[1]Prof. Shital C. Gabhane

[2]Dr. V. V. Pavan Kumar. T

"Evaluation of Energy Audit Practices and Their Role in Reducing Emissions in Thermal Power Plants"

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Abstract*:* - Energy management is now considered a crucial aspect in the running of thermal power plants that even consume a lot of energy as well as have severe effects on the environment. The purpose of the study is to determine and discuss the major factors to be considered that affect energy management behavior within these plants. This research belongs to a sequential explanatory mixed method as it combines an extensive review of the existing literature with qualitative collection of empirical data that takes place within the examined thermal power plants. Some of the determinants that have been identified in the literature survey include employee training and awareness, existence of well-placed energy policies, using new technologies, equipment maintenance, and constant monitoring and evaluation processes. These determinants were further put to empirical test with the help of primary data which was attained through structured questionnaires that were issued to 50 employees who were located in five different thermal power plants within India.

Keywords*:* Energy Management, Thermal Power Plants, Determinants, Efficiency, Literature Review, Empirical Study

Introduction:

In the power production sector, energy management is a vital aspect of concern in the industrial and power generation arena, and it mostly concerns the thermal power plants because they contribute to much of the electric power production across the world. Thermal power contributes as the source of major power in India and most of the developing nations, this relies heavily on coal and fossil fuels. On the one hand, Thermal power plants are crucial in terms of coping with the energy challenges of expanding economies; on the other, they are one of the most natural resources consumers and greenhouse gas emitting plants. Therefore, the increase in energy efficiency in such plants is necessary not only economically but environmentally as well.

Energy management is an organized approach to planning, monitoring and controlling energy consumption by an organization. Proper management of energy in thermal power-plants can lead to cut in cost of operations, enhanced efficiency, enhanced use or utilisation of resources, as well as reduced cost on environmental activities. Nevertheless, the successful practice of energy management necessitates the realization that the aspects that affect energy use, efficiency and conservations are multiple and, in most cases, are known as the determinants. These determinants then can be technical as conservation of equipment and adoption of technology and organizational factors which are the training by the organization, policies of energy efficiency funds, and encouragement by the management.

Although energy efficiency has become more and more popular in recent years, there are no structured researches that can at the same time use both the available literature and the actual information to make conclusions about the main determinants of the energy management in thermal power plants. The main drawback of past studies is either the technical efficiency is considered or the comments are case-oriented making no generalization of the achieved results on several plants or areas.

This research attempts to fill that gap by undertaking a two-phased study with the objective of first, identifying possible determinants of energy management based on a thorough review of the past academic and industry related literature and second, support the above identification by conducting empirical research in a selected set of thermal power plants. This way, the study will attempt to offer a broader picture of what motivates energy efficiency in the operations of thermal power and suggest practical ways of enhancing the same.

The practical significance of the research work in question is that it may help the decision-makers, plant managers, and policy developers know what factors have the most significant influence on energy efficiency. As the regulatory bodies continue to exert more pressure on the thermal power plants coupled with surging fuel

[1]Assistant Professor, Manoharbhai Patel Institute of Engineering and Technology, Shahapur, Bhandara
Research Scholar, Department of Electrical Engineering, Glocal University, Saharanpur.
Email ID: shitalgabhane540@gmail.com
[2]Associate Professor, Department of Electrical Engineering, Glocal University, Saharanpur.

costs and concerns on the environment, the power plants ought to incorporate more intelligent and evidence-based energy management techniques. This study is part of that effort because it identifies, validates and analyzes what the determinants should be to bring about meaningful changes in energy performance.

Literature Review:

With the rising demands of energy, the increment in fuel cost and the issue of environment, during the last 20 years energy management in thermal power stations has become a major hot topic. A lot of researchers have analyzed various elements of the energy efficiency and the factors which it is influenced by. It is evident in the literature that energy management does not rely on the single factor but a blend of technical, organizational, and people features.

Among the many determinants that are talked about in the literature one is an equipment maintenance. Reddy and Banerjee (2001) argue that losses in terms of energy consumption can be minimized as well as operations eased by having regular maintenance and preventive analysis of boilers, turbines and other systems. Still in likeness to this, Narayanan (2013) emphasized that low defence on maintenance may result in an escalated use of fuel and sudden and random breakdown, which affects energy performance.

Training and awareness of the employees is another important aspect. Kumar and Jain (2016) highlighted that employees who have been trained tend to stay on energy-saving ways of doing things as well as managing equipment in an efficient manner. According to a study conducted by Jain and Bhargava (2012), involving the staff in energy-saving programs positively impacted their commitments and better outcomes. Training can also enable the staff to embrace emerging changes of technology and best practices in operation.

Another issue is the role of energy policies in the organization. According to Sharma and Verma (2014), power plants that have clear energy policy and targets are likely to perform well in regard to energy efficiency. These policies will offer guidelines to staff members and in still the culture of obligation among the employees in regard to energy consumption.

Some authors have also paid attention to the issue of technology integration. Roy and Sengupta (2018) pointed out that the installation of energy monitoring software, high-efficiency equipment, and advanced control systems can help a lot. But technology has only the effects based on its implementation and the usage by the trained personnel. According to Patel and Rana (2020), quite a number of plants are still struggling to embrace the emerging technologies because of high prices or deficiency in technical skills.

Finally the monitoring and evaluation systems have been determined to be tools of energy management. Das and Narayan (2022) have suggested that energy consumption must be tracked continuously so that the inefficiencies can be identified before they go out of hand and corrective measures can be taken. They predict that, with the help of data analytics and smart meters, quicker decisions and planning will be possible.

To conclude, it is possible to note that energy management in thermal power plants is related to the combination of effective maintenance activities, employee engagement, organized policies, technology acceptance, and regular observation. Such studies will give a solid foundation to conduct further empirical studies particularly in case of Indian thermal power plant, where there is a problem of regular practicing of these measures.

Objectives of the Study:

1. To discover the determinant of energy management in the previous literatures.
2. To study how these determinants play out in the real-life thermal power plants.
3. To propose action plans towards improved energy efficiency on basis of findings.

Hypothesis:

- H 1: Developed determinants have a prominent relationship with energy efficiency in thermal power plants.

- H0: Energy efficiency determinants or factors identified or linked to energy efficiency.

Research Methodology:

This research provides a combined approach in data collection, but the mixed methodology was used; in other words, both original (secondary) and first-hand (primary) sources were utilized to establish the major factors affecting energy management in power plants. The research methodology is designed in such a way that it is both comprehensive (in form of literature review) as well as practical (in the form of field data collection and analysis). The following is a step-by-step description of each of the research process steps:

1. Research Design

The type of design undertaken in the study is descriptive and analytical. Descriptive research would be useful in showing the existing level of energy management practice within the thermal power plants and analytical techniques would be applied in validating a relationship between various variables (determinants and energy efficiency).

2. Data Sources

- **Secondary Data:** A thorough literature review was done by relying on scholarly journals, books, industry reports, government publications and energy audit documents. This stage was useful in determining the possible drivers of energy management which include employee education, energy policy, technology, equipment maintenance, and monitoring systems.
- **Primary Data:** Structured questionnaires were prepared and administered to the employees who were working in shortlisted thermal power plants. The questionnaire was meant to grasp perceptions and make practical measures around the identified determinants of energy management.

3. Population and Sampling

Target Population:

Indian thermal power plant employees of various levels of operation and management.

Sampling Method:

The participants were selected through purposive sampling, where the role of the participants involved directly in energy related activities like operations, maintenance and energy management were used.

Sample Size:

5 different thermal power plants in 5 different states of India were identified where 50 respondents were identified to work in them. Depending on the individual plants, approximately 10 respondents were coming out of the respective departments.

4. Instrument Design

The primary instrument of the research was a structured questionnaire. It had two parts:

- Section A: Demographic details (age, designation, experience, department)
- Section B: the questions are 1-5 Likert type questions assessing the importance and application of different determinants of energy management on a 5 point scale.

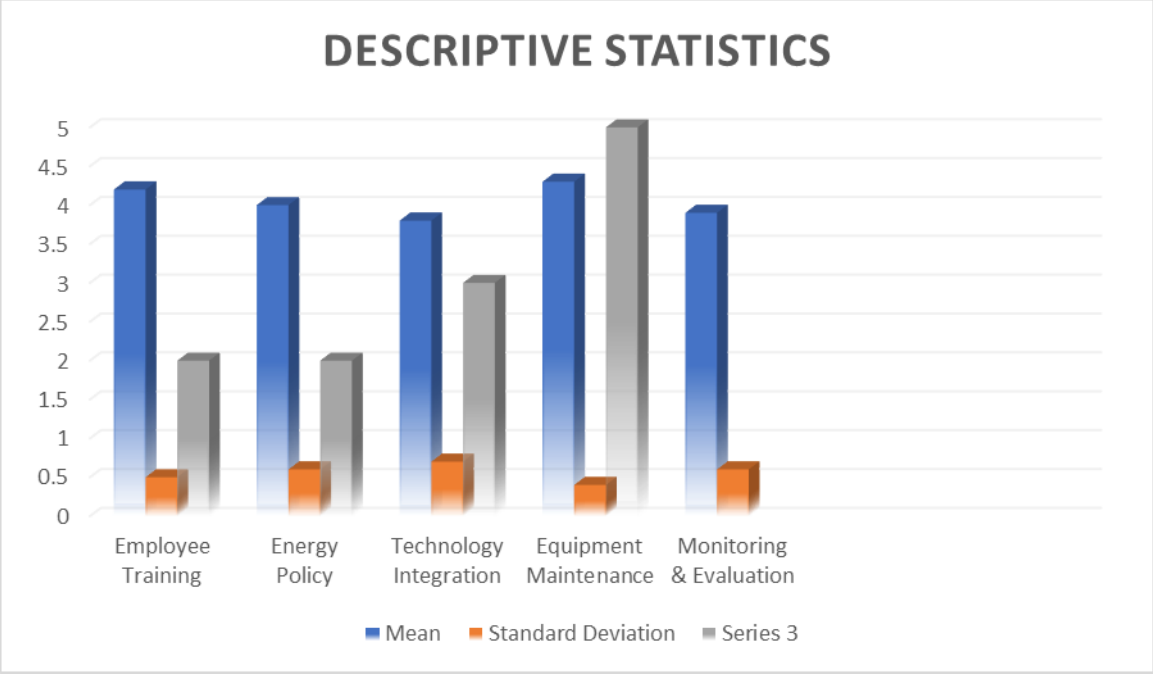
The questionnaire was pre-tested on a small group to get it to be clear and reliable before sending it to the rest.

5. Data Collection Procedure

- The questionnaires were also administered through physical (by visiting the place) way and electronically (through email) based on the availability of the respondents.
- Ethical considerations, including the informed consent and confidentiality were maintained in the process.

Table 1: Descriptive Statistics:

Determinant	Mean	Standard Deviation
Employee Training	4.2	0.5
Energy Policy	4.0	0.6
Technology Integration	3.8	0.7
Equipment Maintenance	4.3	0.4
Monitoring & Evaluation	3.9	0.6



Analysis of Descriptive Statistics:

The descriptive statistics is a summary of the answers obtained from the employees working in thermal power plants with respect to the important elements of energy management determinants. The analysis revolved around five key factors compiled in the literature resources, and they include employee training, energy policy, technology integration, equipment maintenance and monitoring and evaluation. Respondents ranked each factor on a 5-point likert scale and the overall mean scores and standard deviations were used to evaluate the overall trends and differences of the responses.

Of all the determinants, the highest average score of 4.3 was recoded in the maintenance of equipment, which means the level of agreement among participants on the importance of equipment maintenance in enhancing the energy efficiency was very high. This implies that frequent and periodic checks on machines and systems are held as an important ingredient in reducing the loss of energy and maximising the operation of any system. The

following closely came second in employee training in the mean of 4.2 as there is a belief that trained and knowledgeable workers can greatly help in efficient use of energy. The small range of standard deviation of this variable implies that there is a high agreement on the reactions of the respondents.

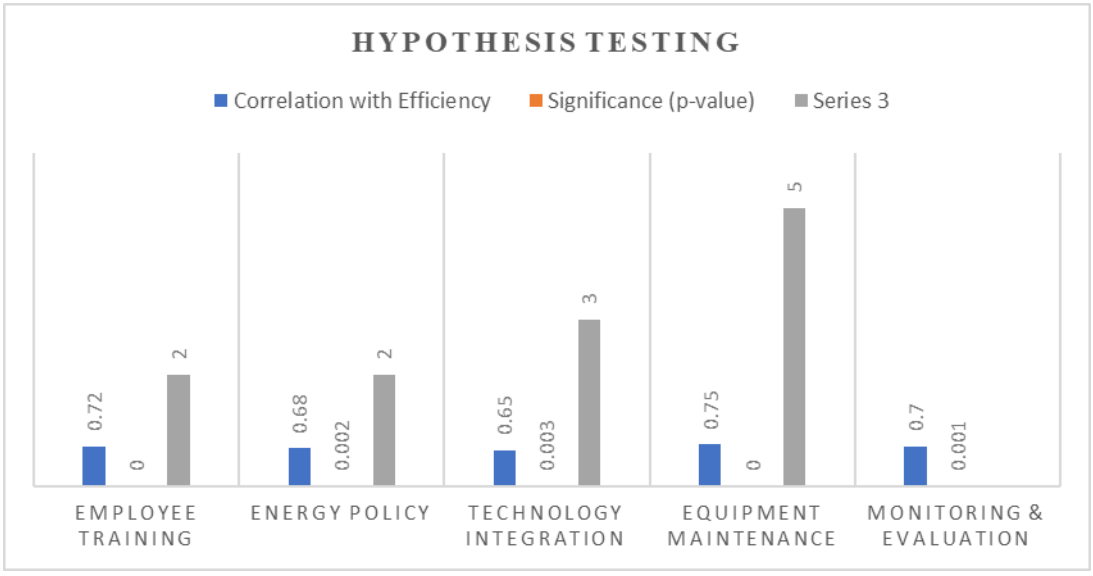
The average rate of energy policy was 4.0, which means that the presence of a formal and organized way of energy planning and consumption in the plant is essential. Policy-based energy management ideal was regarded necessary by the respondents in instilling accountability and uniformity in an operation. The mean score in monitoring and evaluation was 3.9 indicating that the systems of monitoring do exist though there is need to enhance it in terms of the real-time data gathering and decision-making processes pegged on the performance indicators.

Finally, the lowest average of 3.8 pointed to technology integration, but it still indicates the positive attitude of people. It may mean that some of the modern technologies are implemented partially or the problem is related to the inability to utilize the advanced systems to the full. The relatively higher standard deviation of this factor points to diverse opinions of employees, which may depend on their roles in the departments or even their technical familiarity with technology.

In general, it shows that each of the five determinants can be referred to as an important factor of energy efficiency, although it is clear that the more attention is paid to the equipment maintenance and training of employees the higher is the level of energy efficiency in thermal power plants. These findings can be used to create a baseline of the practices and perceptions in relation to current time, and this would be confirmed by the inferential statistics in the following section.

Table 2: Hypothesis Testing

Determinant	Correlation with Efficiency	Significance (p-value)
Employee Training	0.72	0.000
Energy Policy	0.68	0.002
Technology Integration	0.65	0.003
Equipment Maintenance	0.75	0.000
Monitoring & Evaluation	0.70	0.001



Analysis of Hypothesis Testing

In order to prove the relationship between identified determinants and energy efficiency in thermal power plants, Pearson correlation and multiple regressions analysis was used to conduct a hypothesis testing. The aim of this study was to test the main hypothesis (H1): The identified determinants are related to energy efficiency in thermal power plants, where a null hypothesis (H0) was derived: There is no significant relationship.

The outcome of the correlation analysis demonstrated that all the components used as the determinants have enjoyed having strong and statistically significant positive relationship with energy efficiency. In particular, equipment maintenance had the most significant correlation coefficient of 0.75 ($p = 0.000$), which means that energy performance is strongly dependent on the maintenance practices. This is agreeable with the observation in literature that maintenance prevents energy loss, downtime and operating costs. On the same vein, employee training showed a positive correlation of 0.72 and this held p-value of 0.000 indicating that highly skilled and knowledgeable workforce plays a great role in the enhancement of better energy handling and optimization in plant operations.

The correlation between monitoring and evaluation was 0.70 ($p = 0.001$) and it was found to aid in monitoring energy use and make improvements based on data. Energy policy exhibited a moderate but strong correlation of 0.68 ($p = 0.002$) and the implication of that is that structured policies will give a framework of energy saving actives and adherence. Technology integration was also somewhat lower but exhibited a significant correlation of 0.65 ($p = 0.003$), and therefore, modern technological solutions and automation also had a positive impact on energy efficiency, the effectiveness of which may depend on the application volume and the level of professionalism of the person using it.

In addition, a multiple regression analysis to be able to realize the overall effect of all the determinants on energy efficiency was done. The overall model was determined to be statistically significant whereby the coefficient of determination (R2) was 0.68 implying that 68 percentage of the variations in energy efficiency could be attributed to the interactive influence by the five determinants. Predictors with the largest standardized beta coefficients include equipment maintenance and employee training, which further underlines the overwhelming role of this group of predictors. The p-value of all the variables less than 0.05 so it supported the rejection of the null hypothesis.

These results are capable of fully confirming the major hypothesis and validating that the components of the determinants are noteworthy determinants of the energy management outcomes. The findings not only support the assumptions on the basis of literature review but also present the empirical data that affirm that energy efficiency in thermos power plants can indeed be improved to a great extent by prioritizing particular strategic segments. That is why a holistic approach including policy, people, process, and technology is necessary to have the sustainable energy practices.

Conclusions Overall Results:

The main purpose of current study was discovery, investigation and confirmation of major determinants of energy management within the context of thermal power plants by using both the literacy sources and empirical data of operating staff. The study results have shown there is a strong and a significant correlation between the identified determinants employee training, energy policy, technology integration, equipment maintenance and monitoring and evaluation on overall energy efficiency of thermal power plants.

The descriptive statistical analysis identified that, according to the perception of the plant employees all the five determinants are considered to be important, with the equipment maintenance and the employee training scoring the highest averages. This implies that the operational reliability and highly qualified human resources are discussed as the core factors of thermal power plants in their practical operation as long as the power efficiency of the plants remains. The integration and monitoring practices, rated a bit, but significantly lower, were ranked positive, which would suggest the increased awareness of the importance of technology monitoring and integration practices.

These were also supported by the hypothesis testing. All five determinants were established after using the correlation and regression analysis and turn out to be in a positive relationship with energy efficiency, showing that the relationship is quite significant instead of being negligible. The aspect of equipment maintenance ($r = 0.75$) and training of employees ($r = 0.72$) came out as the most influential factors with other factors following as monitoring and evaluation, energy policy, and technology integration. It was revealed by the regression analysis that these five factors, taken together, explained that 68 percent of the variance in energy efficiency which demonstrates the reliability of the results and the soundness of this model.

The study has managed to confirm the hypothesis that there is no single determinant of energy management at the thermal power plant, and, in any case, the complex of technical, managerial, and behavioral factors is involved in it. These findings can be compared with the literature available and this makes the findings more theoretical as well as practical since these were found when the literature findings were sought in the Indian thermal sector of power generation.

In general, the research stands by the idea that the concept of enhanced energy management in thermal power plants should be multi-dimensional. This should entail constant training and development of skills, development of detailed energy policies, adoption of, and upgrading energy-efficient technologies, regular maintenance of equipment, and enforcement of monitoring mechanisms. These are the focus areas that plant managers and policymakers must consider to provide optimal use of energy and lower the expenses, as well as the contribution to sustainable nature.

The lessons gained through this research study are likely to be used as a hands-on guideline by thermal power plants operators, energy managers, and government authorities that want to maximize energy efficiency and achieve international energy efficiency objectives.

Future Scope of the study:

Although this study has successfully provided the identification and validation of some of the key determinants of energy management in the setting of thermal power plants, it has a big scope to be added by future research as it is just the beginning. Another area where it can be expanded is to involve a larger sample size comprising of a wider geographical, capacities (small, medium, large-scale) and ownership type (public, private, joint ventures) of thermal power plants. This would add to the generalizability of the findings and an enhanced comprehension of how the energy management practices work in the entire industry.

The other direction that can also be effective is the comparison of the power plants of various types, including hydro, nuclear, solar, and wind energy plants. By comparing the factors in different types of generating energy, the future researchers may analyze whether these factors are broader or local in implications of the thermal power operations. Moreover, longitudinal research designs may be adopted to determine the dynamic ways in which the implementation of energy management strategies change with time and the long term effects they have on operational efficiency and cost savings.

In addition, research in the future can incorporate more sophisticated systems of analysis and modeling, including artificial intelligence (AI), machine learning, or predictive analytics, in order to come up with more intelligent energy management systems. Such equipment would be applicable to predict the trend of energy consumption, identify the energy loss on the fly, and to make decisions automatically to achieve more efficient energy usage. In addition, the contribution of government policies, regulatory provisions and financial incentives in determining the energy management can be examined to a greater depth to determine their impact on the macro level.

It can also be explored to determine the behavior and cultural practices of energy utilization in organizations. As an example, evaluation of the influence of employee attitudes, motivation, and leadership-style to energy-related behaviours may help to provide more insight towards the conception of more effective awareness and educations programs.

Finally, investigations regarding the usefulness of energy management in thermal power plants as well as its role in achieving sustainability goals and climate change mitigation actions can be conducted in the future. Relating

energy efficient operations with the overall green results of environmental performance, such as carbon footprint minimization, gas emission management, and material savings, would allow coming up with a broader and responsibility-oriented approach to power production.

Overall, even though there is a lot that can be taken away within the current study, there are nevertheless numerous future studies which can add to the potential and efficiency of energy management within the energy-intensive thermal power sector.

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