Kerala Traditional Architecture and Climatic Responsiveness - A Review

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Abstract
Traditional architectural buildings may be found in major parts of Kerala and have developed through time via a steady, persistent search for optimal design. Traditional building architecture in Kerala has long been revered for its reliance on all-natural, low-tech solutions to ensure a pleasant living space. This review paper is a comprehensive investigation of these traditional architectures of the Kerala system. The inside environment is the result of several factors, including the building's orientation, the layout of its interior areas, the existence of a courtyard, the use of readily accessible local materials, the application of any unusual construction techniques, etc. Studies were carried out to conduct a quantitative study by keeping track of the building's temperature and other factors related to occupant satisfaction. The present study shows that the ambient climate management technique used in traditional Kerala building is quite efficient and have better climatic response while maintaining a comfortable internal temperature throughout the year.
Keywords: Kerala, Traditional, architecture, Climate Response, Thermal Comfort.

1. Introduction

Traditional infrastructure has developed over many years as a result of the needs of communities in various climates (Oliver 1997, 1983). Depending on the community's geographical, societal, and literary contexts, these methods of development and designing use readily accessible localized materials (Sassu 2021). There is increased climatic comfort because of the attention paid to climatic and energy-saving details in this architectural style. Deterioration of the ecosystem, wasteful use of materials, emissions of greenhouse gases excessive energy consumption, habitat destruction, etc. are only some of the current issues that traditional construction may help address. This form of architecture, however, is now in danger of extinction since its adherents have mostly abandoned it in favor of the so-called contemporary traditional construction form Maijakairamo 1975; Subramanian 2021).

The majority of a person's life is spent in an enclosed space, whether it's a house or an office. The largest portion of global energy consumption is accounted for by basic energy needs and the provision of interior thermal comfort in the residential and commercial sectors (Chunekar et al., 2016). Selective architectural ideologies from localized traditional architecture may reduce the number of resources required for warming and conditioning a facility's interior spaces. Since it is projected that the home power requirement in India would increase by more than 8 times by 2050 (Shukla et al., 2015), energy utilization must be lowered by employing situational layout having environmentally sensitive solutions. The primary focus of traditional buildings is on providing a secure and comfortable living environment for their inhabitants. It is rooted in communal living, prioritizes protecting the natural world, and has matured through the sustained application of traditional indigenous knowledge (Rudofsky, 1964). To achieve the goals of climate-responsible environmentally friendly construction and provide a pleasant and comfortable place to live, traditional architectures employ an architectural strategy that attempts to decrease power utilization through the utilization of fundamental resources (Rudofsky, 1964). In comparison, contemporary homes have been criticized for their inability to adapt to their surrounding environments and for wasting excessive amounts of energy on things like heating and cooling the inside. Traditional architectural construction is giving way to contemporary homes constructed using cutting-edge tools and resources over time goes by (Sajith et al., 2021). Therefore, architects need to adopt a strategy that is a synthesis of old and modern to preserve our legacy and knowledge of ancient times. An apartment's primary function is to offer a hospitable setting that does not compromise the well-being or productivity of its residents (de 2004). The performance of a structure depends on the quality of its interior not just because it will determine the enjoyment of its residents but also because it will determine the structure's power usage and, by extension, its power sustainably (Nicol et al., 2022; Humphreys and Nicol 2008). In Fig. 1 illustrated the plan and section view of Kerala traditional homes.

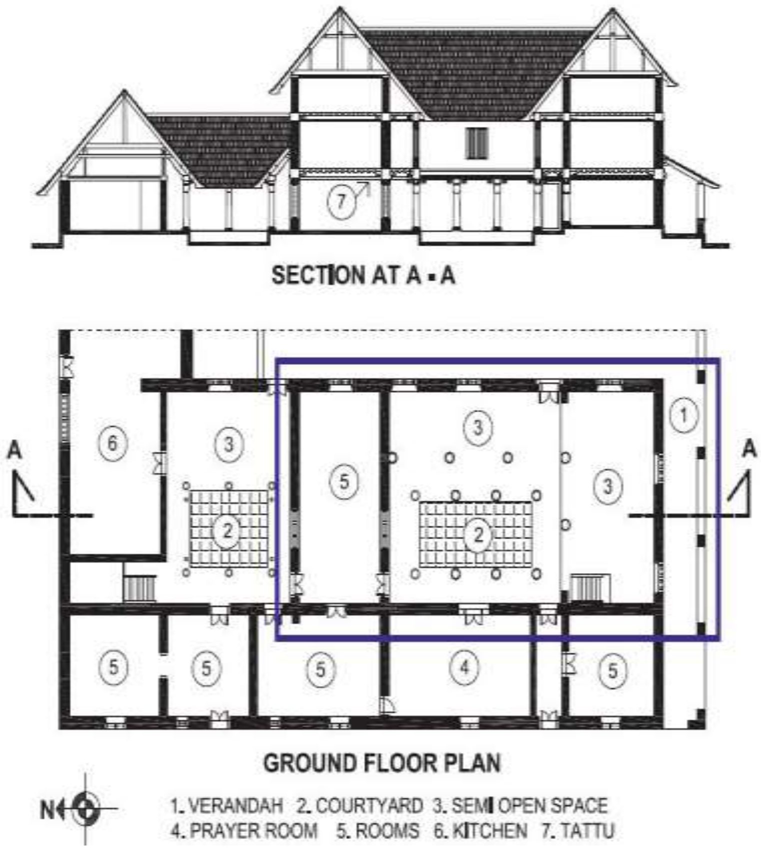

Fig 1: Plan and section view of traditional architecture (Dili et al., 2011)

Several researchers have stressed the significance of energy-saving details in a traditional building. Several authors, including Liu et al. (2010) and Chandel and Agrawal (2008), have argued that it is crucial to use native designing and constructing methods or to go with more adaptable contemporary building design technologies that include elements of traditional architecture and (Agrawal and chandel 2010; chandel et al., 2001). Both Chandel and Sarkar (2015) and Foruzanmehr and Vellinga (2017) demonstrate that incorporating these elements into the contemporary home design may increase efficiency, cost-effectiveness, and sustainability (2011). Energy-efficient design elements, smart use of space, and high-quality building materials were all mentioned as ways to make contemporary homes more pleasant inside by various researchers (Priya et al., 2012; chandel 2006; Padmarajan & UR 2020).

Preservation of local styles of the building has been a topic of study in recent years. Traditional house structures in Kerala have been the subject of several tests and analyses of seasonal data to better comprehend their ability to adapt to changing weather patterns (Dili and Varghese, 2010). To better adapt to changing weather patterns, researchers have examined the courtyards seen in ancient Kerala architecture. Books have been written on the viability of traditional buildings in many places like Budapest, Netherlands, Persia, Thailand, etc., all with an eye toward the evolution of contemporary styles of buildings (Sayigh, 2019). I.G.R.M.S. Bhopal conducted a study on India's traditional buildings, and their findings demonstrated the wide variety of traditional domestic construction that exists throughout India's varied topography and climate zones. India is home to a diverse range of architectural traditions, many of which have found a foothold on the vast and vibrant Indian peninsula. Kerala's traditional architecture reflects the state's heritage of migration and settlement along the waterways that define it. The homes are also indicators of social status based on their level of wealth and opulence (Jency & Atreya 2022). Ettukettu, Nalukettu, Eksala, and Cheri are the four most common types of traditional homes in Kerala. Artisanal attention to detail, inventive use of local materials, situational design solutions for climatic comfort, and strategic use of space all indicate sensitivity to environmental conditions and power savings. Modern dwellings in Kerala, however, disregard this wisdom in favor of a set of housing principles that have nothing to do with the traditions of Kerala. For this reason, it is important to bridge the gap between traditional and contemporary construction by reiterating situational design concepts with contemporary material details. The purpose of this study is to provide suggestions for incorporating climatic comfort tactics from Kerala's rich cultural heritage into today's cutting-edge building practices (Rahman & Halim 2021).

2. Literature Review

Shaeri, J., & Mahdavinejad (2022) analyzed the association between the PMV/PPD model and environmental data to predict thermal comfort in traditional dwellings of Shiraz, Iran. First, a typical home was chosen as a case study, and the PMV/PPD model in DesignBuilder software was used to analyze the thermal comfort conditions in the Talar room. The results showed that the Talar room's PMV was within the convenient range of 1 to 1 in May, June, September, and October. When compared to other variables, PMV's correlations with Ta ($r = 0.84$), Tr ($r = 0.84$), Top ($r = 0.82$), and Tout ($r = 0.82$) were the greatest, while its connection with RH ($r = 0.69$) was the lowest. PMV was shown to have a higher degree of similarity to PPD ($r = 0.95$).

Vakharia & Joshi (2022) discussed that by using local and regional resources following the local climate and with the aid of climate-responsive design methodologies, traditional architecture is developing from the involvement of people living in a broad range of climatic situations across the globe. As people in metropolitan areas adapt to a new way of life and a different environment, the traditional homes they once called home must also relocate. This dissertation examines the effects of climate change on Pune, the cultural capital of Maharashtra State, India, and its vernacular architecture. The literature is used as a basis for a discussion of the causes and effects of vernacular architecture's transformation.

Chatterjee & Nagdive (2022) stated that in India, the local traditional style of the building reflects the difficulties posed by the country's climatic and socioeconomic conditions. Now that current building methods are more streamlined, require less effort, and seem more durable, architects are beginning to question the reliability of traditional styles. This chapter uses case studies to highlight the distinctive qualities of the vernacular architecture of tropical India, focusing in particular on the state of Kerala in southern India, which presents a unique set of environmental and cultural constraints. Several contemporary case studies by trailblazing architects like Laurie Baker and Nari Gandhi have been examined, all of which incorporate the knowledge of the traditional architecture of tropical India by learning from indigenous pre-modern precedents and global trends. In this chapter, we'll go further into how Baker and Gandhi used vernacular architecture in their sustainable building design approach, and then we'll extend an open invitation to policymakers, planners, and architects to apply this insight to their policies and projects.

Hailu et al., (2021) stated that sustainable design relies heavily on providing occupants' thermal comfort, which is vital to preserving a risk-free interior space. When it comes to thermal comfort, historic and contemporary structures have various requirements, standards, and preferences. Therefore, the purpose of this research is to compare and contrast the thermal comforts of contemporary and historical structures in Semera city, Ethiopia, and to discover the elements that either contribute to or detract from thermal comfort within these buildings. Both subjective and objective measures were used in this investigation. The ASHRAE thermal sensation scale, with its seven discrete values, serves as the basis for this subjective evaluation. The level of thermal comfort inside was determined using an adaptive comfort model following ASHRAE guidelines. The findings showed that 88% of respondents are content with the interior environment in classic homes, however, just 22% are satisfied with the same in contemporary homes based on votes for thermal feeling between -1 and +1. Similarly, 83 percent of those living in conventional homes said they'd rather have the temperature inside stay about the same or be adjusted slightly. On average, conventional residences met the Adaptive Comfort Standard's 80% acceptance range. According to the research conducted, conventional construction methods and materials, in conjunction with microclimate consideration, significantly contribute to the control of the internal climate.

Manzano-Agugliaro et al. (2015) addressed the characteristics of traditional construction all over the globe that take into account the local bioclimatic. Dwellings are designed, planned, and spatially organized in a variety of various ways depending on the particular bioclimatic zone they are located in. Utilization of these climatic-sensitive design principles, as well as their implementation into contemporary structures by the construction sector, would boost the utilization of climatic design in the process of urban architecture. According to the findings of the research, the incorporation of bioclimatic parameters into building design would provide a more pleasant interior atmosphere and reduce the amount of energy required to maintain a tolerable temperature inside structures.

Dili et al. (2010) studied features of Kerala's traditional constructions and found that the utilization of regional resources and special techniques of construction, as well as the presence of complex building concepts, inner open courtyards according to traditional grids, fractions, and size, verandahs, and positioning of the structure, all, contribute to the formation of a pleasant interior climate in households without the need for the use of any additional power sources. According to the research, these neutral climates - responsive elements allowed for the maintenance of warmer interior air temperatures during the winter and cooler indoor air temperatures during the summer. The characteristics also provide a constant, mild flow of wind throughout the structure, which, along with the building's thermal mass, keeps the building's humidity and temperature stable no matter the weather outside. As a result, contemporary homes may benefit from incorporating the design and material utilization qualities of traditional homes.

3. Factors affecting Traditional Architecture

Traditional architecture is shaped by the varying economic, social, and environmental factors of its respective regions. The construction process, orientations, exterior layout, open spaces, sun position, apertures, and the utilization of naturally ventilated air are all key structural aspects of diverse climate conditions. In this part, we'll look at the factors at play in the varying energy efficiency of regional and local traditional forms across the globe.

3.1. Role of Regional Environment and Geography

Different types of building materials and architectural styles are used because they are best suited to the weather of their respective locations. Singh et al. (2009) distinguished some solar energy features example building design techniques, geographic modeling and organizing of various locations consistent with solar radiation and air currents route and position, and the utilization of domestic substances for example “wood”, “cane”, “bamboo”, rock, clay, and “jute” in the study of 42 ancient traditional construction of “North-East India”. It was discovered that individuals adapted their homes to new ways of living by making them more self-sufficient in terms of energy usage. As a consequence, viable, low-cost, and energy-efficient alternatives emerged, most of which are disregarded in today's architectural practices. Assam's climate, traditional building techniques, and modern living standards have all contributed to the development of a distinctive local style of architecture known as "Assam type." The author argues that contemporary homes might benefit from improved thermal comfort with fewer heating and cooling systems by adopting some of the Traditional bio-climatic design aspects (Satheendran & Chandran 2020).

Climate has a crucial impact on the evolution of spatial and architectural elements of buildings, as shown by Canas et al. (2004) in their research of Spanish vernacular dwellings. The study of 212 traditional homes in five distinct climate regions of Spain revealed some bio-climatic strategies tailored to each area, including optimal solar radiation utilization in conjunction with a rain protection strategy for the oceanic climate; protection from cold winters and hot summers through planning constructions by an elevated thermodynamic material and the utilizing compact buildings in the mountainous region. The benefits of these elements may be realized by incorporating them into contemporary building practices (Fathima & Chithra 2021).

Traditional architectural structures' design components, geographical arrangement, and constructing dynamics are quite good in the prevailing environment, leading to natural climatic comfort, according to Nguyen et al (2011). Six distinguished traditional dwellings throughout three different climatic zones were studied for their inside materials, attitude, structural arrangement, and construction processes. These dwellings utilize 17 bio-climatic methods, including building geometry, sun daylighting, naturally ventilated air, transverse airflow, stack air - conditioning, and single-side air circulation. Increased thermodynamic masses, evaporated conditioning, ground temperature control, passive air conditioners via color, thermally isolation of substances, solar radiation, and rainfall drainage are others. Passive techniques for preserving indoor comfort conditions in Vietnam's climate include natural ventilation, the orientation of the building, and sun daylighting (Joshima et al., 2021).

3.2.Considerations of social class and cultural background

Human, cultural, and economic elements all have a role in shaping a region's built environment. These characteristics, as shown by Hanita et al. (2012), have the potential to override the benefits of vernacular systems and the drawbacks of conventional ones. By comparing the two, we see that the human element is crucial in determining the design, construction, and architectural characteristics of the constructed mass. The buildings' energy efficiency reflects this as well. Based on the research, it was recommended that Oman's modern home designs use more vernacular elements. Selected architectural features, spatial patterns emblematic of Oman's sociocultural and climatological features, and interior environmental conditions were the subjects of these surveys. Researchers looked for commonalities between the two approaches to combine their strengths. The findings of the research emphasize the need of taking into account both human and environmental aspects in contemporary home design and planning (Mamtha 2021).

Building methods, aesthetic preferences, and spatial organization are the three defining features of vernacular architecture. Each trait evolves in response to certain environmental, geographical, sociocultural, and economic conditions. Large or compact buildings, a variety of ceilings, wall surfaces, floor finishes, and some architectural components are all elements of the civil engineering process. Weather, terrain, and available building materials all have a role in shaping the design and development of the buildings themselves. Similar design features include the placement of housings, passageways, and different interior spaces; the outline, size, and elevation of rooms; the availability of "central open spaces" such as "courtyards"; the availability of verandas; the availability of doors and windows; the availability of sunspaces; and the building's external and internal aesthetics (Afreen & KP 2021). Table 1 illustrates the basic characteristics of traditional construction.

Table 1: Basic characteristics of traditional construction

S. No.	Characteristics of architecture	Factors affecting characteristics	Features of characteristics
1	Design	"Demographic profile, Socio-cultural characteristics, Socio-economic characteristics"	Room structure: Size and numbers, shape, number of stories, Courtyard position.
2	Construction	Climate, topography	Massive construction and Lightweight Construction
3	Planning	Climate, socio-cultural factors	Compact layout

Economic variables, such as the capacity to spend on façade decorating or interior aesthetic treatments, social factors, and ritual elements, such as events, festivals, and traditional values all play a role. Some of the elements of the design include a tighter building layout in cold climates and a more open one in hot, humid regions to either reduce or maximize the need for mechanical ventilation. Ceiling overhangs over "courtyards" are examples of protecting shading mechanisms that may be installed above openings and at the entrance to provide shelter from sunlight, rainfall, and air currents. Traditional architecture's distinguishing traits and details, and the elements that influence them (Chellappa & Srivastava 2022).

4. Energy Management and traditional construction

The cost of heating and cooling the average Indian home accounts for roughly half of all energy utilized (Energy Conservation Building Code 2007). The movement to reduce the amount of energy used to keep buildings pleasant has gained speed in recent years (Arens et al., 2010) all around the world. The research recommended basing temperature settings in buildings on actual data collected in real-time from occupants in such spaces. Based on these findings various researchers investigate have shown a correlation between thermodynamic comfort, power economy, and the use of passive climate management strategies in conventional traditional construction (Edward and Kurian 2008; Dili et al., 2009; 2010).

4.1.Environmental benefits with the design of the building

The quantity of energy needed to run a building is determined by its form, orientation, and construction mass; as a result, the choice of architectural style should be based on these considerations. Buildings of equal size may be designed in a variety of ways, and as Bostancioglu et al., (2010) illustrated the connection between building budget, warming expenses, the right form, and the right orientation. Options for thermally shielding and suitable building components for the sidewalls, ceilings, and domes were considered and ultimately chosen to make up the compartment. To decrease the price of domestic structures and decrease operation expenditures, relationships were identified among infrastructure prices, warming input prices, the proper shape, and the appropriate position of the facility. Development expenditures and annually warming expenditures for several constructing methods were calculated by factoring in warmth input utilization over multiple time intervals, annual fuel requirements for options available, annual utilization of biogas, and surface sun exposure of buildings. By dividing the total cost by the number of periods in the period and using an interest rate multiplier, we were able to determine that the square and rectangle plan types resulted in the lowest building costs, yearly heating expenditures, and total life cycle costs (Minunno et al., 2020).

4.2.Embedded Power and Material Costs

Elemental and operational energy used in producing, transporting, constructing, and maintaining modern materials all adds up to a significant energy footprint. However, as compared to conventional contemporary materials, traditional resources utilize “very less energy during consumption”. The construction of a demonstration home by Shukla et al. (2009) was analyzed to determine the feasibility of employing “low-energy materials”. The embodied energy of the house's primary “structure, foundation, flooring, finishes, furnishings, maintenance, and electrical work” were all evaluated. Traditional homes were shown to provide significant energy savings and lower annual carbon dioxide emissions when compared to conventional homes (Rasheed et al., 2021).

Using both embodied and operational energy, Praseeda et al. (2014) compared traditional and cutting-edge materials for their energy use. The study found that switching from traditional to contemporary wall materials increases embodied energy. Climate is proven to have a major impact on operational energy. More operating energy is required to ensure interior thermal comfort under very severe climatic conditions. Modern construction materials aren't as good as the passive environmental management measures that are integrated into traditional structures. “Rubble stone masonry”, “burned clay brick masonry”, and “stabilized soil blocks” were compared in different climate zones to determine which material was the most energy efficient for residential usage. In warm-humid and mild climate zones, the results revealed that traditional buildings built with various wall materials did not significantly vary in operational energy usage. For hot-dry climates, however, the operating energy requirements of various walling materials show wide variations. The embodied energy of homes rises noticeably when rubble stone masonry is replaced with burned “clay brick masonry” or stabilized “soil block masonry”. Consequently, the replacement of traditional materials with more contemporary alternatives such as cement and burned clay bricks has a negative impact on the internal thermal comfort environment and increases the amount of energy needed to keep the home at a comfortable temperature throughout the year (Mohan & Adarsh 2021).

Traditional construction materials are very efficient in keeping the interior at a constant temperature, which in turn reduces the need for additional heating or cooling from the outside (Priya et al., 2012). Vernacular materials are renewable resources that, when combined with solar passive methods, may create hospitable indoor environments without using any additional energy. Air traps in "courtyards", solid sidewalls, roofs, and an inclined dome are all considered, the study area for which being the coastal belts of Nagapattinam. Local materials having better thermal resistance, such as mud, mud-brick, and brick, are proven to be particularly useful in preventing interior temperatures from fluctuating. A linear layout of buildings separated by shaded streets, with the streets oriented such that overhangs and sloped roofs provide maximum shading, helps to minimize the building's exposure to the sun and the peak heat flux into the building's interior. To create a pleasant indoor thermal environment, designers should make use of local materials and implement features such as higher ceilings, the provision of verandas to act as a buffer between the exterior and interior environments, openings such as ventilators and skylights to provide cross-ventilation via the stack effect, and so on. The research indicates that if these principles were implemented, fewer artificial techniques would be required to provide thermal comfort. Gupta (2014) found that cutting down on the need to transport building supplies had a positive effect on the environment by lowering emissions of greenhouse gases. Rammed earth building uses far less energy than conventional methods since the embodied and operational energies are so much lower. The findings of the study indicate that the reinforced soil building technology is appropriate for potential diffusion so long as the physical qualities of soil including compressing resilience, good adhesion, and buckling resilience are improved. Based on the results of the investigation, it seems that locally sourced earth, once stabilized, has promising construction applications. A case study of full-scale walls presently under architecture indicated that the rammed earth's physical capability in respect of buckling and compression stiffness was on par with other architectural components. The findings of the study indicate that the reinforced soil construction technique is appropriate for further diffusion so long as the physical properties of soil, including its physical properties, good adhesion, and impact resilience, are improved (Ajay 2021).

Reddy & Jagadish (2003) investigate the energy that is "embodied" in various styles of masonry construction. Brick and soil-cement block structures have the highest overall power inputs, with an analysis showing that replacing any of these materials might result in a 50% reduction in energy use. According to the findings, the embodied energy of a building may be reduced by using non-traditional building components and techniques. These include the use of stabilized soil slabs, pre-engineered ceiling architecture, and filling tile ceilings. Researchers have looked at the whole amount of energy used in the construction process from raw material extraction to finished product assembly to determine the embodied energy of various building materials. The research shows that conventional building materials including aluminum, steel, cement, and lime exhibit very high energy consumption, whereas lime pozzolana cement uses much less energy. For this reason, many resources may be preserved if lime pozzolana cement is used instead of cement in construction. In comparison to more traditional materials like brick, stone, and hardwood, compost slabs were shown to be one of the best energy-efficient options. Ramesh (2012) examined traditional houses' construction metals and relevant techniques for roofing possibilities regarding overall incarnated energy consumed by structure, and he concluded that furnace ash cement, fly ash cement, and fiber-reinforced composite adhesive are all viable substitutes for cement. One may be using concrete sisal-based hybrid walls instead of wooden mixtures or tiles. Traditional materials such as mud phuska and mud layers, as well as modern alternatives such as "lime mortar terracing, flat terracing, lime concrete, pressed clay, and cavity lime concrete" reduce structures' total energy needs (Krishnankutty et al., 2021).

4.3.Traditional architecture and its effect on thermal comfort

The pursuit of thermal comfort has influenced the development of the vernacular building. It is observed that a traditional house's thermal comfort performance is higher than that of a contemporary one. thermal comfort is influenced by four factors: the ambient temperature, the outside temperature, the relative humidity, and the clothing pattern of the individuals in the area (Jin & Zhang 2021, Hailu et al., 2021). Using thermal comfort models created by Dharmasastha et al., (2022), Zheng et al., (2021), and Chellappa & Srivastava (2022), this research evaluates the thermal performance of vernacular architecture in North East areas of India. Humans' thermal perception, adaptations (which include physiological, psychological, environmental, and behavioral changes), and the climate in a given area are all interconnected. Field measurements of interior and outdoor temperatures in a sample of homes and a survey using a questionnaire designed following ASHRAE-55-2004 are also part of this investigation.

ASHRAE-55-2004 analyses how elements such as temperature, thermal radiation, humidity, and air speed in the interior environment interact with individual characteristics such as human activity and clothing to influence people's comfort in the thermal environment. Predicted Mean Vote and Predicted Percentage of Dissatisfaction (abbreviated PMV and PPD, respectively) calculation techniques and the idea of adaptation have been included in the updated standard (ANSI/ASHRAE Standard 55-2010). It is often used to assess the current thermal climate inside a structure.

The convenience temperatures were calculated using the average monthly temperatures by Singh et al., (2009F). The height of the false ceiling, the width of the doors and windows, and the thickness of the outside walls were all measured since these affect the internal temperature. Variations in regional climate were used as comparison points for these metrics. Using the ASHRAE 7-point sensation scale, we compared "comfort" temperatures with "neutral" temperatures and found that, contrary to expectations, comfort temperatures are always linked to adaptations in both the Humphreys and Auliciens models. According to Diz-Mellado et al., (2021) and Tsay et al., (2022) people living in buildings adjust to the average temperatures within their homes so that they are comfortable there. The idea of adaptation implies that when individuals experience difficulty as a result of a change, they will take steps to alleviate that suffering. It's a hybrid of acclimatization and behavior modification. The level of thermal comfort is a "controlled variable" in the homeostatic system they propose.

The role that thermal characteristics like conductivity, transmittance, and thermal mass play in determining the energy and comfortable a structure are discussed by Mellado et al., (2021). Even with conventionally built structures, it is well recognized that nominal design data does not correspond to in situ observed values. Therefore, we have kept an eye on a single room in a rammed earth structure, developed a computerized model, and compared four distinct scenarios by altering the thermal conductivity value (in situ vs. calculated) and taking thermal mass into account in each. Measured values would result in fewer deviations from the standards' limitations and would even meet the worldwide thermal transmittance (K-value) criterion, which would be useful for analyzing conformity with the Spanish energy conservation code. A more practical strategy for restoring historic buildings would include using thinner insulation and retrofitting systems, promoting the use of rammed earth in new construction, and lowering the carbon footprint caused by the construction materials themselves. The results demonstrate that when evaluating thermal comfort, the building model (S1) that makes use of in-situ data and thermal mass is the one that most closely represents reality. Finally, compared to the option where measured values are utilized, maintaining the same level of comfort during the specified winter season would need 43% more energy, and during the selected summer time, 102% more energy.

Hailu et al., (2021) stated that sustainable design relies heavily on a building's occupants' ability to feel warm or cool as they like, making thermal comfort an integral part of any home's security system. When it comes to thermal comfort, historic and contemporary structures have various requirements, standards, and preferences. Therefore, the purpose of this research is to compare and contrast the interior thermal comforts of contemporary and historical structures in Semera city, Ethiopia, and to determine the elements that either contribute to or detract from these comforts. Both subjective and objective measures were used in this investigation. The ASHRAE thermal sensation scale, with its seven discrete values, serves as the basis for this subjective evaluation. The level of thermal comfort inside was determined using an adaptive comfort model following ASHRAE guidelines. The findings showed that whereas 88% of respondents are content with the interior environment in classic homes based on thermal sensational votes between 1 and +1, just 22% of respondents are happy with the same in contemporary homes. Similarly, 83 percent of those living in conventional homes said they'd rather have the temperature where it is or slightly warmer or colder than somewhere else. On average, conventional residences met the Adaptive Comfort Standard's 80% acceptability band. It was discovered via this research that conventional construction methods and materials, in addition to taking into account microclimate, play a crucial role in controlling the temperature and humidity levels within a structure.

Important findings on the vernacular style's impact on the environment may be gleaned from different studies (Algifri et al., 1992; López-Cabeza et al., 2021), who compared the thermal performance of traditional and standard architecture in terms of materials and techniques. Utilizing transient heat transfer analysis, this research compared the thermal efficiency of conventional Yemeni homes to that of traditional adobe homes. The quantitative findings validated the thermal suitability of the local material (adobe) as an alternative to the more commonplace conventional concrete in terms of lower energy expenditures. Several scholars have investigated the thermal comfort of vernacular homes. Models of thermal comfort used in these investigations are reviewed in this paper. Various models have been utilized in research because they were deemed to be the most suitable in terms of contextual factors concerning certain locations. The thermal comfort of vernacular houses in the Hamirpur region of Himachal Pradesh was analyzed using the adaptive thermal comfort model and ASHRAE Standard 55/ISO 7730. The analysis revealed that the climate context, human variables, and period of study all had significant impacts on thermal comfort.

4.4.traditional architecture's climate-responsive energy efficiency

Characteristics of vernacular architecture in various climate zones were studied by Zhai and Previtali (2010), who also identified 114 vernacular areas. Each region's vernacular architecture has its envelope, ceiling, wall, bedroom, architectural shape, height, door, drainage, connectivity to earth, and sheltering styles. This study analyzed how these factors affected energy usage when modeled and optimized for buildings. Traditional homes with earthen walls and thatched roofs are more energy efficient than modern structures built to strict energy codes.

Natural and passive thermal comfort solutions are used in Kerala's vernacular architecture (Dili et al., 2016) to accommodate the region's hot, humid environment. The research confirms that climate-responsive elements in the area are grounded in Vaastu shastra (Indian traditional architecture). Heavy precipitation, high relative humidity, and mild temperatures are typical for Kerala at the moment. Since just two seasons—rainy and dry—tend to dominate, all aspects of planning and design have adapted appropriately (López-Cabeza et al., 2021). Open courtyards, sloped walls and ceilings, cottages at the ceiling end to boost air circulation, ornament nets as air circulation systems for basement areas created by exaggerated timber roofs, and beams containing various walls are all common features. Other common regional components include sludge, limestones, marble rock slabs, cement concrete, timber, and wood for masonry artwork (Joseph et al., 2020). Table 2 displays the variety of traditional architectural styles seen in various climates and places. Variations in traditional buildings are a result of cultural, socioeconomic, climatic, and geographical influences embraced by local populations.

Table 2: Characteristics of traditional buildings that are both energy-efficient and well-suited to their respective climates have been identified (Zhai et al., 2010).

Parameter	Climate		
	Cold	**Hot**	**Composite**
Room structure	Single room structure with fire pit	Single-room structure with good ventilation	Three-four rooms with or without fire pit
Building shape	South-facing, L and U shaped	East-west axes, circular, rectangular	Generally South facing and Rectangular
Courtyard	Not present	Present	Not present
Layout	Compact	Loosely packed	Partially compact
Materials	Roof- slates, thatch, bark, felt, wood, turf, palm leaves	Roof- slates, thatch, bark, felt, wood, turf, palm leaves	Walls- adobe, stone, roof- wood, bamboo and slates, thatch
Building Storey	Multi	Single	Double
Grills	Not used	Intricately carved in stone, wood, Translucent screens	wooden carved jalis
Construction	Massive	Lightweight	Massive

The issues of high temperatures, humidity, and precipitation caused by direct and strong solar radiation are all dealt with by this bio-climatic passive technology. The use of passive strategies such as orienting buildings to take advantage of the sun and wind, designing courtyards and interior spaces to maximize airflow and natural ventilation, protecting the building from the rain with a pitched roof, elevating the foundations of individual blocks to prevent dampness, providing shade from the elements with large overhangs, and using insulating materials like laterite for external walls and wood for interiors are all recommended. These have several practical applications in contemporary homes for achieving and maintaining a comfortable interior temperature (Joseph et al., 2020).

5. Kerala Traditional Architecture

Traditional Kerala buildings are both historic and attractive. The structures are constructed using the guidelines laid down in Vaastushastra, the Indian architectural tradition. The primary idea behind Vaastushastra, a body of knowledge said to have originated in the Vedic period, is that the land and the structure should be seen as mutually supportive. Throughout India, local variations of Vaastushastra have emerged. These regional styles have evolved over the last 500 years, but in Kerala, they have stayed mostly unchanged (Joy & Paul 2021).

5.1.The Basic Form

The nalukettu is the standard unit of a traditional Kerala house, consisting of four separate units that surround a central courtyard. They typically have a square or rectangular layout, with a roof that slopes inward on all sides except the courtyard, which is left open to the sky. To avoid getting wet or too much sun, the courtyard is encircled by a covered verandah. Figure 1 depicts a typical floor plan for a traditional Kerala home. Each of the surrounding blocks, as well as the courtyard itself, is meticulously set out following the prescribed size, scale, and proportions. The structures may have one or two more stories, or additional modules with private courtyards, depending on the size and status of the family living there.

If the modules are repeated, the nalukettu becomes an ettukettu (eight-block building) or a collection of similar courtyards. In many cases, the sunken courtyard serves as the enclosure's focal point. The verandas that go out to the courtyards provide welcome shade from the hot sun (Gupta & Jameel 2020).

Gables (mughappu) are installed at the eaves to improve airflow and to vent excess heat, and roofs have high slopes of up to nearly 45 degrees. In addition, a wooden fake ceiling (tattu) is installed in the rooms to create an attic area, which is then ventilated with beautiful jalli. The lower levels stay cooler because of the huge insulated air gap created by this roof. Walls on the top levels are made up of rows of struts joined by spaced slats; this fenestration design allows air to circulate freely, keeping the rooms cool and providing a soft glow (Dhileep et al., 2022).

5.2.Construction Material

Mud, laterite, granite stone blocks, lime mortar, wood, bamboo, clay roofing tile, and coconut palm leaves are some of the most prevalent materials used in traditional Keralan architecture. While granite stone is robust and durable, its usage is restricted to the foundation of structures owing to its limited availability outside of the highlands. Building blocks made of laterite, which may be found at shallow depths, are a popular choice in Kerala since they are inexpensive, readily available, and simple to work with. The effects of air exposure only serve to strengthen and lengthen its lifespan. Lime mortar is the traditional adhesive for laterite blocks used in traditional construction. The walls are plastered with lime mortar that has had its strength and performance boosted by the inclusion of vegetable juices. The laterite walls are either left unfinished or covered with a lime mortar finish on the outside (Gupta & Jameel 2020).

Keralan architecture also makes extensive use of wood. All sorts of trees and plants are used, from bamboo (Bambusa Oldhamii) to teak (Tectona Grandis). The distinctive features of Kerala residential architecture include the careful selection of wood, precise joinery, skillful construction, and delicate carving of columns, walls, and roof frames. The traditional architecture incorporates a wide variety of mud products, such as mud mortar for laterite masonry and mud filler for wood floors, as well as mud walling, bricks, and clay tiles (for roofing and flooring). Natural admixtures are often kneaded into the mud that is readily accessible in the area. Roofs and walls are often thatched with coconut and palm fronds for further protection (Nair et al., 2022).

5.3.Activities Areas

Both the interior rooms centered on the courtyard and the exterior verandahs and portico make up the bulk of the living space in a traditional Kerala home (poomukham). As a result of the design of the home, the occupants may easily relocate their routines to take advantage of the best circumstances for each season. The use of courtyards is a significant feature of traditional Kerala architecture. They serve as the hubs of daily life, hosting a variety of activities such as washing, cooking, sleeping, and socializing. Afternoons are spent relaxing on the front porch, while the rear verandah serves as a workspace and gathering spot for the ladies. The two side verandas may be utilized as bedrooms or extra storage. During the dry season, the inner courtyard serves as a storage area and a place to dry, clean, and prepare grains, food, etc. Most of the house's activity takes place in the courtyard, making it an important practical space. The verandahs that encircle the courtyard determine the flow of traffic since they serve as the primary access points to the house's most important rooms (Viswanathan & Bhowmik 2021).

6. Analyzing Factors

The typically warm and humid environment of Kerala necessitates that the traditional homes of the state be structured to mitigate the following significant issues.

- Humidity levels are too high.
- We've seen some serious downpours recently.
- High ambient temperatures and
- The impact of the sun's intense rays.

Humidity levels inside are high because the air cannot release enough moisture to allow for evaporation. The building's orientation toward the prevailing wind, the existence of an internal courtyard, and the way the interior is laid out all work together to keep the necessary air circulation going strong. Pitched roofs covered with burned clay roofing tiles, thatch, etc., keep water from penetrating the interiors during the region's frequent and strong rainstorms. Constructing on taller, raised plinths helps keep out dampness to a greater degree. High-intensity solar rays are blocked by large roof overhangs, which also shade the walls and verandas. Even while jalli walls keep out the heat and glare of the sun, they don't restrict the flow of air that's essential to good ventilation. To keep the inside cool, insulating materials like laterite and wood have been used for the outside walls, ceiling, and roof.

6.1.Orientation of Building

Authentic Keralan architecture adheres closely to vasthusasthra's insistence that all four cardinal directions be respected. The improved climate control allows for optimal comfort throughout the year. Using the classic methods based on the sun's path and shadows, we may accurately calculate the cardinal directions. The building has access from the south and the east. The north and south sides of the building house daytime activities, while the west side houses night-time activities.

6.2.Inside Space Arrangement

In spatial planning, the arrangement of rooms is critical. On the southern side, where there is plenty of natural light and breezes, are the semi-open living quarters. Since most of the wind blows from the southwest, the kitchen was strategically placed in the northeast corner of the structure. This keeps the hot air in the kitchen where it belongs and out of the rest of the house. The bedrooms and other living quarters are situated around the courtyard to take advantage of cross ventilation throughout the year.

6.3.Courtyard Location

Buildings that completely or partially enclose an open area are known as "courtyards" or "patios," and they are frequent in warm, humid climates. Microclimates may be altered in these types of areas, thus the name. They are expected to improve the interior comfort conditions of the enclosing building volume since they experience better microclimatic conditions than the surrounding open regions. True if all areas of the building can get sunlight and there is enough ventilation throughout.

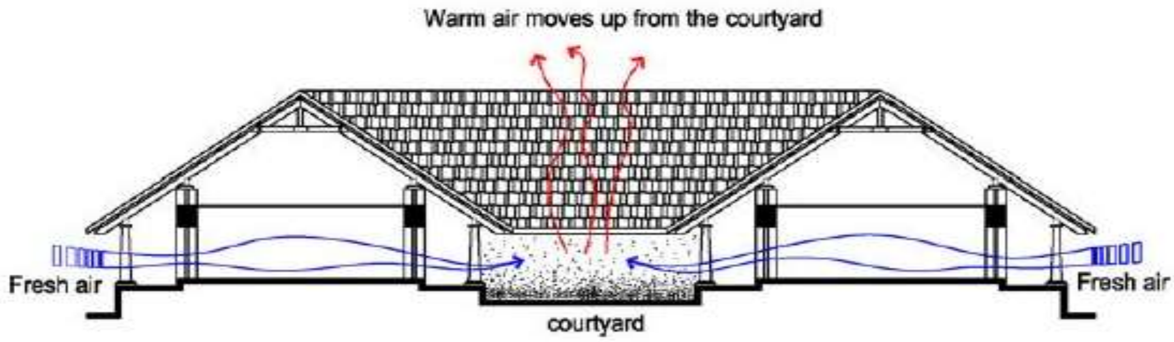

Fig 2: Air movement in traditional architecture (Dili et al., 2010)

Because chilly air is heavier than the heated air around it, it sinks and stays there in the courtyard. The courtyard serves as a natural air conditioner and has many other benefits. In the afternoon, the sun's rays will warm the top level of the courtyard more than the lower levels. As a result, the air in the top section of the courtyard becomes warmer and brighter, rising. As a result, the courtyard experiences a drop in pressure, which causes a breeze to blow in from the open windows and doors as discussed in Fig. 2. After sundown, the phenomena persist until the air in the courtyard has cooled to a comfortable temperature due to convective movement. To learn more about how a courtyard affects airflow and what that looks like when the wind dies down, researchers used smoke to simulate windless conditions. The smoke was produced outside the structure and was permitted to enter the inside. Then, the traffic pattern within and outside the structure was studied. The smoke floated up into the courtyard and in through the partially open door. Seconds after the smoke was turned off, it was no longer detectable within the structure. Given the preceding discussion, it is obvious that convective movement does occur inside the structure (SADANAND & NAGARAJAN 2020).

6.4.Openings and use of natural ventilation

The majority of the dwellings here are spread out over wide plots of land. Therefore, structures are made more permeable to improve ventilation. By leaving open areas between structures, more wind may be captured, improving ventilation. Most structures have several doorways, windows, and other types of ventilation apertures. The availability of open or semi-enclosed areas also allows for substantial ventilation. Open gables (mughappu) are another distinctive element of Keralan traditional architecture, as are the wooden jalli (azhi) that are strategically placed around the outside walls. Courtyard effects are achieved by strategically placing wooden jalli (azhi) on the outside walls.

6.5.Thermal protection

Walls and roofs can keep warm interiors comfortable because of the materials and methods used in their construction. Most vernacular structures have double-layer laterite masonry with a space in between that is filled with fine sand, making the outside walls rather thick (up to a maximum of 750 mm). Due to this, the outside wall is very well insulated. Under the roof, a timber ceiling (tattu) is installed for thermal insulation. As a result, there is plenty of dead air space in the attic to prevent unwanted heat from seeping in through the roof. Openings (jalli) on each side of this volume of air allow for optimal cross-ventilation. The roof's underside benefits from ventilation thanks to the gap between the clay tiles utilized for the surface.

When the inside temperature is greater than the exterior temperature for any reason, and the building's insulation prevents rapid heat loss, thermal insulation may have the opposite effect (Rijal 2021). Vernacular architecture in Kerala solves this issue by allowing outside air to flow in continuously via apertures in the exterior wall.

7. Findings and Discussion

Through the analysis of available literature on Kerala's traditional architecture, this study attempts to conduct a statistical examination of the thermal performance and climatic responsiveness of traditional and contemporary structures in Kerala. The outside temperature varies by 12 degrees Celsius (from 22 degrees to 34 degrees) during the day. But at the same time, interior temperatures were shifting between 26 and 30 degrees Celsius, a difference of just approximately 4 degrees Celsius between night and day as discussed in Fig. 3.

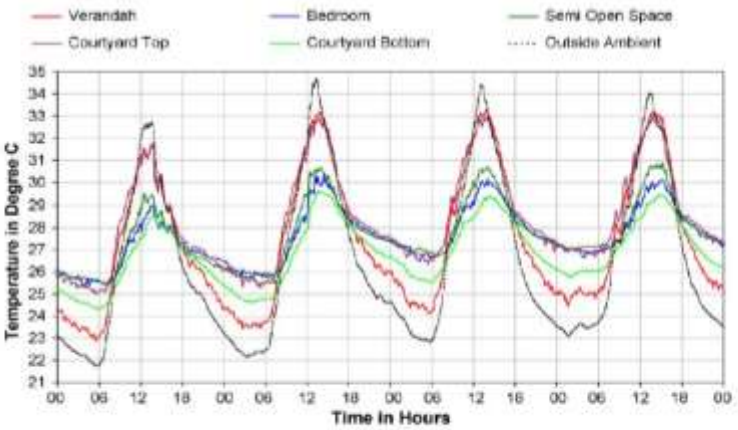

Fig 3: Plot between temperatures and time

The bottom half of the courtyard is around 5 °C cooler than the hottest point outside, whereas the top section of the courtyard is only about 1.5 °C cooler than the hottest point outside. Verandah temperatures fluctuate throughout the day with those of the upper courtyard. Overnight, the bedroom temperature shifts in time with the top courtyard and the semi-open area. As a whole, the chamber is cooler than the semi-open region outside the courtyard by around 4.8 degrees Celsius throughout the day. Even when the ambient temperature drops to a low of 22 degrees Celsius at night, the air inside remains a comfortable 26 degrees Celsius. The difference between the highest temperatures inside and outside is 0.33, and there is no lag in between.

Due to good thermal insulation, the interior temperature displays negligible diurnal fluctuation as discussed in Fig. 3. The building envelope doesn't transmit heat. The lack of a temporal lag between external and internal air temperatures demonstrates the building's thermal insulation and natural ventilation. When it's hot outside, heat scalars are only carried within by wind, which lessens heat intensity.

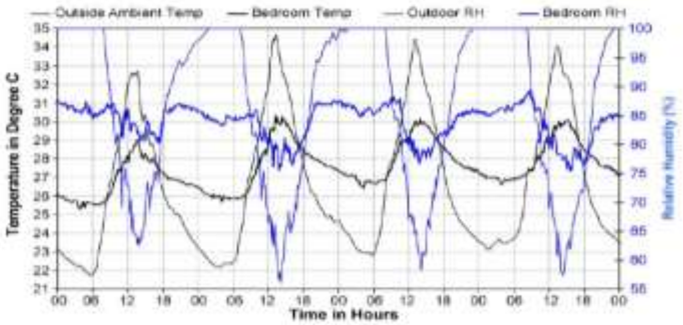

Fig 4: Plot of temperature and RH vs. time

Figure 4 displays the difference between indoor and outdoor temperatures and relative humidity. From the graph, we may infer that there is an inverse connection between temperature and RH. When temperatures are highest, relative humidity (RH) outside is at its lowest, at 58%. When the temperature inside a building hits a high of 30.8 degrees Celsius throughout the day, the relative humidity drops to a low of around 77%. Though nighttime sees the highest relative humidity levels outside (97–100%), and indoors (in the bedroom), RH levels seldom get over 84%. When the RH outside varies by around 40% from day to day, the RH inside only varies by about 10%.

Figure 5 depicts the differences in RH across many settings (outdoor, courtyard, semi-open area, and bedroom). As with the rest of the partially open area, the relative humidity in the bedroom varies. The courtyard's relative humidity (RH) varies the greatest among the indoor environments, yet at night, it only varies by around 3% compared to the bedroom and the semi-open area. The courtyard achieves its lowest relative humidity (RH), approximately 66%, throughout the day.

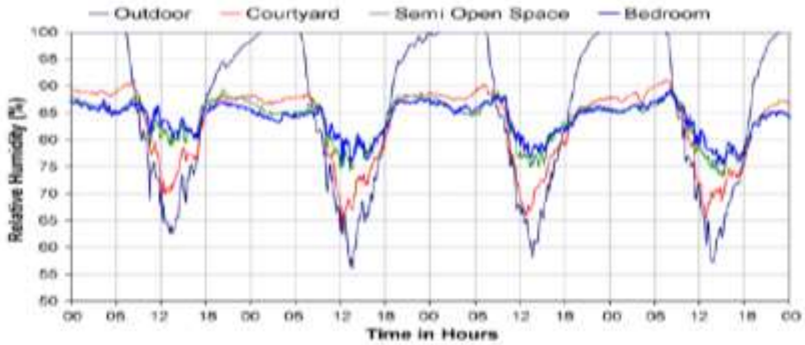

Fig 5: Relative humidity plot with time

Fig 5 demonstrates building RH control. Indoor RH is roughly 85% whereas outdoor RH approaches saturation. This is due to the optimal temperature of interior air volume. Fig 6 displays the air velocity data collected every 5 minutes over 3 days. The outer wind speed varies widely, with a peak at roughly 3.5 m/s, while the inside air velocity is kept constant at around 0.5 m/s. The recording interval was adjusted to 5 minutes to allow for a more comprehensive study of the airflow. As a result, what would normally be a continuous plot of airflow is seen as a series of breaks on the graph.

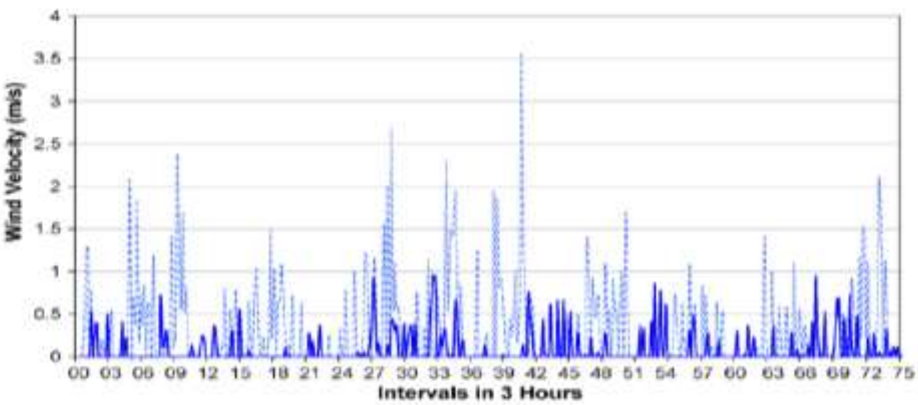

Fig 6: Plot of wind velocity concerning the time

Outdoor air loses heat when it enters a building's interior. As air goes from outside to within, it exchanges heat with cooler surfaces and courtyard air. The lower courtyard is the building's coolest portion as discussed in Fig. 6. As mentioned in the qualitative analysis, colder air sinks. A building's environmental systems are crucial to its sustainability, and its energy usage is directly related to the thermal comfort of its occupants. According to the definition (Shaeri et al., 2018), thermal comfort is a state of mind that indicates contentment with the surrounding conditions in terms of air temperature, humidity, and wind speed. Because of this, the interior environment should be built and regulated passively to ensure the comfort and health of its residents with the minimum amount of external energy.

As can be seen in Fig. 3, the temperature difference between night and day inside is much less than the temperature difference between night and day outside. The reduction factors for the diurnal change of interior air temperature throughout the winter and summer are 0.22 and 0.28, respectively (Dili et al., 2010). Compared to the other two seasons, the decrement factor is found to be somewhat higher during the monsoon period. When the building's temperature throughout the day is compared to the seasonal temperature swings and factors of reduction, it becomes clear that the system can keep the interior at a comfortable level throughout the year.

8. Conclusion

A global survey of research on vernacular architecture is provided to pinpoint energy-saving characteristics that boost interior thermal comfort. The present study with a discussion of the current state of the earth as a building material, statutory requirements, and adaptations of vernacular design for enhancing energy efficiency in the contemporary setting. Traditional or local architecture provides answers that work together with the environment. Vernacular architecture has traditionally placed a premium on the ability to regulate the internal climate. Time-tested passive management mechanisms may be found in traditional buildings all across the world, and they are currently being culled by investigators in the field of energy economic and environmentally friendly architecture.

Kerala's traditional architecture has advanced throughout the centuries thanks to a persistent and persistent search for better, more effective, and more flawless solutions. Kerala's cultural wealth necessitates the intensive quantitative study of traditional architecture's environmental management systems. According to the qualitative research, The surroundings are kept comfortable in Kerala homes thanks to some design features, including a courtyard within the residences and apartments, optimal window openings for uninterrupted airflow, a strongly thermal insulating construction enclose for climatic comfort, verandahs to shield the exterior masonry from solar irradiance, and a pitched roof to keep out the rain.

This reviewed study's results corroborate the conclusions derived from the qualitative research. It follows that research into Kerala's vernacular architecture has shown that its passive environment management system is very efficient at maintaining a comfortable indoor temperature. For human existence to be sustainable, energy-efficient, and pleasant, architecture must make prudent use of acceptable materials and apply relevant traditional methods. Therefore, modern design for warm-humid climates may benefit from the practices used in Kerala's vernacular residential buildings. As a result, it is safe to say that the traditional architecture of Kerala makes use of an efficient passive and natural management system to maintain a pleasant interior temperature climate even during the summer, traditionally the most uncomfortable time of year to spend inside.

References

[1] Afreen, A., & KP, H. S (2021). MUSLIM CULTURE IN THEKKEPURAM, CALICUT: LEGACY AND CHALLENGES. Chief Editor.

[2] Aggarwal, R. K., & Chandel, S. S. (2010). Emerging energy scenario in Western Himalayan state of Himachal Pradesh. Energy Policy, 38(5), 2545-2551.

[3] Ajay, V. S. (2021). Investigation of Different Fishing Gears and Crafts Operated along the Marine Coast of Kuzhuppilli Village, Ernakulam, Kerala with Special Reference to Munambam Harbour. Poult Fish Wildl Sci, 9, 227.

[4] Algifri, A. H., Gadhi, S. B., & Nijaguna, B. T. (1992). Thermal behaviour of adobe and concrete houses in Yemen. Renewable Energy, 2(6), 597-602.

[5] Arens, E., Humphreys, M. A., de Dear, R., & Zhang, H. (2010). Are ‘class A’temperature requirements realistic or desirable?. Building and Environment, 45(1), 4-10.

[6] Bostancioğlu, E. (2010). Effect of building shape on a residential building's construction, energy and life cycle costs. Architectural Science Review, 53(4), 441-467.

[7] Cañas, I., & Martín, S. (2004). Recovery of Spanish vernacular construction as a model of bioclimatic architecture. Building and Environment, 39(12), 1477-1495.

[8] Chandel, S. S. (2006). Strategy for the promotion of passive solar housing technology in western Himalayas. International Energy Journal, 7(4).

[9] Chandel, S. S., & Aggarwal, R. K. (2008). Performance evaluation of a passive solar building in Western Himalayas. Renewable energy, 33(10), 2166-2173.

[10] Chandel, S. S., & Sarkar, A. (2015). Performance assessment of a passive solar building for thermal comfort and energy saving in a hilly terrain of India. Energy and Buildings, 86, 873-885.

[11] Chatterjee, D., & Nagdive, A. (2022). How to Incorporate Sustainable Solutions Through Vernacular Architecture: Case Studies From Tropical India. In Handbook of Research on Issues, Challenges, and Opportunities in Sustainable Architecture (pp. 70-91). IGI Global.

[12] Chellappa, V., & Srivastava, V. (2022). Science mapping approach based review of thermal comfort studies in Indian residential buildings. Journal of Engineering, Design and Technology.

[13] Chunekar, A., Varshney, S., & Dixit, S. (2016). Residential electricity consumption in India: what do we know. Prayas (Energy Group), Pune, 4.
[14] De Dear, R. (2004). Thermal comfort in practice. Indoor air, 14(s 7), 32-39.
[15] Dharmasastha, K., Samuel, D. L., Nagendra, S. S., & Maiya, M. P. (2022). Impact of indoor heat load and natural ventilation on thermal comfort of radiant cooling system: An experimental study. Energy and Built Environment.
[16] Dhileep, M., Ramya, K. M., & Kurian, B. (2022). Aspects of proportions in Indian traditional domestic architecture. Interdisciplinary Science Reviews, 47(1), 62-75.
[17] Dili, A. S., Naseer, M. A., & Varghese, T. Z. (2010). Passive control methods of Kerala traditional architecture for a comfortable indoor environment: comparative investigation during various periods of rainy season. Building and Environment, 45(10), 2218-2230.
[18] Dili, A. S., Naseer, M. A., & Varghese, T. Z. (2010). Passive environment control system of Kerala vernacular residential architecture for a comfortable indoor environment: A qualitative and quantitative analyses. Energy and Buildings, 42(6), 917-927.
[19] Dili, A. S., Naseer, M. A., & Zacharia Varghese, T. (2010). The influence of internal courtyard of Kerala traditional residential buildings in providing a comfortable indoor environment. International Journal of Earth Sciences and Engineering, 3(1), 2-5.
[20] Diz-Mellado, E., López-Cabeza, V. P., Rivera-Gómez, C., Galán-Marín, C., Rojas-Fernández, J., & Nikolopoulou, M. (2021). Extending the adaptive thermal comfort models for courtyards. Building and Environment, 203, 108094.
[21] Edward, S., & Kurian, D. (2008). Thermal performance of traditional buildings in Kerala. The Journal of the Indian Institute of Architects, 7-8.
[22] Energy Conservation Building Code 2007, Bureau of Energy Efficiency (BEE); May 2008.
[23] Fathima, L., & Chithra, K. (2021). Shapegrammar: A Tool for Research in Traditional Architecture.
[24] Foruzanmehr, A., & Vellinga, M. (2011). Vernacular architecture: questions of comfort and practicability. Building Research & Information, 39(3), 274-285.
[25] Gupta, J., & Jameel, N. (2020). Architecture shaped by socio-cultural influence and climate: Lessons learnt from study of vernacular architecture of Kerala. International Journal of Cultural Inheritance & Social Sciences, 2(3), 15-33.
[26] Gupta, R. (2014). Characterizing material properties of cement-stabilized rammed earth to construct sustainable insulated walls. Case Studies in Construction Materials, 1, 60-68.
[27] Hailu, H., Gelan, E., & Girma, Y. (2021). Indoor thermal comfort analysis: a case study of modern and traditional buildings in hot-arid climatic region of Ethiopia. Urban Science, 5(3), 53.
[28] Humphreys, M., & Nicol, F. (2008). Adaptive thermal comfort in buildings. Kinki Chapter of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan.
[29] Jency, P. A., & Atreya, S. (2022). Exploring Aesthetics of Vaastu Shastra: Transformation of Domestic Architectural Spaces. In International Conference of the Indian Society of Ergonomics (pp. 1691-1704). Springer, Cham.

[30] Jin, Y., & Zhang, N. (2021). Comprehensive Assessment of Thermal Comfort and Indoor Environment of Traditional Historic Stilt House, a Case of Dong Minority Dwelling, China. Sustainability, 13(17), 9966.

[31] Joseph, D., Thanikal, J. V., & Joseph, E. (2020). Climatic Responsiveness of the Vernacular Houses towards Developing a Passive Design Sense for Architecture to Reduce Energy Dependency–Case Study. Int. J. Innovative Sci. and Research Tech, 5(10), 1239-1243.

[32] Joshima, V. M., Naseer, M. A., & Prabha, E. L. (2021). Assessing the real-time thermal performance of reinforced cement concrete roof during summer-a study in the warm humid climate of Kerala. Journal of Building Engineering, 41, 102735.

[33] Joy, N. M., & Paul, S. K. (2021). Analysis of the Economic Value and Status of the Ecosystem Services Provided by the Ashtamudi Wetland Region, a Ramsar Site in Kerala. Journal of the Indian Society of Remote Sensing, 49(4), 897-912.

[34] Kairamo, M. (1977). Vernacular architecture and its adaptation to the needs of modern life: the situation in Finland. Monumentum Louvain, 15, 50-56.

[35] Krishnankutty, J., Blakeney, M., Raju, R. K., & Siddique, K. H. (2021). Sustainability of traditional rice cultivation in Kerala, India—a socio-economic analysis. Sustainability, 13(2), 980.

[36] Liu, J., Hu, R., Wang, R., & Yang, L. (2010). Regeneration of vernacular architecture: new rammed earth houses on the upper reaches of the Yangtze River. Frontiers of Energy and Power Engineering in China, 4(1), 93-99.

[37] López-Cabeza, V. P., Carmona-Molero, F. J., Rubino, S., Rivera-Gómez, C., Fernández-Nieto, E. D., Galán-Marín, C., & Chacón-Rebollo, T. (2021). Modelling of surface and inner wall temperatures in the analysis of courtyard thermal performances in Mediterranean climates. Journal of Building Performance Simulation, 14(2), 181-202.

[38] Majid, N. H. A., Shuichi, H., & Takagi, N. (2012). Vernacular Wisdom: The basis of formulating compatible living environment in Oman. Procedia-Social and Behavioral Sciences, 68, 637-648.

[39] Mamtha, K. B. (2021). Rediscovering ammaveedus of travancore (Doctoral dissertation).

[40] Manzano-Agugliaro, F., Montoya, F. G., Sabio-Ortega, A., & García-Cruz, A. (2015). Review of bioclimatic architecture strategies for achieving thermal comfort. Renewable and Sustainable Energy Reviews, 49, 736-755.

[41] Mellado Mascaraque, M. Á., Castilla Pascual, F. J., Pérez Andreu, V., & Gosalbo Guenot, G. A. (2021). Evaluation of the Thermal Comfort and Energy Demand in a Building with Rammed Earth Walls in Spain: Influence of the Use of In Situ Measured Thermal Conductivity and Estimated Values. Buildings, 11(12), 635.

[42] Minunno, R., O'Grady, T., Morrison, G. M., & Gruner, R. L. (2020). Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. Resources, Conservation and Recycling, 160, 104855.

[43] Mohan, R. P., & Adarsh, P. (2021). Strength Characterisation of Nanochemical Stabilized Kuttanad Clay for Pavement Construction. AIJR Proceedings, 137-145.

[44] Nair, P., Singh, D. P., & Munoth, N. (2022). "Heritage Village" Designation Impact on the Village: A Case Study on the Perception of the Residents of Kalpathy Village (Kerala). Journal of The Institution of Engineers (India): Series A, 103(2), 493-500.

[45] Nguyen, A. T., Tran, Q. B., Tran, D. Q., & Reiter, S. (2011). An investigation on climate responsive design strategies of vernacular housing in Vietnam. Building and Environment, 46(10), 2088-2106.

[46] Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and buildings, 34(6), 563-572.

[47] Oliver, P. (1983). Earth as a building material today. Oxford Art Journal, 5(2), 31-38.

[48] Oliver, P. (1997). Encyclopedia of vernacular architecture of the world.

[49] Padmarajan, A., & UR, H. K. A Study on the Tourist Perception with Special Reference to Historical Padmanabhapuram Palace, Thuckalay, Kanyakumari District.

[50] Praseeda, K. I., Mani, M., & Reddy, B. V. (2014). Assessing impact of material transition and thermal comfort models on embodied and operational energy in vernacular dwellings (India). Energy Procedia, 54, 342-351.

[51] Priya, R. S., Sundarraja, M. C., Radhakrishnan, S., & Vijayalakshmi, L. (2012). Solar passive techniques in the vernacular buildings of coastal regions in Nagapattinam, TamilNadu-India–a qualitative and quantitative analysis. Energy and Buildings, 49, 50-61.

[52] Rahman, F., & Halim, N. TOURISM-RELATED URBAN REGENERATION OF HISTORIC CITIES: A REGENERATION STRATEGIES FOR KOCHI, KERALA. Environment, 6(26), 130-142.

[53] Ramesh, S. (2012). Appraisal of vernacular building materials and alternative technoligies for roofing and terracing options of embodied energy in buildings. Energy Procedia, 14, 1843-1848.

[54] Rasheed, S., Venkatesh, P., Singh, D. R., Renjini, V. R., Jha, G. K., & Sharma, D. K. (2021). Ecosystem valuation and eco-compensation for conservation of traditional paddy ecosystems and varieties in Kerala, India. Ecosystem Services, 49, 101272.

[55] Reddy, B. V., & Jagadish, K. S. (2003). Embodied energy of common and alternative building materials and technologies. Energy and buildings, 35(2), 129-137.

[56] Rijal, H. B. (2021). Thermal adaptation of buildings and people for energy saving in extreme cold climate of Nepal. Energy and Buildings, 230, 110551.

[57] Rudofsky, B. (1964). Architecture Without Architects: A Short Introduction to Non-Pedigreed. Architecture. New York: Doubleday.

[58] SADANAND, A., & NAGARAJAN, R. V. (2020). NATURE-INSPIRED ARCHITECTURE OF LAURIE BAKER AND TOYO ITO: A COMPARISON. Eco-Architecture VIII: Harmonisation between Architecture and Nature, 195, 3.

[59] Sajith Kumar, S. V., NisarKannangara, S. K., & Smrithilal, K. (2021). AN ETHNOGRAPHY OF HOUSING OF MUTHUVAN COMMUNITY IN IDUKKI DISTRICT OF KERALA: PROSPECTS AND POLICY.

[60] Sassu, M. (2002). Vernacular housing construction. University of Pisa: Pisa, Italy.

[61] Satheendran, S. S., & Chandran, S. S. (2020). Development of a Cloud Based Spatial Information System for Karunagappally Municipality, Kerala, The God's Own

Country. Journal of Emerging Technologies and Innovative Research (JETIR), 7(7), 2304-2310.
[62] Sayigh, A. (Ed.). (2019). Sustainable vernacular architecture: how the past can enrich the future. Springer.
[63] Shaeri, J., & Mahdavinejad, M. (2022). Prediction Indoor Thermal Comfort in Traditional Houses of Shiraz with PMV/PPD model. International Journal of Ambient Energy, 1-19.
[64] Shaeri, J., Yaghoubi, M., Aflaki, A., & Habibi, A. (2018). Evaluation of thermal comfort in traditional houses in a tropical climate. Buildings, 8(9), 126.
[65] Shukla, A., Tiwari, G. N., & Sodha, M. S. (2009). Embodied energy analysis of adobe house. Renewable Energy, 34(3), 755-761.
[66] Shukla, Y., Rawal, R., & Shnapp, S. (2014). Residential buildings in India: Energy use projections and savings potentials. Growth, 800, 1000.
[67] Singh, M. K., Mahapatra, S., & Atreya, S. K. (2009). Bioclimatism and vernacular architecture of north-east India. Building and Environment, 44(5), 878-888.
[68] Subramanian, S. V. (2021). The Architectural Tradition of Ponnani, Kerala: A Historic Malabar Port Town. Journal of Traditional Building, Architecture and Urbanism, (2), 385-396.
[69] Tsay, Y. S., Chen, R., & Fan, C. C. (2022). Study on thermal comfort and energy conservation potential of office buildings in subtropical Taiwan. Building and Environment, 208, 108625.
[70] Vakharia, M. N., & Joshi, M. Thermal Characteristics of Vernacular Architecture in Warm Humid Region.
[71] Viswanathan, P., & Bhowmik, I. (2021). Compatibility of institutional architecture for rubber plantation development in North East India from a comparative perspective of Kerala.
[72] Zhai, Z. J., & Previtali, J. M. (2010). Ancient vernacular architecture: characteristics categorization and energy performance evaluation. Energy and buildings, 42(3), 357-365.
[73] Zheng, Z., Zhang, Y., Mao, Y., Yang, Y., Fu, C., & Fang, Z. (2021). Analysis of SET* and PMV to evaluate thermal comfort in prefab construction site offices: case study in South China. Case Studies in Thermal Engineering, 26, 101137.