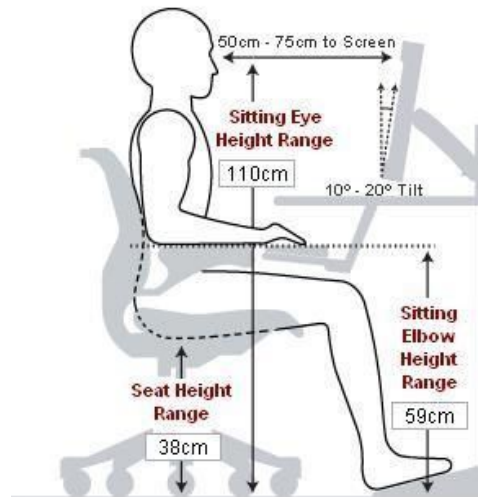


Fig. 2: Ergonomically designed VDT work station.

Participants:

Ten undergraduate engineering students were trained in the field lab and used as office workers. Participants are all of same age group (18 years old). Wages have been given to all participants at a fixed rate per hour. To increase the performance of the participants a financial appreciation was given depends on their performance. Among the participants, whoever completed the task in minimum duration with minimum error was given an incentive at the rate of double the wages. All the participants were advised to take rest during previous night. Before the commencement of the experiments the participants have given their consent for their participation. All participants in the field lab sat as per the schedule shown in table 1. First two hours one temperature level (A₁) was fixed and illumination levels (B₁/B₂/B₃) has been changed in each 40 mins. When beginning of each treatment combination, 10 mins adaptation time (ADT) has been given to the participants. After the adaptation time the neurobehavioral test was conducted as per the schedule. One hour lunch break was given to all the participants. Actual field lab was shown in fig 3.

Neurobehavioral Test:

In our research work, Neurobehavioral approach was adopted to evaluate the effect of indoor temperature, illumination on the office worker's productivity. We have computerized the neurobehavioral test. This test consists of twelve parts. They were letter search, direction, object overlapping, memory span, picture detection, figure-digit, logical sequences, comprehensive reading, numerical addition, logical conclusion, picture match and reasoning. These tasks are implemented in. NET computer language.

Table 1: Time duration of an experiment day

	ADT	A ₁ B ₁	ADT	A ₁ B ₂	ADT	A ₁ B ₃	ADT	A ₂ B ₁	ADT	A ₂ B ₂	ADT	A ₂ B ₃	Break	A ₃ B ₁	ADT	A ₃ B ₂	ADT	A ₃ B ₃
		Test		Test		Test		Test		Test		Test	Lunch	Test		Test		Test
9A M	9.1 0	9.4 0	9.5 0	10.2 0	10.3 0	11. 0	11.1 0	11.4 0	11.5 0	12.2 0	12.3 0	1.0 0	2.0 0	2.3 0	2.4 0	3.2 0	3. 3 0	4P M
	Time of the day (12 hours clock)																	
	Legend: ADT- Adaptation time – 10 mins										Test – Neurobehavioral Test – 30 mins							
	A ₁ B ₁ , A ₁ B ₂ , A ₁ B ₃ , , etc., - Treatment level of combinations																	



Fig. 3: Picture of field Lab

Letter search was perception based visual search. Direction was perception based visual and hand reaction test. Object overlapping was perceptual spatial orientation test. Memory span was a concentration and memory recall test. Picture detection was a learning and memory test. Figure -digit was modalities test for checking the learning and memory. Logical sequences were thinking and executive function test. Comprehensive reading was thinking and executive function test. Numerical addition was mathematic procedures, response test. Logical Conclusion was conditional conclusion test. Picture match was thinking and executive function test. Reasoning was logical test. The above mentioned twelve tests were conducted.

Experiment Procedure:

Indoor temperature, relative humidity in %, and room illumination have been measured every 15 mins in the field lab. Temperature and relative humidity have been measured by digital hygrometer. Illumination was measured by digital lux meter. Time taken to complete the tasks has been measured by the timer set in the computer programme. The measurement results can be retrieved from the database folder of respective neurobehavioral test. The illumination was measured at the keyboard in the VDT workstation of each participant. Indoor temperature and relative humidity has been randomly measured near to each work station.

All the 10 participants were present on the day. The different combination of indoor room temperature (17°C, 21°C, 28°C) and illumination levels (500, 750, 1000 lux) has been set in the field lab. The illumination and temperature were recorded during the test conducted for each treatment combinations. Treatment combinations were randomly selected. The response time (Y₁), error (Y₂) has been recorded in the format as shown in table 2.

Table 2: Schedule of Experiments (output: Response time – Y_1 and Number of Errors – Y_2)

Subject	A1			A2			A3		
	B1	B2	B3	B1	B2	B3	B1	B2	B3
S1									
S2									
S3									
....									
S10									

Data Collection and Analysis:

Data has been collected from .NET software language database file. From this database file the response time and error rate was taken for analysis. The output total response time (Y_1) of each volunteer has been noted in the format as shown as in the table 2 with respect to the treatment combination. MINITAB 16 was used for statistical data analysis. 95% confident interval level maintained for the data analysis. Randomized block factorial design (Montgomery D.C, 2009) was proposed for data analysis. Table 3 and 4 shows all the independent and combined effect of temperature, and illumination for reaction time response (Y_1)and Error (Y_2) respectively. Fig 4a, 4b shows the residual plots for Reaction time and error.

Table 3: Test result for Reaction time (Y_1)

Source	F_0	$F_{0.05, v1, v2}$	MS	F table value	Comparison	Effect	% of contribution
Temperature (A)	111.77	$F_{0.05, 2, 72}$	110043.33	3.07	>	S	40.92
illumination (B)	57.54	$F_{0.05, 2, 72}$	56655.30	3.07	>	S	21.07
AB	13.56	$F_{0.05, 4, 72}$	13348.33	2.45	>	S	9.93
BLOCK	9.05	$F_{0.05, 9, 72}$	8912.25	1.96	>	S	14.91

Table 4: Test result for Error (Y_2)

Source	F_0	$F_{0.05, v1, v2}$	MS	F table value	Comparison	Effect	% contribution of
Temperature (A)	29.15	$F_{0.05, 2, 72}$	1276.74	3.07	>	S	21.595
illumination (B)	8.40	$F_{0.05, 2, 72}$	368.04	3.07	>	S	6.225
AB	7.97	$F_{0.05, 4, 72}$	349.08	2.45	>	S	11.809
BLOCK	10.11	$F_{0.05, 9, 72}$	442.75	1.96	>	S	33.699

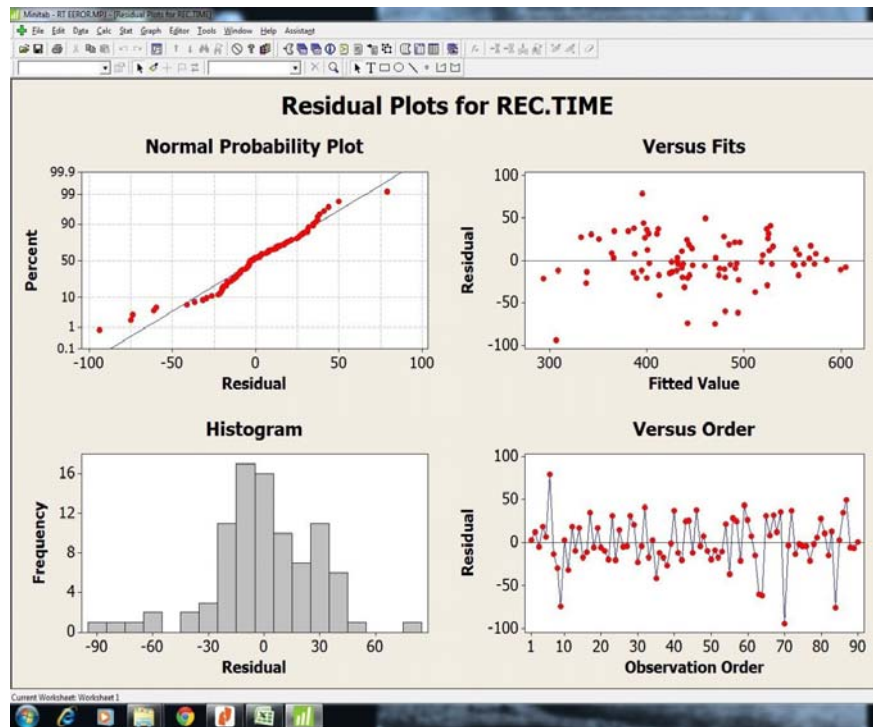


Fig. 4a: Residual plot for reaction Time

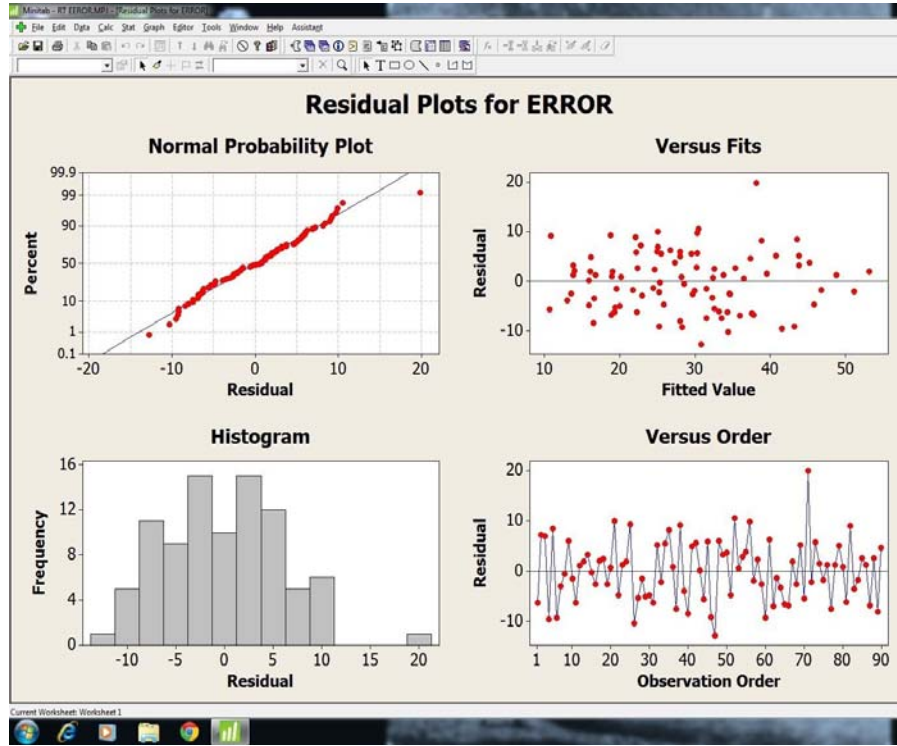


Fig. 4b: Residual plot for Error

Multi Response Performances:

In this experiment two output responses such as Reaction time (Y_1) and Error (Y_2) have been investigated. The output reaction time and error for each volunteer can be recorded from the database folder in the .NET file folder. The multi response performance index may also be identified by using Assignment of weights (Krishnaiah, K, Shahabudeen, P, 2012). These two factors at each three level with two responses Reaction time (Y_1) and Error (Y_2) has been analyzed by Assignment of weights method. In this method only 9 selected trials has been taken for analysis. These trials have been mentioned in the table 5. The optimum level of each factors have also been identified for the best performance. The weights and Multi response performance index (MRPI) Values is shown in the table 5. The level totals of MRPI values and optimum levels of each factor are shown in table 6. The least error with short duration to complete the task was the objective to improve the performance. So “smaller the better” was followed for both the responses Y_1 and Y_2 . Multi Response Performance Index for Y_1 and Y_2 has been shown in fig 5. The least value of 298.03 (trail 6 in table 5) was considered as optimum level of multi response.

Table 5: Weights and MRPI Values for the Experiment

Trial	Factor		Responses		weights of Y_1	weights of Y_2	MRPI
	A	B	Y_1	Y_2			
1	1	1	5254	265	0.128161971	0.103354134	700.75
2	1	2	5579	415	0.136089767	0.161856474	826.42
3	1	3	4442	395	0.108354677	0.154056162	542.16
4	2	1	3968	262	0.096792292	0.102184087	410.84
5	2	2	4333	230	0.105695817	0.089703588	478.61
6	2	3	3394	209	0.082790584	0.081513261	298.03
7	3	1	5268	207	0.128503476	0.080733229	693.67
8	3	2	4431	259	0.108086352	0.101014041	505.09
9	3	3	4326	322	0.105525064	0.125585023	496.94

Table 6: Level totals of MRPI and Optimum Level for each factor

Factors	Level			Optimum Level
	1	2	3	
Indoor room Temperature	2069.33	1187.48	1695.70	A_2
illumination	1805.26	1810.12	1337.13	B_3

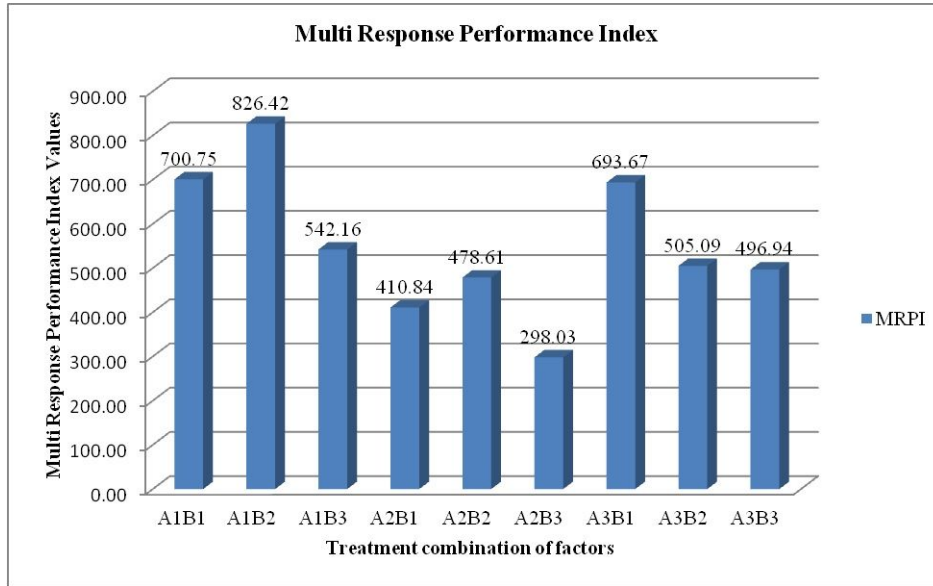


Fig. 5: Multi Response Performance Index

Discussion: Reaction time response (Y_1):

The study result of reaction time indicates that the indoor room temperature has significant effect on the office worker’s productivity. Similarly the effect of illumination also has significant effect on the performance of office workers. Referring to the table 3, from the study result it may be noted that all the independent and combined effect of temperature, illumination have significant effect on the performance of office workers. Particularly the temperature has more significant effect than the effect of illumination. The effects of indoor room temperature has 40.92% of contribution on the office worker’s performance. Similarly the illumination has 21.07% influence of contribution on the productivity of office workers. The combined effects of factors have 9.93% contribution on the productivity of workers.

Error response (Y_2):

From the table 4, the indoor room temperature has 21.59% of contribution on office worker’s output error response. Similarly illumination has 6.22% of contribution on office worker’s productivity. Interaction effect of indoor temperature and illumination has also significant effect (11.8%) on performance. Block effect of the error response has much more contribution (33.69%) on this experiment. This shows the volunteers were concentrating on time to complete the task, not concentrate on error. So the block effect on error was more.

Multi response: Reaction time and Error response (Y_1 and Y_2):

The percentage of contribution of indoor room temperature much higher than the illumination on the both responses Y_1 and Y_2 . Block effect has 33.69% of contribution in error response (Y_2). Table 5 shows that the weights and MRPI Values for multi response Y_1 and Y_2 . The Combined factors of optimum level A_2B_3 has least value of MRPI. Indoor room temperature of 2nd level ($A_2=21^\circ\text{C}$), Illumination of 3rd level ($B_3=1000\text{ lux}$) given best performance of office workers. The graphical illustration of multi response performance chart is shown in fig 6

Optimum Level: A_2B_3 . (21°C , 1000lux):

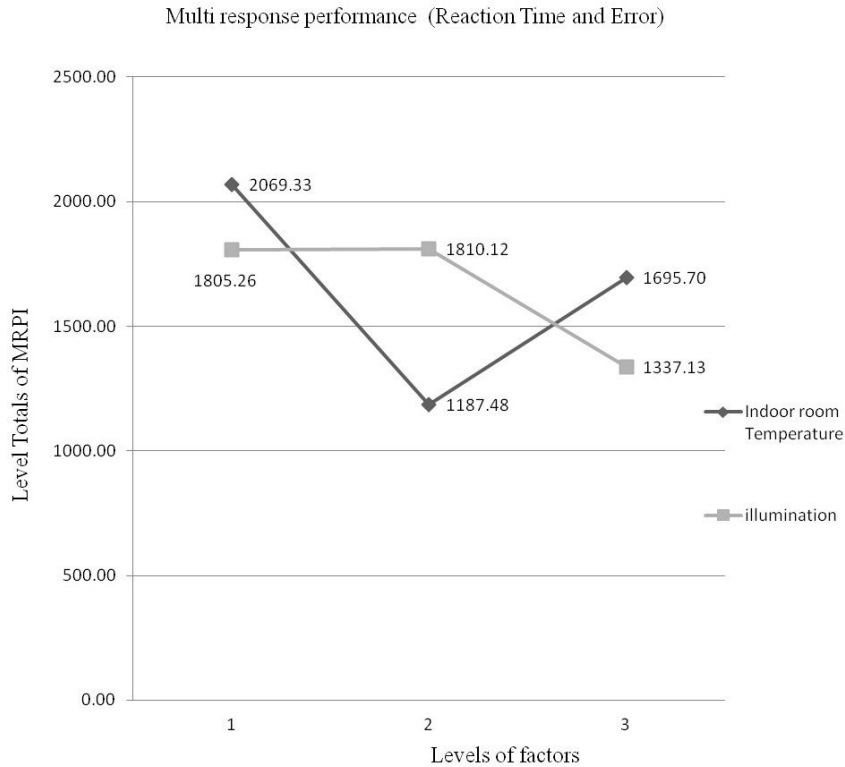


Fig. 6: Multi Response Performance Chart

Conclusion:

From the study result, the temperature and illumination are independently significant on the productivity of the office workers have been understood. It may further be noted that the indoor room temperature has more significant effect than either independent or combined effect of illumination. From this, it may be concluded that the impact of indoor room temperature is more on the office worker’s performance than the effect of illumination. Block effect of the error response was more contribution on office worker’s performance. While considering the reaction time response, the block effect has very low contribution. But the block effects of both the responses Y_1 and Y_2 have significant effect.

From this, we can understand that the volunteers are more concentrate to do the NBT in short duration. So that reaction time response has less contribution of block effect obtained from this experiment. They were not cared about the errors. So the block effect was more in error response analysis. More over some of the volunteers were not wasting for thinking answer for unknown question in their test duration. They responded immediately to answer any one from the given choice. All the volunteers were completed the task before the time limit. But some of the volunteers had done more error in NBT. For this reason the block effect was more in error output response. The optimum level of this two factors (A_2B_3 ie., 21°C, 1000lux) may improve the productivity and performance of office workers.

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