Examining the Influence of Climatological Parameters on Building Cluster Geometry and Design Features in a Rural Indian Context: The Case of Sugganahalli Village (India)

Jeswin Varghese – Nitte Institute of Architecture, India – jeswin.21uar008@student.nitte.edu.in
Andrea Magdalene Pais – Nitte Institute of Architecture, India – andrea.21uar002@student.nitte.edu.in
Suchi Priyadarshani – Indian Institute of Science, India – suchip@iisc.ac.in
Monto Mani – Indian Institute of Science, India – monto@iisc.ac.in

Abstract

Nature has been fundamental in influencing the design of traditional habitations across the globe. Climatological factors such as wind directions, sun path, precipitation, etc., play a vital role in the design of buildings for occupants and community comfort keeping the local lifestyles into account. This research aims to explore the impact of climatological parameters (solar geometry and wind patterns) on the design of vernacular settlements. This study particularly looks into orientation of streets and building units, materials, and building features. The study is based on real-time on-site fieldwork complemented with computational models.

1. Introduction and Motivation

Sugganahalli village is located approximately 100 kilometers from Bengaluru (India) and consists of varying building typologies, involving vernacular (predominantly timber and stone with earth-based plaster), conventional (Fired clay bricks and cement mortar plaster), and mixed/transitioning building types. Architectural features present in the vernacular typologies respond to the existing climate and social requirements, predominantly characterized by sloped roofs, courtyards, overhangs, absence of compound walls, and pedestal stone in front of houses for gatherings see Fig. 3.

Vernacular knowledge is time-tested and refined over generations to be the most optimal for the environment, climatic context and lifestyle (Henna et al., 2021; Priyadarshani et al., 2023). This knowledge is now slowly being lost to modernization. With the rising demand for conventional dwellings to cater to the aspirational needs of the community, a decline in vernacular construction is evident (Moothedath et al., 2015). With the shifts in material use, space allocation for functionality is also changing. The influence of this archetype shift does not necessarily conform to the traditional knowledge previously used and has led to practical difficulties and shifts in community living patterns (Shastry et al., 2014).

The work aims to identify the impact of vernacular dwelling features that help to regulate indoor air temperatures. The objectives of the work are:

1. To examine Sugganahalli village (India) settlement cluster (geometry, mutual shadowing, and ventilation patterns) in response to prevalent climatic conditions.
2. To examine the impact of vernacular and conventional building features (Roof profile, material assembly, window and door sizes, attic spaces, ceiling height) on indoor air temperatures.

Part of
Pernigotto, G., Ballarini, I., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2025. Building simulation applications BSA 2024. bu,press.
https://doi.org/10.13124/9788860462022

Fig. 1 – Map representing the different typologies in Sugganahalli Village

2. Methodology

2.1 Documentation of the Cluster & Dwelling

On-site mapping of buildings was done in order to document the building typologies, the lifestyle of the people, and the features of the buildings, see Table 1. The on-site air temperature was recorded for the two types of dwellings, (Conventional and Vernacular) using Supco LTH sensors (accuracy ±0.5 °C). The installed sensors measured both indoor and outdoor temperatures.

A site map was developed (see Fig. 1) showing varying building typologies in the settlement.

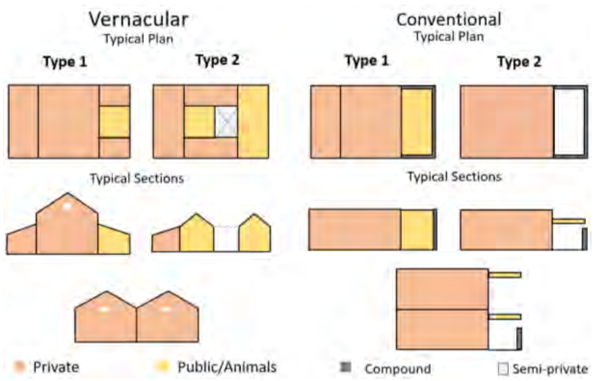

Fig. 2 – Subtypes within vernacular and conventional dwellings

The dwellings in the settlement were classified into three types:

1. Conventional (burnt bricks or AAC blocks for walls with cement plastering and RCC roof).
2. Vernacular (Earth-based materials, i.e., stone masonry or mud walls, mud or lime plaster, and timber frame with tiles or thatch).
3. Mixed (Initially built with vernacular materials and retrofitting done with conventional materials).

Fig. 3 – Images of the village's vernacular (left) and conventional (right) dwellings

Table 1 shows the features, building practices, and materials utilized in both of these building typologies. Fig. 2 illustrates the typical plans of the building typologies found on site.

Two representative dwellings were identified, as shown in Fig. 3. To do a comparative study, the dwellings were selected for different typologies (conventional and vernacular), ensuring similar dimensions, planning, orientation, and building features.

Table 1 – Difference in conventional and vernacular dwelling features

Feature	Conventional	Vernacular
Material	Brick / Cement	Stone / Mud
Walls	230 mm	450 mm
Openings	D–900 x 2100 mm W– 900 x 750 mm	D– 900 x 2000 mm W– 750 x 600 mm
Roofs	Flat roof	Sloped / Courtyard
Roof Material	RCC slab / Asbestos sheets	Timber frame with thatch/tiles
Long-axis orientation	East-West	East-West
U-value (wall)	1.58 (W/m²-K)	1.00 (W/m²-K)
Age of the dwelling	12 – 15 years	70-100 years
Material source	Manufactured	Locally sourced (1km radius- hillock)

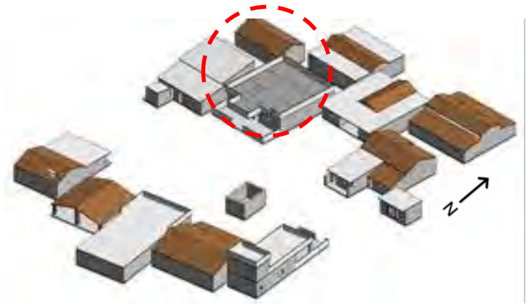

Fig. 4 – 3-D Conventional house with context modeled on Autodesk Revit®

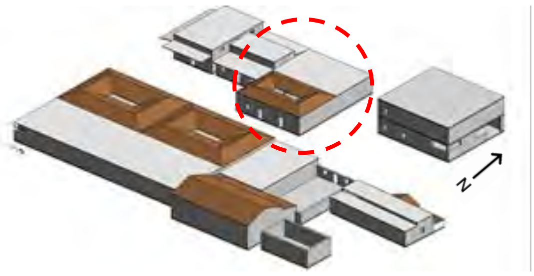

Fig. 5 – 3-D Vernacular house with context modeled on Autodesk Revit®

2.2 Simulation

The Sugganahalli village cluster, consisting of around 150 buildings, has been modeled in Design Builder and Revit. Settlement-level block models have been used to study the overall cluster-level planning strategies. Wind patterns (see Fig. 8) and solar gain (see Fig. 9, Fig. 10) were the major parameters studied at the site level. A cluster-level analysis was done to investigate solar exposure (see Fig. 13) using Autodesk CFD.

At the building level, the impact of the cluster, ventilation rates, vernacular features, and materials were examined using the Design Builder tool.

Validation of the building model in Design Builder was done with on-site recorded data. The RMSE (%) and MBE (%) are within acceptable limits as dictated by ASHRAE guidelines. (“Standards and Guidelines,” n.d.), i.e. RMSE – 30% and MBE – 10%

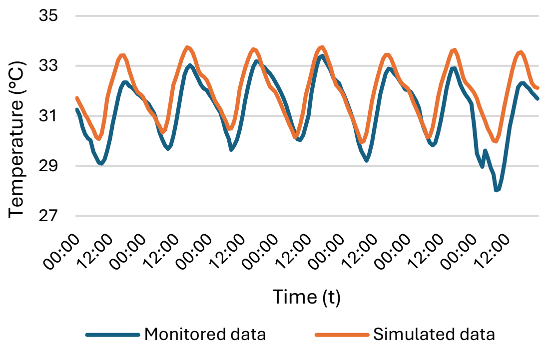

Fig. 6 – Validation of conventional dwelling for indoor air temperature

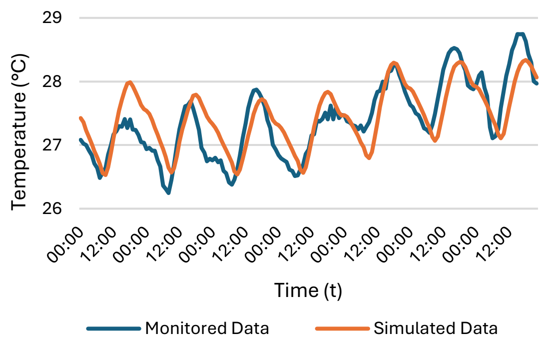

Fig. 7 – Validation of vernacular dwelling for indoor air temperature

The simulation model shows a good fit to the existing building on-site based on RMSE and MBE values calculated using Equations 1 and 2.

$$RMSE\% = \frac{100}{\bar{x}_i}\sqrt{\frac{\sum_1^n (x_i - x_s)^2}{n}} \quad (1)$$

$$MBE\% = \frac{\sum_1^n (x_i - x_s)}{\sum_1^n (x_i)} \times 100 \quad (2)$$

x_i - Measured data *n – Number of readings*

x_s - Simulated data *$\bar{x}_i$ - Mean of measured data*

3. Results and Discussions

3.1 Site Level Analysis

The analysis was done at site level for wind patterns (direction) and flow (see Fig. 8) and solar irradiance (see Fig. 13). The dwellings on site are majorly oriented such that the longer side faces the East-West direction. The clustering of the blocks is such that the longer wall is mutually shaded by the surrounding blocks. Even though each building has the longer side facing the East-West direction, the overall form of the settlement has the shorter side facing the East-West direction (see Fig. 1).

Wind analysis for the settlement was done by taking the major wind direction and speed for the location ("Global Wind Atlas," n.d.). The clustering of the houses resulted in wind movement, as shown in Fig. 8. The longer side of the dwellings (East-west orientation) are oriented perpendicular to the wind direction. The impacts of orientation (see Fig. 9 and Fig. 10) and mutual shadowing (see Fig. 11 and Fig. 12), were individually examined to understand whether the cluster geometry and the building features had a role to play in keeping the indoor temperature comfortable.

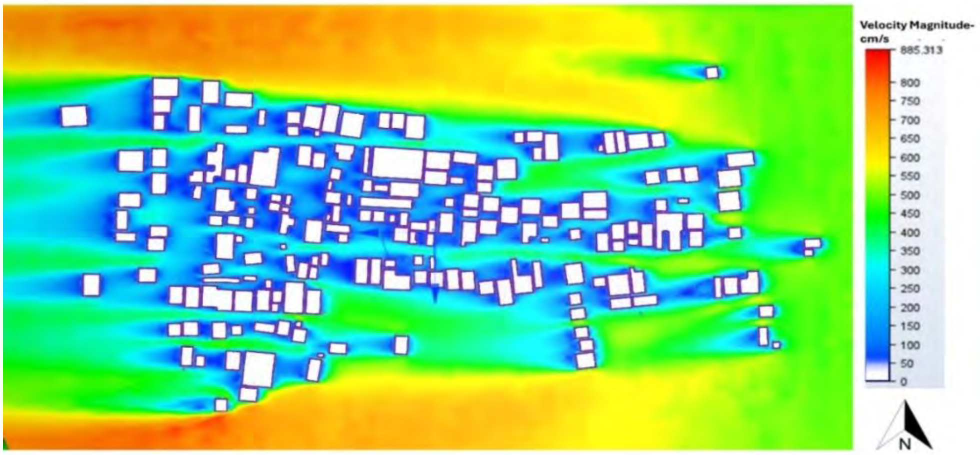

Fig. 8 – Wind analysis for major wind direction in the settlement (developed using Autodesk CFD)

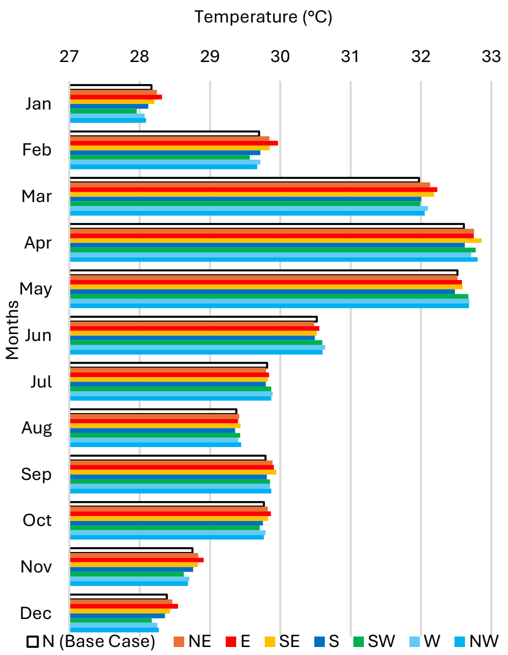

Fig. 9 – Impact of orientation on mean indoor air temperature (conventional dwelling

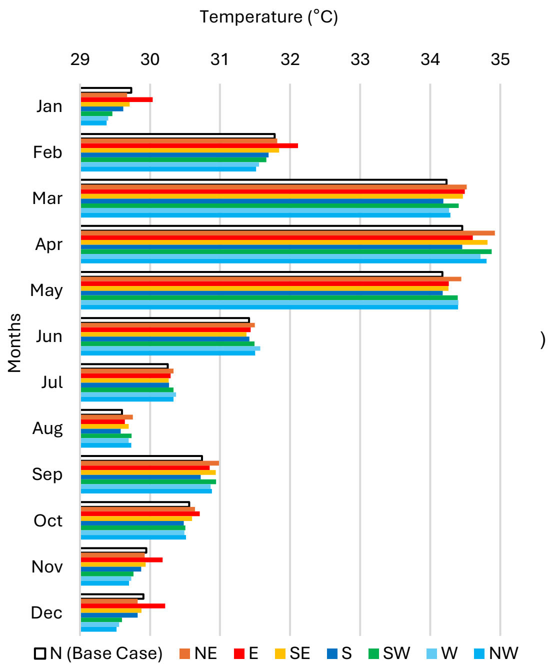

Fig. 10 – Impact of orientation on mean indoor air temperature (vernacular dwelling)

3.2 Building Level Analysis

3.2.1 Cluster orientation

The orientation of the cluster was examined for the 8 ordinal directions at increments of 45°. The whole cluster was rotated for this simulation and not individual dwellings.

Orientation shows a low influence on the indoor temperatures in both conventional and vernacular typologies, as shown in Fig. 9 and Fig. 10. While north is taken as the base case. In the case of conventional dwelling, the east-facing orientation experiences the most heat gain (+0.1 °C), but the difference compared to the west-facing orientation with the least heat gain is negligible in comparison to the base case (north-facing) (see Fig. 9).

In the case of vernacular dwelling, east facing showed the most heat gain (+0.2 °C). South-facing showed negligible heat gain. The base case of North was nearly equal to south orientation, as shown in Fig. 10.

The impact of orientation was found to be negligible, i.e., in the range of -0.1 °C to +1.0 °C for the conventional dwelling and -0.6 °C to +0.5 °C for the vernacular dwelling. This suggests that orientation may not be a critical factor in managing indoor temperature for this specific site and climate.

3.2.2 Mutual shading

The conventional and vernacular dwellings were studied in isolation without neighboring building units to examine mutual shadowing. In the case of conventional dwelling, an increase of the average indoor air temperatures by +0.9 °C was observed when compared to the building with neighboring building units (see Fig. 11). The removal of the neighboring cluster in the case of vernacular typology had an overall increase in average air temperatures by +0.5 °C, as shown in Fig. 12, with the effect being most evident during summer months (Mar-May). This highlights the potential benefits of strategic building placement and the influence of neighboring structures on shading as evident from Fig. 13. The cluster shows less impact on vernacular typology due to the low U-value building envelope.

3.2.3 Ventilation

Window and door sizes were altered, transitioning from conventional typology (750x900 mm, 900x2100 mm) to vernacular typology (600x750 mm, 700x2000 mm) in the conventional dwelling. There was no significant difference in average temperature compared to the base case, as shown in Fig. 14). In fact, a slight warming effect (+0.1 °C) was observed when compared to the base case.

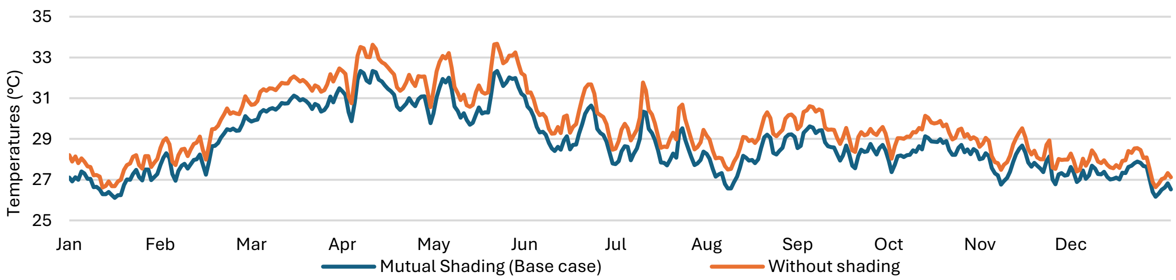

Fig. 11 – Impact of mutual shading on average indoor air temperature in Conventional dwellings

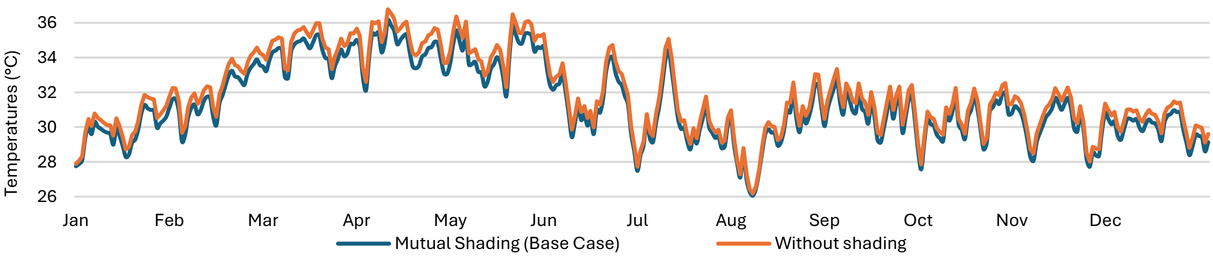

Fig. 12 – Impact of mutual shading on average indoor air temperature in Vernacular dwellings

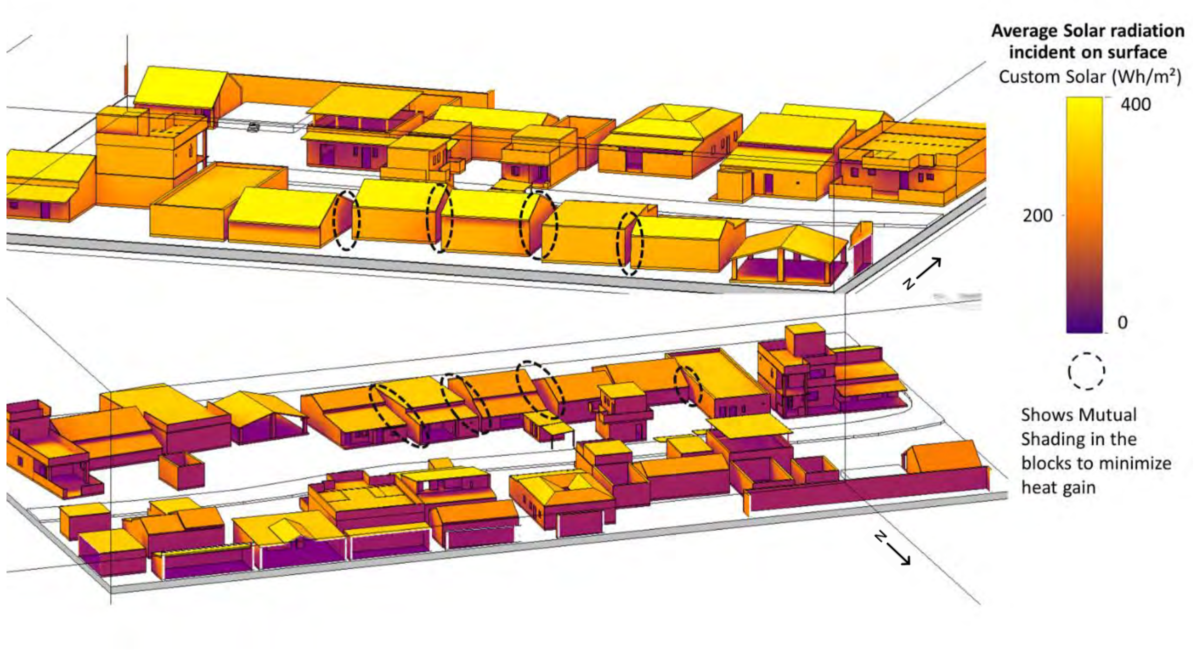

Fig. 13 – Solar Radiance distribution, developed using Autodesk Revit®

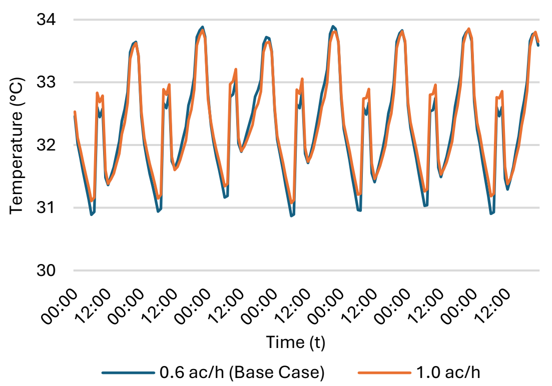

Fig. 14 – Impact of ventilation rates on diurnal indoor air temperature in conventional dwelling

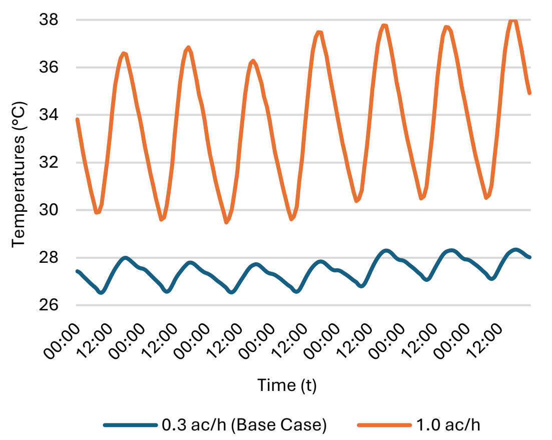

Fig. 15 – Impact of ventilation rates on diurnal indoor air temperature in vernacular dwelling

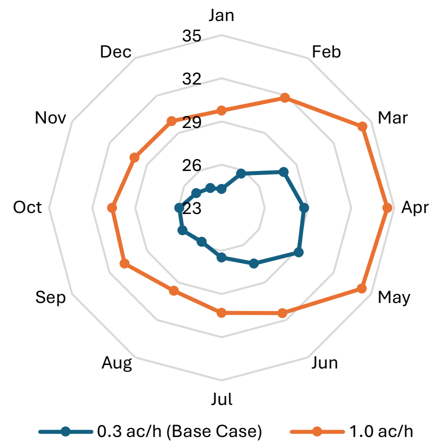

Fig. 16 – Impact of ventilation rates on monthly mean indoor air temperature in vernacular dwelling

There is an evident rise in temperature (nearly +4.5 °C) in vernacular typology for the diurnal temperatures (see Fig. 15) and monthly average temperatures (see Fig. 16) when ventilation rates were increased from 0 (infiltration only) to 1.0 ac/h (recommended ac/h for living spaces as per ("CIBSE Guides," n.d.)). The heat buffer effect of the walls and roof of vernacular type kept the indoor air cooler than ambient outdoors (Shastry et al., 2014). Contrary to the notion that ventilation contributes to keeping indoors cooler, in this case, increasing the ventilation rates makes the indoors warmer, as outdoor air was much warmer.

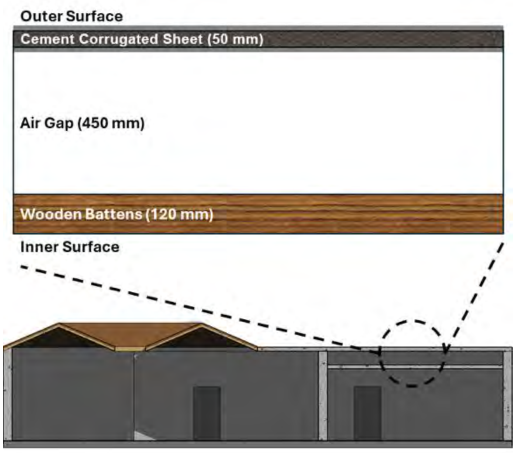

Fig. 17 – Roof assembly of vernacular house with attic space

3.2.4 Attic spaces

In vernacular typology, attic spaces serve multiple purposes beyond just storage. However, another purpose of the attic lies in its role as a thermal buffer. By creating an air gap (450 mm) between the ceiling and the roof, the attic space acts as an additional insulation layer, as shown in Fig. 17. Removing the attic space resulted in higher average indoor air temperatures of +0.3 °C throughout the year. The attic keeps the building cooler by around -0.3 °C during summer (Mar-May), as shown in Fig. 18.

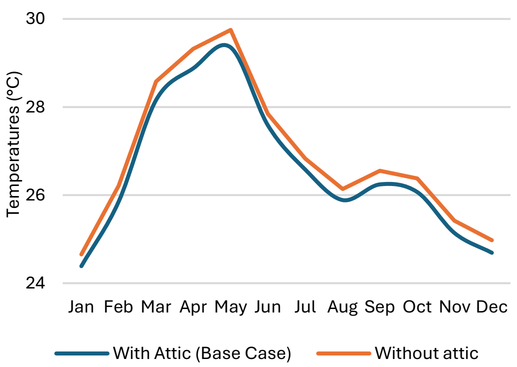

Fig. 18 – Impact of attic space on monthly mean indoor air temperature in vernacular dwelling

3.2.5 Roof geometry

Roof types were studied, three vernacular roof types (R1, R2, R3) and one conventional roof type (R4) were identified, as shown in Fig. 19. These roofs were modeled and simulated to see the impact of the roofs on indoor air temperatures.

Slopes of the roof are mainly facing in the north-south direction, which are also facing the street. This facilitates the rainwater to flow into the drains rather than flowing to the narrow spaces between the building blocks, since they are closely clustered.

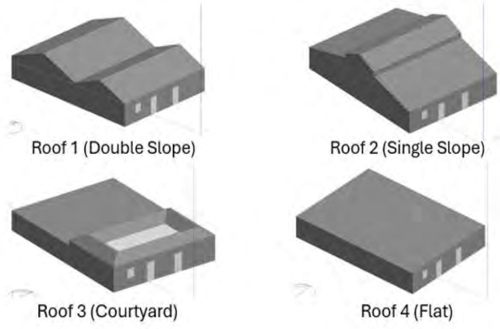

Fig. 19 – Roof Types (R1, R2, R3, R4)

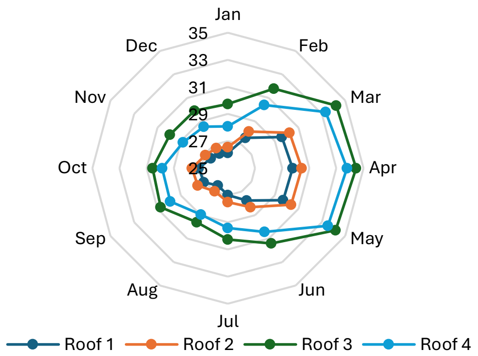

Fig. 20 – Impact of roof geometry on monthly mean indoor air temperature in vernacular dwelling

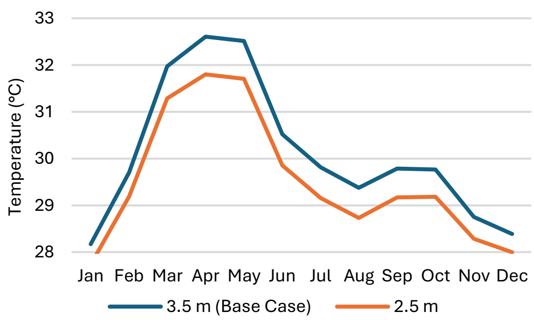

Fig. 21 – Impact of ceiling height on monthly mean indoor air temperature in conventional dwelling

The simulations showed that R1 and R2 kept the indoors comfortable, as shown in Fig. 20.

The courtyard type and flat roof with conventional materials resulted in higher indoor temperatures, see Fig. 20. This relates well to the previous inference of higher ventilation leading to an increase in indoor temperatures, as shown in Fig. 15 and Fig. 16.

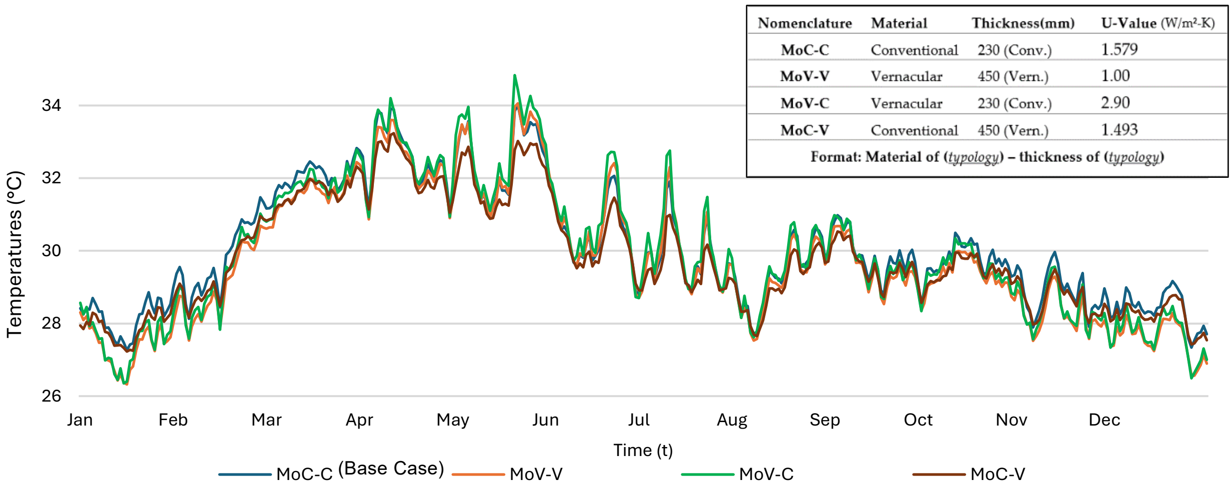

Fig. 22 – Graph representing the base case with various material assemblies and thickness (Daily variation)

3.2.6 Ceiling height

The typical ceiling height found in vernacular dwellings is 2.5 m. A ceiling height reduction (from 3.5 m to 2.5 m) in the conventional dwelling resulted in a notable cooling effect on average indoor air temperature by -0.7 °C (see Fig. 21).

3.2.7 Material assembly

Material assembly and thickness are crucial for achieving lower indoor air temperatures. Fig. 22 reveals that employing vernacular materials with their typical wall thickness (450 mm) proves most effective in maintaining stable, lower indoor air temperatures (-0.3 °C on an average compared to the base case). Even with a standard wall thickness (210 – 230 mm), vernacular materials outperform conventional ones in lowering temperatures with a standard wall thickness of 230 mm (-0.2 °C). Notably, a thicker wall similar to that in vernacular typology, even with the material assembly of conventional typology, provides the most benefit towards cooling (-0.3 °C). These findings show the inherent thermal benefits of vernacular materials and the importance of considering wall thickness during design.

4. Conclusions

Vernacular features and planning have been known to impact a dwelling's thermal performance significantly. This study examines a few buildings in a vernacular Indian setup.

On a cluster geometry level, the mutual shadowing contributed to the overall comfort in the dwelling. The vernacular building features contributing to keeping the indoors comfortable were material assembly and wall thickness, attic space, ceiling height, and specific roof geometry. The low ventilation rate in vernacular dwellings contributes significantly in maintaining the effect of these passive cooling strategies. The incorporation of these features in conventional dwellings would be beneficial in keeping indoors comfortable. This can help to reduce the dependence on insulative materials and mechanical ventilation strategies for cooling (fans, A.C.s, insulation materials), leading to less energy consumption and eventually promoting sustainability. Further, more buildings in vernacular contexts must be studied to determine their potential benefits for energy efficiency and occupant comfort.

Acknowledgement

The authors thank Mr. Raghupathy for local support during the study.

References

CIBSE Guides. "Comprehensive technical guidance on key areas in building services engineering". Accessed April 9, 2024. https://www.cibse.org/knowledge-research/knowledge-resources/engineering-guidance/cibse-guides

Energy Data Info. "Global Wind Atlas". Accessed April 9, 2024. https://globalwindatlas.info/en/

Henna, Khadeeja, Aysha Saifudeen, and Monto Mani, 2021. "Resilience of Vernacular and

Modernising Dwellings in Three Climatic Zones to Climate Change." *Scientific Reports* 11 (1). https://doi.org/10.1038/s41598-021-87772-0

Moothedath Chandran, Kumari, Nallaval Chinnaswamy Balaji, and Monto Mani, 2015. "Understanding Transitions in a Rural Indian Building Typology in the Context of Well-Being." Vol. 109. https://www.nature.com/articles/s41598-021-87772-0

Priyadarshani, Suchi, Roshan R. Rao, Monto Mani, and Daniel Maskell, 2023. "Examining Occupant-Comfort Responses to Indoor Humidity Ratio in Conventional and Vernacular Dwellings: A Rural Indian Case Study." *Energies* 16 (19). https://doi.org/10.3390/en16196843

Shastry, Vivek, Monto Mani, and Rosangela Tenorio, 2014. "Impacts of Modern Transitions on Thermal Comfort in Vernacular Dwellings in Warm-Humid Climate of Sugganahalli (India)." *Indoor and Built Environment* 23 (4): 543–64. https://doi.org/10.1177/1420326X12461801

ASHRAE 2024. "Standards and Guidelines". Accessed April 9, 2024. https://www.ashrae.org/technical-resources/standards-and-guidelines