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RESEARCH ARTICLE

Incorporating Climate-Responsive Vernacular Strategies and Modern Architectural Design: Sustainable Housing Model in North India

Namita Singh[1*], Suruchi Modi[2]

Abstract

Contemporary North Indian housing does not consider passive cooling of buildings, thermal comfort, and sustainable provision of climate-responsive vernacular architecture, leading to high energy consumption and poor indoor comfort. This research paper provides a detailed concept of implementing vernacular design concepts in modern architecture practice to provide sustainable housing in North India. The paper relies on the literature review, the climate of North Indian areas (Haryana, Punjab, Uttar Pradesh, Delhi, Uttarakhand, etc.), and the case studies of traditional dwellings to define vernacular features such as courtyard planning, high thermal-mass walls, shaded verandahs, jaali screens, and strategic orientation to achieve the current standards of energy performance and occupant comfort. The proposed paradigm combines environmental (climatic), architectural (design and material), and socio-cultural issues into the modern house design. It is a combined approach that enhances thermal performance (minimising indoor temperatures to 35°C and cooling power needs for buildings) and preserves cultural heritage in homes. We describe the framework's components, highlighting their advantages and disadvantages, and present diagrams that illustrate the interaction between passive features and modern technologies. This research provides architects and politicians with practical guidance on constructing climate-resilient and energy-efficient homes that align with the local culture.

Keywords: Climate-responsive design; Vernacular architecture; Sustainable housing; North India; Thermal comfort; Passive cooling; Modern vernacular integration.

Introduction

The energy consumption that causes climate change and North Indian living is less comfortable and consumes more energy. The current-day city residential design of high amounts of concrete, glass and mechanical air-conditioning could not fit the hot summers and volatile climate of North India. Conversely, the vernacular architecture in this area developed over many centuries with climatic-adaptive features that can uncontrollably adjust the indoor environments. Courtyard houses (havelis), adobe or stone houses, kathkuni-type timber-stone buildings and other indigenous types are thermally resistant. According to Indian field research, under the same circumstances, the inside temperature of vernacular rural houses is far lower than the modern houses, at 7-10°C. In composite climates, modern houses are capable of consuming five times as much energy as rustic houses of the same size. These significant differences emphasise one of the most important opportunities: the combination of vernacular with modern architecture to advocate sustainability. There are numerous climate zones of North India, including the hot, sticky Punjab and Haryana plains, the Ganges valley and the frozen, alpine territory of Uttarakhand. Vernacular architecture was adapted to its various environments in a clever manner. In arid climates, brick walls and thick mud reduce the amount of heat that enters and leaves the building, especially during the day. Internal courtyards and narrow alleyways of historic cities such as Jaisalmer have been shaded by historic microclimates. Haveli buildings of

[1]Research scholar Sushant University, Associate Professor Chandigarh University, India

[2]HOD, Senior Professor, Sushant University, Gurugram, India

***Corresponding Author:** Namita Singh, Research scholar Sushant University, Associate Professor Chandigarh University, India, E-Mail: bamel.namita@gmail.com

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the Indo-Gangetic plains were traditional with windows that created courtyards, verandahs and portable screens known as 'jaali' to block the summer heat and allow the sun to shine in winter. Timber-framed stone buildings such as the kathkuni architecture at Himachal Pradesh possess small surfaces, few windows, and roofs that are insulated to retain heat in cold hill climates. These vernacular solutions were sustainable in terms of local resources and passive comfort. Nevertheless, despite all this richness of the traditional knowledge, the post-independence Indian architecture, in most cases, disregarding local climatic logic, adhered to western models and western modernism in style. Thermally inefficient houses use lots of air conditioning during summer and heating during winter in extreme weather. Fast urbanisation and high-rise apartments have minimised climate-preventing courtyards and powerful walls too. But India is beginning to feel the need to revive and redefine indigenous concepts of design in the contemporary structure. Michael and Jennifer are lured into using modern vernacular methods due to the marriage of cultural wisdom and technological innovation. The sustainable housing and building regulations that are in force in the Indian government now prioritise passive architecture. The National Building Code of India and Energy Conservation Building Code (ECBC) suggest climate-based design methods in the hot-dry, warm-humid, composite, temperate, and cold zones to minimise the energy requirement of the buildings. The current study questions are: How can we systematically connect climate-responsive vernacular practices with the contemporary architectural design to create a model of sustainable housing in North India? North India is rich in vernacular architecture with the present speedy growth and climate change. Some of the components of this integration have been mentioned in previous literature, like the advantages of courtyards in urban environments or the application of traditional insulating materials, yet architects need a global framework. This paper reconciles vernacular architectural lessons and existing structural, functional and regulatory design requirements into unified design concepts and methods in order to bridge that gap. This is important because of its multidisciplinary approach. Real sustainable housing should be able to comply with environmental (energy efficiency, climate resilience), architectural (structural integrity, functionality, aesthetics) and socio-cultural (habitability, cultural consonance, occupant well-being) standards. These variables have been balanced in vernacular design during its time, and we are striving to implement it to suit contemporary housing requirements.

Literature Review

Vernacular Architectural Strategies in North India

The architecture of North Indian vernacular has various styles, yet climate-friendly architecture brings all of them together. The trial-and-error period enabled traditional builders to discover architectural features that reduce climatic extremities. A characteristic element is a courtyard. The central courtyard (aangan) in havelis in Punjab, Haryana, Uttar Pradesh and Delhi controls temperature and is used as the social centre of the home. Open to the sky, courtyards facilitate ventilation and daylight while shading surrounding rooms. During peak summer, courtyard surfaces cool off at night, creating downdraft breezes in the evening and early morning that help flush heat from the house. Studies show that courtyards can create microclimates 2–4°C cooler than outside in hot conditions, and well-designed courtyards in contemporary simulations have reduced indoor temperatures by about 3–5°C. Vernacular courtyard houses also typically feature thick walls around the courtyard and arcaded verandahs, which further buffer interiors from direct sun (see Figure 1). The socio-cultural function of the courtyard is interwoven with its climate function – it is a space for family gathering, chores, and religious activities, underscoring how climate-responsive design also reinforced community living.

Another key vernacular strategy is the use of high thermal mass materials and insulation through construction techniques. In the hot-dry and composite climates of the plains, traditional homes were built with locally available materials like adobe (sun-dried mud brick), burnt brick with lime mortar, or stone. Walls often 45–60 cm thick absorb heat during the day and release it slowly at night, moderating indoor temperatures. In the arid regions of Rajasthan and Punjab, many old houses were whitewashed with lime plaster, both for waterproofing and for its high solar reflectance to keep the building cool. In the mountainous north (Himachal Pradesh, Uttarakhand), vernacular architecture used a combination of wood and stone in thick, cavity walls. The *kathkuni* technique in Himachal – laying timber beams horizontally with infill of stone masonry – creates a wall with air gaps and wood that provide natural insulation, keeping homes warm in freezing winters. These houses often have small windows to prevent heat loss, and a *dhajji dewari* pattern (timber lattice infill) to resist earthquakes while also adding insulation. Figure 2 shows an example of a *kathkuni* house in the hills, characterized by its alternating wood-stone courses and overhanging slate roof.

Ventilation and shading elements are also prominent in North Indian vernacular design. *Jali* screens – perforated lattices in stone or wood – have been used since medieval times (notably in Mughal-era architecture) to filter intense sunlight and induce airflow by pressure differentials. These screens admit dappled daylight and breeze but cut down direct solar gain, effectively reducing indoor overheating. In warm, humid sub-regions, such as parts of Uttar Pradesh during the monsoon, vernacular homes incorporate operable vent panels at high levels (near roof or gable ends) to exhaust hot air and encourage upward ventilation.

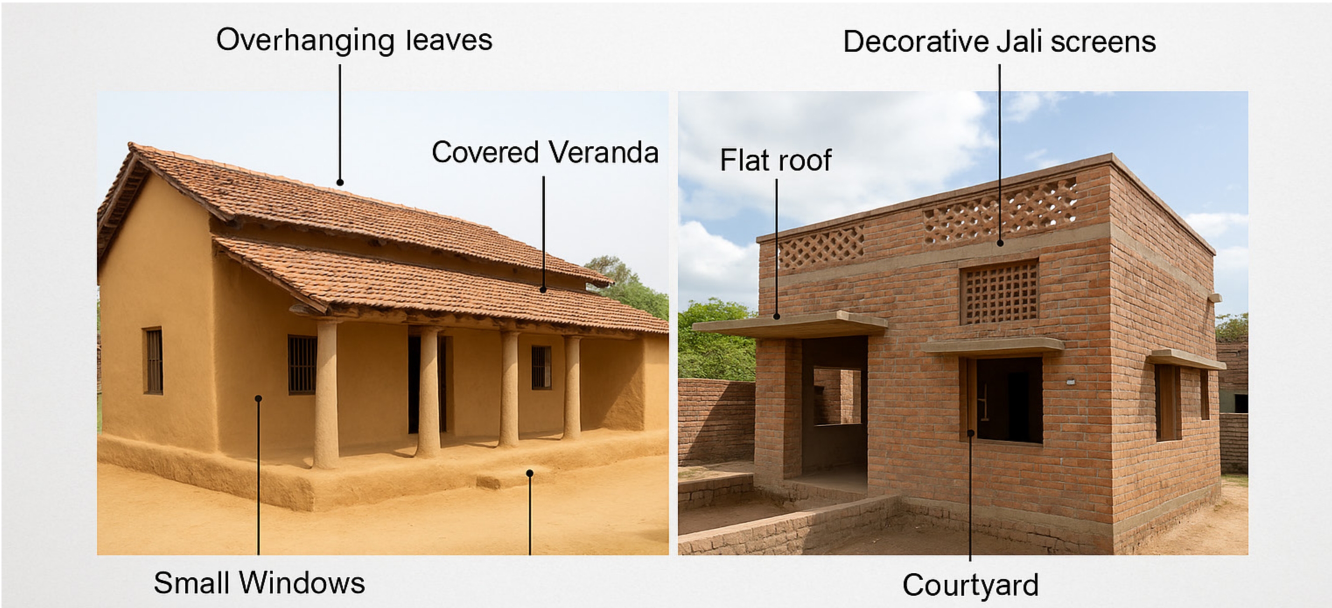

Figure 1: *Section of a traditional North Indian courtyard house, illustrating climate-responsive features: central courtyard (cooling via cross-ventilation and nocturnal radiation), surrounding rooms with thick masonry walls (thermal mass), shaded verandahs or colonnades, high vents near the roof (to exhaust hot air), and a roof terrace for nocturnal cooling.* (Schematic illustration by author, inspired by historic *haveli* layouts)

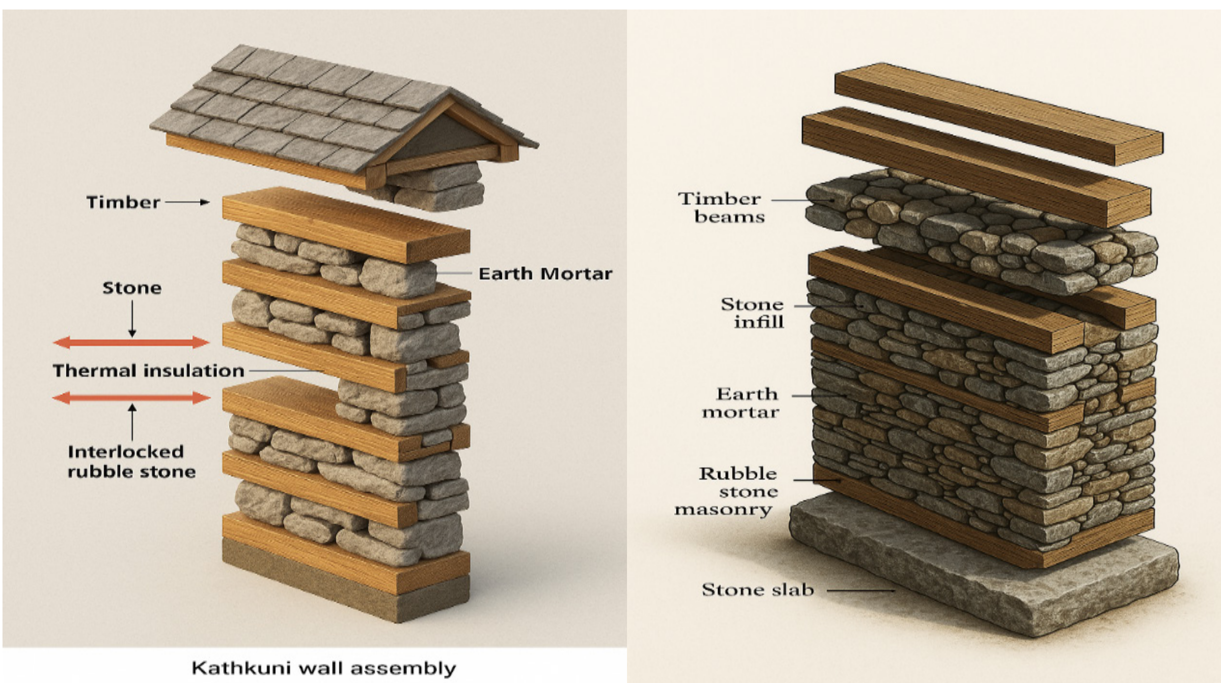

Figure 2: A vernacular kathkuni style house in a village of Himachal Pradesh. Alternating layers of timber and stone create thick insulated walls, and the wooden projected balconies are deeply shaded by a slate roof. Such construction keeps interiors warm in winter and cool in summer through thermal mass and minimal thermal bridging (Photo: Architectural Digest India).

Chhajjas (projecting eave canopies) and deep verandahs are ubiquitous features, protecting walls from sun and rain. According to Indraganti (2018), vernacular typologies of the coastal Kerala dwellings to Maharashtra wada have an extensive roof overhang in warm-humid and composite climates. Vernacular climate adaptations include traditional Punjab havelis, which have wraparound verandahs on the ground floor, and colonial-era hill station houses, which have deep porches. Lastly, traditional settlement patterns and space organisation helped to promote building-based approaches. Tight twisting lanes and proximity to buildings in compact historic cities such as Old Delhi or Lucknow reduced direct exposure of building faces to the sun and formed mutual shadow effects. Clusters of homes often shared common courtyards or wells. In rural settings, extended family homes were planned with semi-private courtyards (*angaṇ*) for women and children (the *zenana* in Mughal parlance) and outer areas for men and outsiders – a cultural spatial hierarchy that also had environmental advantages (e.g. multiple courtyards serving different functions, improving airflow through the complex). In the hills, houses were frequently built into south-facing slopes to maximize solar gain in winter, with terraced fields and vegetation aiding in microclimate control.

Performance of Vernacular vs. Modern Housing

A body of research has quantitatively demonstrated the superior environmental performance of vernacular housing in India relative to modern construction. Mani *et al*. (2016) found that when rural Indian homes transition from traditional materials to modern materials (e.g. mud to cement, thatch to concrete), the embodied energy of the house increases by ~4 times and operational energy by ~40 times. A recent field survey in Himachal Pradesh (composite climate) compared energy use of traditional rural houses versus modern urban houses of similar size, and reported that modern houses consumed 5.4 times more annual energy on average. The modern houses had an average Energy Performance Index (EPI) of ~39 kWh/m^2/year, whereas the vernacular houses averaged only ~7.9 kWh/m^2/year. This dramatic difference is attributed to vernacular homes requiring little active cooling or heating – their passive design keeps indoor conditions within or near comfort range most of the year.

Thermal comfort studies reinforce these findings. A study by Shastry *et al*. in a West Bengal village (warm-humid climate) observed that the introduction of modern materials (e.g. replacing mud walls with brick and cement) raised the indoor average temperatures by 7–10°C compared to the original vernacular houses. Another investigation monitored two adjacent homes in a central Indian town – one a traditional mud-and-brick house, the other a contemporary concrete house – and found that on a 40°C day the vernacular house's indoor air was 5–6°C cooler than the outside, whereas the modern house's interior was hotter than outdoors until late evening. Residents of vernacular houses also report higher satisfaction and lower incidence of heat stress. These outcomes are linked to features like natural ventilation, thermal mass, and night-time cooling that are inherently present in vernacular architecture but often absent or insufficient in modern designs.

However, contemporary construction in North India has shifted heavily toward reinforced concrete frames with infill brick walls, plastered and painted, and often large glass windows – a typology that performs poorly without mechanical HVAC. Single brick walls and flat concrete roofs heat up in the summer and are poor at keeping heat in during the cold seasons. Most urban, mid-range houses are not responsive to the climate, and thus the use of air conditioners and electric heaters has expanded, which intensifies the demand for energy. The literature review proposes the reinvention of vernacular practices in contemporary buildings to minimise this performance gap. The energy and comfort shortcomings of modern dwellings can be significantly reduced through passive cooling (courtyards, wind catchers, evaporative cooling pools), shading devices and high thermal capacity or insulation. A simulation study established that retrofitting a typical Delhi flat by adding a ventilation shaft at the centre and window jaali shade can help cut down peak summer temperature inside the flats by 2-3°C and cooling energy requirements by 20-30%. A contemporary courtyard house in the area near Hyderabad divides the house into four blocks surrounding an open core to ensure complete cross-ventilation and avoid air-conditioning.

Contemporary Approaches and Theoretical Frameworks

Sustainable architecture and urban design literature inform the blending of vernacular and modern design. Principles of critical regionalism as articulated by Frampton promote the models that are sensitive to the local climate and culture, as well as employ contemporary practices. This philosophy defines present-day vernacular architecture. The architectural practices such as those of Laurie Baker advocated the low cost and climate-friendly design (walls should breathe) of India, whereas INTACH has recorded the ancient methods of adapting to the present times. New scholarship suggests the systematic frameworks of the vernacular inclusion. A five-fold strategy framework introduced by Patil *et al*. (2025) to reintroduce courtyard typologies in Indian cities comprises (i) the integration of the courtyard passive design into the building codes and its incentivisation, (ii) the adaptation of the courtyard into a vertical/high-rise format, (iii) the optimisation of the courtyard dimensions and airflow, (iv) the cultural retention in the courtyard and (v) the mainstreaming of the courtyard by interdisciplinary education.

Table 1 shows the North Indian vernacular methods and their literature advantages.

Socio-Cultural Dimensions of Vernacular Design

Vernacular design embodies socio-cultural sustainability as well as environmental performance, which is crucial for modern integration. Traditional housing fostered extended families, community, and cultural rites. The courtyard was used for daily activities, social meetings, marriages, and domestic festivities as well as climate. A haveli's spatial hierarchy (outside public courtyard vs. interior private courtyard) reinforced social structure (gendered spaces, visitor receiving places, etc.). Flexible courtyard-like spaces (even smaller or semi-open) can preserve these functions by introducing nature and cultivating community, despite modern housing tendencies towards nuclear families and privacy. Residents cherish these spaces for well-being and social cohesion, studies show. Vernacular methods often used local labour and crafts to integrate buildings into local economies and knowledge networks. The elaborate fretwork, carvings, and paintings in antique Punjabi havelis (like the Bodlan village haveli with Sikh religious murals) reflect cultural identity through architecture. Employing local art, craft themes, or materials in a traditional style (like the new Parliament building in New Delhi employing Indian motifs and sandstone jaalis produced by local artisans) helps maintain cultural continuity in modern architecture. Traditional materials' health benefits are increasingly becoming more apparent: Lime plaster and mud regulate indoor humidity and are non-toxic; terracotta or mud floors are softer on joints (anecdotes relate mud flooring to arthritis relief). These factors improve occupant comfort overall. According to the literature, North Indian vernacular architecture was an early integrator of climate appropriateness, resource efficiency, and habitability. Today, we can apply these concepts to construct sustainable housing without the need to create new designs. Modern restrictions, including high population density, multi-storey development, modern amenities, and safety requirements, prevent us from copying ancient designs. Instead, a systematic framework is needed to translate vernacular strategies into modular components that architects can apply in new designs, supported by modern engineering and simulations. The next section describes the methodology adopted to develop such a framework.

Methodology

This research follows a multi-stage methodology combining qualitative analysis of vernacular design principles with quantitative evaluation of their impact, in order to formulate a design framework applicable to modern housing. The overall approach can be described as a comparative analytical framework development, comprising the following steps:

Climate Analysis of North Indian Regions

We first characterized the climates of the target geographic scope – broadly covering the plains (Punjab, Haryana, Delhi, Uttar Pradesh) and hill states (parts of Punjab/Haryana in Shivalik foothills and Uttarakhand/Himachal Himalayas). Historical climate data (temperature ranges, humidity, solar radiation, wind patterns) were reviewed from Indian Meteorological Department records and climate classification studies. North India spans three of India's five major climatic zones: hot-dry (e.g. western Punjab, Rajasthan border areas), composite (e.g. Delhi, eastern Punjab, U.P.), and cold (high-altitude Himalayas). We created seasonal climate profiles for representative locations (Delhi for composite, Jaipur for hot-dry, and Shimla for cold) to identify the predominant environmental challenges (such as extreme summer heat of 45 °C in the plains, or sub-zero winter nights in hill towns). This climate analysis established the functional requirements for passive design – e.g. need for cooling and shading in summer, need for heat retention and sun access in winter – which informed which vernacular strategies are relevant where.

Literature Survey and Case Study Selection

A thorough literature review (as presented in the previous section) was conducted to catalogue vernacular architectural elements in North India, along with documented effects on thermal performance and energy use. We selected case studies of traditional dwellings representative of different sub-regions: (a) A Punjabi *haveli* (courtyard mansion) for the plains, (b) A typical rural mud house from the composite Gangetic plain (such as in Western U.P.), and (c) A *kathkuni* house from Himachal's hills. Historical architectural plans and images were augmented by field data from past studies (e.g., temperature readings by Henna *et al*. 2021 in vernacular compared to modern homes). Case studies of recent "vernacular-inspired" initiatives were also explored to understand application. The Pearl Academy of Jaipur and the 2023 award-winning Telangana Courtyard House, which used four courtyards and indigenous materials, were examples. Comparing these situations revealed common design variables, including building orientation, layout (courtyard vs. corridor), wall/roof materials, shading devices, natural ventilation, etc.

Vernacular-Modern Criteria Synthesis

We created a tentative list of design principles for an integration framework based on climatic needs (step 1) and design strategies (step 2). Each principle included the vernacular strategy and its modern equivalent. For instance, "Incorporate a central open-to-sky courtyard or atrium for passive cooling and stack ventilation" could mean a multi-level atrium or a series of smaller skywells in modern multi-storey apartments, but the function is the same. We made sure each concept addresses climate issues (high solar gain, low winter temps, ventilation needs) and modern limits (structural viability, space limitations, privacy, etc.). Where available, we prioritised strategies based on quantitative performance data. If thermal modelling showed that wall insulation saved more energy than a ventilator, the framework would favour it. Due to scope, we used simplified calculations and simulation findings from the literature to test assumptions. Using Sarkar's (2024) data on energy use, we predicted energy savings if modern houses followed

Table 1: Vernacular climate-responsive strategies in North India and their observed benefits

Vernacular Strategy	*Climate Function & Benefit*	*Source Example(s)*
Courtyard (central open space)	Enhances natural ventilation; provides shaded microclimate; nighttime cooling of surfaces lowers indoor next-day temperatures (courtyards ~2–4 °C cooler)	Lucknow and Varanasi courtyard houses; Simulation in warm-humid climate
Thick walls (mud, brick, stone)	High thermal mass delays and reduces heat transfer; stabilizes indoor temperature (dampens diurnal peaks)	Vernacular house in Mandi: ~45 cm stone walls keep interior ~5°C cooler on hot days; Jaisalmer houses with 60 cm sandstone walls
Jaali (perforated screens)	Filters solar radiation while permitting airflow; maintains privacy and diffuses light; reduces direct heat gain by ~30–50% (qualitative)	Mughal-era havelis and modern adaptations (new Delhi Parliament uses sandstone jaalis on façade for cooling)
Verandahs & overhangs	Provide buffer spaces and shade to walls and windows; protect from rain (especially in monsoon); allow indoor-outdoor living in comfort	Traditional bungalow houses (e.g. Kolkata, Lahore) with 3m deep verandahs reduce wall temperatures
High vents and clerestories	Exhaust hot air (stack effect); improve cross-ventilation; especially useful in humid seasons for removing internal heat and moisture	Vernacular examples: high *jaali* openings in Rajasthan for hot air escape; Gandhi's Sevagram ashram with continuous clerestory for ventilating during monsoon
Compact massing (in hot-dry/cold)	Reduces surface area exposed to elements; mutual shading between units; retains heat in cold climates and reduces sun exposure in hot-dry climates	Jaisalmer fort town: tightly packed houses shade each other; Leh/Ladakh houses clustered on south slopes minimize wind exposure
Material insulation layers	Use of cavity walls, thatch or mud insulation on roofs, and air gaps; keeps heat out in summer and in during winter; also improves acoustic comfort	Kathkuni walls with timber-air-stone layers insulate (Himachal); Thatch or mud-plastered roofs in village huts lower interior temps vs. tin roofs (empirical rural studies)

vernacular measures, driving the framework's energy efficiency recommendations.

Framework Formulation

Diagramming and Component Definition: Framework development was the methodology's core. Site and layout, form and orientation, envelope design (materials and construction), passive systems (ventilation and cooling/heating), and cultural and aesthetic elements were topic categories for integrated design principles. Each category included unique techniques (e.g., "Envelope" includes wall construction, roof design, insulation, and shading; "Passive Systems" includes courtyards, wind catchers, night purge ventilation, etc.). A conceptual diagram (Figure 3 in the Results section) shows vernacular inputs (left side, e.g., angling building to catch prevailing winds, courtyards) and modern inputs (right side, solar PV panels, HVAC for peak times) and how they overlap to create a sustainable design solution (centre).

Validation and Expert Review

Their feedback highlighted the need for water management features like tanks or baolis for cooling/humidity in traditional dwellings and rain gardens or ponds in modern designs. Thus, the final framework includes this input and its components, expected benefits (e.g., energy savings, comfort increase), and any drawbacks. Architectural design theory, environmental engineering (for energy/comfort analysis), and cultural context form the interdisciplinary process. We followed these steps to guarantee the framework was academically sound and useful. The Results section will outline the framework, including diagrams (Figure 3 and Figure 4) and tables that summarise this methodical procedure.

Results

Framework for Integrating Vernacular Strategies in Modern Design

This research produced a framework for sustainable housing design that combines vernacular climate-responsive practices with current architectural design criteria. This framework is conceived as a guiding model for architects and developers in North India. It is composed of a set of design principles organized into five interrelated components, as outlined below and illustrated in Figure 3.

Component 1

Site Planning and Orientation. Principle: Orient and mass buildings like vernacular villages to take advantage of site features and climate. This involves orienting the building's longitudinal axis east–west to minimise east/west solar exposure (a concept observed in vernacular farms and havelis) and capture southwest cooling breezes in summer. Clusters of dwelling units should form shaded courtyards or wind corridors, like old towns did with narrow roadways. Modern plots can funnel winds by angling blocks, a desert vernacular ventilation method. Improved orientation can minimise direct solar gains on walls by ~30% during peak summer, enhancing passive cooling and reducing HVAC loads. Plot shape and regulatory setbacks may limit orientation options in crowded metropolitan areas.

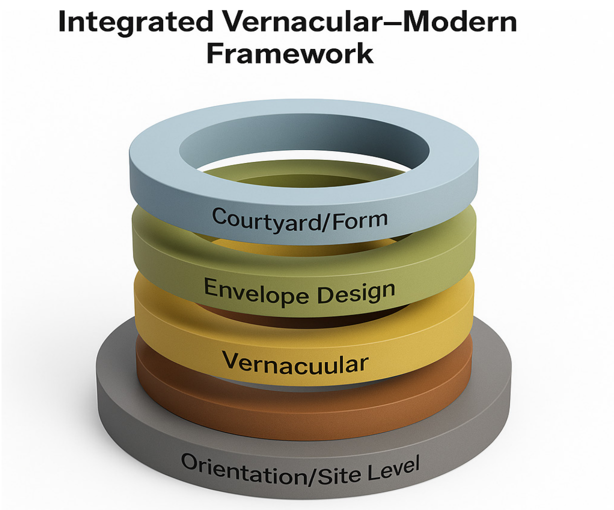

Figure 3: Conceptual framework diagram synthesizing vernacular and modern design elements for sustainable housing

Component 2

Building Form and Courtyard Integration. Principle: Use compact building forms with courtyard voids or atria as structural lungs. For stack ventilation and daylight, every low-rise house should have at least one courtyard (even a modest lightwell) or courtyard-equivalent space (e.g., a row house's double-height ventilated atrium). The design scales to vertical sky courts or staggered voids in multi-storey apartments. The framework recommends 15–25% open courtyard area to floor area in hot-dry/composite conditions (traditional havelis) and 5–15% in cold climates (smaller courtyards to reduce heat loss). Courtyards in modern designs can lower indoor air temperature by ~2–3°C through cross-ventilation and night cooling, while offering psychological comfort and multi-use space. Limitation: Urban buildings may need design incentives such Floor space ratio relaxations to incorporate courtyards, which restrict buildable space.

Component 3

Passive Envelope Design (Walls, Roof, Windows). Principle: Install the building envelope utilising indigenous materials and methods that fulfil modern thermal standards. To emulate 45 cm solid walls' heat attenuation, use high thermal mass walls such as compressed stabilised earth blocks, cavity walls with an inner mud brick layer, or insulated cavities with local brick. Traditional white limewash and lime plaster or high albedo coatings should be applied to exterior surfaces. The framework recommends a vented double roof (influenced by vernacular South Indian lofts) or a green/earth roof for thermal mass. Modern roofs can utilise insulation boards with clay tiles to mimic the thermal effect of a 200 mm thatch or mud roof in vernacular huts. Optimise window size and shade with jaali screens or modern perforated shutters to minimise direct sun by at least 50% while letting light and air in. The focus of vernacular design was geometric shade via deep reveals, verandahs, and jaalis, not low-e glass. A house's cooling energy demand can drop 20–40% with an optimised envelope. A study found that using mud blocks instead of concrete blocks in a modern vernacular prototype lowered cooling load by ~26%. Limited: Some traditional materials, including mud, have reduced structural capacity; the framework supports hybrid building (e.g., reinforced frames with sustainable infill) to meet safety codes. Earthen plaster may require more maintenance, which could be addressed by community training or material innovation.

Figure 4: Framework-based prototype sustainable dwelling for composite climate in North India showing passive cooling strategies and vernacular design elements

Component 4

Passive and Hybrid Thermal Comfort Systems. Principle: Use indigenous passive cooling and heating techniques with modern technology. (a) Natural Ventilation Design—aligning openings for cross-breezes and using ventilation shafts (influenced by desert wind catchers and badgir towers) to suck air from courtyards through top vents. During dry seasons, water bodies or fountains in courtyards (a nod to Mughal gardens and stepwells) humidify and cool the air. In modern residences, this may be a small pond or mist feature in the atrium. «Nocturnal ventilation»—designing windows and vents that may safely remain open at night to flush heat—was typical in communities with jaali or ventilator apertures left open. (d) Solar Gain Management—deep roof overhangs and changeable external screens for summer shading, removable for winter sun (traditional dwellings used deciduous vines or seasonal cloth canopies; modern homes could utilise moveable louvres). (e) In frigid climates, thermal storage and passive solar—e.g., a sunspace or dark Trombe wall (like Ladakhi dwellings with south-facing glass and enormous heat storage walls). Advantage: These passive systems can keep indoor operative temperatures within an acceptable comfort band (adaptive comfort range of 20–32°C, following Indian standards) for most of the year without HVAC. Simulations in a composite environment indicated that night ventilation and evaporative cooling in a courtyard might eliminate air-conditioning on 70% of summer days. Limitation: Passive methods alone may not cover cooling needs during extreme heatwaves caused by climate change; hence, the framework permits hybrid supplementation.

Component 5

Cultural Continuity and Aesthetics. Principle: Design elements that represent local culture and encourage user acceptance improve continued passive feature use. To encourage tenants to participate with the place, a dwelling arrangement could include a small tulsi plant courtyard or sacred area (borrowing from the ancient Indian sacred courtyard with a basil plant). Aesthetic gestures include using regional motifs in jaali patterns or facade relief, using locally handcrafted materials (stone, wood) for finishes, and designing spatial layouts to accommodate cultural practices (such as a vestibule or covered porch for neighbour interaction, like the otla in vernacular homes). This may seem intangible, but homes that resonate culturally are more likely to be maintained in ways that keep their climate-responsive features working (e.g., villagers maintain mud floors for tradition and comfort; in a modern context, pride in a vernacular-style feature could prevent it from being demolished or altered). Benefit: Cultural integration boosts occupant happiness and psychological comfort, which post-occupancy studies link to building performance. It preserves traditional knowledge and skills, promoting social sustainability. Limitation: Adding decorative jaali while still using AC risks superficial application. This component must work with the technological ones to ensure cultural components are functional. Figure 3 shows the framework comprised of these parts.

Illustrative Design Application

To demonstrate how the framework can be applied, consider a prototype design for a sustainable housing cluster in Haryana (composite climate). The cluster includes 10 low-rise row-house units for a residential development. Using the framework:

Site & Form

The units are arranged in two rows facing north-south, with a shared linear courtyard (community aangan) in between. Each house also has a small private courtyard. This layout replicates the traditional *mohalla* feel and ensures mutual shading. The houses are two storeys high (avoiding high-rise to maintain vernacular scale) and oriented to have minimal west-facing walls.

Envelope

Walls are proposed as 300 mm thick compressed earth blocks with 50 mm external insulation and lime plaster – giving thermal mass inside and insulation outside, analogous to a mud wall but structurally suitable. Roofs are vaulted with perforated terracotta tiles below and insulation above, creating an air gap – inspired by vernacular tiled roofs with attics. Windows on the external facade are kept small and shaded by deep chajjas. Larger openings face the courtyard, but those too have *jaali* screens (made of CNC-cut terracotta panels) that the residents can close for privacy or during heat waves. Figure 4 shows a section through one unit.

Passive systems

Each house has a rooftop solar chimney (a modern equivalent of a small wind tower) painted black to enhance stack effect, pulling air from the ground-floor courtyard through the house – a technique borrowed from Rajasthan's historic buildings that used tall ventilators. Ceiling fans and operable vents assist in moving air. For cooling, the design includes a shallow pool in the central community courtyard (evaporative cooling source) and ample greenery (trees strategically planted to shade in summer). For winter heating, the front facades have larger south windows with insulated shutters that can open to allow sun in, similar to traditional *dhajji* houses in hills opening south verandahs on sunny winter days.

Cultural & Social

The aesthetic is vernacular-modern: houses have a base of local random rubble stone (recalling traditional plinths), earthen-colored plaster, and ornamental jali panels featuring a pattern common in Haryana's heritage architecture. Verandah spaces in front of each house encourage neighbors to sit outside and chat (recreating the sociable *otla* or threshold). The shared courtyard is designed for community events and nightly outdoor sleeping in summer (a practice in villages to cope with heat). By design, the development encourages revival of such low-energy lifestyles.

Benefits and Performance Outcomes

The combined methodology performs sustainability, comfort, and cultural relevance research objectives with a lot of advantages:

Better thermal comfort

Homes built in accordance with the framework have adapted cooling throughout all of the year with a minimum of active cooling. As stated, the temperature can be cooled by 3 to 5 degrees Celsius in the case of courtyards and ventilation. Thick insulation also reduces the level of heat. The high thermostat setpoints can be achieved through natural control (fans, night ventilation) by the residents at the time when the adaptive comfort model of India allows up to approximately 30°C with the help of fans. This enhances the habitability in severe climatic conditions (heat waves, cold spells), eliminating the use of grid power.

Energy saving and emission

It will save a lot of energy through less cooling and heating. There are comparative studies that such designs could reduce domestic energy consumption by more than half when adopted on a large scale. Until up to 50 per cent of new urban homes in North India take these measures, this could reduce millions of kWh of power consumed each year as a way of reducing climate change. It lowers the emissions of the building sector, which fulfils the targets of the Paris Agreement of India.

Home-based characteristics are more resistant to the climate, e.g., thick walls to provide thermal buffering during power outages, courtyards to safely gather and breathe air during pandemics and sloping roofs in a mountainous landscape to be more weather-resistant. Therefore, the structure generates housing that is sustainable in day-to-day use and more resilient to disasters and weather extremes.

Cultural and social advantages

Houses designed under these concepts could contribute to the well-being of the residents. The semi-open spaces (courtyards, verandahs) encourage exercise, gardening and socialisation and disrupt the isolation of AC. It is also possible to make modern houses more psychologically acceptable and pleasant by retaining some of the familiar features (like an aangan or mud finishes), particularly to those that are relocating to urban centres (contributing a huge portion of the urban migration in India). Building with traditional materials and workforce (i.e., stone carvers to make jaalis and carpenters to make wooden roofing) can facilitate the employment within the community and promote the sustainable livelihood.

Policy alignment

The framework favours national and regional policies, such as the Eco-Niwas Samhita on household energy saving and state climate action plans, such as those in Haryana and Delhi, which mandate passive cooling of buildings. GRIHA rewards passive architectural features that are part of our framework. This explicit design standard can be used to guide green building certification. Given that a lot of vernacular strategies embrace low-cost materials and approaches, they may be utilised alongside low-cost (but effective) housing programmes such as the Pradhan Mantri Awas Yojana to deliver low-cost but effective design interventions.

Limitations and Challenges

The framework is promising, yet it has limits and practical issues:

Urban density constraints

Providing courtyards or open space in high-density urban areas is difficult. The framework suggests vertical courtyards/atria, but they require design ingenuity and developer buy-in. There is a risk that market-driven developments may prioritize floor area over passive features unless incentivized.

Cultural evolution

Socio-cultural patterns have changed – e.g. nuclear families may not immediately value a large courtyard or shared spaces due to privacy preferences. There could be an initial reluctance to adopt some vernacular-inspired aspects (like an external mud plaster finish in an upscale urban context might be seen as "rustic" or lesser). Overcoming this requires awareness-raising and demonstrating the lifestyle benefits of such design. Modern aesthetics can also be blended (vernacular does *not* mean replicating historical styles exactly, but reinterpreting them elegantly, as many contemporary architects have shown).

Construction knowledge and materials

Some vernacular methods are in danger of being lost; contractors today may not know how to build a proper jack-arch roof or mud wall. There will be a learning curve and possibly higher initial cost to reintroduce these, unless capacity building is done. Moreover, availability of traditional materials in large quantities (e.g. natural lime, good quality bamboo or timber in certain regions) is a concern – sustainable sourcing or alternatives (like compressed earth blocks for mud, or engineered timber) need to be ensured.

Climate change uncertainties

Adapting designs based on historical performance may not be sufficient for future climates with more frequent 45+°C days or uncertain monsoon patterns. Passive designs may need phase-change materials for intense heat or mixed-mode systems for increased humidity. The framework can adapt to new passive cooling technologies like earth-air tunnels and mist cooling.

Discussion

This study's integration paradigm suggests a road to more sustainable and context-appropriate housing in North India.

Energy and Environment Implications

The potential of the framework to reduce energy consumption in building constructions by a factor of four contributes to sustainability in the world. The residential constructions in India consume a high amount of energy and maximum electricity (especially due to the development of air-conditioning). Through the creation of housing that takes advantage of nature to heat or cool itself, we reduced fossil fuel consumption and made the grid more stable. A passive design approach would help decrease the ownership of air conditioners in India, which will rise. Other authors have reported similar results, including a 55% decrease in energy use in a modern villa with courtyards and insulated walls over a control villa without such facilities. The real facts support our paradigm. It illustrates the fact that the greenest energy is the one that is not utilised. Material sustainability is another environmental problem. Low-embodied-energy materials such as mud, bamboo and stone were used in vernacular building. Where feasible we would advise that they should be used or as an alternative (stabilised earth, fly-ash bricks, sustainable forestry lumber). This has the potential to cut down the embodied carbon of construction as compared to all-concrete. This is important because Henna *et al*. (2021) discovered that the environmental footprint of vernacular Indian buildings was roughly 2.5 times lower compared to modern buildings and emphasises the significance of environmentally friendly materials and passive design. Nonetheless, the increase in the wood usage should be managed in order to prevent deforestation. The structure promotes life-cycle thinking of operational energy, source of materials, and end-of-life (vernacular buildings could be biodegradable or made towards recycling).

Socio-Cultural and User Acceptance

How modern people will embrace these incorporated vernacular characteristics is a key topic. One criticism of vernacular revival is its suitability for modern life. Our framework addresses this by not simply copying old designs but marrying them with modern needs, such as maintaining privacy even with courtyards (through screening or partial roofs) or accommodating modern kitchens and bathrooms (absent in old houses in the same form) without compromising passive strategies. Education matters. Occupants may need help opening windows, using shade devices, etc. in climate-responsive dwellings. Traditional folks instinctively opened their jharokha windows at night or sprinkled water on the courtyard floor to cool it. The cultural transition requires relearning these behaviours. Growing awareness of sustainability and health is encouraging homebuyers to choose eco-friendly amenities. More clients are interested in "modern vernacular" dwellings, say architects at Morphogenesis, a leading Indian sustainable design business. This suggests market adoption, which the framework may boost via design solutions.

Comparison with Related Frameworks and Studies

Vernacular principles are being integrated globally in diverse ways. Our framework is comparable to bioclimatic architecture, which Olgyay and others promoted, but it is culturally specific. Comparable systematic frameworks include Patil *et al*.'s Five-Fold Strategy for courtyards (2025). Their framework focused on policy and planning to re-establish courtyards in urban design (including FAR incentives), while ours is an architectural design framework that blends building design features. The regulatory support they suggest (e.g., fast-track clearances for climate-responsive designs) could help apply our framework's design principles. A related study is the Adaptive Comfort Model integration. Indraganti and other adaptive comfort researchers have developed design guidelines for naturally ventilated buildings in India that emphasise high thermal mass and controlled openings to keep indoor comfort within adaptive model limits (e.g., 80% acceptability given outdoor mean temperatures). Our framework creates naturally ventilated buildings except on extreme days.

Implementation Strategies and Policy Recommendations

A multi-pronged implementation strategy is needed to make the framework effective:

- Local development authorities in North Indian states could implement suggestions from this framework into building byelaws or model codes. As several green building standards have done, communities could require a courtyard or equivalent for ventilation in new residential complexes over a particular size. The ECBC-R (residential) may reward designs that use passive elements beyond efficient appliances. This supports mainstreaming courtyard designs through codes.
- To encourage private developers to adopt sustainable design measures, the government can grant extra Floor Area Ratio (FAR) incentives. A developer could get an extra level or lower fees if simulations show that their design (using our framework principles) has 20% higher energy performance and integrated courtyards. Green construction policies worldwide increasingly include incentives, which were explicitly proposed for India.
- Demonstration Projects: Visualising results. This system

can create pilot houses or communities that prove the concept. This could be done through government housing programmes or public-private partnerships. Showing that a modern, comfortable house can be built for the same price and utilise half the energy can change public thinking. The “Model Village” concept, where new residences are built sustainably, could work (aligning with India’s smart village programmes).

- Indian architecture and engineering curricula should incorporate indigenous architecture and its use in modern design. This prepares young professionals to apply the framework instinctively. Some schools offer design studios for this, but mainstreaming it is crucial. Rebuilding that capability will require workshops for builders and contractors on adobe construction, lime plaster, passive cooling, etc. The framework could be used to create workshop technical manuals.
- Engage the community in design decisions when implementing in existing communities, such as adapting an old neighbourhood or building dwellings for rehoused people. Locals may know which way dust storms blow and where to plant buffers, which can be lost if not consulted.

Limitations of the Study and Future Research

The basis of our broad research was research synthesis and analytical argumentation. Every aspect was not measured in any fresh or done in a full-scale simulation. In this way, the performance promises of the framework (3-5°C cooling and 50 per cent energy reduction) are not tested in a real-life example but established through previous research. Control houses should be built by constructing one or more houses in accordance with the framework and comparing their performance by season. This would provide high-fidelity data and may indicate unexpected challenges (e.g., more humidity indoors because of minimal air exchange in a hermetically enclosed, thick-walled construction, which must be ventilated). More studies are required in the cost-benefit analysis. Recent additions such as specialised insulation or double-glazed jaali panels are more expensive than vernacular. An intensive cost analysis would convince the stakeholders of cost savings in the long term. Our framework can be used by the designers and builders as a checklist or software plug-in to analyse a design in regard to these principles and estimate its impact. It would simplify adoption.

Conclusion

This paper has explored the climate and culture of North India to harmonise the traditional and modern sustainable dwelling design. It provides a comprehensive structure that integrates climate-responsive vernacular design, such as courtyards, thermal mass structure, shaded facades and natural ventilation using contemporary architectural design and technology. The structure relies on the comprehensive literature review, climatic analysis, and synthesis to demonstrate how the elements of vernacular can be repackaged and adapted to contemporary housing to enhance thermal comfort, energy efficiency, and socio-cultural enrichment. The conclusion made is that vernacular-informed design is a rational and technical response to sustainable development as opposed to nostalgia. Through the experience gained by studying the North Indian houses and modifying them (say, by incorporating a courtyard in a multi-storey structure or by creating a mixture of mud and insulation and an RCC frame), we will be able to create energy-efficient and climate-resistant houses. The benefits that are projected by the framework have been supported by numerous research and examples, such as a 50%+ reduction in the annual energy consumption, 3-5°C lower indoor temperatures on hot summer days, and improved habitable conditions. Such residences are not merely climate machines, but they nurture community and wellness through cultural integration. The framework gives architects a roadmap by defining its components and design criteria. Benefits include environmental (lower carbon footprint, urban heat island), economic (lower energy bills for residents, opportunity for employing local materials), and social (culturally compatible living environments, legacy skill maintenance). We also highlighted obstacles like crowded metropolitan areas and the need to revive construction skills and provided solutions like regulatory incentives and education. The research emphasises a paradigm shift from globalised architecture’s glass-and-concrete homogeneity to glocal architecture, which is global in performance standards but local in design. This is crucial for India and other developing nations with high housing demand and resource restrictions. By implementing frameworks like the one presented, India can achieve housing for all goals while addressing climate change and cultural sustainability.

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