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Enhancing Human Comfort and Improving Illuminance Level in Smart Class Room through Optimization Approach

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ABSTRACT

Energy conservation and management are the keys to use fuel and electrical energy in the most efficient way. Proper energy management can lead to big savings on the operating costs of a building. In this study, a smart class room of an educational building situated in Trichy, Tamil Nadu, India is considered for the energy audit with the aim of reducing energy consumption and better human comfort in terms of illuminance level. The objectives are achieved by replacing the existing CFL lamps with LED bulbs of different power capacity placed in different positions in the room. Taguchi's Design of Experiment (DoE) is used to design the experiment and a hybrid approach of combing Taguchi's Signal-to-Noise (S/N) ratio and Grey relational analysis is applied to obtain the best illuminance level with reduced energy utilization. Using statistical tool, Analysis of Variance (ANOVA), it is found that by increasing the number of LED bulbs with moderate power capacity improves illuminance in the smart class room.

Keywords - Energy conservation, Energy Audit, LED bulbs, Optimization approach, Grey relational method

1. INTRODUCTION

Introduction Lighting system, is another important part of buildings. The electrical energy used to power lights can easily be reduced by eliminating unwanted electrical fixtures. Simple modifications of lighting systems can greatly reduce the energy used while still providing quality and illumination needed for various purposes [1,2]. Energy efficiency means utilizing the minimum amount of energy for heating, cooling, equipment's and lighting that is required to maintain comfort conditions in a building [3,4]. An important factor impacting on energy efficiency is the building envelope. This contains building elements between the interior and the exterior such as walls, windows, doors, roof and foundations. All the building elements must work together to keep the building heat in the winter and cool in the summer. The effective energy utilization may be possible by insulating water pipes and water heater through thermal mass storage systems, Energy audits etc. The continual performance test to be conducted to ensure that the heating and cooling, equipment's and lighting are working effectively and efficiently [5]. In the residential sector, space heating and cooling accounts for 43 percent of total primary energy use. Therefore, total energy demand from this sector is fairly sensitive to weather and varies considerably by region in a single year and over time in a given location. Other significant end uses of energy in the residential sector include water heating, lighting, refrigeration, electronics, wet cleaning and cooking (Fig. 1).

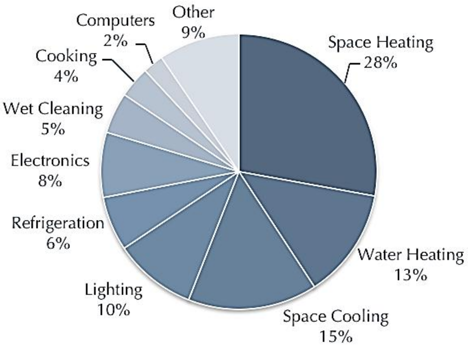

Fig. 1 Residential Buildings Primary Energy End Use Splits

Building designs and construction techniques can maximize the use of natural light and ventilation, which minimizes the need for artificial light and HVAC equipment. Using building shading techniques, installing windows to minimize or maximize solar intake (depending on the region), and properly insulating against unwanted air flow between indoor and outdoor spaces improve energy use. Many other options are available and “green” builders are continually creating innovative ways to maximize efficiency in building spaces. Even as residential energy use has increased overall, the amount of energy used per square foot of residential buildings, a measure of energy intensity, has decreased, due to the increased efficiency of consumer appliances and recent regional building trends, such as improved residential building energy codes. Energy intensity indicators are used to compare energy use in buildings through time. These indicators are used to examine energy-use trends in the different types of buildings in the residential and commercial sectors. They show how the amount of energy used per unit of output or activity has changed over time. Using less energy per unit of output reduces energy intensity; using more energy per unit increases the energy intensity. Educational Institutions are often overlooked as a contributor to energy intensive operations in India within the commercial buildings sector. An energy cost is one of the manageable costs within an institute’s budget and can be managed effectively [6].

Resultant cost and energy savings will go a long way in reducing energy use within the sector and provides a venue for reinvestment within the educational institute itself. School buildings in particular, are important among other kinds of buildings, where students can learn correct patterns of energy consumption and inspire by energy efficiency. This issue currently is an increasing concern in several countries and made authorities to take some measures towards more saving and energy efficiency in schools [7]. The energy audit performed in school, is designed to provide the teachers and students the necessary background and framework to conduct an energy survey of their school building. The step-by-step approach guides them through the process of analyzing energy consuming appliances and systems. After gathering data, teachers and students identify energy-related issues and brainstorm solutions. Then they rate the costs and benefits associated with their proposed solutions and put together an action plan. Finally, as an extension, teachers and students can monitor the impacts of their plan over time. The school energy audit also introduces opportunities and careers available in the energy management industry. The activities in the school energy audit closely parallel the tasks performed by engineers and other technicians in this growing field. A building gains heat energy as well as losing it, and both processes usually occur at the same time. In locations with a temperature climate, the overall gains are less than the overall losses, but the heat gains may still provide useful energy savings [8]. The factors affecting heat gains are indicated in Fig. 2.

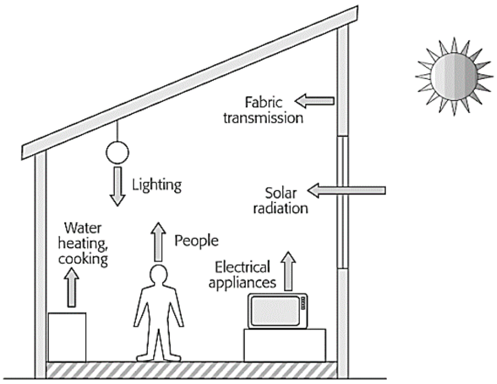

Fig. 2 Typical heat gains in a building [8]

2. LITERATURE SURVEY

Energy audits can be considered as the first step towards understanding how energy is being used in a given facility. They indicate the ways in which different forms of energy are being used and quantify energy use according to discrete functions. Energy audits do not provide the final answer to the problem. They identify where the potential for improvement lies and therefore, where energy management efforts must be directed. There is no uniform methodology, which can be used for conducting an energy audit of all equipment and systems [9]. Building energy efficiency measures include many technologies, such as improved lighting [10], energy efficient appliances, increased insulation, and reducing unnecessary infiltration as well as high-efficiency windows. Among the most significant energy efficiency measures are improvements in HVAC systems. The reason for the significance of HVAC is that air conditioning is the fastest growing energy use in the country and most air conditioning system rely on electric power for their operation and control [11].

Jing et al. [12] studied energy performance of commercial 30 office buildings in Hong Kong, based on utility bills, design documents and on-site measurement. Energy utilization index and carbon emission of each building have been calculated and compared with previous studies. An energy breakdown of 30 buildings by end-user systems was derived, showing that 68% of energy on average was consumed by HVAC system, while lighting accounted for 14% and the other systems shared the else 18% of consumption. Chandel et al. [13] reviewed the energy efficiency initiatives and regulations for residential buildings in India. A case study of building regulations of Hamirpur town with composite climate, located in north western Himalayan state of Himachal Pradesh, India is carried out to identify implementation problems for energy regulations at local level. It is found that energy efficiency measures are not followed strictly at local level although National codes or state regulations exist because of inappropriate regulation structure, ineffective enforcement and non-availability of detailed technical methodology. Building envelope, climatic and site conditions, building materials, water conservation, waste water recycling, heating, natural day lighting, cooling, ventilation are found to be important parameters for improving energy efficiency in buildings. Griego et al. [14] made an energy efficiency optimization of new and existing office buildings in Guanajuato, Mexico. The results from the optimization analysis indicate that the most cost-effective potential for energy conservation in both new and existing offices is achieved by reducing office equipment loads and more efficient lighting technology and controls. Over 49% annual energy savings can be achieved cost-effectively for both retrofit and new construction commercial office buildings.

Sait [15] presented an auditing and analysis of energy of some educational buildings in hot and humid area, considering constructing materials used, energy consumption, cooling load and lighting by recording temperature and relative humidity for several places inside the building. Thermal images for the interior zones were generated to provide information about the temperature distribution and give an idea about air or heat leak from or into the building. Based on the analysis of auditing exercise, some recommendations were suggested to reduce the electrical energy consumptions which can reach up to 35.3% and the A/C units' efficiency can also be increased by 31%. Mardookhy et al. [16] made a study on energy efficiency in residential buildings in Knoxville, Tennessee. The heating, ventilation, and air conditioning (HVAC) system and lighting system are two major factors influencing energy consumption in residential buildings. About 52–72% of the average energy consumed by residential buildings is used to keep buildings at comfortable temperatures, provide hot water, and circulate fresh air indoors. Theodosiou and Ordoumpozanis [17] investigated the energy efficiency, thermal environment and indoor air quality in public nursery and elementary school buildings in the city of Kozani, located at the cold climatic zone of Greece. The survey, conducted both by in-field measurements and by questionnaires, reveals problematic building envelope, the improper control of heating and lighting systems, the absence of proper legislative measures and, above all, the lack of interest concerning the efficiency of such buildings are the main factors in the reported efficiency. Alajmi [18] made an energy audit of an educational building in a hot summer climate, considered in this case study is a 2-story educational facility with a total floor area of 7020 square meter located in a harsh hot summer climate (State of Kuwait) and served by 4 air-cooled reciprocating chillers. Energy assessments proved that the building and its mechanical and electrical systems were improperly maintained and inefficiently operated. Interestingly, the non-retrofitting ECOs saved 6.5% of the building's annual energy consumption, while the retrofitting ECOs can save up to 49.3%; this results in a 52% total saving.

The energy shortages coupled with increasing energy prices being witnessed in various states in India is forcing the commercial and domestic sectors to look at ways and means for reducing their energy consumption and adopting technologies that result in lowering their energy intensity. Literature review indicates lack of research works in this area of research pertaining to the performance assessment of utility equipment and optimizing the performance of the system adopted in the domestic building. Most of the research works are eccentric about the energy consumption by air conditioning system and utility power usage. A new energy audit perspective is considered in this research work, studying the influence of LED bulbs and its position on illuminance level for human comfort. The aim of this research work is to audit a smart class room for lower energy consumption with at most human comfort based on energy. Experimental investigation is being carried out to study the energy scenario of the considered smart class room for various conditions. To investigate the energy audit procedure by considering different power of LED bulbs with different positions and measuring the illuminance in the smart class for maximizing the human comfort and brightness.

3. METHODOLOGY

For performing the energy audit, to optimize the consumption of energy, and to perform experimental studies, a smart class room is identified from the Higher Secondary School at Trichy, Tamil Nadu, India. The smart class room is of size 7m x 5m x 3m (Length x breadth x height) made of brick masonry work. The class room is built for a capacity of 30 students and is equipped with electrical utilities as shown in Fig. 3. The measuring equipment used during the energy audit process in the smart class room are watt-hour meter for measuring the energy consumption, luminance meter for measuring illuminance in the room and power factor meter for measuring power factor in smart class room.

Fig. 3 Smart class room for experimental work

Watt-hour meter measures the amount of electrical energy used by the dwelling electrical system. The watt-hour meter measures the amount of power consumed over a specific amount of time. It is a meter that registers the amount of watt-hours delivered by the electric utility of the customer [19]. The advantages of electronic watt-hour meter are: high sensitivity, no friction losses, less loading effect, low load, full load, power factor and creeping adjustments are not required and high frequency range and high accuracy such as ±1% [20]. The specifications of Power monitor PM-01, shown in Fig. 4 (HTC Instruments) have an RMS Voltage (V) of 195 ~ 265 Vrms with a basic accuracy of ± 0.5%. The RMS Current (A) range is 0.02 ~ 10Arms with ± 1% accuracy, active Power range of 5 ~ 2200 W with 1% accuracy having a power factor (COSΦ) of 10 ~ 2200 W with an accuracy of <0.01 PF.

Fig. 4 (a) Power Monitor PM – 01 (b) Lux Meter LX – 104 (c) Power factor Meter MP14

The luminance meter is designed to measure the light source average illuminance or surface brightness over a specified area. The luminance meter has an optical system that focuses an image on a detector. Looking through the optical system allows the operator to identify the area being measured and usually displays the illuminance of the area. The important characteristics of a luminance meter are its spectral response, its sensitivity and the quality of its optical system [21]. Lux meters are cheaper and simpler to use and therefore be used as a rapid, simple method of determining whether a particular lighting installation meets the design requirements. The specification of lux meter LX-104 shown in Fig. 4 (HTC Instruments) have a measuring range of 400,000Lux with accuracy of ±5%±10d (<10,000 Lux) and maximum resolution of 0.1 Lux / 0.01Fc with measuring rate of 1.5 times /sec.

Power factor meter indicates the instantaneous power factor of the circuit, whose power factor is varying according to the circuit and load conditions, which can directly indicate the power factor. Power factor is a measure of how effectively an equipment converts the voltage and current supplied by a power source into watts of usable power delivered to the lamp. In general, the power factor is determined from the design and is considered high (if above 0.90), low (below 0.79), or "corrected" (0.80 to 0.90). Power factor addresses the effective use of power supplied to an equipment. Energy conservation and economic considerations dictate the use of power factor-corrected and high power factor equipment's [22]. Digital power factor meter has been developed on the basis of many techniques and ideas such as binary rate multiplication (BRM), voltage to frequency conversion technique (VFC) with counting, approximating cos ϕ by series, reconstructing a DC voltage proportional to the power factor, etc. [23]. The power factor meter MP14 shown in Fig. 4 (SELEC) has specifications of 7 segment LED display, with 1Ø-2 wire electrical connection, having a measuring range of -1.000 to +1.000 with an accuracy of ± 0.5% ±1 Digit working under a supply voltage of 240V AC ±20% (50/60 Hz), 110V AC ±20% (50/60Hz) with dimensions of 48 x 96mm.

3.1 Taguchi's Design of Experiment

Design of Experiments (DoE) refers to the process of planning, designing and analyzing the experiment so that valid and objective conclusions can be drawn effectively and efficiently [24]. In order to draw statistically sound conclusions from the experiment, it is necessary to integrate simple and powerful statistical methods into the experimental design methodology [25]. Taguchi's Design of Experiments (DoE) is a statistical technique that is used to study many factors simultaneously and most economically [26]. By studying the effects of individual factors on the results, the best factor combination can be determined. When applied to a design, the technique helps to seek out the best design among the many alternatives [27]. Taguchi's technique is a powerful tool in quality optimization. Taguchi's technique makes use of a special design of Orthogonal Array [28] to examine the quality characteristics through a minimal number of experiments [29]. The experimental results based on the Orthogonal Array (OA) are then transformed into S/N ratios to evaluate the performance characteristics.

In this study, experiments are designed considering number of LED bulbs used for illuminance in the room for human comfort, power of the LED bulbs and position of the bulbs; horizontal (placed in the side walls), vertical (Placed hanging over the roof) and inclined (placed at room corners at 45°). With respect to these conditions, different variable levels are chosen as given in Table 1.

Considering number of LED bulbs with different power ratings and different positions with respect to wall conditions for better illuminance, Table 2 shows the different combinations of the selected parameters using Taguchi's DoE.

Table 1 L_9 Orthogonal Array for Human comfort

Parameter / Level	Level I	Level 2	Level 3
No. of LED Bulbs	2	4	6
Power (Watts)	6	9	12
Position of Bulb	Horizontal	Vertical	Inclined

Table 2 Experimental L_9 Orthogonal Array for illuminance

Trial No	No. of LED Bulbs	Power (Watts)	Position of Bulbs
1	2	6	Horizontal
2	2	9	Vertical
3	2	12	Inclined
4	4	6	Vertical
5	4	9	Inclined
6	4	12	Horizontal
7	6	6	Inclined
8	6	9	Horizontal
9	6	12	Vertical

For analysis, there are three categories of performance characteristics, (i.e.) Smaller-the-better, Larger-the-better and Nominal-the-better, to determine the Signal-to-Noise (S/N) ratio in Taguchi's technique. The impact of noise factors on performance is measured by means of S/N ratio. If the S/N ratio is larger, the product will be more robust against noise. For Smaller-the-better category, the quality characteristics are usually an undesired output and for Larger-the-better category, the quality characteristics are usually a desired output and for Nominal-the-best category, the quality characteristics are usually a nominal output.

Smaller-the-better (Minimize):

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

Larger-the-better (Maximize):

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

Nominal-the-better:

$$S / N = 10 \log \left(\frac{\overline{y}}{s_y^2} \right) \tag{3}$$

where $\overline{y}_i$ represents the experimentally observed value of i^{th} experiment and n is the no. of replications of each experiment.

3.3.4 Grey Relational Analysis

Grey Relational Analysis (GRA) is used to determine the optimum condition of various input parameters to obtain the best quality characteristics [30]. Grey Relational analysis is broadly applied in evaluating or judging the performance of a complex project with meagre information [31]. However, the data to be used in Grey analysis must be preprocessed into quantitative indices for normalizing raw data for another analysis. Preprocessing raw data is a process of converting an original sequence into a decimal sequence between 0.00 and 1.00 for comparison. If the expected data sequence is of the form "Higher-the-better", then the original sequence can be normalized as,

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{4}$$

where $x^{o}_{i}(k)$ is the original sequence, $x^{*}_{i}(k)$ the sequence after the data preprocessing, max $x^{o}_{i}(k)$ the largest value of $x^{o}_{i}(k)$, and min $x^{o}_{i}(k)$ imply the smallest value of $x^{o}_{i}(k)$. When the form "Smaller-the-better" becomes the expected value of the data sequence, the original sequence can be normalized as,

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{5}$$

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results [32]. Thus, the grey relational coefficient can be expressed as,

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta . \Delta_{\max}}{\Delta_{0i}(k) + \zeta . \Delta_{\max}} \tag{6}$$

where Δ_{oi} (k) is the deviation sequence of the reference sequence, which is given by,

$$\Delta_{0i}(k) = \left\| x_0^*(k) - x_i^*(k) \right\| \tag{7}$$

$$\begin{aligned} \Delta_{\max} &= \max_{\forall j \varepsilon i} \max_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\|, \\ \Delta_{\min} &= \min_{\forall j \varepsilon i} \min_{\forall k} \left\| x_0^*(k) - x_j^*(k) \right\| \end{aligned} \tag{8}$$

ζ is distinguishing or identification coefficient: $\zeta \varepsilon$ [0, 1]. $\zeta = 0.5$ is generally used. After obtaining the grey relational coefficient, normally the average of the grey relational coefficient is taken as the grey relational grade [33]. The grey relational grade is defined as,

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} {}_i \zeta_i(k) \tag{9}$$

4. RESULTS AND DISCUSSIONS

In this set of experimentation carried out in the smart class room, LED bulbs of different power, varying in numbers with positions altered is used. Energy auditing is performed with the designed L_9 orthogonal array, as per Taguchi's design and the total energy consumed by the LED bulbs is recorded with power factor and illuminance level is measured for better visibility inside the smart class room. The measured output responses are provided in Table 3.

Table 3 Measured output responses for different lighting conditions

Trial No.	Energy Consumed (kW-h)	Power Factor	Illuminance (Lux)
1	0.012	0.72	256
2	0.018	0.82	283
3	0.024	0.75	263
4	0.024	0.77	276
5	0.036	0.79	266
6	0.048	0.78	274
7	0.036	0.81	293
8	0.054	0.85	297
9	0.072	0.88	281

Observation made from the experimental results shows that, with increase in number of LED bulbs fixed inside the smart class room, energy consumption increases drastically with increase in power factor and illuminance level. When LED bulbs are increased from 2 to 4, energy consumption increases by 100%, power factor by 2.19% and illuminance level by 1.75%. With further increase in LED bulbs from 4 to 6, energy, power factor and illuminance increases by 50%, 8.55% and 6.24%. Increasing the power of LED bulbs increases power consumption by 50%, power factor by 6.95% and illuminance level by 2.55%. When power is increased from 6 to 9 W, energy utilized increases by 33.33%, power factor decreases by 2% and illuminance decreases by 3.3%. Position of fixing the LED bulbs plays a vital role in providing proper illuminance level inside the smart class room. When position of LED bulbs are changed from horizontal to vertical, illuminance increases by 1.57% and when changed from vertical to inclined, level of illuminance decreases by 2.14%. For analyzing the obtained data from experimental smart class room, a hybrid Taguchi based with Grey Relational Analysis technique is used [34]. Initially the output responses are converted in to signal-to-noise (S/N) ratio depending upon, whether it has to minimized or maximized. Energy consumed inside the smart class room has to be minimum, for which the formulae in Eq. (3.1) is applied, whereas power factor and illuminance level has to be higher, for which the formulae in Eq. (3.2) is applied. Followed by this, data pre-processing is done, which converts all the S/N data in between 0 to 1. During normalizing, energy consumption should be lower, for which the formulae in Eq. (3.5) is applied, whereas for power factor and illuminance level, normalizing formulae for maximizing in Eq. (3.4) is applied. The S/N ratio and normalizing sequence of hybrid Taguchi-GRA is shown in Table 4.

Table 4 Calculation of S/N ratio and Normalizing sequence of GRA

Trial No	S/N ratio			Normalizing Sequence		
	Power Consumed	Power Factor	Illuminance	Power Consumed	Power Factor	Illuminance
1	38.416	-2.853	48.165	0.000	0.000	0.000
2	34.895	-1.724	49.036	0.226	0.648	0.675
3	32.396	-2.499	48.399	0.387	0.203	0.182
4	32.396	-2.270	48.818	0.387	0.335	0.506
5	28.874	-2.047	48.498	0.613	0.462	0.258
6	26.375	-2.158	48.755	0.774	0.399	0.457
7	28.874	-1.830	49.337	0.613	0.587	0.909
8	25.352	-1.412	49.455	0.839	0.827	1.000
9	22.853	-1.110	48.974	1.000	1.000	0.627

Deviation sequence in the grey relational procedure is carried out after normalizing the S/N ratio, which is followed by determining the grey relational coefficient as per the formulae given in Eq. (3.6). By taking the average of the grey relational coefficient of all the output responses, a common grey relational grade has to be calculated in order to convert the single objective optimization into multi-objective optimization as shown in Table 5.

For obtaining the response table of grey relational grade, shown in Table 6, average values of grey relational grade corresponding to each parameter level of input factors are considered and from that the optimum conditions are evolved by choosing the level values with larger grey grade. The best/optimal parameter levels are identified from the response table as number of LED bulbs as 6 with power of 9W and positioned vertically for better illuminance. Main effects plot of grey relational grade is drawn based on response table which is shown in Fig. 5.

Figure 6 shows the interaction plot which identifies the influence of various inputs over the output grey relational grade. From the linear plot drawn, it is obvious that a considerable relationship exists between the position of the LED bulbs inside the smart class room and the power of LED bulbs used, represented by non-parallel lines. In between number of LED bulbs used and power of LED bulbs, a moderate interaction effect is observed, similar to that the relationship between number of LED bulbs and its position.

Table 5 Calculation of Grey relational coefficient and grade

Trial No.	Deviation Sequence			Grey Relational Coefficient			Grey Relational Grade
	Power Consumed	Power Factor	Illuminance	Power Consumed	Power Factor	Illuminance	
1	1.000	1.000	1.000	0.333	0.333	0.333	0.333
2	0.774	0.352	0.325	0.393	0.587	0.606	0.529
3	0.613	0.797	0.818	0.449	0.386	0.379	0.405
4	0.613	0.665	0.494	0.449	0.429	0.503	0.460
5	0.387	0.538	0.742	0.564	0.482	0.403	0.483
6	0.226	0.601	0.543	0.688	0.454	0.480	0.541
7	0.387	0.413	0.091	0.564	0.548	0.846	0.652
8	0.161	0.173	0.000	0.757	0.743	1.000	0.833
9	0.000	0.000	0.373	1.000	1.000	0.573	0.858

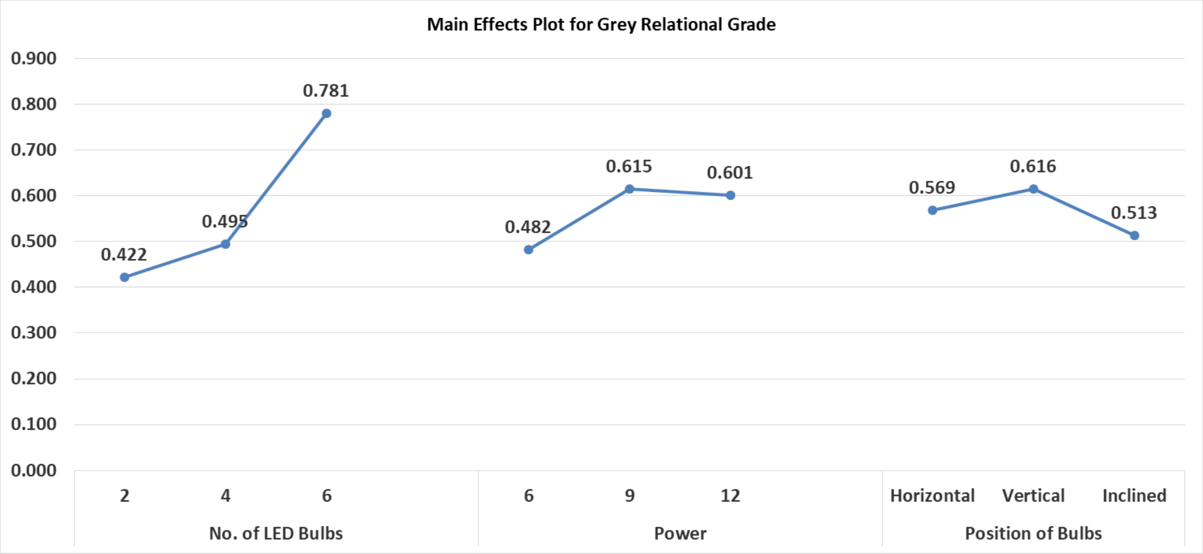

Fig. 5 Main effects plot of Grey relational grade

Table 6 Response table for grey relational grade

Factors	Level 1	Level 2	Level 3	Max - Min
No. of LED Bulbs	0.422	0.495	0.781	0.359
Power	0.482	0.615	0.601	0.133
Position of Bulbs	0.569	0.616	0.513	0.102

From the statistical ANOVA table formulated for grey relational grade given in Table 7, it is found that the number of LED bulbs used inside the smart class room is the most prominent parameter that contributes towards the grey relational grade by 81.80%, followed by the power of the LED bulbs by 12.10% and position of the LED bulbs inside the room by 5.95%. The ‘S’ value of ANOVA is 0.0138, R^2 value is 99.86% with R^2 (adj.) value of 99.42%. Figure 7 shows the percentage contribution of input parameters over the grey relational grade.

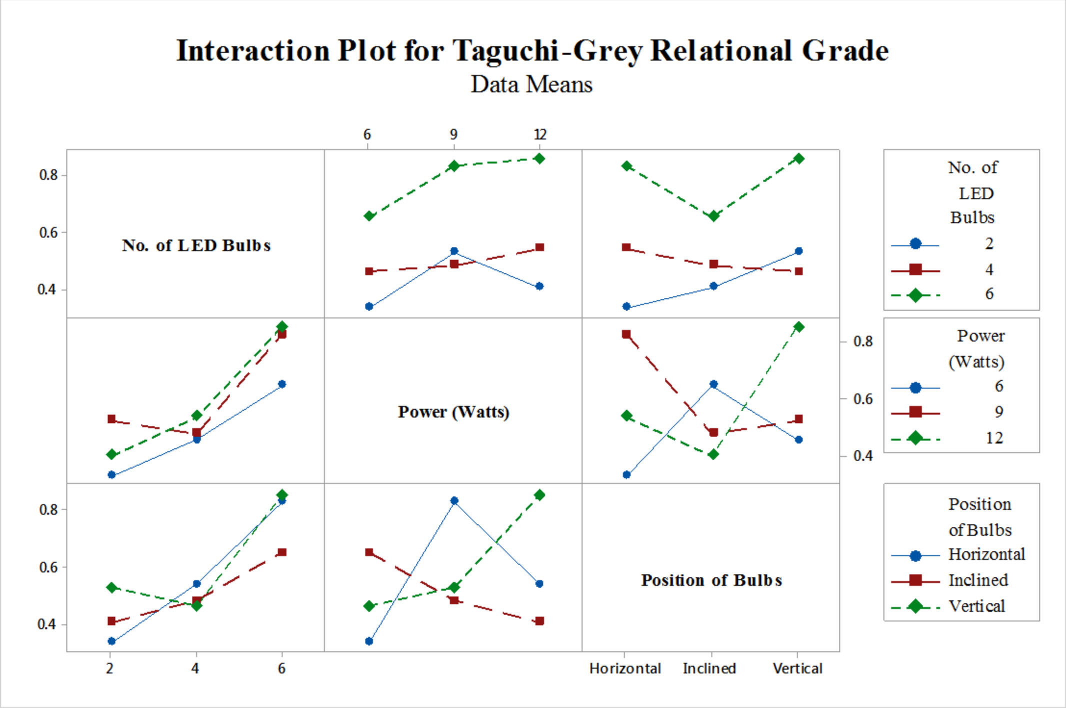

Fig. 6 Interaction plot of Grey relational grade

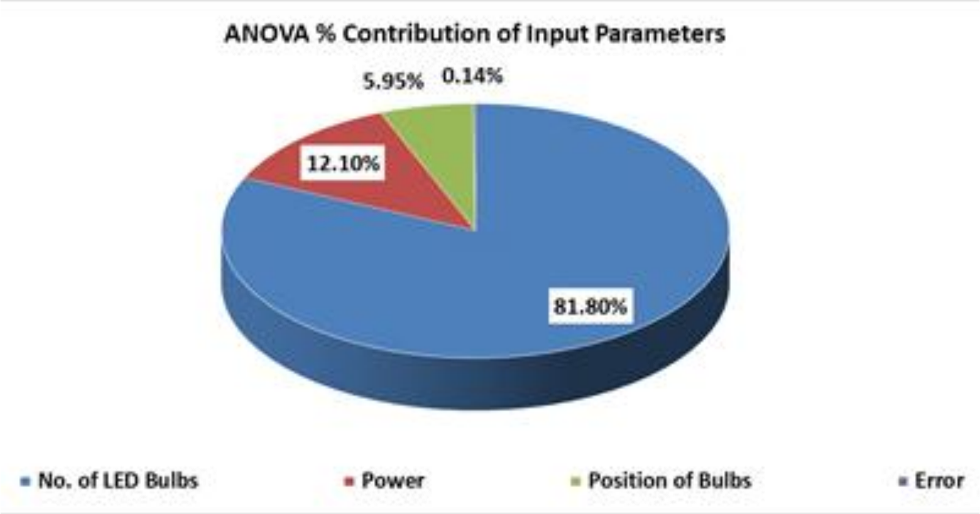

Fig. 7 Percentage contribution of Grey relational grade

Table 7 ANOVA table for Grey relational grade

Factors	DoF	SS	MS	F Value	P Value	% Contribution
No. of LED Bulbs	2	0.2162	0.1081	566.339	0.002	81.80%
Power	2	0.0320	0.0160	83.795	0.012	12.10%
Position of Bulbs	2	0.0157	0.0079	41.230	0.024	5.95%
Error	2	0.0004	0.0002			0.14%
Total	8	0.2642	0.0330			100.00%

4.1 Validation experiment for Taguchi-Grey analysis

With the identified optimal input parameters, a confirmation experiment is performed with the same experimental smart class room to validate the obtained results. For the optimum condition of: number of LED bulbs as 6 with power of 9W and the LED bulbs positioned vertically, the outputs obtained are energy consumption of 0.054 kW-h, power factor of 0.87 and illuminance level of 299 lux. With the output of confirmation experiment, improvement in power factor by 9.12% and level of illuminance inside the smart class room by 8.12% is observed.

.5. CONCLUSION

In this study, analysis and optimization on energy consumption and indoor comfort are made for a smart class of a school building. Taguchi's grey relational technique is employed for optimizing energy consumption and for better illuminance.

1. With increase in number of LED bulbs fixed inside the smart class room, energy consumption increases drastically with increase in power factor and illuminance level. Also, increasing the power of LED bulbs increases power consumption, power factor and illuminance level. Position of fixing the LED bulbs plays a vital role in providing proper illuminance level inside the smart class room and vertical position of LED bulbs provides better illuminance than horizontal and inclined position.

2. The optimal parameter levels are identified as 6 numbers of LED bulbs of 9W power and positioned vertically for better illuminance.

3. From interaction plot, a considerable relationship exists between the position of the LED bulbs and the power of LED bulbs used. In between number of LED bulbs used and power of LED bulbs, a moderate interaction effect is observed, similar to that the relationship between number of LED bulbs and its position.

4. ANOVA results shows that, number of LED bulbs in smart class room is the most prominent parameter that contributes towards the grey relational grade by 81.80%, followed by the power of the LED bulbs by 12.10% and position of the LED bulbs inside the room by 5.95%.

5. Observation from confirmation experiment shows that an improvement in power factor by 9.12% and level of illuminance inside the smart class room by 8.12% is achieved.

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