Optimization of Indoor Air Quality Characteristics in Theatre Hall using Response Surface Methodology

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Abstract— Influence of indoor air quality characteristics were carried out in theatre hall to improve the occupant's health and comfort in sitting indoor environment. This investigation is mainly focused on the optimization of indoor air quality characteristics of theatre hall using Response Surface Methodology. This paper studied the influence of different running modes of indoor Temperature, CO, O_2, CO_2, Relative Humidity and oxygen level. The comfort parameters were observed experimentally and better optimized indoor air quality factors were obtained by using Response surface Methodology in interior theatre hall environment. The thermal and human comfort measurement are planned as per design of experiment and conducted in one hundred to five hundred of five different human loads. Indoor and outdoor measurement of air temperature, relative humidity, carbon dioxide, Carbon monoxide, Oxygen and relative velocity were carried out in indoor at various levels of Fresh air supply, air velocity and human load. The experimental and optimized data were compared with International Standards, ASHARE 62 and etc. The results shown that the comfort level increased while fresh air supply decreased, finally this investigation is focussed on the optimized comfort parameters for the fresh air supply and air velocity in comfort theatre hall indoor environment.

Key words: Indoor Air Quality, Human Load (H), Fresh Air Supply (F_s), Air Velocity (A_v)

I. INTRODUCTION

Indoor air quality (IAQ) is an important factor in the design of high quality buildings. Although innovations in air-conditioning and other forms of cooling or ventilation, which can be viewed as technological solutions to the problem of producing and maintaining energy efficient environmental conditions that are beneficial for human health, comfort and productivity [1]. Unhealthy buildings have been 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. Theatres are the most complex of all auditorium structures and often have more than one performance per day. Intelligent buildings are significant contributors of comfort living environment in indoor. The subsequent impacts of indoor and outdoor pollutants has led to the demand of sustainable comfort in indoor, there is a target to make all new theatre zero discomfort for good comfort environment. Because people spend two to three hours have entertained in closed hall continuously. Comfort sitting environment should have major impact on occupants comfort, and health with energy saving. Theatre indoor can be namely composed of thermal, acoustic indoor air, and lighting environment. The increase of indoor temperature will however affect the indoor human thermal comfort level. Furthermore, unlike other building types, the use of opening windows for air intake and extract ventilation is not possible, requiring a different approach. Theatres frequently operate at high occupancy level, and tend to have higher sensible (and latent) heat loads. Air must be distributed over a wide area, both within the auditorium and the stage, with numerous supplies and return registers. The various attempts to evaluate systematically the theatre environmental performance in modern theatre hall assembled with the advance technologies have been carried out on indoor environment [2]. Many research projects have been implemented on various prototypes of possible applications in indoor and conducted user studies with a focus on the functional ability of the systems. Indoor and outdoor pollutants sources that release gases or particles into the air are primary cause of indoor air quality problems in indoor. Inadequate ventilation can increase indoor pollutants levels. High temperature and humidity levels can also increase some pollutants concentration in indoor environment [3]. From the view of ventilations, increasing the amount of fresh air in indoor certainly can improve air quality. But it also conflicts with energy saving. Therefore, it is important to determine appropriate volume of outdoor fresh air for improving indoor air quality [4]. The air quality of theatre hall should meet the requirements in order to provide with satisfactory service. The aim of this study was to predict the feasibility of achieving comfort indoor. Thirumal et al. [5] modeled and optimized the performance characteristics of composites using response surface methodology (RSM) techniques.

Based on the above studies, the present investigation is focussed determination of better values indoor air quality characteristics and their corresponding conditions using Response Surface Methodology.

II. EXPERIMENTAL PROCEDURE

A. Measurement Setup & Assumptions

100 to 500 human load densities seated in the theatre hall was selected for the field study of indoor air quality in indoor environment. A series of indoor air quality measurements were carried out in different level of human load, fresh air supply, and air velocity as the level of minimum and maximum for the measured session. The theatre was surrounded by semi urban environment. The indoor air quality measurable parameters such as Temperature, Relative Humidity, and Relative velocity, Carbon Dioxide, Carbon Monoxide, O_2 and Suspended Particulate Matter were recorded by using direct reading instruments and dust sampler. IAQ probe with sensors was used to record the CO_2 level, temperature, and relative humidity, whereas a NDIR sensor with a measuring range of 0-5000 ppm and an accuracy of 40 ppm or 10% of reading, whichever is greater, was used to measure carbon dioxide particulates matter was observed by the APM821 (0.5 – 1 LPM) sampler. CO sensor

with a measuring range of 0 – 1000 ppm and an accuracy of 5% and O_2 sensor with a measuring range of 0-30% and an accuracy of 1% were used. The outdoor air quality parameters are tabulated in Table 1, the data are taken as the level of minimum and maximum for the measured session.

Time	Temp (^{0}c)	Co_2 (ppm)	Co (ppm)	O_2 (%)	Air Velocity (m/s)	RH (%)
9AM to 17 PM	31-38.4	380-560	2	18.9-19.6	0.6-2.1	38-56

Table 1: Outdoor Air Quality Parameters

In this, Experimental measurements are planned using full factorial design. The Three variable parameters are Fresh air supply (F_s), Air velocity (A_V), Human load (H). Total 75 experiments are carried out. The level of factorial experimental design is shown in Table 2.

	Human load (No's)	Fresh air supply (%)	Air velocity (m/s)
1	100	20	3
2	200	40	5
3	300	60	7
4	400	80	-
5	500	100	-

Table 2: Variable Parameters & Their Levels

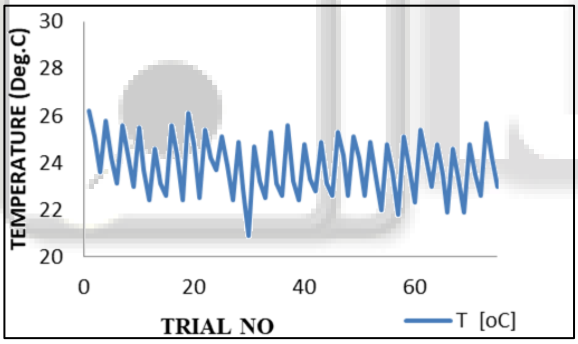

Fig. 1: Trail No VS Temperature

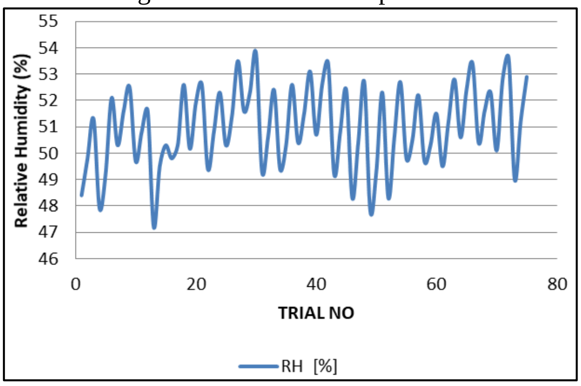

Fig. 2: Trail No VS Relative Humidity

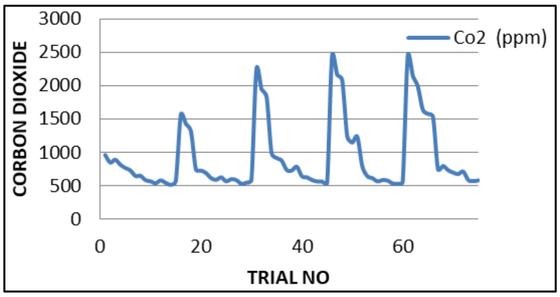

Fig. 3: Trail No VS Carbon Dioxide

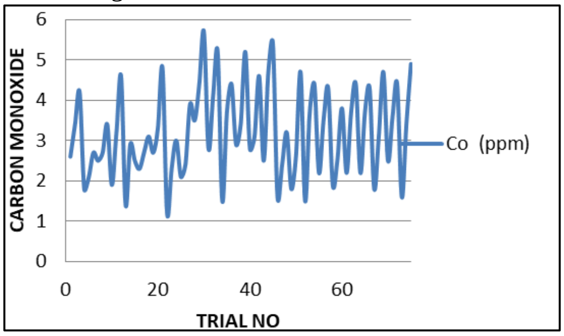

Fig. 4: Trail No VS Carbon Monoxide

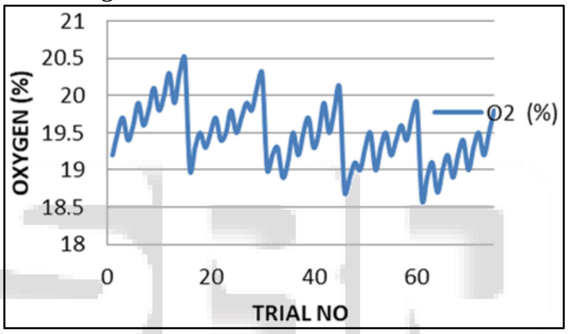

Fig. 5: Trail No VS Oxygen

The temperature, relative humidity, carbon di oxide, carbon monoxide and oxygen levels for various indoor air quality conditions are shown in Figures 1 to 5.The non-linear behaviour was obtained in all the IAQ responses.

– The following assumptions were made for the controlled environment inside the Theatre hall.
– When the doors of the hall are closed, the leakage is negligible.
– The CO_2 emission and oxygen consumption rate per person are constant.
– No volatile organic component emission is present inside the hall.
– The inside controlled environment is allowed to attain equilibrium with outdoor conditions before the experiment started.

The experimental results are observed by direct reading instruments and APM 821 Sampler with desired precision accuracy (Table 3). The Response surface methodology was used to predict the better comfort parameters from the experimental results.

B. Response Surface Methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for wide range of model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called Trails, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

III. RESULTS & DISCUSSION

A. *Regression Analysis*

Regression analysis is a statistics tool it's used to investigate the effects of coefficient in a process. Based on the fit summary value the best model for given set of value is suggested by RSM tool. The mathematical relationship for correlating the responses and the considered process variables are obtained from the coefficients resulting from the design expert software output.

The regression equations obtained using Design Expert 10.0 Statistical Software is given as below.

$T=5.40058-0.00044hl-0.002205F_s-0.07025Av+0.00000502hl*Fs+0.0000006082hl*Av-0.0000102069Fs*Av$

$RH=6.81502+0.000125hl+0.000364Fs+0.053002Av$

$CO_2=42.69920+0.058257hl-0.55376Fs-1.57796Av-0.000550Hl-0.00051146hl*Av+0.011045Fs*Av-0.0000085083hl^2+0.003743Fs^2+0.081442Av^2$

$CO=0.90396+0.333253hl+0.000721848Fs+0.14788Av$

$O_2=4.35601-0.0002653hl+0.0006144Fs+0.014965Av-0.00000044708hl*Fs+0.000001199hl*Av+0.0000280Fs*Av+0.0000001573hl^2+0.000002974Fs^2-0.000307Av^2$

The coefficient of correlation R^2, values for IAQ models of temperature, relative humidity, carbon dioxide, carbon monoxide and oxygen levels are 0.8789, 0.9436, 0.6260, 0.9740 and 0.6728 respectively.

The contour plots for temperature, relative humidity, carbon dioxide, and carbon monoxide and oxygen levels for various indoor air quality conditions are shown in Figures 6 to 10.

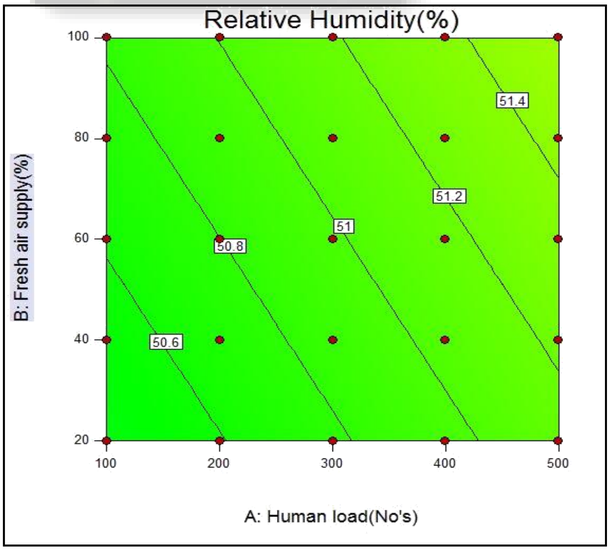

Fig. 6: Design Plot for Relative Humidity

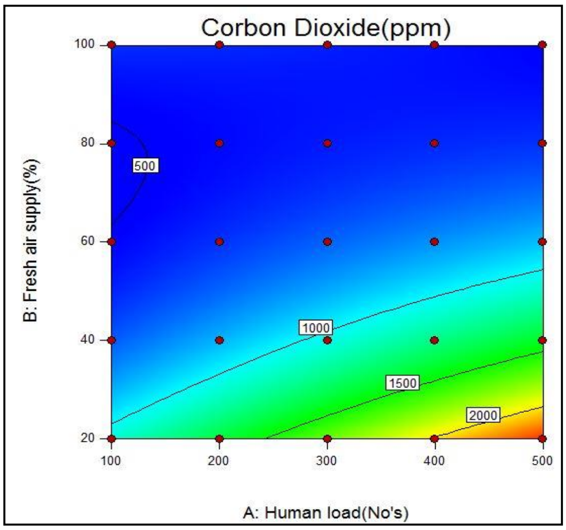

Figure 1.Design plot for Carbon Dioxide (ppm)

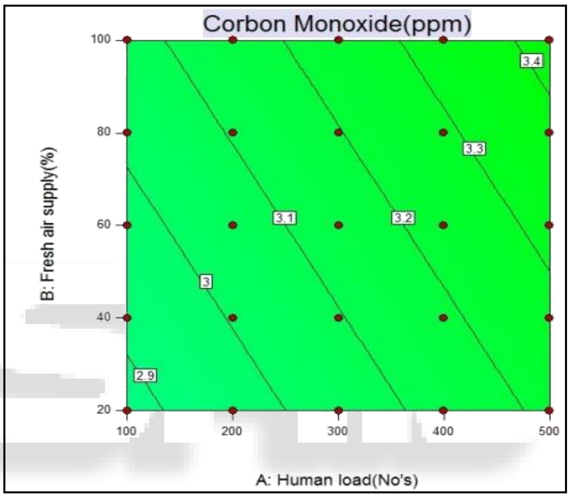

Figure 2 Design plot for Carbon Monoxide (ppm)

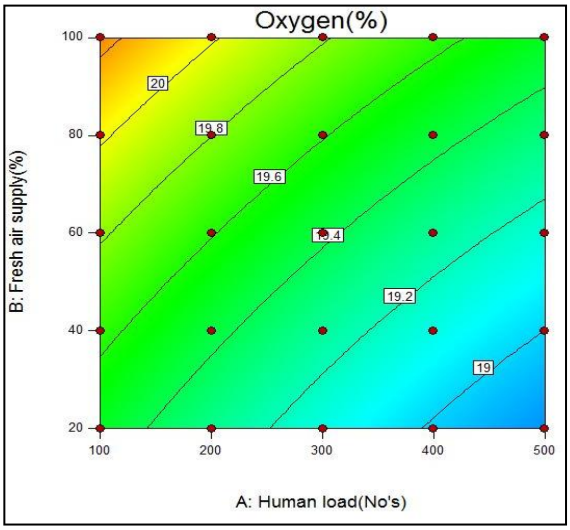

Figure 3 Design plot for Oxygen (%)

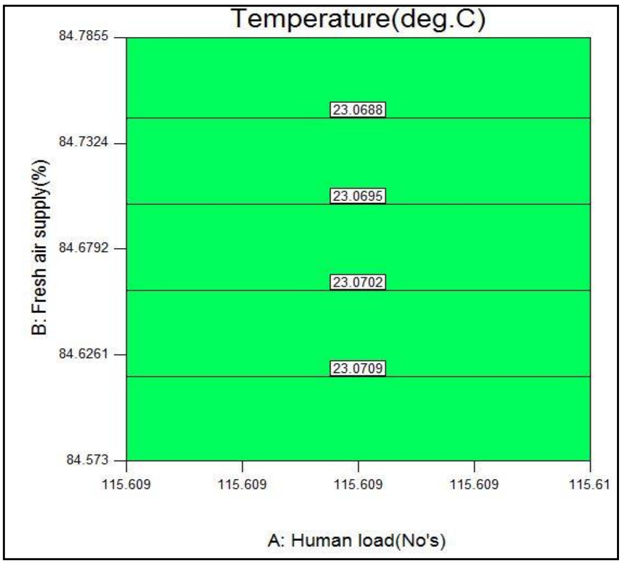

Fig. 4: Design plot for Temperature (Deg.C)

B. *Optimized Results in RSM*

The optimum comfort parameters are predicted by using Response surface methodology from the Experimental Results. The desirability values and corresponding plots are shown in Figures 7 -10. The comfort parameters determined using Response Surface Methodology is given in Table 3. The multi objective optimization was carried out by setting the following conditions for IAQ responses.

Temperature = 23
Relative Humidity = 50 %
Carbon dioxide level: Minimum
Carbon monoxide level: Minimum
Oxygen: 19%

S.No	H(No's)	F (%)	Av(m/s)	RSM Results (Predicted results)				
				T(deg.C)	RH (%)	CO2 (ppm)	CO (ppm)	O2 (%)
1	100	60.30	4.16946	24.6102	50.001	522.694	2.56561	19.7166
2	200	65.7109	3.90011	24.6204	50.000	582.918	2.53038	19.5223
3	300	68.1863	3.68582	24.6631	50.0297	643.52	2.51589	19.3294
4	400	68.4305	3.58993	24.6525	50.1366	709.635	2.55161	19.1517
5	500	68.595	3.482	24.651	50.234	770.239	2.58182	19.0155

Table 3: Optimized Results for Response surface Methodology

IV. Conclusion

The comfort sitting environment of the theatre hall under fresh air supply, air velocity and human load were determined using Response surface methodology. RSM predicted the better comfort conditions within the level of observed values under five different human load conditions.

The optimized temperature values for 100, 200, 300,400 and 500 human load conditions are 24.61^{0}C, 24.620C, 24.660C, 24.650C and 24.651^{0}C respectively.

The optimized Relative Humidity values for 100, 200, 300,400 and 500 human load conditions are 50.001, 50.00, 50.029, 50.136 and 50.234 respectively.

The optimized Carbon Dioxide values for 100, 200, 300,400 and 500 human load conditions are 522.69, 582.918, 643.52, 709.65 and 770.239 respectively.

The optimized Carbon Monoxide values for 100, 200, 300,400 and 500 human load conditions are 2.5656, 2.530, 2.5158, 2.5516 and 2.5818respectively.

The optimized Oxygen values for 100, 200, 300,400 and 500 human load conditions are 19.716, 19.522, 19.329, 19.1597 and 19.015 respectively.

References

[1] Ashrae. Ashrae fundamentals handbook.Ashrae Inc.; 1972.
[2] P. Thirumal, Optimization of IAQ characteristics of an air-conditioned car using GRA and RSM, Journal of Mechanical Science and Technology 28 (5) (2014).
[3] I.Daniel Lawrence, Study and Analysis of Indoor Air Quality Characteristics on Air Conditioned Application in Hospital Room, International Journal of Engineering Research & Technology, Vol. 3 Issue 9,720-724.
[4] I.Daniel Lawrence, Experimental Analysis And Thermal Comfort Index Of Air Conditioned Meeting Hall, International Journal of Research in Engineering and Technology, Vol. 3 Issue11, 1-8.
[5] Fanger PO. Thermal comfort. New York: McGraw-Hill; 1973.

