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Thermal comfort and daylight assessment of vernacular house in Amaravati, Andhra Pradesh

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Vernacular architecture, deeply rooted in local traditions, reflects the socio-cultural and climatic influences of its region. However, modernization and structural modifications have led to changes in indoor thermal conditions and daylighting. This study evaluates thermal comfort and daylight performance in a traditional vernacular house in Amaravati, Andhra Pradesh, emphasizing the role of passive design strategies in enhancing indoor environmental quality (IEQ). Using Design Builder software, this study assesses the impact of passive cooling techniques and daylight optimization in a heritage dwelling. The results indicate a 20% improvement in thermal comfort due to passive strategies, but a 25% reduction in natural lighting due to structural modifications. This highlights the need for context-specific retrofitting strategies that balance thermal and visual comfort while preserving the architectural integrity of heritage structures. This is the first study to quantitatively assess passive techniques for improving IEQ in vernacular houses of Amaravati, contributing to sustainable design and heritage conservation.

Keywords: Adaptive retrofitting, Adaptive reuse, Indoor environmental quality (IEQ), Natural lighting levels, Socio-cultural and Socio-economic influences, Thermal comfort, Vernacular architecture

IPC Code: Int Cl.[25]: E04C 1/00, E0H 5/00, E04H 15/14

The term "vernacular architecture" denotes architectural styles that are deeply rooted in tradition and indigenous practices. It emphasizes the notion that such architecture is intrinsically tied to its geographic location and the culture of its people. Vernacular architecture refers to regionally influenced architectural styles that have evolved through generations, responding to local climate, available materials, and cultural practices[1]. It is not just about preserving traditional methods but understanding how passive design strategies can be adapted for contemporary needs. Vernacular architecture comprises homes and structures constructed using traditional technologies that harmonize with the local environment and available resources[2]. While architects play a crucial role in design, a substantial proportion of homes in India continue to be crafted by their owners, resource-sharing communities, or regional artisans and builders. Many homes in India are still built by homeowners, local artisans, and communities, showcasing indigenous building techniques[2]. These structures are designed with climate-responsive strategies, naturally enhancing thermal comfort and day lighting.

Ebrahimian *et al.*[1] explored innovative construction materials and techniques rooted in vernacular architecture across various regions. Their study underscored the significance of conserving and adapting traditional practices—such as rammed earth and bamboo-for integration into modern building systems. Abdelmoneim *et al.*[3] evaluated the thermal efficiency of traditional building envelopes in Egypt, specifically comparing materials like mud brick, adobe, and limestone. The findings revealed that mud brick offers superior thermal performance, whereas limestone is the least efficient. The research advocates for the preservation of traditional construction methods and materials due to their environmental and performance advantages. Mgbemene *et al.*[2] analyzed passive solar design strategies inherent in traditional rural architecture in Pakistan. Their research demonstrated that how elements like building orientation, shading devices, and natural ventilation are effectively employed in these layouts to enhance solar gain and sustain indoor thermal comfort.

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Studies have demonstrated that passive techniques in heritage buildings significantly improved indoor environmental quality. A case study conducted in the Amaravati Region of Andhra Pradesh revealed that incorporating solar passive design elements, such as courtyards, shaded verandas, and strategic ventilation, enhances energy efficiency and occupant comfort[4]. Additionally, transformations in vernacular dwellings have been influenced by socio-economic changes, including shifts from joint to nuclear families, property subdivisions, and structural deterioration over time.

A key strategy for preserving heritage structures while improving their functionality is adaptive reuse—retrofitting existing buildings to meet contemporary needs rather than demolishing them[5]. However, this process poses challenges, particularly in maintaining thermal comfort and day lighting while adapting spaces to evolving user needs.

This study explores the impact of retrofitting a traditional dwelling in the Amaravati Region, where a second-generation home extension has altered its architectural form. By analyzing the design principles and passive strategies of vernacular dwellings, this research aims to identify effective methods to enhance thermal comfort and natural lighting in heritage buildings. The findings will contribute to sustainable conservation practices, ensuring that architectural heritage remains functional while reducing energy consumption and environmental impact.

Methodology

This research focuses on the impact of adaptive retrofitting on thermal comfort and natural lighting in a traditional residence in Amaravati, Andhra Pradesh. The selected dwelling, over 80 years old, was chosen based on architectural authenticity and historical significance. The research involves comprehensive documentation, including architectural drawings, photographs, and historical records, to analyze the building's planning, design, and spatial configuration.

The assessment includes monitoring indoor environmental parameters such as temperature, humidity, and lighting levels, providing insights into the interplay between traditional elements, retrofitting, and modern comfort standards.

To evaluate thermal comfort, indoor temperature, humidity, and lighting levels were monitored. The Fanger Comfort Analysis Method[9] in Design Builder software was used to assess thermal performance, while daylight analysis for indoor lighting levels was conducted using Revit Insight Lighting Simulation. These simulations helped quantify the effectiveness of passive design strategies within the retrofitted structure. The study also investigates how retrofitting by the second generation has altered the building's environmental performance. Data collection included on-site measurements and software-based simulations, ensuring an objective assessment of the dwelling's thermal and daylighting efficiency.

Documentation of sample dwelling

Understanding the context

Situated in a warm and humid climate, as outlined in the Energy Conservation Building Code (ECBC) of 2007, this region encounters temperatures ranging from 17°C to 28°C in winter and escalating to 34°C to 42°C during the summer months. Annual rainfall, averaging around 90 cm, plays a pivotal role in the climatic dynamics.

The village nestled adjacent to the Krishna River, benefits from a distinctive microclimate, shaping its architectural response. The primary pathways run perpendicular to the river, while secondary and main streets adopt a parallel orientation. This deliberate settlement morphology results in an array of East-West oriented streets and sub-streets, strategically navigating the climatic nuances. Noteworthy is the prevalence of row housing, a design choice that emerges as a direct response to the prevailing climate. Detailed site location is found in Figure 1-3.

The arrangement ensures that the built form primarily receives direct sunlight on its shorter side,

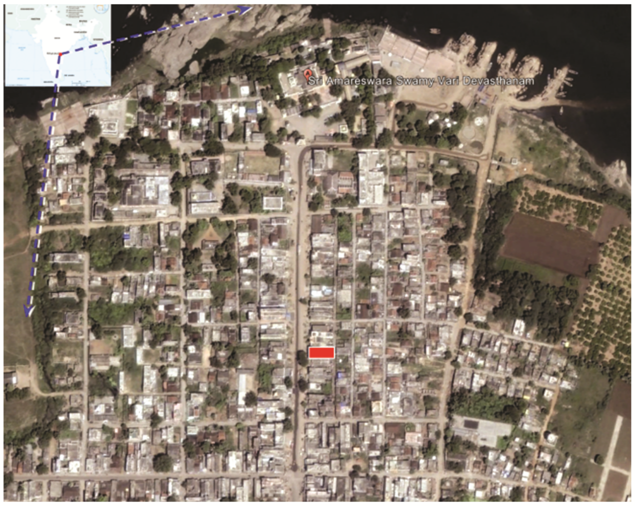

Fig. 1 — The location of Amravati, India, (Source: Google maps)

Fig. 2 — Front elevation of the selected sample

Fig. 3 — Site plan of the selected sample house, India, (Source: Google maps)

mitigating heat gain and fostering a more thermally comfortable environment. This thoughtful alignment of urban planning with climatic conditions demonstrates a nuanced approach to architecture, where form seamlessly integrates with function to optimize comfort and livability in this warm and humid context.

This ancient village possesses outstanding qualities and diversity, encompassing geographical, linguistic, religious, and social-cultural facets. The chosen sample for study represents a nuanced exploration of vernacular architecture in this context, aiming to recognize and understand the relevance of generic sustainability concepts. As Amaravati undergoes transformation into the envisioned capital, the study delves into the city's dynamic narrative, where ancient heritage converges with contemporary aspirations. Through this exploration, the research seeks to bridge the historical and modern identity of Amaravati, contributing to the understanding of sustainability in the context of its rich and multifaceted heritage.

Description of the selected sample

The selected dwelling is an 80-year-old ancestral property that holds immense historical and sentimental value. Over the years, it has undergone changes resulting in three distinct sections, each with its unique character and purpose. This west-facing house is thoughtfully oriented along the East-West axis.

The dwelling spans 9 meters in width and 17 meters in length, with a plinth height of 300 mm, reflecting the architectural norms of its time. A notable feature is its advantageous positioning, with a wide road at the front and a smaller road at the rear, creating a seamless connection to an open backyard accessible from the kitchen.

One of the intriguing aspects of this property is the emphasis on privacy. The majority of the private spaces are thoughtfully located on the first floor, ensuring a sense of seclusion and tranquility for the occupants. This layout not only caters to the functional needs of the household but also preserves the heritage and legacy of this cherished ancestral home.

Typology

The architectural typology under examination dates back to 1930, boasting a remarkable 88-year history. Initially conceived as a unified residential structure, it underwent subsequent segmentation to accommodate evolving requirements as shown in Figure 4-7. The building now comprises four distinct sections, a transformation that, unfortunately, poses challenges to its original design intent, particularly in terms of cross-ventilation.

Originally conceptualized for singular occupancy, the residence presently functions as a divided entity. The ground floor accommodates the owners, ensuring their proximity to the building's core functions. Meanwhile, the upper two segments have been repurposed for rental purposes, serving as a pragmatic revenue-generating strategy. While this adaptive reuse aligns with contemporary needs and economic considerations, the division of the building introduces complications in terms of airflow and natural ventilation.

This study delves into the aftermath of this architectural evolution, examining how the division into four parts has influenced not only the spatial dynamics but also the environmental aspects of the structure. By dissecting the layers of this historical metamorphosis,

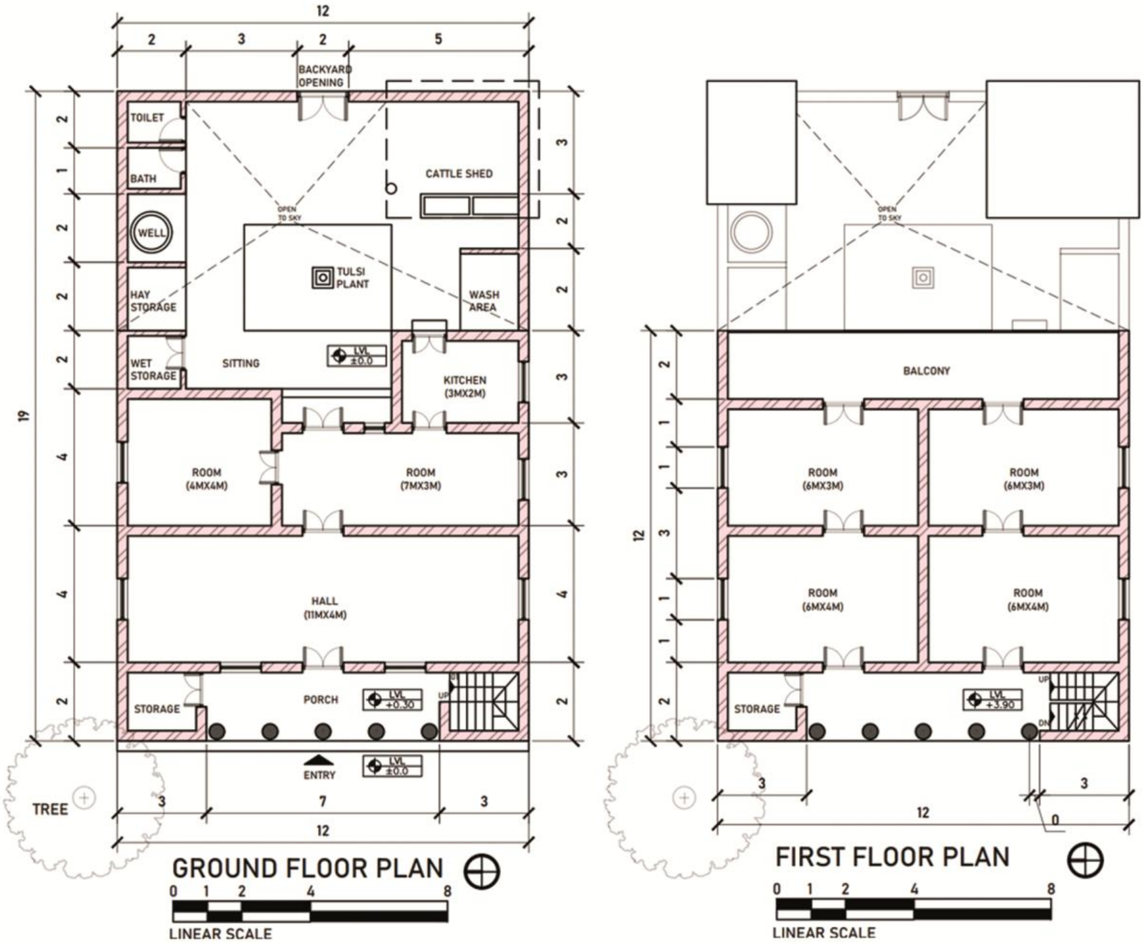

Fig.4 — First generation floor plans of the selected sample

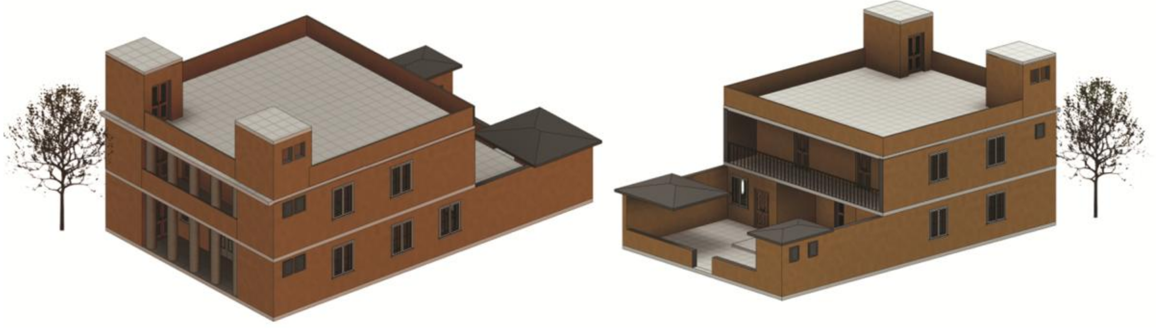

Fig.5 — Rear-side view of first transformation of original form of building used for simulation, generated using revit software

the research seeks to unravel the implications for cross-ventilation, contributing insights that blend architectural history with practical considerations for sustainable and habitable living spaces.

Building components

The residence under study has load-bearing burnt clay brick walls. The roof is composed of mud and wooden beams as primary and secondary beams. The internal and external walls are of the same thickness and are plastered with lime mortar. A portion of the roof is made of a wooden framework and is covered with terracotta tiles. The roof's east and west sides are projected to lessen the direct sun contact. The total number of windows is three out of which two are blocked and are being used as cupboards, thus disrupting the cross ventilation.

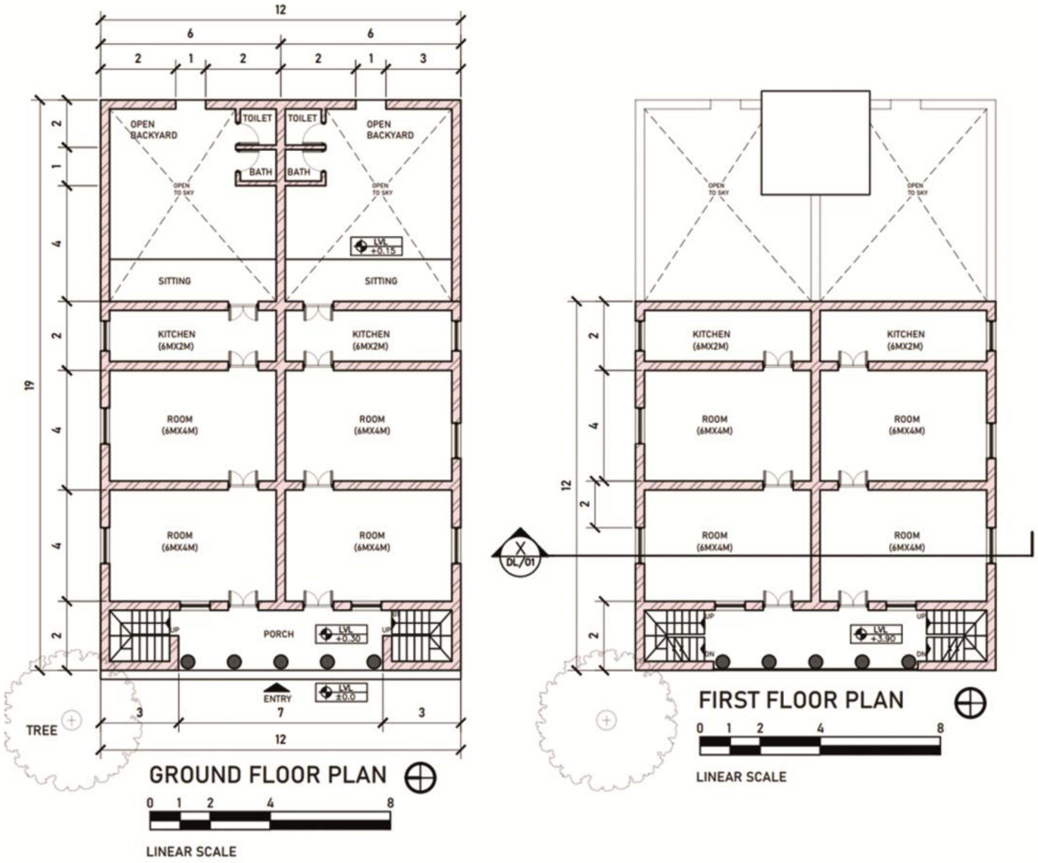

Fig.6 — second generation altered floor plans of the selected sample

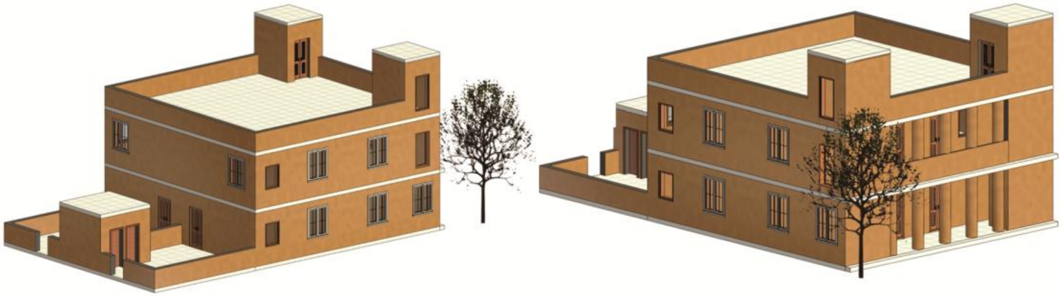

Fig.7 — Rear-side view of first transformation of original form of building used for simulation, generated using revit software

In building performance analysis, building components refer to the individual elements that make up the structure of a building, such as external walls, internal partitions, roofs, windows, and doors. Each of these components plays a critical role in determining the overall thermal behavior of a structure. The Quantity column typically describes the physical dimensions, thickness, or configuration of the component-for instance, a 350 mm thick external wall or a window measuring 900 mm x 1200 mm-which are essential inputs in thermal simulation software. The U-value, expressed in W/m²·K, measures the rate of heat transfer through a building component; it represents how well a material conducts heat. Lower U-values indicate better insulation and reduced heat loss, which is vital for energy-efficient building design. For example, a flat roof with a reflective paint coating having a U-value of 1.52 W/m²·K performs better thermally than a wall with a U-value of 1.87 W/m²·K. Understanding these parameters is essential for evaluating and enhancing the thermal comfort and energy performance of buildings[7,8], especially in warm and humid climates where passive strategies are crucial.

Analysis

The residence under study was built in 1930 and like most of the houses at the time this residence was also designed with solar passive heating and cooling techniques using vernacular techniques. Thick walls for thermal insulation and cross ventilation were provided to accommodate the warm humid climate. Planning, orientation, and building materials all influence how effectively the solar passive strategies work. The traditional design principles identified in the case study are discussed below.

Passive techniques & their changes over time

Traditional residences utilized various passive techniques to enhance thermal comfort and natural lighting. For thermal comfort, key strategies included courtyards, high ceilings, shaded verandas, cross-ventilation, and breathable materials like lime plaster and clay tiles. These elements helped regulate indoor temperatures by promoting airflow and reducing heat buildup. For natural lighting, features such as large windows, skylights, and open floor plans ensured sufficient daylight penetration, minimizing the need for artificial lighting.

Over time, these passive strategies have been compromised due to modern modifications. Courtyards have been reduced or enclosed, limiting natural ventilation and increasing indoor temperatures. Lower ceilings have replaced high ceilings, restricting air circulation and causing heat stagnation. Similarly, verandas, which provided shaded outdoor spaces, have been altered or removed, leading to higher indoor heat gain.

In terms of natural lighting, the size and placement of windows have changed, reducing daylight autonomy and increasing reliance on artificial lighting. Skylights, once crucial for even light distribution, have been reduced or eliminated. Additionally, traditional materials with high thermal mass have been replaced with modern cement-based materials, which retain heat and contribute to higher indoor temperatures.

These changes highlight a shift away from climate-responsive design, increasing energy consumption for cooling and lighting. To restore passive benefits, modern designs should reintegrate courtyards, optimize window placement, and use ventilated facades and reflective materials for improved thermal comfort and daylighting.

Thermal comfort analysis - Fanger comfort analysis

The research focuses on a residence situated in a warm and humid climatic context, and to assess thermal comfort, a meticulous analysis was conducted using the fanger comfort analysis method. Given the absence of meteorological data specific to the study area, climatic data from Vijayawada, in close proximity, was utilized. The study reveals that, depending on activity levels, the perception of thermal comfort is closely related to specific ranges of skin temperature and sweat evaporation rate. He created a set of correlations that provided the PMV as a function of six variables-air temperature, mean radiant temperature, air velocity, air humidity, clothing resistance, and activity level-by fusing this data with the previously mentioned thermal energy balance equations.

The thermal comfort analysis range was derived through simulations and is visually represented in Figure 8a & 8b). Thermal analysis is differentiated between first-generation and second-generation houses to discern thermal comfort levels before and after transformations. Individual rooms are treated as distinct zones to comprehensively evaluate their thermal performance throughout the year. The simulation, executed in Design Builder software over an entire year (365 days), captures the nuances of thermal behavior, contributing to a nuanced understanding of the dwelling's thermal dynamics pre- and post-transformation. The input parameters for the simulations are detailed in Table 1, providing a comprehensive foundation for the thermal analysis framework.

Based on the arrived results of the simulations and the observations made, we can say that 50% of the year indoor spaces were thermally comfortable in the first generation plans when taken on a yearly scale, as observed in the Figure 8a. Mainly in the months of march- october which were summer and rainy seasons, the indoor comfort has deteriorated due to the presence of high radiation and humidity whereas in the second generation plans, around 75% of the year the indoor spaces were thermally comfortable.

Table 1 — Parameters considered for the thermal comfort and lighting analysis

S. no	Building component	Quantity	U-value
1.	External wall	350 mm Thick	1.87 w/m^2.°k
2.	Internal wall	350 mm Thick	1.87 w/m^2.°k
3.	flat roof with reflective paint coating	200 mm Effective thickness	1.52 w/m^2.°k
4.	Windows with no insulation	900 mm x 1200 mm	N/A
5.	Doors	1200 mm x 2100 mm	N/A

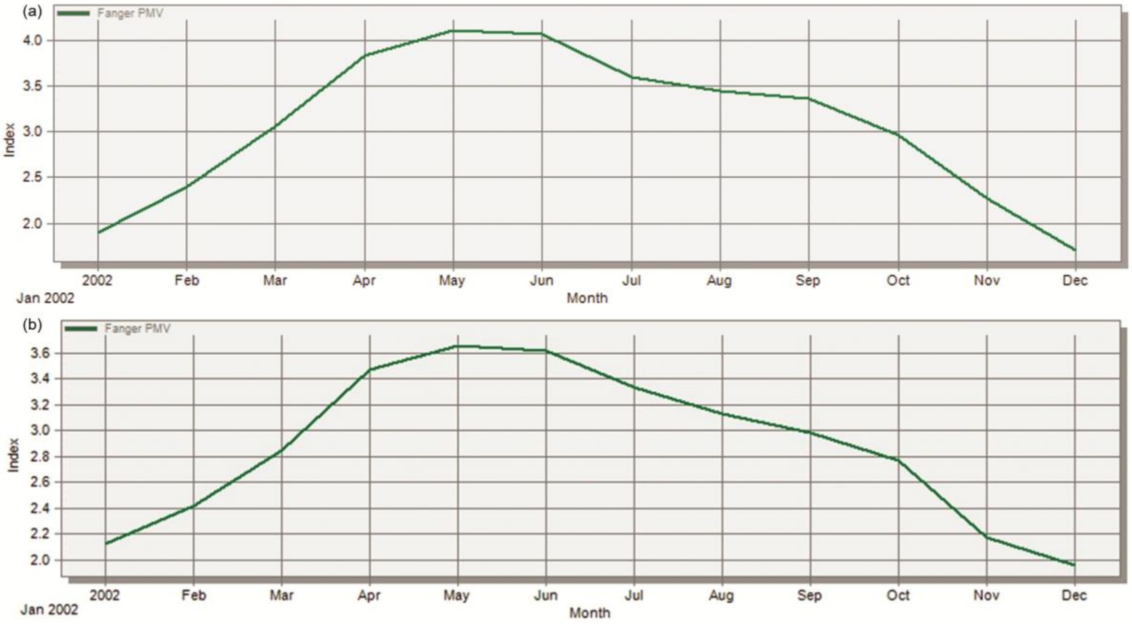

Fig. 8 — Analysis of the thermal comfort of the (a) first generation house, (b) second generation house for the whole year of 365 days, calculated using Design builder software

Daylight analysis

We’ve conducted a daylight analysis for indoor lighting levels, along with a lighting simulation using Revit Insight. The daylight simulation covers the entire year, spanning all 365 days. We’ve determined that the external daylight levels reach up to 8700 Lux, as specified by the Energy Conservation Building Code (2007)[10] in India. To assess daylight autonomy, we’ve focused on the enclosed spaces of the house, considering factors that impact how much natural light is available. Daylight autonomy (DA) is a measure of how often daylight can meet the required lighting levels in a space throughout the day[11]. For this analysis, we've accounted for all openings, including windows, doors, skylights, and courtyards, based on the current conditions of the building.

Based on the arrived results of the simulations and the observations made, we can say that 70% of indoor floor space received natural lighting in the first generation plans when taken on a yearly scale, as observed in the (Fig. 9a). Where as in the second generation plans, only 45% of indoor floor spaces received natural lighting when taken on a yearly scale.

Results

The thermal comfort analysis, conducted using fanger comfort analysis in DesignBuilder, evaluates the indoor climate of a traditional residence in Amaravati under first-generation and second-generation modifications. Since meteorological data for the study site was unavailable, climatic data from Vijayawada was used as a reference. The analysis considers key variables such as air temperature, mean radiant temperature, humidity, air velocity, clothing resistance, and activity level, helping to determine the Predicted Mean Vote (PMV)[12] values for different spaces in the house.

The findings reveal that in first-generation plans, 50% of the year was thermally comfortable, particularly in winter months. However, during the summer and monsoon seasons (March-October), indoor thermal comfort deteriorated due to high solar radiation and humidity levels. The second-generation modifications improved indoor thermal conditions, with 75% of the year falling within thermally comfortable ranges. This improvement is attributed to changes in material use, ventilation strategies, and spatial modifications introduced by the second generation. Figure 8a & Figure 8b visually depict the thermal comfort analysis across both generations, confirming the effectiveness of adaptive retrofitting strategies in enhancing indoor climate conditions.

The daylight analysis, performed using revit insight lighting simulation, assesses natural light penetration in indoor spaces. The daylight autonomy metric was used to determine the percentage of time when indoor illuminance levels met the required threshold of 8700 Lux, as per India’s Energy Conservation Building

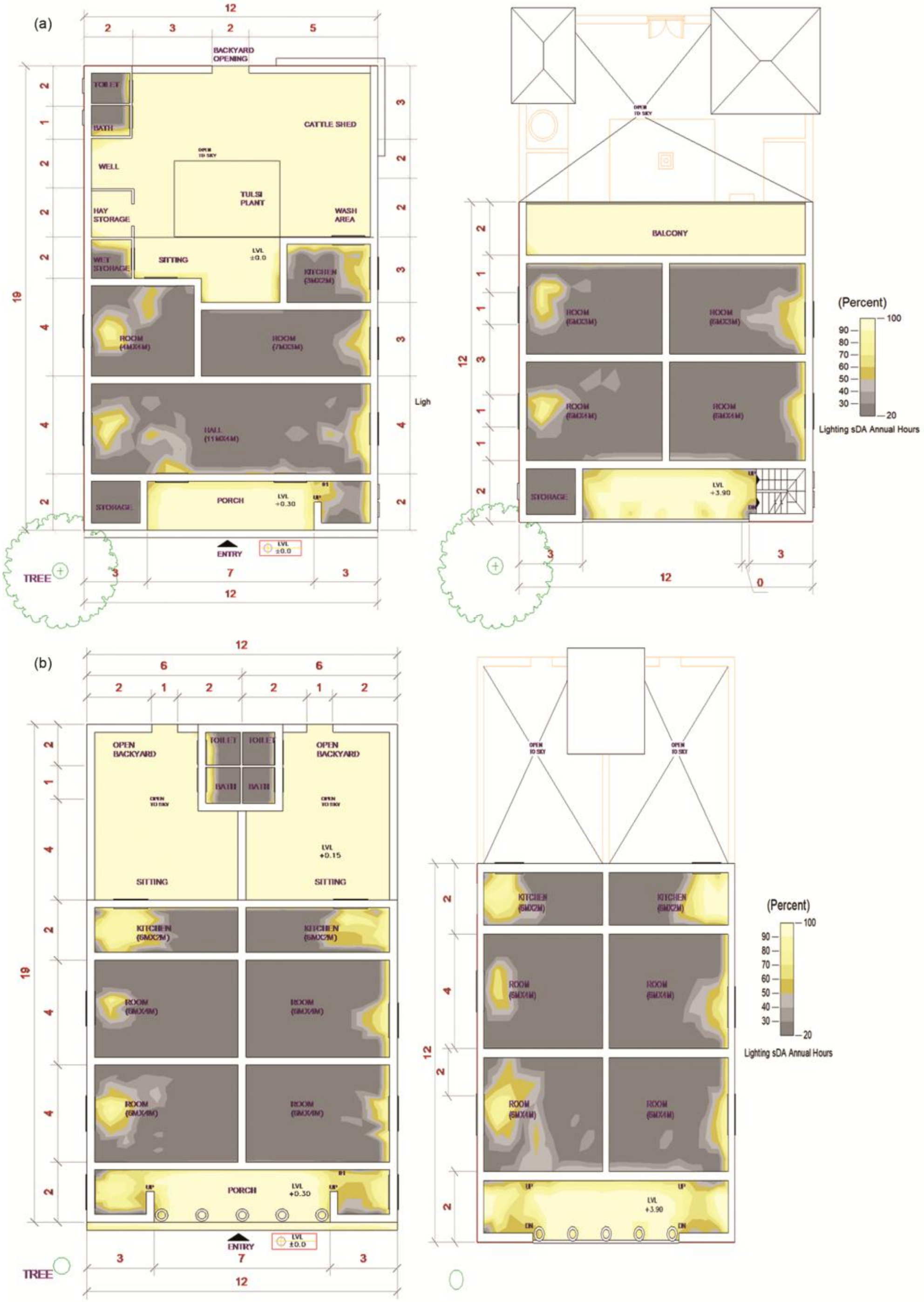

Fig. 9 — Analysis of the Day-light autonomy of (a) first generation house, (b) second generation house for the whole year of 365 days, calculated using revit software, Insight simulation tool

Code (ECBC)[6]. In the first-generation house, 70% of the floor area received sufficient daylight throughout the year. However, in the second-generation house, only 45% of the indoor floor area achieved the same level of daylight autonomy. Figure 9a & 9b illustrate these variations, highlighting the reduction in daylight penetration due to changes in spatial organization and retrofitting interventions.

Overall, the thermal comfort levels improved significantly in the second-generation house, while natural daylight availability decreased. These results underscore the trade-offs between thermal comfort enhancements and daylighting efficiency, emphasizing the need for balanced retrofitting strategies that optimize both parameters.

Discussion

The findings indicate that adaptive retrofitting significantly enhances thermal comfort in traditional residences while impacting daylighting performance. The increase in thermal comfort from 50% to 75% of the year suggests that material modifications, passive ventilation techniques, and spatial alterations played a crucial role in regulating indoor temperatures and humidity levels. These strategies can be incorporated into contemporary building designs, particularly in warm and humid climates, to enhance energy efficiency without excessive reliance on mechanical cooling systems.

However, the reduction in daylight autonomy in the second-generation house suggests that modifications such as reducing open courtyards, altering window placements, or adding shading devices may have unintentionally restricted natural light penetration. To address this, future retrofitting efforts should integrate skylights, light shelves, and reflective materials to restore daylight efficiency while maintaining thermal comfort.

Furthermore, the findings emphasize the importance of preserving traditional architectural elements that inherently support passive cooling and natural lighting strategies. Modern buildings can benefit from vernacular design principles, incorporating features such as large shaded verandas, high ceilings, and strategic cross-ventilation to enhance thermal and visual comfort sustainably.

By striking a balance between heritage conservation and modern thermal efficiency, architects can develop sustainable retrofitting frameworks that improve energy performance while retaining cultural and historical value. Future research could explore hybrid approaches, combining traditional techniques with innovative materials and smart building technologies, to further optimize both thermal comfort and daylight performance.

Conclusion

This research has thoroughly explored the repercussions of retrofitting a second-generation home on the Indoor Environmental Quality (IEQ) of an 80-year-old heritage dwelling. Simultaneously, it scrutinizes the potential advantages of integrating passive design strategies to enhance the structure's overall sustainability. The insights generated from this study contribute significantly to the ongoing discourse on optimizing thermal comfort and natural lighting in heritage buildings, with a specific focus on the distinctive context of the Amaravati Region.

There's a notable improvement in thermal comfort, with an increase of up to 20% after the adaptive transformation by the second generation. However, this improvement comes at a cost, with natural lighting levels indoors dropping by 25%. These results highlight the delicate balance needed when implementing retrofitting strategies. They emphasize the importance of taking a thoughtful, context-specific approach to heritage preservation and sustainable design in architectural interventions.

Acknowledgments

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Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

KC - Conceptualisation, methodology, data collection and analysis, writing & editing. KKM & DS - Guidance, supervision, data analysis and content validation.

Ethical Approval

The research was conducted in accordance with ethical research standards. Informed consent was obtained from the residents prior to all measurements, surveys, and interactions. The participants were made aware of the purpose of the study, and their privacy, comfort, and confidentiality were respected throughout the research process. No personal or identifiable information has been disclosed in the publication.

Data Availability

The data supporting the findings of this study- were collected through on-site measurements, surveys, and interactions with the residents. Due to privacy concerns and the confidentiality agreed upon with the participants, the raw data are not publicly available. However, summarized or anonymized data may be made available by the authors upon reasonable request.

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