Experimental Analysis of Energy Consumption in Ceiling Fan

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Abstract

Most people target only lights when they think about electricity savings. Compared to lights that are switched on only in the evening, ceiling fans are on for most part of the day and even during night. The total number of hours that the fan is in operation is proportional to the energy consumption of the fan. Ceiling fans are one of the main energy consuming sources. We are facing the energy crisis, it is important to reduce the energy consumption in every energy consuming device. Hence energy reduction in ceiling fan is perhaps one of the most important parameter. Every energy reduction process starts with identification of energy consumption sources. Ceiling fans are extensively used to create an indoor breeze, improve the space air distribution and hence enhance the feeling of comfort. The fan speed, number of blades, and downrod length all play an important role in deciding the energy consumption. In this study, response surface methodology is used to predict energy consumption characteristics. The experiments were conducted to develop mathematical model based on different fans, number of blades, room volume, downrod lengths and fan speeds. This paper will help to find out the optimum level of parameters to minimize the energy consumption.

Keywords
L81 Array, MINTAB 16, Response Surface Method, Ceiling Fan, Energy consumption

1. Introduction

People feel discomfort when they get sweat in a space with a stagnant air. Therefore people try to create air breeze around their bodies either naturally or mechanically to enhance body convective heat transfer .Air motion helps sweat evaporation and accordingly brings body comfort feeling. Ceiling fans are used in offices; residences as an alternative in summer for comfort. The flow pattern features induced by ceiling fans are very helpful for people having interest working in this field. So knowing flow characteristics, as a result of ceiling fan rotation would help improving the fan design in addition to selecting its optimum placement to save energy. Therefore it is very important to select and control the input parameters for energy saving. Various prediction methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables. The response surface methodology (RSM) is helpful in developing a suitable approximation for the true function relationship between the independent variables and the response variable that may characterize the energy level for ceiling fan.[1] It has been proved by several researchers that efficient use of statistical design of experimental techniques, allow development of an empirical methodology, to incorporate a scientific approach in analysis of ceiling fan energy consumption .Even though sufficient literature is available on analysis of ceiling fan energy consumption, no systematic study has been reported so far to correlate the process parameters and energy consumption. Hence, in this investigation, the design was used to conduct experiments for exploring the interdependence of the process parameters and second order mathematical model for energy consumption was developed from the data obtained by conducting the experiments.

2. Experimental identification of important parameters

From the literature and previous work done among many independently controllable parameters affecting energy consumption, the parameters viz. Fan Blades (A),Room volume (B),Downrod length (C) Fan speed (D)were selected as primary parameters for the study. These parameters are contributing to the energy consumption in the ceiling fan. Different combinations of parameters were used to carry out the trial runs. This was carried out by varying one of the factors while keeping the rest of them at constant values. Table 1 shows the various parameters and their levels considered during the experimentation.

Table 1. Parameters Level selected for the Experimentation

Parameters	**Levels**		
	Low (1)	**Medium (2)**	**High (3)**
Fan (A)	2	3	4
Room Size in m3 (B)	66.56	167.19	355.84
Rod Length in inch (C)	6.5	10.25	12
Speed Knob Position (D)	2	3	4

For conducting experiments three different fans of various blades mainly (2, 3, 4), three different room size, three different rod length, and three different fan speed position were selected. Using clamp meter energy consumption level in (kW) was recorded. Rod length for fan was measured. Reading in different room, using different rod at different regulator knob position were recorded as in observation Table 2.

3. Development of mathematical model

3.1 Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical technique useful for analyzing problems in which several independent variables or responses are considered to optimize the desired output. In many experimental conditions, it is possible to represent independent factors in quantitative form as given in Eq. (1).Then these factors can be thought of as having a functional relationship or response as follows

$Y=\Phi(x1,x2\ldots xk)$…………………... Eq.(1).

Between the response Y and x1, x2… xk of k quantitative factors, the function Φ is called response surface or response function. For a given set of independent variables, a characteristic surface is responded. In the present investigation, RSM has been applied for developing the mathematical model for characteristics of energy [7]. In applying the response surface methodology, the independent variable was viewed as surface to which a mathematical model is fitted.

Table 2. Observation table

Down rod Length level	**Run Order**	**Fan blades level**	**Room Volume level**	**Fan speed level**	**Energy Consumption measured (watt)**
1	1	1	1	1	0.386604
1	2	1	1	2	0.447822
1	3	1	1	3	0.522816
2	4	1	1	1	0.379848
2	5	1	1	2	0.44478
2	6	1	1	3	0.513646

Down rod Length level	Run Order	Fan blades level	Room Volume level	Fan speed level	Energy Consumption measured (watt)
3	7	1	1	1	0.38173
3	8	1	1	2	0.443813
3	9	1	1	3	0.518221
1	10	1	2	1	0.366597
1	11	1	2	2	0.426765
1	12	1	2	3	0.481712
2	13	1	2	1	0.377185
2	14	1	2	2	0.439589
2	15	1	2	3	0.508561
3	16	1	2	1	0.374164
3	17	1	2	2	0.428505
3	18	1	2	3	0.494278
1	19	1	3	1	0.379691
1	20	1	3	2	0.442081
1	21	1	3	3	0.514178
2	22	1	3	1	0.375094
2	23	1	3	2	0.434157
2	24	1	3	3	0.497448
3	25	1	3	1	0.355169
3	26	1	3	2	0.416342
3	27	1	3	3	0.483553
1	28	2	1	1	0.332564
1	29	2	1	2	0.393652
1	30	2	1	3	0.486167
2	31	2	1	1	0.34351
2	32	2	1	2	0.412415
2	33	2	1	3	0.521486
3	34	2	1	1	0.347231
3	35	2	1	2	0.423069
3	36	2	1	3	0.539721
1	37	2	2	1	0.331019
1	38	2	2	2	0.404062
1	39	2	2	3	0.509884
2	40	2	2	1	0.316716
2	41	2	2	2	0.376953
2	42	2	2	3	0.454104
3	43	2	2	1	0.341376
3	44	2	2	2	0.406711
3	45	2	2	3	0.513912
1	46	2	3	1	0.341376

Down rod Length level	Run Order	Fan blades level	Room Volume level	Fan speed level	Energy Consumption measured (watt)
1	47	2	3	2	0.405748
1	48	2	3	3	0.510413
2	49	2	3	1	0.31456
2	50	2	3	2	0.374396
2	51	2	3	3	0.461948
3	52	2	3	1	0.334897
3	53	2	3	2	0.400037
3	54	2	3	3	0.505121
1	55	3	1	1	0.33479
1	56	3	1	2	0.403581
1	57	3	1	3	0.478373
2	58	3	1	1	0.335458
2	59	3	1	2	0.40045
2	60	3	1	3	0.467309
3	61	3	1	1	0.340704
3	62	3	1	2	0.410222
3	63	3	1	3	0.47915
1	64	3	2	1	0.334233
1	65	3	2	2	0.398412
1	66	3	2	3	0.471664
2	67	3	2	1	0.328381
2	68	3	2	2	0.394842
2	69	3	2	3	0.454356
3	70	3	2	1	0.328601
3	71	3	2	2	0.395556
3	72	3	2	3	0.447321
1	73	3	3	1	0.332906
1	74	3	3	2	0.400756
1	75	3	3	3	0.468077
2	76	3	3	1	0.328381
2	77	3	3	2	0.39181
2	78	3	3	3	0.45764
3	79	3	3	1	0.341152
3	80	3	3	2	0.40623
3	81	3	3	3	0.470896

The mathematical equations for energy consumption by using response surface method (RSM) is

Energy Consumption = 0.41653- 0.01913 * A - 0.00639 * + 0.00040 * C + 0.07126 * D + 0.00248 * AB + 0.00193 * AC + 0.00088 * AD - 0.00499 * BC -0.00218 * BD + 0.00010 * CD + 0.00294 * ABC - 0.00007 * ABD - 0.00119 * ACD - 0.00185 * BCD + 0.00038 * ABCD

Where,
A=Fan blades level
B=Room Volume
C=Down rod length
D=Fan speed

3.2 Optimizing parameters

Contour plots show distinctive circular shape indicative of possible independence of factors with response.[7] Contour plots play a very important role in the study of the response surface. By generating contour plots using software for response surface analysis, the optimum is located with reasonable accuracy by characterizing the shape of the surface. If a contour patterning of circular shaped contours occurs, it tends to suggest independence of factor effects while elliptical contours as may indicate factor interactions Response surfaces have been developed for both the models, taking two parameters in the middle level and two parameters in the X and Y axis and response in Z axis. The response surfaces clearly reveal the optimal response point. RSM is used to find the optimal set of process parameters that produce a maximum or minimum value of the response. In the present investigation the process parameters corresponding to the energy consumption are considered as optimum. Hence, when these optimized process parameters are used, then it will be possible to attain the minimum energy consumption. Figure1 presents three dimensional response surface plots for the energy consumption. The surface plots generated are almost circular which reveals that there is lest dependency of the parameters on the energy consumption.

3.3 Surface plots

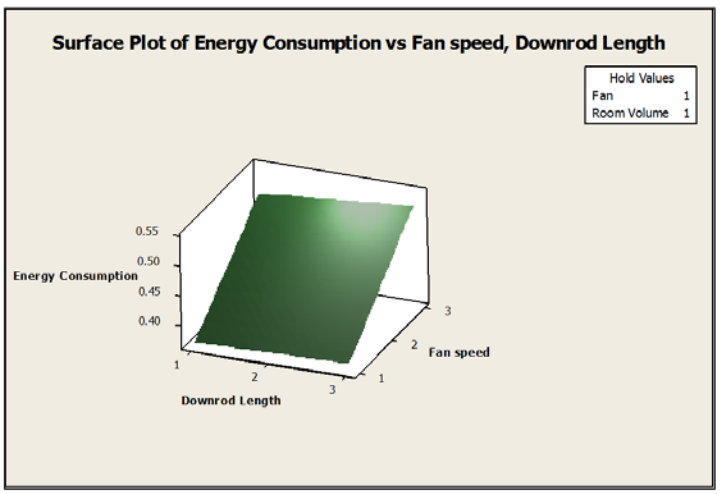


Figure 1. : Surface plot of Energy consumption vs fan speed and down rod length.

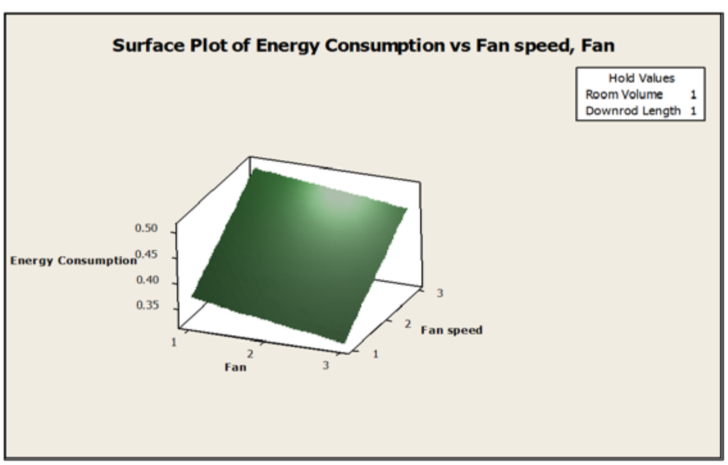


Figure 2. : Surface plot of Energy consumption vs fan speed and fan.

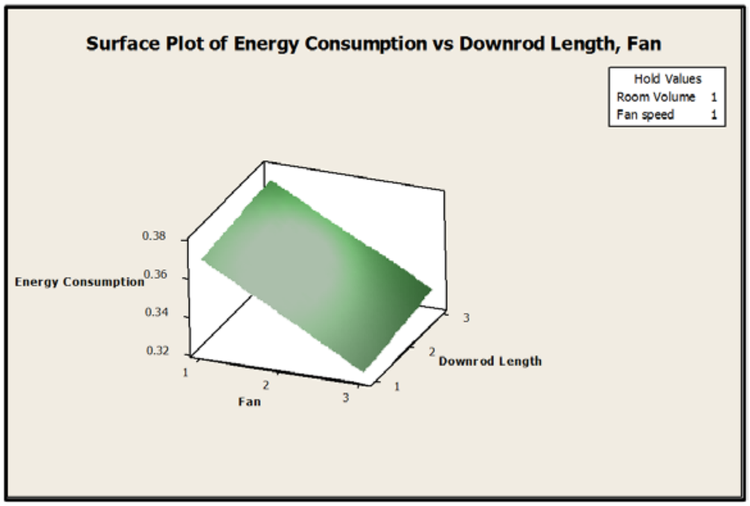


Figure 3. : Surface plot of Energy consumption vs fan and down rod length.

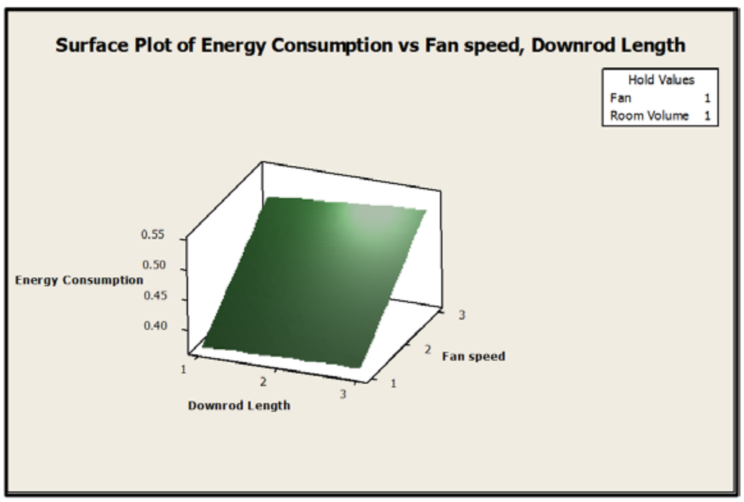


Figure 4. : Surface plot of Energy consumption vs fan speed and down rod length.

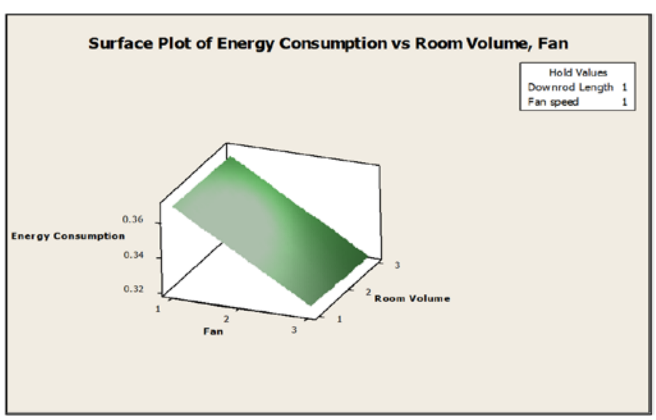


Figure.5. : Surface plot of Energy consumption vs fan and room volume.

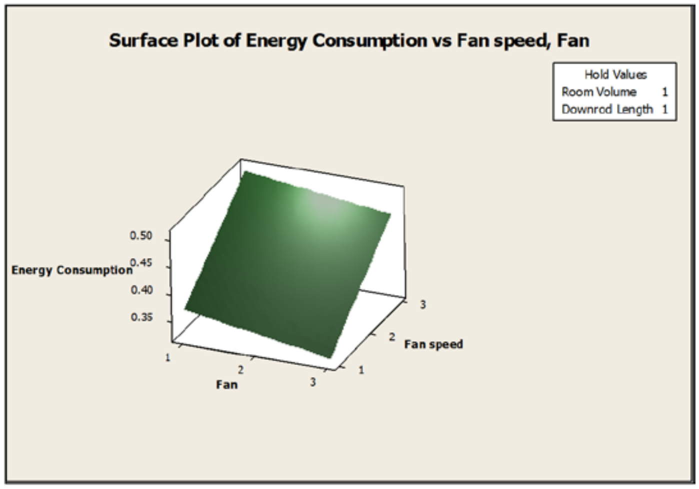
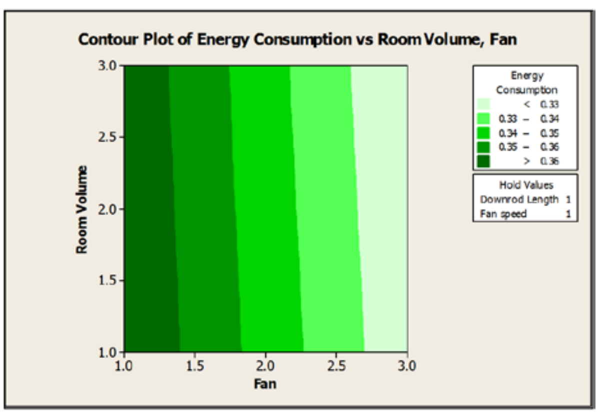


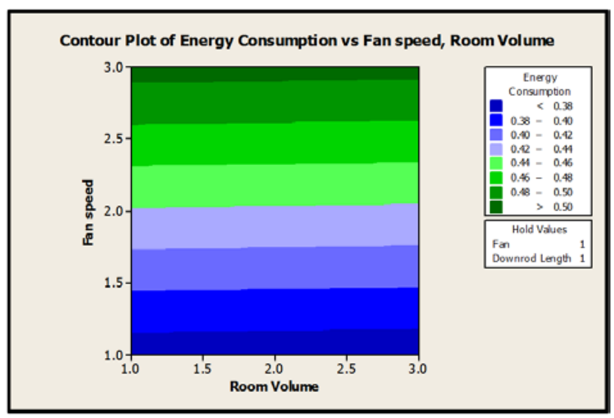
Figure 6. Surface plots for energy consumption vs fan speed and fan

Surface plot shows the dependency of the response variables and the input variable considered in the study. Figure 1 to figure 6 shows the various response surface plots of energy consumption. From the nature of the graph it is clear that the parameters considered for the investigation has direct influence on the ceiling fan energy consumption.

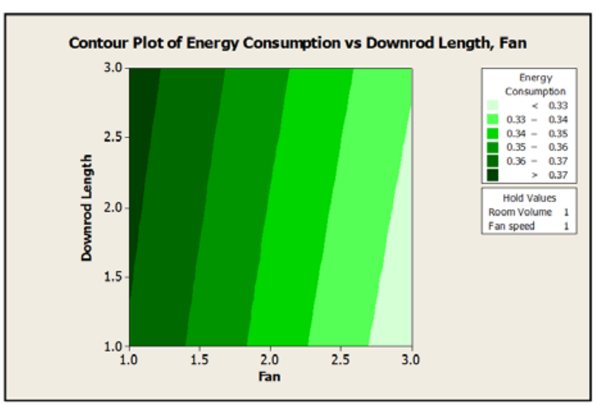
3.4 Contour plots



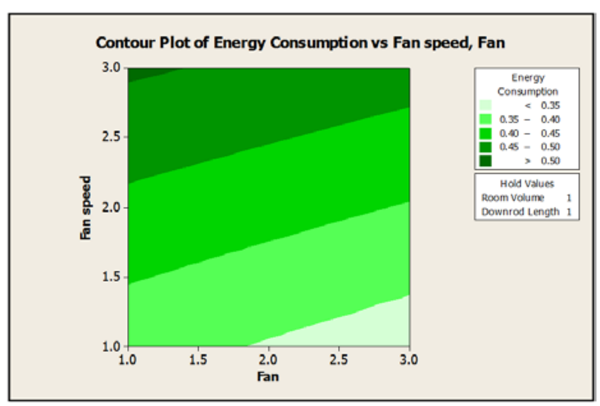
a



b



c



d

Figure 7. Contour Plots for Energy Consumption

Contour plot shows the interaction effect of the two input parameters considered for the investigation. Figure 7 shows the various contour plots of energy consumption. From the nature of the graph it is clear that all the graph has non circular nature , this indicates that the parameters has no interaction influence on the energy consumption.

3.5 Response Optimization

Table 3. Parameters for optimization

Parameter	Goal	Lower	Target	Upper	Weight	Import
Energy Consumption	Minimum	0.315	0.315	0.53	1	1

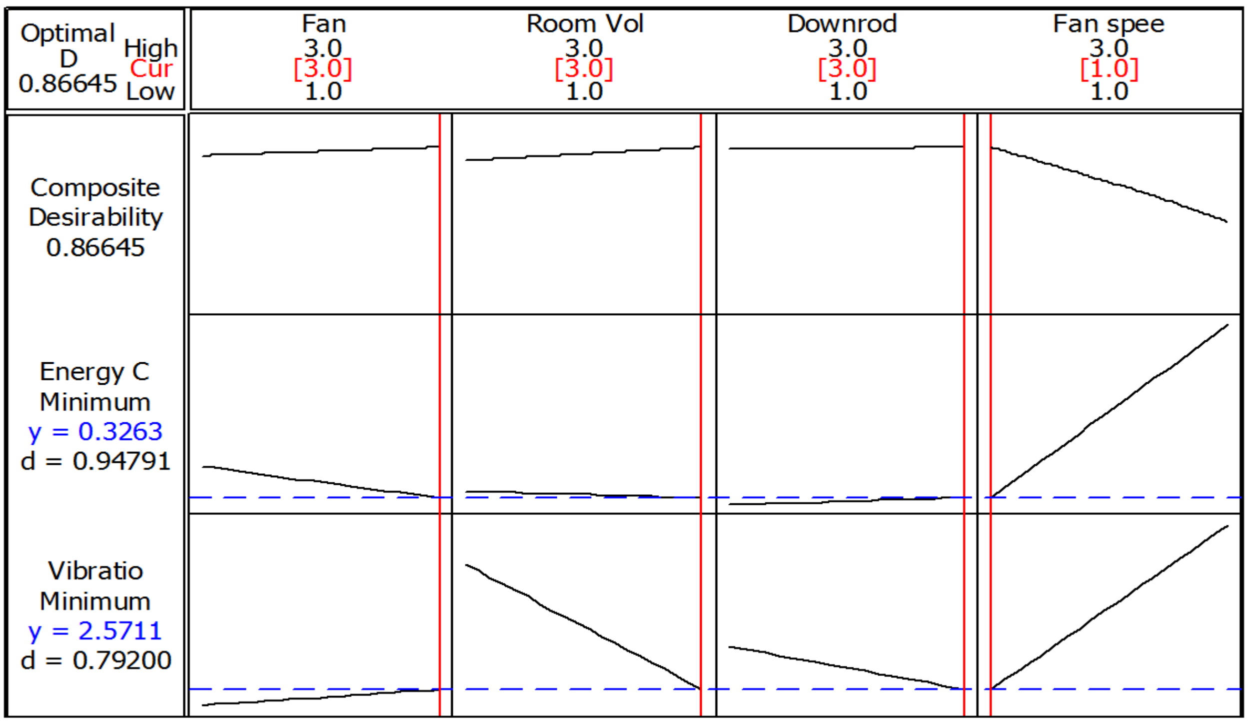


Figure 8. Optimization plot

3.6 Global Solution

Fan blades level = 3
Room Volume level = 3
Down rod Length level = 1
Fan speed level = 1

Energy Consumption = 0.320608,
Desirability = 0.974156
Composite Desirability = 0.974156

4 Conclusions

The desirability function approach is one of the most widely used methods in industry for the optimization of multiple response processes. It is based on the idea that the "quality" of a product or process that has multiple quality characteristics, with one of them outside of some "desired" limits, is completely unacceptable. The method finds operating conditions ***x*** that provide the "most desirable" response values. From the experimentation we got the global value of energy consumption 0.315 kW with the set up of Fan having four blades, 355.84 m3 Room Volume, 12 inch Down rod length and Desirability function of 0.947912 which is the Probability of achieving energy consumption. The desirability function values are very close to one indicates that best set of parameters are achieved through thus analysis. From the above we conclude that the present work is off great importance to save the energy consumption in widely used ceiling fans, from the literature review it has been observed no work has been highlighted the issue of energy consumption in the ceiling fan. The present work the parameters considered is very effective which has been neglected by the researcher. Hence the optimum values for the input parameters considered are fan blade(with four blade), room volume level 3(355.84 m3), down rod length 1(6.5 inch) and the fan speed level is 1 (knob 2). A lot of energy can be saved through the use of optimized parameters setting during the regular use of fan as per the size of beneficial area.

Parameters	**Levels**		
	Low (1)	**Medium (2)**	**High (3)**
Fan (A)	2	3	4
Room Size in m3 (B)	66.56	167.19	355.84
Rod Length in inch (C)	6.5	10.25	12
Speed Knob Position (D)	2	3	4
Minimum energy consumption	0.320608 Watt		

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Biography

Rupesh Bhortake is Professor in Mechanical Engineering Department of TSSM's, PadmabhooshanVasantdata Patil Institute of Technology, Savitribai Phule Pune University, Pune, Maharashtra, India. His research interests include manufacturing, noise and Vibration. He is a member of Indian Society for Technical Education (ISTE) and Institute of Engineers.

Vaishali Bhortake is supporting staff for the documentation for the research work.