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Investigating Indoor Air Quality for the Split-Type Air Conditioners in an Office Environment and Its Effect on Human Performance

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Abstract: *Due to presence of occupants in the specified volume of design offices the oxygen content goes on decreasing as people continuously inhale oxygen and generate carbon dioxide thus reducing oxygen level and increasing carbon dioxide level which is detrimental for human health. For a particular office space the number of occupants and their time of occupancy adversely affect the performance level of the occupants. Medical reports show that if carbon dioxide concentrations are above the specified levels as mentioned in ASHRAE guidelines, decision-making ability of human will be adversely affected. The present study has been conducted for measurement of carbon dioxide levels in air conditioned industrial design centers for different volumes, different time and different occupancy in generation of carbon dioxide. In the present case the Taguchi method is used to evaluate the parameters which affect the health and performance of the occupants working in design centers. It has been observed that number of occupants, volume and time of occupancy play significant role as compared to temperature of the design center. Based on the results obtained from analysis it is suggested to automate proper air ventilation while using small air conditioners.*
Keywords: *Indoor air quality, split air conditioning, carbon dioxide, Taguchi, human performance.*

I. Introduction

Due to global warming the people working in design centers are found to be working in air conditioned environment. The studies proved better output from these employees in comparison to those in non air conditioned environment, specially in Indian scenario as air conditioned environment provides better thermal comfort on the cost of energy consumption (Ng, Malcolm Owen, et al., 2011). People working in such organizations have to work for 6-9 hours in such built environment inside buildings. International standards have been suggested for maintaining indoor air quality in such enclosures (Andrew, 2015). Medical studies also prove the adverse effects which people are also aware (Madureira, et al., 2015). There is a need to design and develop such appropriate control strategies which reduce the exposure to poor indoor air and thus minimizes its adverse effects on health. Role of designer as a manager is required for focusing on the micro-environment around a human body at that workplace and considering this environment in terms of providing thermal comfort and inhaled air quality by suitable methods and alterations (Melikov, et al., 2015). For any organization good air quality is thus considered to be one of the key ways of gaining competitive advantage which is hard to imitate if the skills are fully utilized. Any gaps and areas for intervention are removed for developing healthier environment which may lead to better steer on skill. Ecological models are particularly applicable to physical activity because the behavior must be done in specific physical settings. Environmental and policy variables are associated with physical activity behaviors of young people and adults (Sallis, et al., 1998). The human performance is mainly dependent upon factors such as headcount or payroll costs (Hiltrop, et al., 1994). One must be aware of the conditions which affect human health and do a role so as to avoid adverse effect on employees' decision making performance. It is well known that the carbon dioxide content in the atmosphere is increasing alarmingly and in fact it is one of the indices of environmental degradation(Nawaz, I., et al 2003). Health is more affected by carbon dioxide at 1000 ppm as compared to 600 ppm in working environment (Satish, et al., 2012). Total quality management including human resource and reengineering is required for success of any organization (Schonberger, 1994). For this purpose the present study has been carried out for proper design conditions especially for people working in small unit air conditioned environment. Split type air conditioners are preferred in offices where less number of people have to be accomodated but these designs do not have ventilation access which is very much essential as per ASHRAE and OSHA standards (Lin, et al., 2011). In a similar work (Shin, et al., 2005) observed that the carbon dioxide concentration is a function of ventilation rate and the number of occupants in a test room and a real classroom thus effect the performance of the employee. Taguchi method was found to be superior for evaluation of performance optimization of indoor air quality based on health, safety, environment and ergonomics (Azadeh et al., 2015).

II. Experimentation and methodology

The experiments were conducted based on design of experiments (DOE) as per Taguchi method (Kalsi, et al., 2016). Designing should be such that it remains unaffected by uncontrollable environmental factors. The signal (product quality) to noise (uncontrollable factors) ratio (i.e; S/N ratio) should be high. This project basically studies the maximum deviations possible in terms of carbon dioxide levels in ppm in air conditioned workplaces. To study the levels of carbon dioxide inside enclosed industrial workplaces DOE layout was thus matrixed for the purpose of determining carbon dioxide levels inside enclosed spaces. This data obtained from the combinations of various parameters can thus be used as a solution for minimizing carbon dioxide level in such workplaces installed with split type air conditioners. Various process parameters and their levels considered for design center workplaces are shown in Table 1.

Table 1: Parameters and their levels for industrial design centers

Sr No	Symbol	Parameters	Levels			Units
			I	II	III	
1	A	Volume of the enclosed space	85	110	170	m^3
2	B	No of People	10	15	20	-
3	C	Time of occupancy	4	6	9	Hours
4	D	Temperature	23	25	27	°C

In Table 1,

A = Volume of the enclosed space is 85 m3, 110 m3 and 170 m3 for three levels ie. level 1, level 2 and level 3 respectively.
B = Numbers of people are 10, 15 and 20 for three corresponding levels.
C = Time of occupancy in hours by the people for three corresponding levels is 4, 6 and 9.
D = Temperature of the three corresponding levels is 23, 25 and 27 ^{0}C.
The parameters A, B, C and D are matrixed in the form of L-27 orthogonal array as per Taguchi's method.

III. Results and discussion

The different levels of carbon dioxide for different volume, time, occupancy and temperatures were obtained as shown in Table 2. On the basis of results available in medical literature (Satish, et al., 2012). The effects of high carbon dioxide levels on human are also indicated in the table.

Table 2: Orthogonal array carbon dioxide (CO_2) levels in ppm

S.No.	Parametric Values	Initial CO_2 level	Raw Data: CO_2 in ppm at three different points			$R_{average} = (R_1 + R_2 + R_3)/3$ (ppm)	S/N Ratio	Observations	
			CO_2 in ppm at one end (R_1)	CO_2 in ppm at the other end (R_2)	CO_2 in ppm at the center (R_3)			CO_2 more than limiting values of ASHRAE in ppm(Andrew, 2015)	Remarks on likely effect on human body(Satish, et. al., 2012)
1	A = 85 B = 10 C = 4 D = 23	355	514	525	518	519	54.30	-----	Healthy Level
2	A = 85 B = 10 C = 6 D = 25	362	753	758	762	757.66	57.58	-----	Moderate reductions in decision making ability
3	A = 85 B = 10 C = 9 D = 27	358	995	1105	1112	1070.6	60.59	70	Drowsiness and erratic performance decrement
4	A = 85 B = 15 C = 4 D = 25	385	785	790	779	784.66	57.89	-----	Moderate reductions in decision making ability
5	A = 85 B = 15 C = 6 D = 27	379	1202	1215	1228	1215	61.69	215	Drowsiness and erratic performance decrement
6	A = 85 B = 15 C = 9 D = 23	365	1742	1736	1730	1736	64.79	736	Drowsiness and erratic performance decrement
7	A = 85 B = 20 C = 4 D = 27	347	1173	1185	1194	1184	61.46	184	Drowsiness and erratic performance decrement
8	A = 85 B = 20 C = 6 D = 23	332	1554	1556	1689	1599.66	64.08	599.66	Drowsiness and erratic performance decrement

9	A = 85 B = 20 C = 9 D = 25	347	1864	1858	1843	1855	65.36	429.33	Drowsiness and erratic performance decrement
10	A = 110 B = 10 C = 4 D = 25	364	395	410	423	409.33	52.24	-----	Healthy Level
11	A = 110 B = 10 C = 6 D = 27	381	536	515	525	525.33	54.40	-----	Healthy Level
12	A = 110 B = 10 C = 9 D = 23	369	890	882	926	899.33	59.07	-----	Moderate reductions in decision making ability
13	A = 110 B = 15 C = 4 D = 27	354	501	515	527	514.33	54.22	-----	Healthy Level
14	A = 110 B = 15 C = 6 D = 23	341	964	923	958	948.33	59.53	-----	Moderate reductions in decision making ability
15	A = 110 B = 15 C = 9 D = 25	329	1402	1418	1416	1412	62.99	45	Drowsiness and erratic performance decrement
16	A = 110 B = 20 C = 4 D = 23	337	896	899	902	899	59.07	78	Moderate reductions in decision making ability
17	A = 110 B = 20 C = 6 D = 25	361	1350	1356	1361	1355.66	62.64	206	Drowsiness and erratic performance decrement
18	A = 110 B = 20 C = 9 D = 27	353	1526	1520	1537	1527.66	63.68	388	Drowsiness and erratic performance decrement
19	A = 170 B = 10 C = 4 D = 27	375	366	354	364	361.33	51.15	-----	Healthy Level
20	A = 170 B = 10 C = 6 D = 23	346	402	398	396	398.66	52.01	-----	Healthy Level
21	A = 170 B = 10 C = 9 D = 25	377	525	519	517	520.33	54.32	-----	Healthy Level
22	A = 170 B = 15 C = 4 D = 23	358	414	426	418	419.33	52.45	-----	Healthy Level
23	A = 170 B = 15 C = 6 D = 25	364	520	525	529	524.66	54.39	-----	Healthy Level
24	A = 170 B = 15 C = 9 D = 27	337	764	762	769	765	57.67	-----	Moderate reductions in decision making ability
25	A = 170 B = 20 C = 4 D = 25	351	469	465	476	470	53.44	-----	Healthy Level
26	A = 170 B = 20 C = 6 D = 27	346	688	697	700	695	56.83	-----	Moderate reductions in decision making ability
27	A = 170 B = 20 C = 9 D = 23	387	1285	1284	1289	1286	62.18	286	Drowsiness and erratic performance decrement

*A = Volume of the enclosed space (m^3); B = No of People (No.s); C = Time of occupancy (Hours); D = Temperature (°C).

On the basis of carbon dioxide levels shown in table 2, the analysis of variance (ANOVA) was computed using Minitab Statistical Software and the same has been presented in table 3.

Table 3: Analysis of Variance for carbon dioxide level deviations (Raw Data)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Volume	2	161.166	161.166	80.583	71.06	0.000
Occupancy	2	157.328	157.328	78.664	69.36	0.000
Time	2	164.617	164.617	82.308	72.58	0.000
Temperature	2	2.886	2.886	1.443	1.27	0.304
Residual Error	18	20.414	20.414	1.134		
Total	26	506.410				
DF - degrees of freedom, SS - sum of squares, MS - mean squares(Variance), F-ratio of variance of a source to variance of error, P < 0.05 - determines significance of a factor at 95% confidence level						

On the basis of the results presented in table 2, signal to noise ratio (S/N) plots are obtained using the formula $S/N = -10 * \log(\Sigma(1/Y^2)/n)$. Since we designed this process for maximum value of carbon dioxide, so signal to noise ratio curve is presented for larger is better as shown in figure 1.

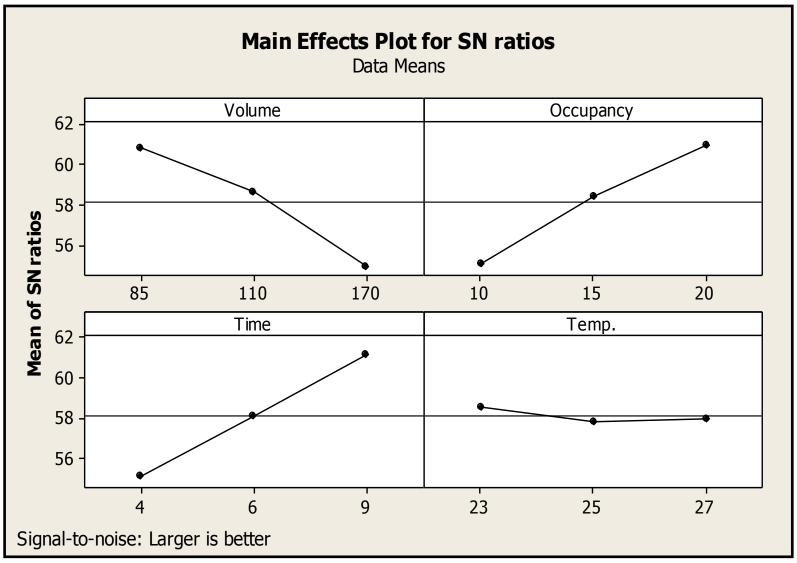

Figure 1: S/N Curve of Raw Data.

Percent contribution of process parameters is obtained by following formulae (Lochner, et al., 1990) and the same is presented in figure 2:

$$P=(SSqAdj/SSqTotal)*100$$

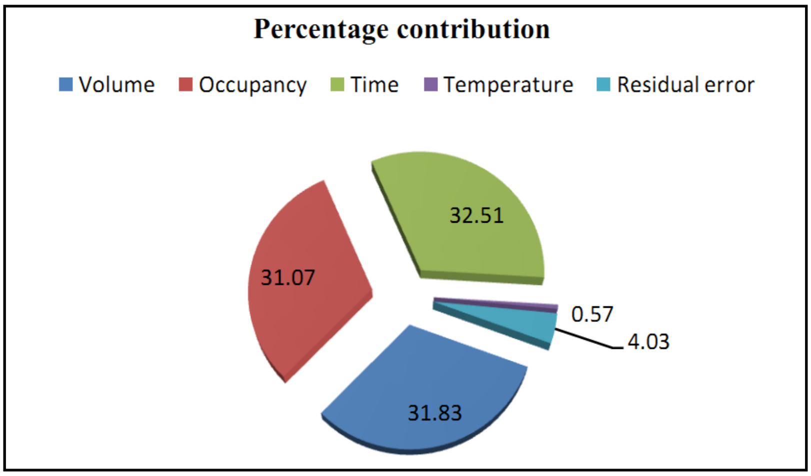

Figure 2: Percentage contribution of process parameters.

The contour plots were generated for occupancy levels versus time of occupancy, keeping the design center volume constant as 85 m^3 as shown in figure 3.

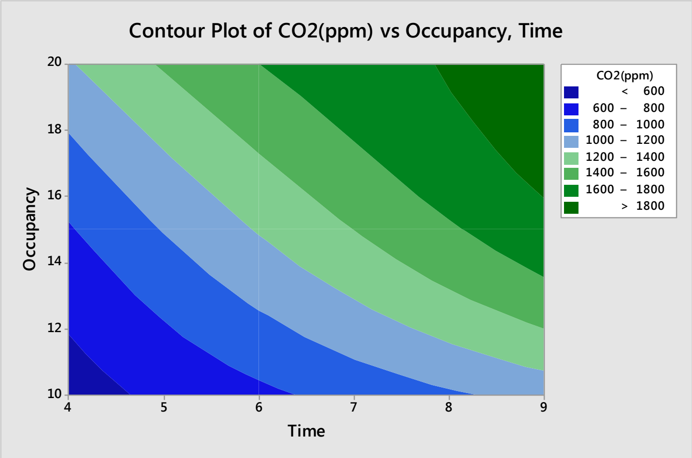

Figure 3: CO_2 response for volume 85 m^3

The contour plots were generated for occupancy levels versus time of occupancy, keeping the design center volume constant as 110 m^3 as shown in figure 4.

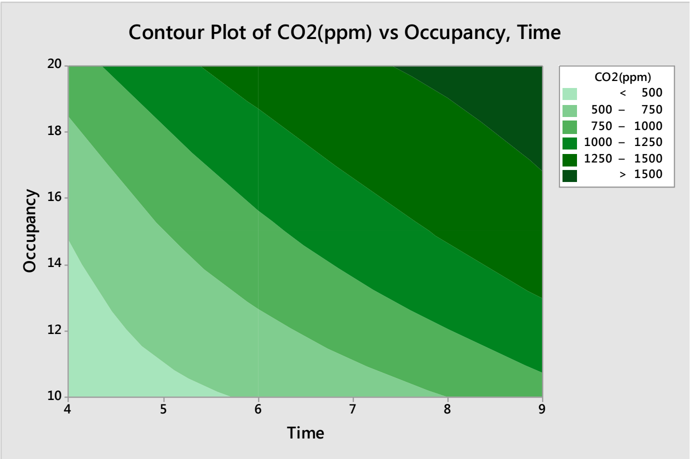

Figure 4: CO_2 response for volume 110 m^3

The contour plots were generated for occupancy levels versus time of occupancy, keeping the design center volume constant as 170 m^3 as shown in figure 5.

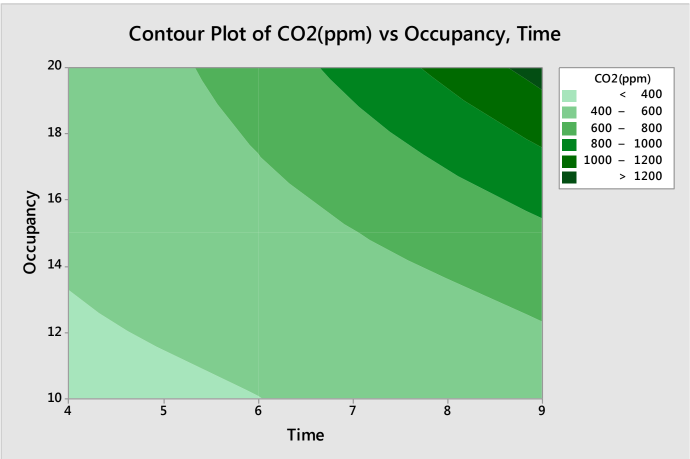

Figure 5: CO_2 response for volume 170 m^3

Thus these results from the assessment of the indoor air quality in air conditioned design centers show that the CO_2 concentration at times was significantly high above 1000 ppm, under different conditions during the assessment so it seems to have varying impact over occupant's health, comfort, performance and productivity.

IV. Conclusion and future scope

From the results it is evident that the generation of carbon dioxides is about 31.83 % dependent on the volume of the office, 31.07 % on the occupancy of employees/occupants/humans and 32.51 % for time of work period. However, the effects of temperature are not found to be much significant. The present investigation reveals that the results obtained by the split air conditioner do not conform to the international standards of air quality like ASHRAE and OSHA. It is therefore suggested that for maintaining proper percentage of carbon dioxide in indoor air conditioned environment some provisions of air ventilation need to be integrated in the present split air conditioner design to validate fitness of this equipment in such office workplaces. Depending upon the available results one can also plan the number of occupants, time of occupancy, time etc. for better human comfort and efficiency.

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