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A Parametric Approach for Decision Making of Low-carbon Building Envelope Design

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Abstract

Buildings are major contributors of total carbon emissions than all other categories globally. to reduce these emissions by some quantity must propose the better design before construction. For that, this study proposed a different combinations of building envelope analyzed. From that the best configuration can be implemented for construction to reduce emissions from building at different stages. Through the use of e-QUEST version 3.65, a total of some wall construction materials like-Agrocrete, KJS thermo insulated blocks, AAC block, Fly Ash brick, Resource Efficient Hollow brick and some roof construction typologies—Cement Screed + XPS Insulation + Mother Slab, Mother Slab+ Bitumen + Tiles, Mud Phuska + Brick Tile, Mud Phuska + PCC etc. The main aim of this study is to identify the wall and roof design configuration that decreases the building cooling demand, hourly peak cooling demand, total operational energy demand, energy performance index (EPI) and Carbon emissions at different stages. It specifically focuses on measuring the quantity of heat that is transmitted through various wall, roof and window designs. The four categories that make up this studies technique are base case simulation, parametric framework, decision-making parameters, and optimal outcome. It shows that the best combination of solutions lowers the annual operational demand as well as the monthly, daily cooling demands and carbon emissions.

Keywords: Emissions, EPI, e-Quest, Building Envelope.

INTRODUCTION

The purpose of this paper is to fill the knowledge gap in developing energy-efficient structural plans by simplifying envelope features. The high rise in Jaipur, Rajasthan as well as other places, where the subject of a contextual investigation in this paper that uses a parametric multi-objective improvement method to find the ideal wall and rooftop configuration. The review quantifies the amount of intensity that is convectively and conductional moved inside the structure space by different wall and rooftop plans by taking into account a variety of factors, including the yearly energy execution file, hourly pinnacle cooling interest, least cooling interest, and absolute structure interest. The study also discusses other research areas that have an emphasis on multi-objective advancement-based methods for evaluating architectural features and developing energy-efficient layouts [1, 2, 3]. This paper also discusses the necessity to handle the growing need for cooling in India and offers solutions, such as Energy Effectiveness Frameworks and sustainable energy sources are used by the executives to reduce energy use. The results of this investigation can be used to inform future building plans and renovations that reduce energy use and emissions [4].

Methods for collection the data, consistency verifications, uncertainty analysis, impact assessment, and interpreting results are described,

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with LCA framework of ISO 14040 & EN 15978 as the basis for analysis [5]. It also recognizes that India does not have a centralized LCA inventory. Although green buildings typically emit less CO_2 than conventional structures, they are more expensive to build initially, which makes it challenging to build many of them. So, in order to increase and disseminate public knowledge of green buildings, both the CO_2 emissions and the energy consumption of such buildings should be taken into account.

LITERATURE REVIEW

F. Bano et al. [6] this paper is a real-world case study of an apartment complex in Jaipur, Rajasthan, India, which has high-rise residences. When deciding how to design a building's envelope with the various wall and roof assembly combinations, the parametric multi-objective optimization technique is used. This paper's goal is to determine the optimal wall and roof scenario while accounting for the annual energy performance index (EPI), the hourly peak cooling demand, the minimum cooling demand, and the total building demand. This research is innovative in that it measures the amount of heat (in kW) that is convectively and conductional transported within the building space by various wall and roof designs. There is now a sizable research gap for the creation of energy-efficient building designs with regards to optimization of envelope characteristics.

Ciardiello A et al. [7] determine the ideal WWR, orientation, and shape for residential apartment buildings and show how these factors affect cooling and lighting requirements. When compared to the current situation, it shows that the best set of single solutions cuts energy usage by 40% and increases occupant comfort by 52%.

Shiel P and Zhang J et al. [8, 9] the many steps of the optimization process for residential building typology are shown in certain multi-objective optimization-based research within the same context. The four steps of this methodology are the base model, the optimization setup, multi-criteria decision making (MCDM), and determining the robustness of Pareto solutions. These studies examine algorithmic and parametric optimization techniques to evaluate the many building features, producing a collection of mono solutions.

Gagnon et al. [10] Richard has examined the performance of buildings using sequential and holistic design techniques using a parametric optimization approach. Overall, it was discovered that the complicated issues relating to building design can be resolved via parametric study. I X ECBC et al.

[11] According to ECBC-R, the overall operational energy demand can be reduced by 30% by selecting contrasting materials for the walls and roofing. Various tools and techniques are available to assess the acceptability and utility of building materials for decision making.

J. M. Rey-Hernandez et al. [12] It is a serious issue for the nation, and the building industry needed to change using the tools at hand. Energy Efficiency Management System (EEMS) and Renewable Energy Sources are two ways to cut back on energy use (RES). To meet the energy requirement, EEMS concentrates on constructing passive designs, lighting, and HVAC systems, whereas RES uses solar PV, geothermal, and biomass.

M.W.K. Sudhakar et al. [13] India ranks fourth in the world for economic growth. However, individuals desire a greater level of living and wellbeing. The need for air conditioning is expected to quadruple over the next 15 years, according to LBNL research. In 2040, Indians anticipated to rank as the fourth-largest contributor to global electricity demand.

$$\text{Energy Savings} = \frac{(\text{Energy Cost for Baseline Building} - \text{Energy Cost for Taxpayers Building})}{\text{Energy Cost for Baseline Building}}$$

Aqil Muhammad et al. [14] It has been carried out in a lab with Galvanized Iron sheet roofing & concrete walls, making for an unappealing place to actually live. Economic thickness of insulation, such as utilizing coconut pith insulation board of 5 mm upon this wall and 5 mm jute fiber underneath the roof with 0.3 m air gap, and using low E-glass windows, were shown to improve human comfort to acceptable levels. It is now possible to keep the temperature between 75 and 80 degrees Fahrenheit (24 and 27 degrees Celsius), and the humidity around 40 and 49 percent, even though these conditions were previously far from ideal [15].

Heidari, Mohammad, et al [16] the findings showed that a phased strategy for the retrofits might result in an estimated 40,000 CAD investment in an existing residential structure in Ontario that would save 78% on energy and reduce emissions by 96%. The reported energy and pollution savings for Vancouver are 85% and 100%, respectively.

Mathew, Veena, et al. [15] The EC layer is found to have the greatest temperature gradient. Using the e-quest DOE tool, the energy performance of a double glazing and ECW for a warm and humid region is assessed. When compared to double-glazed windows, an ECW's annual energy consumption is found to be 30% lower. Additionally, there is a 10% reduction in energy use with the ECW compared to baseline during the monthly study of energy use. Measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

Methodology

Through site visits and direct surveys, the authors determined the kind of material utilized in Indian construction methods for cheap housing. Materials including Agro Crete, KJS thermos-insulated blocks, redbrick, AAC block, Fly ash brick, Cast Concrete brick, Resource Efficient Hollow brick, Exposed Red brick + AAC block are used for wall construction and Cement Screed + XPS Insulation + Mother Slab, Mother Slab+ Bitumen + Tiles, Mud Phuska + Brick Tile, Mud Phuska + PCC are utilized for roof construction.

The methodological hierarchy used to decide on the envelope design for a specific case study of the residential structure is shown in Figure 1. Base case simulation technique, optimization setup, decision parameters, and identification of the optimal solution are the four sections that make up this document. The optimization tool is e-quest version 3.65. The US Department of Energy created it. The ability to simulate several, alternative simulation cases—each of which is a parametric modification of the basic case—is provided by e-quest. In an e-quest parametric run, a maximum of five alternative design parameters may be optimized with the base case. In this study, the optimization of two design parameters—the wall and the roof—is taken into account [17].

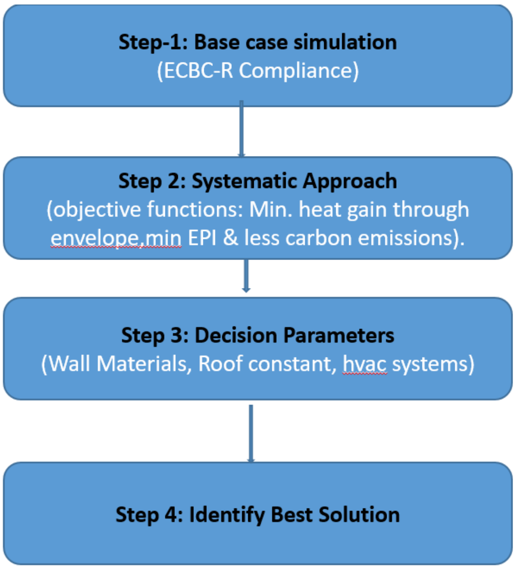

Figure 1. Methodological structure adopted for parametric simulation.

Preliminary Results

Table 1 shows trail parametric simulation combinations of some of the wall and roof combinations of selected materials. The all trail combinations considered are only wall is changing and the roof kept constant. Material used for roof is cement screed, XPS insulation, mother slab whose thickness are 20 mm, 50 mm and 100 mm respectively and the corresponding 'U' value is 0.5 w/m² -k. Materials used for wall are red brick, AAC block, cast concrete, fly ash brick and resource efficient hollow brick the thickness are 230 mm, 250 mm, 200 mm, 150 mm, 200 mm respectively and the corresponding 'U' values are mentioned in the below

Table 1. Wall and roof combinations

Roof Material	U-Value	Wall Material	U-Value
Cement Screed 20 mm+XPS insulation 50 mm+mother slab 100 mm	0.5	Red Brick	2.1
		AAC Block	0.65
		Cast Concrete	3.4
		Fly ash Brick	1.5
		Resource-efficient hollow brick	2.25

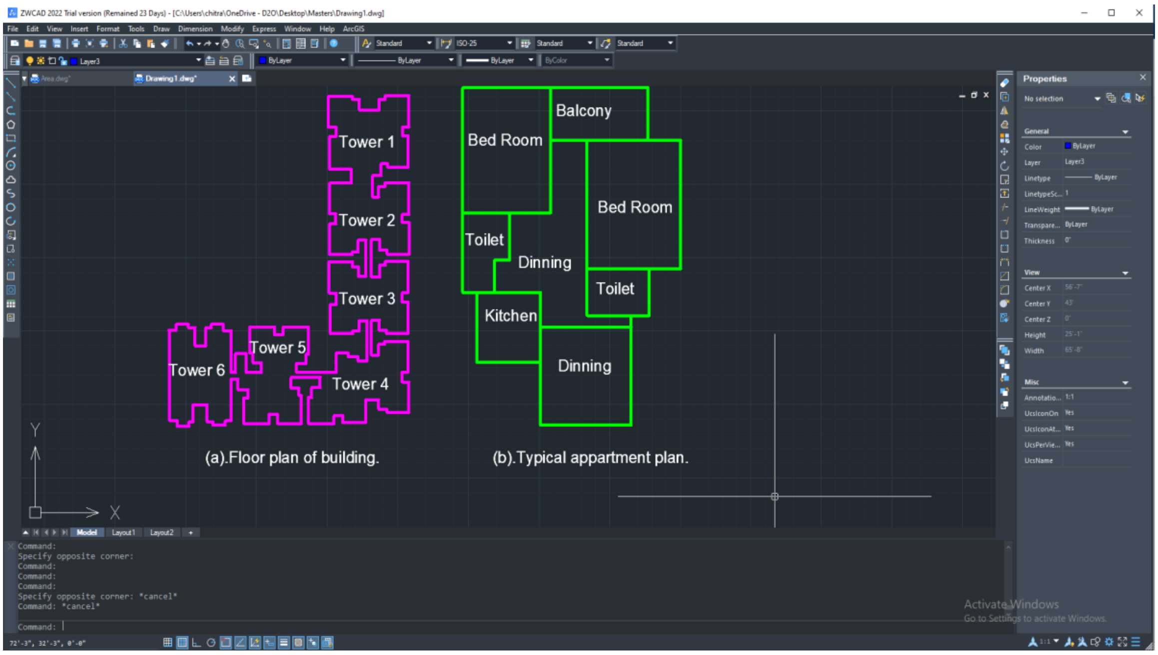

Figure 2. (a) Floor plan of building (b) Typical apartment plan.

Floor plan of the simulated residential building is mentioned in Figure 2 (a) and it having 6 towers of the same typical apartment plan (Figure 2 (b)). The selected building is in 'L' shape of containing garden area in front of the building or at the entry. Apartment plan contains 2 bedrooms, 1 balcony, drawing, etc. are mentioned in the Figure 2 (b). The site area of the considered building was shown in Table 2:

- For making 3D model on e-quest, firstly draw a floor plan (zoning) and for that drawing used ZW cad 2D wireframe.
- This building have nine floors and there is a need to must draw nine different layers with different colors and import that cad file to e-quest model. Initial zoning was performed on the ZWCAD software, and then it was transferred to the e-quest software for the model zoning in the Wizard mode of e-quest (Figure 3).
- After constructing the building in e-quest have to follow the other screen also to give different technical input specifications.

- This study is a high-rise residential building situated in Jaipur, Rajasthan (India) and other countries. According to ECBC, Jaipur city comes under a composite climate. The average mean temperature lies between 15-34 degrees Celsius. In the detailed simulation mode of the building wizard, different building operational schedules such as occupancy, lighting, cooling, heating, and infiltration are attached. Jaipur city (India) weather file is used as a reference for weather conditions. Cooling and heating schedules attached based on the NBC -2016 thermal comfort model of the air-conditioning building that is shown in Table 3. Split air conditioning is included in the considered simulation study with the BEE five-star rating air conditioners for more energy saving.

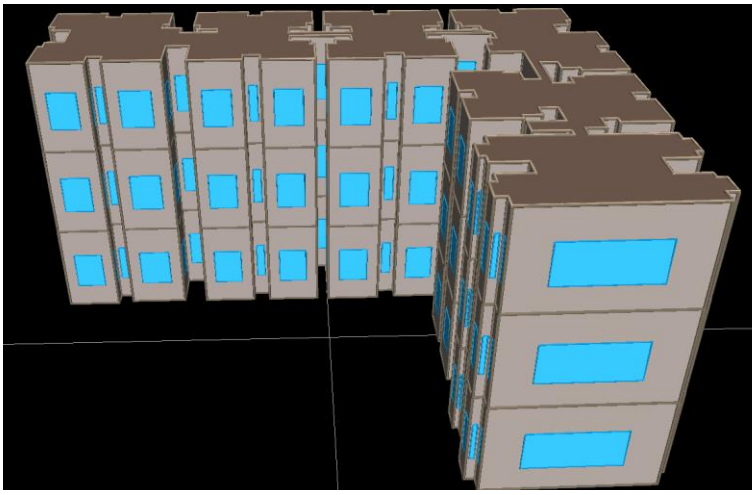

Figure 3. e-Quest model of building design.

Table 2. Site specifications

Specifications	Measurement
Total Site Area	10722.92 m²
Build-up Area	16390 m²
Footprint Area	1693 m²
No. of Floors	G+9
No. of Towers	6
WWR	10.31

Table 3. List of constraint parameters considered.

Climate Type	Composite	Units
Lighting	0.25	W/ft².
Occupancy	250	m²/person
HVAC	PTAC(dx cooling & furnace heating	SEER-16(as per BEE 5 star compliance)
Sizing Ratio	2.25	
EPD	0.25	W/ft²

Table 4 shows the Physical properties of wall and roof material considered during parametric optimization. Physical properties are more effect the building energy consumption. "Resistance to heat transmittance" (R-value) or "Thermal performance value" is the primary determinant of how energy-efficient a building's walls are (U-value). Heat cannot enter or leave the building through walls that have a high R-value or low U-value. The thickness of wall material's and roof material also plays a major role in building energy rate. Therefore, it is important to select the proper thickness of considered wall material before design or before energy evaluation. Do not use the word "essentially" to mean "approximately" or "effectively" [18].

Table 4. Physical Properties of wall material to be considered.

Material	Thickness (mm)	Density(Kg/m cube)	Specific heat (KJ/Kg k)	Conductivity (w/m k)
Red Brick	230	1760	0.8	0.85
AAC Block	250	642	1.24	0.184
Cast Concrete	200	2200	1.05	1.403
Fly-ash Brick	150	1620	0.93	0.856
Resource-Efficient Hollow Brick	200	1520	0.65	0.631

The graphical representation of five optimized combinations accounting above are monthly peak cooling demand, total cooling demand and total operational energy demand in (kWh x 10^3) shown in Figure 4. Cement screed + XPS insulation + mother slab with cast concrete shown the highest cooling demand among all other combinations. Total operational demand almost for all 5 combinations is nearly same.

Table 5. Comparision between ECBC Standards with Proposed Model

Parameters	Baseline Model (ECBC Std.)	Proposed Model
u-value (Wall)	0.071	Parametric Approach
u-value (Roof)	0.053	0.5
u-value (Door)	0.5	0.5
u-value (Glass Glazing)	0.57	0.57
Climate Zone	1 A	1 A
Parametric Approach	**U-values**	
Red Brick	0.37	
AAC Block	0.11	
Cast Concrete	0.599	
Fly Ash Brick	0.26	
Efficient Hollow Brick	0.44	

Using the baseline scenario and the proposed scenario as comparisons, this table offers a thorough study of the U values, which measure thermal transmittance (Table 5). The baseline case's U values were taken directly from the ECBC standards, assuring compliance to recognized energy conservation laws. On the other hand, the U values for the proposed example were established using combinations of the envelope materials used inside the building. The proposed scenario seeks to maximize thermal performance and energy efficiency while surpassing the ECBC's baseline guidelines by taking into consideration various material combinations.

Heat transfers via walls, windows, roofs, and other components can be reduced by using building envelope materials with lower U values. This results in less energy being used for heating or cooling, which lowers carbon emissions [19]. Buildings that use less energy not only help their residents save money, but they also benefit the environment by producing less greenhouse gas emissions (Table 6).

Table 6. Overall Energy Consumption of materials.

Material	Electric Energy Consumption (KWH)	Gas Consumption (Mbtu)
Red Brick	184.69	1092.1
AAC Block	187.96	652.74
Cast Concrete	184.09	1391.2

Fly Ash Brick	185.64	923.5
Efficient Hollow Brick	184.43	1192

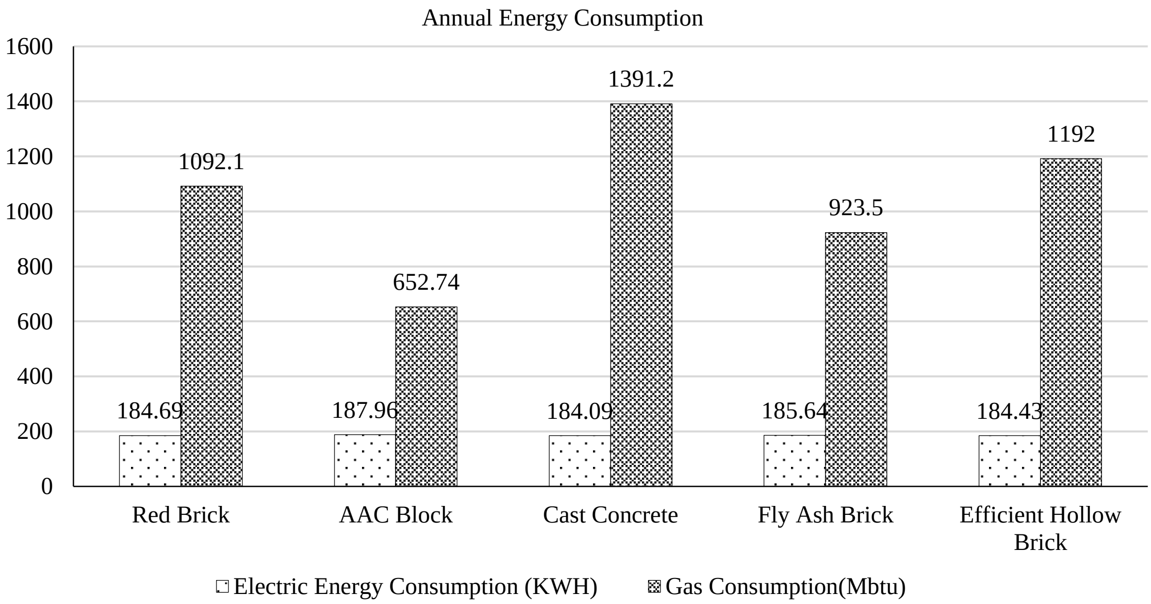

Figure 4. Graphical representation of annual energy consumption.

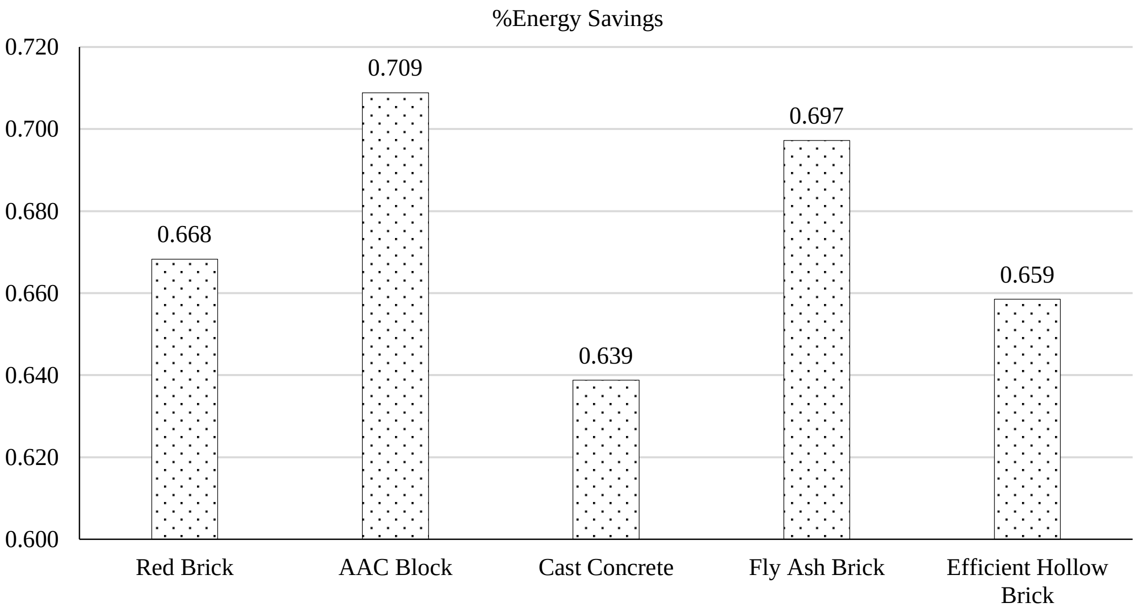

Figure 5. Energy Savings of materials to be considered w.r.t baseline model.

EPI (W/m²K), hourly peak cooling demand (kW), and space cooling demand (W²m). of all optimized combinations was graphically represented in the Figure 5 [20]. It reveals that Cement screed +XPS insulation + mother slab with cast concrete has recorded highest in energy performance index, hourly peak cooling demand. The combination Cement screed + XPS insulation + mother slab with AAC block shown lowest values.

To illustrate the differences between ECBC standards and the proposed parametric approach, I have prepared a comparison table (Table 7) below:

Table 7. Comparison between ECBC Standards and Proposed Parametric Approach

Aspect	ECBC Standards	Proposed Parametric Approach
Compliance Method	Prescriptive	Performance-based
Evaluation Criteria	Absolute	Relative
Flexibility	Limited	Higher
Design Consideration	Component-level	System-level
Scope	Building Envelope	Building Envelope and Systems
Applicability	Specific to India	Potential for Global Adoption
Limitations	May not account for all scenarios	Subject to definition and selection of KPIs
Benefits	Prescribed energy savings	Flexibility to optimize energy performance based on specific context

CONCLUSION

Identification and description of the key external "technical parameters" that influence the thermal performance of tall building envelopes was the goal of the parametric analysis described in this paper. Based on the results of the simulation, it can be seen that a building's heating load is more affected by an increase in insulation layer thickness than its cooling load is. According to the analysis, the thermal properties of the glazing type, such as the shading coefficient, are the primary role in reducing cooling and heating energy loads in proportion to solar gains. In other words, lower shade coefficient can dramatically decrease the solar benefits even for large glazing areas. The largest energy savings in buildings come from thicker insulation. Additionally, the insulation utilized in the wall construction technique can prevent conduction of heat through the opaque portion. With the difference in cooling & heating loads energy savings reaching up to 70%, these data demonstrate the enormous impact even minor modifications in facade design may have on a building's performance. The simulation's ideal façade arrangement uses Thermal Blocks for the walls and 32 mm glazing with the least amount of shade (0.184). An energy simulation must be performed to calculate the building's annual heating and cooling demands while thermal insulation is used. This simulation should be used along with an economic analysis that takes into account both the cash savings and the cost of thermal insulation. Among all the selected combinations the AAC Block shows higher energy savings and Cast Concrete shows lower energy savings.

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