Library Progress International *Print version ISSN 0970 1052*
Vol.44 No.3, Jul-Dec 2024: P. 22913-22950 *Online version ISSN 2320 317X*

Original Article *Available online at www.bpasjournals.com*

Influence of Building Components on Energy Consumption: A Simulation-Based energy Efficiency Analysis using Equest

S.A.S Vishnu Havish[1*], Y. Himath Kumar[2]

[1] Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (KL Deemed to be University), Guntur, Vaddeswaram, India. Email:samudralaadithya13@gmail.com

[2] Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (KL Deemed to be University), Guntur, Vaddeswaram,India.Email: himathkumar007@kluniversity.in

How to cite this article: S.A.S Vishnu Havish, Y. Himath Kumar (2024) Influence of Building Components on Energy Consumption: A Simulation-Based energy Efficiency Analysis using Equest. *Library Progress International,* 44(3), 22913-22950.

ABSTRACT
The energy efficiency of buildings is heavily influenced by the choice of construction materials and components, such as walls, doors, and windows. This study looks at how various combinations of these elements impact overall energy consumption through a simulation-based analysis. Using *eQuest*, a detailed energy modelling tool, various configurations of wall types (brickwork, cool exterior, plastering), doors (wood, glass, glass aluminium frame), and windows (wood, fiberglass, glass aluminium frame) were tested to evaluate their effect on annual electric consumption. The simulation aimed to identify which component configurations led to the most significant reductions in energy use. key findings reveal that configurations with plastering walls generally demonstrated lower annual energy consumption compared to brickwork or cool exterior walls. Additionally, the combination of plastering walls, wood doors, and wood windows resulted in the lowest energy consumption, achieving an annual electric usage of 913.74 kWh. In contrast, certain combinations with brickwork walls and glass door options showed higher energy demands. These results suggest that, by optimizing wall, door, and window types, building energy efficiency might be quite improved, leading to more sustainable design choices. The information this study offers can guide architects and builders in selecting materials that enhance energy performance, contributing to reduced environmental impact and operational costs in building construction.
KEYWORDS
Impact of Building Components, Energy Usage, EQuest Simulation Analysis, Energy Performance Evaluation, Simulation Tools for Energy Optimization, Building Envelope and Energy Efficiency.

INTRODUCTION

Energy consumption in buildings accounts for a significant portion of global energy use, which raises critical concerns regarding environmental sustainability and economic viability. As the demand for energy-efficient building designs continues to grow, understanding the influence of various building components on energy consumption has become paramount. This study aims to investigate how specific building elements affect energy usage, leveraging simulation tools to provide valuable insights into energy efficiency.

Recent research highlights the importance of effective building energy modelling methodologies. For instance, Serag et al. (2024) emphasized the need for accurate calibration of energy models, particularly in residential settings, to enhance predictive capabilities and improve energy management strategies [1]. Additionally, Huang et al. (2024) evaluated the impact of window films on indoor environments and found that Such changes can greatly lower air conditioning electricity consumption, illustrating how even Making small changes to building elements can result in significant energy savings. [2].

Moreover, Amani and Sabamehr (2024) conducted a comparative analysis of energy efficiency in residential buildings in cold climates, further demonstrating the role of localized climate considerations in shaping energy performance outcomes [3]. Ni (2023) also contributed to the discourse by identifying various factors influencing energy savings in residential structures, underlining the necessity of a comprehensive understanding of component interactions [4]. But in spite of these developments, there remains a notable gap in detailed studies emphasizing on the component-level insights provided by simulation tools.

Simulation-based analyses, such as those described by Crawley et al. (2006), offer robust frameworks for assessing the energy efficiency of buildings across different scenarios and configurations [5]. Tools like eQuest provide a platform for such simulations, allowing for detailed examinations of how specific components—such as insulation, windows, and HVAC systems—affect overall energy consumption [19].

This study seeks to fill the existing research gap by utilizing eQuest to conduct a simulation-based analysis of building components' influence on energy consumption. By focusing on component-level interactions, the research aims to contribute to the expanding corpus of research on building energy efficiency design, ultimately fostering more sustainable practices in the construction industry [18].

Introduction to equest Software

Equest or Quick Energy Simulation Tool, is a well-regarded software for modelling and analysing the energy performance of buildings. Leveraging the powerful DOE-2 simulation engine, it provides users with detailed information about trends in energy use, which is crucial for making wise choices on energy efficiency. Known for its user-friendly interface, eQUEST enables users to input building specifications, create 3D models, and simulate various design scenarios, which makes it an effective tool for both preliminary and advanced energy analysis.[6]

By integrating advanced simulation capabilities with accessible graphical features, eQUEST has become popular among architects, engineers, and energy consultants aiming to improve building sustainability [20]. The software is especially advantageous for projects involving sustainable design or retrofitting, as it allows for comparative analysis of energy-saving strategies and helps streamline sustainable building practices. Through simulations, users can evaluate the impacts of design choices on energy use and ultimately contribute to more environmentally friendly construction practices (Wagle et al., 2023).

LITERACURE REVIEW

Energy-efficient buildings require an integrated approach to design, particularly focusing on core building components, such as windows, doors, and walls, which play critical roles in thermal performance. El-Darwish and Gomaa (2017) highlighted the importance of retrofitting building envelopes to achieve significant energy savings, with attention to enhancing insulation and reducing thermal bridging. They found that optimized retrofitting strategies, particularly for windows and walls, can significantly lower energy usage by minimizing heat gain or loss through the building envelope. This approach underscores how design modifications to building components can directly improve thermal comfort and energy efficiency, thereby advancing sustainable practices in the built environment [6].

Building energy simulations have increasingly utilized advanced tools to evaluate and optimize energy performance. Gan, Lo, and Ma (2020) examined the application of simulation tools in achieving green building certifications and improving energy efficiency. Their study identified eQUEST as one of the reliable tools for simulating energy performance due to its robust DOE-2 simulation engine and user-friendly interface. eQUEST's ability to analyze various design scenarios makes it particularly suitable for assessing the potential impacts of modifications in building components like walls and roofs, and in integrating sustainable strategies early in the design process [7].

Another critical consideration is the thermal performance of roofs, especially in hot climates. Rawat and Singh (2022) conducted a comparative study on the effectiveness of cool roofs across different regions. Their findings revealed that cool roofs significantly reduce indoor temperatures and energy demand in areas where solar radiation levels are strong, which aligns with the broader objective of sustainable building design by managing solar heat gain through innovative roof materials [8].

Despite the advancements in energy simulation and retrofitting research, certain gaps remain. Many studies have focused on individual building elements or standalone simulation tools, while fewer have explored the comprehensive impact of an integrated approach involving multiple simulation tools and a broad range of design parameters [17]. Moreover, while artificial intelligence (AI)-based models have been proposed to enhance energy use predictions in buildings, these are often contrasted between single and ensemble models, leaving a requirement for a more unified approach that combines both predictive accuracy and practical applicability (Wang & Srinivasan, 2017). In order to close these gaps, this study will look at how well different building components in a combined simulation environment, utilizing eQUEST for a holistic energy assessment and offer information on improved design techniques for environmentally friendly structures practices [9].

METHODOLOGY

This study employs the eQUEST simulation tool to model and analyze energy performance in a mid-rise residential building located in Andhra Pradesh, India. The model is designed in the shape of an "H" with dimensions of 140 feet in length and 90 feet in width. Andhra Pradesh's climate, which is characterized by high temperatures and humidity, is factored into the simulation parameters, enabling an assessment that is region-specific and relevant to local building energy needs [10].

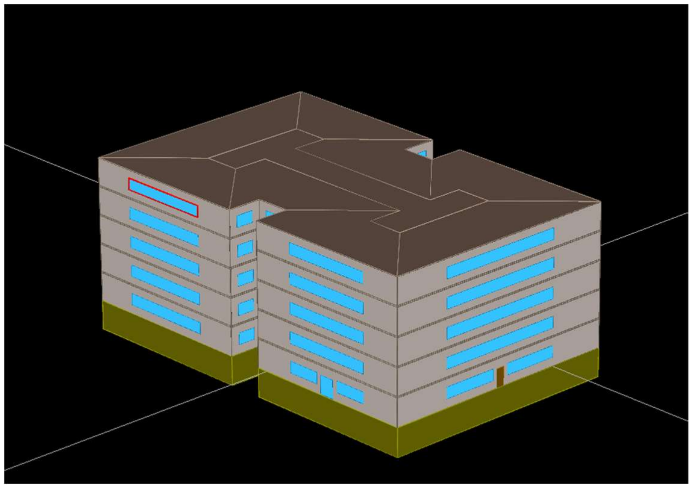


Fig 1: building model for analysis

Model Design and Simulation Setup

The mid-rise residential building model in eQUEST incorporates standard baseline features commonly found in such buildings. eQUEST was selected due to its DOE-2 simulation engine, which effectively simulates energy use under various design and operational scenarios, making it particularly suitable for analysing residential building performance [11]. Building occupancy schedules, lighting, and HVAC systems were defined to reflect realistic usage patterns, as informed by occupant Behavior studies in similar settings [16]. These settings align with research demonstrating the energy savings potential when adaptive simulations are used to match building operation with occupancy patterns [12].

Energy Metrics

To evaluate the energy efficiency of the building, the primary metric used is the total annual energy consumption, measured in kilowatt-hours (kWh). This metric captures the building's total energy consumption and provides insights into consumption patterns for different building systems, including lighting, HVAC, and plug loads [14]. Simulation outputs include both total and peak energy consumption data, allowing for an analysis of demand under varying occupancy and climatic conditions [15]. The analysis includes additional metrics such as thermal comfort levels, which were measured based on indoor temperature and relative humidity to ensure that energy reductions do not compromise occupant comfort [13].

Building Components

This study examines the impact of different wall, door, and window combinations on the annual energy consumption of a mid-rise residential building. Using eQUEST, a total of 39 configurations were simulated by systematically varying three types of walls, three types of doors, and three types of windows.

3 TYPES WALLS	3 TYPES DOORS	3TYPES WINDOWS
BRICKWORK WALL [BWW]	WOOD DOOR [WD]	WOOD WINDOW [WW]
COOL EXTERIOR WALL [CEW]	GLASS DOOR [GD]	FIBERGLASS WINDOW [FGW]
PLASTERING WALL [PW]	GLASS ALUMINUM FRAME DOOR [GAFD]	GLASS ALUMINUM FRAME WINDOWS [GAFW]

Table 1: Different building components used for analysis

Each unique combination of wall, door, and window type was simulated to understand its impact on the building's total annual energy consumption, leading to 39 different combinations (3 walls × 3 doors × 3 windows). This all-encompassing strategy enables a comparative analysis of all possible material configurations within the building envelope.

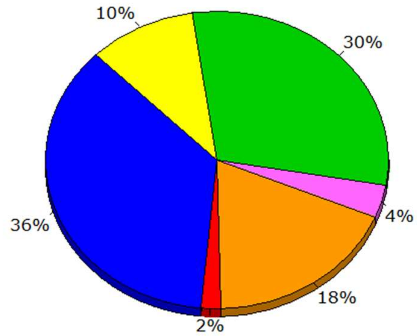
1. BRICKWORK WALL
2. COOL EXTERIOR WALL
3. PLASTERING WALL
4. BRICKWORK WALL + WOOD DOOR
5. BRICKWORK WALL + GLASS DOOR
6. BRICKWORK WALL + GLASS ALUMINUM FRAME DOOR
7. COOL EXTERIOR WALL + WOOD DOOR
8. COOL EXTERIOR WALL + GLASS DOOR
9. COOL EXTERIOR WALL + GLASS ALUMINUM FRAME DOOR
10. PLASTERING WALL + WOOD DOOR
11. PLASTERING WALL + GLASS DOOR
12. PLASTERING WALL + GLASS ALUMINUM FRAME DOOR
13. BRICKWORK WALL + WOOD DOOR +WOOD WINDOW
14. BRICKWORK WALL + WOOD DOOR +FIBERGLASS WINDOW
15. BRICKWORK WALL + WOOD DOOR +GLASS ALUMINUM FRAME WINDOWS
16. BRICKWORK WALL + GLASS DOOR+WOOD WINDOW
17. BRICKWORK WALL + GLASS DOOR +FIBERGLASS WINDOW
18. BRICKWORK WALL + GLASS DOOR +GLASS ALUMINUM FRAME WINDOWS
19. BRICKWORK WALL + GLASS ALUMINUM FRAME DOOR+WOOD WINDOW
20. BRICKWORK WALL + GLASS ALUMINUM FRAME DOOR+FIBERGLASS WINDOW
21. BRICKWORK WALL + GLASS ALUMINUM FRAME DOOR+GLASS ALUMINUM FRAME WINDOWS
22. COOL EXTERIOR WALL + WOOD DOOR+WOOD WINDOW
23. COOL EXTERIOR WALL + WOOD DOOR+FIBERGLASS WINDOW
24. COOL EXTERIOR WALL + WOOD DOOR+GLASS ALUMINUM FRAME WINDOWS
25. COOL EXTERIOR WALL + GLASS DOOR+WOOD WINDOW
26. COOL EXTERIOR WALL + GLASS DOOR+FIBERGLASS WINDOW
27. COOL EXTERIOR WALL + GLASS DOOR+GLASS ALUMINUM FRAME WINDOWS
28. COOL EXTERIOR WALL + GLASS ALUMINUM FRAME DOOR+WOOD WINDOW
29. COOL EXTERIOR WALL + GLASS ALUMINUM FRAME DOOR+FIBERGLASS WINDOW
30. COOL EXTERIOR WALL + GLASS ALUMINUM FRAME DOOR+GLASS ALUMINUM FRAME WINDOWS
31. PLASTERING WALL + WOOD DOOR+WOOD WINDOW
32. PLASTERING WALL + WOOD DOOR+FIBERGLASS WINDOW
33. PLASTERING WALL + WOOD DOOR+GLASS ALUMINUM FRAME WINDOWS
34. PLASTERING WALL + GLASS DOOR+WOOD WINDOW
35. PLASTERING WALL + GLASS DOOR+FIBERGLASS WINDOW
36. PLASTERING WALL + GLASS DOOR+GLASS ALUMINUM FRAME WINDOWS
37. PLASTERING WALL + GLASS ALUMINUM FRAME DOOR+WOOD WINDOW
38. PLASTERING WALL + GLASS ALUMINUM FRAME DOOR+FIBERGLASS WINDOW
39. PLASTERING WALL + GLASS ALUMINUM FRAME DOOR+GLASS ALUMINUM FRAME WINDOWS

RESULTS

The results of the simulation show notable variations in annual electric consumption based on various building material combinations. Each component's impact on energy usage has been systematically analysed, highlighting the influence of insulation types, door and window materials, and overall construction methodology.

Actual building annual energy consumption

the distribution of annual electricity consumption in a building, totalling 924.88 kWh. The major consumers are area lighting and refrigeration, which account for 36% and 30% of the total usage, respectively. Other significant categories include pumps and auxiliary equipment (18%) and miscellaneous equipment (10%), with ventilation fans, water heating, and space cooling consuming the remaining portions.



Electricity

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	333.19	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	17.16	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.44	-	-	-
Vent. Fans	32.55	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	924.88	-	-	-

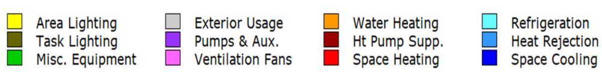
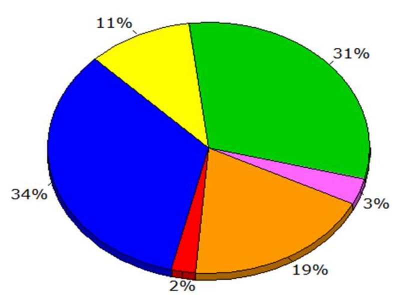


fig 2: pie chart of actual building consumption and table 2: actual building annual electricity consumption

1.Brickwork Wall: Brickwork walls, valued for their durability and thermal mass, can help stabilize indoor temperatures but can raise the need for energy. if not adequately insulated. The building's annual electricity consumption across various end uses, including space cooling (303.39 kWh), hot water (169.45 kWh), and miscellaneous equipment (277.69 kWh), totals 897.27 kWh.



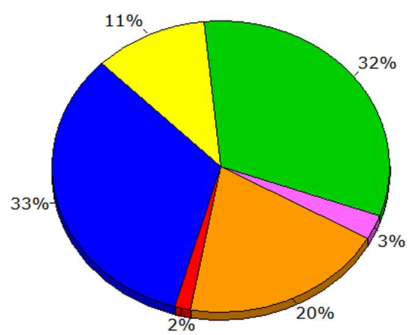
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	303.39	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	21.43	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.46	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	897.27	-	-	-

fig 3: pie chart of combination1 electricity consumption and table 3: combination1 annual electricity consumption

2.Cool Exterior Wall: Cool exterior walls, engineered to reflect solar radiation, can reduce heat absorption and improve energy efficiency in warm climates. In this building, annual electricity consumption reaches a total of 865.83 kWh, with notable uses in space cooling (287.14 kWh), hot water (169.44 kWh), and miscellaneous equipment (277.69 kWh).



Electricity

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	287.14	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.25	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.44	-	-	-
Vent. Fans	23.46	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	865.83	-	-	-

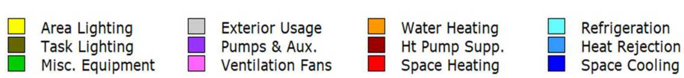
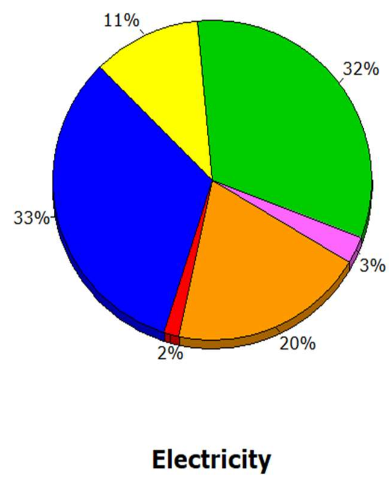


fig 4: pie chart of combination2 electricity consumption and table 4: combination2 annual electricity consumption

3.Plastering Wall: Plastering interior walls can create a smoother finish and improve insulation when paired with suitable materials, potentially reducing energy expenses. This building's annual electricity consumption is 858.85 kWh, with primary uses in space cooling (280.47 kWh), hot water (169.43 kWh), and miscellaneous equipment (277.69 kWh).

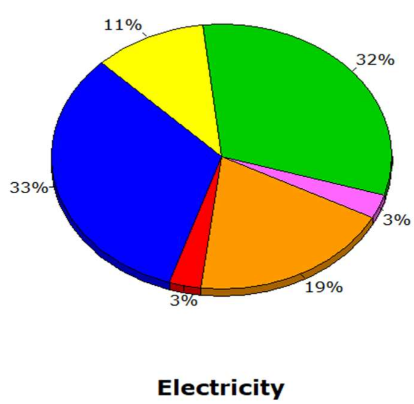


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	280.47	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.13	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.43	-	-	-
Vent. Fans	23.28	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	858.85	-	-	-

fig 5: pie chart of combination3 electricity consumption and table 5: combination3 annual electricity consumption

4.Brickwork Wall + Wood Door: A combination of brick walls and wood doors affects energy efficiency; while wood doors provide reasonable insulation, they may not match the efficiency of alternative materials. This building's annual electricity consumption totals 881.17 kWh, with significant usage in space cooling (287.04 kWh), hot water (169.45 kWh), and miscellaneous equipment (277.69 kWh).

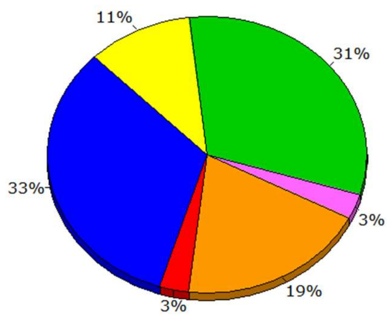


	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	287.04	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	26.53	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	25.61	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	881.17	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

fig 6: pie chart of combination4 electricity consumption and table 6: combination4 annual electricity consumption

5.Brickwork Wall + Glass Door: Combining brick walls with glass doors adds visual appeal and natural lighting but can lead to higher thermal losses, illustrating the balance between design and energy efficiency. This building's annual electricity usage is 883.16 kWh, with major contributors being space cooling (289.30 kWh), hot water (169.45 kWh), and miscellaneous equipment (277.69 kWh).



Electricity

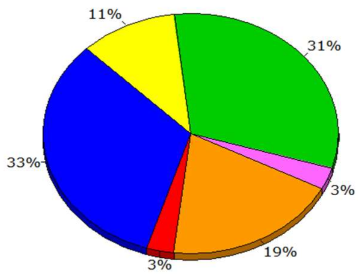
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	289.30	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	26.11	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	25.76	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	883.16	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

fig 7: pie chart of combination5 electricity consumption and table 7: combination5 annual electricity consumption

6.Brickwork Wall + Glass Aluminium Frame Door: Combining brick with an aluminium-framed glass door allows for the assessment of modern materials that improve durability while exploring energy loss through glass. The table shows the annual energy consumption by end-use in a building, with electricity usage broken down by various categories. Space cooling has the highest electricity consumption at 289.06 kWh (x1000), followed by miscellaneous equipment at 277.69 kWh (x1000). The total annual electricity consumption across all end-uses amounts to 883.00 kWh (x1000).

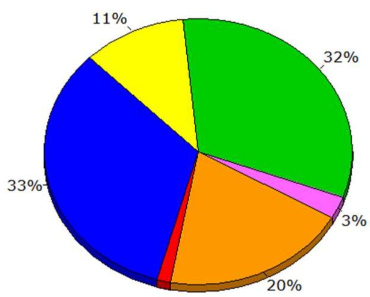


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	289.06	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	26.19	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	25.76	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	883.00	-	-	-

fig 8: pie chart of combination6 electricity consumption and table 8: combination6 annual electricity consumption

7.Cool Exterior Wall + Wood Door: The table outlines annual electricity usage by end-use in a building, reaching a total of 864.68 kWh (x1000), with space cooling and miscellaneous equipment as primary consumers. A cool reflective wall paired with a wood door facilitates analysis of traditional materials in enhancing energy efficiency.

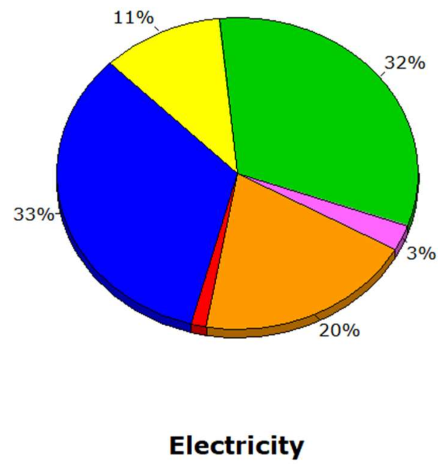


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	287.10	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.29	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.43	-	-	-
Vent. Fans	23.32	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	864.68	-	-	-

fig 9: pie chart of combination7 electricity consumption and table 9: combination7 annual electricity consumption

8.Cool Exterior Wall + Glass Door: The table displays annual electricity usage by end-use in a building, with a total consumption of 866.82 kWh (x1000), where space cooling and miscellaneous equipment are the major contributors. A cool reflective wall combined with a glass door provides insights into reducing energy losses typically associated with glass installations.

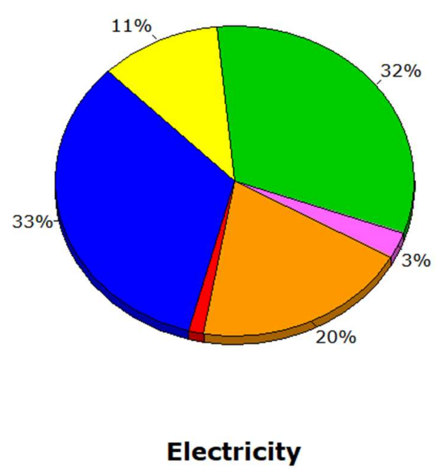


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	289.60	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	11.90	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.43	-	-	-
Vent. Fans	23.35	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	866.82	-	-	-

fig 10: pie chart of combination8 electricity consumption and table 10: combination8 annual electricity consumption

9.Cool Exterior Wall + Glass Aluminium Frame Door: This setup evaluates the effectiveness of energy-efficient materials in conjunction with reflective walls. The table displays annual energy consumption by end use in a building, with electricity usage totalling 866.60 kWh. Categories include space cooling, space heating, hot water, ventilation, lighting, and miscellaneous equipment, highlighting the impact of each on overall energy use.



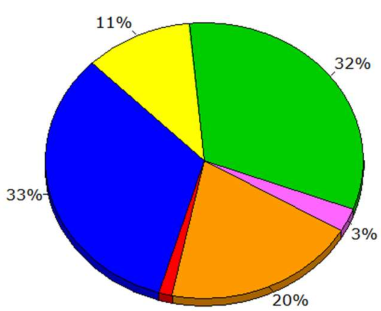
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	289.31	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	11.98	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.43	-	-	-
Vent. Fans	23.35	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	866.60	-	-	-

Area Lighting / Task Lighting / Misc. Equipment / Exterior Usage / Pumps & Aux. / Ventilation Fans / Water Heating / Ht Pump Supp. / Space Heating / Refrigeration / Heat Rejection / Space Cooling

fig 11: pie chart of combination9 electricity consumption and table 11: combination9 annual electricity consumption

10.Plastering Wall + Wood Door: The table summarizes annual energy consumption by end use in a building, with a total electricity consumption of 860.49 kWh. Energy is allocated across different categories, including space cooling, heating, hot water, ventilation, lighting, and miscellaneous equipment, emphasizing each category's contribution to overall energy usage.



Electricity

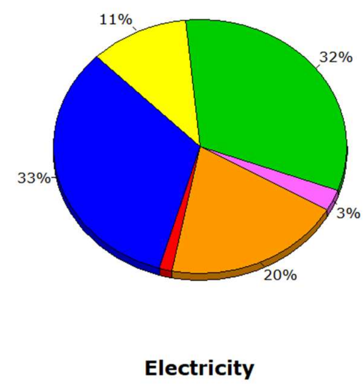
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	283.04	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	11.94	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.47	-	-	-
Vent. Fans	23.51	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	860.49	-	-	-

Area Lighting / Task Lighting / Misc. Equipment / Exterior Usage / Pumps & Aux. / Ventilation Fans / Water Heating / Ht Pump Supp. / Space Heating / Refrigeration / Heat Rejection / Space Cooling

fig 12: pie chart of combination10 electricity consumption and table 12: combination10 annual electricity consumption

11.Plastering Wall + Glass Door: This variation assesses the impact of glass doors on the overall energy efficiency of a plastered wall setup. Energy is allocated across different categories, including space cooling, heating, hot water, ventilation, lighting, and miscellaneous equipment, emphasizing each category's contribution to overall energy usage. the annual electricity consumption in a building, totalling 860.52kWh.



Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	285.33	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	11.65	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.47	-	-	-
Vent. Fans	23.54	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	862.52	-	-	-

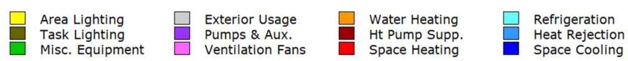
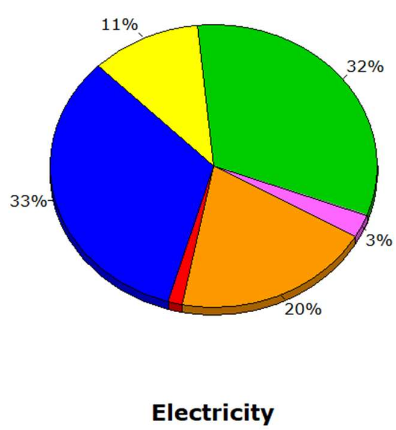


fig 13: pie chart of combination11 electricity consumption and table 13: combination11 annual electricity consumption

12.Plastering Wall + Glass Aluminium Frame Door: Similar to the previous configurations, this setup allows for the evaluation of modern materials on plastering wall performance. Energy is allocated across different categories, including space cooling, heating, hot water, ventilation, lighting, and miscellaneous equipment, emphasizing each category's contribution to overall energy usage. the annual electricity consumption in a building, totalling 862.44kWh.



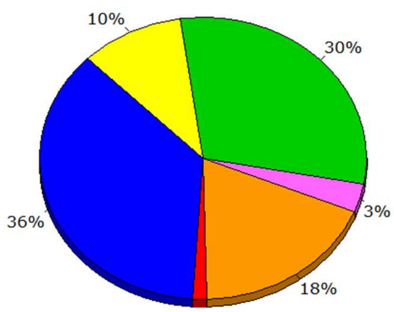
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	285.26	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	11.63	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.47	-	-	-
Vent. Fans	23.54	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	862.44	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 14: pie chart of combination12 electricity consumption and table 14: combination12 annual electricity consumption

13.Brickwork Wall + Wood Door + Wood Window: This classic configuration examines the synergy of traditional materials and their combined effect on energy consumption. the annual electricity consumption in a building, totalling 920.46kWh.



Electricity

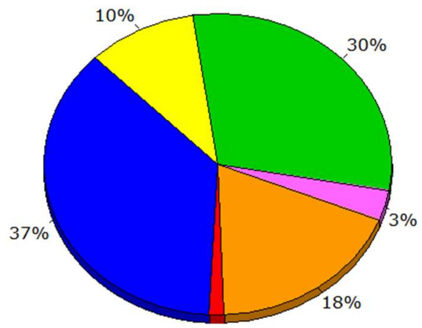
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	335.95	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.94	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.58	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	920.46	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 15: pie chart of combination13 electricity consumption and table 15: combination13 annual electricity consumption

14.Brickwork Wall + Wood Door + Fiberglass Window: By introducing fiberglass windows, this variation assesses how contemporary materials can improve thermal efficiency. the annual electricity consumption in a building, totalling 924.22kWh.



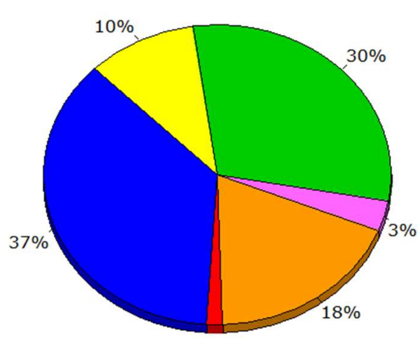
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	339.54	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.72	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.97	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	924.22	-	-	-

fig 16: pie chart of combination14 electricity consumption and table 16: combination14 annual electricity consumption

15.Brickwork Wall + Wood Door + Glass Aluminium Frame Windows: This setup analyses the influence of energy-efficient window frames on overall performance. the annual electricity consumption in a building, totalling 923.02kWh.



Electricity

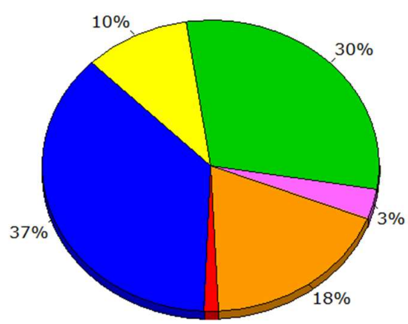
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	337.53	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.39	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.11	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	923.02	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 17: pie chart of combination15 electricity consumption and table 17: combination15 annual electricity consumption

16.Brickwork Wall + Glass Door + Wood Window: This combination helps evaluate the interplay between glass and wood in terms of thermal loss and energy savings. the annual electricity consumption in a building, totalling 923.28kWh.



Electricity

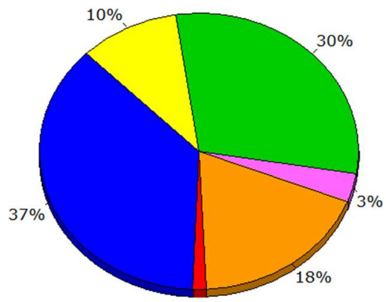
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	338.75	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.69	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.85	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	923.28	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 18: pie chart of combination16 electricity consumption and table 18: combination16 annual electricity consumption

17.Brickwork Wall + Glass Door + Fiberglass Window: This configuration allows for a comparison of how the combination of glass and fiberglass can affect energy consumption. the annual electricity consumption in a building, totalling 927.01kWh.



Electricity

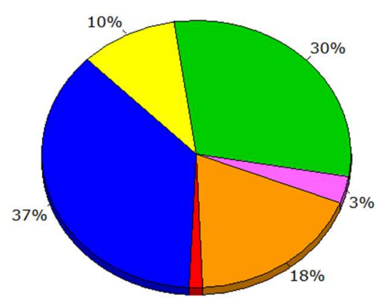
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	342.32	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.45	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.24	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	927.01	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 19: pie chart of combination17 electricity consumption and table 19: combination17 annual electricity consumption

18.Brickwork Wall + Glass Door + Glass Aluminium Frame Windows: The focus here is on how high-performance windows can enhance energy efficiency in conjunction with glass doors. the annual electricity consumption in a building, totalling 925.83kWh.



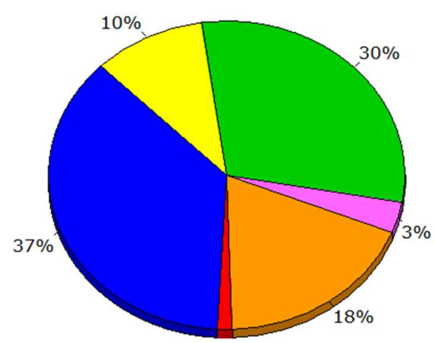
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	340.34	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.13	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.37	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	925.83	-	-	-

fig 20: pie chart of combination18 electricity consumption and table 20: combination18 annual electricity consumption

19.Brickwork Wall + Glass Aluminium Frame Door + Wood Window: This variation assesses the energy impact of mixing aluminium and wood materials in a single configuration. the annual electricity consumption in a building, totalling 923.11kWh.



Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	338.51	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.76	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.85	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	923.11	-	-	-

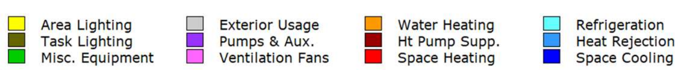
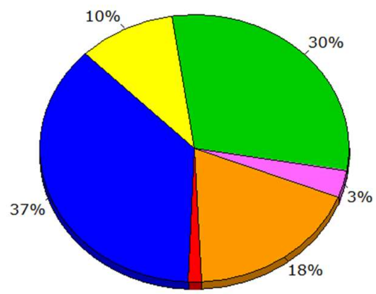


fig 21: pie chart of combination19 electricity consumption and table 21: combination19 annual electricity consumption

20.Brickwork Wall + Glass Aluminium Frame Door + Fiberglass Window: Similar to previous configurations, this setup examines the benefits of using aluminium frames alongside fiberglass windows. the annual electricity consumption in a building, totalling 926.86kWh.



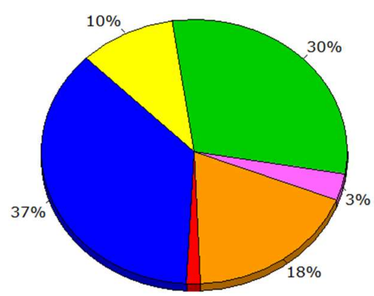
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	342.09	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.53	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.25	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	926.86	-	-	-

fig 22: pie chart of combination20 electricity consumption and table 22: combination20 annual electricity consumption

21.Brickwork Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: This configuration allows for the evaluation of uniform material benefits in energy performance. the annual electricity consumption in a building, totalling 925.65kWh.



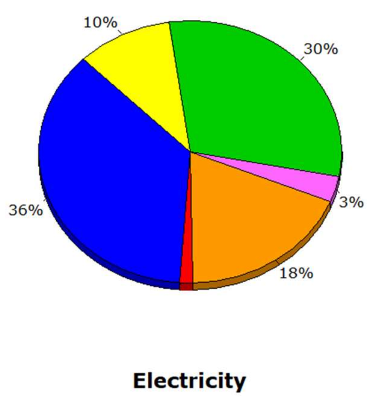
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	340.09	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.18	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.38	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	925.65	-	-	-

fig 23: pie chart of combination21 electricity consumption and table 23: combination21 annual electricity consumption

22.Cool Exterior Wall + Wood Door + Wood Window: The combination examines how reflective walls can enhance the performance of traditional wooden fixtures. the annual electricity consumption in a building, totalling 918.78kWh.



Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	334.61	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.78	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.39	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	918.78	-	-	-

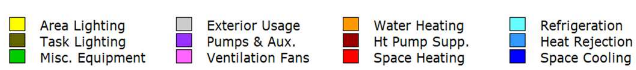
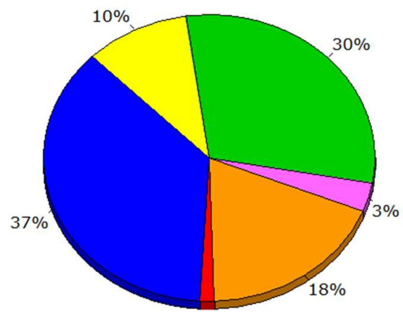


fig 24: pie chart of combination22 electricity consumption and table 24: combination22 annual electricity consumption

23.Cool Exterior Wall + Wood Door + Fiberglass Window: This setup focuses on energy savings through modern window materials alongside cool wall technology. the annual electricity consumption in a building, totalling 922.56kWh.



Electricity

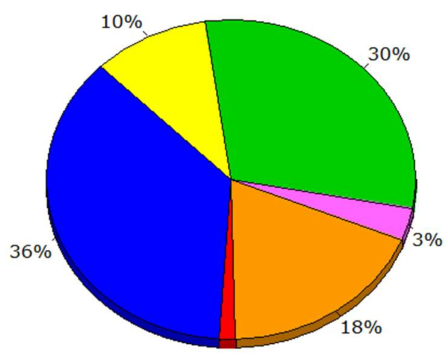
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	338.23	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.55	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.79	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	922.56	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 25: pie chart of combination23 electricity consumption and table 25: combination23 annual electricity consumption

24.Cool Exterior Wall + Wood Door + Glass Aluminium Frame Windows: This variation explores how energy-efficient windows work with traditional doors and cool walls. the annual electricity consumption in a building, totalling 921.36kWh.



Electricity

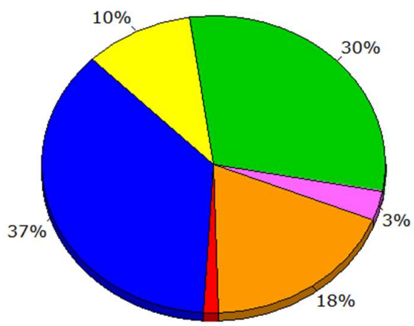
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	336.21	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.24	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.92	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	921.36	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

fig 26: pie chart of combination24 electricity consumption and table 26: combination24 annual electricity consumption

25.Cool Exterior Wall + Glass Door + Wood Window: This configuration assesses the balance between light, aesthetics, and energy performance. the annual electricity consumption in a building, totalling 921.47kWh.



Electricity

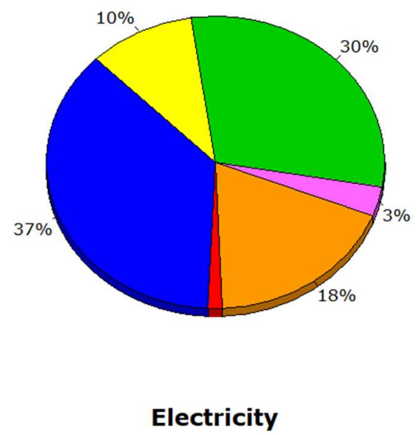
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	337.35	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.49	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.64	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	921.47	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

fig 27: pie chart of combination25 electricity consumption and table 27: combination25 annual electricity consumption

26.Cool Exterior Wall + Glass Door + Fiberglass Window: Analysing this combination allows for a comparison of energy loss and gains between glass and fiberglass. the annual electricity consumption in a building, totalling 925.24kWh.

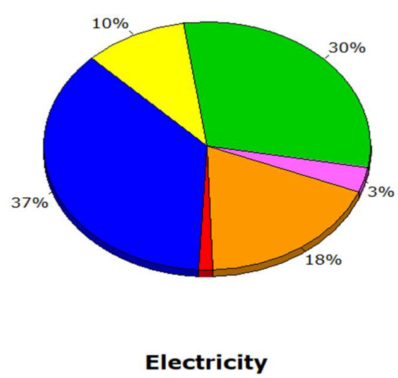


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	340.95	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.26	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.03	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	925.24	-	-	-

fig 28: pie chart of combination26 electricity consumption and table 28: combination26 annual electricity consumption

27.Cool Exterior Wall + Glass Door + Glass Aluminium Frame Windows: The focus here is on maximizing energy efficiency through modern materials. the annual electricity consumption in a building, totalling 924.06kWh.



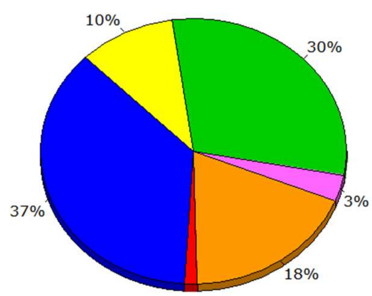
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	338.95	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.95	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.16	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	924.06	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 29: pie chart of combination27 electricity consumption and table 29: combination27 annual electricity consumption

28.Cool Exterior Wall + Glass Aluminium Frame Door + Wood Window: This setup evaluates how a combination of aluminium and wood impacts energy consumption. the annual electricity consumption in a building, totalling 921.31kWh.



Electricity

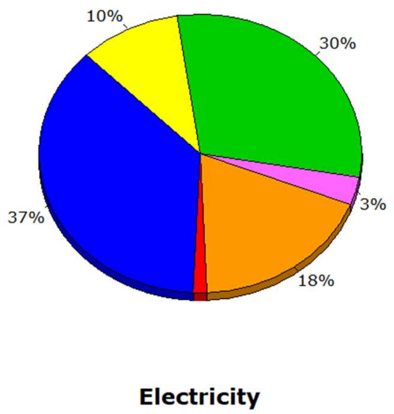
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	337.11	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.57	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	29.64	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	921.31	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 30: pie chart of combination28 electricity consumption and table 30: combination28 annual electricity consumption

29.Cool Exterior Wall + Glass Aluminium Frame Door + Fiberglass Window: This configuration allows for a detailed assessment of modern materials' performance in energy savings. the annual electricity consumption in a building, totalling 925.09kWh.

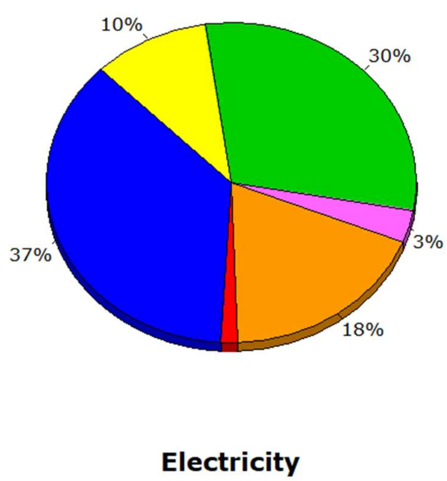


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	340.72	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	12.34	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.04	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	925.09	-	-	-

fig 31: pie chart of combination29 electricity consumption and table 31: combination29 annual electricity consumption

30.Cool Exterior Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: This configuration assesses the cumulative effect of energy-efficient components. the annual electricity consumption in a building, totalling 923.90kWh.



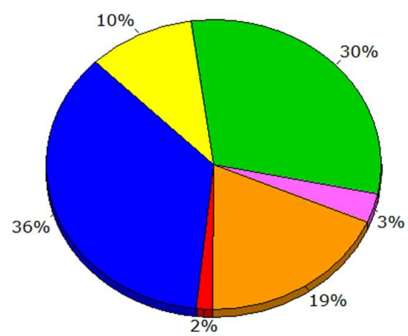
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	338.71	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.02	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.46	-	-	-
Vent. Fans	30.17	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	923.90	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 32: pie chart of combination30 electricity consumption and table 32: combination30 annual electricity consumption

31.Plastering Wall + Wood Door + Wood Window: This combination examines traditional materials for their collective impact on energy use. the annual electricity consumption in a building, totalling 913.74kWh.



Electricity

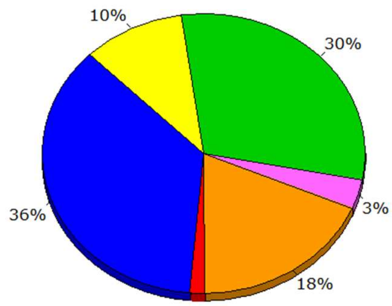
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	328.15	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.87	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	29.74	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	913.74	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 33: pie chart of combination31 electricity consumption and table 33: combination31 annual electricity consumption

32.Plastering Wall + Wood Door + Fiberglass Window: This setup evaluates how integrating modern window materials with plastering walls influences energy efficiency. the annual electricity consumption in a building, totalling 917.60kWh.



Electricity

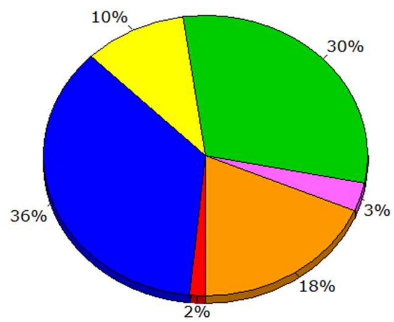
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	331.81	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.64	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.16	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	917.60	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 34: pie chart of combination32 electricity consumption and table 34: combination32 annual electricity consumption

33.Plastering Wall + Wood Door + Glass Aluminium Frame Windows: This combination assesses the impact of aluminium frame windows on plastered wall performance. the annual electricity consumption in a building, totalling 916.27kWh.



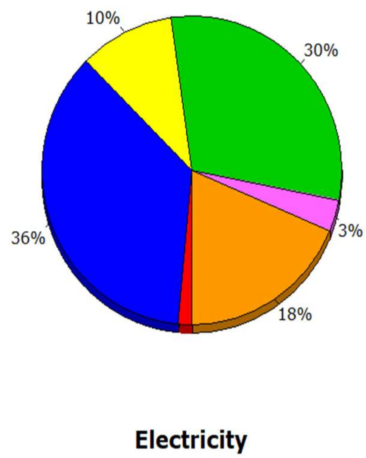
Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	329.65	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	14.36	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.27	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	916.27	-	-	-

fig 35: pie chart of combination33 electricity consumption and table 35: combination33 annual electricity consumption

34.Plastering Wall + Glass Door + Wood Window: Here, the focus is on how glass doors and wooden windows interact in terms of energy consumption. the annual electricity consumption in a building, totalling 916.46kWh.

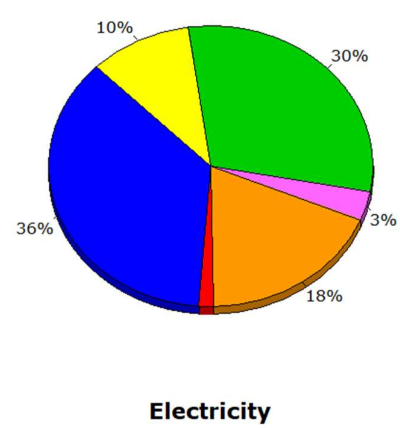


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	330.87	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.61	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.00	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	916.46	-	-	-

fig 36: pie chart of combination34 usage of electricity and table 36: combination34 annual usage of electricity

35.Plastering Wall + Glass Door + Fiberglass Window: This variation allows for the evaluation of energy efficiency with mixed materials. the annual usage of electricity in a building, totalling 920.32kWh.

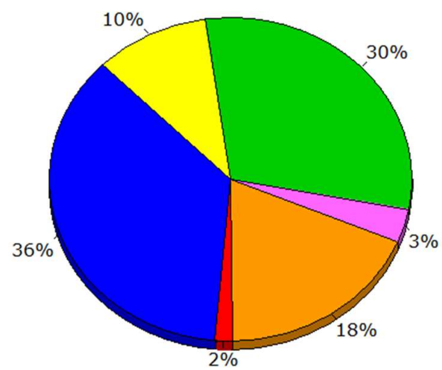


Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	334.52	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.39	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.42	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	920.32	-	-	-

fig 37: pie chart of combination35 usage of electricity and table 37: combination35 annual usage of electricity

36.Plastering Wall + Glass Door + Glass Aluminium Frame Windows: This configuration assesses the energy impact of using aluminium alongside glass. the annual usage of electricity in a building, totalling 918.96kWh.



Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	332.36	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	14.09	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.53	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	918.96	-	-	-

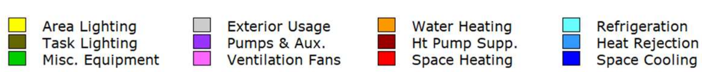
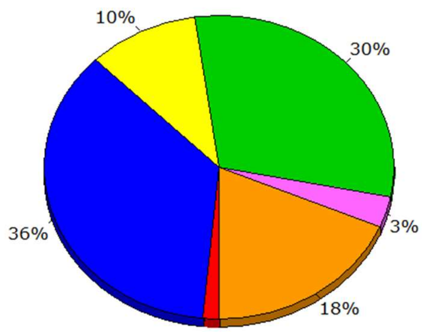


fig 38: pie chart of combination36 usage of electricity and table 38: combination36 annual usage of electricity

37.Plastering Wall + Glass Aluminium Frame Door + Wood Window: This setup examines how combining modern and traditional materials affects performance. the annual usage of electricity in a building, totalling 916.19kWh.



Electricity

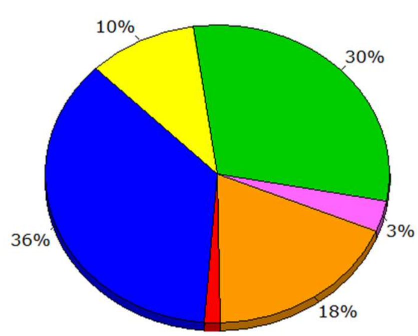
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	330.56	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.66	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	29.98	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	916.19	-	-	-

Area Lighting, Task Lighting, Misc. Equipment, Exterior Usage, Pumps & Aux., Ventilation Fans, Water Heating, Ht Pump Supp., Space Heating, Refrigeration, Heat Rejection, Space Cooling

fig 39: pie chart of combination37 usage of electricity and table 39: combination37 annual usage of electricity

38.Plastering Wall + Glass Aluminium Frame Door + Fiberglass Window: Here, the focus is on assessing how different door and window materials can enhance overall energy efficiency. the annual usage of electricity in a building, totalling 920.07kWh.



Electricity

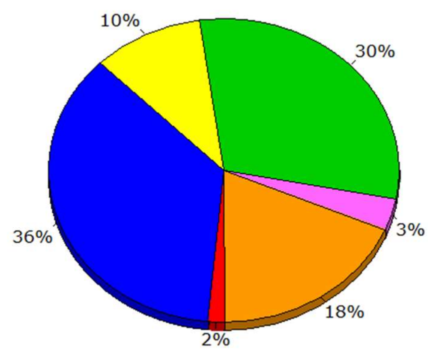
Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	334.22	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.44	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.41	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	920.07	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

fig 40: pie chart of combination38 usage of electricity and table 40: combination38 annual usage of electricity

39.Plastering Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: This combination evaluates its effectiveness of consistent modern materials on energy consumption. the annual usage of electricity in a building, totalling 917.12kWh.



Electricity

Annual Energy Consumption by Enduse

	Electricity kWh (x000)	Natural Gas Btu	Steam Btu	Chilled Water Btu
Space Cool	331.11	-	-	-
Heat Reject.	-	-	-	-
Refrigeration	-	-	-	-
Space Heat	13.85	-	-	-
HP Supp.	-	-	-	-
Hot Water	169.45	-	-	-
Vent. Fans	30.18	-	-	-
Pumps & Aux.	-	-	-	-
Ext. Usage	-	-	-	-
Misc. Equip.	277.69	-	-	-
Task Lights	-	-	-	-
Area Lights	94.85	-	-	-
Total	917.12	-	-	-

Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

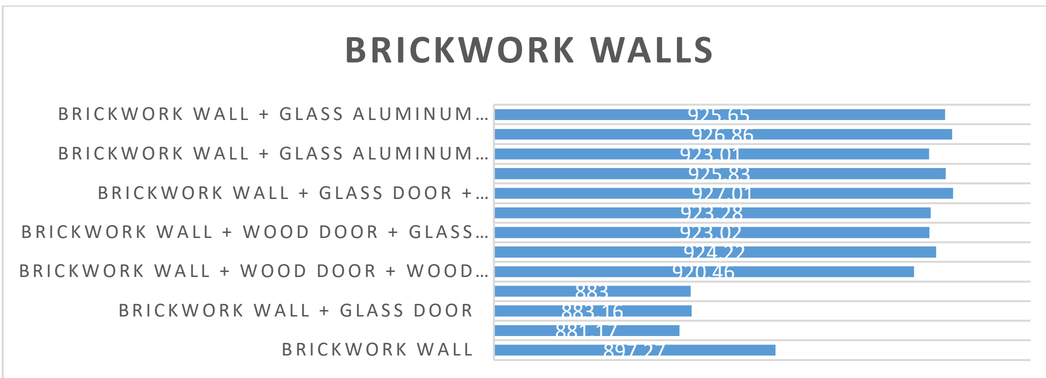
fig 41: pie chart of combination39 usage of electricity and table 41: combination39 annual usage of electricity

DISCUSSION

The analysis of the throughout the year electric consumption across various building combinations reveals intriguing insights into how specific components influence energy usage. The building with a plastering wall

demonstrated the lowest energy consumption across the board, with the base plastering wall consuming 858.85 KWH. This finding aligns with building science principles that suggest smoother, less porous surfaces, like plastering, often exhibit superior qualities for thermal insulation in comparison to brickwork or other textured surfaces. Cool exterior walls also showcased significantly lower energy usage, particularly the combination with a wood door, which recorded the lowest consumption at 864.68 KWH. The cool exterior walls are designed to reflect more sunlight and absorb less heat, which directly reduces the cooling load and overall energy consumption. In contrast, combinations involving additional glass components, such as glass doors and windows, consistently showed higher energy usage. This is likely because to the increased heat conductivity of glass, which can lead to increased heat transfer and thus a greater need for heating or cooling.
Comparing the components:
comparing the types of walls used in building are brickwork wall, cool exterior wall, and plastering wall. the annual electricity consumption

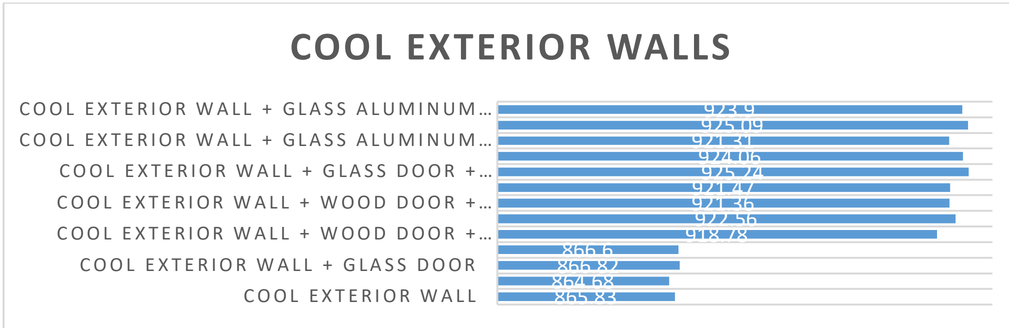
Brickwork Wall:



Graph 1: comparing brickwork walls

- Brickwork Wall: 897.27 KWH
- Brickwork Wall + Wood Door: 881.17 KWH
- Brickwork Wall + Glass Door: 883.16 KWH
- Brickwork Wall + Glass Aluminium Frame Door: 883.00 KWH
- Brickwork Wall + Wood Door + Wood Window: 920.46 KWH
- Brickwork Wall + Wood Door + Fiberglass Window: 924.22 KWH
- Brickwork Wall + Wood Door + Glass Aluminium Frame Windows: 923.02 KWH
- Brickwork Wall + Glass Door + Wood Window: 923.28 KWH
- Brickwork Wall + Glass Door + Fiberglass Window: 927.01 KWH
- Brickwork Wall + Glass Door + Glass Aluminium Frame Windows: 925.83 KWH
- Brickwork Wall + Glass Aluminium Frame Door + Wood Window: 923.11 KWH
- Brickwork Wall + Glass Aluminium Frame Door + Fiberglass Window: 926.86 KWH
- Brickwork Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: 925.65 KWH

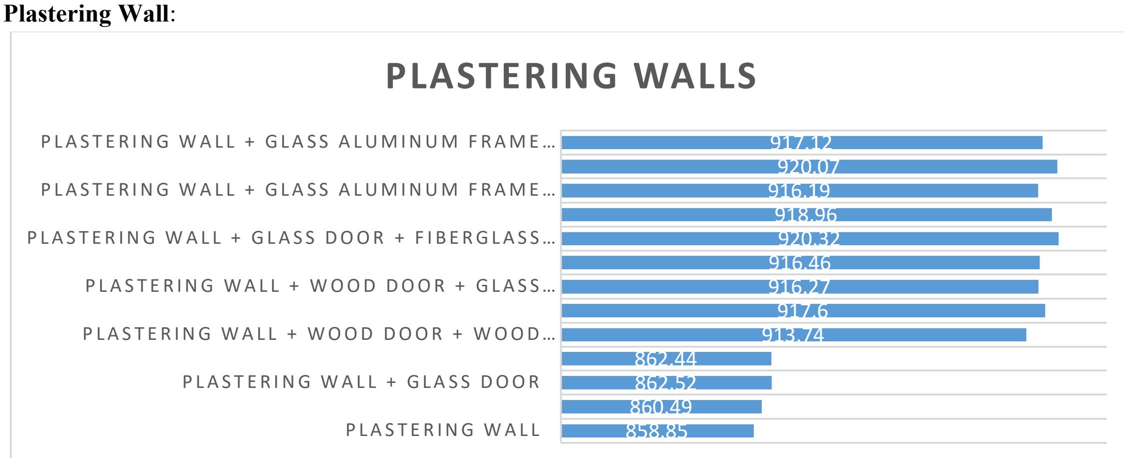
Cool Exterior Wall:



Graph 2: comparing cool exterior walls

- Cool Exterior Wall: 865.83 KWH
- Cool Exterior Wall + Wood Door: 864.68 KWH
- Cool Exterior Wall + Glass Door: 866.82 KWH
- Cool Exterior Wall + Glass Aluminium Frame Door: 866.60 KWH
- Cool Exterior Wall + Wood Door + Wood Window: 918.78 KWH
- Cool Exterior Wall + Wood Door + Fiberglass Window: 922.56 KWH
- Cool Exterior Wall + Wood Door + Glass Aluminium Frame Windows: 921.36 KWH
- Cool Exterior Wall + Glass Door + Wood Window: 921.47 KWH
- Cool Exterior Wall + Glass Door + Fiberglass Window: 925.24 KWH
- Cool Exterior Wall + Glass Door + Glass Aluminium Frame Windows: 924.06 KWH
- Cool Exterior Wall + Glass Aluminium Frame Door + Wood Window: 921.31 KWH
- Cool Exterior Wall + Glass Aluminium Frame Door + Fiberglass Window: 925.09 KWH
- Cool Exterior Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: 923.90 KWH

Plastering Wall:



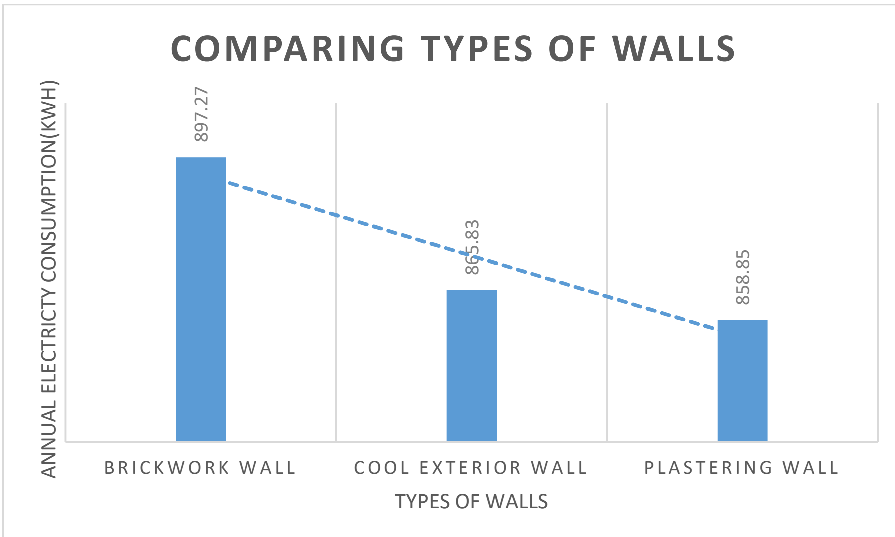
Graph 3: comparing plastering walls

- Plastering Wall: 858.85 KWH
- Plastering Wall + Wood Door: 860.49 KWH
- Plastering Wall + Glass Door: 862.52 KWH
- Plastering Wall + Glass Aluminium Frame Door: 862.44 KWH
- Plastering Wall + Wood Door + Wood Window: 913.74 KWH
- Plastering Wall + Wood Door + Fiberglass Window: 917.60 KWH
- Plastering Wall + Wood Door + Glass Aluminium Frame Windows: 916.27 KWH
- Plastering Wall + Glass Door + Wood Window: 916.46 KWH
- Plastering Wall + Glass Door + Fiberglass Window: 920.32 KWH

- Plastering Wall + Glass Door + Glass Aluminium Frame Windows: 918.96 KWH
- Plastering Wall + Glass Aluminium Frame Door + Wood Window: 916.19 KWH
- Plastering Wall + Glass Aluminium Frame Door + Fiberglass Window: 920.07 KWH
- Plastering Wall + Glass Aluminium Frame Door + Glass Aluminium Frame Windows: 917.12 KWH

Comparing the building components solely with regard to the types of walls.

The graph illustrates the yearly electricity usage related to three distinct wall types: Brickwork Wall, Cool Exterior Wall, and Plastering Wall. The Brickwork Wall has the highest annual electricity consumption at 897.27 kWh, while the Cool Exterior Wall and Plastering Wall consume less energy, with values of 865.83 kWh and 858.85 kWh respectively. According to this pattern, using plastering walls can lead to more energy-efficient buildings compared to brickwork walls.



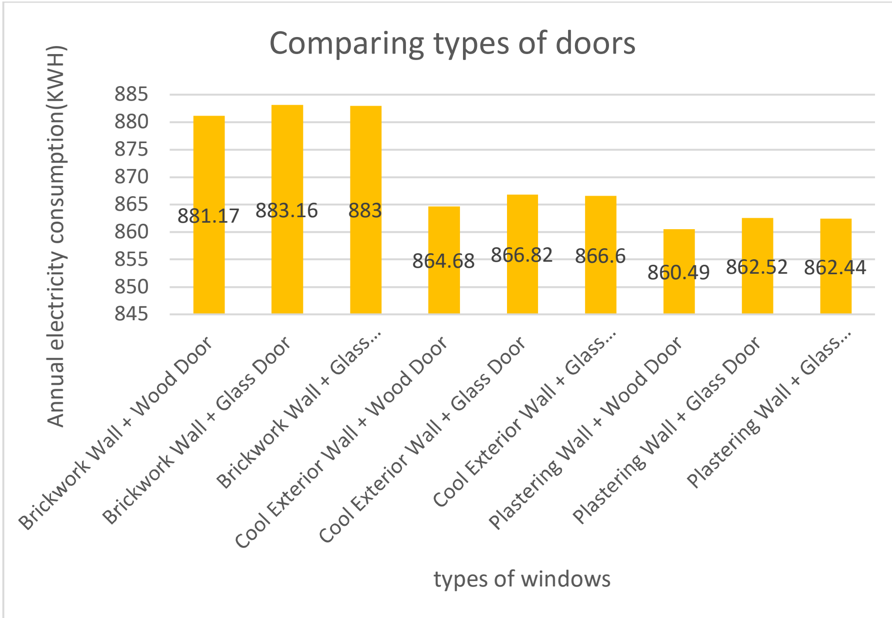
Graph 4: comparing types of walls

Our results are consistent with other research that emphasizes the energy efficiency of materials with higher thermal insulation properties. Research has consistently demonstrated that materials like plastering and cool exterior treatments reduce heat transfer, leading to reduced heating energy needs and cooling. This confirms what we've noticed, which plastering walls and cool exterior walls perform better in relation to energy usage compared to brickwork walls. However, some studies might show varying results based on different climatic conditions and building designs, highlighting the necessity of context-specific analysis.

The results of our experiment can significantly influence building design, particularly in climates with extreme temperatures where efficient thermal insulation is crucial. For hot climates, using cool exterior walls can help reflect more sunlight and reduce cooling loads. In contrast, for colder regions, plastering walls can provide better insulation, thus minimizing heating requirements. On top of that, these insights can direct the selection of wall types in different building types. For instance, residential buildings may benefit more from plastering walls due to their need for consistent indoor temperatures, while commercial buildings might prioritize cool exterior walls to reduce cooling costs during peak hours.

Comparing the building components solely with regard to the types of doors.

The graph presents a comparison of annual electricity consumption based on different combinations of wall, door, and window types. The combinations involving Brickwork Walls exhibit the highest energy consumption, particularly when paired with glass doors and windows, reaching up to 883.16 kWh. In contrast, Cool Exterior Walls and Plastering Walls show lower electricity consumption across all door and window combinations. Notably, the combination of Plastering Walls with glass doors and windows demonstrates the lowest energy usage at 860.49 kWh and 862.44 kWh, respectively.



Graph 5: comparing types of doors

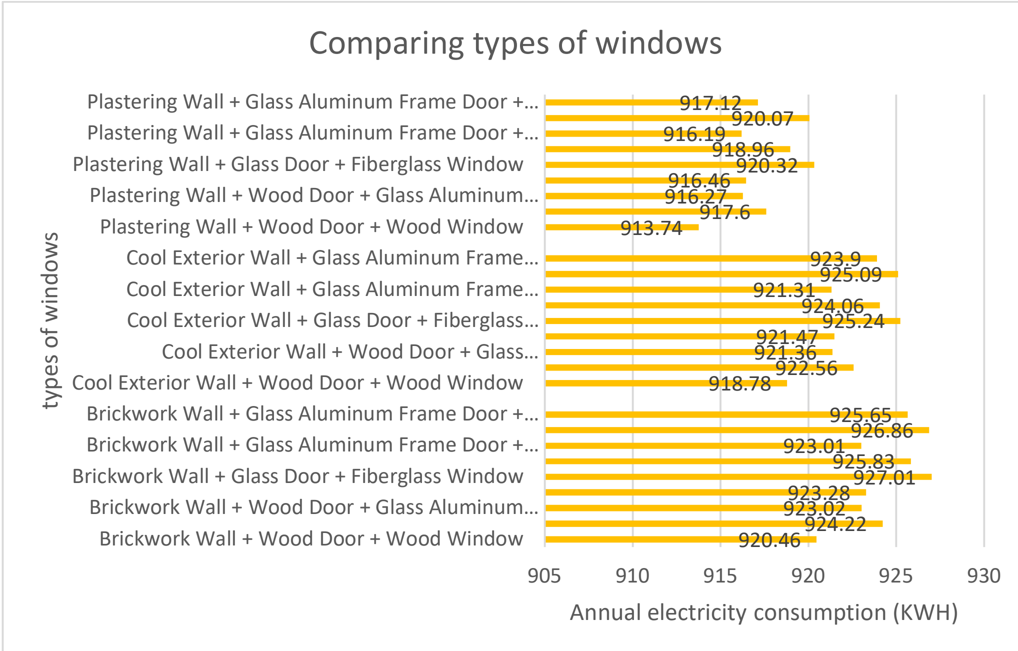
The findings align with previous research highlighting the energy efficiency of well-insulated wall materials and the effect it had of door and window types on overall building energy performance. Similar research endeavors have revealed that the use Many substances with superior thermal characteristics, like cool exterior finishes and plastering, significantly reduces heating and cooling loads. This alignment suggests that enhancing wall insulation and selecting energy-efficient doors and windows can lead to substantial energy savings. However, some studies may show variations due to differences in climatic conditions and specific building designs, indicating the necessity of localized assessments.

The outputs of this investigation offer useful insights for architects and builders aiming to optimize energy efficiency in building designs. For hot climates, incorporating cool exterior walls can effectively reduce cooling demands, while in colder climates, plastering walls can help maintain indoor warmth, thereby minimizing heating requirements. Additionally, choosing wood doors and windows over glass ones can further enhance energy efficiency, as shown by the lower consumption in these combinations. These results can guide the design of both residential and commercial buildings, helping to achieve sustainable and cost-effective energy performance tailored to specific environmental conditions and usage needs.

Comparing the building components solely with regard to the types of windows.

The graph compares annual electricity consumption based on various combinations of wall, door, and window types. Each combination includes a specific type of wall (Plastering Wall, Cool Exterior Wall, Brickwork Wall) paired with different types of doors (Glass Aluminium Frame Door, Glass Door, Wood Door) and windows (Glass Aluminium Frame Window, Fiberglass Window, Wood Window).

The combinations involving Plastering Walls generally show the lowest electricity consumption, with the combination of Plastering Wall, Glass Aluminium Frame Door, and Glass Aluminium Frame Windows having an annual consumption of 917.42 kWh, which is among the lowest in the dataset. Conversely, Brickwork Walls tend to result in higher electricity consumption, particularly in conjunction with Glass Aluminium Frame Doors and Windows, with some combinations reaching up to 925.63 kWh.



Graph 6: comparing types of windows

These results are consistent with other studies showing that well-insulated wall materials and efficient door and window combinations can significantly reduce energy consumption. Research has repeatedly demonstrated that materials having superior thermal characteristics, like plastering and cool exterior finishes, along with energy-efficient door and window designs, contribute to lower heating and cooling loads. This validates what we found that plastering walls and cool exterior walls, paired with appropriate doors and windows, are more energy efficient. However, variations in results can occur based on regional climatic conditions and specific building designs, underscoring the value of it of context-specific analysis.

The knowledge gained from this research can direct architects and builders in optimizing building designs for different climates and building types. In hot climates, utilizing cool external walls can drastically lower cooling demands, while plastering walls can maintain indoor warmth in colder climates, thereby minimizing heating requirements. The choice of doors and windows also plays a crucial role; for instance, wood doors and windows tend to enhance energy efficiency compared to glass counterparts.

Limitations and Future Research:

Despite The insightful information contained in this research has several limitations. The analysis was to comply with a specific set of building component combinations and a single climate context, which may not capture the full variability encountered in different regions or building types. Future research should expand on these findings by testing a broader range of climates and including real-world validation to ensure the practical applicability of the results. Additionally, investigating the long-term performance of these materials and their robustness across a range of environmental circumstances would contribute a more thorough comprehension of their benefits and limitations. Such Long-term investigations that track energy usage over time could be part of the investigation and in diverse real-world settings, thereby offering more robust recommendations for energy-efficient building design.

CONCLUSION

The analysis of different wall, door, and window types highlights their impact on annual electricity consumption and, consequently, on energy efficiency.

- Walls: Among the three wall types, *Brickwork Walls* lead to the highest electricity consumption at 897.27 kWh annually, while *Plastering Walls* show the lowest at 858.85 kWh, making them more energy efficient.

- Windows: The range in electricity consumption across window types shows variability depending on the wall and door combinations. The lowest consumption is 913.74 kWh, associated with *Plastering*

Wall + Wood Door + Wood Window, while the highest is 927.01 kWh, for *Brickwork Wall + Wood Door + Wood Window*.

- Doors: Different door types also affect energy use. *Brickwork Wall + Wood Door* leads to the highest annual electricity consumption at 883 kWh, while *Plastering Wall + Glass Door* has the lowest at 860.49 kWh.

The data shows that energy consumption varies significantly based on material combinations. *Plastering Walls* and *Wood Doors* generally show better energy efficiency across various configurations, while *Brickwork Walls* and certain *Glass Door* configurations tend to be less efficient.

For architects and builders, these findings emphasize the importance of selecting energy-efficient materials to reduce building energy use. Utilizing *Plastering Walls*, *Wood Doors*, and appropriate window combinations can contribute to more sustainable building designs, promoting energy conservation and reducing costs for building occupants.

REFERENCE

1. Serag, H., Mahmoud, M., Kamel, T., & Fahmy, A. (2024). Comparative Validation of a Building Energy Model Calibration Methodology with a Focus on Residential Buildings. *Civil Engineering and Architecture*, *12*(3), 1447–1462. https://doi.org/10.13189/cea.2024.120314
2. Huang, H., Hu, W., Chen, C., Lin, T., Lin, F., Cheng, C., Su, T., & Yu, P. (2024). Evaluation of the effects of window films on the indoor environment and Air-Conditioning electricity consumption of buildings. *Energies*, *17*(6), 1388. https://doi.org/10.3390/en17061388
3. Amani, N., & Sabamehr, A. (2024). Energy Efficiency of Residential Buildings in Cold and Dry Climates using Simulation-based Comparative Analysis: Case Study in Tabriz. *Iranica Journal of Energy and Environment*, *15*(4), 379–391. https://doi.org/10.5829/ijee.2024.15.04.06
4. Ni, X. (2023). The influencing factors of energy saving in residential buildings based on energy consumption and emission reduction. *The International Journal of Multiphysics*, *17*(4). https://doi.org/10.21152/1750-9548.17.4.371
5. Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2006). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment*, *43*(4), 661–673. https://doi.org/10.1016/j.buildenv.2006.10.027
6. Wagle S, Gopalakrishnan B, Li H, Liu Z, Chaudhari S, Sundaramoorthy S. Simulating energy performance of buildings: a study using eQUEST and Energy Star® portfolio manager. *Architectural Engineering and Design Management.* 2023; doi:10.1080/17452007.2023.2270679.
7. El-Darwish I, Gomaa M. Retrofitting strategy for building envelopes to achieve energy efficiency. *Alexandria Engineering Journal.* 2017;56(4): doi: 10.1016/j.aej.2017.05.011.
8. Gan VJL, Lo IMC, Ma J. Simulation optimization towards energy-efficient green buildings: Current status and future trends. *Journal of Cleaner Production.* 2020;254: doi: 10.1016/j.jclepro.2020.120012.
9. Rawat M, Singh RN. A study on the comparative review of cool roof thermal performance in various regions. *Energy and Built Environment.* 2022;3(3): doi: 10.1016/j.enbenv.2021.03.001.
10. Wang Z, Srinivasan RS. A review of artificial intelligence-based building energy use prediction: Contrasting single and ensemble prediction models. *Renewable and Sustainable Energy Reviews.* 2017;75: doi:10.1016/j.rser.2016.10.079.
11. Gong X, Phinaitrup B, Zhang Q, Wang Q. Case study on the energy-saving potential of adaptive lighting in office buildings based on occupant behavior simulation. *Applied Energy.* 2021;299: doi:10.1016/j.apenergy.2021.117177.
12. Holst J, Lawrence T, Miroslav A. Investigating energy efficiency in high-rise office buildings using eQuest and real occupancy data. *Energy Efficiency Journal.* 2019;12(4): doi:10.1007/s12053-019-09770-2.
13. Korkas CD, Baldi S, Michailidis I. Occupancy-based demand response and thermal comfort optimization in microgrids with renewable energy sources and storage. *Applied Energy.* 2016;163: doi:10.1016/j.apenergy.2015.10.140.

14. Su X, Ahn C. Predictive assessment of building energy performance using eQuest modeling in different climatic zones. *Building Simulation Journal.* 2020; doi:10.1007/s12273-020-0640-z.
15. Sathyamoorthy GL, Santhosh T. Energy analysis of a green building using eQuest software. Int J Eng Adv Technol. 2019;8(6):1527-1532. doi:10.35940/ijeat. F1273.0986S319
16. Sousa J. Energy simulation software for buildings: review and comparison. Procedia Eng. 2012; 30:163-170. doi: 10.1016/j.proeng.2012.01.840
17. Negrao CP, Silva SA. Energy efficiency through building envelope optimization and HVAC systems: An eQuest analysis. Renew Sustain Energy Rev. 2020;114:109315. doi: 10.1016/j.rser.2019.109315
18. Corgnati SP, Corrado V, Filippi M. A method for defining HVAC system energy requirements in the early design stages. Energy Build. 2008;40(6):1037-1043. doi: 10.1016/j.enbuild.2007.10.002
19. Lin Y, You X, Wang S. a Comparative Study of Building Energy Modeling and Simulation Using DOE-2, DeST, and Energy Plus. Building Simulation 2018;8(1):112-20. doi: 10.1007/s12273-017-0375-1.
20. Pérez-Lombard L, Ortiz J, González R. A Review of Building Energy Simulation Programs for Evaluation of Energy Efficiency and HVAC Design. Building and Environment. 2017;43(2):361-67. doi: 10.1016/j.buildenv.2017.01.002.