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Comparative of Two Building Envelopes for Energy Efficiency and Environmental Sustainability

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Abstract

This study investigates two distinct building shells (envelope) types in a resort located in Matheran, a hill station renowned for its environmental significance, for their thermal performance. Given that no new construction is allowed in Matheran, enhancing energy performance in older structures is critically important, to reduce environmental impact while maintaining sustainability. Buildings are predominantly skin dominated, with the building shell contributing significantly to heat gain and loss, which can account for up to 73% of the total thermal load. This study primarily aims to conduct a comparison between two distinct building envelopes: a modern RCC- framed clay brick structure and a traditional load-bearing Laterite stone construction structure. Both envelopes are analyzed for their thermal performance and energy efficiency using simulation models in ECOTECT and eQUEST software. The results reveal that the traditional Laterite stone envelope outperforms the RCC-framed clay brick structure in terms of thermal performance, offering better insulation and lower heat gain, thus resulting in improved energy efficiency. To improve the modern RCC envelope's energy efficiency, modifications were proposed in the areas of roof, wall, and fenestration properties. Simulations of these modifications demonstrated a significant improvement in thermal performance, with a reduction in cooling loads by 15% and overall energy consumption by 10%. The study highlights the research gap in the thermal performance analysis of building envelopes in Matheran, a region that requires sustainable solutions due to its eco-sensitive status. By providing quantifiable results, this paper contributes valuable insights for the design and renovation of energy-efficient resort envelopes in such regions. The findings underscore the importance of retrofitting existing structures for sustainability and the reduction of fossil fuel dependency, offering a viable path for green development in protected areas like Matheran. The study's impact extends to both the architectural community and policymakers, advocating for environmentally conscious development in sensitive tourist locations.

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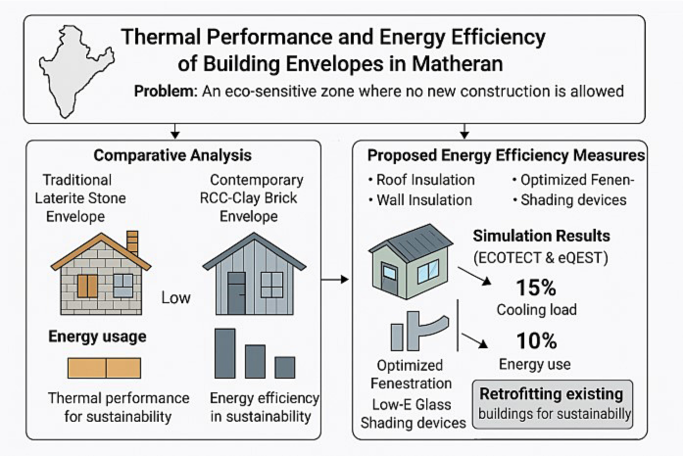


Fig. 1 : Graphical Abstract

Introduction

Recently, managing energy resources has surfaced as a key global priority, driven by environmental impact of Carbon dioxide emissions as well as other greenhouse gases. These emissions are largely responsible for the acceleration of climate change, leading to rising global temperatures, unpredictable weather patterns, and adverse effects on biodiversity. Simultaneously, the rapid depletion of fossil fuels, which have long been the main source of energy, further exacerbates the problem.[1] As globalization progresses, the need for energy has increased dramatically, exerting considerable strain on both natural resources and the environment. Among the many sectors contributing to energy consumption, the hospitality industry has emerged as a key player. With the growth of tourism worldwide, resorts have become prominent contributors to the escalating energy crisis.[2]

The hospitality sector, with its diverse and large-scale facilities, demands a significant amount of energy to operate effectively. Hotels and resorts, in particular, are energy-intensive due to their complex and content-specific design, which includes numerous functional areas like guest rooms, dining facilities, conference halls, kitchens, and recreational zones. Each of these spaces has distinct energy requirements, resulting in elevated total energy usage.[3] The collective energy needs for heating, cooling, illumination (lighting), ventilation, and running different appliances lead to significant carbon emissions, which further intensify the environmental harm caused by the tourism sector. This presents a significant challenge for Hospitality industry stake-holders and policymakers, who must balance the need for energy consumption with the urgency of minimizing environmental impact.

One key area through which energy consumption can be optimized is the envelope of the building, which is crucial for the thermal efficiency of a resort.[4] The building envelope—comprising walls, roofs, windows, and floors—acts as a barrier between the interior environment and the external climate. Its thermal properties directly affect energy used to stabilize indoor conditions of the structure, along with general comfort level of visitors. A thoughtfully crafted envelope can greatly diminish the reliance on artificial heating and cooling, resulting in decreased energy use and a smaller carbon footprint. And, poor thermal performance can result in excessive energy use, thereby increasing environmental impact.[5]

Considering these issues, this study's objective is to investigate the efficiency of the exterior shell (envelope) of the resort building located in Matheran, a renowned hill station in India. The focus will be on assessing the envelope's role in the resort's energy conservation, considering its thermal properties, design features, and material choices. Through the examination of these elements, the research seeks to uncover possibilities for enhancing energy efficiency, diminishing energy usage, and lessening the project's environmental footprint. Furthermore, the paper will assess the possibilities of incorporating sustainable construction methods and energy-saving technologies, including passive design approaches, renewable energy systems, and high-performance insulation materials, to improve the thermal efficiency of buildings.[6]

Given the growing concern over environmental degradation and the urgent need for energy conservation in the hospitality sector, this research hopes to contribute valuable insights that can guide future resort designs, renovations, and operational practices towards greater sustainability and energy efficiency. Through a deeper understanding of the thermal performance of envelopes, the hospitality industry can take meaningful steps towards reducing its carbon footprint while ensuring the comfort and satisfaction of guests.

Need of the Research

Over the past several years, there is notable rise in tourism in Matheran, considering its location from both Mumbai and Pune. The town, known for its serene landscapes, lush green surroundings, and the tranquility, attracts thousands of tourists, has witnessed a consistent rise in visitors. This influx of tourists has directly impacted local businesses, resorts, and home stays, which have become a primary source of livelihood for many residents. Despite Matheran being designated as an Eco-sensitive zone (ESZ) in 2003, there has been a rise in the construction of new buildings and transformation of residences as family-run lodging. This growth continues despite the regional authority's imposition of a ban on any new construction in the region. The primary objective behind the ban was to protect the fragile ecosystem of Matheran. However, this increase in tourism and hospitality developments has created a paradox, where the rise in facilities contradicts the environmental preservation efforts aimed at maintaining Matheran's natural beauty.[7]

A serious spurt in tourists puts tremendous stress on Matheran's infrastructure, including its transportation, waste management, water supply, and most notably, energy needs. This unregulated growth of both new and existing resorts, in tandem with the influx of tourists, has led to escalating energy demands. These demands are satisfied by traditional energy sources like electricity, fuel, wood, and oils, which lead to a higher carbon footprint. This pressure on Matheran's energy resources, combined with the area's fragile ecosystem, can severely disrupt its environmental balance, further compromising its allure and beauty.

The essence of tourism in Matheran lies in its environment. Tourists come for the peace, quiet, and natural surroundings, making it imperative to conserve the town's ecological quality. The continued growth of tourism, if left unchecked, could undermine the very characteristics that make Matheran, an attractive tourist destination. Therefore, it is crucial to recognize the need for environmentally sound development and operations within the tourism sector. Realizing this, necessitates, the implementation of sustainable methods in resort and home stay operations, with special emphasis on managing energy usage. By fostering energy saving operations, it is possible to reduce operational costs while simultaneously enhancing the comfort and quality of services offered to tourists in the resort.

In line with the goal of preserving Matheran's unique environmental heritage, there is an urgent need to implement measures aimed at reducing the energy footprint of existing resort facilities. This is especially important as no new construction is allowed in Matheran, requiring an emphasis on enhancing the energy performance of current infrastructure. By assessing the present energy consumption patterns in the selected resort and suggesting efficient solutions, the study aims to contribute to a more sustainable and eco-friendly tourism model in Matheran.[8]

Thus, the need for this study lies in the identification and implementation of energy conservation strategies that will facilitate the sustainable growth of tourism in Matheran, without compromising the area's ecological integrity or the quality of services offered to visitors.[9]

Aim

The main aim is to ensure efficient energy utilization in Matheran resort by conducting a relative assessment of two varied structural shells (envelopes), representing modern and traditional construction, to identify which one offers greater energy savings potential. Further, making the one envelope more energy efficient by applying strategies individually or in combination.

To accomplish this goal, objectives of this study are outlined below

- Exploring energy conservation methods for resorts and their capacity to reduce energy consumption as based on prior findings.
- Conducting a relative assessment of distinct building shells (envelopes) in the resort, which are the traditional construction utilizing laterite stone as a load-bearing material and modern reinforced concrete framework with clay brick walls.
- Implementing same principle to the resort simulation (computational) model.
- Identifying most efficient envelope for energy conservation based on the simulation analysis.
- Further, making the modern envelope, energy efficient by using green strategies.

Importance of the Research

The energy efficiency of a building's shell (skin) based on its thermal performance is a way to assess the average heat gain through that envelope.[5] It serves as a metric for the energy efficiency of the building, allowing for design flexibility while addressing the retrofitting of the existing resort, which is necessary for Matheran, owing to its status as an eco-sensitive zone since 2003, thereby prohibiting new developments.

For a specific location, climate conditions may remain constant, while architectural elements can differ. Consequently, it is crucial to examine heat gain factors for both envelopes according to their material properties.

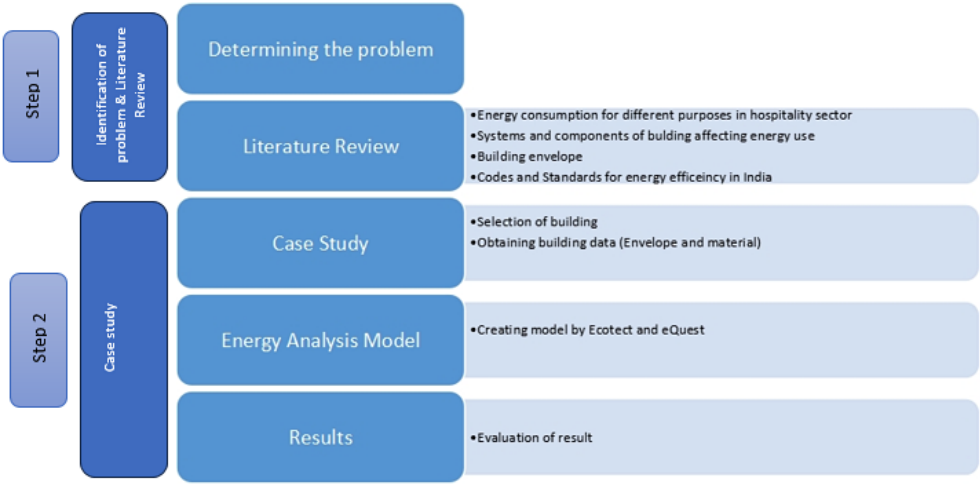


Fig. 2: Study framework

Table 1 : Key areas of a resort

Three distinct zones of hotel		
Guest Rooms	**Public areas**	**Service area**
Bedrooms, bathrooms/ showers, toilets)	(Reception, lobby, bars, restaurants, meeting rooms, swimming pools)	(Kitchen, offices, store rooms, laundry, staff facilities, machine rooms and other technical areas)
Individual spaces with extensive glazing, utilization and varying energy loads	Spaces with high rate of heat exchange with the outdoor environment (high thermal losses) and high internal loads (occuants, equipments and lighting)	Energy intensive areas typically requiring advanced air handling (ventilation, cooling, heating)

Source - Author

Energy Management in Hospitality Sector

Resorts significantly use energy and fossil fuels to deliver top-notch services to their guests, which can be efficiently minimized without affecting service quality, leading to potential cost savings.

Energy Consumption for Different Purposes

Resorts are often structured as a fusion of three unique components, with each part serving a distinct function.

The energy usage of resorts is affected by both structural and functional attributes

Fig. 3: Factors related to structural and functional attributes that affecting usage of energy in resorts

Source - Author

Energy Optimization through Passive Design Solutions

Architectural planning and site orientation, climatic aspects like ambient temperature, relative humidity and radiant heat affect the design.[10] As per D. K. Ching, in his book 'Green building illustrated', it is imperative to focus on planning, siting, and form of the building while integrating comprehensive solutions for temperature regulation, ventilation, and illumination, thus aiming to reduce power consumption of buildings throughout their operational life.[5]

Table 2: Aspects of the building shell

External walls	Roof	Fenestration	Shading devices	Building colour and texture
•Major part that is exposed to external environment •The ability of wall materials to store heat and their heat conduction characteristics influence internal thermal comfort. •Should be reflective and light coloured (can save energy for cooling by 12%)	•Captures the highest amount of solar radiation since shading cannot occur. •Shape of the roof •Significant overhangs to shield envelope walls and fenestrations from solar heat gain and rains. •Constructed from a material that has minimal thermal mass and high albedo. •Techniques to reduce heat gain - green roofs, reflective roof tops, cool roofs.	•Energy efficient windows and glazing o enhance the quality of air indoors and providing proper insulation •Factors like solar heat gain coefficient (SHGC), visible light transmittance (VLT) and U-value •Double glazed windows acts as good insulators and provides thermal resistance better than single glazed windows •Low-e glass	•Shading devices reduce solar heat gain in east, west and south facades thus reducing energy consumption for cooling • They additionally protect walls and windows from water penetration and safeguard construction materials from degradation due to the sun's ultraviolet rays.	•The outer surface of external walls ought to be light-colored and reflective. •Affects the amount of solar energy absorbed • Smooth, light-coloured finishes tend to reflect more than dark, rough finishes •Light colour has high emissivity and thus preferred where solar radiation is high.

Buildings are projected to lower energy usage by an average of 20-50% through the implementation of suitable design strategies in various areas, including the building shell (skin), temperature regulation and air conditioning I.e.HVAC, ranging 20-60%, ventilation, illumination ranging 20-50%, hot water supply ranging 20-70%, refrigeration ranging 20-70%, as well as electrical appliances and gadgets like devices and automated systems ranging 10-20% (United Nations Development Program).[1]

Envelope of the Building

The term ‘Shell or Envelope or skin’ signifies the external structure of a building. This shell incorporates structures like walls, glazing, doors, and the roof. Approaching the design of the building from the outside in—starting from the edges of the building site and progressing through its envelope to its interior—offers numerous advantages. By systematically layering and ensuring the integrity and consistency of each layer, significant reductions in various energy loads can be achieved.[5]

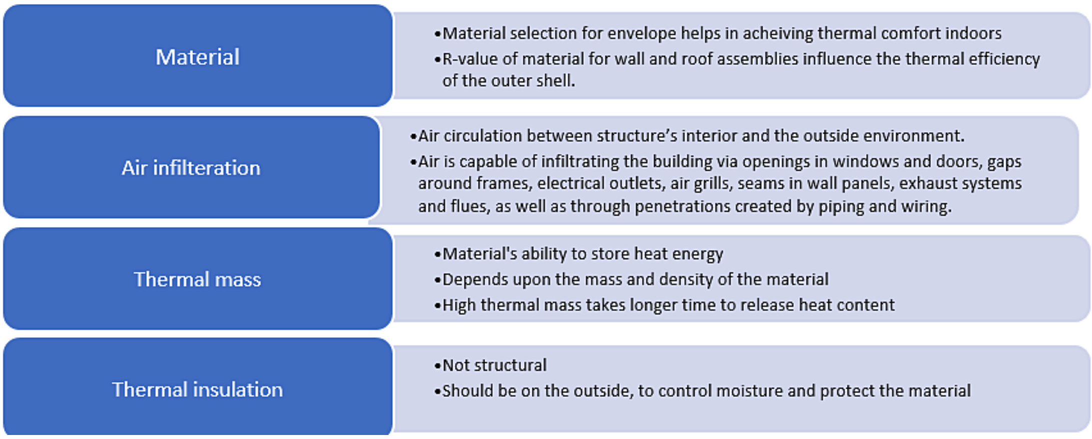
The main aspects of the shell that determine the performance of the structure are as follows

The attributes of a building's outer shell, including its shape and direction, the materials used, the quality of construction, and how it interacts with external conditions, influence the thermal influx permeating it, thereby affecting requirement of energy needed for regulating temperature of the space.

Table 3: Sustainable impacts from energy-efficient methods

Approach Method	Benefits	Environmental Benefits	Comment
Enhancement of building envelopes through the application of ECBC compliance methods for both the building envelope and roof design.	• Reduced energy usage • Manage the energy consumption of the building during the. design phase • Promote building planning and design that is responsive to climate considerations. • Predict the future energy demand for air conditioning. • Recommend methods for enhancing energy efficiency in structures by utilizing the ECBC compliance.	• Lowered greenhouse gas emissions. • Offers choices and promotes the use of energy-efficient, building -integrated systems.	It's more advantageous to enhance energy efficiency during the design phase instead of the occupancy phase.

Properties of outer wall within the structure’s shell



Energy Modeling Software for Sustainable Building Design

Energy simulation involves software-driven evaluative method enabling stackholders to assess structure's efficiency by implementing required design changes.[11]

Softwares used in Analysis

Ecotect

Ecotect is chosen for its visual and spatial thermal analysis capabilities. It allows for early-stage assessment of solar gains, daylighting, and thermal loads, making it ideal for comparing envelope materials and orientation impacts.

Strength

Easy integration with Autodesk tools and climate data files.

Use in this study

To understand surface heat gains, solar exposure, and daylight penetration.

eQUEST

eQUEST is selected for its detailed HVAC energy modeling and annual energy use simulation. It is widely used in industry for simulating cooling/heating loads, enabling performance comparison of retrofitted vs. baseline envelopes.

Strength

Allows precise energy use simulations for buildings.

Use in this Study

For assessing cooling load reductions and electricity consumption due to insulation and passive strategies.

Materials and Methods

This study employs a comparative, simulation-based approach to evaluate the energy performance of two building envelope types—traditional (laterite stone) and modern (RCC with clay brick infill)—in a selected resort in Matheran, Maharashtra.

Case Study Selection

A resort featuring both traditional and modern guestroom blocks was chosen to ensure a consistent climatic and functional context for comparison.

Data Collection was done through

- On-site surveys to document construction details, orientation, and material use.
- Staff interviews to understand appliance usage and energy behavior.
- Utility bills and meter readings across seasons to track energy use.
- Climatic data from reliable sources for temperature, humidity, and solar exposure.

Envelope Characterization

- Traditional envelope: Laterite stone load-bearing walls, Mangalore tile roofing, low insulation.
- Modern envelope: RCC frame with clay brick infill, flat slab roof, minimal insulation.

Thermal properties like U-value and thermal mass were derived from field data and standard databases.

Simulation Modelling- Energy Simulations were Conducted using Ecotect and eQuest, with

- Accurate input of Building parameters, dimensions, materials, and internal loads.
- Identical usage patterns for comparison.
- Focus on annual cooling loads.

Comparative Analysis- Simulation Results were Analyzed to

- Compare energy consumption and thermal comfort.
- Identify the more energy-efficient envelope in passive conditions.

Modern Envelope Optimization- The Modern Envelope was Enhanced using

- Insulation, shading devices, reflective roofing, natural ventilation, and efficient glazing.

Optimized models were simulated again to assess improvements.

Performance Evaluation- The upgraded Modern Envelope was Benchmarked Against

- Its original (unmodified) version.
- The traditional envelope baseline.

This validated the effectiveness of applied energy-saving strategies.

Overview of the Study Area

Matheran

This hill station lies between the Mumbai-Pune metropolitan corridor, nearly 65 kms from Mumbai in Raigad District, while Pune is situated about 125 km away. The Eco-sensitive area (ESA) of Matheran covers 214.73 sq. km of both the town and its surrounding regions. A significant portion—over 60%—of Matheran is designated as 'reserved forest'. Its geographical coordinates are 18.9866° North and 73.2679° East.

Fig. 5: Location of Matheran
Source – Google Maps

Matheran map
Source – Google Maps

Climatic Data

Owing to its elevated position, it experiences less temperature in winters than the nearby urban centers. Winter extends from November to February, during which the day temperature ranges between 28º C– 31ºC and the nighttime temperature can drop to about 12°C - 13°C. The annual rainfall is more than 3800 mm mainly from June – September. The summer months are very warm, and the temperature may rise upto 33ºC – 34ºC while the nighttime temperature can decrease to mid-twenties.

Locale of Study

Resort Woodlands

The Woodlands resort, the structure under investigation, is located within interiors of Matheran thus, it is open from all sides and surrounded by trees. It is interesting to study because of two different types of envelope designs and strategic location. A road that is 4.5 meters wide runs along the north-western edge of the plot. The establishment is a G+1 full-service resort featuring a restaurant, a party hall, a gaming area, and more than 33 guest rooms with configurations of 2, 3, and 4 beds, encompassing a total gross floor area of 1715 m. The primary structure was built in the late 1800s, while the other buildings were erected during the eighties. However, the resort received slight refurbishment approximately 15 years earlier that did not prioritize energy efficiency. Because the surrounding trees shade numerous regions, their proximity has both beneficial and negative consequences. On the one hand, they cause windbreaks by blocking favorable winds and preventing daylight from penetrating.

Orientation and Planning

Oriented diagonally along a NE-SW axis, the structure's long axis; that is, the NW as well as SE facades are larger than the NE and SW facades. The structure chosen for analysis is oriented in direction that TERI recommends.[12] It claims that in order to prevent solar heat gain, structures in tropical regions should be oriented with their longer axis running north-south.

While orienting the structure, the site's layout was taken into consideration rather than minimizing heat absorption from the sun on the eastern and western sides. Getting as many open areas in front of as many rooms as possible was the main consideration.

Building Shell (Envelope) of the Resort

Determining how much energy is needed for heating and cooling depends critically on the energy performance of the structure's shell I.e. facade comprising of walls, slabs, roofing system, fenestration and entry/exits.

Fig. 6 : The Woodlands resort in Matheran
Source – Author

Opaque Components

External Walls

The structure is constructed in two ways: the traditional one is an external wall of 350 mm thick Laterite stone, while the modern one is framed by RCC and composed of 230 mm burnt clay brick. The outside and interior walls are painted after they have been covered with cement plaster, which is 18 mm and 12 mm thick, on walls. Light yellow paint has been applied to some of the outside walls to brighten the façade. White or light exterior wall coatings can save 12% on cooling energy, according to Cheung *et al.* (2005).[13]

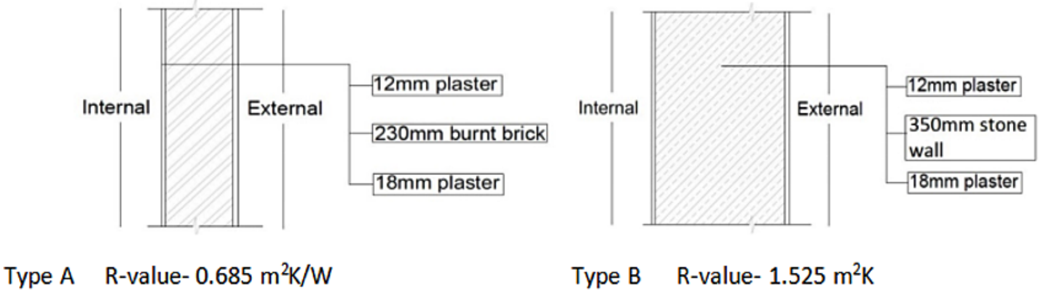


Fig. 7: Wall construction types
Source – Author

Roof

The roof of a modern framed structure is roughly 150 mm thick RCC with 50 mm brick bat as a water-proofing course and 20 mm PCC, whereas the traditional Laterite stone structure has a pitched roof with timber frames, steel sheets used for roofing, along with an attic space.

As the roof is exposed to the most solar radiation and is hard to protect with shading, it becomes a key element in a building's energy efficiency.

According to Vijay Kumar *et al.*, concrete roofs in single or two-story buildings in India, typically made with 150 mm thick reinforced cement concrete (RCC) and a waterproof layer of 75–100 mm thick lime brick mortar, contribute to around 50%-70% of the total heat entering the occupant zone. These roofs are primarily responsible for the high electricity costs in air-conditioned buildings.[14]

Natural Ventilation and Lighting through a Fenestration System

The NE and NW windows are too small and so are ineffective in letting natural light or ventilation. These units must therefore have their lights on for the majority of the day.

According to Handbook on Energy Conscious Buildings by J.K. Nayak and J.A. Prajapati, windows should be positioned diagonally opposite one another for adequate cross ventilation.[9] Nevertheless, there are two pairs of windows on the lateral walls of this building, but cross-ventilation is not possible in any of the guest rooms. Because none of the rooms in the structure are equipped with windows on opposite walls to enable cross-ventilation, answer may be to place two windows adjacent to each other on the same wall instead of a single window. as proposed by the same handbook. Another option, as suggested by the same book, is to feature two windows, one located at the sill and the other situated above the lintel. This proposal would expand the possibilities for fan-induced ventilation and stack ventilation.

Each guest room's ratio of window area to floor space (WFR) as calculated. Similarly, the ratio of window area to wall area(WWR) was calculated. Analysis revealed WWRs ranging from 0.13 to 0.26. Some guest rooms fell below Liping *et al.*'s (2007) recommended optimum of 0.24.[3] While others exceeded this (reaching 0.26), adequate light wasn't achieved due to southeast-facing tree obstructions.

Table 4: Guestrooms' ratio of window area to wall area (WWR) and window area to floor space (WFR)

Rooms	Orientation of Window	Area of room (in Sq.M.)	Area of Window (in Sq.M.)	Area of wall (in Sq.M.)	WFR (Window to floor ratio)	WWR (Window to wall Ratio)
Room 1 & 3	N-W	30.5	2.88	18.7	0.094	0.15
Room 2	N-W	30.5	4.32	18.9	0.14	0.22
Room 4	N-W	16	2.4	13.5	0.15	0.177
Room 5	N-E	37.7	1.8	13.5	0.047	0.133
Room 6	S-W	38	3.6	28.8	0.094	0.124
Room 7	S-E	32.5	0.6	12.3	0.018	0.048
Room 8	N-E	44	5.4	23.7	0.122	0.227
Room 9 & 10	S-E	25.6	3.6	13.5	0.14	0.266
Room 11 & 12						
Room 18 & 19	N-E	18	1.8	13.5	0.1	0.133
Room 13	S-E	29.5	3.6	13.5	0.12	0.266
Room 14	N-W	16.6	3.6	15.6	0.21	0.23
Room 15, 16 & 17	N-W	15.6	2.25	10.5	0.14	0.214
Room 20	N-E	20.9	3.6	14.7	0.17	0.24
Room 21 & 23	N-W	18	1.8	13.5	0.1	0.133
Room 22 & 24	S-E	18	1.8	13.5	0.1	0.133
Room 25 & 26	N-E	18	1.8	13.5	0.1	0.133
Room 27 & 29	N-W	19.5	1.8	10.8	0.09	0.166
Room 28 & 30	S-E	24.8	1.8	10.5	0.072	0.171
Room 31, 32&33	N-W	15.6	2.25	10.5	0.14	0.214

Since none of the windows in the remaining guest rooms reach the lintel level (2 meters) from the skirting, their WWRs are below the suggested value of 0.24 (between 0.13 and 0.23).

Summary

The case study resort building's key features are outlined in the table below, along with the references that were used to compare them.

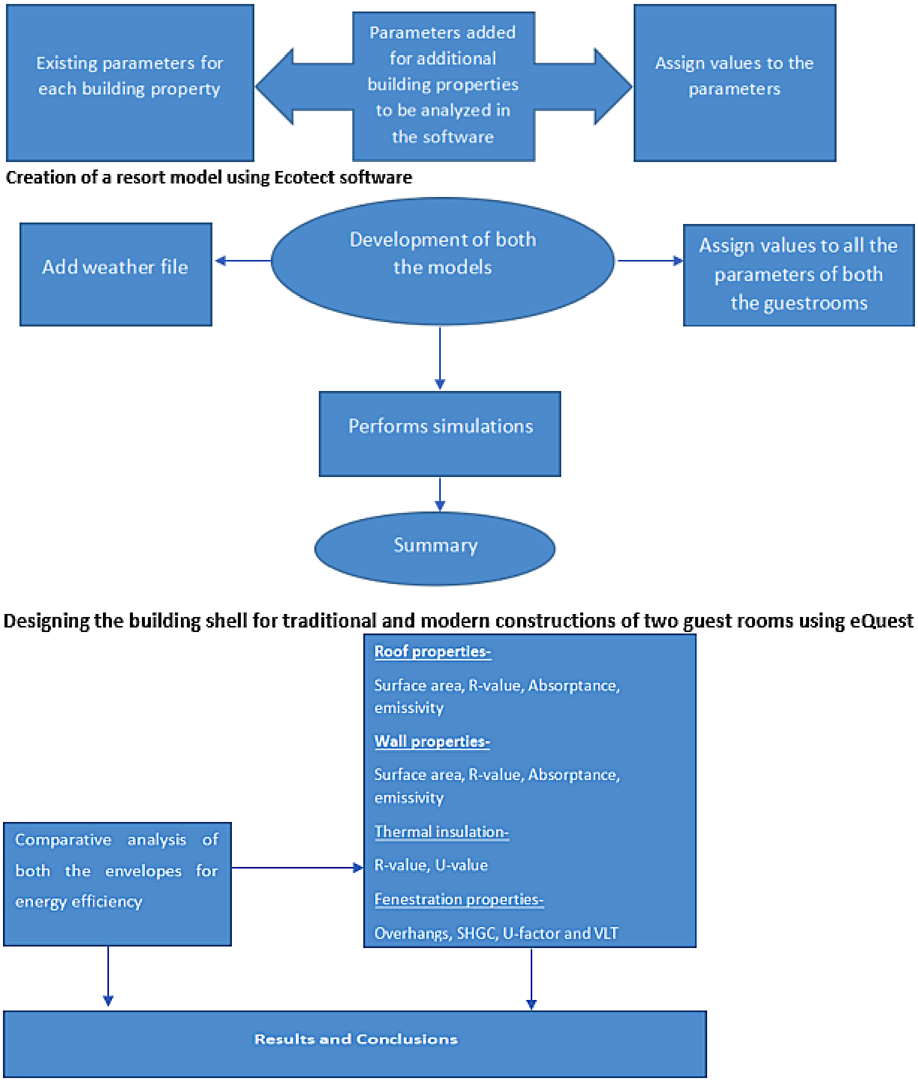
Table 5: An overview of the resort building case study

Characteristics (Building – resort Woodland)		**Source**
Location	Chinoy Road, Matheran, Maharashtra 410102	
Orientation	Oriented in 2070 N direction and the front faces North-West	TERI-Best orientation-longer axis north south
Conditioned floor area	792 sq.m.	
No. of floors	G + 1	
Building shape	‘U’ shape with one wing smaller	TERI- EPI of Circular building form is lowest
Height	15ft. old building, 10ft. new building (floor to ceiling)	TERI- less is better as it lessens the surface area to floor area ratio i.e. Area ratio
No.of rooms	33 rooms	
Other spaces	Reception area, dining area, party hall, toilets, gaming area, pantry, kitchen, storerooms, staff facility	
Surroundings	No building shades, tree shades, paver blocks surrounding the building (Reflectance-0.2)	Best is green grass surrounding the building (Reflectance- 0.26)
Construction		
Construction type	Main building- Load bearing	As per ECBC,
Exterior wall	Laterite stone wall 1 ½ “thick 18mm plaster on the exterior 12 mm plaster on the interior	U factor-0.261W/m2K R- value of insulation alone – 3.5 m2K/W
Roof	Low pitched roof with gable Corrugated M.S. sheets No shingles EPS insulation R-4 Gypsum false ceiling	
Interior Floors	Vitrified tiles	
Windows	Gross window area: evenly distributed throughout all rooms, accounting for 12% of the conditioned floor area (or 112 square meters). Window wall ratio-0.31-04, so VLT-0.2 Single pane window with 6mm frosted glass (U = 5.8 W/m2K, SHGC = 0.82 Wooden frames (U factor-2.8 W/m2K, frame conductance = 0.47, frame width = 60mm)	As per ECBC, vertical fenestration U-factor-3.3 W/m2K Maximum SHGC- 0.25
Doors	1mX2.1m (U value- U factor-2.8 W/m^2K)	
Exterior shading	No shading and overhangs on windows	

Construction type	New building-Framed structure with clay brick wall
Exterior wall	Clay Brick wall with 230 mm thickness
	Clay Brick internal walls with 150 mm thickness
	18mm exterior plaster
	12 mm interior plaster
Roof	R.C.C. flat roof – 150mm
	Water proofing course -50mm
Interior Floors	Vitrified tiles
	½" gypsum board ceiling

Methodology

The methodology used involved creating an Ecotect simulation model of the entire resort, simulating the environment of two guestrooms in eQuest aligned in the same direction, except differing component properties, and implementing energy-efficient measures to one envelope.



Determining which of the two Envelopes Provides the Highest level of Energy Efficiency

Development of Simulation Model

The values assigned to parameters for many aspects of the building, including its the form, placement, and elements of the building envelope were influenced by the materials available.

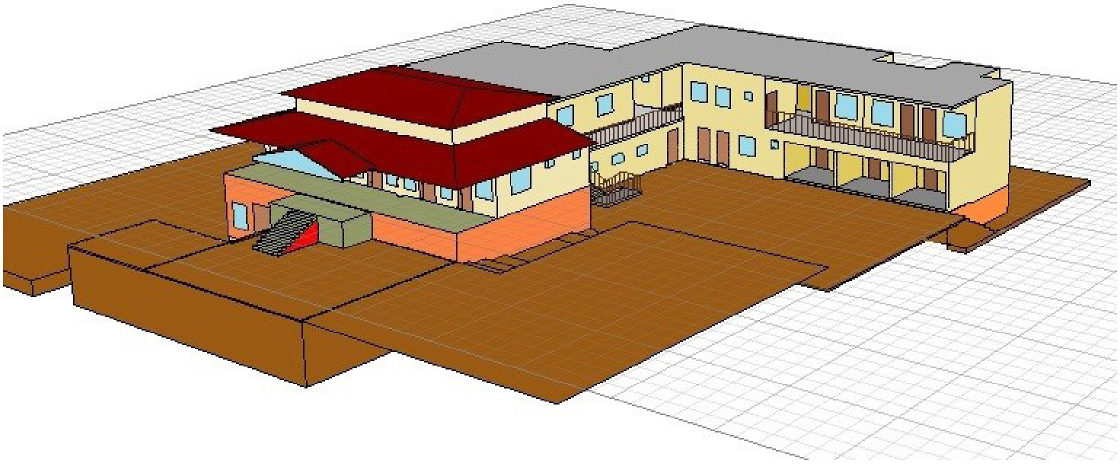


Fig. 8: Ecotect model of resort

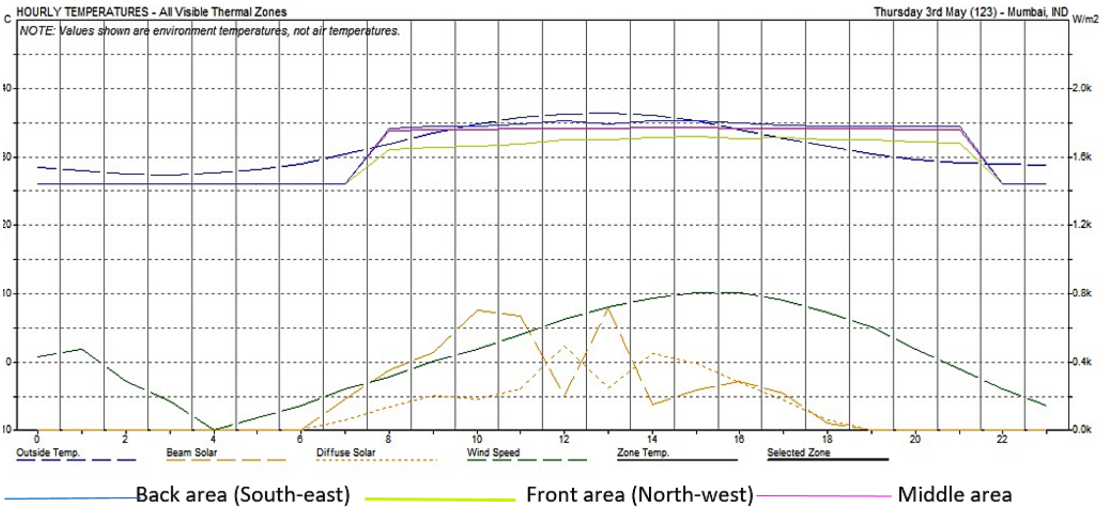


Fig. 9: Resort's hourly temperature profile

Source: Ecotect energy performance simulation tool

The resort was simulated for using Ecotect software, hourly thermal profiles, passive heat gains , and monthly heating and cooling degree days were analyzed.

Passive gains display the heat gains through all the factors, which aids in identifying which parameter to concentrate on in order to reduce the heat.[9]

The hourly temperature profile shows the interior temperature of each zone to identify the crucial time of day. The cooling need is determined by the monthly degree days.

Hottest Day Hourly Temperatures Profile

Hourly temperature graphs show the temperatures inside and outside of all the model's visible thermal zones during a 24-hour period.

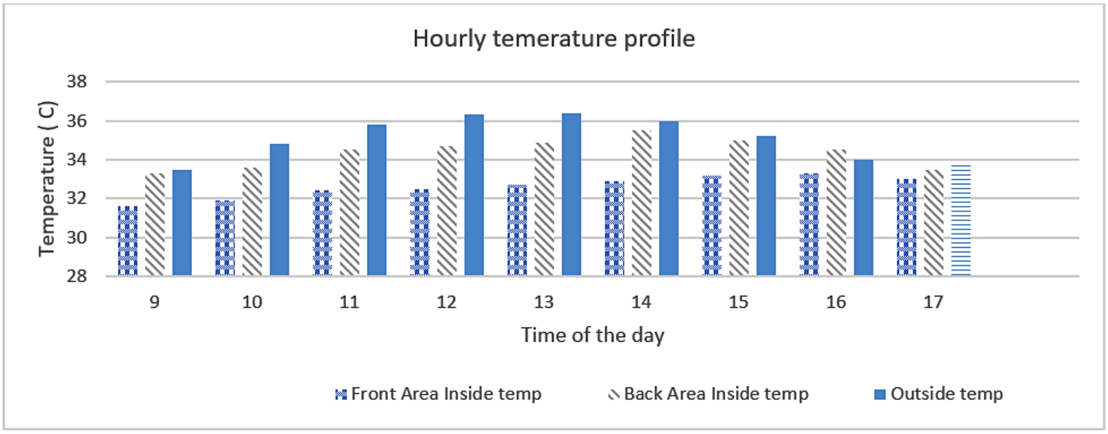


Fig. 10: Hourly temperature profile comparison bar chart
Source: Author

According to the bar charts below, the front zone's interior temperature stays lower than that of the back and middle zones.

Passive Gains Breakdown

The passive gains breakdown may be further reduced if thermal barrier is implemented, also the wall and roof parts are white washed, even if Sol-air or indirect heat gain is at its highest.

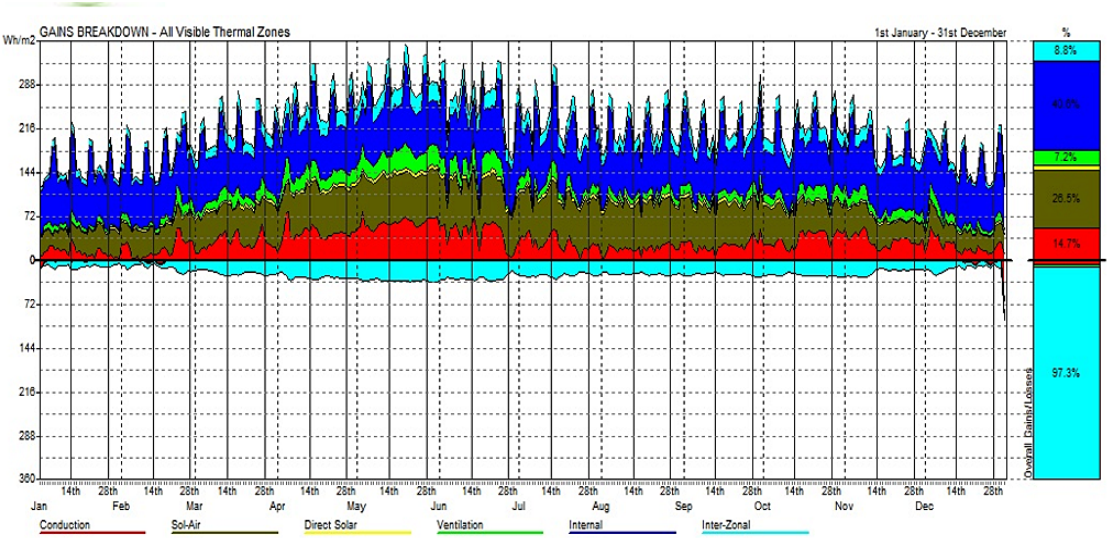


Fig. 11: Overall passive gains breakdown graph
Source: Ecotect energy performance simulation tool

Evaluation of the Two Envelopes for Energy Efficiency

To compare the energy efficiency of the two envelopes, two guestrooms were chosen: one with a 350 mm thick traditional load-bearing Laterite stone construction, and another modern RRC framed with a 230 mm clay brick wall that was same in area, form, orientation, and area of window. The energy-saving potential of the two guest rooms was assessed through simulations conducted in eQuest.

The building properties analysed are listed in the table below:

Table 6: List of building properties analyzed

Properties	Values used for traditional guestroom (Laterite stone wall)	Values used for modern guestroom (brick wall)
Building configuration	Single -storey, width to depth ratio of 1:2	Single -storey, width to depth ratio of 1:2
Roof and wall properties		
Absorptance	Roof- 64 (Red galvanized sheet) Wall-0.4 (Laterite stone)	Roof-0.7 (R.C.C. slab) Wall-0.4 (Red clay bricks)
Emissivity	Roof-0.88 (Red galvanized sheet) Wall-0.7 (Laterite stone1:2 width to depth ratio, one-story)	Roof-0.54 (R.C.C. slab) Wall-0.7 (Red clay bricks)
Insulation	**Roof-R-value-4.68 m^2.K/W** Air film outside-R-0.06 Al sheets-R-value-0.14 Wooden floor – R-0.6 Expanded polystyrene-R- 3.75 Air layer inside-R- 0.13 **Wall-R-value-1.52 m^2.K/W (Laterite stone)** Air film outside-R-0.06 18mm outside plaster-R-0.025 380mm laterite stone wall-R-1.28 12mm inside plaster-R-0.02 Air layer inside-R-0.14	**Roof-0.424 (R.C.C. slab)** Air film outside-R-0.06 20 mm PCC-R- 0.03 50mm Brick bat – R – 0.08 150mm RCC slab-R-0.104 12mm inside plaster-R-0.02 Inside ceiling air layer-R-0.13 **Wall-R-0.685 m^2.K/W (Red clay bricks)** Air film outside-R-0.06 18mm outside plaster-R-0.025 230mm clay brick wall-R-0.44 10mm inside plaster-R-0.02 Air layer inside-R-0.14
Construction Type	Load bearing construction with 380mm thick laterite stone wall and wooden frames with Al commercial sheets with 20mm expanded polystyrene under the board insulation	R.C.C. framed structure with 230mm clay brick wall and 150mm thick slab with brick bat and PCC
Fenestration (Openings)		
Distribution of Windows	Windows (12% of floor area), only on the front side (North-west)	Windows (12% of floor area), distributed in two orientations (North-east & South-east)
Exterior shading	Verandah projection acts as shading	No overhangs
Glazing U-factor	1.09 (6mm frosted glass)	1.09 (6mm frosted glass)
Glazing SHGC	0.72(6mm frosted glass)	0.72(6mm frosted glass)

Different values were assigned to the respective parameters in order to analyze the effect of changing attributes of various construction assemblies and elements. The three building assemblies and elements are (i) layout, (ii) the walls as well as roof, and (iii) the windows. The impact of thermal mass on specific measures was also examined by plotting the hourly temperature variation, heat gains and losses per hour, monthly energy demands and discomfort levels and fabric-derived heat gains.[5]

Roof and Wall Properties

Heat gain or loss via the building envelope is determined by the exposed surfaces' emissivity, absorptance, and R-value. Because of the difference in the angle of incident solar radiation, the roof and walls contribute to varying amounts of thermal influx. Therefore, the impact of R-value, absorptance, and emissivity was analyzed for both the roof and the walls.[13]

Table 7: Properties of the walls and roof assumed for simulation.

Properties of roof/wall	Old Traditional building		New modern building		As per ECBC	
	Wall	Roof	Wall	Roof	Wall	Roof
Solar reflectivity	0.6	0.36	0.6	0.3	>0.7	>0.7
Surface emissivity	0.7	0.88	0.7	0.54	>0.75	>0.75
Absorptance	0.4	0.64	0.4	0.7	0	0
Insulation (Resistance R-value)	1.525 m^2.K/W	4.68 m^2.K/W	0.685 m^2.K/W	0.42 m^2.K/W	2.1 m^2.K/W	3.5 m^2.K/W

Fenestration (Openings) Properties

The U-factor, SHGC, shading and window distribution in various orientations all affect how much heat is gained or lost via windows. Two-layer, low-emissivity, triple-glazed windows are associated with lower U-factor values, while the building’s existing single-pane glazing, is related with greater values. In a similar way, high SHGC values are linked to clear glazing, while lower values are linked to tinted or reflective glazing. The fenestration characteristics of modern and traditional envelopes are similar.[5]

Table 8: Window characteristics for modeling

Fenestration Properties	Old Traditional building	New modern building	As per ECBC, WWR≤40%
U-value	1.09 W/m^2.K	1.09 W/m^2.K	3. 3W/m^2.K
SHGC	0.72	0.72	0.25

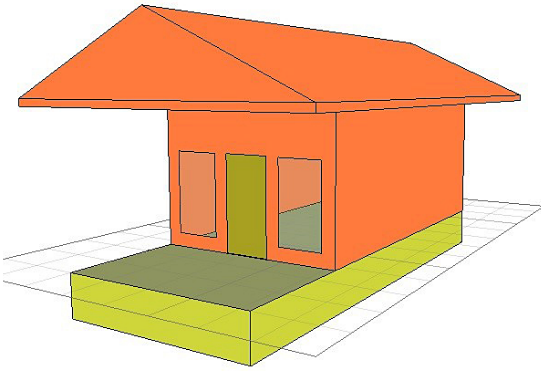
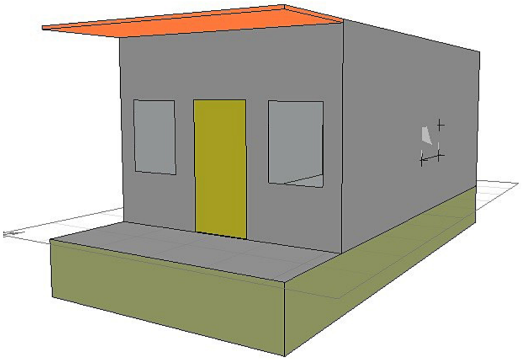
Comparative of Two Envelopes

Study is done on both guest rooms to determine the most energy-efficient envelope derived from the assessment of energy-saving opportunities in various elements like the walls, roof, and window features.

Result

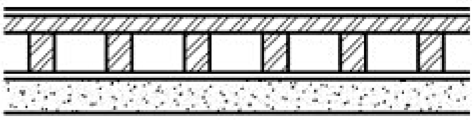
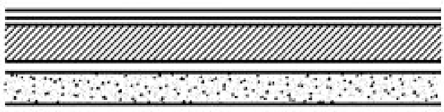
This investigation aims to assess and compare the energy efficiency of two distinct guestroom: a traditional guestroom with a Laterite stone structure and a modern guestroom with an RCC (Reinforced Cement Concrete) structure. The analysis's main goal is to evaluate each design's thermal performance and energy efficiency. Simulations were carried out using Ecotect and eQuest to analyze the thermal behavior of both building types under typical climatic conditions. The results highlight the influence of different materials, insulation strategies, and building configurations on overall energy consumption for cooling.[8]

Table 9: Chart Comparing the Two Envelopes

TRADITIONAL BUILDING	MODERN BUILDING
	

General Characteristics

Roof configuration and material composition

TRADITIONAL BUILDING	MODERN BUILDING
	
Wooden floor, 1/2" plywood, metal corrugated sheet, and expanded polystrene, R=4.68 m^2.K/W	20 mm PCC + Brickbat coba 50 mm (average thickness) + 150 mm RCC slab + plaster of 12 mm thickness, R = 0.424 m^2.K/W

Composition	Thermal resistance coefficient R-value (m^2.K/W)
Air Film (Outside)	0.06
Corrugated metal sheet	0.14
Wooden flooring	0.6
Insulation-Expanded polystrene	3.75
Air film (Inside)	0.13

The Energy Conservation Building Code (ECBC) specifies an R-value of 3.5 m²·K/W for roof assemblies

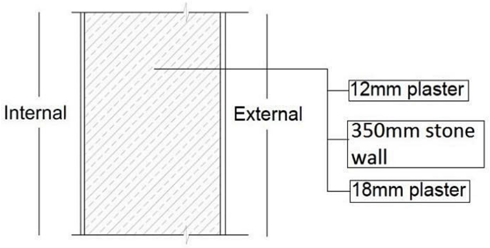
Composition	Thermal resistance coefficient R-value (m2.K/W)
Air Film (Outside)	0.06
20mm PCC	0.03
50mm brick bat	0.08
RCC slab of 150 mm thickness	0.104
Plaster- 12 mm thickness	0.02
Air film (Inside)	0.13

The Energy Conservation Building Code (ECBC) specifies an R-value of 3.5 m²·K/W for roof assemblies

Wall configuration and material composition

TRADITIONAL BUILDING	MODERN BUILDING
A wall composed of 18 mm internal plaster, 350 mm thick stone masonry, and 12 mm	This assembly includes 18 mm of internal plaster, a 230 mm clay brick layer, and 12 mm of external

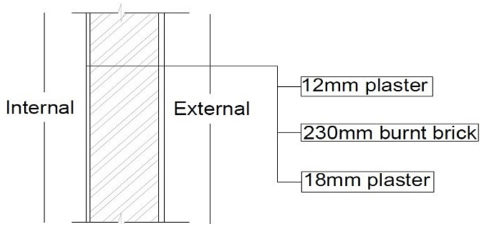
external plaster offers a thermal resistance (R-value) of 1.525 $m^2 \cdot K/W$.



Composition	Resistance R-value ($m^2.K/W$)
Air Film (Outside)	0.06
18mm cement plaster	0.025
380mm stone wall	1.28
12mm cement plaster	0.02
Air film (Inside)	0.14

The Energy Conservation Building Code (ECBC) specifies an R-value of 3.5 $m^2 \cdot K/W$ for roof assemblies

plaster, achieving an R-value of 0.685 $m^2 \cdot K/W$.



Composition	Resistance R-value ($m^2.K/W$)
Air Film (Outside)	0.06
18mm cement plaster	0.025
230mm clay brick wall	0.44
12mm cement plaster	0.02
Air film (Inside)	0.14

The Energy Conservation Building Code (ECBC) specifies an R-value of 3.5 $m^2 \cdot K/W$ for roof assemblies

The substantial thickness of the stone wall acts as thermal mass, helping to further lower heat transfer.

Solar reflectivity of the wall and the roof

Terracotta-colored aluminium sheet on the roof has a solar reflectivity of 0.36, whereas the wall's solar reflectivity is 0.6. The ECBC recommends a solar reflectivity of >0.7 for the roof.

Cement plaster's (PCC) solar reflectance is between 0.2 and 0.3.
The wall's solar reflectivity is 0.6, while the ECBC advises that the roof's solar reflectivity be greater than 0.7.

Emissivity of the wall and the roof

Terracotta colored aluminum sheet has an emissivity of 0.88.
The emissivity of the wall = 0.7
ECBC recommended emissivity for roof= >0.75

Cement plaster's (PCC) emissivity is 0.54.
The wall's emissivity is 0.7.
ECBC recommended emissivity for roof= >0.75

Wall and the roof solar absorptance

Solar absorptance is influenced by the color of the surface.
Solar absorptance=1- Solar reflectivity

Roof	= 1-0.36 = 0.64
Wall	= 0.4

The ECBC suggested a solar absorptance of zero.

Solar absorptance is influenced by the color of the surface.
Solar absorptance= 1- Solar reflectivity

Roof	= 1-0.30 = 0.70
Wall	= 0.4

The ECBC suggested a solar absorptance of zero.

Fenestration properties (Openings)	
Thermal transmittance (U- value)	
The thermal transmittance of the window, which includes single-pane frosted glass and a wooden frame, is 1.09 W/m²·K. ECBC specifies a U-value of 3.3 W/m²·K as a standard.	The thermal transmittance of the window, which includes single-pane frosted glass and a wooden frame, is 1.09 W/m²·K. ECBC specifies a U-value of 3.3 W/m²·K as a standard.
SHGC (Solar Heat Gain Co-efficient)	
The solar heat gain coefficient measures 0.72, and the ECBC suggests that the SHGC be 0.25.	The solar heat gain coefficient measures 0.72, and the ECBC suggests that the SHGC be 0.25.

As discussed, simulations were performed on the existing traditional and modern guestrooms. The results are analysed in the following sections. The thermal analysis was done in Ecotect and eQuest. In general, the traditional guestroom which is made up of 350mm thick Laterite stone has R-value of 1.52m^2 k/W and has higher thermal mass as compared to the 230mm thick clay brick wall. Also, though the roof is corrugated aluminum sheet, but the traditional guest room has an attic as well as roof insulation of 1" EPS. Thus, it resulted in significant savings.

The modern guestroom is an RCC building with an uninsulated clay brick wall that is 230 mm thick. The roof is also RCC without insulation, thus even though with same building configuration, orientation, shape, size, the energy saving is less. The graph below, which corresponds to the May month, which is hottest, showed the modern guestroom's cooling energy consumption 1.21 times greater than that of the traditional guestroom during highest temperatures.

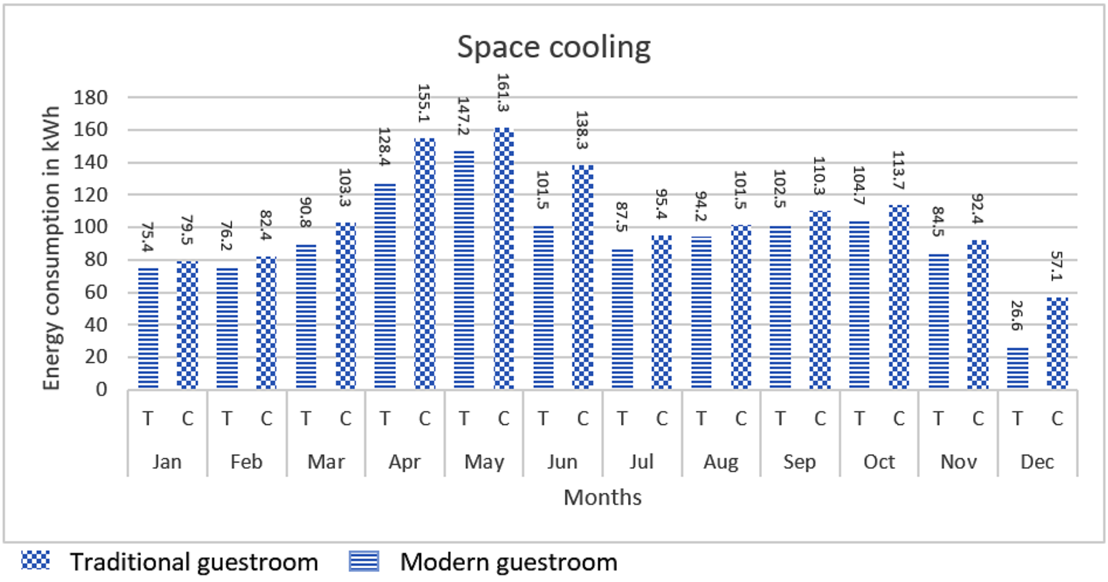


Fig. 12: Monthly space cooling energy consumption by end-use

The energy needed to cool the similar space in a modern guest room is 1288kW, whereas energy needed for space cooling in a traditional guestroom is 1109kW for a year. Therefore, 15% more energy is needed for the modern envelope than for the traditional one.

Thermal Analysis In Ecotect

This facilitates the comparison of the two envelopes by assessing the hourly temperature variation, hourly heat gains and losses, and the breakdown of passive heat gains.

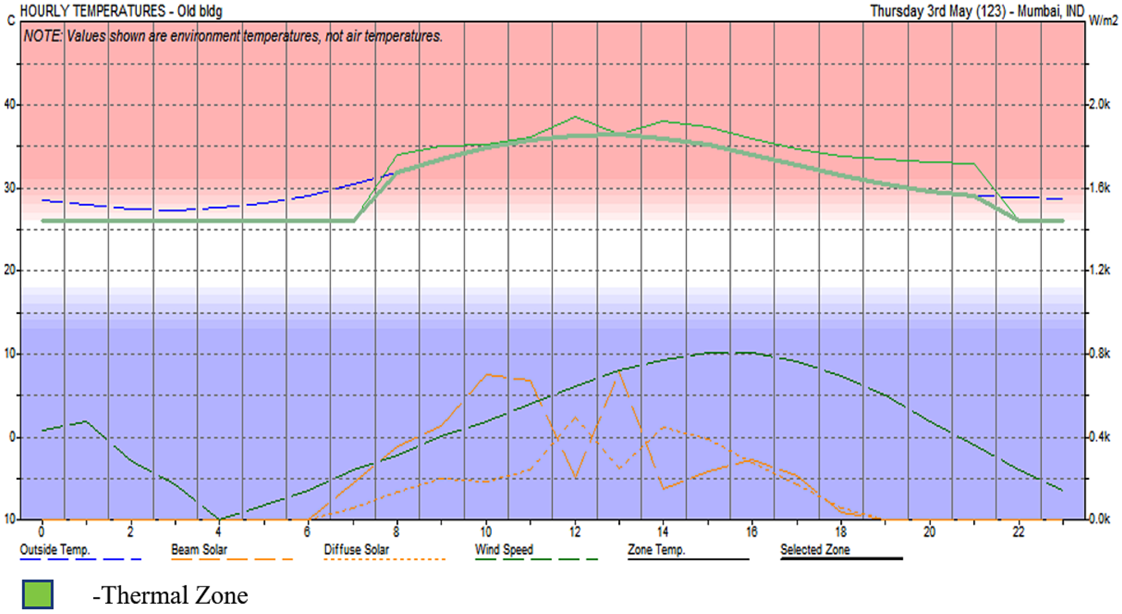


Fig. 13: Traditional envelope's Hourly temperature profile

Source:Ecotect energy performance simulation tool

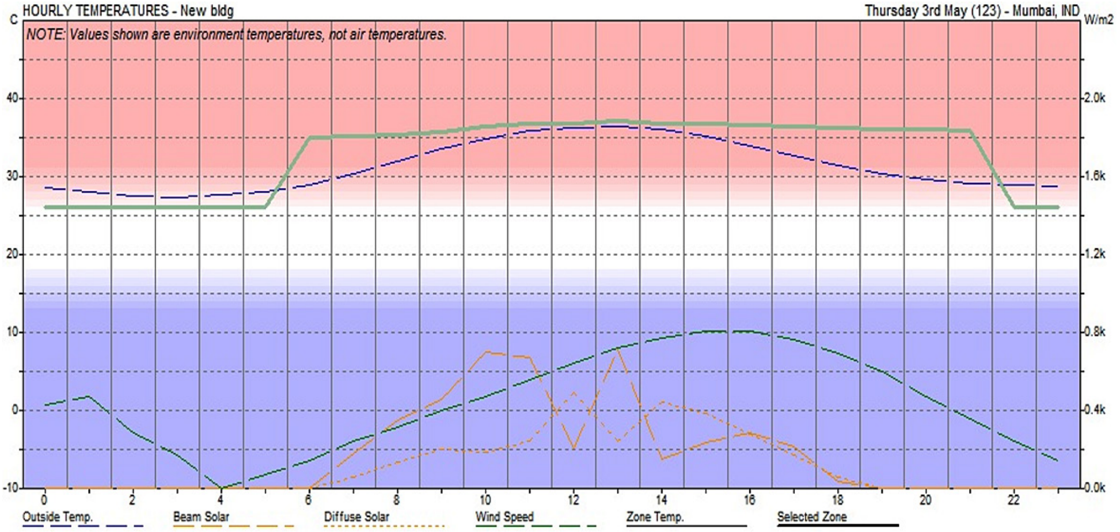


Fig. 14: Hourly temperature profile of modern envelope

Source:Ecotect energy performance simulation tool

Hourly Temperature Profile For Average Hottest Day

The hourly thermal profiles of the modern and traditional envelopes reveal that, from 6 a.m. to 9 p.m., traditional guestroom's typically colder than its modern counterpart. Consequently, compared to modern guestrooms, the traditional guestroom remains approximately 5% cooler.

In contrast to the modern structure shell with 230mm thick clay brick wall of R-value- 0.685 m2k/W, traditional structure shell with 350mm thick Laterite stone wall has a higher thermal mass, which accounts for the temperature differential. In addition, the roof assembly's R-value is 4.68 m2k/W higher than the modern one's, which is 0.424 m2k/W. In contrast to the modern envelope's roof finished with PCC, traditional envelope's aluminium sheet roof has a higher reflectivity. Additionally, a traditional roof has a higher emissivity than a modern one. All of this aids in keeping the old envelope's temperature higher than the modern one.

Table 10: Comparison of the two guestrooms' hourly temperature profiles Source: :Ecotect energy performance simulation tool

Traditional guestroom				**Modern guestroom**			
Hourly temperature profile							
Hourly Temperatures - One Day In May				**Hourly Temperatures - One Day In May**			
Hour (C)	**Indoor (C)**	**Outdoor (C)**	**Temp.dif (C)**	**Hour (C)**	**Indoor (C)**	**Outdoor (C)**	**Temp.dif (C)**
00	26.0	28.5	-2.5	00	6.0	28.5	-2.5
01	26.0	28.0	-2.0	01	26.0	28.0	-2.0
02	26.0	27.5	-1.5	02	26.0	27.5	-1.5
03	26.0	27.3	-1.3	03	26.0	27.3	-1.3
04	26.0	27.6	-1.6	04	26.0	27.6	-1.6
05	26.0	28.1	-2.1	05	26.0	28.1	-2.1
06	26.0	29.0	-3.0	06	35.0	29.0	6.0
07	26.0	30.4	-4.4	07	35.1	30.4	4.7
08	33.9	31.9	2.0	08	35.4	31.9	3.5
09	35.0	33.5	1.5	09	35.8	33.5	2.3
10	35.3	34.8	0.5	10	36.4	34.8	1.6
11	36.1	35.8	0.3	11	36.7	35.8	0.9
12	36.2	36.3	2.2	12	36.7	36.3	0.4
13	36.5	36.4	0.1	13	37.1	36.4	0.7
14	36.6	36.0	2.1	14	36.8	36.0	0.8
15	36.4	35.2	2.2	15	36.8	35.2	1.6
16	36.0	34.0	2.0	16	36.7	34.0	2.7
17	34.7	32.7	2.0	17	36.4	32.7	3.7
18	33.8	31.5	2.3	18	36.2	31.5	4.7
19	33.4	30.4	3.0	19	36.1	30.4	5.7
20	33.2	29.6	3.6	20	36.1	29.6	6.5
21	33.0	29.1	3.9	21	35.9	29.1	6.8
22	26.0	28.9	-2.9	22	26.0	28.9	-2.9
23	26.0	28.8	-2.8	23	26.0	28.8	-2.8

Hourly heat transfer data indicates that the fabric gain in the modern envelope is often more significant than in the traditional one. This increase occurs greater from 7 a.m. to 6 p.m. The substantial thermal mass of the walls combined with the EPS insulation in the ceiling cause the traditional guestroom to gradually increase in temperature.

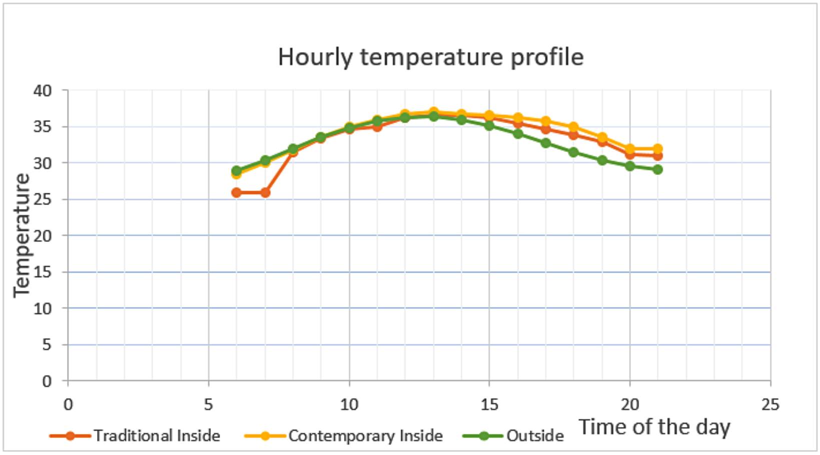


Fig. 15: Comparison of the two guestrooms' hourly temperature profiles
Source: :Ecotect energy performance simulation tool

Table 11: Breakdown of passive heat gains for both envelope types.

Traditional Guestroom			**Modern Guestroom**		
Passive gains breakdown					
FROM: 1st January to 31st December			**FROM: 1st January to 31st December**		
CATEGORY	**LOSSES**	**GAINS**	**CATEGORY**	**LOSSES**	**GAINS**
FABRIC	4.4%	6.1%	FABRIC	2.2%	13.8%
SOL-AIR	0.0%	8.4%	SOL-AIR	0.0%	20.1%
SOLAR	0.0%	6.7%	SOLAR	0.0%	2.5%
VENTILATION	5.0%	7.5%	VENTILATION	0.8%	6.2%
INTERNAL	0.0%	70.1%	INTERNAL	0.0%	51.5%
INTER-ZONAL	90.6%	1.3%	INTER-ZONAL	96.9%	5.9%

But in modern guestrooms the slope of fabric gains is steep after 7am due to lack of insulation on wall as well as roof.

Discussion

The analysis of the simulations points to the traditional guestroom being more energy efficient than the modern one. Compared to modern construction, the traditional construction in Laterite stone resulted in 17% energy savings due to its wall's thermal mass and insulation in the roof.

"The lower cooling demand in the traditional guestroom is attributed to the high thermal mass of Laterite stone and effective roof insulation. These findings align with Givoni (1998), who emphasized the role of thermal mass in passive cooling. The lack of insulation in the modern envelope significantly increases heat gains, indicating a need for retrofit strategies.[10] Additional research results in a more energy-efficient envelope for the modern guestroom by altering its fenestration, wall, and roof R-values as well as its emissivity and absorptance properties.

Retrofitting Modern Guestroom

In one-storey building, the heat absorption and dissipation from the walls and roof account for larger percentage of the building energy use. As a result, upgrading the walls and roof may also save energy.

Therefore, the most effective way to enhance the energy efficiency of the modern guestroom is by adding insulation, with placing it above the deck being more effective than below, as it prevents heat from entering the structure.

Application of Green Roof

The following factors are taken into account when choosing a green roof for the current modern guestroom retrofit

- Energy consumption in buildings.
- biodiversity and habitat.
- roof life.
- air quality; and
- the decrease of storm water flow
- Aesthetics and recreation

Table 12: Thermal parameters of green roof

Insulation	Thickness (m)	Thermal conductivity(k)	R-value (m^2.k/W)
Layer of Gravel drainage	0.06	0. 27	0.24
Total assembly	0.1		2.15
Polyisocyanurate Insulation	0.05	0.02	2.13
RCC roof	0.175	1	0.42
Total	0.425	1.29	5.6

Insulating surfaces with high absorptance and low emissivity is a more efficient way to save energy. Therefore, green roof insulation seems to be the optimal choice.[2]

Wall Insulation

Since EIFS (External Insulation and Finish System) is over the deck insulation and reduces heat entry into the building structure itself, it was employed for simulation purposes for wall insulation. The following factors were taken into account before choosing EIFS.[7]

- Insulation used over the deck
- Water resistant.
- Sustainable (Eco-certified)
- Offers better energy efficiency than insulation placed beneath the board.

The specifications of EIFS is as follows

Table 13: Thermal parameters of EIFS

Material	R value
230 mm clay brick wall	0.68
EIFS	4
Total	4.68

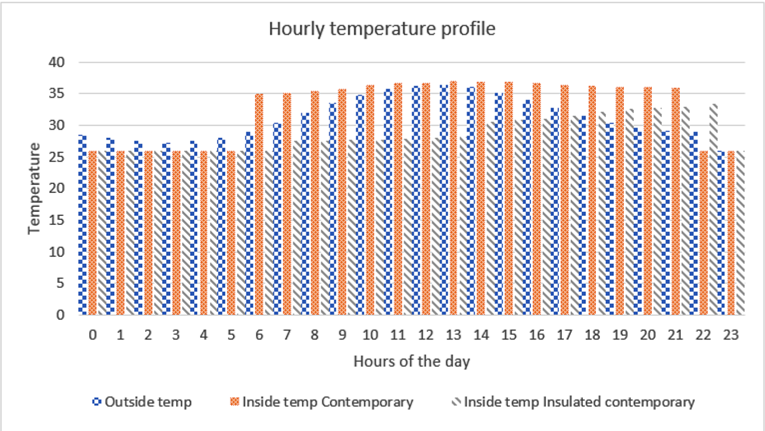


Fig. 16: Hourly thermal profile comparative between modern and insulated modern envelopes

Aforementioned chart shows how the hourly temperature profile in the insulated modern envelope differs from the regular, due to the application of insulation on the roof and wall. The hourly temperature profile of the shell (envelope) is 12% lower than its counterpart as a result of this insulation. Additionally, although the daily temperature on average outside is 31.3°C, or 8% lower than the outside temperature, the average temperature inside drops from 32.8°C to 28°C.

Thus, it is seen in thermal analysis that the insulated modern envelope responses much better than the modern envelope and is a better option to be utilized in Matheran which will help reduce the cooling costs and because of green roof, it will help in maintaining the ecology of the area.

The traditional guestroom performed better in terms of energy efficiency, requiring 15% less energy for cooling than the modern guestroom. This was due to the traditional guestroom's higher thermal mass (350mm Laterite stone) and roof insulation. The modern guestroom, with 230mm brick walls and no insulation, had higher cooling energy usage.

Thermal analysis showed that the traditional guest-room maintained cooler temperatures through-out the day, especially due to its higher R-value walls and better roof insulation. The modern guestroom gained more heat due to lack of insulation.

Retrofitting the modern guestroom with EIFS wall insulation and a green roof significantly improved its energy performance, reducing cooling needs and internal temperatures, making it more energy-efficient and environmentally friendly.

Conclusion

The comparative evaluation aimed to determine the more effective building envelope between traditional and modern guestrooms while optimizing the energy efficiency of the contemporary design for Matheran's warm and humid climate. The results indicated that the traditional load-bearing guestroom constructed with Laterite stone outperformed the RCC and clay brick modern structure in terms of reducing peak cooling demands. This traditional model achieved approximately 17% energy savings due to the thermal inertia of its walls combined with roof insulation. Key elements for minimizing energy consumption associated with cooling include enhanced R-values, greater surface reflectivity, and high emissivity in roofing materials. The traditional envelope, in comparison, demonstrated a 65% reduction in fabric heat gains.

Given that current construction practices typically employ RCC and brick systems, the study extended its focus to improving the modern guestroom. Since Matheran is protected under eco-sensitive regulations that prohibit new construction, the approach involved enhancing the existing structure through over-deck insulation rather than under-deck alternatives or rebuilding entirely. The use of green roofing in combination with an EIFS (External Insulation and Finish System) comprising polyisocyanurate insulation for the roof and EPS panels for the walls led to a 10% improvement in the hourly indoor temperature profile compared to the uninsulated version. When insulation was applied to both the walls and roof of the modern guestroom, a 22% decline in fabric heat gains was observed, significantly aiding in the reduction of cooling energy requirements. Consequently, the cooling load for the insulated contemporary room dropped by 20%, which translated into a 24% decrease in yearly electricity consumption. Altogether, the implementation of these energy-efficient strategies has the potential to yield energy savings of up to 55%

Technical Recommendations for Industry and R&D

- Roof insulation enhancement can be done with the use of polyisocyanurate insulation boards (higher R-value) for better thermal resistance and increase roof reflectance using cool roofing materials (white or high-albedo coatings). Future research should explore alternative eco-friendly insulation materials that provide high thermal resistance while being locally sourced and sustainable.
- Wall insulation and envelope design can be enhance by applying EIFS with EPS or mineral wool to minimize heat gain and consider ventilated facades to improve heat dissipation.
- Passive cooling strategies can be integrated through green roofs and shading elements to lower indoor temperatures and utilize high-performance glazing for better thermal control. Further research can be on development of

climate-responsive building envelopes that incorporate passive cooling techniques like ventilated facades, and shading devices can further enhance energy efficiency.

- Energy monitoring and smart systems can be implemented through real-time IoT-based energy monitoring for efficient cooling load management.
- Encouraging government incentives for adopting energy-efficient retrofitting solutions in eco-sensitive zones like Matheran can accelerate the transition towards sustainable hospitality architecture

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Conflict of Interest
The author does not have any conflict of interest.

Data Availability Statement
The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions
The sole author was responsible for the conceptualization, methodology, data collection, analysis, writing, and final approval of the manuscript.

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