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DETERMINATION OF OPTIMUM VENTILATION STRATEGY FOR DISPLACEMENT VENTILATED ROOM USING TAGUCHI METHOD

V.V. POTDAR
Vice-Principal and Professor in Mechanical Engineering Department, A. G. Patil Institute of Technology, Solapur, India.

V.K.PRAVEEN
Professor, Mechanical Engineering Department, P. D. A. College of Engineering, Gulbarga, India.

P.S.KARANDE
Assistant Professor, Mechanical Engineering Department, A.G.Patil Institute of Technology, Solapur, India.

J.S.MUJAWAR
Assistant Professor, Mechanical Engineering Department, A.G.Patil Institute of Technology, Solapur, India.

ABSTRACT

HVAC engineers, world-wide, are facing challenges related to system design and operation because of development of variety of air distribution systems, innovative diffusers and variations in demand patterns among the ventilation system users. Further, due to the concerns about Indoor Air Quality (IAQ) impact on workers' health and productivity, newer ventilation strategies which integrate responsive and flexible elements, have grown in popularity for indoor spaces. In this paper attempts are made to develop and implement a practical and robust optimum ventilation strategy, with the aim of helping the building designers and HVAC operators to improve the Indoor Air Quality(IAQ) by reducing the contaminant particle concentrations. Taguchi's method based on Design of Experiments(DOE) is used along-with actual experimentation in a displacement ventilated "Ventilation Test Room"(VTR). Number of experiments conducted is based on Taguchi method using L9 Orthogonal Array with three level and three factors. The main effect plots for the means for the Particle Removal Efficiency were obtained using Minitab 14 Software. For this study, to evaluate the significance of the parameters in effecting the desired quality characteristic of our interest (i.e. Particle Removal Efficiency), Analysis of variance (ANOVA) was performed keeping the objective "larger is better". The input parameters considered are air velocity, particle source location and particle size. The results will help in deciding the most influential parameter for highest Particle Removal Efficiency which in turn will help the HVAC system designers and operators in maintaining these parameters and providing clean and healthy indoor air for the occupants.

KEYWORDS: Indoor environment, Ventilation system, Taguchi method, Particle Removal Efficiency

INTRODUCTION

In buildings and human occupied places ventilation is of utmost importance for maintaining acceptable indoor environment. Ventilation could control the air temperature, relative humidity, air speed, and chemical species concentrations in the air of the enclosed spaces. There are many standards to formulate the requirements of indoor environment, and ventilation design should be optimal for creating and maintaining an environment to satisfy the requirements. Traditionally, researchers and engineers applied a "trial-error" process in designing ventilation, which means predicting and evaluating the ventilation performance with different design variables to find a scenario that has the best agreement with the design objective. Researchers and engineers normally predicted or evaluated the ventilation performance typically by analytical and empirical models, experimental measurements, and computer simulations.

With the development of computer technology, the Computational Fluid Dynamics (CFD) simulations are most popular for predicting ventilation performance recently. The CFD simulation could provide the field distributions of air velocity, air temperature, species, etc. With a validated turbulence model, the CFD simulation would be more accurate and informative than the analytical models, empirical models, multi-zone models, and zonal models and much faster than the experimental measurements.

However, since this "trial-error" process requires CFD simulations for many scenarios, it would need days or months to obtain an optimal design for a ventilated space. At the same time, the "trial-error" process with the other methods may be inaccurate, non-informative, expensive, and time-consuming. Most importantly, because of the complexity of fluid flow, it is less likely that the repeated trials in an interactive analysis and design procedure can lead to a truly optimal design. The optimization approach on the other hand provides scope of using some statistical tools to decide the influential parameters related to system design and help in reducing number of experiments required to arrive at the most feasible solution.

LITERATURE REVIEW

H. Brohus et al (1999) studied the effect of renovating an office building on occupants' Comfort and Health.

P. Wargocki et al (2000) carried out studies on the effects of outdoor air supply rate in an office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity.

M. Wetter and J. Wright (2003) evaluated the feasibility of application of genetic algorithm optimization methods for issues related to indoor ventilation studies.

L. Lu et al (2005) conducted elaborate studies concerning optimization of HVAC Systems in built environment .

S.W. Wang and X.Q. Jin (2000) focussed on operational aspects of HVAC systems and developed a model based optimal control system using genetic algorithm.

J.A. Wright et al (2002) used multi-criterion genetic algorithm for optimization of building thermal design.

SCOPE OF RESEARCH

Based on literature review carried out, it is observed that the research on evaluation of particle removal efficiency by using Taguchi method is not yet fully explored. Even-though efforts on determining optimal ventilation strategy using other optimization methods are partially successful, there is ample scope for carrying out research on determination of appropriate ventilation strategy using Taguchi method.

There are many parameters that govern the indoor air quality. It is essential to find out the influential parameters from the point of view of particle removal efficiency. Various ventilation methods have variable impacts on indoor air quality. Further, inlet air velocities, particle source locations and particle sizes also have influence on quality of indoor air.

It is important to evaluate most influential parameter with the objective of improving particle removal efficiency through combination of statistical methods and experimental methods. Thus there is a research gap which can be explored.

The major objective of this research is to study the effects of various input parameters i.e., Air velocity, Particle source location and Particle size on the Particle Removal Efficiency.

METHODOLOGY

In this process, experiments are carried out in a " Ventilation Test Room" which is well-equipped with appropriate instruments. Air velocity is measured by using pre-calibrated hot wire anemometer and particle concentrations are measured by using pre-calibrated Particle counter. The particle removal efficiency is computed from the measured data at various measurement points. Taguchi method is briefly described below. Input Parameters and their Levels for the study of various types of ventilation are shown below in Table 1.

Table 1 Ventilation Input parameters

Input Parameter	Symbol	Unit	Levels		
			Level 1	Level 2	Level 3
Air velocity	v	m/s	1.5	2.5	3.5
Particle source location	L	m	1.00	1.50	2.00
Particle size	d	µm	0.5	2.5	10

Table 2 Taguchi Orthogonal Array Design for ventilation study.

Experiment	Air Velocity	Particle Source location	Particle Size
1	1.5	1.00	0.5
2	1.5	1.50	2.5
3	1.5	2.00	10
4	2.5	1.00	2.5
5	2.5	1.50	10
6	2.5	2.00	0.5
7	3.5	1.00	10
8	3.5	1.50	0.5
9	3.5	2.00	2.5

EXPERIMENTATION

The experimentation is carried out in Ventilation Test Room which is equipped with hot wire anemometer for air velocity measurement and particle counter for contaminant concentration measurements. These equipments were pre-calibrated to measure these parameters correctly.The experimental set-up is as shown in figure A.

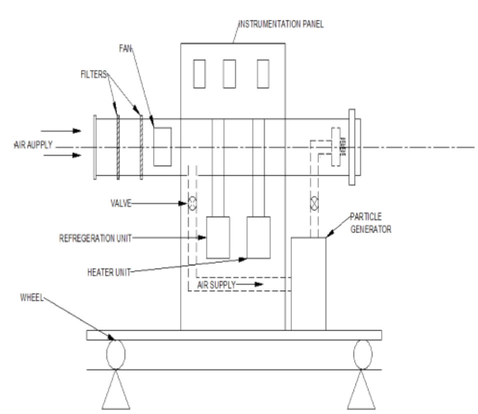

Figure A Experimental set-up for Ventilation Studies

Air is supplied to the Ventilation Test Room through appropriate ducting. In the present case displacement ventilation strategy is adopted. The measured contaminant particles are supplied in the test room through particle generator. By using a traversing unit particle concentrations at various locations in the room are carried out. Three different supply air velocities, particle source locations and particle sizes are used. Nine test runs are carried out. Particle Removal Efficiency is computed for each test run.The results of these trials are tabulated in Table 3.

Table 3 Details of test runs

Test Runs	**Parameters**			
	Air Velocity	**Particle Source location**	**Particle Size**	**Particle Removal Efficiency**
1	1.5	1.00	0.5	1.041
2	1.5	1.50	2.5	0.835
3	1.5	2.00	10	0.652
4	2.5	1.00	2.5	1.063
5	2.5	1.50	10	1.014
6	2.5	2.00	0.5	0.947
7	3.5	1.00	10	1.085
8	3.5	1.50	0.5	1.021
9	3.5	2.00	2.5	0.883

RESULTS AND DISCUSSIONS

These experiments are conducted according to Taguchi Design method by using proper instrumentation in a Ventilation Test Room.. Experiments are varied to complete 9 altered trials with parameters like Air velocity, Particle Source Location, Particle Size which are varied to measure Particle Removal Efficiency for displacement ventilation configuration.

The objective of this research was to study the effect of various input parameters like Air velocity, Particle Source Location, Particle Size on the Particle Removal Efficiency. The discussions regarding most influential input parameter is provided.

INFLUENCES ON PARTICLE REMOVAL EFFICIENCY

A) TAGUCHI ANALYSIS

The S/N ratios for Tool Wear are calculated as given in below Equation. Taguchi method is used to analysis the result of response of parameter for "Larger is better" criteria.

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Where S/N ratios calculated from observed values, y_i represents the experimentally observed value of the i^{th} experiment and n=1 is the repeated number of each experiment in L-9 Orthogonal Array is conducted. (Refer Table: 4)

Table: 4

Air Velocity	Particle Source location	Particle Size	Particle Removal Efficiency	PSNRA1	PMEAN1
1.5	1.00	0.5	1.041	2.92256	1.4
1.5	1.50	2.5	0.835	-1.93820	0.8
1.5	2.00	10	0.652	-4.43697	0.6
2.5	1.00	2.5	1.063	4.08240	1.6
2.5	1.50	10	1.014	0.00000	1.0
2.5	2.00	0.5	0.947	-0.91515	0.9
3.5	**1.00**	**10**	1.085	**5.10545**	**1.8**
3.5	1.50	0.5	1.021	1.58362	1.2
3.5	2.00	2.5	0.883	-1.93820	0.8

Chart shows the optimum solution of the given set of parameters is given by the value having SN ratio is largest i.e 5.10545.

MINITAB RESULTS AND GRAPHS

From Fig 1 and 2, it can be observed that the parameters Air velocity, Particle Source Location, Particle Size affect Efficiency.

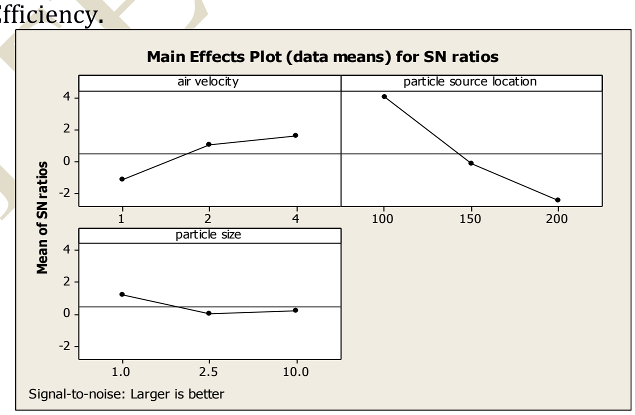

Fig 1: Main Effects Plot of SN Ratios for Particle Removal Efficiency

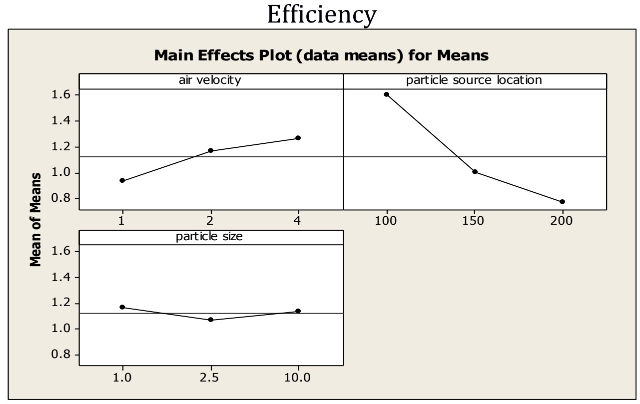

Fig 2: Main Effects Plot of Means for Particle Removal Efficiency

From Table 5 it is concluded that Particle Source Location is more influencing parameter on Particle Removal Efficiency than Air velocity and Particle Size.

Table 5: Response table for Signal to Noise Ratios Larger is better)

Level	Air velocity	Particle Source Location	Particle Size
1	-1.15087	4.03680	1.19701
2	1.05575	-0.11819	0.06867
3	1.58362	-2.43011	0.22283
Delta	2.73450	6.46691	1.12835
Rank	2	1	3

B) REGRESSION ANALYSIS

(Particle Removal Efficiency v/s Air velocity, Particle source location, Particle size)

The regression equation is,

Particle Removal Efficiency = 2.13 + 0.102 v - 0.00833 L + 0.0004 d

Table 6 Predictor table

Predictor	Coef	SE Coef	T	P
Constant	2.1317	0.2335	9.13	0.000
air velocity	0.10238	0.04262	2.40	0.061
particle source location	- 0.008333	0.001302	-6.40	0.001
particle size	0.00036	0.01350	0.03	0.980

S = 0.159452 R-Sq = 90.3% R-Sq(adj) = 84.5%

ANALYSIS OF VARIANCE

Table 7 Table for Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	1.18843	0.39614	15.58	0.006
Residual Error	5	0.12712	0.02542		
Total	8	1.31556			

B) ANALYSIS OF VARIANCE FOR S/N RATIO OF SR

Analysis of variance for Efficiency is given in Table: 8. These values are obtained from MINITAB 14 software.

Table: 8 Analysis of Variance for S N ratios

Particle source location	Particle Removal Efficiency	RESI1	FITS1
1.00	1.041	-0.200000	1.60000
1.50	0.835	-0.200000	1.00000
2.00	0.652	-0.166667	0.76667
1.00	1.063	0.000000	1.60000
1.50	1.014	0.000000	1.00000
2.00	0.947	0.133333	0.76667
1.00	1.085	0.200000	1.60000
1.50	1.021	0.200000	1.00000
2.00	0.883	0.033333	0.76667

Table: 9 One way ANOVA for Efficiency v/s Particle source location

Source	DF	SS	MS	F	P
Particle source location	2	1.1089	0.5544	16.10	0.004
Residual Error	6	0.2067	0.0344		
Total	8	1.3156			

S = 0.1856 R-Sq = 84.29% R-Sq (adj) = 79.05%

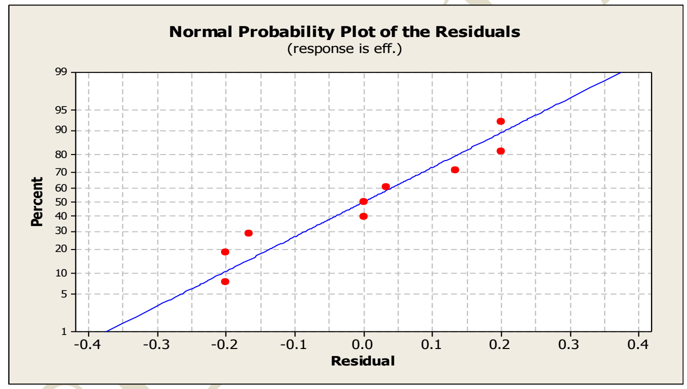

Fig 3: Normplot of Residuals for particle removal efficiency.

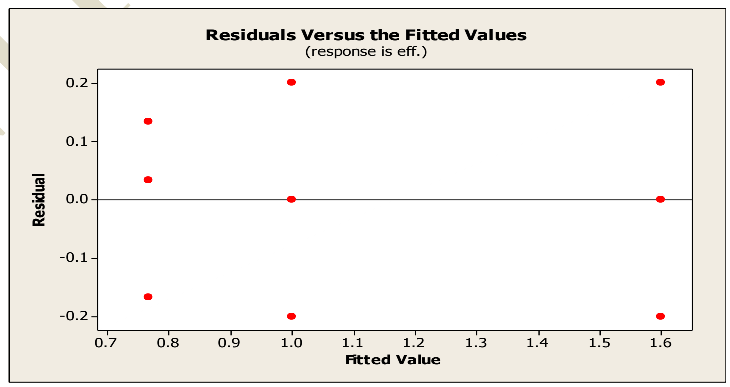

Fig 4: Residuals vs Fits for particle removal efficiency

Residuals vs Order for Particle Removal Efficiency:

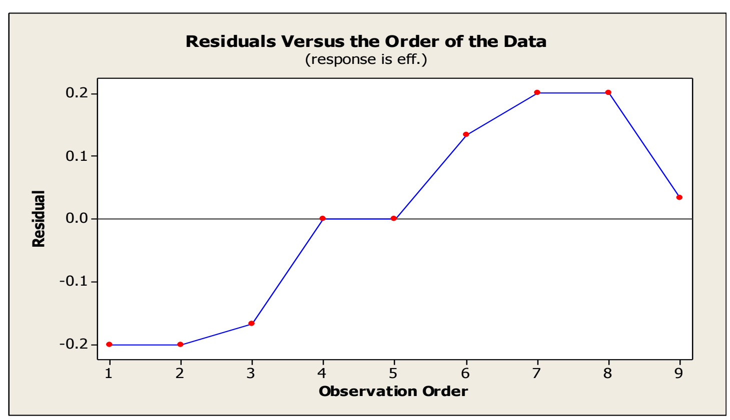

Fig 5: Residuals vs Order for Particle Removal Efficiency

CONCLUSIONS

The following conclusions can drawn from the experimentation and analysis-

1. Air velocity, Particle source location and particle size are found to be the influential parameters for Particle Removal Efficiency.
2. Maximum Particle Removal Efficiency is obtained at air velocity of 3.5 m/s.
3. Maximum Particle Removal Efficiency is obtained at source location of 100 m distance from opposite wall of the Ventilation Test Room.
4. Maximum Particle Removal Efficiency is obtained when the contaminant particle size is 10μm.
5. For determination of optimal ventilation strategy these studies provide useful guidelines for HVAC system engineers and operators. This, in turn, will help in providing cleaner and healthier indoor environment.

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