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Green Building: Energy Efficiency Optimisation Strategies using MATLAB

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Abstract: This research paper explores the integration of optimization techniques in the realm of green building construction, aiming to minimize environmental impact while maximizing resource efficiency. With the pressing need to mitigate climate change and reduce the carbon footprint of the construction industry, the study investigates various methodologies for optimizing the design, materials, and processes involved in sustainable building practices. The paper delves into the core principles of green building, emphasizing the importance of energy efficiency, renewable resources, and innovative construction techniques. It analyzes the application of optimization models, such as life cycle assessment (LCA), Building Information Modeling (BIM), and parametric design, in streamlining decision- making processes throughout the building life cycle. Moreover, the research assesses case studies and real-world implementations of optimization strategies in green building projects across different geographical locations and scales. It examines the economic feasibility, environmental benefits, and social impacts of these strategies, emphasizing the need for a holistic approach to sustainable construction. By synthesizing existing knowledge and exploring novel approaches, this paper aims to provide insights into the role of optimization in advancing the goals of green building, ultimately contributing to the creation of more ecofriendly and resilient built environments.

I. INTRODUCTION

In the 27 EU member states in 2019 (EU 27), households consumed 26 % of end-use energy [19]. The extent and duration of the dominance of the thermal characteristics of pre-existing houses on energy use depends on construction rates, floor areas and specifications of new dwellings [14]. Average replacement rates for existing housing stocks in the European Union (EU) are <0.1 % [1], so the majority of Europe’s existing dwellings will remain in 2050 [9]. In the United Kingdom, for example, around 75 % of dwellings that will exist in 2050 have already been constructed [16]. Achieving lower energy use and associated greenhouse gas emissions thus requires energy refurbishment of existing dwellings; together with greater efficiency and harnessing renewable technologies in the generation of energy supplied to houses [1], [6], [7], [8], [9], [10], [11].

Integrated Design Process is required to achieve ultra-low-energy design (Ferrara, Sirombo, and Fabrizio Citation2018). Quantitative energy analysis should be carried out in the early stage. However, limited by the low efficiency of the trial and error process, the possibilities of the design are often not fully explored (Attia Citation2018). Meanwhile the communication cost, within the design team and between designers and clients is considerable. Automatic optimization, with Genetic algorithm, Particle Swarming Optimization, etc., is another way to efficiently improve the energy performance of the design.[14]

Reducing energy use and lowering emissions are two of the most important considerations when designing green buildings (Ferdosi et al., 2022). Structures across the world should make use of energy efficiency solutions and operations (Ma’bdeh et al., 2022). Windows and insulation, heat/cold regulators, ventilation systems, and energy-efficient pumps can reduce energy use by 50% (Al-Sakkaf et al., 2023). Smart meters and intelligent management systems can also help (Onososen and Musonda, 2022). An adequate supply of electricity may be ensured by using smart meters. Carbon dioxide emissions may be reduced by 5 to 16% with smart meters, which reduce peak demand. In addition, using environmentally friendly construction materials can significantly decrease emissions of greenhouse gases and other hazardous pollutants (Martínek et al., 2020).

Buildings are becoming more environmentally friendly because of the notion of developing smart buildings (Larsen et al., 2022). Modern digital services and analytics can improve a building management system’s efficiency and environmental friendliness (Xu et al., 2022). It has been possible to save a significant amount of energy and provide a more comfortable environment for people and the environment, thanks to sensors for automatic control of lights and air quality (Harja et al., 2022). Smart buildings can play an essential role in power management by connecting with energy networks at a higher level through smart grid technologies (e.g., state or national level) (Soust-Verdaguer et al., 2022). A sustainable and energy-efficient city power is efficiently distributed across the city and among its many structures (Yoffe et al., 2022).

In this paper, the main goal of this idea is to save energy, automate processes, create an efficient power management system, and ensure that the building's residents are satisfied (Bradu et al., 2022, Shukla and Shukla, 2021). For the last several years, experts in this field have been drawn to this dimension to regulate power consumption within green buildings and create a preferred atmosphere for building occupants. Commercial, business, and residential buildings all use electricity significantly (Zhao and Kok Foong, 2022, Meng et al., 2022). Thus, they must be considered when implementing energy management and conservation measures. The user's comfort management within the green building must be overlooked to have an effective energy management system (Valencia et al., 2022). Smart user identification, internal and exterior environment monitoring, AI decision making, and ubiquitous infrared communication. AI-EMM's architecture enables rapid installation and flexible plug-and-play for most home and building management applications without infrastructural adjustments. This project aims to design and construct an energy-efficient smart building management controller. Two phenomena must be considered while constructing an effective building energy management system. As a result of finite power generating resources, it is imperative to minimize energy usage while maintaining occupant comfort levels inside buildings. It is a multi-objective optimization issue since it aims to improve comfort for the user while minimizing power consumption. This is a multi-objective optimization problem. The work done in this suggested architecture for energy conservation systems is mostly focused on this idea.[23]

The main contribution of this paper is,

1) AI approaches have been included in a wide range of engineering systems to help them accomplish various objectives. It is possible to create intelligent buildings by coupling new technology with energy management systems and focusing on the needs of the people who use them.
2) The primary goal of this integration is to efficiently control the building's energy consumption while ensuring that its occupants are satisfied with the building's interior environment.
3) LSTM prediction model to increase the capacity of predicting how much energy a building would need. As the external environment changes, the built model can adjust and retain a high level of predictive capability.
4) Consideration of input qualities and data relevancy are key factors in this process. This research examines the impact that binary characteristics have on the overall energy usage of buildings.[23]

II. METHODOLOGY

A. Selection of Inputs and Outputs

The most crucial phase in the process of performance evaluation while utilizing DEA is the selection of input and output. In this paper the selection of inputs and outputs are made based on the data that we acquired from various Research papers. Following inputs and outputs parameters related to green building are selected for analysis in the present work:

1) Inputs

Input 1 = Cost
Input 2 = Energy Consumption
Input 3 = Solar Panel

2) Outputs

Output = Energy Reduction
Input generally reflects the resources utilized by green building.
Input 1, which is cost , a fundamental parameter in green building that refers to the total cost of the project. It is a crucial factor in determining the quality of the work produced and delivered.
While the initial cost of a green home may seem daunting, the long-term benefits of energy savings, financial savings, and environmental impact make it a worthwhile investment.
Economies of scale can help reduce costs as adoption of green building practices expands. Increasing demand for green materials and technology can lead to innovation and efficiency in the production process, ultimately reducing costs.
Over time, the falling costs of sustainable building materials may make green buildings more fitable.

Input 2, energy consumption refers to the building's energy used for various purposes,including heating, cooling, lighting, electrical appliances and other products that use electricity. Green building practices are specifically designed to reduce a building's overall energy use, including lab or and energy.

On average, green buildings can reduce energy consumption by 20% to 30% compared to conve ntional buildings. This includes saving energy, air conditioning, lighting and other energy consu mption during the daily operation of the building.

Green building uses smart technology, including building automation systems, to increase energy efficiency. These systems adjust lighting, HVAC, and other equipment based on real time data, live patterns, and external conditions to optimize performance.

Buildings with LEED certification, a widely recognized green building rating system, use less energy than other uncertified buildings. LEED promotes energy efficiency, water conservation and sustainable practices in buildings and operations.

The energy use of green buildings is an important aspect of building and design. The use of green energy is clearly defined, including good design, renewable energy, smart technology and goo d practices. The aim is to create structures that not only reduce environmental impact but also provide long-term energy savings and sustainability. Provide residents with a healthy home.

Input 3, Solar panels, also known as photovoltaic (PV) panels, are devices that convert sunlight into electricity. It plays an important role in green building by increasing energy efficiency, sustai nability and reducing environmental impact.

Solar panels consist of solar cells made of semiconductor material, usually silicon. These cells work together to produce electricity when exposed to sunlight.

The efficiency of solar panels refers to the percentage of sunlight they can convert into electricity. More efficient panels can convert sunlight into usable electricity.

The inclusion of solar panels in green building design represents a sustainable building approach that includes words such as energy efficiency, environmental responsibility and reducing the environmental impact of solar panels. Create an environment. Advances in technology and increasing adoption have made solar energy an important part of the world's energy mix.

The use of solar panels in green buildings not only reduces environmental impact, but also prom otes financial savings, energy independence and has a positive impact on the environment.

The output, energy reduced refers to efforts and strategies aimed at reducing the overall energy consumption of a building while maintaining or improving its performance and comfort. The goal of energy conservation in green building practices is to reduce the environmental impacts associated with energy use and promote long-term savings.

Energy savings and reductions in green buildings are achieved through the use of design ideas, techniques and business practices that ensure efficiency and safety.

Green buildings can often reduce energy consumption by 20% to 50% compared to traditional buildings. This reduction is achieved through the integration of energy efficiency, technology and renewable energy.

B. DEA

Data envelopement analysis (DEA), a non-parametric method, is used to evaluate the relative efficacy of a collection of decision-making units (DMUs).It is a widely used technique in operations research and management science for evaluating the performance and efficiency of organizations, such as companies, schools, hospitals, and government agencies.

DEA is particularly useful when dealing with multiple inputs and outputs, where the goal is to assess how efficiently DMUs convert inputs into outputs. The inputs and outputs can be tangible quantities, such as labor, capital, or materials, as well as intangible factors like customer satisfaction or environmental impact.

DEA, basically developed by Charnes et al. [56566], is a non-parametric approach for generating the efficiency frontier for the DMUs. It is a LP (linear programming) method that deals with the multiple inputs and multiple outputs without pre-assigned weights and without imposing any functional form on the relationships between variables.

1) The CCR model

The CCR (Charnes, Cooper, and Rhodes) model, also known as the Data Envelopment Analysis (DEA) CCR model, is a linear programming-based technique used for assessing the relative efficiency of multiple decision-making units (DMUs) or organizations. It is widely applied in operations research and management science to measure the efficiency of entities such as companies, banks, hospitals, and educational institutions.

The CCR model assumes constant returns to scale (CRS), meaning that the input-output ratios of efficient DMUs can be replicated by scaling up or down their inputs and outputs proportionately. The model calculates an efficiency score for each DMU based on its input and output data, comparing them to the best performing DMU, also known as the efficient frontier.

The CCR model assumes constant returns to scale (CRS), meaning the efficiency scores are based on the assumption that the DMUs are operating at an optimal scale size. If you want to consider variable returns to scale (VRS), you can use other DEA models like the Banker, Charnes, and Cooper (BCC) model.

Efficiency is calculated as the weighted average of the inputs and outputs.

The solution of DEA must be weighted to maximise its efficiency under certain constraints. Each DMU has input and output weights. In other words, it allows each unit to pick most favorable weights for its specific situation. The CCR model uses linear programming to calculate efficiency scores for each DMU based on their input and output data. Here are the key formulas used in the CCR model:

a) Input-oriented CCR Model

Minimize:

Efficiency score (θ) = $1/\rho$

Subject to: θ * Sum(wj * xj) <= Sum(vi * yi) for all i

Sum(wj) = 1 wj>= 0 for all j

In this formula, θ represents the efficiency score for a DMU, ρ represents the input efficiency measure (the sum of weights assigned to inputs), xj represents the input values for DMU j, vi represents the output weights, and yi represents the output values for DMU i. wj represents the weights assigned to each DMU's inputs, and it should be non-negative.

b) Output-oriented CCR Model

Maximize:

Efficiency score (θ) = ρ

Subject to: θ * Sum(vi * yi) >= Sum(wj * xj) for all i

Sum(vi) = 1

vi >= 0 for all I,

In this formula, θ represents the efficiency score for a DMU, ρ represents the output efficiency measure (the sum of weights assigned to outputs), yi represents the output values for DMU i, wj represents the input weights, and xj represents the input values for DMU j. vi represents the weights assigned to each DMU's outputs, and it should be non-negative.

The CCR model is solved using linear programming techniques to find the optimal weights (wj or vi) that maximize the efficiency score while satisfying the constraints. The resulting efficiency scores provide a relative measure of efficiency for each DMU, with scores ranging from 0 to 1, where 1 represents full efficiency.

An comparable model is typically addressed since it needs fewer computations and is simpler to use than the problems as indicated above. By first transforming the optimisation issue into an LP problem and then applying the duality principal, the corresponding representation is created. Dual is necessary because it reduces the number of constraints from n + m + s + 1 in the primal to m + s in the dual, making the linear problem easier to solve. The number of constraints for primal depends on the number of DMUs, whereas the number of constraints for dual depends on the number of inputs and outputs.

III. CORRELATION

Correlation refers to the statistical measure of the relationship between two sets of data. The correlation coefficient, often denoted as "r," quantifies the strength and direction of the linear relationship between two variables. The correlation coefficient can range from -1 to 1, where:

1 : Perfect positive correlation

0 : No Correlation (Variables are independent)

-1 : Perfect negitive correlation

A positive correlation suggests that as one variable increases, the other tends to increase as well.

This type of correlation is often viewed as a favorable or "good" association between variables.

A negative correlation suggests that as one variable increases, the other tends to decrease. Negative correlations are not inherently "bad" but indicate an inverse relationship between variables.

Whether a positive or negative correlation is considered "good" depends on the specific circumstances and the objectives of the analysis. Both types of correlation provide valuable information about the relationships between variables, and their interpretation should be grounded in a thorough understanding of the context and the underlying dynamics of the data.

CORRELATION

	COST[Cr.]	NERGY CONSUMPTION [KW/m^2/	SOLAR PANNEL [KW	NERGY SAVED [%]
COST[Cr.]	1			
ENERGY CONSUMPTION [KW/m^2	0.7258986257	1		
SOLAR PANNEL [KW]	0.7383838354	0.9387970247	1	
ENERGY SAVED [%]	0.3019954276	0.2038966531	0.2050622154	1

Fig.:- Correlation between inputs and outputs

IV. REGRESSION

Regression refers to the statistical technique used to model the relationship between one or more independent variables and a dependent variable. It provides coefficients that represent the rate of change in the dependent variable for a unit change in the independent variables.

REGRESSION

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.3031674337
R Square	0.09191049286
Adjusted R Square	-0.3621342607
Standard Error	17.00399068
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	175.5858056	58.52860186	0.2024260651	0.8910978283
Residual	6	1734.814194	289.1356991		
Total	9	1910.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	37.84632705	9.812314976	3.857023255	0.00839124307	13.83645729	61.8561968	13.83645729	61.8561968
COST[Cr.]	0.009959186695	0.01754472715	0.5676455729	0.5908671633	-0.03297121401	0.0528895874	-0.03297121401	0.052889587
ENERGY CONSUMPTION [KW/m^2	0.0002448564911	0.05844308692	0.004189657049	0.9967929728	-0.1427602252	0.1432499382	-0.1427602252	0.143249938
SOLAR PANNEL [KW]	-0.001025415623	0.0273312769	-0.03751802841	0.9712890998	-0.06790264085	0.0658518096	-0.06790264085	0.065851809

V. RESULTS AND DISCUSSION

DMUs	Efficiency
1	1.0000
2	0.7049
3	0.1972
4	0.0687
5	0.1250
6	1.0000
7	0.6520
8	1.0000
9	1.0000
10	1.0000

Table 1 : Efficiency

The above results were obtained by employing the CCR (Charnes, Cooper, and Rhodes) model in the DEA method to optimize the energy efficiency. The results shows the Overall Efficiency of each Decision Making Unit observed in the Design mix that have been calculated through this method.

Overall Efficiency can be simply defined as the ratio of the weighted sum of Outputs to the weighted sum of inputs. It indicates how a particular DMU will perform within the available proportions of input parameters that have been given to that DMU. In this case the Overall efficiency will show a direct relationship of the Energy efficiency of green buildings as output that is fetched by 3 Inputs namely cost, energy consumption and solar panels. Overall efficiency scores of all 10 DMUs are given in Table1. It is clear from the CCR result that only five DMUs are identified as perfectly efficient with efficiency score equal to 1. And rests of the DMus are relatively inefficient having efficiency scores below 1. The average overall efficiency score of all the 10 DMUs is 0.674,which reflect that there is greater room for efficiency improvement.

VI. CONCLUSION

The present experimental analysis deals with the optimization of energy efficiency by carrying out Data envelopment analysis considering three Input parameters i.e. cost, energy optimization and solar panel and one output parameter i.e. energy reduced. In conclusion, the application of Data Envelopment Analysis (DEA) in optimization has provided valuable insights and guidance for improving the efficiency and performance of decision-making units (DMUs). DEA serves as a powerful tool for benchmarking, identifying inefficiencies, and optimizing resource allocation. These parameters were so selected that it gives meaningful results for energy reduced.

Following main outcomes are drawn:

1) Through the DEA analysis, we have gained insights into the efficiency levels of the DMUs under consideration. The efficiency scores and rankings obtained from the analysis are clearly shown in the tables above and they have provided a clear understanding of how well each DMU utilizes its available resources to generate outputs. This information is crucial for identifying inefficient DMUs and understanding the potential for improvement.
2) Through the optimization process using DEA, we have been able to identify the most efficient DMUs and understand the factors that contribute to their superior performance.
3) Both regression and correlation analyses are performed, which helps to gain insights into the nature and strength of relationships within datasets.
4) Different green building measures have been optimized as respective Decision Making Units using the DEA Approach. By utilizing DEA's efficiency frontier; we have been able to identify the optimal combination of inputs and outputs that can be achieved by each DMU.

5) Furthermore, this DEA optimization provides a comprehensive approach for organizations to optimize resources and reduce costs. By leveraging DEA's efficiency analysis, correlation, regression and benchmarking capabilities, we can identify inefficiencies, uncover material saving opportunities, and adopt cost-effective strategies.

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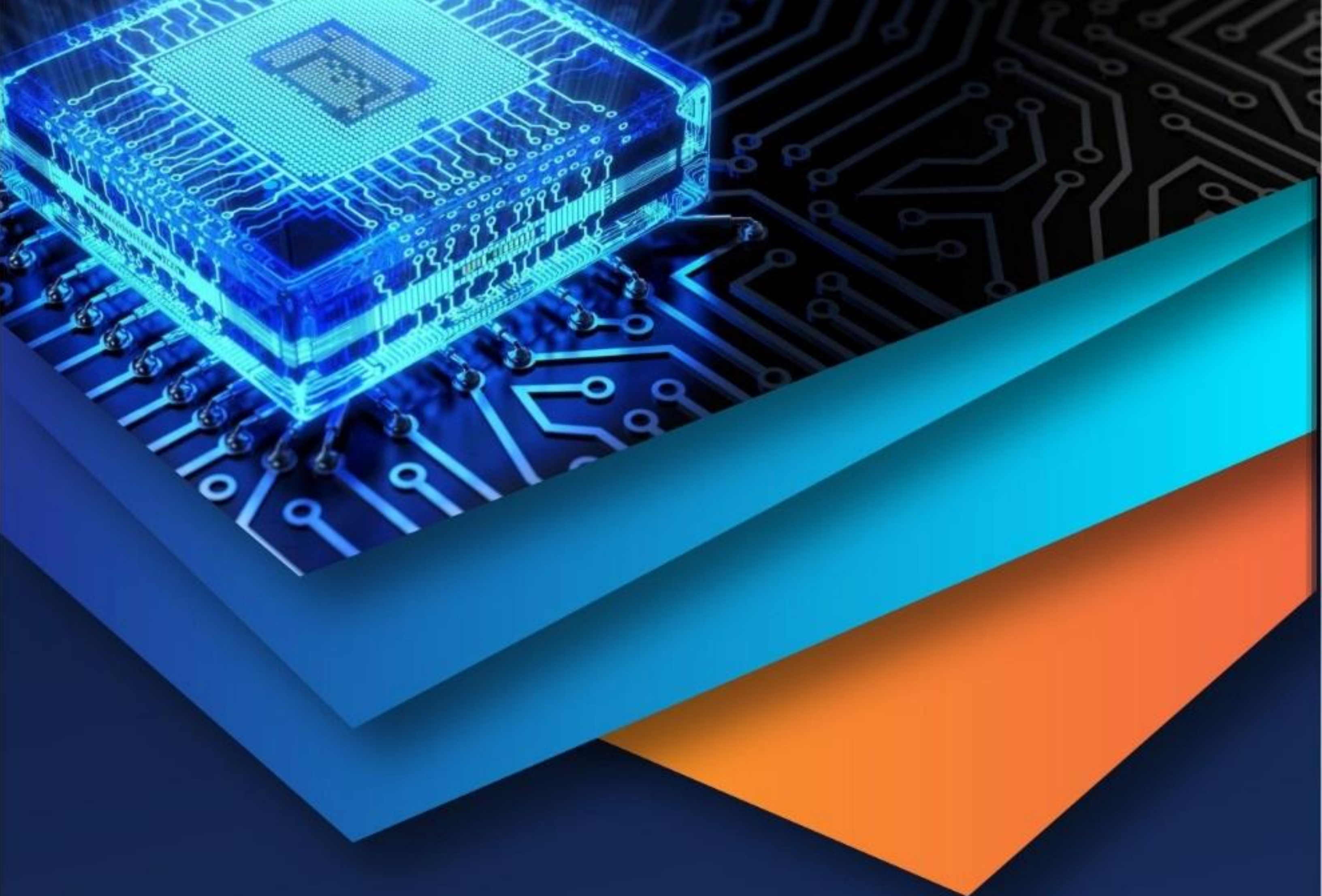

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