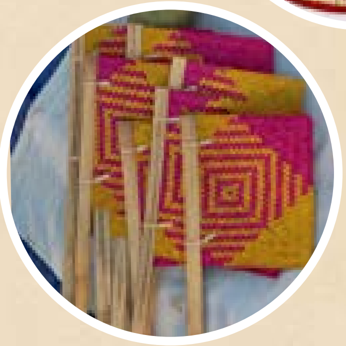
Local Cooling and Heating Practices in Rural India



OZONE CELL

Ministry of Environment, Forest and Climate Change
(MoEF&CC)

LOCAL COOLING AND HEATING PRACTICES IN RURAL INDIA

SEPTEMBER 2026

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भूपेन्द्र यादव

BHUPENDER YADAV

MESSAGE

Rising temperatures and increasing heat stress are emerging as critical challenges across regions, with significant implications for thermal comfort and cooling needs in both urban and rural areas. Addressing these challenges will require energy-efficient and sustainable approaches that respond to local climatic and socio-economic conditions while drawing on traditional knowledge and locally adapted practices.

India's diverse climatic conditions have shaped not only the way communities live, but also the ways in which they create comfortable living environments. Across rural India, generations of communities have developed practices to cope with heat and cold by making thoughtful use of local materials, building forms, natural resources and the surrounding environment.

These practices represent more than traditional ways of maintaining thermal comfort. They reflect a body of knowledge built through generations of observation, experience and adaptation to local conditions. There is value in revisiting and understanding this traditional knowledge which is not only part of our past; it can also offer valuable insights for addressing the challenges of the future. These practices can be further strengthened by integrating them, where appropriate, with modern technologies to meet local needs.

The report, "**Local Cooling and Heating Practices in Rural India**," documents diverse traditional practices from across rural India and highlights their potential relevance in addressing emerging thermal comfort needs. Such documentation is important not only for preserving India's rich traditional knowledge, but also for understanding how these practices can be strengthened and, where appropriate, complemented with modern technologies to develop context-specific and sustainable solutions.

(Bhupender Yadav)

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MESSAGE

Changing climatic conditions and rising temperatures are reshaping the need for cooling and heating across regions. As we look for solutions that are sustainable and locally appropriate, it is equally important to look back at the knowledge and practices that communities have developed and refined over generations.

Across the rural region, communities have adapted traditional practices for their homes and everyday practices to the climatic conditions around them. The choice of locally sourced materials, building types, use of natural resources and daily routines reflects a practical understanding of how to stay comfortable in varying conditions of heat and cold. Much of this knowledge remains embedded in everyday life, even as it receives limited recognition.

The report on **"Local Cooling and Heating Practices in Rural India,"** documents the diverse and not widely recognized traditional cooling-heating practices from across rural India. It offers an opportunity to understand how communities have traditionally responded to heat and cold, and to consider what these approaches can teach us as we seek more sustainable and locally appropriate solutions.

I congratulate the team associated with the preparation of this report.

(Kirti Vardhan Singh)

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सत्यमेव जयते

LiFE
Lifestyle for Environment

MESSAGE

Cooling and heating are often viewed today primarily through the lens of technology. Yet, long before modern cooling and heating systems became widely available, communities across rural regions of India developed ways of responding to heat and cold that were closely suited to their local climate and resources.

Rural cooling and heating approaches extended beyond mechanical systems to include the design and orientation of homes, the use of local materials, natural ventilation, water-based cooling practices, and locally suited methods of heating. They reflect a practical understanding of climate and locally available resources developed through generations of experience. These approaches are particularly relevant in the context of India's diverse climatic conditions and the need for energy-efficient thermal comfort solutions.

The India Cooling Action Plan (ICAP) recognizes passive cooling and sustainable building design as important elements of sustainable cooling. In this context, the report, *"Local Cooling and Heating Practices in Rural India,"* provides useful insights into vernacular architecture, building materials, traditional water-cooling practices, and the socio-economic context of thermal comfort in rural India. The knowledge documented in the report can inform further research and contribute to the development of context-specific cooling and heating solutions.

I commend the team for bringing out this publication and encourage its wider dissemination.

(Tanmay Kumar)

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEE	Bureau of Energy Efficiency
CA/BA	Courtyard Area-to-Built-up Area Ratio
EAT	Earth–Air Tunnel
GI	Galvanized Iron
HCFC	Hydrochlorofluorocarbon
HPMP	HCFC Phase-out Management Plan
MoEF&CC	Ministry of Environment, Forest and Climate Change
NCR	National Capital Region
RH	Relative Humidity
SDG	Sustainable Development Goal
SHG	Self-Help Group
S/V	Surface-to-Volume Ratio
TERI	The Energy and Resources Institute
UNEP	United Nations Environment Programme
W/L	Width-to-Length Ratio
WWR	Window-to-Wall Ratio
ZECC	Zero Energy Cool Chamber

EXECUTIVE SUMMARY

As India faces increasingly extreme heat and climate variability, ensuring thermal comfort in rural areas has become a critical concern. With over 68% of India's population living in rural areas, many of which are disproportionately vulnerable to the effects of climate change, there is an urgent need for sustainable and context-appropriate solutions to manage heat stress. This report presents an in-depth, multidimensional analysis of rural cooling in India, focusing specifically on passive cooling solutions tailored to the diverse climatic conditions across the country's rural landscapes.

The study analyses the rural cooling practices across different climatic zones , socio-cultural factors, and regional gaps, aiming to provide a comprehensive understanding of how passive cooling strategies can offer both short-term relief and long-term resilience to rural communities. The goal is to identify practical, low-cost, and locally adapted solutions that align with the principles of sustainability and climate resilience.

This report also highlights the critical importance of passive cooling solutions in addressing the thermal comfort needs of rural India, especially in the context of climate change. By leveraging traditional knowledge, region-specific approaches, communities can create a more sustainable and climate-resilient rural infrastructure.

Based on the findings, the report presents climate-specific recommendations for strengthening rural thermal resilience through passive cooling, nature-based solutions, sustainable construction practices, and community-centred interventions. It emphasises the need for coordinated action involving policy makers, rural development agencies, technical institutions, researchers, local governments, and communities to mainstream climate-responsive design into rural housing, infrastructure, and village planning.

The report concludes that rural cooling extends far beyond reducing indoor temperatures; it encompasses the creation of climate-resilient, energy-efficient, culturally appropriate, and environmentally sustainable rural habitats. By combining traditional knowledge with scientific understanding and region-specific design principles, India has a significant opportunity to strengthen rural resilience to extreme heat while advancing sustainable development, improving quality of life, reducing future cooling demand, and supporting national climate and energy goals.

Chapter 1

INTRODUCTION

1.1 Background and Context

India's rural population, constituting nearly two-thirds of the country, is increasingly exposed to the adverse impacts of rising temperatures and climate variability.[1] With projections indicating more frequent and intense heatwaves—especially across agrarian and semi-arid zones—the urgency of addressing thermal comfort in rural areas has never been more critical. Rural communities often lack access to sustainable cooling infrastructure, leading to implications not only for health and productivity but also for food security, education, housing, and gender equity.

The concept of "rural cooling" goes beyond conventional air conditioning. It encompasses passive cooling, thermally efficient housing, sustainable, localized heating needs in cooler zones, and context-specific behavioural and architectural adaptations. Despite its importance, rural cooling remains underrepresented in mainstream energy and climate dialogues, largely overshadowed by urban-centric cooling strategies.

1.2 Objectives of the Study

This report provides a multidimensional assessment of rural cooling in India, structured to reflect the diversity of rural India's climatic zones, different vernacular architectures, material usages, drinking water cooling and socio-economic conditions. Anchored in scientific, technical, and policy-based evidence, the study focuses on:

- Mapping thermal comfort across different climatic zones;
- Documenting vernacular and passive cooling-heating practices;
- Evaluating region-specific challenges and gaps;
- Identifying viable, contextually adapted cooling and heating strategies;
- Assessing socio-cultural dynamics influencing technology adoption and usage;
- Proposing recommendations for inclusive thermal comfort.

The report synthesises climatic analysis, building science, socio-economic research, and traditional insights to recommend a climate-zone-wise solution for sustainable rural cooling and heating.

[1] Government of India, Press Information Bureau. (2023, January 31). *Economic Survey highlights thrust on rural development* [Press release]. Government of India. Retrieved September 1, 2025, from Press Information Bureau website

The study also contributes to several United Nations Sustainable Development Goals (SDGs), including SDG 3: Good Health and Well-being, by reducing health risks associated with thermal stress; SDG 7: Affordable and Clean Energy, through the promotion of passive and energy-efficient solutions; SDG 11: Sustainable Cities and Communities, by supporting climate-resilient and sustainable housing practices; SDG 12: Responsible Consumption and Production, through the use of locally available and resource-efficient materials; and SDG 13: Climate Action, by promoting climate adaptation and reducing the environmental impacts of cooling and heating.

Through this study, the report seeks to document and examine the traditional knowledge, vernacular practices, and locally evolved strategies used by rural communities across India to achieve cooling and heating. It aims to understand their relevance across different climatic and regional contexts and identify opportunities for approaches to rural thermal comfort.

Chapter 2

CLIMATIC ZONE ANALYSIS

2.1 Introduction: The Centrality of Thermal Comfort in Rural Development

Thermal comfort is a foundational parameter influencing rural well-being, health, productivity, and energy demand. In India's rural context, where over 68%[2] of the population resides maintaining thermal comfort through passive means is essential for sustainable development.

Defined as the state of mind in which individuals express satisfaction with the surrounding thermal environment, thermal comfort is governed by a dynamic interplay of climatic parameters, human physiological factors, and adaptive behaviours. For rural India, thermal comfort is not merely a physical state but a socio-technical concern intersecting with material affordability, vernacular practices, and energy access.

In rural India, where diverse climatic conditions prevail can be analysed across the five climatic zones defined by the Bureau of Energy Efficiency (BEE) which hot-dry, warm-humid, composite, temperate, and cold achieving thermal comfort is critical for designing sustainable and energy-efficient cooling solutions. This is particularly challenging in rural settings, where access to mechanical cooling systems is often limited, and reliance on passive strategies and adaptive behaviours is common.

These climatic variations, together with vernacular building practices, material availability, and socio-economic factors, lead to highly heterogeneous thermal comfort needs across the country. As a result, understanding and evaluating thermal comfort in rural contexts requires a grounding in the fundamental principles governing heat exchange between the human body and its surrounding environment.

Thermal comfort is rooted in the balance between internally generated metabolic heat and heat dissipation to the environment. The human body continuously produces heat through metabolic processes and must dissipate this heat to maintain thermal equilibrium. Heat exchange occurs through four primary mechanisms: conduction, convection, radiation, and evaporation. The effectiveness of these mechanisms is influenced by environmental parameters such as air temperature, relative humidity, air velocity, and mean radiant temperature, as well as personal factors including clothing

[2] Chandramouli, C. (Registrar General & Census Commissioner, India). (2011, July 15). *Rural–Urban distribution of population: Provisional population totals [PDF]*. Census of India 2011. Ministry of Home Affairs, Government of India. Retrieved September 1, 2025, from the Census of India website

insulation and metabolic rate .Globally, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55[3] provides a globally recognised framework for assessing thermal comfort, identifying six primary determinants:

Determinant	Description
Air Temperature	Primary indicator influencing sensible heat gain or loss in the human body
Relative Humidity	Governs evaporative cooling via perspiration; critical in warm-humid zones
Air Velocity	Enhances convective and evaporative heat loss; vital in passive cooling strategies
Mean Radiant Temperature	Sum of radiation from surrounding surfaces impacting human perception of warmth
Clothing Insulation	Modulates heat exchange; highly contextual depending on seasons and cultural norms
Metabolic Rate	Reflects activity level; rural agricultural work increases cooling needs significantly

These factors interact dynamically with building design, occupant behaviour, and local climate, making thermal comfort a complex interplay of environmental and personal variables. In rural India, traditional practices such as high ceilings, thick mud walls, and natural ventilation are often employed to mitigate extreme temperatures, reflecting adaptive thermal comfort principles.

2.2 Understanding Climatic Zones in India

India's National Building Code 2016,[4] originally introduced in NBC 2005, framework divides the country into five broad climatic zones: **Hot-Dry, Warm-Humid, Composite, Temperate, and Cold**, each demanding tailored thermal comfort strategies. These zones demonstrate considerable heterogeneity in ambient temperatures, solar radiation, rainfall patterns, and diurnal variations, significantly affecting thermal needs and comfort thresholds.[5]

Figure 1 illustrates the geographical extent and regional variation of India's five climatic zones across the country.

Further, understanding these variables is essential to inform climate-resilient rural cooling strategies. Each zone characteristics and features are discussed in Table 1.

[3] American Society of Heating, Refrigerating, and Air-Conditioning Engineers. (2023). ANSI/ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy [Standard summary]. Retrieved September 1, 2025, from ASHRAE website

[4] Bureau of Indian Standards. (2016). National Building Code of India 2016 (Vol. 2, Part 8, Section 1). New Delhi, India: BIS.

[5] Bureau of Energy Efficiency. Energy Conservation Building Code User Guide (Version 0.2 [Public]) [PDF]. Government of India. Retrieved September 1, 2025, from https://beeindia.gov.in/sites/default/files/ECBC%20User%20Guide%20V-0.2%20(Public).pdf

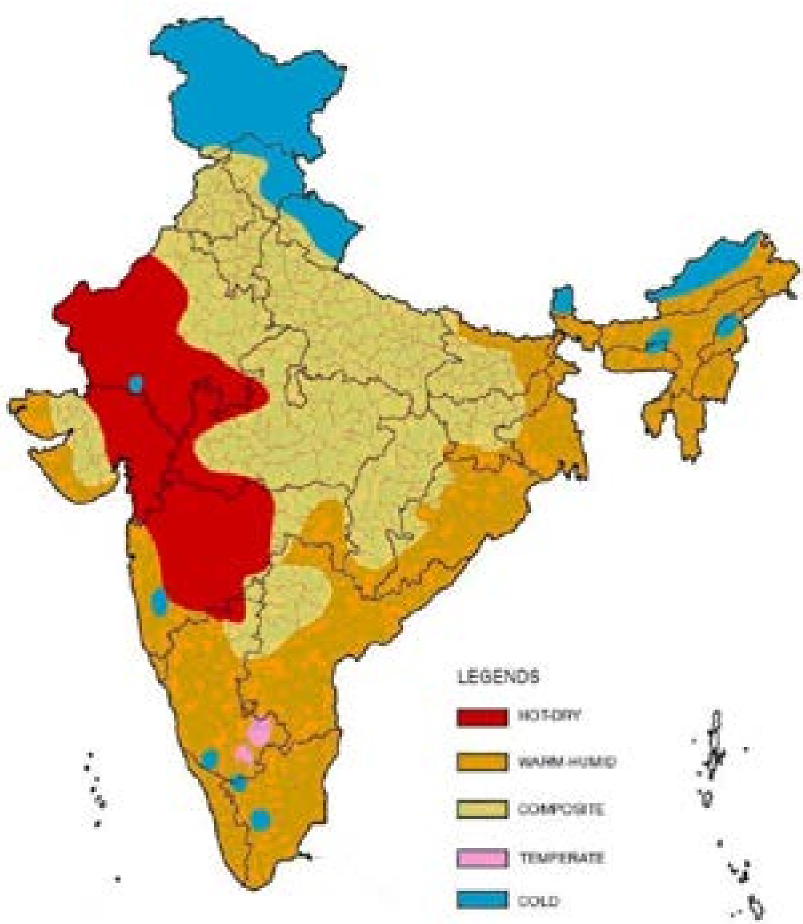
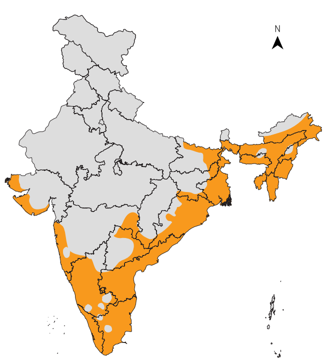
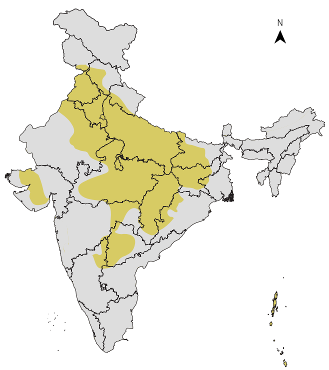
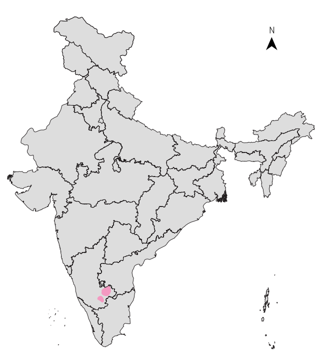
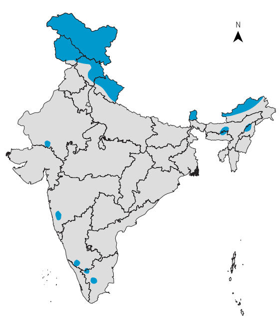


FIGURE 1 Climatic Zones of India as per Energy Conservation and Sustainable Building Code 2024

TABLE 1 Climatic zones of India showing regional distribution, climatic characteristics, key thermal comfort challenges, and preferred passive design strategies.

Climatic-Zone	Regions	Characteristics				Key Thermal Comfort Challenges	Preferred Passive Strategies
		Temperature range (°C)	Indoor Comfort Temperature Range (°C)	Relative Humidity (RH%)	Precipitation		
Hot-Dry Climate 	Rajasthan, Gujarat, Western Madhya Pradesh, Central Maharashtra	Summer daytime temperatures: 40°C to 45°C Nighttime temperatures: 20°C–30°C	26-30	30-50	Below 500 mm/year	High solar radiation, minimal groundwater availability, and heat stress.	Shading, thermal mass, night-time ventilation, evaporative cooling
Warm-Humid Climate 	Kerala, Tamil Nadu, Odisha, and parts of Andhra Pradesh	Daytime temperatures typically range from 30°C to 35°C Night temperatures remain high (25°C–30°C). The diurnal variation is modest (5°C–8°C)	26-29	<60	Annual rainfall typically exceeding 1200 mm	Persistent humidity, ineffective evaporative cooling	Cross-ventilation, raised floor structures, large operable openings, and ceiling fans

Climatic-Zone	Regions	Characteristics				Key Thermal Comfort Challenges	Preferred Passive Strategies
		Temperature range (°C)	Indoor Comfort Temperature Range (°C)	Relative Humidity (RH%)	Precipitation		
Composite Climate 	Delhi, Jaipur, Uttar Pradesh, Bihar, Chhattisgarh, and Jharkhand	Summer temperatures ranging from 32°C to 43°C during the day and 27°C–32°C at night Humidity is also dynamic-dry conditions prevail in summers, whereas monsoons bring elevated humidity (50%–95%)	25–29 (summer); 17–22 (winter)	40–60	Annual rainfall ranging between 500–1300 mm.	Seasonal extremes	Shaded courtyards and verandas, operable skylights, adaptive ventilation, thermal mass walls
Temperate Climate 	Western Ghats (Maharashtra), parts of Karnataka, and sections of Andhra Pradesh.	Summers ranging from 30°C to 34°C during the day and 17°C–24°C at night The diurnal variation remains moderate (8°C–13°C).	24–28	50–70	Annual rainfall typically exceeding 1000 mm	Mostly comfortable; occasional summer heat spells	Natural ventilation, daylighting, use of low thermal mass materials

Climatic-Zone	Regions	Characteristics				Key Thermal Comfort Challenges	Preferred Passive Strategies
		Temperature range (°C)	Indoor Comfort Temperature Range (°C)	Relative Humidity (RH%)	Precipitation		
Cold Climate 	Himalayan and sub-Himalayan regions, including Jammu & Kashmir, Himachal Pradesh, Uttarakhand, and parts of Arunachal Pradesh, Sikkim, and Ladakh.	Long, harsh winters, with daytime temperatures ranging from 4°C to 11°C Summer temperatures remain moderate, with daytime highs of 17°C–24°C and nights between 4°C–8°C.	20–22	40-60	Precipitation also fluctuates: <200 mm/ year in cold/ sunny zones, but up to 1000 mm/ year in cold/ cloudy zones	Winter thermal discomfort; low ambient temperatures	Insulation, passive solar heating, airtight building envelopes

Chapter 3

PASSIVE THERMAL COMFORT STRATEGIES IN RURAL INDIA

This chapter presents a comprehensive climate zone-wise analysis of existing rural cooling and heating practices. This section explores the interplay of passive design elements such as building orientation, ventilation, thermal mass, shading, local building materials, water-based systems, and food preservation practices.

Cooling and heating in rural contexts are deeply intertwined with local traditions, resource availability, and environmental conditions. Vernacular architecture, natural ventilation, and passive cooling methods, such as evaporative cooling and the use of locally sourced materials, have long been employed to mitigate extreme temperature impacts. The findings presented here will feed into subsequent chapters that formulate region-specific, sustainable cooling and heating strategies.

Building Structures Incorporating Passive Cooling Techniques in Different Climatic Zones

The conventional architecture of rural India shows a deep, practical understanding of how to stay comfortable in different climates. Over generations, people have used passive methods of cooling and heating by choosing appropriate materials, layouts, and designs that keep homes liveable while minimising the energy use and maximising thermal comfort. Such designs reflect a careful balance between climate and cultural practices. These approaches are especially important in rural areas, where people often cannot afford active cooling systems. The subsequent subsections, delves deeper into these approaches and their impact on thermal comfort.

3.1 Structural Elements in Rural India: Element-wise Description

Rural residential buildings in India demonstrate some degree of climate responsiveness through their structural configuration, material selection, and spatial organisation. The primary building elements, **walls, roofs, floors, openings, courtyards/verandas, and overall layout** collectively govern heat gain, heat loss, ventilation potential, and thermal inertia. These elements operate as an integrated thermal system rather than as isolated components.

Figure 2 presents a functional classification of key structural elements in rural residential buildings in India and their respective roles in passive thermal regulation. The figure organises rural building elements into five primary categories courtyards/verandas, openings, layout, shading elements, and materials and associates each category with its dominant thermal function relevant to indoor comfort.

Courtyards and verandas supports stack ventilation and night-time cooling, while also providing solar shading and thermal buffering (reduction of sudden temperature changes) for adjacent indoor spaces. The courtyard helps release the heat stored during the day, allowing the house to cool more effectively after sunset. Openings, including doors, windows, and vents, are linked to ventilation and daylighting, highlighting their role in regulating airflow and natural light. Building layout is associated with heat retention or heat dissipation, reflecting the influence of compactness and spatial configuration on thermal performance. Shading elements determine solar control as they limit direct solar exposure. Material selection is linked to thermal mass and solar heat gain control, emphasising the role of construction materials in moderating indoor temperature variations.

Overall, the figure illustrates how different structural elements contribute to thermal comfort through functional roles rather than isolated physical mechanisms, underscoring the integrated nature of passive thermal strategies in rural housing. Figure 2 provides a conceptual framework for the detailed, element-wise analysis presented in the subsequent sections.

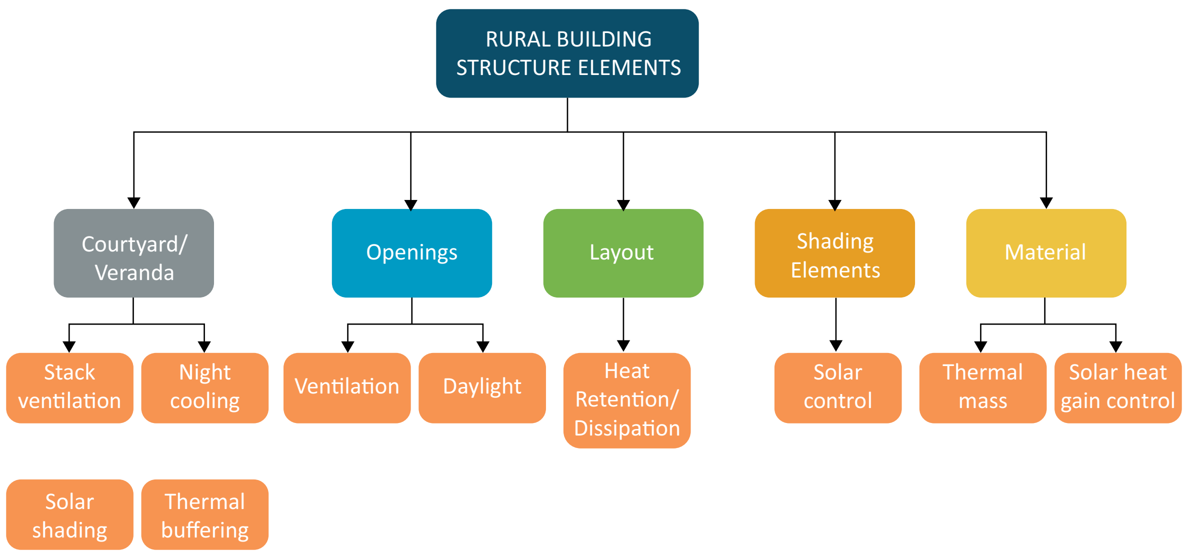


FIGURE 2 Rural Building Structure Elements

3.2 Climate Region-Specific Passive Thermal Strategies in Rural India

The passive thermal strategies adopted in rural housing vary significantly across climatic regions in response to differences in temperature, humidity, solar exposure, and wind patterns. This section examines how building practices, and the use of natural resources are adapted to achieve thermal comfort under distinct climatic conditions. The following subsections present a climate-wise analysis of passive design responses observed in rural India.

3.2.1 Hot-Dry Climatic Region

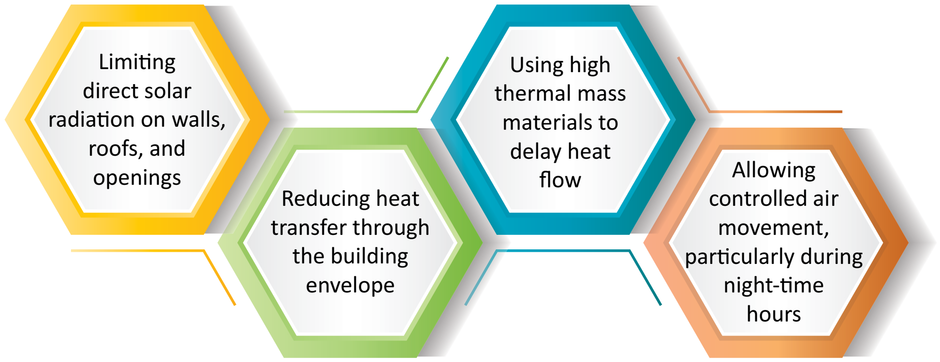
Hot and dry regions of rural India are characterised by intense solar radiation, very high daytime temperatures, low humidity, and large diurnal temperature variation.In such conditions, thermal comfort in rural homes depends on minimising daytime heat gain and allowing stored heat within the

building to dissipate after sunset, when outdoor temperatures fall. This is usually achieved through passive cooling methods that reduce direct sunlight entering the house, limit heat transfer through walls and roofs, and allow controlled airflow.

Key Passive Cooling Principles used in hot and dry region

Passive cooling in hot and dry regions is based on the following principles:

Buildings constructed with thick, high thermal mass materials absorb heat slowly during the day and release it gradually at night, helping maintain more stable and comfortable indoor temperatures.



Although the hot and dry climatic zone is grouped as one category, rural housing practices differ across regions. Variations in building materials, settlement patterns, and local practices are observed between northern and southern parts of this zone. To better understand these differences, the hot and dry region is discussed by dividing it into northern- central and Southern regions.

3.2.1.1 Northern and Central region of the Hot and Dry Climatic zone

One of the common features in hot and dry region are courtyard which are present in Rajasthan and Gujarat. In courtyard-based houses, living spaces are organised inward, reducing direct exposure to harsh external conditions. During the day, courtyards provide shaded semi-open spaces, while at night they act as heat-release zones, allowing stored heat to dissipate through long-wave radiation and natural convection. Courtyards also improve natural ventilation by promoting air movement through adjoining rooms.

Building orientation and layout further support thermal comfort. Houses are often arranged in compact forms with low surface-to-volume (S/V) ratios to reduce exposed wall area.[6] Lower surface-to-volume ratio reduces conductive and radiative heat exchange with the external environment.

Locally available materials also plays a key role in regulating indoor temperatures. In hot and dry regions, construction commonly uses mud, clay, stone, and lime-based materials. High solar reflectance of lime reduces solar heat absorption by wall material.

In addition to this,[7] the thick mud walls provide natural thermal insulation, reducing heat transfer during the day and limiting heat loss at night. This helps protect indoor spaces from intense daytime heat as well as cooler desert winds after sunset, thereby improving thermal comfort in hot and dry climates.

In Rajasthan, rural houses are built using different types of locally available sandstone. Many of these stones have low thermal conductivity, meaning they do not transfer heat easily, reflects a large portion of solar radiation, and warms up slowly, thereby limiting heat transfer to indoor spaces and improving thermal comfort.[8] Sustainable locally available material such as Straws are commonly mixed with mud in walls and roofs. While it does not replace thermal mass, it improves structural stability, reduces cracking due to shrinkage, and enhances insulation by introducing air pockets. This combination results in more stable indoor temperatures over the diurnal cycle.

Figure 3 shows mud–thatch huts in Rajasthan that use locally available earthen materials to moderate indoor temperatures in hot and dry climatic conditions. Thick mud walls and thatched roofs reduce

FIGURE 3 Mud House of Rajasthan

[6] Szokolay, S. V. (2014). *Introduction to Architectural Science: The Basis of Sustainable Design* (3rd ed.). Routledge.

[7] Zhang, Y., Aslani, F., Dyskin, A., & Pasternak, E. (2026). *Effect of saturated lime water curing and CO_2 curing on solar reflectance and thermal radiative properties of cementitious composites. Journal of Building Engineering. Advance online publication*. https://doi.org/10.1016/j.jobe.2026.116212

[8] Pimienta, L., Klitzsch, N., & Clauser, C. (2018). Comparison of thermal and elastic properties of sandstones: Experiments and theoretical insights. *Geothermics*, 76, 60–73. https://doi.org/10.1016/j.geothermics.2018.06.005

heat gain through high thermal mass and insulation, while lime-based surface finishes protect the mud plaster and limit surface cracking. Small, strategically placed openings allow controlled daylight and ventilation without excessive solar heat gain, and the enclosed front courtyard provides a shaded semi-open space that supports daily activities while enhancing privacy and thermal comfort.

While building form, layout, and openings play a major role in reducing heat gain, the thermal performance of rural dwellings in hot and dry regions is further enhanced through careful selection and treatment of wall materials and surface finishes.

In addition to this mud, Lime-based surface finishes are also applied in some regions of rural Rajasthan over thick earthen walls improve durability, maintain wall breathability, and increase some degree of solar reflectance, thereby reducing surface heat absorption and supporting indoor thermal comfort in hot and dry climatic conditions.[9]

Another important climate-responsive building design exist in hot and dry region are The Bhunga house, which are indigenous to the Kutch region of Gujarat. They are a strong example of climate-responsive design suited to hot and dry conditions. These houses are circular in plan, with thick cylindrical walls and a conical roof, as shown in Figure 4. The circular geometry minimises the surface-area-to-volume (S/V) ratio, reducing the extent of wall area exposed to direct solar radiation at any given time. This compact form plays a key role in lowering heat gain. The walls are typically constructed using a composite of mud and cow dung, resulting in high thermal

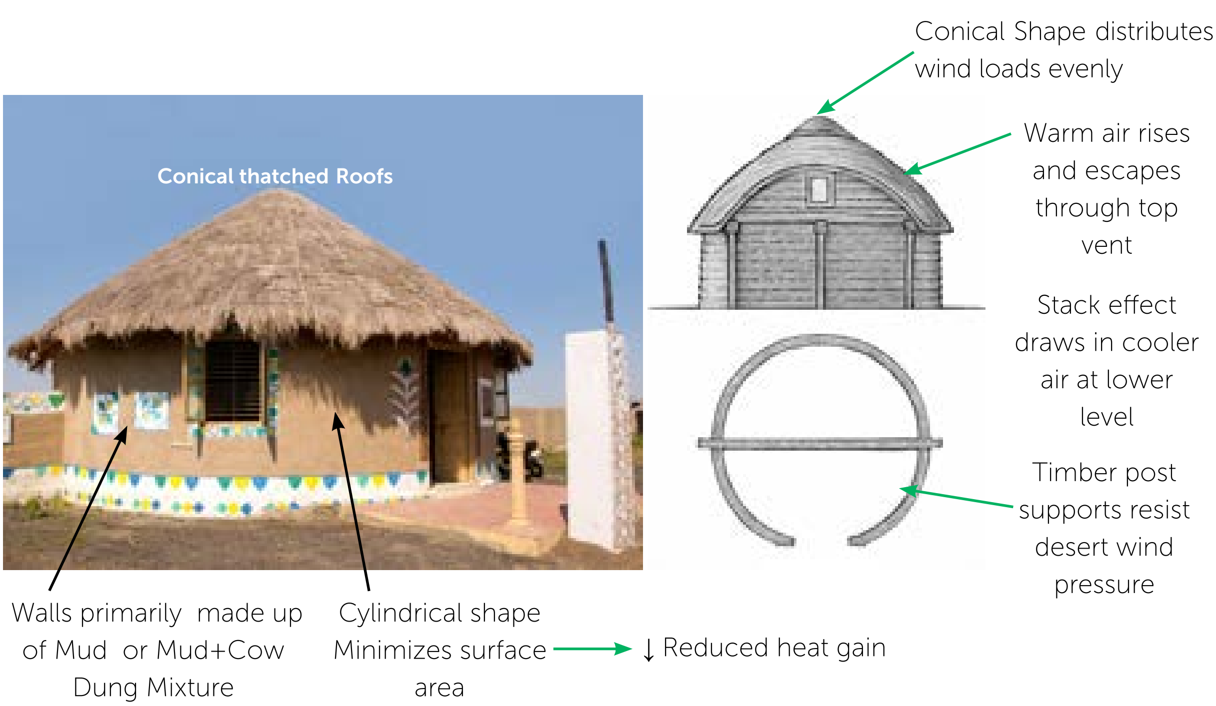


FIGURE 4 Traditional Bhunga House in Rural Gujarat and Its Passive Cooling Features

[9] https://vernacular-architecture.in/regions/west-and-central/

mass. Rural houses in Rajasthan frequently use sandstone, while Bhunga houses in Gujarat rely on mud construction with wooden roof elements.[10] Figure 5 illustrates the use of mud and cow dung composite construction in Bhunga houses, highlighting its role in enhancing thermal comfort under hot–dry climatic conditions.

The conical thatched roof, supported by centrally placed timber posts performs multiple functions. Its shape reduces exposure to direct solar radiation and deflects prevailing desert winds, while the roof height encourages warm air to rise and exit through upper openings. This promotes passive ventilation and improves indoor comfort. Timber posts also enhance structural stability and help the building resist wind pressure common in arid regions.

Bhunga houses in the Bhuj region of Gujarat are constructed as load-bearing structures with mud walls approximately 500 mm thick, which support the entire roof load. The substantial wall thickness provides high thermal mass, enabling the walls to act as a heat sink under extreme climatic conditions.[11]

During daytime, the thick earthen walls absorb heat slowly, delaying its transmission to the indoor space and preventing rapid indoor temperature rise. As outdoor temperatures drop during the night, the stored heat is gradually released to the surroundings, thereby moderating indoor temperature fluctuations across the day–night cycle. This mechanism is particularly effective in arid regions such as Bhuj, which experience large diurnal temperature variations.

In addition to wall thickness, Bhunga houses employ a compact plan, controlled opening-to-wall ratios (≈30%), and breathable mud–straw composites that enhance thermal inertia while allowing vapour diffusion.[11] The compatibility between thick earthen walls and lightweight roofing materials further limits overheating and improves passive thermal comfort in arid climatic conditions.

3.2.1.2 Southern region of the Hot and Dry Climatic zone

In southern region of hot and dry climate, rural houses such as Kalaburagi in Karnataka, compactness is achieved at the settlement level. Houses are built in dense clusters, creating narrow streets and

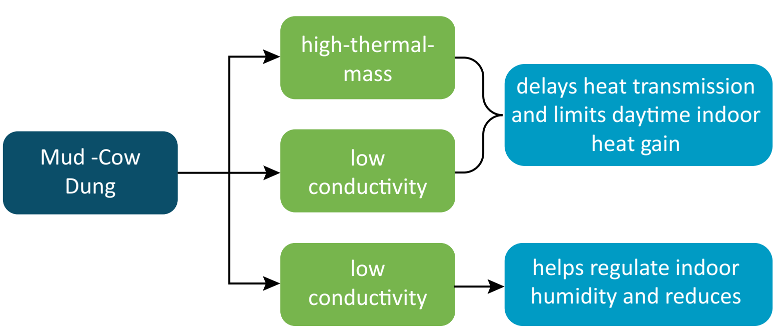


FIGURE 5 Thermal benefits of mud and cow dung wall construction in Bhunga houses

10 Hadawale, S., & Chichkhede, N. (2021.). Understanding indigenous knowledge systems of Bhunga architecture: A literature review. International Journal of Scientific & Engineering Research. https://www.ijser.in/conf/NDCSAPT/NDCSAPT09.pdf

11 Sonawane, M., & Vakharia, B. (2023). Comparative analysis of thermal performance of vernacular dwelling in arid climate of India. International Journal of Technology, Engineering, Arts, Mathematics & Science, Special Issue 1, 403–408.

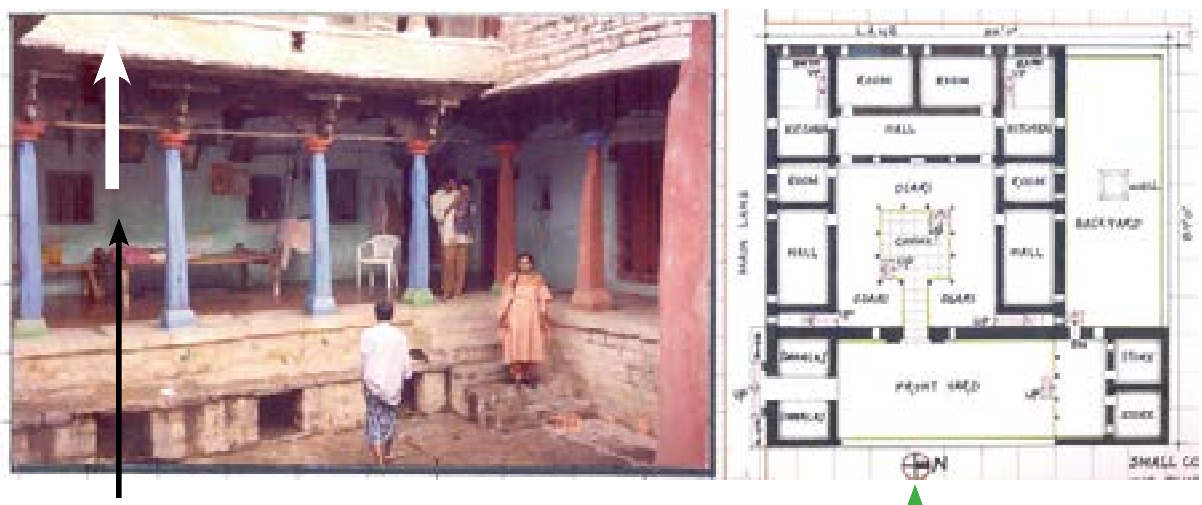
shared walls that provide mutual shading. This collective form significantly reduces solar exposure, particularly on east and west façades, which are most vulnerable to low-angle sunlight.

In Kalaburagi, large rural families live in houses built around central courtyards to manage the intense heat. The courtyard is not an aesthetic feature but a functional thermal space that regulates airflow, daylight, and daily activities.

During the day, shaded portions of the courtyard are used for household activities, while rooms around it remains relatively cool due to thick walls and limited openings. At night, the open courtyard releases stored heat to the sky, enabling cooler air to enter surrounding rooms. Arrows in the Figure 6 A indicate upward heat movement at night and shaded zones during the day.

The houses are typically oriented along the east–west axis, which minimizes solar exposure on the longer façades. They are arranged in compact clusters, reducing the surface-to-volume ratio and enabling mutual shading between buildings (Figure 6 B).

Ventilation strategies in Kalaburagi housing are involves small, recessed openings that limit hot air entry during the day, while night-time ventilation allows accumulated heat to escape. Small windows reduce the entry of hot air and strong sunlight during the day. At night, when the outside air becomes cooler, these openings allow warm air stored inside the house to escape.



Upward movement of warm air which is lighter creating local cooling effect

east–west axis

A) A rural courtyard house with shaded verandahs and inward-looking planning

B) Plan of a courtyard dwelling showing rooms arranged around a central open courtyard.

FIGURE 6 Centrally placed courtyard acting as the thermal core of the dwelling[13]

[13] Seta, F., Biswas, A., Khare, A., & Sen, J. (Eds.). (2017). Understanding built environment: Proceedings of the National Conference on Sustainable Built Environment 2015. Springer. https://doi.org/10.1007/978-981-10-2138-

Deep verandahs, stone balconies, and projecting sunshades act as thermal buffers between outdoor and indoor spaces. These elements reduce direct solar penetration and create comfortable transitional zones. In images, arrows can highlight solar shading paths and buffer zones formed by verandahs (Figure 7).

FIGURE 7 Cooling features of traditional rural houses in Kalaburagi, Karnataka

The most critical cooling element in Kalaburagi houses is the high thermal mass envelope. Walls in traditional Kalaburagi houses are constructed using locally available stone (e.g., finely cut or rough-tooled sandstone, basalt, or Shahabad stone) bonded with lime mortar, with typical thickness ranging from approximately 1″6″ to 3″6″ (about 450–1050 mm).[13] These walls absorb heat slowly during the day and release it gradually after sunset. Figure 8 depicts Basalt and Shahabad stone masonry bonded

[13] Kumari, A., Wanti, J., Swamy, V., & Sakri, S. (2020). Vernacular passive cooling techniques – a case study of a vernacular house in Allur Village, Kalaburagi, India (IJERTV9IS080150). International Journal of Engineering Research & Technology, 9(08), 334–341. https://doi.org/10.17577/ijertv9is080150

FIGURE 8 Basalt and Shahabad stone masonry bonded with lime mortar

with lime mortar, illustrating the high-thermal-mass wall construction commonly used in vernacular houses of the Kalaburagi region.

The interior spaces are enclosed by thick stone walls and minimal openings, which enhance thermal mass and reduce direct heat gain. The deep wall sections and shaded internal seating areas illustrate how rural construction uses material mass to delay heat transfer and maintain cooler indoor conditions during the day.

The combined effect of courtyards, compact form, shading, controlled ventilation, and high thermal mass results in indoor temperature reductions of approximately 4–6°C compared to outdoor conditions during peak summer periods.[14,15] More importantly, these houses maintain thermal stability, avoiding sharp temperature fluctuations.

Overall, these features demonstrate the evolution of indigenous construction knowledge, where settlement planning, locally available materials, and architectural elements have been refined over generations to respond effectively to the climatic conditions of the Deccan Plateau.

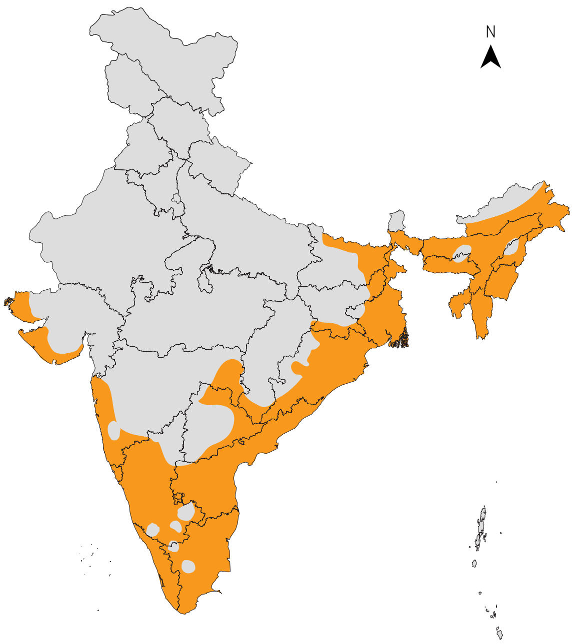
3.2.2 Warm-Humid Climatic Region

Warm and humid regions of rural India include coastal and high-rainfall areas such as Kerala, Tamil Nadu, Odisha, Andhra Pradesh, and the Northeastern states. These regions experience high ambient temperatures (30–35°C), high night-time temperatures (25–30°C), low diurnal variation (5–8°C), and persistently high relative humidity (70–90%). Annual rainfall generally exceeds 1200 mm and is concentrated during extended monsoon periods.

[14] Givoni, B. (1998). Climate considerations in building and urban design. John Wiley & Sons.

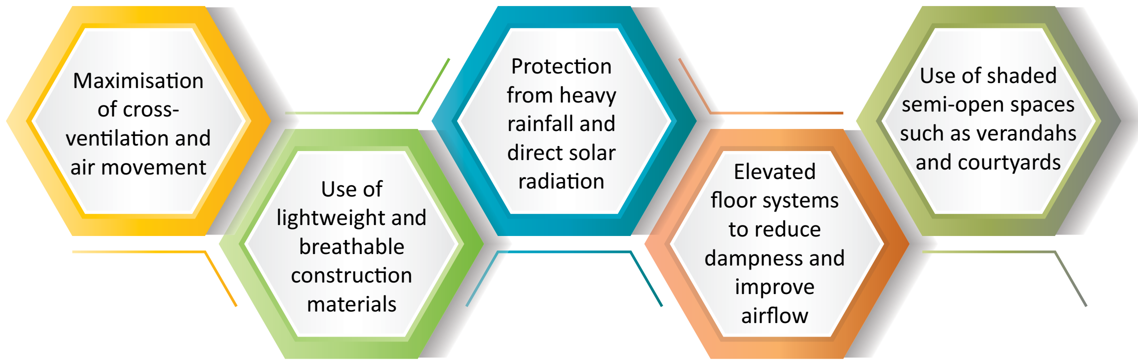
[15] Reddy, B. V. V., & Jagadish, K. S. (2003). Embodied energy of common and alternative building materials and technologies. Energy and Buildings, 35(2), 129–137. https://doi.org/10.1016/S0378-7788(01)00141-4

Thermal discomfort in this climatic zone is primarily caused by high humidity and restricted evaporative cooling rather than extreme air temperatures. High humidity reduces the evaporation of sweat from the skin, limiting the body's natural cooling mechanism and making people feel hotter even when air temperatures are moderate.Therefore, thermal comfort strategies focuson enhancing natural ventilation, preventing indoor moisture accumulation, and limiting solar heat gain., rather than storing or releasing heat.[16]



Passive Cooling Principles in Warm and Humid Regions

Passive cooling in warm-humid climates is based on the following principles:



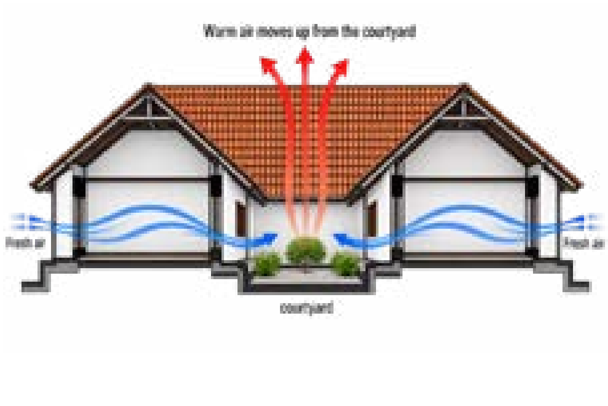
Southern Coastal Warm and Humid Climatic zone (Kerala and Coastal Tamil Nadu)

In the southern warm-humid climatic zone, rural housing traditionally incorporates courtyards and deep verandahs as key passive thermal-regulation elements. In Kerala, the nalukettu house typology is organised around centrally placed courtyards that function as thermal cores. The traditional Nalukettu house is organised around a single central open courtyard (Nadumuttam), enclosed by four interconnected wings that create a compact inward-looking layout.[17]

These courtyard enable cross-ventilation, facilitate stack-driven airflow, and allow hot air to escape during the night. Verandahs located around courtyards and along external façades act as shaded buffer zones, limiting direct solar gain, protecting openings from intense rainfall, and moderating the transition between outdoor and indoor environments.

16 Koenigsberger, O. H., Ingersoll, T. G., Mayhew, A., & Szokolay, S. V. (1974). Manual of Tropical Housing and Building: Climatic Design. Longman.
17 https://www.keralatourism.org/kerala-article/2012/nalukettu-kerala-mansion/155

Figure 9 illustrates a rural nalukettu house with a centrally located open courtyard and surrounding verandahs. The courtyard functions as the thermal core of the dwelling,facilitating stack-driven ventilation by allowing warm indoor air to rise and escape through the courtyard, particularly when outdoor conditions become more favourable during the evening and night. During the day, warm air rises and escapes through the open courtyard, drawing relatively cooler outdoor air from the shaded verandahs and peripheral rooms into interior spaces. The verandahs visible around the courtyard and



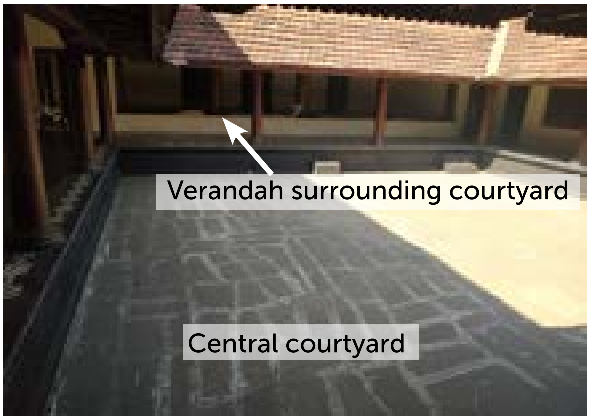
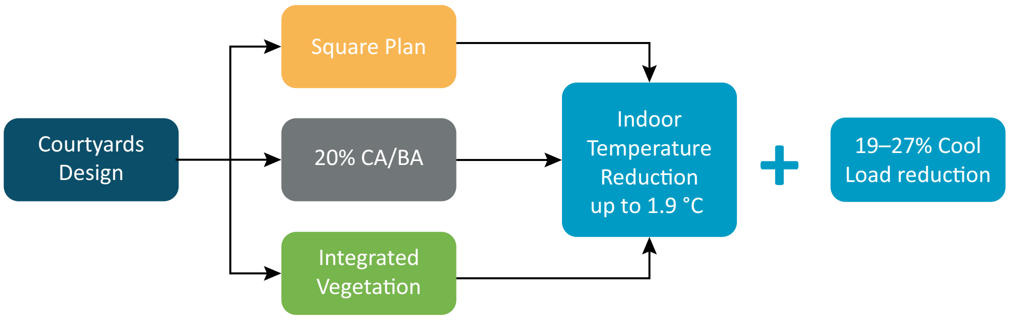


FIGURE 9 Nalukettu house in Rural Kerala (Left) and interior of Nalukettu House showing courtyard (right)

DID YOU KNOW?



Optimum orientation of courtyards[18] in rural Indian homes can reduce indoor temperatures by 0.5–5°C compared to outdoors. The effectiveness of courtyard depends on proportions:

- the width-to-length (W/L) ratio controls sunlight penetration and airflow,
- the courtyard area-to-built-up area (CA/BA) ratio defines its capacity to act as a heat sink.

For example, a courtyard with a 20% CA/BA ratio, square layout, and vegetation can lower temperatures by up to 1.9°C and reduce cooling loads by 19–27%, improving comfort, energy efficiency, and wellbeing in hot climates.

[18] Modifying School Courtyard Design to Optimize Thermal Conditions and Energy Consumption in a Hot Arid Climate | Journal of Architectural Engineering | Vol 30, No 4

along the external façade act as shaded buffer zones between outdoor and indoor spaces. These semi-open areas reduce direct solar heat gain on walls and openings, protect the building envelope from heavy monsoon rainfall, and promote continuous cross-ventilation.

Where external site conditions permit, ,the houses are generally aligned on the east-west axis, so longer sides face north and south. This minimizes heat gain from low-angle morning/ evening sun on east and west sides(Figure 10). Buffer spaces (staircases, verandahs, service areas) are placed on the south side to reduce heat penetration. The openings are positioned with prevailing seasonal winds (often east or west in India) to enable cross-ventilation. In some cases, the buildings are oriented at ±45° to wind direction to maximize airflow.

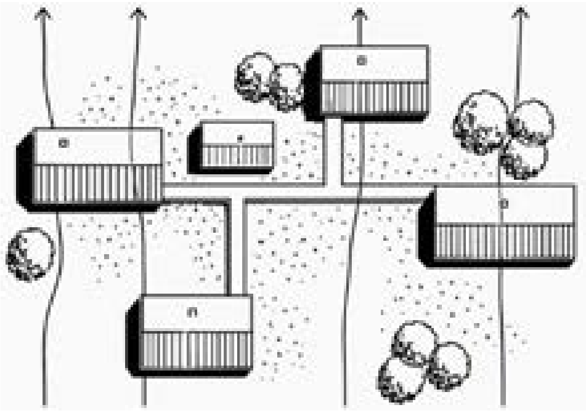


FIGURE 10 Building orientation and spacing to facilitate natural ventilation in a warm–humid climate.
In Warm and Humid, Dwellings structures need to be oriented away from each other giving them a clear scope for cross ventilation without any obstructions.[19]

In southern Kerala, rural houses predominantly use locally available materials to enhance thermal performance and climatic suitability.

External walls are traditionally constructed using thick laterite masonry, which provides high thermal mass. In many vernacular houses, double laterite walls with a sand-filled cavity further enhance thermal insulation.[20] Laterite's open pore structure contributes to moisture buffering, helping moderate indoor humidity when used in naturally ventilated buildings.

Due to this, Laterite walls exhibit a temperature reduction of 3-4°C,[21] while not highly insulative, their porosity and thermal inertia make them effective in warm-humid and well-ventilated environments. Roofs consist of pitched timber frameworks covered with Mangalore pattern clay tiles, which facilitate ventilation at the roof level while providing effective shading.

The combined effect of laterite masonry, ventilated tiled roofs, courtyards, verandahs, and natural ventilation creates a stable indoor microclimate by reducing solar heat gain, enhancing air movement, and responding effectively to the region's warm-humid climate. Field measurements of traditional Kerala vernacular houses have shown indoor diurnal temperature variations of only about 4°C despite outdoor variations of approximately 12°C, while temperatures in the lower courtyard were observed to be up to 5°C lower than the maximum outdoor temperature, demonstrating the effectiveness of

[19] Subramanian, C. V., & Kamalesvari, S. (2016). Daylight and sustainable architecture for warm humid climate. International Research Journal of Engineering and Technology (IRJET), 3(12)
[20] 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.
[21] P., U., & Damle, R. (2024). A case study on thermal performance in residences with laterite stone and rammed earth walling materials in a warm and humid climate (pp. 19–29). https://doi.org/10.62576/KRLD3397

these integrated passive cooling strategies .These characteristics are illustrated in Figure 11, which presents a rural residential building in Kerala constructed using laterite stone walls, timber structural elements, and a pitched roof with Mangalore clay tiles.[20]

FIGURE 11 Traditional residence in Kerala with laterite stone, timber and Mangalore clay tiles

3.2.3 Eastern and North-eastern Warm and Humid Regions

In the eastern and north-eastern warm-humid regions of India, including Assam, Meghalaya, Nagaland, and Odisha, rural housing typologies are strongly shaped by high rainfall, humidity, periodic flooding, and locally available materials. Dwellings in these regions commonly adopt elevated or lightweight construction systems to enhance ventilation, reduce moisture ingress, and improve thermal comfort.

In the northeastern states of India, rural houses are often raised on stilts, creating an elevated living platform above ground level. This configuration protects dwellings from seasonal flooding while allowing air to circulate beneath the floor. The resulting airflow helps remove heat and moisture from beneath the house, keeping indoor spaces cooler and more comfortable. The lightweight construction also prevents excessive heat from being stored in the building, allowing it to cool more quickly. From a thermal perspective, these dwellings have a relatively high surface-to-volume (S/V) ratio, which allows heat to escape more easily and improves natural cooling as indicated in Figure 12.

FIGURE 12 Raised house in rural Assam

In addition to stilt houses, Assam-type houses commonly adopt L-shaped or rectangular layouts with rooms arranged along verandahs to promote natural cross-ventilation. Washrooms are traditionally located away from the main dwelling to reduce indoor moisture levels and maintain hygienic indoor conditions.[22]

Bamboo, along with locally available mud and Sal wood, is widely used in traditional houses as they are readily available, flexible, and strong. Bamboo is used to frame upper wall sections, ceilings, and partitions. Walls are commonly constructed using split bamboo woven into mats (wattle) and plastered with a mixture of mud, often reinforced with cow dung or other natural fibres (daub), as depicted in Figure 13.[22]

In Many traditional Assam-type houses also incorporate bamboo or timber false ceilings that separate the occupied living space from the roof. These ceilings reduce summer heat gain while allowing warm air to accumulate in the roof space, thereby improving indoor thermal comfort. This ceiling

[22] Choudhury, A. S. D., & Chettry, V. (2023). Investigation of bioclimatic design features in vernacular architecture of Northeast India: Case studies of Assam-type houses and stilt houses (Chang Ghar) in Assam, India. Indian Journal of Traditional Knowledge, 22(3), 664–673. https://doi.org/10.56042/ijtk.v22i3.5757

FIGURE 13 Traditional wattle-and-daub wall showing woven bamboo mesh and mud plaster.

arrangement promotes air movement through the roof space, helping remove accumulated heat and moisture before they enter the occupied living spaces.[22] Timber planks are often used for flooring, particularly in elevated or damp conditions, as they provide thermal comfort and resistance to moisture.

Roofs are typically steeply sloped to facilitate rapid drainage during heavy rainfall. Traditionally, timber roof frames with thatch roofing were common, while many contemporary rural houses use galvanized iron (GI) sheets. Wide roof overhangs also provide shade and protect walls from driving rain.

Mud plaster used in these regions (as depicted in Figure 14) is often stabilised with lime to improve its durability and resistance to moisture. In some local traditions, natural additives such as plant-based oils or resins are also incorporated to further enhance weather resistance. A raised plinth protects the base of the walls from rainwater and ground moisture, improving the longevity of the structure. The combination of bamboo and mud produces a lightweight wall system that is easy to repair, structurally resilient, and well suited to warm-humid climates. While the mud plaster moderates heat transfer and helps maintain comfortable indoor conditions, the bamboo framework provides strength, flexibility, and supports natural ventilation.

[22] Choudhury, A. S. D., & Chettry, V. (2023). Investigation of bioclimatic design features in vernacular architecture of Northeast India: Case studies of Assam-type houses and stilt houses (Chang Ghar) in Assam, India. Indian Journal of Traditional Knowledge, 22(3), 664–673. https://doi.org/10.56042/ijtk.v22i3.5757

FIGURE 14 Mud Wattle daub Construction in Warm and Wet Regions of India

The combined use of lightweight local materials, elevated construction, sloping roofs, ventilated ceilings, verandahs, and carefully planned openings enables these traditional houses to respond effectively to high rainfall, humidity, and seasonal flooding while maintaining comfortable indoor conditions with minimal reliance on mechanical cooling.

Another feature that can be observed among the Karbi tribe in Assam is a fascinating example of vernacular tribal architecture adapted to the local hilly environment and cultural practices. Roofs are constructed using locally available thatch, typically long grasses known as *phelang*, which are renewable and well suited for high rainfall conditions (Figure 15). The steeply pitched thatch roofs allow rapid rainwater runoff while providing effective thermal insulation and shading.

FIGURE 15 Rural houses of Karbi tribe (Assam) [23]

[23] Eastern and North-East India. Vernacular Architecture of India. https://vernacular-architecture.in/regions/east-and-northeast/

Together, these design features help keep the house cool, dry and comfortable throughout the year. The raised floor improves air circulation, the steep roof quickly drains rainwater, and the thick thatch layer reduces heat entering the house. These features show how local communities have adapted their homes to the region's warm, humid and high-rainfall climate.

However, in rural tribal settlements of Odisha such as Santhal, Juang, Gadaba, Saora and Kondh regions, houses are primarily constructed using locally available materials such as mud, bamboo, timber, stone, and thatch. Together, these elements help the houses withstand theregion's scorching summers and heavy monsoons while also carrying forward rich cultural traditions. Each community has its own style of construction, with differences in form, layout and decoration that are as much about comfort and survival as they are about identity and aesthetics.

Santhal houses (Figure 16) typically have mud walls, thatched roofs and verandahs that open into central courtyards. Their thick walls slow down the movement of heat into the house , while the sloping roofs ensure that rainwater drains off quickly during the monsoon.

FIGURE 16 Pictures of Santhal House [24]

Juang dwellings, as depicted in Figure 17 are usually small, low in height and rectangular in shape. Built with mud walls and thatched roofs, they are often clustered close together. This compactness not only strengthens social bonds but also helps maintain thermal comfort.

Saora houses (Figure 18) are often arranged in linear patterns on hill slopes. Their mud walls are decorated with ikons or wall paintings, and the houses themselves are compact in volume, which helps them retain warmth during cooler nights.

Kondh houses tend to be long and rectangular with low roofs. They usually face inward for community safety, and it is common for cattle shelters to be built as part of the dwelling, creating a shared system of warmth and security.

[24] Odisha Tourism. Tribal Museum, Bhubaneswar: A delightful collection of tribal heritage. https://odishatourism.gov.in/content/tourism/en/blog-details/tribal-museum-bhubaneswar-a-delightful-collection-of-tribal-heritage-odishabloggerstrail.html

FIGURE 17 Juang house in Odisha[25]

FIGURE 18 Traditional Saora Houses[26]

Across all these types, certain features stand out. Thick earthen walls (0.3–0.6 m) act as a thermal mass, thatched roofs provide natural insulation, and raised plinths protect homes from dampness and flooding during monsoons. Wall paintings are not only cultural expressions but also practical, since lime-based coatings improve weather resistance.

Overall, housing typologies in the eastern and north-eastern warm-humid regions demonstrate effective integration of form, materials, and spatial organization to address ventilation, moisture control, and thermal comfort through passive design strategies. These traditional housing practices have evolved over generations through local experience and understanding of the climate. They demonstrate how indigenous knowledge, combined with locally available materials, can provide comfortable living conditions while reducing dependence on mechanical cooling.

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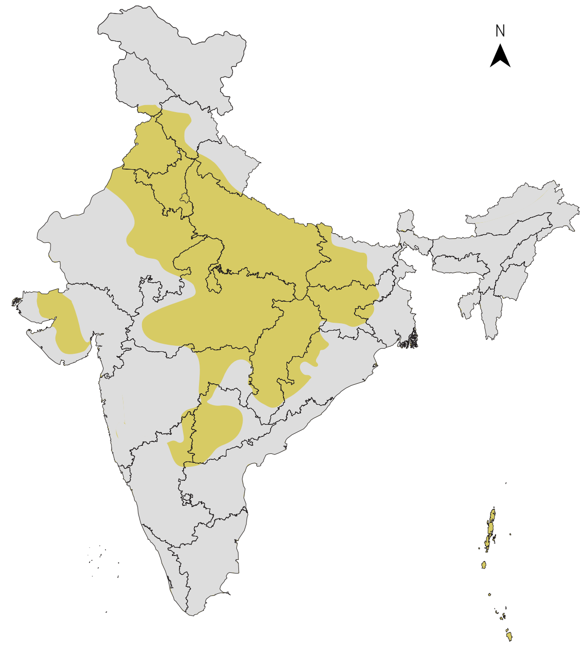
[25] Lunar Secstacy. (2021, May 14). Few traditional tribal houses of Odisha. https://lunarsecstacy.com/2021/05/14/few-traditional-tribal-houses-of-odisha/

[26] Sengupta, A. (2017, January 21). A leisurely tour of Bhubaneswar's Tribal Museum. Mint. https://www.livemint.com/Leisure/gbevxzVS6F20wCcuTKYsAN/A-leisurely-tour-of-Bhubaneswars-Tribal-Museum.html

3.2.4 Composite Climatic Region

Composite climate zones cover extensive parts of north and central India, including the National Capital Region (Delhi), Punjab, Haryana, Uttar Pradesh, Bihar, Madhya Pradesh, Chhattisgarh, Jharkhand, eastern Rajasthan, and parts of Gujarat and Maharashtra, with lower pockets in the plains of Uttarakhand. These regions experience sharp seasonal contrasts from scorching dry summers to humid monsoons, and cold winters, requiring buildings to respond dynamically across the year.



Key Passive Cooling Principles used in the composite region.

Orienting buildings, courtyards, and primary facades to optimise daylight and winter solar gain while minimising harsh summer exposure, supported by overhangs, verandas, recessed openings, and seasonal shading devices.

Appropriate wall thickness, insulation, and roofing systems to reduce summer heat gain, prevent winter heat loss, and protect against monsoon moisture.

local building material mud (wattle-and-daub, cob) or thick masonry that moderate temperature fluctuations, provide breathability, and enhance seasonal adaptability.

Windows, courtyards, ventilators, and operable skylights to enable cross-ventilation in summer, stack effect cooling, moisture management during monsoons, and controlled airflow in winter.

Integrating verandas and transitional spaces that function as shaded living areas in summer and sunlit gathering spaces in winter

Design elements and their features in enhancing thermal comfort in Indo-Gangetic plains

In the Indo-Gangetic plains of Delhi, Uttar Pradesh, and Bihar, traditional dwellings are shaped by the need to cope with extreme seasonal contrasts rather than a single dominant climate. Buildings are typically elongated along the east–west axis to minimise low-angle solar gain from the east and west, while thick masonry walls and inward-looking plans moderate daytime heat. Semi-open courtyards act as thermal buffers remaining shaded during peak summer hours and releasing stored heat at night while verandahs, recessed openings, and adjustable screens allow spaces to be opened up during hot months and enclosed to retain warmth during cooler winters. Research shows orientation and courtyard placement can lower peak indoor temperatures by 2–4°C during hot periods while maintaining winter comfort.[27,28]

[27] Building Materials & Technology Promotion Council (BMTPC). (2013). Energy efficient building design for composite climate. Ministry of Housing and Urban Poverty Alleviation, Government of India

[28] Singh, M. K., Mahapatra, S., & Atreya, S. K. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India. Building and Environment, 45(2), 320–329. https://doi.org/10.1016/j.buildenv.2009.06.009

For example, Clay Tile/Khaprail Roof Houses are usually found in Bihar villages, with sloping roofs covered in clay tiles (khaprail). These tiles are typically handmade and laid in patterns that help shed rain and create cool interiors. Locally made baked clay tiles (khaprail) that are porous and have good thermal mass, they absorb heat during the day and release it slowly, keeping interiors cooler. Stacked in the shape of sloping hip/gable roofs to provide shade and rapid water drainage during monsoon, which protects mud walls and reduces heat buildup. They typically extend beyond the wall line, shading walls and windows, which reduces direct sun on the house and keeps interior air cooler. The overlapping tile layout creates small air gaps. These small air gap beneath the tiles acts as an insulating layer while allowing hot air to escape, helping keep the rooms below cooler during summer.

Simpler mud-walled rural houses with tile or thatched/phuska roofs are also common in older Bihar villages. Walls are also generally made up of local mud or sun-dried bricks, which generate high thermal mass, slowing heat transfer and helping maintain a stable, cooler interior climate during hot summers. Figure 19, illustrates house in a composite region in which the left side shows the mud walled thatched roof, and right side shows mud-wall with a khaprail roof.

FIGURE 19 Clay tile and thatch roofing in a typical rural houses in Bihar

These houses often have smaller openings placed to promote cross-ventilation, allowing air movement while limiting direct solar heat gain. Hence the structure provides natural ventilation through ridge gaps, eaves, and smaller windows, which lets hot air escape and pulls cooler air in. Many houses also incorporate an internal open courtyard, commonly known as an angan, which acts as a ventilation core facilitating air circulation, daylight penetration, and thermal regulation across seasons. Figure 20 Depicts all these passive elements of house in composite region.

What is Khaprail and how does it help in space cooling?

Khaprail is a traditional Indian roofing material, typically made from fired clay.

Each tile has a distinct curved or half-barrel shape. This design increases the surface area exposed to the air, which aids in heat dissipation. The tiles are laid in an overlapping, interlocking pattern. This system creates a series of small, air-filled pockets or a gap between the tiles and the supporting roof structure (often wooden rafters or timber frame). This space allows hot air to rise and escape, drawing cooler air in from below. This constant movement of air acts as an insulating layer that prevents heat from the sun-baked tiles from radiating directly into the room below.

FIGURE 20 Typical rural house with khaprail roofs, mud walls and open courtyard called "Angan"

Design elements and their features in enhancing thermal comfort in the extended Indo-Gangetic plain

Rural households in Jharkhand are also constructed with 450 mm-thick cob walls (depicted in Figure 22), which provide adequate load-bearing capacity and structural stability without the need for reinforcement.[29] Cob walls are a form of earthen construction, made by stacking layers of clay mixed with sand and straw. An average hut is usually 5-6 metre long and 3-4 metre wide.

This indigenous building technique where successive layers of mud are applied to form thick walls has endured for centuries due to its local material availability, low cost, and climatic responsiveness. During peak summer conditions, when outdoor daytime temperatures can reach 42°C, the high thermal mass of cob walls allows them to absorb heat slowly during the day and release it gradually after sunset. This helps keep indoor temperatures more stable and can reduce indoor temperatures by approximately 7°C.[29]

However, the same thermal mass leads to a thermal lag effect i.e is delayed release of stored heat at night. While outdoor temperatures may drop significantly, the walls release stored heat slowly, limiting night-time cooling and resulting in indoor temperatures remaining up to 7°C higher than outdoor conditions. To address this limitation, cob wall dwellings are traditionally paired with some passive cooling such as ventilation strategies. Sloped thatched or khaprail roofs provide effective shading and reduce solar heat gain (example shown in Figure 21). In addition, small, strategically placed window openings enable cross-ventilation, facilitating heat dissipation and improving indoor air movement. Together, these design elements help moderate indoor temperatures and maintain acceptable levels of thermal comfort.

This thermal lag effect is however very effective in keeping the interiors hot in winters. When outdoor temperatures fell to 3–4°C, the interiors remain stabilized around 13°C,[29] preventing extreme cold stress and improving thermal comfort.

FIGURE 21 Typical huts in Jharkhand with Mud wall and khaprail roof[29]

FIGURE 22 450 mm thick mud wall[29]

[29] Gupta, J., & Jain, J. (2023). Thermal performance of mud in composite climate: An overview. KALPA: RVCA Annual Magazine, 4, 75–80. https://rvca.edu.in/wp-content/uploads/2024/07/12.-Thermal-Performance-of-Mud-in-Composite-Climate-An-Overview.pdf

Design elements and their features in enhancing thermal comfort in central India

Some traditional houses are built using locally available materials such as bamboo, wood, along with mud/clay integrated wattle and daub scheme and locally known as 'Ghotul'.[30] These Ghotuls are tribal youth dormitories found in both Chhattisgarh and Madhya Pradesh. The sloping roof systems, typically finished with tiles or thatch, incorporate bamboo sticks laid beneath the outer covering to create ventilated air gaps. These gaps act as natural insulation layers, buffering rapid temperature changes and reducing direct heat transfer into the interior during hot periods. The projecting roof edges also provide localised shading, protect wall surfaces and openings from direct solar exposure, and help reduce unwanted thermal gain while efficiently draining monsoon rainfall.

This roofing system rests over thick mud walls, whose high thermal mass allows them to absorb heat slowly during the day and release it gradually when temperatures fall. Such walls stabilise indoor conditions by moderating extreme outdoor variations. The inclusion of wooden structural members, with their relatively low thermal conductivity, further limits heat transfer, helping interiors remain cooler in summer and warmer in winter.

Openings are treated with equal sensitivity. Bamboo sticks are often used to create simple window shutters or rear doors that allow ventilation. Their semi-permeable nature supports cross-ventilation and enables the quick dissipation of accumulated indoor heat, especially during warmer months (Figure 23).

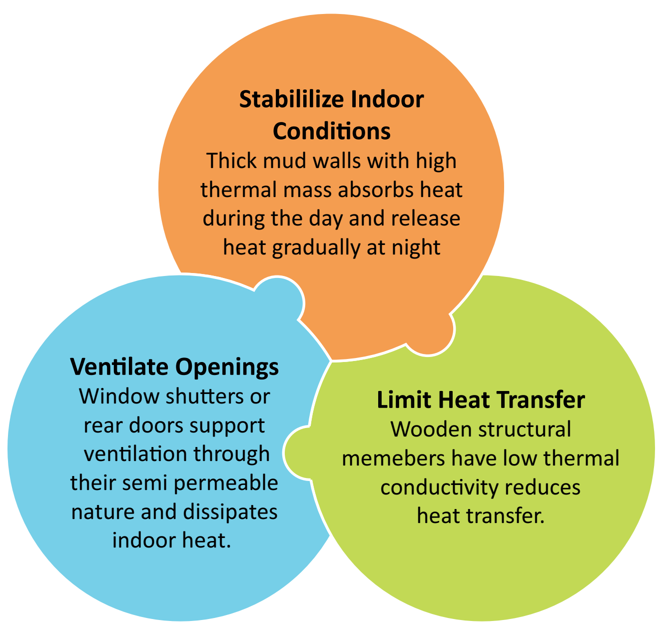
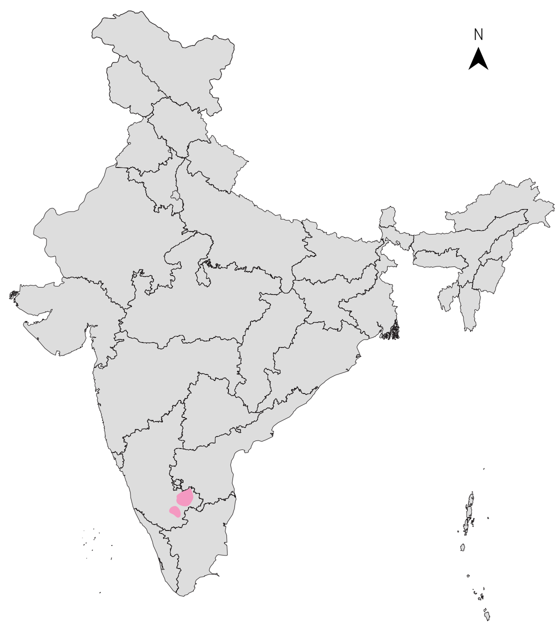


FIGURE 23 Thermal Regulation Cycle in traditional buildings

[30] https://en.wikipedia.org/wiki/Ghotul

Across the broader composite climatic belt from the Indo-Gangetic plains to the plateau regions of Jharkhand and central India these passive principles persist, though expressed through region-specific materials and construction traditions. While the architectural vocabulary shifts from courtyard masonry homes to cob dwellings and bamboo-mud Ghotuls, the underlying logic remains consistent: balancing thermal mass, shading, and ventilation to negotiate extreme seasonal contrasts. Together, these examples demonstrate how adaptive, low-energy design can maintain thermal comfort year-round while offering valuable lessons for contemporary sustainable housing.

3.2.5 Temperate Climatic Region

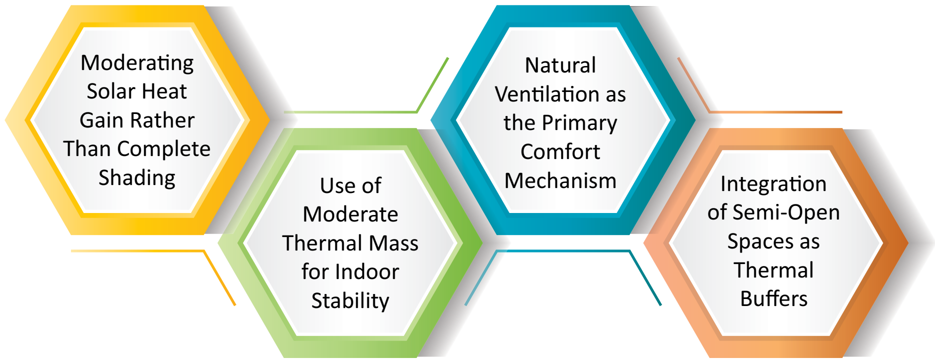


The temperate climatic zone of India represents an extremely limited geographical area characterized by moderate temperatures, relatively low humidity, and comfortable thermal conditions throughout most of the year. The temperate zone is one of the smallest climate zones in India, comprising very specific pockets primarily in southern Karnataka.

The temperate climatic region is characterised by moderate ambient temperatures, limited thermal extremes, and relatively low diurnal temperature variation compared to hot-dry and cold regions. Outdoor temperatures generally remain within a comfortable range for most of the year, reducing the need for either intensive cooling or heating. As a result, thermal comfort in rural dwellings in this zone primarily depends on maintaining indoor thermal stability, ensuring adequate ventilation during warmer periods, and avoiding excessive heat loss during cooler nights or seasonal transitions.

Key Passive Thermal Comfort Principles Used in Rural Temperate Regions

Passive strategies in rural temperate regions focus on comfort moderation, adaptability, and thermal continuity, rather than extreme heat exclusion.



Rural houses in the temperate climatic region of India, mainly found in parts of southern Karnataka, are designed to provide comfort under moderate weather conditions. As shown in Figure 24, these houses typically have sloping tiled roofs, moderately thick walls, and open, well-ventilated rooms. The walls are thick enough to help maintain stable indoor temperatures without storing excessive heat. These design features work together to provide comfortable indoor conditions throughout the year. The sloping tiled roofs reduce heat entering the house while allowing quick drainage of rainwater during the monsoon. Open, well-ventilated rooms improve air circulation during warmer months, while the walls help reduce sudden indoor temperature changes, keeping the indoor environment comfortable across different seasons.

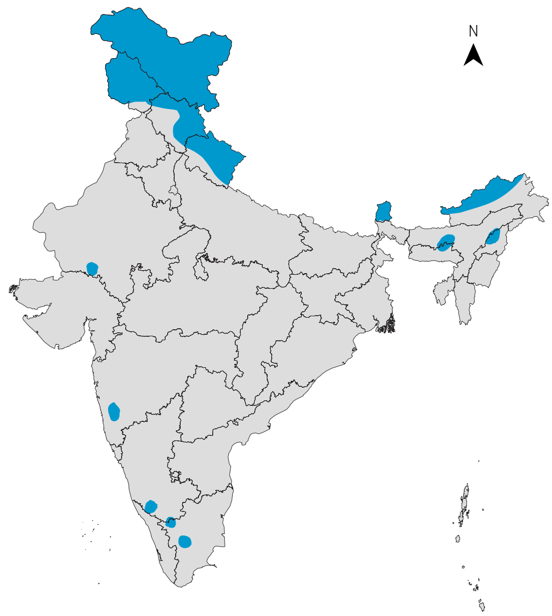
In addition to this, Trees and surrounding vegetation play an important role by providing shade and creating a cooler outdoor environment. Figure 24 depicts rural houses in the temperate climatic region of southern Karnataka, showing tiled roofs, shaded surroundings, and naturally ventilated spaces suited to moderate climatic conditions.

Unlike houses in very hot or very cold regions, these dwellings do not rely on heavy walls, deep courtyards, or tightly closed spaces. Instead, indoor comfort is achieved through natural airflow, shaded spaces, and simple building forms that prevent overheating during warm periods while remaining comfortable during cooler times. This balanced approach reflects the relatively mild climate of the temperate region, where passive design and everyday living practices are generally sufficient to maintain comfortable indoor conditions.

FIGURE 24 Rural houses in the temperate climatic region of southern Karnataka

3.2.6 Cold Climatic Region

Rural settlements in India's cold climatic zone — including Ladakh, Lahaul–Spiti, upper Himachal Pradesh, Uttarakhand, Sikkim and parts of Arunachal Pradesh experiences prolonged winters, frequent sub-zero temperatures, low absolute humidity and strong winds. In such environments, the primary thermal comfort requirement is heat retention and protection from heat loss, rather than heat dissipation. Indoor spaces must maximise daytime solar heat gain while minimising conductive and air-infiltration losses through walls, roofs and openings. Rural Himalayan households predominantly achieve winter comfort through passive architectural measures, which have various elements discussed in the upcoming sections.



Rural houses in cold Himalayan regions are compact multi-storey load-bearing structures constructed from locally available earth and stone. A key thermally functional organization of the houses is the vertical zoning of activity spaces. Ground floors house livestock and storage rooms, while family living spaces occupy upper floors. During winter, animal body heat from ground-floor stables passively warms the floor above, forming a biological heat-buffer layer that reduces heating demand in occupied rooms.[31] Ground floors have minimal openings, thick stone walls and dark interiors to retain heat and reduce air infiltration, directly improving thermal conditions of upper living spaces. Internal or semi-open courtyards act as heat traps. They store sunlight during the day in their thick walls and create a warmer space for daily activities.

Roof construction also plays a critical role in heat retention in cold-climate dwellings. Roofs are typically layered with wooden members, earth, and straw or organic matter, creating both thermal mass and insulation. These layered roof systems reduce upward heat loss and help maintain stable indoor temperatures during prolonged winter periods. The various elements of thermal comfort elements are shown in Figure 25.

South-facing orientation is used to capture winter sunlight. Houses have larger openings on the south side, while the north and west walls have very few openings to block cold winds and reduce heat loss. Ventilation is limited and highly controlled, balancing indoor air quality maintenance with the need to retain heat. Small vents and airtight construction prevent excessive heat loss, while allowing moisture-induced ventilation necessary for health. Figure 26 depicts a remote Ladkahi house with smaller vents which prevent excessive cold air inside the living areas making it thermally comfortable. Window-to-wall ratios in cold-region rural houses are kept deliberately low to minimise heat loss. Openings are

[31] Ferrari, E. P. (2018). High altitude houses: Vernacular architecture of Ladakh (Florence University Press).

FIGURE 25 Central courtyard opening in a traditional rural house in Ladakh

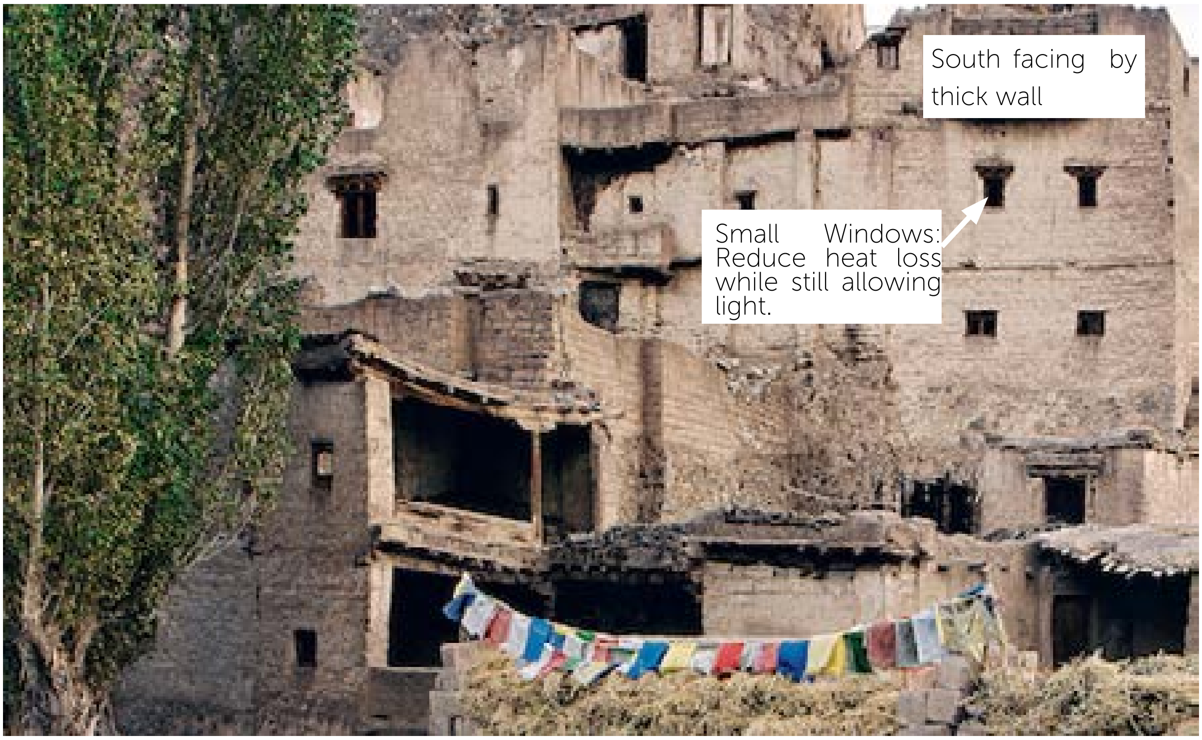


FIGURE 26 Traditional Rural house in a remote village in Ladakh

concentrated on the south-facing walls to balance solar heat gain with reduced conductive and infiltration losses, while north- and west-facing walls often remain nearly blank.

Quantitative analysis of window-to-wall ratios (WWR) from documented case studies further highlights this strategy. North and north-west walls typically exhibit extremely low WWR values, ranging from 0.0% to about 2.4%, effectively minimising heat loss due to cold winds. In contrast, south and south-east walls show higher WWR values, generally between 10.0% and 14.7%, allowing controlled solar heat gain during winter. Despite this orientation-based variation, the overall WWR of the buildings remains relatively low, ranging from approximately 4.5% to 12.1%, ensuring a balance between solar access and heat retention

Building materials in such regions are chosen to store heat and reduce heat loss. Mud brick, rammed earth, and stone masonry have high thermal mass, which allows walls to absorb heat from occupants, cooking activities, and sunlight during the day and release it slowly during cold periods. Studies show that houses built with traditional mud and stone walls can maintain indoor temperatures about 5–6°C higher than outdoor temperatures during winter, highlighting the effectiveness of these materials in retaining heat.[32]

Analysis of Ladakhi rural dwellings indicates that wall thickness varies vertically to optimise thermal performance. Ground floor walls are typically 600–735 mm thick to maximise heat retention, while first-floor walls range between 400–500 mm. Upper floors, where present, have comparatively thinner walls of approximately 230–350 mm, balancing structural efficiency with reduced thermal mass requirements.[33] Table 2 depicts key passive elements in cold Ladakhi house with their thermal function.

TABLE 2 Key envelope parameters in vernacular cold-region dwellings

Building Element	Typical Values Observed	Thermal Function
Ground floor wall thickness	600–735 mm	Heat retention, wind protection
Upper floor wall thickness	230–500 mm	Balanced thermal mass
North wall WWR	0.0–2.4 %	Minimise heat loss
South wall WWR	10.0–14.7 %	Solar heat gain
Overall building WWR	4.5–12.1 %	Controlled daylight & heat

Research indicates that such wall systems can increase indoor temperatures by approximately 0.7–3.5 °C during winter nights, helping reduce discomfort during the coldest hours. High thermal mass construction also helps stabilise indoor temperatures throughout the day and night. Compared to low-mass buildings, traditional houses show a reduction in daily indoor temperature fluctuations of about 0.9–1.2°C, resulting in more stable indoor conditions.[34]

32 International Journal of Research Publication and Reviews. (2022). Thermal behaviour of traditional houses in Kinnaur, Himachal Pradesh. International Journal of Research Publication and Reviews, 3(7).https://ijrpr.com/uploads/V3ISSUE7/IJRPR5921.pdf

33 Mehta, D., Gajjar, V., & Bhavsar, F. (2021). Sustainable potentiality of achieving thermal comfort in vernacular Ladakhi dwellings in cold desert of India: Case study of Ladakhi houses in Leh, Ladakh. International Seminar on Vernacular Settlements (ISVS 12), Faculty of Architecture, Silpakorn University, Bangkok, Thailand, 380–397.

34 Sharma, R., & Sharma, V. (2022). Thermal performance study of traditional slate-roofed mud houses. Visions for Sustainability, 18, 1–15 https://ojs.unito.it/index.php/visions/article/view/8940

In addition, studies report that traditional masonry construction in Himalayan regions offers approximately 25–30 % greater heat retention than modern masonry systems, making it well suited for rural housing in cold climates.[35]

3.3 Climatic Zone-Based Natural Solutions

Before technology-driven living, human settlements relied on natural features like terrain, geology, water sources, vegetation, slope orientation, and soil conditions to regulate heat and cold.[36,37] In rural India, this evolved into nature-based techniques to reduce environmental discomfort,[38] shaping settlement practices closely adapted to the local environment and ecology.[39]

Use of Water Bodies for Thermal Comfort in Rural Regions

Water bodies have long played a vital role in enhancing thermal comfort in rural settlements. Beyond providing water for domestic needs and agriculture, ponds, rivers, tanks and other traditional water systems help regulate the local microclimate by reducing build-up heat, promoting evaporative cooling, and supporting surrounding vegetation. Recognising these benefits, traditional rural settlements across India deliberately integrated water bodies into their settlement planning as climate-responsive infrastructure (Table 3). This strategic location of settlements in proximity to water bodies eventually reflects an environmentally responsive planning approach rooted in local ecological knowledge. Beyond ensuring water security, these systems enhanced thermal comfort by promoting evaporative cooling, retaining soil moisture, maintaining favourable humidity levels, and moderating diurnal temperature variations.[40,41,42,43]

[35] Bhat, T. M., Kumar, R., & Singh, J. (2025). SVR-based comparative assessment of thermal performance of traditional and contemporary masonry structures in Himalayan region.

[36] Tao, J., Chen, H., & Xiao, D. (2017). Influences of the natural environment on traditional settlement patterns: A case study of Hakka traditional settlements in Eastern Guangdong Province. Journal of Asian Architecture and Building Engineering, 16(1), 9–14.

[37] Yu, H., Luo, Y., Li, P., Dong, W., Yu, S., & Gao, X. (2021). Water-facing distribution and suitability space for rural mountain settlements based on fractal theory, south-western China. Land, 10(2), 96.

[38] Meetei, K. B., Tsopoe, M., Giri, K., Mishra, G., Verma, P. K., & Rohatgi, D. (2023). Climate-resilient pathways and nature-based solutions to reduce vulnerabilities to climate change in the Indian Himalayan region. In Climate change in the Himalayas (pp. 89–119). Academic Press.

[39] Uniyal, S., Lodhi, M. S., Pawar, Y., Thakral, S., Garg, P. K., Mukherjee, S., & Nautiyal, S. (2024). Passive solar heated buildings for enhancing sustainability in the Indian Himalayas. Renewable and Sustainable Energy Reviews, 200, 114586.

[40] Poole, G. C., & Berman, C. H. (2001). An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms

[41] Srivastava, A., & Chinnasamy, P. (2021). Water management using traditional tank cascade systems: A case study of semi-arid region of Southern India. SN Applied Sciences, 3(3), 281.

[42] Ramabrahmam, K., Keesara, V. R., Srinivasan, R., Pratap, D., & Sridhar, V. (2023). Climate change impact on water resources of tank cascade systems in the Godavari Sub-Basin, India. Water Resources Management, 37(6), 2853–2873.

[43] Pacini, N., Giberti, G. S., & Harper, D. (2024). Linking hydrology to biodiversity, ecosystem services and climate within the Lake Naivasha Catchment. Africa-Europe Group for Interdisciplinary Studies, 1, 128–155.

TABLE 3 Water Body–Based Passive Practices for Thermal Comfort Across Climatic Zones

Water Body Type	Thermal Comfort Mechanism	Hot-Dry Zone	Semi-Arid / Composite Zone	Warm-Humid Zone	Temperate / Cold Zone
Natural Depression Ponds[44]	Evaporative cooling, soil moisture retention, and enhanced evapo-transpiration	Johads (Alwar) recharge aquifers; Khadins (Jaisalmer) retain runoff; Talabs (Bhuj) cool settlements	Bundelkhand talabs recharge wells; vegetated ponds reduce land temperature (2–4°C); ponds with agroforestry lower surface heat	Koraput ponds support gardens and cool courtyards; Srikakulam paddy ponds maintain humidity	Kumaon & Himachal upland ponds support livestock and soil moisture
Settlements along Rivers/ Natural Drainage[40,45,46]	Evaporative cooling, ventilation corridors, riparian shading, and moderated diurnal temperatures	Banas villages use riverbeds as cooling corridors; Saurashtra check dams reduce temps (3–5 °C); Paithan shaded ghats	Betwa–Ken riparian buffers; Narmada ghats store coolth; Son floodplain moisture aids comfort	Kerala canals act as wind corridors; Odisha plantations reduce heat; Sundarbans creeks lower indoor temps (2–3 °C)	Coorg tributaries with bamboo buffers; Ladakh terraces and tree belts moderate extremes
Cascade Reservoir Systems[41]	Largescale evaporative cooling, humidity regulation	Rayalaseema tank chains cool land; Karnataka kere systems maintain humidity; Warangal tanks reduce heat (2.5–3 °C)	Dhamtari cascades regulate airflow; Satpura tanks trap fog; Bhandara linked tanks buffer diurnal range	Palakkad cascades channel cool airflow; Kasaragod terraced ponds shade homesteads	Coorg coffee-estate cascades stabilise climate; Garhwal & Ladakh tanks buffer frost

[44] Robinson, G. M. (2024). Risk and resilience in Indian cities: Floods, heat islands and the work of Professor R. B. Singh. In Climate change, vulnerabilities and adaptation: Understanding and addressing threats with insights for policy and practice (pp. 3–22). Cham, Switzerland: Springer Nature.

[45] Singh, P. K., Dey, P., Jain, S. K., & Mujumdar, P. (2020). Hydrology and water resources management in ancient India. Hydrology and Earth System Sciences Discussions, 2020, 1–20.

[46] Arya, E. V., & Rao, M. S. (2023). Assessing climatic anomalies and trends: A comprehensive study of rainfall indices, minimum and maximum temperature.

Water Body Type	Thermal Comfort Mechanism	Hot-Dry Zone	Semi-Arid / Composite Zone	Warm-Humid Zone	Temperate / Cold Zone
Floodplains & Backswamps[47]	Latent heat exchange, soil moisture storage, wetland evapo-transpiration, and temperature buffering	Ghaggar–Hakra backswamps cool food storage; North Gujarat floodplain ponds enable evaporative cooling	Lower Ganga levee–backswamp systems delay heating; Bundelkhand floodplains reduce frost	Sundarbans backswamps buffer humidity; Mahanadi wetlands regulate heatwaves; Godavari floodplains stay 1.5–2 °C cooler	Coorg valley basins retain fog; Tons Basin & Ladakh rivers provide thermal stability

Representative examples of rural settlements located in proximity to Johads, rivers, cascade reservoir systems, and floodplains highlight the role of traditional water bodies as climate-responsive infrastructure that enhances local thermal comfort through microclimatic regulation (Figure 27).

FIGURE 27 Representative examples of rural settlements associated with Johads,[48] rivers,[49] cascade reservoir systems,[50] and floodplains,[51] illustrating the role of traditional water bodies in enhancing local thermal comfort across different climatic regions of India

[47] Das Sarkar, S., Sarkar, U. K., Lianthuamluaia, L., Ghosh, B. D., Roy, K., Mishal, P., & Das, B. K. (2020). Pattern of the state of eutrophication in the floodplain wetlands of eastern India in context of climate change: A comparative evaluation of 27 wetlands. Environmental Monitoring and Assessment, 192(3), 183.

[48] South Asia Network on Dams, Rivers and People. (2020, August 30). Patodi Johad: Narela youth rejuvenate a dry pond. https://sandrp.in/2020/08/30/patodi-johad-narela-youth-rejuvenate-a-dry-pond/

[49] Shutterstock. (n.d.). Majuli, biggest island in river Brahmaputra [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/majuli-bigest-island-river-brahmaputra-1238318665

[50] Google Earth Image

[51] Shutterstock. Bengal villages: Royalty-free images, stock photos & pictures. https://www.shutterstock.com/search/bengal-villages?image_type=photo&page=16

Climate-Responsive Orientation and Siting Practices in Traditional Rural Settlements

Traditional Indian rural settlements demonstrate cautious orientation and siting practices shaped by climate, topography, and local ecological knowledge (Figure 28; Figure 29). Traditional settlements improved thermal comfort by adopting north-south street layouts, selecting south-facing mid-slope sites, building on elevated platforms, and avoiding frost-prone valleys. These features also promoted natural airflow and reduced exposure to climatic extremes.

FIGURE 28 Rural settlements at Wayanad of Kerala, located within the dense tropical forest[52]

FIGURE 29 Rural settlements at the forest village of Nongriat located, Shillong[53]

The use of high thermal mass materials and proximity to springs or streams further moderates temperature and humidity through passive means[54,55] (Table 4; Table 5). Together, these practices reveal climate-responsive design approaches that ensured resilience and comfort without mechanical systems and remain relevant for contemporary sustainable rural planning.[56,57,58]

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52 Wix. [Image of traditional architecture/heritage image] [Photograph]. https://static.wixstatic.com/media/f1ba22_d4fc57960d6642438671d9ad9d3dcd98~mv2.jpg/v1/fill/w_1000,h_632,al_c,q_85,usm_0.66_1.00_0.01/f1ba22_d4fc57960d6642438671d9ad9d3dcd98~mv2.jpg.

53 Shutterstock. Image of the forest village of Nongriat located in Shillong in the Indian state of Meghalaya [Photograph]. https://www.shutterstock.com/image-photo/image-forest-village-nongriat-located-shillong-1219398871

54 Katurji, M., & Zhong, S. (2012). The influence of topography and ambient stability on the characteristics of cold-air pools: A numerical investigation. Journal of Applied Meteorology and Climatology, 51(10), 1740–1749.

55 Chaudhary, A. S. (2017). The integration of climate responsive design and traditional settlement in high altitude: A case study of Spiti Valley. International Journal of Civil Engineering and Technology, 8(3).

56 He, B. (2017). Influences of elevated heating effect by the Himalaya on the changes in Asian summer monsoon. Theoretical and Applied Climatology, 128, 905–917.

57 Farooq, M., Rashid, H., Meraj, G., Kanga, S., & Singh, S. K. (2022). Assessing the microclimatic environmental indicators of climate change of a temperate valley in the Western Himalayan region. In Climate change, disaster and adaptations: Contextualising human responses to ecological change (pp. 47–61). Cham, Switzerland: Springer International Publishing.

58 Asquith, L., & Vellinga, M. (2006). Vernacular architecture in the 21st century: Theory, education and practice. Abingdon, UK: Taylor & Francis.

TABLE 4 Climate-responsive rural settlement practices across different climatic zones.[59,60]

Settlement / Practice Type	Climate Zone	Communities / Regions (States)	Cooling & Adaptation Features
Settlements within/ near Dense Tropical Forests	Semi-Arid/ Composite	Bastar of Chhattisgarh	Villages use forest ponds for cooling and winter buffering.
	Warm-Humid	Wayanad of Kerala; Simlipal of Odisha	Moist forests sustain shade and humidity, buffering settlements.
	Temperate/ Cold	Coorg of Karnataka; Tawang of Arunachal Pradesh; Dzongu Valley, Sikkim	Coffee–forest estates aid moist cooling; conifer forests reduce wind chill; bamboo thickets buffer wind and moisture.
Sacred Forest & Riparian Buffers	Hot-Dry	Aravalli fringe of Rajasthan (Bishnoi/Bhil Orans, Devbanis)	Sacred groves shelter springs, provide shade, and cool stored water.
	Semi-Arid/ Composite	Satpura of Madhya Pradesh (Gond & Baiga Sarna groves)	Sacred forest patches near water bodies provide cooler surroundings.
	Warm-Humid	Kodagu of Karnataka (Devarakadu groves); Rayagada & Koraput of Odisha; Khasi Hills of Meghalaya (Law Kyntang groves)	Groves near river sources stabilize hydrology, provide shaded storage, and maintain cooler surroundings.
	Temperate/ Cold	Coorg of Karnataka (Aiyappa/ Snake-god shrines); Ziro Valley of Arunachal Pradesh; Kinnaur of Himachal Pradesh)	Sacred groves regulate humidity, shade streams, and buffer cold winds for storage.
Valley-Based Settlements for Heat Escape	Semi-Arid/ Composite	Satpura Foothills of Madhya Pradesh	Valley settlements use cold-air drainage to escape heat.
	Warm-Humid	Kuttanad of Kerala	Canal–valley homes use water corridors for ventilation and cooling.
	Temperate/ Cold	Coorg of Karnataka; Tons Basin of Uttarakhand; Ladakh	Fog-retaining valleys stabilize climate; valley airflows reduce diurnal swings; high-altitude valleys buffer thermal extremes.

59 Prasad, V. K., Badarinath, K. V. S., & Eaturu, A. (2008). Effects of precipitation, temperature and topographic parameters on evergreen vegetation greenery in the Western Ghats, India. International Journal of Climatology, 28(13), 1807–1819.

60 Bhuyan, M. J. (2022). Rural hydrological environment of a floodplain village in the Brahmaputra Valley, Assam: Status, changes and livelihood issues.

TABLE 5 Orientation practices for enhancing thermal comfort across different climatic zones.

Practice	Climate Zones	Communities / Regions (States)	Cooling & Adaptation Features
North–South Orientation of Streets	Hot-Dry	Jaisalmer of Rajasthan; Ahmedabad of Gujarat	Narrow shaded lanes, jaali windows, and courtyards ensure ventilation; pols align to catch western breezes and shade water storage.
	Composite	Old Bhopal of Madhya Pradesh; Ranchi of Jharkhand	Planned streets with water channels, shaded vending zones; bamboo screens and raised platforms enhance airflow.
South-Facing Mid-Slope Settlements	Temperate	Kodagu of Karnataka	South-facing slopes capture morning sun; mud–wood houses retain heat.
	Cold	Spiti Valley of Himachal Pradesh; Leh of Ladakh; Dirang of Arunachal Pradesh	Sun-facing slopes reduce frost; stone–mud architecture stores heat; terraces protect from winds.
Elevated Hill Platforms (Thermal Mass Materials)	Composite	Bundelkhand of MP & UP; Udaipur of Rajasthan	Stone/mud plinths, lime-washed walls; regulate summer heat and winter cold.
	Temperate	Kodagu of Karnataka	Lateritic hillocks, high-thermal-inertia walls; buffers against extremes.
	Cold	Lahaul-Spiti of HP; Tawang of AP)	Elevated stone-mud houses avoid frost pockets; thick walls provide insulation.
Avoidance of Frost-Prone Valleys	Cold	Spiti of HP); Leh of Ladakh; Tawang & Dirang of AP	Settlements on slopes/ridges avoid frost pockets; improved thermal comfort.
	Temperate	Kodagu of Karnataka	Homesteads on slopes avoid dew and cold-air stagnation in valleys.
Near Springs & Streams (Wind-Aligned)	Warm-Humid	Wayanad of Kerala; Koraput of Odisha	Houses aligned with valley breezes; streamside cooling supports ventilation
	Composite	Bastar of Chhattisgarh	Riparian groves with clustered homes aligned to evening breeze corridors.
	Temperate	Kodagu of Karnataka	Homesteads near springs capture downslope winds; verandahs enable cooling airflow.

The practices presented in Table 5 demonstrate how traditional settlement planning and architectural responses are closely adapted to local climatic conditions, using orientation, topography, vegetation, and thermal-mass materials to enhance thermal comfort and climate resilience (Figure 30 – Figure 35).

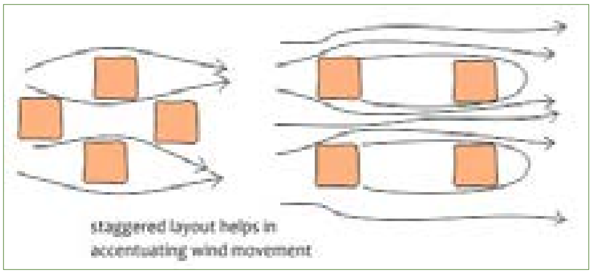

FIGURE 30 North-South street alignment in hot-climate villages promotes natural ventilation and cross-breezes[61]

FIGURE 31 Linear North–South Street Pattern in Chettinad, Tamil Nadu (Warm-Humid Zone)[62]

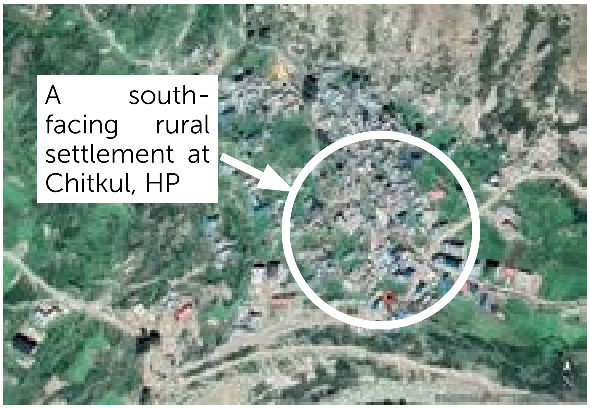

FIGURE 32 A south-facing rural settlement at Chitkul, Himachal Pradesh designed to maximise exposure to solar radiation during the winter months[63]

FIGURE 33 Spiti Valley settlements located on elevated platforms to reduce ground moisture and mitigate the associated frost pocke[64]

FIGURE 34 Cottages typically sited on mid-elevation slopes in Coorg, Karnataka to maintain balanced moisture and thermal conditions[65]

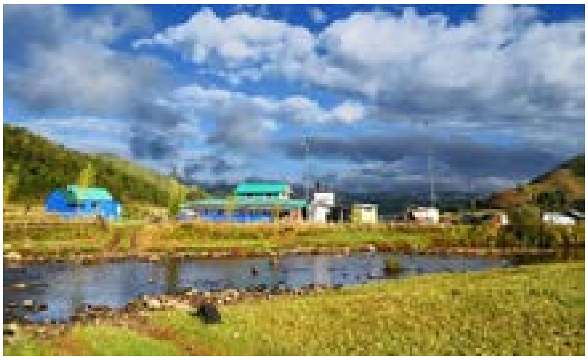

FIGURE 35 Streamside settlements at Mawphlang, Meghalaya, leveraging the cooling and shading properties of riverine streams[66]

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61 NZEB. Form & orientation. Net Zero Energy Buildings. https://nzeb.in/knowledge-centre/passive-design/form-orientation/

62 Kumar, V. S. (2024). Passive design strategies in vernacular architecture. Journal of Emerging Technologies and Innovative Research, 11(6), e718–e725. https://www.jetir.org/papers/JETIR2406493.pdf

63 Google Earth Image

64 https://www.shutterstock.com/image-photo/kee-monastery-spiti-valley-himachal-pradesh-2429096423?trackingId=f6021143-a382-4d02-a513-745c131fe607&listId=searchResults

65 https://www.shutterstock.com/image-photo/house-remote-village-isolated-mountain-coverd-1839350707?trackingId=fa2db0b3-b265-444d-85fd-37174d3adb8d&listId=searchResults

66 WanderOn. (n.d.). Homestays in Meghalaya. https://wanderon.in/blogs/homestays-in-meghalaya

Nature-based solutions continue to offer practical and low-cost opportunities for improving thermal comfort in rural areas. Conserving ponds, rivers, forests, wetlands and other natural features, while incorporating climate-responsive settlement planning, can reduce heat stress, improve resilience to climate change and complement passive building design in future rural housing and development programmes.

Chapter 4

DAY TO DAY COOLING AND HEATING PRACTICES IN RURAL AREAS

4.1 Household Practices and Tools

Rural households in India have traditionally used a range of locally adapted practices to maintain indoor thermal comfort, enabling cooling in extreme summers and heating in cold climates. Rooted in centuries-old knowledge systems, these practices integrate natural resources, seasonal patterns, and cultural traditions. Unlike modern mechanical systems, they are energy-efficient, sustainable, and embedded within the socio-cultural fabric of rural life (Figure 36).[67] Practices vary across the five climatic zones of India, such as Hot-Dry, Warm-Humid, Composite, Temperate, and Cold, reflecting local ecology and community lifestyles. They enhance resilience where electricity or advanced infrastructure is limited and offer low-cost, sustainable solutions relevant to climate change and energy security.[68] The following section documents key household practices for cooling and heating, highlighting their climatic distribution and regional case studies.

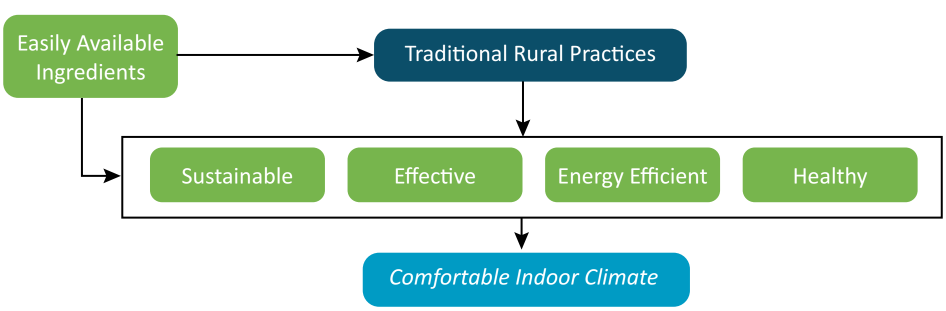

FIGURE 36 Sustainable and healthy household cooling and heating practices using locally available resources in rural India

4.1.1 Household Practices and Tools for Rural Cooling

1 Earthen Water Coolers (Matka, Surahi, Ghara)

Earthen vessels remain one of the most widespread rural cooling devices, using evaporative cooling through porous clay (Figure 37). Water stored in these containers percolates slowly to the outer surface, where it evaporates, thereby lowering the internal temperature.[69]

[67] Ravindra, K., Agarwal, N., Kaur-Sidhu, M., & Mor, S. (2019). Appraisal of thermal comfort in rural household kitchens of Punjab, India and adaptation strategies for better health. Environment International, 124, 431–440.

[68] Marliya, K., & Kesavaperumal, K. T. (2023). Thermal adaptations of houses in vernacular settlements: Insights from the diverse climates of Tiruchirapalli, India.

[69] Heffta, D. I., & Mbuge, D. O. (2023). Past and present evaporative. Engineering Principles, Modeling and Economics of Evaporative Coolers, 301.

1.1 **Hot-Dry Zones:** Clay pots are placed in shaded courtyards or semi-open verandas. In the desert villages of Rajasthan and Gujarat, families often store multiple matkas in clusters, placed on raised stands with damp cloth coverings, reducing temperatures by 8–10°C compared to ambient air.

1.2 **Warm-Humid Zones:** In Odisha and West Bengal, Jute and coir holders are often wrapped around earthen pots to retain moisture and prolong cooling.

1.3 **Composite Zones:** In the village landscape of Uttar Pradesh, Surahis (elongated-necked earthenware) are preferred for daily drinking water, particularly in urban-rural fringes.

FIGURE 37 Use of traditional earthen matkas for cooling drinking water in rural India[70,71]

2 Hand Fans

Hand fans, commonly known as Phankha or Vishari, are among the most accessible and widely used cooling tools in rural India. Made from palm leaves, bamboo, cane, cloth, wool, or leather, their forms vary by region based on the availability of natural materials (Figure 38). Beyond providing immediate thermal relief, hand fans embody local craftsmanship, women-led collective practices, and sustainable livelihood traditions. Traditional handcrafted hand fans as nature-based cooling tools in rural India illustrate region-specific designs and cultural adaptations: (a) & (b) dried palm-leaf hand fans from Kerala and West Bengal; (c) bamboo hand fan from Kerala; (d) bamboo hand fan from Bihar; (e) bamboo hand fan from Assam; (f) cane and bamboo hand fan from southern India; (g) bamboo and reed hand fan from eastern India; (h) lightweight leather hand fan from Gujarat; (i) & (j) wool-thread hand fans for summer cooling from Uttar Pradesh, Haryana, and Punjab; (k) beaded (moti-bharat) hand fans from Saurashtra, Gujarat; and (l) hand fan varieties made by rural women in Rajasthan.[72]

2.1 Hot-Dry Zones

Leather and embroidered cloth fans are common in Gujarat and Rajasthan, offering durability in extreme heat while supporting local artisan communities.

[70] Dreamstime. (n.d.). Indian woman holding clay water pot at tubewell [Photograph]. Dreamstime. https://www.dreamstime.com/indian-woman-water-pot-indian-woman-holding-clay-water-pot-tubewell-image101149482

[71] Shutterstock. (n.d.). Potters selling colorful earthen pots (Ghada Matka) on street market [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/potters-selling-colorful-earthen-potsghada-matka-2607462281

[72] Richmond, J., Agrawal, S., & Urpelainen, J. (2020). Drivers of household appliance usage: Evidence from rural India. Energy for Sustainable Development, 57, 69–80.

- In Kutch of Gujarat, women craft embroidered cloth fans as part of household and community activities, often decorated with mirror work or bead embroidery (moti-bharat).
- In Rajasthan, leather fans are valued for their sturdiness, particularly in desert regions where palm or bamboo is scarce.

2.2 Warm-Humid Zones

Palm-leaf and bamboo 'visharis' are commonly found in Kerala, Tamil Nadu, Odisha, Assam, and West Bengal, valued for their lightweight durability and breathability in humid climates.

- In Kerala, palm-leaf hand fans are widely used in rural households for daily cooling.
- Painted palm-leaf fans combine functional use with decorative motifs, sustaining craft traditions, usually found in Odisha.
- In Assam, bamboo hand fans are durable and crafted in a variety of shapes, supporting rural artisans.
- Palm-leaf fans are integral to the households and cultural events of West Bengal, often distributed during religious gatherings.

FIGURE 38 Traditional and handcrafted hand fans

2.3 Composite Zones

Bamboo and wool-thread fans dominate, often produced by women self-help groups (SHGs) for household use and market sales.

- In Bihar, women SHGs engaged in manufacturing bamboo fans and sold in weekly markets (haats).
- In Punjab and Haryana, wool-thread fans are unique to the region, woven to generate stronger airflow during peak summer heat.
- In Uttar Pradesh, bamboo and cane fans are commonly carried to agricultural fields, serving both functional and cultural roles.

3 Chik Blinds (Bamboo, Reed, Sarkanda Mats)

Chik blinds serve as solar shading devices in rural households. Hung on windows, verandas, or courtyard openings, they reduce solar heat gain while maintaining airflow.[73] When sprinkled with water, they function as evaporative coolers, making interiors considerably cooler in peak summers (Figure 39; Figure 40). Locally available materials like bamboo, sarkanda grass, reed, or coir are typically used, with regional variations reflecting climate and culture (Table 6).

3.1 Hot-Dry Zones

FIGURE 39 Bamboo chik blinds in a rural Indian veranda providing passive cooling[74]

FIGURE 40 Woman in Assam making chik blinds, supporting traditional cooling practices

Sarkanda grass and bamboo chik blinds are widely hung in verandas, courtyards, and window openings of the rural cottages of Rajasthan and Gujarat to combat harsh summer heat.

- Sarkanda blinds, sold in summer markets, are routinely soaked in water to keep rooms cool.
- In Jaipur and Jodhpur of Rajasthan, bamboo blinds protect against dust storms while providing cooling shade.
- In Ahmedabad of Gujarat, Sarkanda blinds are commonly used in old residential 'pols' to reduce the need for mechanical cooling.

[73] Singh, S. (2019). Moving lights as moving spaces: Reinterpreting traditional bamboo chik making. In Functional Textiles and Clothing (pp. 427–443). Singapore: Springer Singapore.

[74] Shutterstock. (n.d.). Bamboo blinds as Asian traditional home decoration [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/bamboo-blinds-asian-traditional-home-decoration-1238284693

3.2 Warm-Humid Zones

Reed and coir chik blinds are adapted for humid climates usually found in Kerala and Tamil Nadu. They resist fungal growth and allow cross-ventilation without trapping moisture.

- In Kerala, Coir mat blinds are popular in coastal households for their durability against salt-laden winds.
- In Chennai and Thanjavur of Tamil Nadu, reed blinds are used on verandas, often rolled up during rains.

3.3 Composite Zones

In the rural landscape of Punjab, Haryana, Uttar Pradesh, and Bihar, decorative cotton-threaded chik blinds are both functional and aesthetic, often dyed in bright colours to match household décor.

- In Punjab and Haryana, blinds made of cotton thread interwoven with bamboo strips decorate homes while shading interiors.
- In the rural homes of Varanasi, Sarkanda blinds are sold in local bazaars, used by both households and roadside tea stalls.
- In Bihar, reed blinds are used seasonally, especially during April-June peak summer months.

TABLE 6 Types of materials used for making chik blinds in different climatic regions of India

Climatic region	Material used for chik blind	Purpose of chik
Hot-Dry (Rajasthan, Gujarat)	Sarkanda grass (*Saccharum munja*), Bamboo splits Palm leaves	Readily available and inexpensive Reflect heat while allowing airflow
Hot-Humid (Kerala, Tamil Nadu)	Reed mats Coir (coconut fibre) Palm fronds	Moisture-resistant Breathable and non-fungal in humid conditions
Composite (Delhi, Punjab)	Bamboo slats Cotton-threaded Chik	Good for both summer and winter Can be insulated with cloth or plastic
Cold (Kashmir, Himachal Pradesh)	Less common due to low cooling Fabric-backed bamboo blinds	Used more for light control than cooling
Moderate (Maharashtra)	Thin cane or reed Chik Woven pandanus or screw-pine leaves	Lightweight and suited for breezy, moderate climates

4 Khus Mats (Vetiver Roots)

Khus mats are woven from the fragrant roots of Vetiveria zizanioides. When kept wet and hung-over doors or windows, they act as natural bio-coolers, cooling incoming air through evaporation while releasing a refreshing fragrance (Figure 41, Figure 42). In many rural households, khus mats are combined with ceiling or hand fans to enhance circulation of cooled air. They are highly valued in hot interiors, shops, and community halls before the widespread availability of electric coolers.[75]

[75] Balasankar, D., Vanilarasu, K., Preetha, P. S., Umadevi, S. R. M., & Bhowmik, D. (2013). Journal of medicinal plants studies. J. Med. Plants, 1(3), 191–200.

4.1 Hot-Dry Zones

Khus mats are extensively used in the rural households of Uttar Pradesh, Rajasthan, Delhi during extreme summers. Mats are hung at entrances or windows and watered regularly, providing evaporative cooling.

- Shopkeepers hang khus mats at doorways, sprinkling them every few hours, usually practices in Lucknow and Kanpur of Uttar Pradesh.
- In Bikaner and Jaipur, household khus mats are often combined with clay water pots to maintain a fragrant, cool indoor atmosphere.

4.2 Composite Zones

In the states like Madhya Pradesh, Haryana, and Bihar, Khus mats are often paired with ceiling or table fans to circulate the cooled, fragrant air indoors.

- In Bhopal and Gwalior of Madhya Pradesh, households used mats as natural air coolers until the 1980s; many traditional homes still retain the practice.
- In Haryana, mats are placed in community halls during summer events, cooled with dripping water.
- In Bihar, traders use khus mats in rural shops to keep indoor temperatures tolerable.

FIGURE 41 Sprinkling water on vetiver (khus) mats to enhance natural cooling in rural homes[76]

FIGURE 42 Rural woman weaving khus mats, sustaining traditional evaporative cooling practices[77]

5 Roof Water Sprinkling

Roof water sprinkling is a traditional passive cooling technique in rural India, where water is sprinkled over flat mud, thatch, or cement roofs, especially during peak summer afternoons. The evaporative process increases latent heat loss, reducing heat conduction indoors and lowering indoor temperatures (Figure 43). This method is simple, sustainable, and widely practised in areas with limited access to mechanical cooling.[78]

[76] Amazon. (n.d.). [Image of traditional/heritage item] [Photograph]. Amazon. https://m.media-amazon.com/images/I/91g5E5bwWkL._SL1500_.jpg

[77] Local Samosa. (n.d.). [Image of traditional/heritage subject] [Photograph]. Publive . https://img-cdn.publive.online/filters:format(webp)/local-samosal/media/media_files/2025/05/27/3-khus-110161.png

[78] Nahar, N. M., Sharma, P., & Purohit, M. M. (2003). Performance of different passive techniques for cooling of buildings in arid regions. Building and Environment, 38(1), 109–116.

5.1 Hot-Dry Zones

- In Rajasthan villages like Jaipur and Alwar, water is sprinkled on flat mud roofs during extreme heatwaves, often combined with periodic whitewashing to reflect solar radiation.
- In Bundelkhand (Tikamgarh, Chhatarpur), households sprinkle water on thatched roofs of semi-open verandas, reducing indoor temperatures by 2–4 °C during afternoons.
- In Saurashtra, Gujarat, roof sprinkling is applied in combination with tree shade near homes, enhancing microclimatic cooling.

5.2 Composite Zones

- In semi-urban villages of Delhi NCR, residents sprinkle water on flat cement roofs to improve thermal comfort, especially in houses without shaded courtyards.
- In Patna, Bihar, flat concrete terraces are regularly sprinkled during peak summer months, often combined with wet cloths over window openings for additional cooling.
- Studies in Bundelkhand show that combining roof sprinkling with nearby water storage ponds can lower indoor temperatures by 2–3 °C.

FIGURE 43 Rooftop sprinklers in rural India reducing daytime roof temperatures through evaporative cooling[79]

4.1.2 Household Practices and Tools for Rural Heating

1 Traditional Chulhas

Chulhas are clay-based cooking stoves that not only serve culinary purposes but also act as primary space-heating devices or indoor firepits during winter months due to retained radiant heat (Figure 44).[80,81]

1.1 Cold Zones

- Chulhas are centrally located within the rural homes of Himachal Pradesh and Kashmir to provide maximum heat distribution.
- In Khyah villages of Himachal Pradesh, chulhas in family kitchens double as sitting-area heaters during peak winter nights.
- In the rural settlements of Kashmir, chulhas are used alongside woollen bedding to maintain indoor warmth.

FIGURE 44 Traditional clay chulha in a rural Indian village providing indoor heating while cooking[82]

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[79] Shutterstock. (n.d.). Rooftop sprinkler in action watering to reduce hot temperature [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/rooftop-sprinkler-action-watering-reduce-hot-1151641889

[80] Mohan, R., & Kumar, S. (2011). Enhancement of thermal efficiency of traditional Indian cooking furnace (Chulha). Current World Environment, 6(1), 61.

[81] Mukhopadhyay, B., Weitz, C. A., & Das, K. (2021). Indoor heat conditions measured in urban slum and rural village housing in West Bengal, India. Building and Environment, 191, 107567.

[82] https://www.shutterstock.com/shutterstock/photos/2261595923/display_1500/stock-photo-women-making-rice-bread-in-traditional-soil-vessels-at-wood-fire-from-different-angle-at-village-2261595923.jpg

1.2 Composite Zones

- In Bundelkhand and northern Madhya Pradesh, chulhas are primarily for cooking but contribute secondary heating in winter.
- Households often combine chulhas with stone floors in Uttar Pradesh to store residual heat.

2 Angithi

Angithis are small, portable clay or metal braziers that provide personal or room-specific heating commonly used in the rural households of cold and composite climatic zones (Figure 46).[83]

FIGURE 45 Angithi, a traditional raised brazier used in rural Indian homes for indoor heating during extreme cold[84]

2.1 Cold Zones (Punjab, Himachal Pradesh, Kashmir)

- Widely used indoors in rural households of Punjab, Himachal Pradesh, and Kashmir to provide quick warmth during early mornings and late nights.
- In rural Himachal, metal angithis are placed near sleeping areas to conserve heat.

2.2 Composite Zones

- Occasionally used during peak winter nights for temporary heating in mud-brick homes of Uttar Pradesh.
- Often combined with woollen bedding for improved thermal comfort.

3 Hay/Straw Insulation

Hay or straw is used in the cold and temperate climatic zones as the medium of insulation for roofs, walls, or bedding to reduce heat loss in cold month (Figure 46).[85]

3.1 Cold Zones

- Roofs packed with hay or straw in traditional cottages of Himachal Pradesh and Sikkim act as a barrier against heat loss.
- Straw is also used as the under-layers in Himachal Pradesh for the sleeping areas to maintain warmth during sub-zero nights.

FIGURE 46 Traditional Indian straw hut providing natural insulation and maintaining pleasant indoor temperatures in rural settings[86]

[83] Fleming, L. T., Weltman, R., Yadav, A., Edwards, R. D., Arora, N. K., Pillarisetti, A., Meinardi, S., Smith, K. R., Blake, D. R., & Nizkorodov, S. A. (2018). Emissions from village cookstoves in Haryana, India, and their potential impacts on air quality. Atmospheric Chemistry and Physics, 18(20), 15169–15182.

[84] https://www.shutterstock.com/image-photo/angithi-traditional-vessel-used-cooking-protect-2517132905

[85] Marks, L. R. (2005). Straw-bale as a viable, cost effective, and sustainable building material for use in southeast Ohio (Master's thesis, Ohio University).

[86] Shutterstock. (n.d.). Angithi: Traditional vessel used for cooking and protection from cold [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/angithi-traditional-vessel-used-cooking-protect-2517132905

3.2 Temperate Zones

- Attic layers of straw moderate diurnal temperature variations in the homes of Coorg and Nilgiris at mid-elevations.
- In Coorg, hay is sometimes mixed with mud plaster for improved insulation.

4 Heated Bricks / Hot Water Bottles

In cold and composite climatic zones, bricks heated in fire or bottles filled with hot water provide direct warmth when placed in bedding or near occupants.[87]

4.1 Cold Zones

- Heated bricks wrapped in cloth are placed under bedding in rural homes of Kashmir and Himachal Pradesh.
- In some Ladakhi cottages, stones from firepits are used similarly to retain heat overnight.

4.2 Composite Zones

- Hot water bottles are increasingly used in the rural households of Bihar and Uttar Pradesh where access to heated bricks is limited.
- Combined with angithis or wool blankets for enhanced indoor thermal comfort in the villages of Uttar Pradesh.

The practices listed in Table 7 capture the essence of India's traditional thermal comfort solutions—simple, resource-efficient, and deeply adapted to diverse climates. Serving as a synthesis of region-specific strategies, the table highlights how communities have historically relied on low-cost methods to achieve both cooling and heating needs.

These rural practices demonstrate deep-rooted climate-adaptive ingenuity, tailored to ecological conditions and material availability. They serve not only as tools of survival and comfort but also as sustainable alternatives to energy-intensive mechanical systems. Recognising and preserving such indigenous techniques can inspire eco-friendly architectural and household innovations in modern rural and peri-urban planning.

4.2 Storage of Food and Water

Across the rural landscape of India, subsistence communities have a long-standing history of adapting to climatic extremes through nature-based indigenous techniques and tools for cooling and heating drinking water and food, without relying on non-renewable energy sources. These practices, often indirectly shaped by local terrain, water availability, and ecological knowledge, offer low-cost,

[87] Malan, A., & Sharma, H. R. (2023). Assessment of drinking water quality and various household water treatment practices in rural areas of Northern India. Arabian Journal of Geosciences, 16(1), 96.

TABLE 7 Traditional household practices and tools for thermal comfort across the climatic zones.

Household Practices and Tools	Target Climatic Zones	Temperature / Thermal Effectiveness
Earthen Water Coolers (Matka, Surahi, Ghara)	Hot-Dry Zone, Warm-Humid Zone, Composite Zone	Evaporative cooling lowers stored water temperature by 8–10 °C
Hand Fans (Phankha, Vishari)	Hot-Dry Zone, Warm-Humid Zone, Composite Zone	Provides immediate airflow cooling
Chik Blinds (Bamboo, Reed, Sarkanda Mats)	Hot-Dry Zone, Warm-Humid Zone, Composite Zone	Lowers indoor temperature by 2–4 °C in shaded areas
Khus Mats (Vetiver Roots)	Hot-Dry Zone, Composite Zone	Fragrant airflow circulation enhances thermal comfort indoors
Roof Water Sprinkling	Hot-Dry Zone, Composite Zone	Evaporation from flat roofs lowers indoor temperatures by 2–4 °C during peak summer
Traditional Chulhas	Cold Zone, Composite Zone	Retaining radiant heat provides indoor warming in winter
Angithi (Portable Braziers)	Cold Zone, Composite Zone	Provides quick indoor warmth
Hay / Straw Insulation	Cold Zone, Temperate Zone	Roof and wall insulation reduces heat loss
Shared Bedding and Wool Layering	Cold Zone, Temperate Zone	Conserves body heat
Heated Bricks / Hot Water Bottles	Cold Zone, Composite Zone	Retains warmth in bedding

sustainable solutions for thermal comfort and food safety.[88] A climate zone-wise understanding of such vernacular strategies reveals critical insights into passive, resilient rural living, as shown in Figure 47.

Natural Solutions for Rural Cooling and Heating

1. **Earthenware-Based Evaporative Cooling**: Earthenware vessels such as the *Matka*, *Surahi*, and *Zeer* (pot-in-pot coolers) use the porous nature of clay to promote evaporative cooling (Figure 48). When water seeps through the porous walls of these unglazed clay pots and evaporates from the outer surface, it absorbs latent heat from the inner contents, thereby lowering their

[88] Asquith, L., & Vellinga, M. (Eds.). (2006). Vernacular architecture in the 21st century: Theory, education and practice. Taylor & Francis.

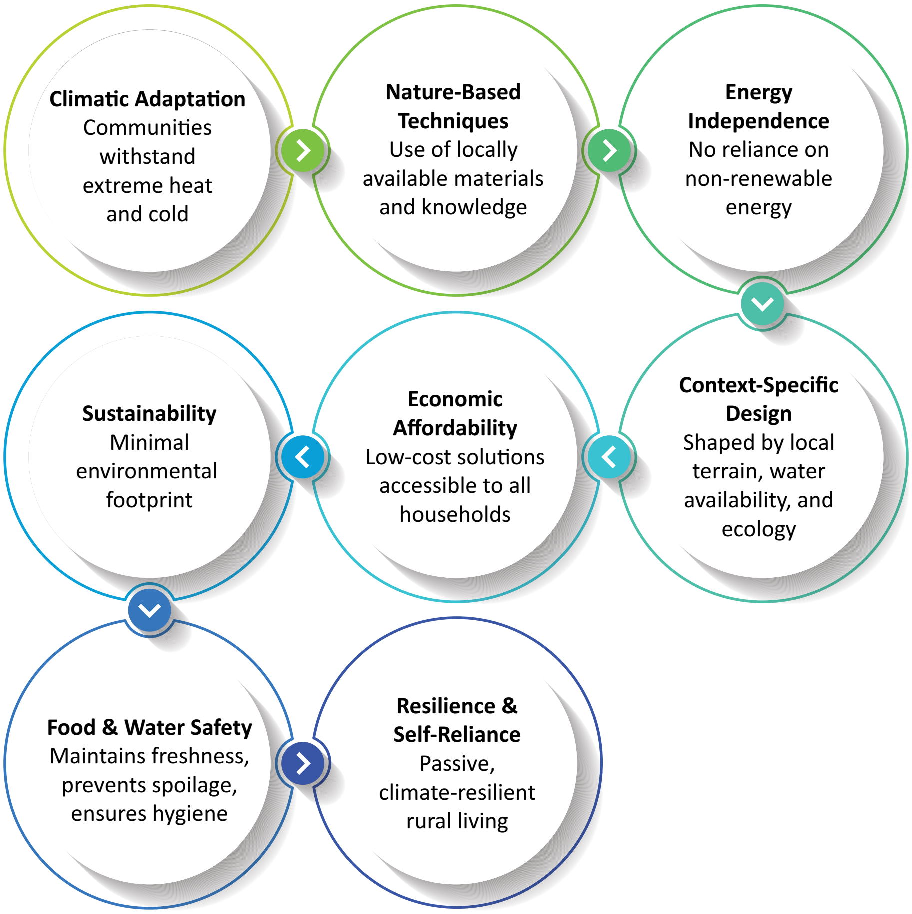

FIGURE 47 Key benefits of indigenous, nature-based cooling and heating practices for food and water storage in rural India

temperature by approximately 6–10 °C (Figure 49). The mechanism is illustrated in the Figure 50, which depicts the sequential cooling effect starting from water seepage through the porous vessel walls, followed by surface evaporation and latent heat absorption, culminating in the cooling of the vessel's interior. This technique is passive, sustainable, and has been used since ancient times to preserve drinking water, dairy products, and perishables in rural households.[89,90] Earthenware-based evaporative cooling has been historically prevalent in several climatic zones of India, where high temperatures and low-cost solutions necessitated sustainable alternatives for cooling.

2. **Zero Energy Cool Chambers (ZECCs)**: Zero Energy Cool Chambers (ZECCs) are simple farm-based chambers that cool the farm produce naturally, without electricity. (Figure 51). They are

[89] Rinker, J., Thomas, M., & Wilson, B. (2014). Designing with climate: Traditional earthenware cooling systems in arid India. Journal of Sustainable Building.

[90] Choudhary, R., Singh, P., & Das, S. (2025). Traditional cooling technologies and their modern relevance. TERI Press.

FIGURE 48 The traditional 'Zeer' or 'pot-in-pot cooler', commonly used in the hot-dry climatic zone of India[91]

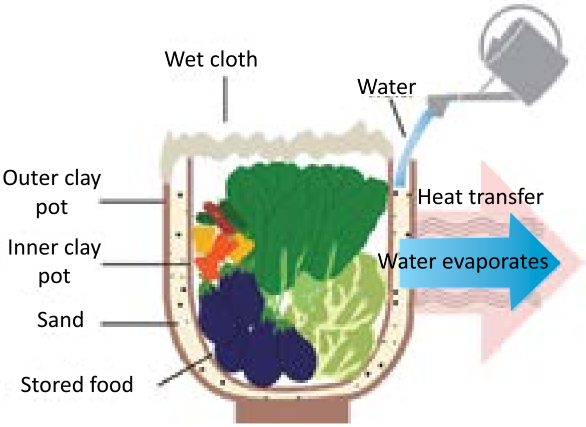

FIGURE 49 Cross-sectional view of the traditional 'Zeer' or pot-in-pot cooler[92]

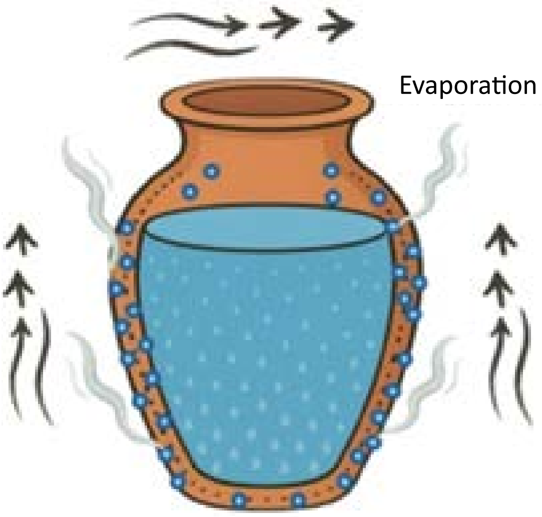

FIGURE 50 Cooling mechanism in earthen pots[93]

typically constructed using locally available materials such as bricks, sand, and bamboo matting, without any external energy input. A ZECC can reduce temperatures by 10–15°C and increase relative humidity up to 90%, significantly prolonging the shelf life of fruits, vegetables, and dairy products (Figure 51).[94]

3. **Clay Urns for Fermented Food Storage:** Clay urns or earthen jars are widely used in rural India for the fermentation and preservation of food items, especially dairy and cereal-based products (Figure 53).[95] The porous nature of these vessels enables mild evaporative cooling, while the alkaline surface chemistry helps maintain a microbiologically favourable

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[91] Shutterstock. (n.d.). Handmade fridge: Horizontal shot of two traditional earthen pots used for cooling water [Photograph]. Shutterstock. https://www.shutterstock.com/image-photo/handmade-fridge-photography-horizontal-shot-two-1431192656

[92] Verploegen, E., Mangino, M., Ognakossan, K. E., Ahamadou, A., & Cissé, F. (2021). A guide to assembling, using, and maintaining clay pot coolers. MIT D-Lab. MIT D-Lab publication

[93] Saagoto, M. S., & Chowdhury, N. (2025). Traditional clay pot coolers as drinking water cooling technology for urban heat adaptation in Bangladesh. Sustainable Energy Technologies and Assessments, 83, 104575

[94] Roy, K. S., & Khurdiya, D. S. (1982). Keep vegetables fresh in summer. Indian Horticulture, 27(1), 5–6.

[95] Khan, D. D., & Banerjee, S. (2020). Revitalizing ancient Indian clay utensils and its impact on health. International Journal of Research in Education and Science Methods, 8, 7.

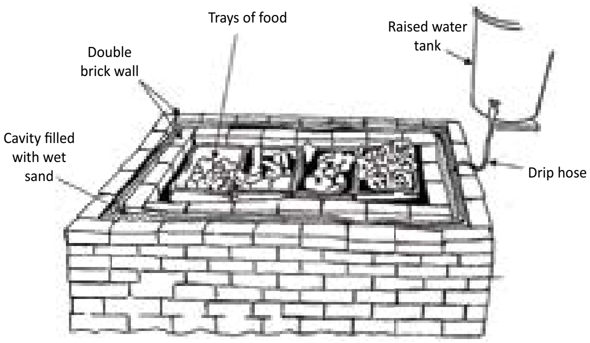

FIGURE 51 Schematic diagram of above-ground Zero Energy Cool Chambers (ZECCs)[96]

FIGURE 52 Evidence of the use of above-ground Zero Energy Cool Chambers (ZECCs) in the hot-dry climatic zone of India[97]

environment. This traditional technique supports the growth of beneficial lactic acid bacteria and inhibits spoilage microorganisms (Figure 54).[98] Urns are often partially buried or kept in shaded areas to maintain consistent temperatures, ideal for making curd, pickles, and fermented rice or millet dishes.

FIGURE 53 Traditional lightly fermented rice water (panta bhaat), commonly consumed in the warm-humid regions of West Bengal and the Northeastern states of India[99]

FIGURE 54 Fermented fish (ngari) is traditionally stored in buried clay urns that maintain a stable temperature in Manipur[100]

96 Lehigh University. (n.d.). Zero Energy Cooling Center (ZECC). https://srrweb.cc.lehigh.edu/app/ZECC

97 Singh, A. K., Poonia, S., Santra, P., & Mishra, D. (2017). Design, development and performance evaluation of low-cost zero energy improved passive cool chamber for enhancing shelf-life of vegetables. Agricultural Engineering Today, 41(4), 72–79.

98 Patra, J. K., Sahoo, S. K., & Swain, M. R. (2017). Nutritional and antioxidant potential of Aegle marmelos fermented fruit juice. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 87(3), 769–775.

99 iStock. (n.d.). Panta bhat or pakhala or fermented rice soup with water is served in clay bowl [Photograph]. iStock by Getty Images. https://www.istockphoto.com/photo/panta-bhat-or-pakhala-or-fermented-rice-soup-with-water-is-served-in-clay-bowl-with-gm1500156397-521692487

100 Majumdar, R. K., Roy, D., Bejjanki, S., & Bhaskar, N. (2016). An overview of some ethnic fermented fish products of the Eastern Himalayan region of India. Journal of Ethnic Foods, 3(4), 276-283.

4. **Earthen Jars Submerged in Streams**: This technique involves placing earthen jars directly in flowing or stagnant natural water bodies, such as streams, springs, or shallow rivers, to utilise the thermal inertia and evaporative cooling of the water (Figure 55). The cool temperature of the stream, often several degrees lower than ambient air temperature, helps in preserving perishable food items and dairy products, especially during the warmer months. The porosity of the earthenware and its partial water saturation facilitate double-layered cooling from both the water medium and evaporative surface loss.[98]

FIGURE 55 Traditional earthen jars in bamboo bags used to cool and ferment food items for a substantially longer period

5. **Bamboo Cages in Shaded Streams:** This indigenous technique involves placing food items inside handmade bamboo cages, which are then anchored in shaded sections of forest streams, rivulets, or spring-fed channels (Figure 56). The combination of flowing cool water, shade, and air circulation significantly lowers the surrounding temperature, providing a natural cooling chamber ideal for preserving leafy vegetables, milk, fermented products, or fruits (Figure 57). This method is completely off-grid and utilises locally available bamboo, binding materials, and community knowledge.[101]

FIGURE 56 Bamboo cage used to cover food items in comparatively cool ambiance of forest and the riparian areas of streams

FIGURE 57 Use of bamboo baskets to store food helps in air circulation and keeps it cooler

[101] Sundriyal, R. C., Upreti, T. C., & Varuni, R. (2002). Bamboo and cane resource utilization and conservation in the Apatani plateau, Arunachal Pradesh, India: Implications for management. Journal of Bamboo and Rattan, 1(3), 205–246.

6. **Blackened Pots on Rock Slabs (Solar Heating):** This traditional solar heating method involves placing soot-blackened earthen or metal pots on sun-exposed stone or mud slabs, typically oriented to receive maximum midday sunlight (Figure 58).

The darkened surface of the pots enhances solar absorption, while the underlying rock slab retains heat, ensuring efficient warming of food or water. Common in regions with clear skies and strong solar radiation, this technique supports low-cost thermal management, especially for early morning or evening consumption.[103] This method also reduces dependence on firewood for reheating.

FIGURE 58 Use of blackened earthen or metal pots in traditional solar heating methods to retain temperature for a longer period[102]

7. **Earth–Air Tunnels (EATs**): Earth–Air Tunnels (EATs), also known as earth tubes or ground-coupled heat exchangers, are traditional passive cooling and heating systems that utilise the thermal inertia of the ground (Figure 59). Air is drawn through underground tunnels (typically 1.5–3 m deep) where it exchanges heat with the relatively constant subterranean temperature. In hot seasons, the system cools the incoming air, while in colder months, it can moderate heating needs. Though now popular in modern sustainable architecture, rudimentary versions of EATs have long been used in traditional food storage structures and animal shelters in rural India.[104]

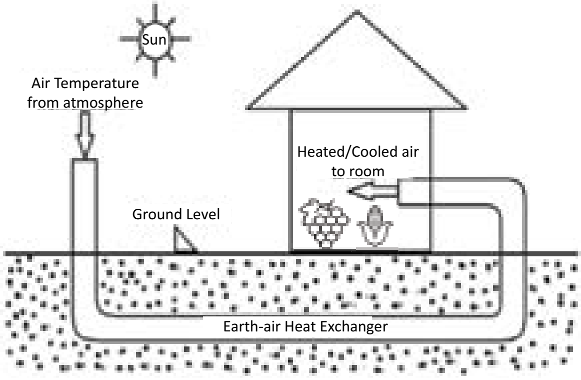

FIGURE 59 Schematic of an Earth–Air Tunnel system, traditionally utilised for food preservation while maintaining comfortable ambient air temperatures[105]

8. **Subterranean Cold Cellars (Sadong, Tsothbang):** Subterranean cold cellars, locally known as *Sadong* in Manipur and *Tsothbang* among the Chakhesang Nagas of Nagaland, are underground storage structures designed to preserve perishable food, seeds, and fermented products in rural highland communities (Figure 60). These cellars are typically dug into hill slopes or beneath traditional houses, taking advantage of the earth's stable subterranean temperatures and natural

[102] https://storage.googleapis.com/stateless-www-justwravel-com/2025/02/00272e4b-authentic-ladakhi-oven-with-pots-on-it-in-ladakhregion.jpg

[103] Kumar, A., Saxena, A., Pandey, S. D., & Gupta, A. (2024). Cooking performance assessment of a phase change material integrated hot box cooker. Environmental Science and Pollution Research, 31(53), 62392–62407.

[104] Bansal, N. K., Sodha, M. S., & Bharadwaj, S. S. (1983). Performance of earth air tunnels. International Journal of Energy Research, 7(4), 333–345.

[105] Gautam, B., Bhattarai, B., Bastakoti, N., & Baral, B. (2021). Estimating the reduction in HVAC load in multipurpose hall with the use of earth air tunnel heat exchanger (at Kathmandu University). Journal of Innovations in Engineering Education, 4(2), 32-41.

insulation. The inner walls are often lined with bamboo mats, wooden planks, or stone, and the floor is usually compacted earth or flat stone to absorb moisture and reduce microbial activity (Figure 61). The entrance is kept small and often sealed with grass or wooden lids to maintain a low internal temperature and prevent pests.[106] In the remote village of Dudran, located in the Baramulla district of Jammu and Kashmir, traditional knowledge has enabled the development of an indigenous milk preservation system known as the *Dodh Khot* (Figure 62). With limited access to electricity and modern infrastructure, local residents rely on naturally cooled stone structures to store milk and fermented dairy products, demonstrating a passive, low-energy alternative to modern cold chain systems. From a thermal perspective, the Dodh Khots serve as an effective passive cooling mechanism. During the summer months, when ambient temperatures often exceed 35°C, these units can maintain an internal temperature 3–5°C lower than outside, helping to keep milk fresh for extended periods, typically 2–3 days without spoilage. In winter, the earthen insulation acts as a thermal buffer, preventing the milk from freezing immediately, which also facilitates the fermentation process to produce curd and butter.

FIGURE 60 Traditional food storage structures for winter storage of vegetables and grains in Ladakh region known as Sadong (underground pit)[107]

FIGURE 61 Traditional cold cellars, known as Tsothbang, used for winter storage of vegetables and grains in the Ladakh region [107]

9. **Blackened Metal Drums for Solar Water Heating:** This traditional technique uses blackened or soft-coated metal drums to absorb maximum solar radiation and heat water naturally. The darkened surface enhances solar heat absorption, while the metallic body quickly conducts heat, making it a cost-effective and low-tech solar thermal system. Typically, 20–100 litre iron or steel

[106] Ali, Z., Yadav, A., Stobdan, T., & Singh, S. B. (2012). Traditional methods for storage of vegetables in cold arid region of Ladakh, India. Indian Journal of Traditional Knowledge, 11(2), 351–353.

[107] Tsewang, T., Acharya, S., Mishra, A., Kumar, K., Verma, V. C., Tiwari, V. K., & Avantika, A. (2023). Traditional methods for vegetable and grain storage in Leh district of trans-Himalayan Ladakh. Indian Journal of Traditional Knowledge (IJTK), 22(3), 478-482.

FIGURE 62 Dodh Khots in Dudran,Jammu and Kashmir[108]

drums are blackened using lamp soot or burnt engine oil and are placed on rooftops, rock slabs, or exposed fields for 4–6 hours under direct sunlight. These drums can heat water to 40–60°C, depending on ambient temperature and exposure. Water from these drums is used for bathing, cooking, and cleaning, especially in high-altitude and water-scarce regions.[109]

10. **Loft Storage and Attic Compartments:** This method involves storing produce or preserved foods in lofts directly above traditional wood-fired hearths (*chulhas*), or in attic compartments beneath the roof (Figure 63). Residual smoke and gentle heat act as natural preservatives, drying the stored items while inhibiting microbial growth. For dairy products such as butter, the heat gradually dehydrates the fat, while the smoke imparts a distinct flavour and enhances shelf life without refrigeration. In the case of vegetables such as onions and garlic, the dry, well-ventilated attic environment prevents sprouting and decay (Figure 64). Containers may include bamboo racks, wooden boxes, or open mesh platforms that allow airflow. This approach is culturally embedded and adapted to local needs, especially where seasonal production and limited market access demand extended storage.[110]

FIGURE 63 Traditional food storage structures for onions in hot-dry and composite climatic zones

FIGURE 64 Corn stored in attic to keep it warm and dry, insulated from lower-level atmospheric moisture[111]

[108] https://www.thecitizen.in/h-upload/2024/03/04/1302978-axhrpqgj9pueckoblkdc6nqjwh7v1xpiv6cj7ymkeontdpgahmuchwibljz-oqu83n-fxupjb0vxlhwzulhrsdayproz0q-i0hw4o9oga5ioqqnvpinftnqr4-qbhp7apjjrgjtly.webp
[109] Bhide, V. G. (1978). Solar space heating and cooling and solar water heaters. In Technology for solar energy utilization (pp. 92–100).
[110] Singh, A. K., Poonia, S., Santra, P., & Mishra, D. (2017). Design, development and performance evaluation of low-cost zero energy improved passive cool chamber for enhancing shelf-life of vegetables. Agricultural Engineering Today, 41(4), 72–79.
[111] https://www.shutterstock.com/image-photo/rows-dried-corn-cobs-hanging-traditional-2604076509

Traditional food preservation methods in India have long relied on passive cooling strategies that are finely adapted to local climatic conditions.[112] The following Table 8 presents a comparative overview of such practices across major climatic zones, highlighting region-specific techniques, materials, and cultural innovations that continue to support food security and resilience.

TABLE 8 Traditional Cooling Practices Across Indian Climatic Zones for Food Preservation

Traditional Practices	Hot-Dry Zone High temperature, low humidity	Composite Zone Hot summers, mild winters, monsoonal rains	Warm-Humid Zone High humidity; low cooling efficiency
Traditional Earthenware-Based Evaporative Cooling Practices	The high evaporation rate makes these techniques particularly effective in reducing temperature for drinking water storage and short-term preservation of dairy and vegetables.[113] • **Barmer (Rajasthan) & Kutch (Gujarat):** Zeer system—outer clay pots filled with moist sand cool the inner pot storing milk and water. • **Jhunjhunu & Dudu (Rajasthan):** Pitchers near Johads use local humidity to improve cooling.[114] • **Vidarbha (Maharashtra):** Matkas in shaded verandas benefit from airflow for water cooling. • **Bellary (Karnataka):** Surahi pots on bamboo stands use elevation for better airflow	Favor intermittent use of evaporative cooling, especially in summer months.[115] • **Agra (Uttar Pradesh):** Dual-pot systems with ash insulation preserve buttermilk and curd. • **Patna (Bihar):** Matkas in wire baskets wrapped with damp jute cloth maximize evaporation. • **Bhopal (Madhya Pradesh):** Earthen pots widely used for storage and drinking, persisting even in urban homes.	Even in humid climates, earthenware remains popular for affordability and cultural familiarity despite limited cooling.[116] • **In the rural West Midnapore district (West Bengal): Matkas kept in shaded c**ourtyards provide mild cooling. • **Kollam (Kerala):** Suspended pots in ventilated sheds gain limited evaporation from airflow. • **Srikakulam (Andhra Pradesh):** Vendors use Surahi pots to keep lemon water and buttermilk cooler during market hours.

[112] Tsewang, T., Acharya, S., Mishra, A., Kumar, K., Verma, V. C., Tiwari, V. K., & Avantika, A. (2023). Traditional methods for vegetable and grain storage in Leh district of trans-Himalayan Ladakh. Indian Journal of Traditional Knowledge, 22(3), 478–482.
[113] Rinker, P., Angermaier, F., & Ouédraogo, F. (2014). The clay pot cooler – An appropriate cooling technology: Information on construction and usage (pp. 1–7).
[114] Choudhary, C. P., Kumari, S., Kumari, P., & Yadav, A. (2025). Assessing the efficacy and climate resilience of traditional water harvesting systems in Jodhpur District, Rajasthan: A geospatial and hydrological modeling approach.
[115] Dubey, A. K., Kumar, P., Saharwardi, M. S., & Javed, A. (2021). Understanding the hot season dynamics and variability across India. Weather and Climate Extremes, 32, 100317. https://doi.org/10.1016/j.wace.2021.100317
[116] Petrucci, C. (2023). Thermal comfort in traditional and sustainable buildings: Comparative analysis of thermal perception in the Middle East and Southeast Asian buildings.

Traditional Practices	Hot-Dry Zone High temperature, low humidity	Composite Zone Hot summers, mild winters, monsoonal rains	Warm-Humid Zone High humidity; low cooling efficiency
ZECC	The high evaporation rate makes ZECCs highly effective for short-term storage of perishables.[117] • **Jodhpur (Rajasthan):** Smallholder farmers build double-walled brick ZECCs with moist sand to store tomatoes, chillies, and leafy greens for weekly markets. • **Solapur (Maharashtra):** ZECCs integrated with vermicompost pits store mushrooms and cow milk cans overnight, reducing spoilage	• ZECCs remain useful during peak summer, helping extend shelf life of fruits and vegetables[107] (Rajesh et al., 2024). • **Varanasi (Uttar Pradesh):** Peri-urban farms use ZECCs to keep cucumbers and bottle gourds fresh for 2–3 extra days. • **Satna (Madhya Pradesh):** Community-run ZECCs operated by self-help groups preserve papaya and guava	Although humid conditions reduce ZECC efficiency, they are still used for select crops.[118] • **Koraput (Odisha):** Tribal groups store turmeric, ginger, and roots in sand-filled ZECCs to slow microbial decay. • **Bankura (West Bengal):** Farmers use ZECCs overnight to hold bananas and leafy vegetables before early-morning market dispatch.
Earthen Jars Submerged in Streams	Streams as natural refrigeration units. Seasonal or perennial streams help cool perishables in arid areas.[119] • **Alwar (Rajasthan):** Small matkas submerged in shallow streambeds to store milk and buttermilk. • **Bhuj (Gujarat):** Pastoralists place goat milk pots in shaded rivulets during grazing routes.	Streams and shaded forest areas for extended storage Cooling enhanced by forest microclimates.[120] • **Latehar (Jharkhand):** Milk and boiled rice stored in submerged pots for 6–8 hours. • **Raipur outskirts (Chhattisgarh):** Markets use large, submerged jars in ponds/channels for beverages and buttermilk.	Stream-submerged jars for short-term preservation. Perennial streams aid food storage before use or sale.[121] • **Koraput (Odisha):** Pickle and curd jars submerged in streams, covered with banana leaves. • **Majuli (Assam):** Fermented rice and milk cooled in rivulets during festivals. • **Udupi (Karnataka):** Temple kitchens submerge pots of coconut water and lentil dishes for rituals.

[117] Rajesh, R. B., Singh, S. N., & Sengar, S. H. (2024). Development of zero energy evaporative cooling storage structure for tribal region of South Gujarat: Zero energy storage structure for tribal region. Annals of Arid Zone, 63(2), 87–100.
[118] Verploegen, E., Ekka, R., & Gurbinder, G. (2019). Evaporative cooling for improved vegetable and fruit storage in Rwanda and Burkina Faso. D-Lab.
[119] Sarkar, N., Somwanshi, A., Dhand, D., & Trivedi, R. (2023). Thermal analysis of a clay pot utilized for cooling water and storing vegetables/fruits. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 45(2), 4146–4159.
[120] Patra, J. K., Sahoo, S. K., & Swain, M. R. (2017). Nutritional and antioxidant potential of Aegle marmelos fermented fruit juice. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 87(3), 769–775.
[121] Khan, D. D., & Banerjee, S. (2020). Revitalizing ancient Indian clay utensils and its impact on health. International Journal of Research in Education and Science Methods, 8, 7.

Traditional Practices	Hot-Dry Zone High temperature, low humidity	Composite Zone Hot summers, mild winters, monsoonal rains	Warm-Humid Zone High humidity; low cooling efficiency
	Warm-Humid Zone	**Composite Zone**	**Temperate Zone**
	High humidity; low cooling efficiency	Hot summers, mild winters, monsoonal rains	Moderate temperatures, cool summers, cold winters
Clay Urns for Fermented Food Storage	High humidity aids natural fermentation. Clay urns help maintain product quality and safety.[122] • **Kollam (Kerala):** Fermentation of *kanji* (rice gruel) and *pazhankanji* (fermented leftover rice) in urns kept in verandas or earthen pits. • **Ganjam (Odisha):** Women's SHGs use buried clay urns to prepare *pakhala bhata* (fermented rice water). • **South 24 Parganas (West Bengal):** Earthen pots used for mustard-based pickles and fish preservation during monsoons.	Seasonal cereals and condiments fermented in clay urns. Urns enable diverse fermentation practices.[123] • **Bastar (Chhattisgarh): Handia** (rice beer) prepared by fermenting steamed rice with herbal starters in sealed earthen pots. • **Hazaribagh (Jharkhand):** Fermented rice and pulses stored in urns, consumed cold in summer as cooling and probiotic food.	Limited but niche fermentation traditions. Clay urns serve small-batch uses in hill communities. • **Madikeri (Coorg):** Fermented bamboo shoots and spiced mango pulp stored in covered earthen jars during monsoon and early winter.
Bamboo Cages in Shaded Streams	High rainfall and dense vegetation make shaded streams ideal for bamboo-based cooling.[124] • **Ukhrul (Manipur):** Bamboo stream enclosures store cooked rice, fermented fish (ngari), or curd during festivals.	This method is seasonal, mostly in early monsoon or post-summer months when streams flow steadily.[114] • **Netarhat (Jharkhand):** Fermented rice cakes (handia) and tubers are submerged during summer feasts.	In upland springs, bamboo cages organize storage and protect food from animals and debris.[125]

[122] Nerurkar, A. S. (2008). Present status of applied microbiology in India.
[123] Ananthanarayan, L., Dubey, K. K., Muley, A. B., & Singhal, R. S. (2019). Indian traditional foods: Preparation, processing and nutrition. In Traditional foods: History, preparation, processing and safety (pp. 127–199). Springer International Publishing. https://doi.org/10.1007/978-3-030-24620-6_5
[124] Ghosal, M. K., & Rath, J. R. (2019). Storage of vegetables in zero energy cool chambers: A review. EAS Journal of Nutrition and Food Sciences, 1(4), 68–73.
[125] Sharma, S., Semwal, A. D., Murugan, M. P., Khan, M. A., & Wadikar, D. (2023). Grain storage and transportation management. In Cereal grains (pp. 269–296). CRC Press. https://doi.org/10.1201/9781003206717

Traditional Practices	Hot-Dry Zone High temperature, low humidity	Composite Zone Hot summers, mild winters, monsoonal rains	Warm-Humid Zone High humidity; low cooling efficiency
	• Zunheboto (Nagaland): Bamboo baskets preserve wild fruits and leafy greens collected during foraging. • **Kollam (Kerala):** Split-bamboo cages protect jackfruit bulbs and coconut water in perennial channels.	• **Kabirdham (Chhattisgarh):** Harvested greens are stored in bamboo structures in streams before sale at local haats.	• **Coorg (Karnataka):** Fine-woven baskets cool curd, milk, and bamboo shoots, often anchored with stones in hillside streams.
	Hot-Dry Zone	**Composite Zone**	**Cold Zone**
	High temperature, low humidity	Hot summers, mild winters, monsoonal rains	Low temperature, long winters, short cool summers, low humidity
Blackened Pots on Rock Slabs (Solar Heating):	Intense sunlight enables widespread use of blackened pots for solar heating.[126] • Barmer (Rajasthan): Blackened brass/terracotta pots warm milk or water on sandstone slabs. • Ahmednagar (Maharashtra): Goat herders heat feed and lentil water (pach) in dark clay pots. • Khammam (Telangana): Women sun-heat bathwater in black-painted aluminium pots, reducing fuelwood use.	Seasonal use, mainly in winter and spring.[127] • **Bhopal (Madhya Pradesh):** Black clay pots sun-heat leftover khichdi or milk. • **Bilaspur (Chhattisgarh):** Soot-blackened aluminium pots warm bathwater for children in courtyards.	Clear skies make solar heating essential for daily use.[128] • **Spiti Valley (Himachal Pradesh):** Blackened copper vessels with barley tea left on roofs for heating. • **Chamoli (Uttarakhand):** Blackened iron pots keep water warm for livestock in winter. • **Leh (Ladakh):** Rooftop black-coated drums heat water and ferment feed.

[126] Mawire, A., Ramokali, M., & Mothupi, M. (2020). A solar thermal experiment with parabolic dish solar cookers for developing countries. European Journal of Physics, 41(5), 055104. https://doi.org/10.1088/1361-6404/ab9997

[127] Misra, N., Pandey, S., Shukla, A., & Sharma, A. (2023). Thermal energy storage for solar water heating, cooking, and ponds. In Thermal energy (pp. 133–154). CRC Press.

[128] Kumar, A., Saxena, A., Pandey, S. D., & Gupta, A. (2024). Cooking performance assessment of a phase change material integrated hot box cooker. Environmental Science and Pollution Research, 31(53), 62392–62407.

Traditional Practices	Hot-Dry Zone High temperature, low humidity	Composite Zone Hot summers, mild winters, monsoonal rains	Warm-Humid Zone High humidity; low cooling efficiency
Earth–Air Tunnels (EATs):	Large temperature gradients make Earth-Air Tunnels (EATs) highly effective.[129] • **Kutch (Gujarat):** Underground milk and ghee chambers linked to air shafts for passive cooling. • **Nizamabad (Telangana):** Semi-underground cattle sheds with sloped vents connected to subsurface airways.	Adapted for both cooling in summer and mild heating in winter.[130] • **Gwalior (Madhya Pradesh):** Stepwell-adjacent chambers with EAT-like air channels for grain/ pickle storage. • **Raigarh (Chhattisgarh):** Buried bamboo ducts aerate fruit pits, extending shelf life. • **Prayagraj (Uttar Pradesh):** Ashram cellars with horizontal earthen ducts regulating airflow.	Prevents freezing of storage and pipes in harsh winters.[131] • **Keylong (Himachal Pradesh):** Stone granaries with subsurface tunnels to reduce condensation. • **Rudraprayag (Uttarakhand):** Herbal huts with underground air tunnels to preserve roots/leaves. • **Tawang (Arunachal Pradesh):** Smoke-drying houses with stone-lined permafrost tunnels for ventilation and moisture control

Communities in India's cold and temperate regions have developed distinct food preservation techniques that leverage earth insulation, solar heating, and architectural features like lofts and attics. These methods not only ensure year-round access to food but also demonstrate adaptive use of local materials and climatic conditions. The Table 9 highlights such traditional practices across different regions.

129 Kshirsagar, M., Kulkarni, S., Meena, A. K., D'costa, D. C., Bhagwat, A., Siddiqui, M. I. H., & Dobrotă, D. (2025). Biomimicry-based design of underground cold storage facilities: Energy efficiency and sustainability. Biomimetics, 10(2), 122.
130 Bansal, N. K., Sodha, M. S., & Bharadwaj, S. S. (1983). Performance of earth air tunnels. International Journal of Energy Research, 7(4), 333–345.
131 Zhou, Y., Liu, M., Zhang, X., Suo, X., & Li, M. (2023). Frost mitigation techniques for tunnels in cold regions: The state of the art and perspectives. Atmosphere, 14(2), 369.

TABLE 9 Traditional Techniques for Preserving Food in Cold Regions of India

Traditional Techniques	Key Features	Regional Examples
Subterranean Cold Cellars (Sadong, Tsothbang, etc.)	Subterranean cellars use earth insulation and stable moisture for food storage in Cold Region[132]	• **Ukhrul (Manipur):** Sadong cellars dug beneath bamboo houses for storing fermented bamboo shoots, dried beef, and seeds; remain 6–8 °C cooler than summer ambient. • **Kohima & Phek (Nagaland)**: Tsothbang multi-tiered pits built into slopes under Angami homes; separate food, tools, and grains; moisture monitored by elderly women. • **Ziro Valley (Arunachal Pradesh)**: Shallow, stone-lined pits near water sources; sealed bamboo containers store pickles and preserved meat. • Yuksom (Sikkim): Buried storage chambers near houses, sealed with grass mats and stones, used for fermented dairy products and tubers.
Blackened Metal Drums for Solar Water Heating	Blackened Metal Drums for Solar Water Heating for cold region[133]	• **Leh (Ladakh):** Rooftop black-coated drums absorb solar heat to keep water warm for daily use and livestock. • **Kargil (Ladakh):** Large iron barrels store fermented feed and prevent freezing by harnessing solar gain. • **Lachen (Sikkim):** Blackened copper pots placed on sun-facing terraces used for heating drinking water.

[132] Virdi, S. S., & Sapra, A. (2023). Schematic design and analysis of underground food stock storage structure for armed forces in mountainous regions of India. In i-Converge: Changing dimensions of the built environment (pp. 142–153). Routledge.
[133] Sharma, S., Semwal, A. D., Murugan, M. P., Khan, M. A., & Wadikar, D. (2023). Grain storage and transportation management. In Cereal grains (pp. 269–296). CRC Press.

Traditional Techniques	Key Features	Regional Examples
Loft & Attic Storage Compartments: Adapted differently across zones	**Cold Zone**:Loft Storage for Dairy Products use gentle residual heat to prevent rancidity and enable long-term storage of butter and dairy.[134]	• **West Sikkim:** Bhutia and Lepcha families store dried churpi butter in wooden boxes above hearths, preserving it for up to six months. • **Dirang (Arunachal Pradesh) & Lahaul–Spiti (Himachal Pradesh):** Yak and cow butter dried in lofts for later use in tsampa and lamp oil. • **Leh (Ladakh):** Dzo (yak–cow hybrid) butter stored above hearths in stone houses ensures year-round supply.
	Hot-Dry & Composite Zones: Lofts and attics harness warm, dry rising air to keep bulbs free of excess moisture, reducing fungal growth and sprouting used for storage of Onions and Garlic.[135]	• **Shekhawati (Rajasthan) & Kutch (Gujarat):** Onions stored on bamboo-mat lofts in kitchens or granaries, dried by cooking heat. • **Alwar (Rajasthan) & Dhar (Madhya Pradesh):** Garlic bulbs strung and hung from roof beams in ventilated attics. • **Patiala (Punjab) & Fatehabad (Haryana):** Elevated mesh racks under roof eaves store onions using household warmth and natural convection.
	Temperate Zone: Attic compartments balance warmth and airflow for storing bulbs, dairy, and herbs suitable for storing Vegetables and Herbs.[136]	• **Kodagu (Karnataka):** Onions and garlic kept in woven baskets in lofts under tiled roofs to prevent decay • **Wayanad (Kerala):** Lofts above indoor hearths used for garlic storage and gentle drying of medicinal herbs.

[134] Shakya, B., Liu, R., Aryal, K., Thomas, S., Shaoliang, Y., & Chettri, N. (2024). Ethnic cuisines from the eastern Himalaya: Revitalising and sustaining mountain food systems. ICIMOD.
[135] Singh, A. K., Poonia, S., Santra, P., & Mishra, D. (2017). Design, development and performance evaluation of low-cost zero energy improved passive cool chamber for enhancing shelf-life of vegetables. Agricultural Engineering Today, 41(4), 72–79.
[136] Kumar, A., Saxena, A., Pandey, S. D., & Gupta, A. (2024). Cooking performance assessment of a phase change material integrated hot box cooker. Environmental Science and Pollution Research, 31(53), 62392–62407.

Chapter 5

SOCIO-CULTURAL AND ECONOMIC DIMENSIONS: CLIMATE-CULTURE-ECONOMY INTERFACE

Thermal comfort in rural India is shaped by more than the physical characteristics of a dwelling. It is influenced by local climate, building materials, household income, occupation, cultural practices, seasonal routines, availability of resources, and access to energy and cooling services. Rural households have historically adapted to climatic conditions through a combination of building design, locally available materials, behavioural practices and social arrangements. These adaptations have developed within particular ecological and socioeconomic contexts and therefore vary considerably across regions.

5.1 Local Materials as Livelihood Resources

Livelihood opportunities related to rural cooling emerge at the intersection of climate conditions, material ecologies, and culturally embedded practices. Agro-climatic realities such as heat intensity, humidity, and seasonal variability shape the choice of locally available materials and spatial forms used for thermal comfort. Over time, these climate-responsive practices become embedded within everyday domestic routines, construction traditions, and craft systems. When mobilized as livelihood activities, such practices translate cultural knowledge into economic value while retaining low-energy, locally appropriate cooling functions, as illustrated in Figure 65. This climate–culture–economy interface thus enables rural cooling solutions that are socially accepted, environmentally sustainable, and economically viable.

FIGURE 65 Livelihood generation with local materials

Traditional earthen pots also have potential as passive cooling solutions with co-benefits of providing livelihood .Traditional earthen pots demonstrate a simple application of evaporative cooling, in which water evaporating from a porous terracotta surface removes heat from the water contained within the vessel. Building on this principle, the CoolAnt Beehive developed in India uses multiple porous terracotta elements arranged in a modular configuration.[137] Water is circulated over the terracotta surfaces, and air passing through the wetted elements is cooled through evaporation. The system combines evaporative cooling with natural ventilation and does not rely on mechanical cooling (Figure 66).

The relevance of this innovation to rural India lies in its potential to translate an established local material and cooling principle into a more structured cooling application. Terracotta components can be produced using pottery and ceramic skills that are already present in many parts of rural India, creating a possible connection between passive cooling, local manufacturing and livelihood generation. Such systems could potentially be explored for suitable rural applications such as shaded semi-open spaces, community facilities, small rural enterprises and other locations where low-energy cooling is required.

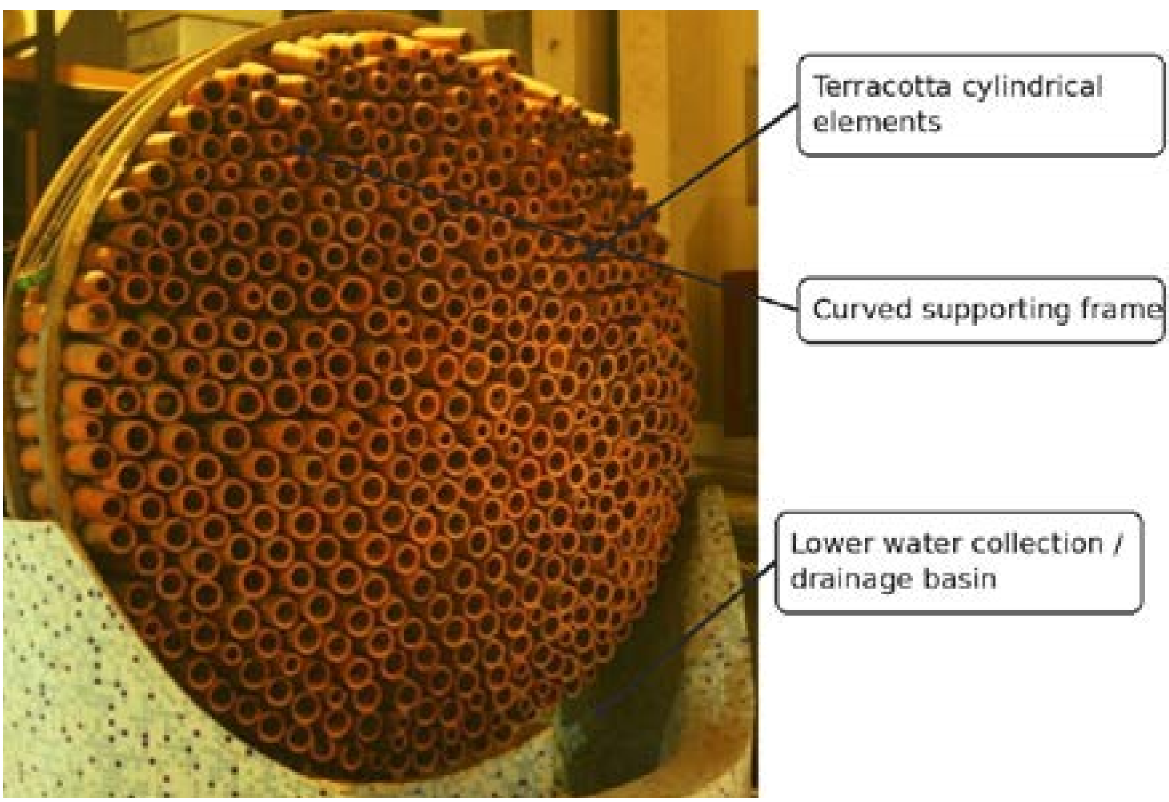

FIGURE 66 CoolAnt Beehive: terracotta-based evaporative cooling system

[137] Sustainable Energy for All. (2021). CoolAnt Beehive: Passive cooling innovation from India. https://www.seforall.org/stories-of-success/coolant-beehive-passive-cooling-innovation-from-india

Bamboo provide another example of the relationship between locally available materials and rural livelihoods. Beyond their use in building components, screens, shading elements and lightweight structures, bamboo and related materials can be processed into a wide range of household, agricultural and craft products. This creates opportunities for local value addition through harvesting, processing, weaving, construction, furniture making and product diversification. Recognizing this The Government of India has explicitly promoted bamboo cultivation, processing, product development, market infrastructure and skill development through the National Bamboo Mission.[138] The restructured Mission also supports value-added product development and processing, linking bamboo production with markets and rural enterprises.

The diversity of products derived from bamboo and ringal in the western Himalayan region illustrates this livelihood potential (Figure 67). Products include baskets, trays, furniture, lampshades, stools, mats, household articles and other utility and decorative items. Such product diversification enables bamboo to function not only as a locally available material but also as an input into small-scale manufacturing, handicrafts and other value-added activities.

Some bamboo products including; Roti serving basket with stand (1), Carrying basket (2), flower pots (3, 5, 6), hat (4), rocking chair (7), ringal muda chair (8), different shape and size baskets (9, 10), basket with handle (11, 12), fruits tray (13), dustbin (14), ladder (15), light lampshade (16, 17), table light lamp (18, 19), chair table set (20), table (21, 27), cups (22), Winnowing tray (23), basket (24), toy (25), tea stool and chair (26), stool (28), sofa (29), wall flower stand (30), pen stand (31, 32) and water bottle (33) [

FIGURE 67 Diversity of bamboo and ringal products supporting local value addition and livelihood activities in the Himalaya region[139]

[138] Press Information Bureau, Government of India. https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=155112&ModuleId=3&reg=48&lang=2

[139] Kumar, S., Rawat, D., Singh, B., & Khanduri, V. P. (2023). Utilization of bamboo resources and their market value in the western Himalayan region of India. Advances in Bamboo Science, 3, 100019

5.2. Climate-Responsive Materials and Rural Livelihoods across Climatic Zones

The potential for climate-responsive cooling and heating practices in rural India is closely linked to local climatic conditions, material availability, traditional knowledge systems and existing skills. Such practices, which have evolved in response to specific environmental conditions, can provide contextually appropriate thermal comfort solutions while also creating opportunities for local employment, entrepreneurship and value-chain development.

Table 10 presents a climate-responsive assessment of locally available materials, traditional practices, skills and associated livelihood opportunities across the five climatic zones considered in this report. It further examines the potential for social inclusion, market development and climate adaptation co-benefits associated with these practices, highlighting their potential contribution to both rural economic development and climate resilience.

TABLE 10 Climate-Responsive Materials and Rural Livelihoods across Different Climatic Zones

Climatic Zone	Local Climate Stressors	Locally Available Materials	Cultural Practices	Presence of Skill / Labour Needs	Social Inclusion	Livelihood Opportunities	Market & Scalability	Adaptation Co-benefits
Hot-Dry Climate Extreme daytime temperatures (>45°C), low humidity, high diurnal variation		Adobe/ mud, lime, sandstone, granite, camel dung, thatch	Thick walls, courtyards, jaalis, stepwells, lime plastering	Semi-skilled masonry, traditional artisans, pottery skills	High women participation in pottery and plastering	Mud–lime plastering (cool roofs, walls) Earthen pot (matka, surahi) making Stone jaali fabrication Thatch panel & shading screen production Terracotta-based evaporative cooling products	Local housing demand; scalable via govt housing schemes, and heritage tourism	Reduced indoor temperatures, lower energy cooling, health benefits
Warm-Humid Climate	High humidity, high night temperatures, low thermal comfort	Bamboo, coir, palm leaves, cane, wood	Raised houses, permeable walls, wide verandahs	Bamboo carpentry, weaving, joinery	Strong SHG involvement (coir, weaving)	Bamboo wall panels & screens Coir mats for shading & flooring Ventilated roofing panels Bamboo louvers & window systems	Tourism facilities, disaster-resilient housing	Reduced humidity stress, indoor air quality improvement
Composite Climate	Seasonal extremes (hot summers, cold winters)	Mud, brick, lime, bamboo, crop residue	Courtyard houses, seasonal shading, roof insulation	Multi-skilled rural masons, retrofit technicians	Good SHG participation	Mud–lime plastering (cool roofs, walls) Earthen pot (matka, surahi) making Stone jaali fabrication Thatch panel & shading screen production	heritage tourism, rural institutions	Reduced indoor heat stress, zero-energy cooling, health benefits

Climatic Zone	Local Climate Stressors	Locally Available Materials	Cultural Practices	Presence of Skill / Labour Needs	Social Inclusion	Livelihood Opportunities	Market & Scalability	Adaptation Co-benefits
Temperate Climate	Moderate summers, cool winters, seasonal rainfall,	Stone, timber, mud brick, lime, slate, thatch	Sloped roofs, shaded verandahs, thick walls, mixed-use courtyards	Semi-skilled masonry, carpentry, roofing	SHG-based crafts, Carpentry	• Timber joinery and window systems • Stone masonry and slate roofing • Passive daylighting elements	Local housing demand, eco-resorts, hill tourism infrastructure	Improved thermal comfort, reduced heating/cooling demand, durability under variable climate
Cold Climate	Prolong cold winters, sub-zero temperatures, strong winds, low humidity	Stone, mud brick, rammed earth, timber, straw,	Compact settlement form, thick walls, south-facing openings, livestock-integrated houses	Skilled masonry, earth construction, timber framing, insulation detailing	Community role in animal rearing , women involvement in wool/ weaving	• High-mass earthen wall construction •Straw–mud insulation panels •Passive solar retrofits (sunspaces, trombe walls)	Disaster-resilient housing, heritage conservation	Heat retention, reduced fuelwood use, lower winter energy demand, health resilience

Chapter 6

RECOMMENDATIONS

The passive cooling strategies presented in the previous chapters demonstrate that rural communities across India's different climatic zones have traditionally used locally available materials, climate-responsive building practices, nature-based solutions, and everyday household practices to maintain comfortable indoor conditions with minimal reliance on mechanical cooling. Many of these practices remain relevant today and can support efforts to improve thermal comfort, reduce energy demand, and enhance climate resilience in rural areas.

The recommendations presented in Table 11 summarise key passive cooling and heating practices used across different climatic zones of rural India. These are organised according to the major climatic challenges and include climate-responsive building practices, nature-based solutions, household-level practices, and traditional food and water storage methods. The table provides a consolidated overview of the different approaches used by rural communities to manage thermal conditions. It also highlights that no single approach is suitable for all regions, as thermal comfort practices vary with local climate, available resources, housing patterns, and traditional knowledge. Together, these examples provide an overview of diverse, climate-specific practices that can help improve thermal comfort and strengthen awareness of traditional approaches used across rural India.

The recommendations presented in this chapter highlight that there is no single passive cooling solution suitable for all regions of India. Instead, effective thermal comfort in rural areas depends on adopting climate-responsive building practices, nature-based solutions, and household practices that are tailored to local climatic conditions, available resources, and traditional knowledge. By integrating these approaches into rural housing and community planning, it is possible to improve indoor thermal comfort, enhance resilience to rising temperatures, and preserve India's rich vernacular building traditions. These recommendations provide practical guidance for promoting sustainable and climate-responsive rural development while supporting environmental sustainability, and improved quality of life.

TABLE 11 Climate-wise Recommendations for Passive Cooling in Rural India

Climatic Zone	Key Climate Challenge	Recommended Rural Building Practices	Nature-Based Solutions	Household Cooling & Heating Practices	Food & Water Storage Practices
Hot-Dry	Intense solar radiation, very high daytime temperatures, low humidity, and large day–night temperature variation result in excessive daytime heat gain while nights become significantly cooler.	• Use courtyard-based rural houses to provide shaded semi-open spaces and facilitate night-time heat release. • Adopt compact building layouts with a low surface-to-volume ratio to minimise heat gain. • Orient longer axis of buildings (preferably along the east–west axis, where feasible) to reduce direct solar heat gain. • Construct thick earthen or stone walls using locally available high thermal mass materials and lime finishes. • Provide deep verandahs, recessed windows and shaded openings to reduce direct solar radiation.	• Conserve and restore traditional water bodies such as johads, khadins and village ponds to moderate the local microclimate • Protect sacred groves, village forests and riparian vegetation to provide shade and reduce surrounding temperatures. • Plant native shade trees around houses, courtyards and community spaces. • Maintain natural drainage channels and seasonal streams to support water management and local cooling. • Retain permeable open spaces and vegetation around rural settlements.	• Store drinking water in shaded earthen pots (matka, surahi or ghara). • Use traditional hand fans made from locally available materials. • Install bamboo or sarkanda chik blinds, preferably sprinkled with water, to reduce heat gain while allowing airflow. • Use wetted khus (vetiver) mats for evaporative cooling. • Where water availability permits, sprinkle water on roofs during peak summer afternoons to temporarily reduce roof temperatures.	• Store drinking water in earthen pots using evaporative cooling. • Use pot-in-pot (Zeer) coolers for fruits, vegetables and dairy products. • Adopt Zero Energy Cool Chambers (ZECCs) for short-term storage of fresh produce. • Store food in shaded, naturally ventilated areas using traditional earthen containers where appropriate.

Climatic Zone	Key Climate Challenge	Recommended Rural Building Practices	Nature-Based Solutions	Household Cooling & Heating Practices	Food & Water Storage Practices
Warm-Humid (Southern & Coastal Region)	High humidity, high temperatures, heavy rainfall and limited evaporative cooling reduce thermal comfort. Buildings therefore need to maximise airflow, minimise moisture accumulation and reduce solar heat gain.	• Design houses around central courtyards to enhance natural ventilation. • Provide deep verandahs and shaded semi-open spaces to reduce solar heat gain and protect against heavy rainfall. • Use locally available climate-responsive materials such as laterite masonry where appropriate. • Construct pitched tiled roofs with ventilated roof spaces. • Maximise cross-ventilation through appropriate building orientation and openings.	• Protect canals, ponds, streams and traditional tank systems that contribute to local cooling. • Conserve dense tropical forests, sacred groves and riparian vegetation to provide shade and moderate surrounding temperatures. • Preserve streamside vegetation and natural wind corridors to enhance airflow. • Maintain homestead trees and vegetation around houses while allowing natural ventilation. • Avoid obstructing natural drainage and water flow.	• Use lightweight palm-leaf or bamboo hand fans for personal cooling. • Install reed or coir chik blinds that allow ventilation while resisting moisture. • Maximise natural ventilation by keeping verandahs and windows open during favourable weather.	• Store drinking water in earthen vessels where appropriate. • Use clay urns for preparing and storing fermented foods such as curd, pickles and traditional cereal-based products. • Where traditionally practised, use earthen jars placed in cool streams for temporary storage of dairy and other perishable foods. • Store food in shaded, naturally ventilated locations to reduce spoilage.

Climatic Zone	Key Climate Challenge	Recommended Rural Building Practices	Nature-Based Solutions	Household Cooling & Heating Practices	Food & Water Storage Practices
Warm-Humid (Eastern & North-Eastern Region)	High humidity, heavy rainfall, seasonal flooding and moisture accumulation require buildings that remain dry, well ventilated and resilient under wet climatic conditions.	• Construct stilt houses or raised-floor dwellings in flood-prone areas. • Use bamboo, timber and mud-based construction systems. • Adopt wattle-and-daub wall systems with stabilised mud plaster. • Provide raised plinths where stilt construction is not feasible. • Construct steeply sloping roofs with ventilated roof spaces and wide overhangs. • Maximise cross-ventilation through verandahs and shaded openings.	• Conserve wetlands, rivers, streams and floodplains that regulate local temperature and moisture conditions. • Protect sacred groves, bamboo forests and riparian vegetation. • Maintain streamside vegetation and natural drainage systems. • Retain village ponds and traditional water bodies. • Preserve forest cover around rural settlements.	• Use lightweight bamboo or palm-leaf hand fans for personal cooling. • Promote natural ventilation by keeping verandahs and windows open during suitable weather conditions.	• Store drinking water in earthen vessels where appropriate. • Store food in shaded, naturally ventilated areas. • Where traditionally practised, use earthen jars placed in cool streams for temporary storage of perishable foods.

Climatic Zone	Key Climate Challenge	Recommended Rural Building Practices	Nature-Based Solutions	Household Cooling & Heating Practices	Food & Water Storage Practices
Composite	Hot summers, humid monsoons and cool winters require rural buildings to respond effectively to changing seasonal conditions throughout the year.	• Use courtyard-based layouts with verandahs and transitional spaces. • Construct thick earthen or masonry walls using locally available materials. • Use sloping clay tile or thatched roofs with ventilated roof spaces. • Use seasonally adaptable strategies that balance thermal mass, shading, ventilation and solar access across summer, monsoon and winter conditions. • Use semi permeable bamboo windows for cross ventilation.	• Conserve village ponds, tanks and traditional water harvesting systems. • Maintain sacred groves and riparian vegetation. • Preserve forests and vegetated landscapes around settlements. • Protect valley drainage and natural breeze corridors. • Retain permeable landscapes and local vegetation.	• Use earthen water coolers during summer. • Use bamboo or wool-thread hand fans. • Install seasonal bamboo or cotton-thread chik blinds. • During hot and relatively dry periods, use wetted khus mats where traditionally practised. • Where water is available, sprinkle water on roofs during peak summer. • During winter, use traditional chulhas, angithis and hot water bottles or heated bricks for supplementary heating.	• Store drinking water in earthen pots. • Adopt ZECCs for short-term seasonal storage of fruits and vegetables. • Use clay urns for fermented foods where traditionally practised. • Store food in shaded, naturally ventilated areas during summer.

Climatic Zone	Key Climate Challenge	Recommended Rural Building Practices	Nature-Based Solutions	Household Cooling & Heating Practices	Food & Water Storage Practices
Temperate	Moderate temperatures with seasonal rainfall require balanced thermal comfort through appropriate solar exposure, ventilation and protection from seasonal moisture.	• Use moderately thick walls and sloping tiled roofs • Provide shaded verandahs and naturally ventilated spaces. • Maintain moderate thermal mass and appropriate solar orientation. • Use seasonal shading and ventilation during warmer periods while allowing useful solar gains during cooler periods.	• Conserve forests, coffee plantations and bamboo vegetation. • Protect springs, streams and associated vegetation. • Maintain natural vegetation around homesteads. • Preserve valley ecosystems to regulate local temperature and humidity.	• Use hay or straw insulation in roofs, walls or attic spaces during winter. • Use layered woollen bedding and blankets to retain body heat. • Adjust bedding and clothing according to seasonal temperature changes.	• Store onions, garlic and seasonal produce in well-ventilated attic or loft spaces. • Use shaded storage areas with adequate airflow for household food items.
Cold	Prolonged winters, sub-zero temperatures, strong cold winds and significant heat loss require buildings to maximise winter solar gain while minimising heat loss.	• Construct compact multi-storey houses using thick stone or earthen walls. • Adopt vertical zoning with livestock shelters on the ground floor and living spaces above. • Use layered insulated roofs with locally available materials. • Orient houses towards the south (where feasible) and minimise north-facing openings. • Provide controlled ventilation and internal courtyards where traditionally practised.	• Conserve forests, tree belts and bamboo vegetation to reduce cold winds. • Protect springs, streams and traditional water sources. • Maintain natural vegetation on hill slopes to reduce erosion. • Preserve natural landforms that provide shelter from cold winds and thermal extremes.	• prioritise passive solar heating, improved insulation, and warm bedding. • Use centrally located traditional chulhas for cooking and space heating. • Use hay or straw insulation for roofs, walls and bedding. • Use layered woollen bedding, quilts and blankets. • Use heated bricks, heated stones or hot water bottles during cold nights.	• Store food in subterranean cold cellars where traditionally practised. • Store grains, dairy products and dried foods in lofts or attic compartments. • Use blackened metal drums for passive solar water heating. • Preserve seasonal produce using traditional cold storage methods adapted to local climatic conditions.

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