

Original Article

Passive Ventilation Features in Traditional Rural Houses of Tamil Nadu: A Comparative Architectural Case Study

K. Chithra¹, M. Bhuvaneshwari², C.V. Subramanian³

¹Department of Architecture, Periyar Maniammai Institute of Science and Technology, Vallam; Research Scholar, School of Architecture and Interior Design, Kattankulathur, Chennai, Tamil Nadu, India.

²Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamil Nadu, India.

³Department of Architecture, Periyar Maniammai Institute of Science and Technology, Vallam, Thanjavur, Tamil Nadu, India.

Corresponding Author: archchithra65@gmail.com

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Abstract -Traditional rural Tamil Nadu houses include courtyard architecture, norisha, shaded over gangs spaces, openings, and local construction material that would affect the non-mechanical environmental design strategies. This study provides a qualitative comparative study of traditional dwellings along with. Pillaiyarpatti, Tamil Nadu. The existing available structures, architectural plans, photographs, and descriptive accounts. Determine building typologies, courtyard orientation, building materials, and possible natural cross-flows. The listed cases show how courtyard-oriented spatial compositions, common masonry building, timber elements, and tiled roofing systems. These architectural features provide opportunities to examine the relationship between building layout and passive environmental design. However, quantitative measurements of indoor temperature, relative humidity, and airflow are not reported in the available documentation. Therefore, the study focuses on architectural characteristics rather than measured thermal performance. The findings provide a descriptive basis for understanding traditional passive-design approaches and indicate the need for further field measurements to evaluate their effectiveness in improving indoor environmental conditions.

Keywords - Natural ventilation, Rural housing, Courtyard architecture, Passive design, Vernacular architecture, Tamil Nadu.

1. Introduction

Natural ventilation and passive environmental design are important considerations in residential architecture, particularly in regions where building design must respond to variations in solar radiation, temperature, humidity, and prevailing winds. Architectural features such as building orientation, courtyards, shaded openings, roof configurations, and construction materials can influence opportunities for natural airflow and indoor environmental conditions.

Traditional residential architecture in Tamil Nadu incorporates several elements associated with climate-responsive design. Courtyards provide open spaces within building layouts, while verandahs, transitional spaces, masonry walls, and traditional roofing systems contribute to the architectural character of rural dwellings. The potential environmental benefits of these features depend on their geometry, construction, orientation, and surrounding climatic conditions.

Previous research has investigated natural ventilation, occupant thermal comfort, and the influence of building

configurations on indoor environmental conditions. Indraganti [2] examined adaptive use of natural ventilation in Indian apartments, while Arfaei and Hançer [1] investigated the influence of the built environment on natural ventilation in a historical urban setting. These studies demonstrate the importance of examining architectural characteristics alongside environmental conditions.

Additional research on traditional Indian dwellings provides a more specific basis for interpreting these architectural features. Radhakrishnan et al. [5] investigated climate-responsive features of Chettinadu houses through a summer field study with indoor and outdoor environmental monitoring. Monika and Marwaha [6] examined courtyard-related indoor thermal conditions in vernacular row houses in Kanyakumari, Tamil Nadu. Rajapaksha et al. [7] analysed a ventilated courtyard in a warm-humid climate and found that its passive-cooling behaviour depends on building openings and airflow patterns. Shastri et al. [8] evaluated a vernacular courtyard dwelling near Bengaluru using thermal monitoring and an occupant comfort survey. Zamani et al. [9] reviewed the influence of courtyard geometry, orientation, openings, and shading on thermal and microclimatic behaviour, whereas



Singh et al. [10] examined thermal performance and occupant comfort in vernacular houses of North-East India. Unlike those field- or simulation-based investigations, the present study documents and compares architectural features of the available Pallathur and Pillaiyarpatti examples without claiming measured ventilation or thermal-comfort improvements.

Quantitative studies of courtyard buildings have since provided explicit numerical benchmarks. Prakash et al. [11] applied computational fluid dynamics to a courtyard building of 10 m × 10 m in plan and 5 m in height with a 3.35 m square courtyard, and reported that adding a roof-level wind-catching opening doubled the average indoor air velocity compared with a closed roof. Toris-Guitron et al. [12] combined hourly field logging with a calibrated simulation of traditional courtyard houses in a warm-humid climate and found that larger courtyards raised solar heat gain and ventilation rate while changing the average operative temperature of the whole building only slightly.

Aloshan and Aldali [13] extended this line of work to nearly 29,000 parametric simulations of courtyard villas in five hot and warm climates and reported that courtyard plan dimensions explained less than 3% of the variance in outcomes, compared with more than 40% for window-to-wall ratio and insulation.

For a traditional courtyard house in a desert climate, Zamani et al. [14] reported that the courtyard air was on average 1.2 °C cooler than the outdoor air on 21 June and that the east and west zones had the highest cooling demand. These studies concern other climates and building types. They are used in this paper only to indicate which variables deserve measurement at Pallathur and Pillaiyarpatti, and none of their values is attributed to the buildings examined here.

However, the application of passive-design principles to individual traditional rural housing examples requires documentation of their architectural arrangements and construction characteristics. Such documentation can help identify possible ventilation pathways and features that may warrant further performance-based investigation.

The present study examines traditional residential examples documented in Pallathur and Pillaiyarpatti, Tamil Nadu. It focuses on courtyard configuration, building layout, opening arrangements, and locally used construction materials. The objective is to compare the architectural features associated with passive environmental design and discuss their possible implications for natural ventilation. Since quantitative indoor environmental measurements are not presented, the study is limited to qualitative architectural analysis. Established principles of tropical climatic design also identify orientation, shading and ventilation openings as relevant architectural variables [3]. In contrast to the present

descriptive study, Miño-Rodríguez et al. [4] combined field observations with thermal modelling to assess rural dwellings; their findings are not measurements of the Tamil Nadu buildings examined here.

1.1. Research Gap and Novelty

The studies reviewed above address natural ventilation, thermal comfort and courtyard behaviour mainly through field monitoring, occupant surveys, simulation or literature review [1, 2, 5-10]. Such studies are valuable for establishing how courtyard and opening configurations may influence indoor conditions, but they do not by themselves document the architectural arrangement of individual traditional rural dwellings in Pallathur and Pillaiyarpatti, Tamil Nadu. In the sources consulted for this study, a side-by-side comparison of the documented architectural features of these two locations, set out in terms relevant to passive ventilation, was not identified. This is the research gap addressed here.

The novelty of the present study is therefore descriptive and methodological rather than performance-based. First, it brings together drawing-based documentation from Pallathur and photograph-based documentation from Pillaiyarpatti within a single comparison.

Second, it applies an explicit set of architectural comparison criteria (Section 2.3) to features that are relevant to passive ventilation. Third, it separates clearly what the available documentation shows from what can only be established through measurement, and it outlines a framework for the field assessment that is still required (Section 6.1). The study does not claim measured ventilation or thermal-comfort improvement.

1.2. Scope and Organization of the Paper

The scope of the paper is limited to the traditional residential examples documented at Pallathur and Pillaiyarpatti, and to their architectural features that are relevant to passive ventilation: courtyard arrangement, layout, openings, materials, roof construction and transitional spaces. Indoor temperature, humidity and airflow are outside the scope because no measurements are available.

Section 2 describes the research methodology, including the objectives, case selection, data collection and the comparison framework. Section 3 discusses the architectural features that are relevant to passive environmental design. Section 4 presents the case study areas and the documented characteristics of the Pallathur and Pillaiyarpatti examples. Section 5 compares the documented features, analyses possible ventilation pathways and discusses implications for rural housing. Section 6 sets out the limitations and a framework for future assessment, and Section 7 gives the conclusion. Sections 2.5, 3.5 to 3.7, 5.4 and 6.3 add the methodological basis and the quantitative evidence drawn from references [11-15].

2. Research Methodology

This study adopts a qualitative comparative architectural approach to examine traditional residential buildings documented in Pallathur and Pillaiyarpatti, Tamil Nadu. The analysis is based on the available building plans, elevations, photographs, architectural illustrations, and descriptions of construction materials.

The analysis is limited to building configuration, spatial organization, courtyard distribution, openings, roofing systems, and locally used building materials. Based on these building features, potential passive environmental design techniques are identified for traditional rural dwellings. The contribution of courtyards and openings to natural ventilation is understood from their spatial arrangement and relation to each other between the buildings. This does not refer to tested ventilation performance. Documentation available did not include quantitative data on indoor air temperature, relative humidity, air velocity or ventilation rate. Therefore, the approach is limited to qualitative architectural analysis, without any numerical statement regarding the indoor thermal performance or energy efficiency.

2.1. Research Objectives

The main aim of the project is to study the passive architectural features integrated in the traditional rural houses of Tamil Nadu. The specific objectives of the study are to explore the courtyards' pattern and spatial composition, to record the construction materials and architectural characteristics of the case studies studied and to make a comparison of features that may result in the opportunities for natural ventilation and daylight access.

2.2. Case Selection and Data Collection

The residential examples included in this study are those documented at Pallathur and Pillaiyarpatti in Sivaganga District, Tamil Nadu. They were included because the available documentation for both locations shows courtyard-based residential arrangements built with locally used materials, which allows their architectural features to be compared.

The cases are not intended to be statistically representative of all traditional rural housing in Tamil Nadu, and the findings are therefore limited to the documented examples.

No new site measurements were taken, and no instruments were used. Data collection consisted of reviewing the documentation as supplied for the study: (i) for Pallathur, architectural drawings of the Padaippu Veedu, comprising elevations, a floor plan and diagrams of spatial organization (Figures 1-4); and (ii) for Pillaiyarpatti, photographs and descriptive accounts of masonry construction, courtyard spaces, tiled surfaces and timber components (Figures 5-7).

The figure captions indicate where the original provenance of an item still requires confirmation.

The documentation was processed in four steps. First, each item was identified by location and type of record. Second, the visible or described architectural features were recorded under the headings of the comparison framework in Section 2.3. Third, the recorded features of the two locations were compared in Tables 1 and 2. Fourth, possible ventilation pathways were inferred from the spatial arrangement of courtyards and openings and are reported only as qualitative possibilities. Because the type of record differs between the two locations (drawings and photographs), the comparison is necessarily uneven; this is taken into account in Sections 5 and 6.

2.3. Architectural Comparison Framework

To keep the comparison consistent, the documented features were examined against seven architectural criteria. These criteria were chosen because orientation, shading and ventilation openings are recognised as relevant variables in tropical climatic design [3], and because courtyard geometry, openings and surrounding enclosure are reported to influence the thermal and airflow behaviour of courtyards [7, 9].

- (1) Courtyard Arrangement: The presence, position and relation of the courtyard to the surrounding rooms.
- (2) Building Layout and Orientation: The overall plan form and, where drawings allow, the orientation of the principal axis.
- (3) Openings and Connections: The doors, windows and internal openings that link rooms with the courtyard and the exterior.
- (4) Construction Materials: The masonry, lime mortar, brick, timber and other materials shown or described.
- (5) Roof construction: The roofing type, structural framing and shading elements.
- (6) Transitional and shaded spaces: The entrances, verandahs and circulation spaces between the exterior, the courtyard and the rooms.
- (7) Documentation type and limits: The kind of record (drawing or photograph) and the information it can and cannot provide.

Where a criterion cannot be determined from the available documentation, this is stated rather than assumed. No criterion is scored numerically, and no weighting is applied, since no measured values are available.

2.4. Reliability and Provenance of the Documentary Evidence

Because the analysis rests on documentation and not on-site measurement, the reliability of that documentation affects how far the observations can be relied on. Three points are noted.

- (1) Provenance: The figure captions state that the original provenance and reuse permission of the supplied figures require verification. In particular, the attribution of Figure 3 to the Pallathur case building, and whether Figure 4 depicts the Pallathur building, are not confirmed. Observations on the Pallathur layout, therefore, rest mainly on the plan, elevations and diagrams shown in Figures 1 and 2, and Figures 3 and 4 are used only as illustrations of architectural character.
- (2) Completeness: The available documents do not give complete building dimensions, dates of construction or measured opening areas. The comparison is accordingly made on the presence and arrangement of features and not on their size.
- (3) Interpretation: Features are read from drawings and photographs, so some observations depend on interpretation. To limit this, features that cannot be determined from the documentation are stated as such, and possible ventilation pathways are reported as qualitative possibilities only.

2.5 Methodological Basis Drawn from Reference Studies

The present study is documentary and uses no instruments. Its framework for later measurement (Section 6.1) is, however, defined against the protocols reported in the reference studies, so that future data can be compared with them directly. Three components are adopted: field monitoring, comfort assessment and numerical simulation.

2.5.1. Field Monitoring

In the Colima study [12], air temperature was logged hourly from 29 May to 1 June 2020 with data loggers of ± 0.35 °C accuracy, at heights of 0.1 m and 1.1 m following ISO 7726, with further loggers at 2.25 m at the volumetric centre of each of four corridors. Outdoor temperature, humidity, solar radiation, wind speed and wind direction were recorded hourly by a separate weather station. Before and after the campaign, 235 simultaneous dry-bulb readings from all loggers were used to derive correction equations, which were accepted when the correlation coefficient was not lower than $r^2 = 0.95$.

2.5.2. Comfort Assessment and Model Validation

The same study judged indoor operative temperature against the adaptive 80% acceptability limits of ASHRAE Standard 55-2017, written as: upper limit (°C) = $0.31 \times t_{pma(out)} + 21.3$ and lower limit (°C) = $0.31 \times t_{pma(out)} + 14.3$, where $t_{pma(out)}$ is the prevailing mean outdoor temperature over the 7 to 30 days before the day considered.

The two limits therefore lie 3.5 °C above and below the comfort temperature [12]. The simulation was accepted after the mean simulated and measured corridor temperatures differed by 1 °C or less, with R^2 between 0.94 and 0.95 and RMSE between 1.00 and 1.31 °C.

2.5.3. Airflow Simulation

In the CFD study of Prakash et al. [11], the computational domain extended 3H upstream, 15H downstream and 5H above and to either side of a building of height H, with the flow modelled by the standard $k-\epsilon$ turbulence model. A grid sensitivity test on four meshes of 4.8, 7.5, 10.5 and $14 (\times 10^5)$ cells identified the third as grid-independent, solutions were converged to 10^{-6} , and facade pressure coefficients were verified against wind-tunnel data. For H = 5 m these multiples correspond to 15 m, 75 m and 25 m at full scale.

These protocols are adopted here as reference specifications only. No measurement made under them is reported in the present paper.

3. Architectural Features Relevant to Passive Environmental Design

3.1. Building Orientation and Openings

Building orientation is a significant factor in the passive design of the environment as it governs the access to sunlight and the interaction of a building with the pre prevailing wind. In particular, the positioning of outside walls, windows, entrances and internal openings can determine the potential for and type of air flow through the home. In existing courtyard houses, the distribution of openings and the connecting system to internal spaces may have led to different flow routes. The direction and the flow rate will likely be affected by wind conditions, pressure difference, architectural form and operation of openings.

3.2. Courtyard-based Spatial Arrangement

Open courtyards are commonly found as characteristic spaces of traditional residential building types. A courtyard can function as a spatial link connecting rooms surrounding the courtyard with the outside, and with daylight access and natural ventilation, in consideration of its size, location and proximity to other opening. However, the architectural effects of a courtyard cannot be judge just by the existence of them. The performance of a courtyard is also related to the height of surrounding walls, linked openings, external barriers and local climate. These are in accordance with other published courtyard study and reviews [7, 9].

3.3. Traditional Building Materials and Roof Construction

Older style homes might also use materials including stone masonry, clay roof tiles, timber, brick work and lime-based construction products. The performance of these materials under the environment is influenced by factors including their thermal conductivity, density, specific heat, thickness and moisture content. The materials used in the construction have been documented in the eight examples above, but laboratory testing and individual thermal characterization of the materials is not available. Hence, no attempt is made to compare quantitatively the performance of the individual materials quantitatively.

3.4. Shading and Vegetation

Other items for consideration in passive environmental planning include shaded entrances, verandahs, projections from roofs and trees and shrubs in the yard. The effect on sun and outdoor microclimates depends on size, orientation and landscape position. The purpose of these features is discussed in conceptual terms in this study. The true environmental effects would be known from further field observations and quantification.

3.5. Courtyard Proportion, Solar Gain and Ventilation Rate: Evidence from Other Studies

The Colima parametric study [12] simulated twenty courtyard-house cases in which the courtyard plan ranged from 5 m × 5 m to 20 m × 20 m and was rotated through four orientations, with the building height held at 5 m. In the critical week, total solar heat gain through the courtyard openings ranged from 740 kW (5 m × 5 m, north-south and east-west) to 5726 kW (20 m × 20 m, northeast-southwest and northwest-southeast), as reported by the authors, a ratio of about 7.7. Over the same cases, the indoor ventilation rate rose from 27.5 to 54.5 air changes per hour, a ratio of about 2.0, whereas the average operative temperature differed by only 0.54 °C between the coolest and warmest cases. The share of total heat gain received through the courtyard openings rose from 31.3% in the 5 m × 5 m north-south case to 63.9% in the 20 m × 20 m north-south case, while gains associated with natural ventilation stayed below 1% of the total. At the scale of whole villas, Alosan and Aldali [13] found annual cooling energy use intensity between 56.4 and 142.1 kWh/m²-year and annual discomfort between 40.6 and 1344.4 hours across their simulated database. Compact courtyards with a low window-to-wall ratio, external insulation and high-performance glazing reduced cooling demand to below 75 kWh/m²-year, whereas elongated courtyards with a higher window-to-wall ratio reduced discomfort to below 70 hours per year in hot-dry climates, often at the cost of higher cooling demand in hot-humid ones.

Two points follow for the present study. First, a larger courtyard can increase air exchange and heat gain together, so ventilation rate alone does not indicate thermal benefit [12]. Second, openings and envelopes appear to matter more than courtyard plan size within the ranges tested [13]. Because both findings depend on climate, the climate class of Pallathur and Pillaiyarpatti should be fixed from long-term meteorological records before any comparison with these studies is made.

3.6. Roof-Level Openings and Roof Form

Roof construction is documented for Pillaiyarpatti (Figure 7), but is not dimensioned. The CFD study of Prakash et al. [11] indicates which roof variables are worth recording. Its model was a 10 m × 10 m × 5 m courtyard building whose 3.35 m × 3.35 m courtyard occupies 11.2% of the plan area (11.2 m² of 100 m²). Introducing an opening between the windward and leeward roof pitches doubled the average

indoor air velocity relative to a closed roof. The authors then varied the leeward roof extension (h/6, h/3 and h/2 of the building height), the roof angle (20°, 30° and 40°), the roof shape and the courtyard-wall opening, and reported that an extended leeward gabled roof improved ventilation and comfort.

The model was an isolated building without surrounding structures, trees or verandahs, as the authors note [11], whereas the houses documented here stand in streets and village plots. The numerical values, therefore, cannot be transferred to Pillaiyarpatti or Pallathur. What transfers is the list of geometric variables (roof pitch, ridge or eave openings, leeward extension) that should be surveyed in Stage 1 of Section 6.1.

3.7. Orientation and Zonal Differences around a Courtyard

Zamani et al. [14] compared zones on the four sides of a courtyard house in Iran and found that the east and west zones had the highest summer cooling demand because of solar radiation, with the largest number of discomfort hours in the east zone. On the longest day of the year (21 June), the courtyard air was on average 1.2 °C cooler than the outdoor air, and its temperature fluctuated less than the outdoor temperature. In the Colima houses [12], the rooms showed smaller thermal swings and more hours within the comfort limits than the corridors, and in the 20 m × 20 m northeast-southwest case, the maximum corridor temperature exceeded the outdoor maximum by 1.8 °C. Together with [14], these findings support recording the orientation, enclosure and use of each room or corridor relative to the courtyard, rather than treating a house as a single zone. The Pallathur drawings, which indicate a north-south axis and rooms of differing access to openings (Section 4.1), would allow zones to be identified from the plan, subject to the provenance checks noted in Section 2.4.

4. Case Study Areas

This study investigates several traditional residential architectural examples found in Pallathur and Pillaiyarpatti of Sivaganga District, Tamil Nadu. These two locations show traditional residential forms with courtyards and locally available building materials. From the existing architectural documentation, the passive-design strategies can be studied and compared for their effectiveness.

4.1. Architectural Characteristics of the Pallathur Residential Example

Architectural drawings of the Padaippu Veedu at Pallathur show elevations of the building, a floor plan and diagrams of spaces organized within the scheme. The drawings reveal a building aligned along a north-south axis, with an internal courtyard and linked residential areas. The courtyard and associated spaces are significant elements of the overall architectural layout of the building. Their

configuration allows for an investigation into the potential impact of openings and internal circulation areas on natural ventilation. The current sketches also suggest that access to fresh air through opening doors and windows may vary in

different rooms, with those in the centre of the structure having less access than those next to the openings. These are quite speculative, however, as they are not based on experimental data of the actual airflow.

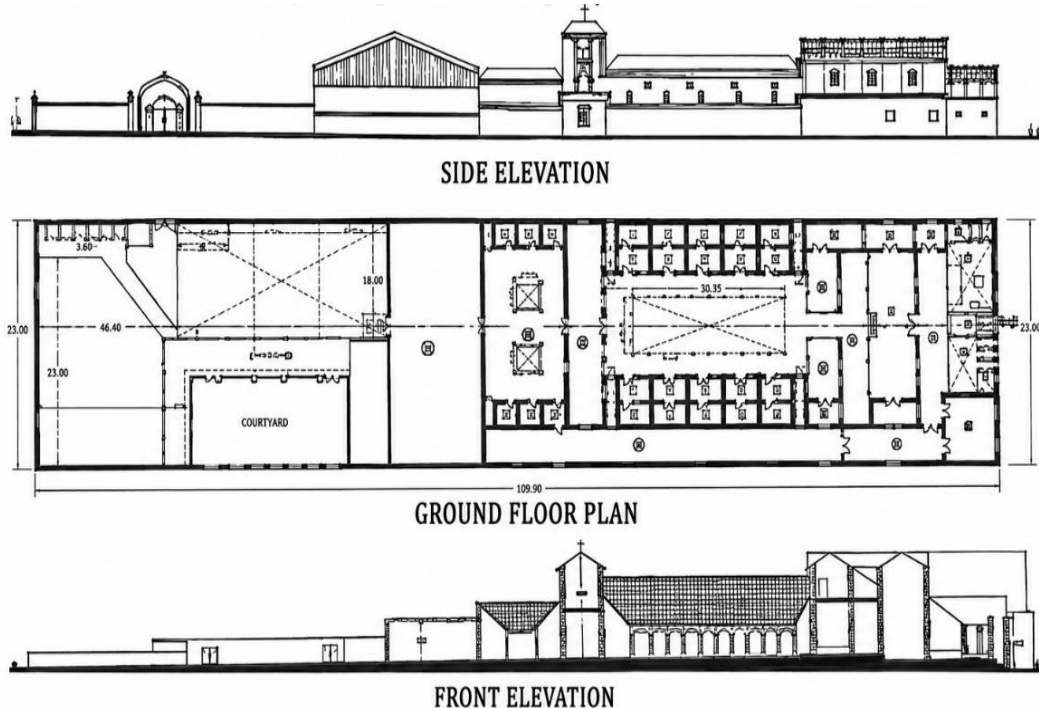
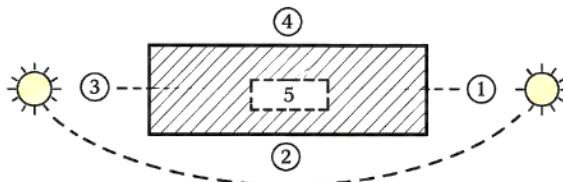


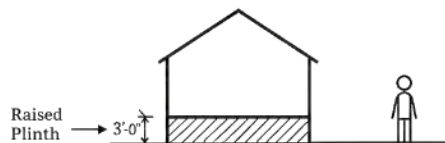
Fig. 1 Architectural plan and elevations supplied as the Padaippu Veedu, Pallathur

01. ORIENTATION OF THE HOUSE



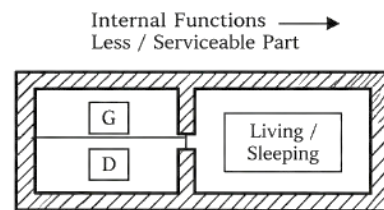
The entrance of the house is towards the west, the main elevation by which the adopted light enters the house. The house is faced towards general sunlight.

03. RAISED PLINTH LEVEL



Houses have higher plinth levels to keep off floods, high water and other natural elements. The raised plinth prevents water from entering the house and provides protection from the surrounding environment.

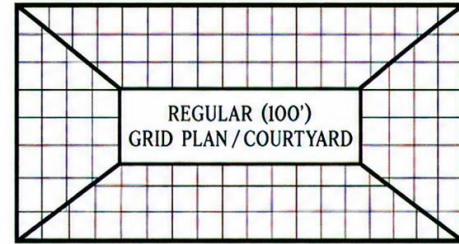
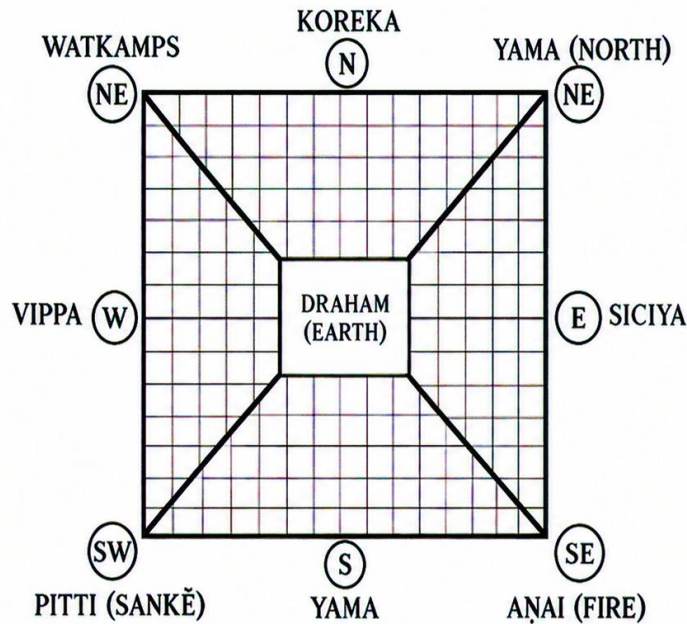
02. SPATIAL ORGANISATION



Each house has main and secondary areas. The main house receives the entrance and the living space, while the back area is used for cooking and other service functions. (Ref. 4) It leads to the rear open space.

EXIT →

04. THE GRID AND THE COURTYARD



ACCORDING TO THE GRID, THE MAIN HOUSE IS ORIENTED TO THE CENTRE, WHERE THE COURTYARD IS. HOUSES AND SPACES ARE PLACED AROUND THE COURTYARD IN A BALANCED WAY. THIS GRID ALSO HELPS IN KEEPING THE CENTRE AS THE MOST IMPORTANT PART OF THE HOUSE.

THE CENTRE IS ALWAYS THE HEART.

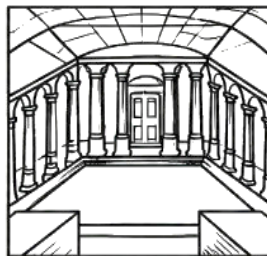
Fig. 2 Schematic orientation, spatial organization and courtyard-grid concepts accompanying the Pallathur documentation

05. FORM OF COLUMNS

USING THE PRINCIPLE OF LAYUNING AND CREATING THE SCHEMING SYSTEM AS SUPRECIC REPRESENTATION.

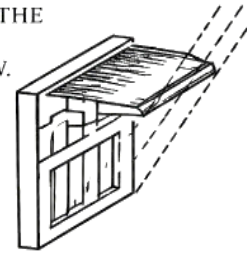


CENTRAL OPEN COURTYARD CREATES THE FIRST SPACE OF OPEN SPACE. THE OUTER ROOMS EXTEND INTO LIGHT FORMED A BUFFER TO OTHER ROOMS.



06. SECTION – ENTRANCE GATE

FEATURES THE ENTRANCE GATE PROVIDED AT OUTSIDE, THE MAIN CONTROLLED THE MOVEMENT OF THE FLOW.



AN ALTERNATIVE FORM WHICH ACTS AS A PROTECTION AND ALSO A BARRIER — WHICH CONTROLS ACCESS AND ENTRY FOR DIFFERENT CULL.

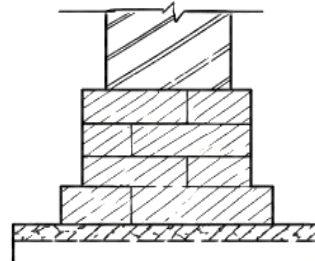
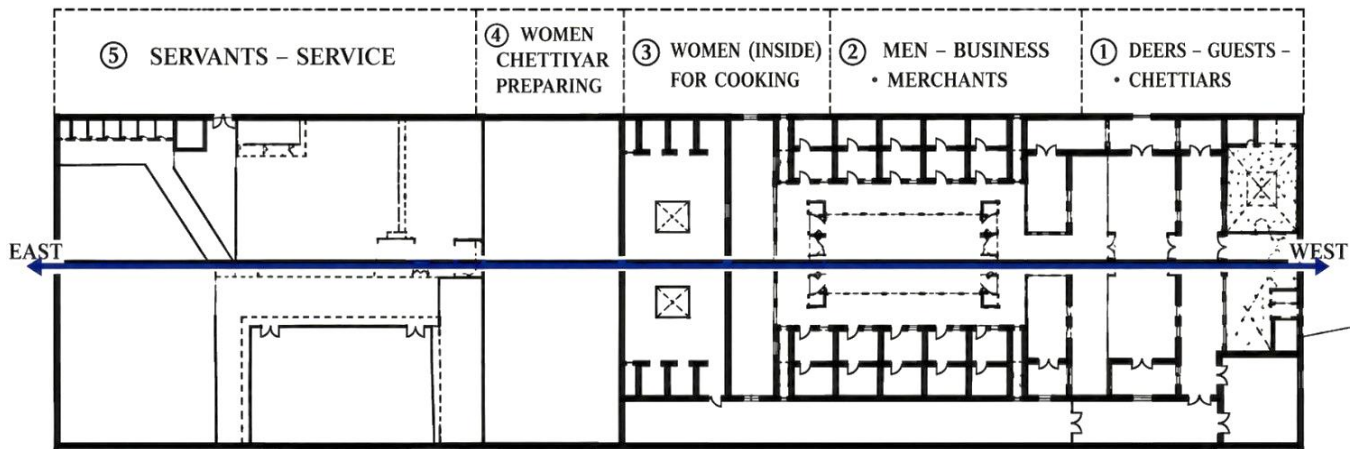


Fig. 3 Architectural illustrations of columns and entrance details; attribution to the Pallathur case building remains to be verified



PLAN OF EARLY CHETTIAR'S HOUSE

THE MAIN AXIS IS ORIENTED WEST / EAST, FACILITATING AIR FLOW AND ENSURING LIGHT AND SHADOW TO THE CENTRAL COURTYARD. THEN THE PAN WATER IS COLLECTED FROM THE COURTYARD AND DRAINED TO STORAGE TANKS.

Fig. 4 An illustrative plan labelled as an early Chettiar residence, whether it depicts the specific Pallathur case building is unverified

4.2. Architectural Characteristics of the Pillaiyarpatti Residential Examples

The photographic documentation of traditional residential buildings in Pillaiyarpatti illustrates masonry construction, internal courtyard spaces, tiled surfaces, and timber structural components. The examples indicate the use of traditional construction materials and courtyard-based architectural arrangements. The relationship between courtyards, surrounding rooms, and exterior openings provides a basis for examining potential natural ventilation pathways. The available photographs and material descriptions do not provide sufficient information to establish wall thermal properties, ventilation rates, or indoor temperature variations.

Accordingly, these architectural characteristics are interpreted as descriptive features rather than evidence of measured environmental performance. Traditional construction materials described in the available documentation include stone masonry, lime mortar, fired bricks, clay roofing tiles, and timber elements. These materials form part of the architectural character of the residential examples. However, their exact compositions, dimensions, and thermal properties have not been experimentally verified in this study. Therefore, their potential contribution to building thermal behaviour is discussed only in relation to established material characteristics and is not presented as a measured outcome.



Fig. 5 (a) A traditional residential street and masonry construction, and (b) An internal tiled courtyard, described as Pillaiyarpatti examples.



Fig. 6 (a) Courtyard-related architectural elements, and (b) Masonry wall construction.



Fig. 7 (a) Traditional clay-tiled roof, and (b) Timber roof-framing and shading elements.

Table 1. Qualitative comparison of documented architectural features in Pillaiarpatti and Pallathur

No.	Architectural feature	Pillaiarpatti	Pallathur
1	Type of available documentation	Photographs of traditional residential examples	Floor plan, elevations and illustrative diagrams
2	Courtyard arrangement	Internal courtyard spaces are visible in photographs	Courtyard spaces illustrated within a longitudinal layout
3	Material characteristics	Masonry, tiled surfaces and timber elements shown or described	Masonry and traditional architectural elements indicated in drawings
4	Roof construction	Tiled roofing and timber components documented	Traditional roofing and structural features depicted
5	Transitional spaces	Courtyard-facing spaces visible	Entrance and internal circulation spaces indicated
6	Possible ventilation pathways	Qualitative possibilities through courtyards and openings	Qualitative possibilities through courtyards and connecting openings
7	Thermal performance	Not quantitatively evaluated	Not quantitatively evaluated
8	Environmental measurements	Not reported	Not reported

4.3. Comparative Interpretation of Courtyard Configurations

The documentation for the two locations allows the courtyard configurations to be compared only in part. At Pallathur, the drawings of the Padaippu Veedu show an internal courtyard linked to residential areas within a building aligned along a north–south axis (Figures 1 and 2). Because plans and elevations are available, the position of the courtyard within the layout and its relation to the surrounding rooms can be read directly from the drawings.

At Pillaiyarpatti, the photographs show internal courtyard spaces with tiled surfaces, together with masonry wall construction and timber components (Figures 5 and 6).

The relation between the courtyards, the surrounding rooms and the exterior openings is visible in the images, but the position of each courtyard within a complete plan, its proportions and the height of the surrounding walls cannot be established from photographs alone. Both locations, therefore, share an internal, courtyard-centred arrangement with masonry construction, but the two sets of evidence support different kinds of observation.

The Pallathur drawings support observations about layout and about the relation between rooms, courtyard and openings, whereas the Pillaiyarpatti photographs support observations about materials, surfaces and the visual character of the courtyard.

Differences in courtyard size, proportion or enclosure height between the two locations are not asserted, because the available documentation does not allow them to be measured. The courtyard configurations are accordingly interpreted as comparable in type, but not as comparable in dimension or performance.

5. Results and Discussion

The qualitative analysis of typologies revealed that courtyard spaces, masonry building construction, conventional construction methods and transition features are the prevailing features across the sample of residential types. These architectural sketches from the Pallathur site show a building layout with internal courtyards and corridors. The layout indicates that there are potentially varying ventilation opportunities for the building, depending on the locations of the rooms in relation to the openings and courtyards. Features preserved in the Pillaiyarpatti images illustrate building materials and courtyard planning. These features highlight the ongoing use of local building methods with architectural significance, but there is not enough information to know how they perform thermally indoors.

One difference emerging is the level and type of available architectural record. For Pallathur, plans and schematic views of the space are available, while for the Pillaiyarpatti examples, these are primarily illustrated via photographs and descriptive textual information. This creates a limitation to an individual parameter of design comparison. In sum, the documented features offer insights that may be used to determine any passive ventilation measures. Any superior thermal comfort performance and ventilation efficiency is not unambiguously concluded due to a lack of environmental measurements.

5.1. Comparative Analysis of Passive Ventilation Features

Table 2 extends Table 1 by setting out the documentary basis for each observation and the qualitative relevance of each feature to passive ventilation. The entries record only what the available plans, photographs and text show or indicate. Entries stating that a feature cannot be determined reflect the limits of the documentation, not the absence of the feature.

Table 2. Expanded comparative analysis of passive ventilation features in Pallathur and Pillaiyarpatti

No.	Architectural feature	Pallathur	Pillaiyarpatti	Qualitative relevance to ventilation
1	Courtyard	Internal courtyard linked to residential areas in a longitudinal layout (Figures 1 and 2)	Internal tiled courtyards with surrounding rooms visible (Figures 5 and 6)	Open space that may connect surrounding rooms with the outdoors; effect depends on proportions, wall height and openings [7, 9]
2	Orientation and layout	North–south axis indicated in the drawings	Not determinable from the photographs	Orientation relative to sun and prevailing wind is a relevant variable [3]; no wind data available
3	Openings	Doors and windows shown in the drawings; rooms near the centre may have less access to openings than rooms next to them (indicative only)	Exterior openings visible in the photographs; sizes not determinable	Distribution of openings may shape possible flow routes through rooms and the courtyard

4	Wall construction	Masonry and traditional architectural elements indicated	Stone masonry, lime mortar and fired bricks are described (Figure 6(b))	Thermal properties not tested; no quantitative comparison made
5	Roof construction	Traditional roofing and structural features depicted	Clay roof tiles, timber framing and shading elements (Figure 7)	Roof form and shading may affect solar exposure [3]; not measured
6	Transitional spaces	Entrance and internal circulation spaces indicated	Courtyard-facing spaces visible	Intermediate zones between exterior, courtyard and rooms; role not measured
7	Documentation basis	Plan, elevations and diagrams	Photographs and descriptive text	Drawings allow layout to be read; photographs allow materials and visual character to be read.
8	Measured environmental data	None reported	None reported	Ventilation effectiveness and thermal comfort cannot be concluded

The documented arrangements allow several possible ventilation pathways to be described in conceptual terms. These are inferred only from the spatial relation between courtyards, rooms and openings, and none has been verified by airflow measurement or simulation.

- (1) Exterior-to-Courtyard Pathway: Where openings connect rooms with both the exterior and the courtyard, air may, in principle, move between the outdoors and the courtyard through the intervening rooms.
- (2) Courtyard as a Shared Zone: The courtyard is open to the surrounding rooms and may serve as a common source of daylight and air for them, which is consistent with the role described for courtyards in the literature [7, 9].
- (3) Transitional-Space Pathway: Entrances, verandahs and circulation spaces lie between the exterior, the courtyard and the rooms and may moderate the connection between them.
- (4) Rooms Remote from Openings: The Pallathur drawings suggest that rooms near the centre of the structure may have less access to openings than those next to them, which would make their ventilation depend more on internal connections than on direct exterior openings.

Whether any of these pathways operates effectively depends on wind conditions, pressure differences, the size and position of openings and courtyard, and the way occupants operate the openings (Section 3.1). Rajapaksha et al. [7] reported that the passive-cooling behaviour of a ventilated courtyard depends on building openings and airflow patterns, which supports treating these pathways as hypotheses to be tested rather than as established performance.

5.2. Architectural Implications for Sustainable Rural Housing

The documented features have implications for how traditional rural housing may be understood from a

sustainability perspective, provided that these implications are read as design considerations and not as demonstrated benefits. Courtyard-centred layouts, openings that connect rooms with open and shaded spaces, and locally used materials such as stone, lime mortar, brick, clay tiles and timber are features that do not depend on mechanical systems for their basic function.

They therefore merit attention in studies of non-mechanical environmental design in rural housing. Three considerations follow. First, conservation and renovation of traditional dwellings may benefit from recording the courtyard configuration, opening arrangement and roof construction before any alteration, since these features appear central to the passive-design character of the buildings. Second, where new rural housing draws on traditional layouts, the relationship between courtyard, openings and surrounding rooms should be treated as a design variable to be checked, because reviews of courtyard behaviour show that geometry, orientation, openings and shading all influence thermal and microclimatic performance [9]. Third, comparable studies of vernacular houses in Tamil Nadu, near Bengaluru and in North-East India have used thermal monitoring and comfort assessment to evaluate such houses [5, 6, 8, 10], which indicates the type of evidence needed before design recommendations can be made. These implications are limited by the absence of measured data in the present study. They should not be read as evidence that the traditional features improve indoor comfort or reduce energy use, and they do not replace the performance-based evaluation described in Section 6.1.

5.3. Positioning of the Findings Relative to Previous Studies

Table 3 summarizes the previous studies cited in this paper, using only the settings and approaches described in the Introduction and in the reference list, and indicates how each relates to the present study.

Table 3. Previous studies cited and their relation to the present study

Ref.	Setting	Approach or focus	Relevance to the present study
[1]	Natural ventilation in a historical urban setting (Walled City of Famagusta)	Study of the influence of the built environment on natural ventilation	Shows that surrounding built form matters; the setting is urban, not rural
[2]	Indian apartments	Adaptive use of natural ventilation for thermal comfort	Indicates the role of occupant use of ventilation; building type differs from rural courtyard houses
[3]	Tropical housing (general design principles)	Established principles of climatic design	Identifies orientation, shading and ventilation openings as relevant variables
[4]	Low-cost rural housing (Ecuadorian Andes)	Field observations combined with thermal modelling	Rural dwellings assessed with field and modelling methods; not Tamil Nadu buildings
[5]	Chettinadu houses, Tamil Nadu	Summer field study with indoor and outdoor monitoring	Closest regional precedent for climate-responsive features of traditional Tamil Nadu houses
[6]	Vernacular row houses, Kanyakumari, Tamil Nadu	Courtyard-related indoor thermal conditions	Regional precedent on the role of courtyards in indoor conditions
[7]	Ventilated courtyard, warm-humid climate	Analysis of passive-cooling behaviour	Shows dependence on building openings and airflow patterns
[8]	Vernacular courtyard dwelling near Bengaluru	Thermal monitoring and occupant comfort survey	Example of combining monitoring with a comfort survey
[9]	Courtyards (literature review)	Review of geometry, orientation, openings and shading	Basis for the architectural criteria used in Section 2.3
[10]	Vernacular houses, North-East India	Thermal performance and occupant comfort	Example of comfort assessment in vernacular houses
[11]	Courtyard building with a roof wind-catching element (CFD model)	CFD with grid sensitivity and wind-tunnel verification	Shows that roof-level openings and roof geometry can change indoor air velocity; the roof construction at Pillaiyarpatti is documented but not dimensioned
[12]	Traditional courtyard houses, Colima, Mexico (warm-humid)	Field logging, calibrated simulation, twenty courtyard cases	Quantitative relation between courtyard size, solar gain, ventilation rate and operative temperature; basis of the monitoring protocol in Section 2.5
[13]	Courtyard villas in five hot and warm climates	Nearly 29,000 parametric simulations with machine learning	Indicates that window-to-wall ratio and insulation outweigh courtyard plan size; modern villas, not rural dwellings
[14]	Traditional courtyard house, Iran (desert climate)	Zonal energy simulation and comparison of courtyard and outdoor air temperature	Supports recording the orientation of each zone relative to the courtyard
[15]	Building energy codes in the United States, the European Union and China	Global review of code design and implementation	Context for how measured data support guidance; not about courtyard housing

The comparison shows that the cited studies largely rely on field monitoring, surveys, modelling or review, whereas the present study documents architectural arrangements. The present findings, therefore, complement these studies by identifying features and possible pathways that could be measured in the same way, and no measured value from the present study can be compared with theirs. Rows [11-15] of Table 3 were added after the numerical protocols were reviewed. They are included for the same purpose as rows [1-10]: to show what each study did and why its results cannot be read as measurements of the buildings examined here.

5.4. Implications for Guidance and Documentation Practice

Guidance for housing generally rests on codes and standards. Sun et al. [15] reviewed building energy codes in

the United States, the European Union and China and reported that they differ in design and implementation, with innovations that include emission caps per square metre of building space, performance certificates with retrofit recommendations, and renewable energy for nearly zero-energy buildings. Their national model estimated that, by 2035, an aggressive commercial-building code in the United States could reduce energy for space heating, cooling, water heating and lighting by 16%, 15%, 20% and 5%, respectively. These figures concern United States commercial buildings, not courtyard dwellings, and carry no implication for rural Tamil Nadu. For courtyard housing specifically, Alosan and Aldali [13] propose that their simulation-derived thresholds be introduced first as prescriptive tables by climate zone and later as performance-based compliance paths. A similar route for

traditional dwellings would require measured evidence, which is the purpose of the staged framework in Section 6.1. Pending such evidence, a consistent record for each documented dwelling would make later guidance possible.

The following minimum items are suggested, using quantities that the reference studies treat as variables.

- (1) Courtyard geometry: Length, width and height, from which the plan aspect ratio and the ratio of courtyard volume to building volume can be computed; the latter ranged from 0.04 to 0.35 in the Colima cases [12].
- (2) Opening schedule: Number, size and position of doors, windows and roof or eave openings on each facade, and whether they are normally open or closed.
- (3) Envelope description: Wall thickness and material, and roof build-up; the Colima sample reported adobe or brick walls of 0.4 m to 1.1 m thickness [12].
- (4) Orientation: Azimuth of the long axis of the courtyard and of each facade.
- (5) Operation: The times at which occupants open the windows, because opening the windows of enclosed rooms from 23:00 to 11:00 lowered the temperature by about 1.1 °C in the Colima study, while opening them outside that period raised it [12].

6. Limitations and Future Research

The study includes only the information of qualitative architectural data of the recorded residential examples. There is a lack of complete information about building dimensions, date of construction, areas of opening measured, recording procedures. The temperature, humidity of the indoor air, air velocity and air change rate were not measured. Thus, the true effect of the courtyard layout, wall construction and roof materials on indoor thermal comfort could not be assessed.

These results should be viewed as architectural observations as opposed to experimentally proven, tested solutions. Subsequent work can then include building surveys, field measurements, and validation tests of airflow simulations to examine the solutions' efficacy.

6.1. Proposed Framework for Future Environmental Assessment

The limitations noted above can be addressed through a staged field assessment of the same or comparable dwellings. The framework below is proposed as a basis for future work and has not been applied in this study.

Stage 1 – Building Survey: Measured plans and sections recording courtyard dimensions, surrounding wall heights, the size and position of doors, windows and other openings, and the orientation of the principal axis, together with confirmed building identity, date of construction and documentation source.

Stage 2 – Material Documentation: Recording wall thickness and roof build-up, and, where feasible, material testing or reference to established material properties, so that the thermal contribution of masonry, lime mortar, brick, clay tiles and timber can be assessed.

Stage 3 – Environmental Monitoring: Simultaneous measurement of indoor and outdoor air temperature, relative humidity and air velocity (and, where feasible, ventilation rate) in the courtyard, in the rooms around it and in rooms remote from openings, over a monitoring period covering the seasons of interest, in the manner of the field studies in [5] and [6].

Stage 4 – Occupant Assessment: A thermal-comfort survey carried out alongside the monitoring, as in [8, 10].

Stage 5 – Simulation and validation: airflow or thermal simulation of the surveyed geometry, validated against the monitored data, in line with the combined field and modelling approach used in [4].

Stage 6 – Comparative Analysis: Comparison of the measured conditions with the architectural features recorded in Table 2, to test whether the possible ventilation pathways described in Section 5.1 operate as described.

Only after such measurements would it be appropriate to draw conclusions on ventilation effectiveness or thermal comfort.

6.2. Priority Questions for Future Testing

The possible pathways described in Section 5.1 can be restated as questions for the field assessment proposed in Section 6.1.

- (1) (Q1) Do openings that connect rooms with both the courtyard and the exterior produce measurably different air movement from rooms with a single connection? (Pathways a and b.)
- (2) (Q2) Do rooms near the centre of the Pallathur-type layout, which the drawings suggest have less access to openings, show different indoor conditions from rooms next to the openings? (Pathway d.)
- (3) (Q3) Do entrances, verandahs and circulation spaces moderate the connection between the exterior and the rooms? (Pathway c.)
- (4) (Q4) How do the documented materials and roof construction relate to indoor conditions once wall and roof build-up have been surveyed? (Stage 2 of Section 6.1.)

These questions are not answered in the present study and are stated so that future measurements can be directed at the features identified here.

6.3 Numerical Basis and Worked Checks for the Proposed Assessment

Table 4 collects reference quantities from the cited studies that the framework of Section 6.1 would use as specifications

or acceptance limits. The worked checks that follow show how they are applied. All input values are taken from the cited papers or are stated assumptions; none is a measurement at Pallathur or Pillaiyarpatti.

Table 4. Reference quantities from cited studies for the proposed field assessment

Ref.	Quantity	Reported value	Use in Section 6.1
[12]	Logger accuracy and heights	± 0.35 °C; 0.1 m and 1.1 m (ISO 7726)	Stage 3, instrument specification
[12]	Inter-instrument calibration	235 simultaneous readings; $r^2 \geq 0.95$	Stage 3, correction of loggers
[12]	Model–measurement agreement	Mean difference ≤ 1 °C; R^2 0.94–0.95; RMSE 1.00–1.31 °C	Stage 5, acceptance of simulation
[12]	Adaptive comfort band (80% acceptability)	$0.31 t_{pma(out)} + 14.3$ to $0.31 t_{pma(out)} + 21.3$ (°C)	Stages 3 and 6, assessment limits
[12]	Courtyard-to-building volume ratio	0.04 to 0.35	Stage 1, computed from survey
[12]	Window operation, enclosed rooms	About 1.1 °C lower when opened 23:00–11:00	Stage 3, occupant operation record
[11]	CFD domain (building height H)	3H upstream, 15H downstream, 5H above and lateral	Stage 5, simulation set-up
[11]	Mesh independence and convergence	Four meshes, 4.8 to 14×10^5 cells; third accepted; 10^{-6}	Stage 5, simulation set-up
[13]	Calibration limits (monthly energy)	NMBE $\leq 10\%$; CV(RMSE) $\leq 30\%$	Stage 5, if energy use is modelled

Check 1 – Adaptive comfort band [12]: For an assumed prevailing mean outdoor temperature of 30 °C, the upper limit is $0.31 \times 30 + 21.3 = 30.6$ °C and the lower limit is $0.31 \times 30 + 14.3 = 23.6$ °C. The band is $30.6 - 23.6 = 7.0$ °C wide and is centred on a comfort temperature of $0.31 \times 30 + 17.8 = 27.1$ °C, which agrees with the stated ± 3.5 °C. The value of 30 °C is an illustrative assumption and not a measured outdoor condition.

Check 2 – Courtyard share of plan area [11, 12]: A courtyard of $3.35 \text{ m} \times 3.35 \text{ m}$ has an area of 11.2 m^2 , which is 11.2% of a 100 m^2 plan. Because the courtyard in [11] has the same height as the building (5 m), its volume ratio is also 0.112 if the building volume is taken to include the courtyard, which lies inside the 0.04 to 0.35 range of [12]. The definition of building volume used in [12] should be confirmed before such a comparison is relied on.

Check 3 – Scaling of the Colima results [12]: The courtyard plan area rose from $5 \times 5 = 25 \text{ m}^2$ to $20 \times 20 = 400 \text{ m}^2$, a factor of 16. Over the same range, solar heat gain rose by $5726 / 740 \approx 7.7$ and ventilation rate by $54.5 / 27.5 \approx 2.0$, while the average operative temperature changed by only 0.54 °C. Heat gain, therefore, did not increase in proportion to plan area, and a large change in air exchange coincided with a small change in temperature.

Check 4 – Calibration agreement [13]: The measured and simulated twelve-month electricity totals were 94,707.16 kWh

and 94,569.94 kWh. Their difference is $94,707.16 - 94,569.94 = 137.22$ kWh, or 0.14% of the measured total, and the authors report that their calibration statistics fall within the ASHRAE Guideline 14 monthly limits listed in Table 4.

Check 5 – Mesh economy [11]: The third mesh (10.5×10^5 cells) was accepted as grid-independent. It contains $10.5 / 14 = 75\%$ of the cells of the finest mesh, a saving of 25% in cell count.

7. Conclusion

A qualitative comparative analysis of the traditional buildings was carried out to generate key architectural ideas. The findings highlight courtyard placement, traditional masonry construction, roofing, and transitional spaces as significant architectural elements of the studied building types. The configuration of the buildings indicates the possible provision of daylight and natural ventilation via courtyards and connecting apertures. To what extent this potential has been realised has not been quantified through environmental monitoring or air flows analysis. The observations can extend the record and provide a comparison of traditional architectural features related to passive design strategies. Additional field studies measuring indoor environmental parameters and assessing building performance are required to verify the effectiveness of the features. The implication being that it shows an indication of the minimum standards of comfort, providing descriptive details, but not quantitative evidence of effective energy efficiency. The numerical

evidence reviewed in Sections 3.5 to 3.7 and 6.3 shows that courtyard size, solar gain and air exchange can change together while the average operative temperature changes little; in the Colima study, a factor of about 7.7 in solar gain corresponded to 0.54 °C in operative temperature [12].

Ventilation features, therefore, need to be assessed together with solar exposure, opening operation and envelope, and the field protocol of Section 6.1 has been specified accordingly. These numbers belong to the cited studies, and no measured value for Pallathur or Pillaiyarpatti is claimed.

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