IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 10, October 2026

DOI: 10.17148/IARJSET.2026.131049

PASSIVE COOLING TECHNIQUES IN BUILDINGS FOR ENERGY SAVINGS IN MADHYA PRADESH, INDIA: AN OVERVIEW

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Abstract: Buildings in Madhya Pradesh experience substantial cooling demand during the hot season, particularly in urban centres such as Indore, Bhopal, Gwalior, Jabalpur and Ujjain. Passive cooling reduces indoor heat gains and improves thermal comfort through building form, orientation, shading, insulation, thermal mass, ventilation, reflective surfaces, courtyards, vegetation and evaporative strategies. These approaches are relevant to the state's varied climate, which includes hot-dry conditions in parts of the region, composite conditions around major urban centres, and a pronounced monsoon season. This review paper discusses the principles and suitability of major passive cooling techniques for residential, educational, institutional and commercial buildings in Madhya Pradesh. It synthesises established building-science literature and Indian energy-efficiency guidance rather than reporting new experimental data. The review indicates that no single technique is universally optimal: effective design combines climate-responsive shading, control of solar gains, appropriate envelope performance and ventilation scheduled around outdoor temperature and humidity. Courtyards, cool roofs and vegetation can support comfort when detailed for local water availability, maintenance and seasonal conditions. The paper concludes with a practical design framework and identifies the need for monitored, location-specific evaluations of energy use and indoor comfort.

Keywords: Passive cooling; building energy efficiency; thermal comfort; cool roofs; shading; natural ventilation; Madhya Pradesh; India.

1. INTRODUCTION

Space cooling is an important component of building energy demand in warm regions. As incomes, urbanisation and expectations of indoor comfort increase, the use of air conditioners and mechanical fans can rise, adding to electricity demand and peak loads. Passive cooling aims to reduce heat entering a building, store or release heat at suitable times, and use natural environmental processes to improve indoor conditions before relying on mechanical cooling. It is therefore a demand-reduction strategy rather than a complete substitute for mechanical systems in every building or season.

Madhya Pradesh contains diverse settlements, construction practices and local microclimates. Many locations experience high summer solar radiation and hot afternoons, while monsoon periods bring higher humidity and changing ventilation opportunities. A design suited to a dry, hot afternoon may perform poorly during humid weather or when warm nights prevent heat rejection. Consequently, passive measures should be selected using local weather data, building use, orientation, occupancy schedules and the intended comfort standard.

This paper provides a narrative review of passive cooling techniques relevant to Madhya Pradesh. It focuses on design principles, applicability, limitations and practical combinations. It does not claim measured energy savings for specific buildings because no building-level dataset or simulation results were supplied.

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2. REVIEW APPROACH AND REGIONAL CONTEXT

The paper synthesises established books, peer-reviewed research and Indian building-energy guidance on climate-responsive design, thermal comfort, natural ventilation, cool roofs and building energy codes. The discussion is a narrative review, not a systematic review with a reproducible database search or statistical meta-analysis. References are provided to support the underlying principles and to guide future site-specific work.

For design purposes, Madhya Pradesh should not be treated as having one uniform climate. Hot-season solar control is important across much of the state, but humidity, rainfall, diurnal temperature range, wind availability and urban heat-island intensity vary by location and season. The Energy Conservation Building Code (ECBC) and Eco-Niwas Samhita provide useful Indian frameworks for envelope and energy-efficient building design; applicability depends on building type, project scope and current state requirements [1, 2]. Climate files from a recognised weather source should be used for detailed simulation rather than relying on a state-wide average.

3. MAJOR PASSIVE COOLING TECHNIQUES

3.1 Building orientation, form and compactness

Building orientation influences the amount and timing of solar radiation received by walls and windows. Where site constraints permit, long building axes can be arranged to reduce difficult-to-shade east- and west-facing exposure. Compact forms generally reduce exposed envelope area per unit of floor area, although deep plans can restrict daylight and cross-ventilation. External shading, window placement and room depth should therefore be designed together rather than optimising one variable in isolation [3, 4].

For educational and institutional buildings, classroom blocks should be planned to limit direct low-angle sun on occupied spaces while maintaining daylight and safe circulation. Orientation must also respond to site access, prevailing winds, noise, neighbouring buildings and functional requirements.

3.2 External shading and solar control

Shading is among the most direct ways to reduce solar heat gain through windows and walls. Fixed overhangs are effective against high-angle sun on appropriately oriented façades; vertical fins, recessed windows, verandahs, balconies, screens and adjustable louvers can address low-angle sun. Trees can provide additional shade when their mature size, root zone, water needs and maintenance are considered. External shading usually intercepts solar radiation before it enters the glazing, making it more effective for cooling than relying only on internal curtains or blinds [3, 5].
In Madhya Pradesh, shading should be prioritised on exposed east and west façades, where low-angle morning and afternoon sun can be difficult to block with horizontal overhangs alone. Shading devices should not unnecessarily obstruct daylight, winter solar access where useful, ventilation openings or emergency egress

3.3 Cool roofs and roof insulation

Roofs are often strongly exposed to solar radiation. A cool roof uses a surface with high solar reflectance and suitable thermal emittance to absorb less solar energy and release heat more effectively. Roof insulation and a ventilated roof cavity can further reduce heat transfer into occupied rooms. Field research in India has documented the potential of reflective roof treatments to lower roof temperatures and improve indoor conditions, although results depend on roof construction, weather, ageing, dust and maintenance [6, 7].

Cool-roof coatings, reflective tiles or membranes may be particularly useful for low-rise homes, schools and institutional buildings with large exposed roofs. Product selection should account for durability, waterproofing compatibility, glare, cleaning and monsoon performance. Roof insulation should be designed with moisture control and local construction practice in mind.

3.4 Thermal mass and night-time heat rejection

Materials such as brick, stone and concrete can store heat because of their thermal mass. When indoor surfaces are shaded from direct sun and night-time outdoor air is cooler than indoor air, thermal mass can delay temperature peaks and release stored heat. However, mass alone does not guarantee a cool building. If it absorbs solar heat during the day and cannot cool at night, it may prolong overheating. The balance between insulation, thermal mass and ventilation must match local diurnal temperature patterns [3, 4].

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Night purging can be considered when outdoor air is sufficiently cooler and cleaner than indoor air. Secure high- and low-level openings, controlled fans, insect screens and safe ventilation paths can help remove stored heat. The strategy should be limited when nights remain hot, outdoor pollution is high, or humidity makes ventilation uncomfortable.

3.5 Natural ventilation and ceiling fans

Cross-ventilation uses pressure differences between openings to move air through occupied spaces; stack ventilation uses buoyancy as warmer air rises and exits through higher openings. Effective layouts require openings on suitable pressure zones, clear internal flow paths and attention to wind direction. Courtyard connections, ventilated stairwells and high-level exhausts can assist where building form permits. Natural ventilation is not automatically beneficial: hot outdoor air can increase indoor heat, and outdoor humidity, dust, noise and security may constrain window opening [3, 8].

Ceiling fans are not strictly passive, because they use electricity, but they are a low-energy comfort measure that complements passive design. Air movement increases perceived cooling for occupants and may allow higher thermostat settings when air conditioning is used. Fan selection should consider airflow, efficiency, controls and room geometry. During hot afternoons, windows may need to be closed or selectively shaded if outside air is hotter than indoors; ventilation should be responsive to actual conditions rather than left uncontrolled.

3.6 Courtyards, verandahs and transitional spaces

Courtyards can provide shaded outdoor space, support daylight and create air movement when their geometry and openings are appropriately designed. Verandahs, arcades and shaded balconies buffer occupied rooms from direct sun and rain. In dry conditions, shaded courtyards may benefit from night-sky cooling and controlled air exchange; during humid monsoon periods, their cooling effect may be smaller. The performance depends on courtyard proportions, surface materials, vegetation, wind access and surrounding building height [3, 4].

These elements are compatible with many regional building traditions, but should be adapted to contemporary requirements for accessibility, safety, usable floor area, rain protection and maintenance. A courtyard should not be assumed to cool every adjoining room without analysis of airflow and solar exposure.

The Overview of Passive Cooling Techniques is summarized in Figure 1.

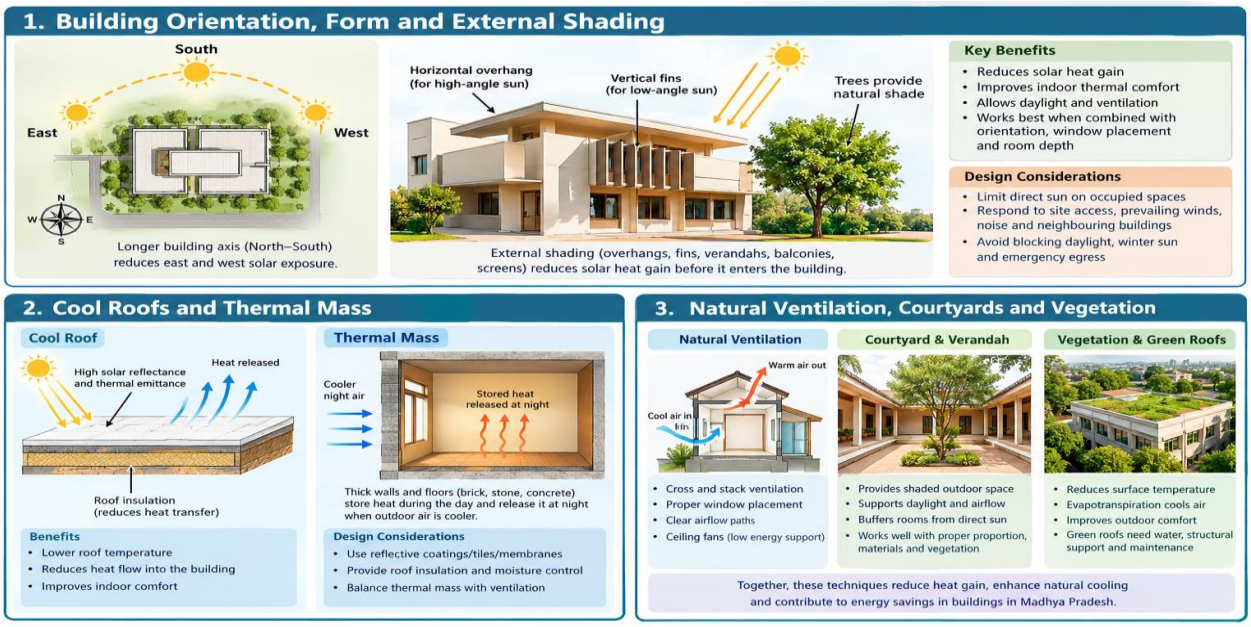


Figure 1. Overview of Passive Cooling Techniques [11]

3.7 Vegetation, green roofs and landscape design

Trees and planted areas can reduce surface temperatures by shading and evapotranspiration, while vegetation around buildings can improve outdoor comfort and reduce reflected solar radiation. Green roofs can shade roof membranes and alter heat transfer, but their performance depends on substrate depth, plant selection, irrigation, drainage, structural

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capacity and upkeep. Reviews of green roofs show that energy and thermal benefits vary substantially with climate, construction and vegetation [9, 10].

In Madhya Pradesh, native or climate-adapted species and water-efficient landscape planning are important. Rainwater harvesting, mulch and drip irrigation may support vegetation while limiting potable-water use. Green roofs should be assessed against simpler cool-roof options because water availability, structural loads and maintenance costs may make reflective roofs more practical for some buildings.

3.8 Evaporative cooling and water features

Evaporative cooling can reduce air temperature as water evaporates, with greater potential when outdoor air is hot and dry. Its effectiveness declines as humidity increases, so it may be less suitable during humid monsoon conditions. Direct evaporative methods add moisture to indoor air; indirect systems can cool without directly humidifying the supply air but may require equipment and water. Water features should not be used as a default design response because they consume water and require hygiene and maintenance [3, 11].

For buildings in water-stressed settings, passive shading, cool roofs and envelope improvements should generally be considered before water-intensive cooling features. Any evaporative strategy should be assessed against local humidity, water quality, consumption and operating needs.

3.9 Insulation, airtightness and efficient glazing

Insulation slows heat transfer through roofs and walls, while suitable glazing and reduced window-to-wall ratios can limit solar gains. Low-emissivity or solar-control glazing may help where large windows are unavoidable, but the most economical solution can often be to reduce exposed glazing and provide effective external shade. Airtightness helps control unwanted infiltration in mechanically cooled buildings, whereas naturally ventilated buildings need intentional, controllable openings. Envelope decisions should be coordinated with the ventilation strategy and local code requirements [1, 2, 12].

Most widely used passive cooling techniques are represented in figure 2.

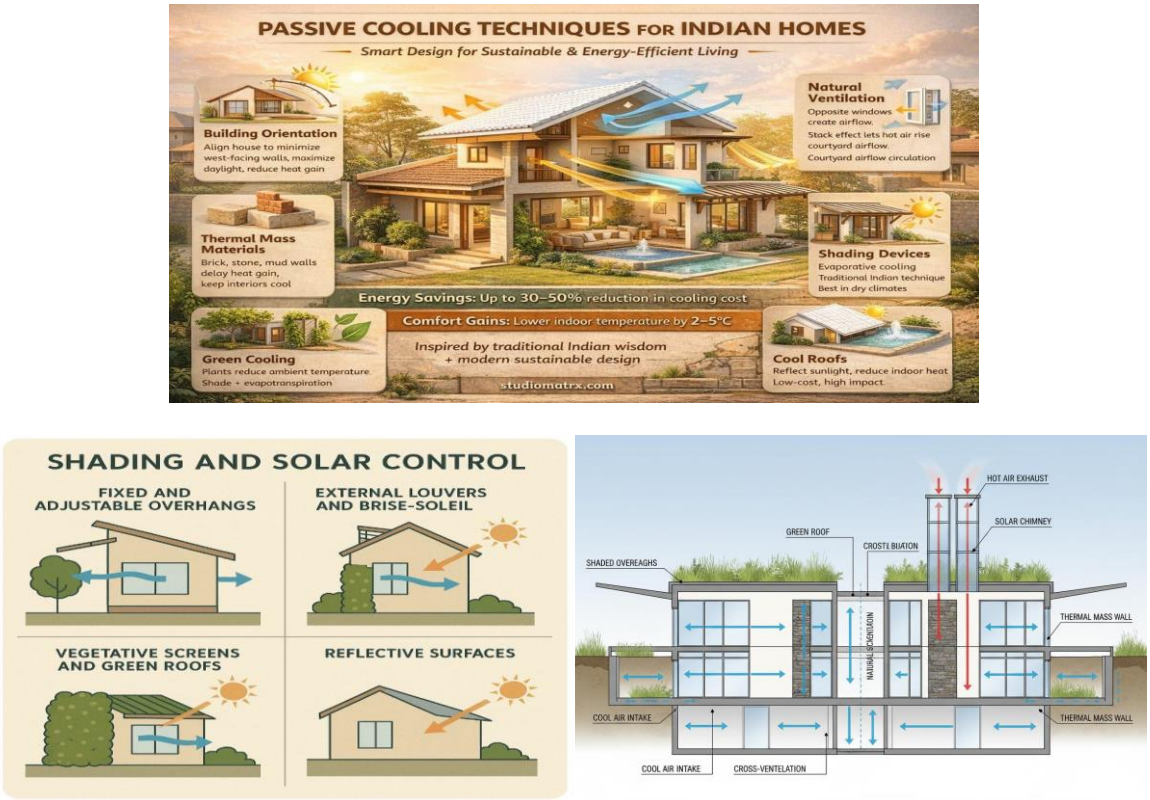


Figure 2. Passive Cooling Techniques in buildings [11]

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4. INTEGRATING STRATEGIES FOR BUILDING TYPES IN MADHYA PRADESH

Residential buildings can combine shaded openings, cool roofs, ceiling fans, insulated roofs where justified, and secure night ventilation when outdoor conditions permit. Low-rise houses may also benefit from verandahs and shaded courtyards. In apartments, external shading, reduced west-facing glazing, efficient fans and roof treatments can be applied at building or unit level, subject to façade and association constraints.

Schools and colleges have predictable occupancy periods and large roof areas. Priority measures include shaded classroom windows, reflective roofs, efficient fans, external shading, good daylight distribution and ventilation controls matched to the timetable. In computer laboratories and other high internal-load rooms, passive measures reduce but may not eliminate mechanical cooling needs.

Offices and commercial buildings often have higher internal heat gains from occupants, lighting and equipment. Passive cooling should be paired with efficient lighting, equipment management, occupancy-based controls and an efficient cooling system where needed. Shading and solar-control glazing are particularly important in buildings with extensive glazed façades.

5. ENERGY-SAVING POTENTIAL AND EVALUATION

Passive measures reduce cooling demand by preventing heat gains and improving comfort, but the energy benefit depends on the baseline building, climate, operation and occupant behaviour. It would be inappropriate to assign a single percentage saving to all buildings in Madhya Pradesh without a defined baseline and evidence. Savings should be quantified through monitored comparison, calibrated simulation or both.

A practical evaluation can compare a baseline design with alternative packages: (A) external shading; (B) cool roof plus roof insulation; (C) improved glazing and window-to-wall ratio; (D) controlled natural or night ventilation; and (E) a combined package. Useful indicators include annual cooling electricity (kWh/m²·year), peak cooling load (kW), indoor operative temperature, occupied hours outside a chosen comfort range, relative humidity, fan energy, water use and first cost. EnergyPlus or another validated building-energy model may be used with a local weather file and documented occupancy, schedules, envelope properties and HVAC assumptions [13].

Thermal comfort assessment should recognise that naturally ventilated occupants may adapt to changing conditions. The adaptive comfort approach described in ASHRAE Standard 55 can be relevant when its applicability conditions are met; it should not be applied indiscriminately to mechanically conditioned spaces [14].

6. PRACTICAL DESIGN FRAMEWORK

1. Collect hourly weather data for the project location, including dry-bulb temperature, humidity, solar radiation and wind.
2. Identify the building type, occupancy schedule, internal heat gains, cooling expectations and constraints on window opening.
3. Reduce solar gains first through orientation, external shading, roof reflectance and appropriate glazing.
4. Select insulation and thermal mass based on local day–night temperature patterns and the planned ventilation mode.
5. Provide controllable cross-ventilation or night purging only when outdoor conditions and security permit.
6. Integrate trees and landscape measures with water availability, drainage, species suitability and maintenance capacity.
7. Evaluate a combined design package against a defined baseline using simulation or post-occupancy monitoring.
8. Commission the building and explain seasonal operation to occupants; passive features require appropriate use and maintenance.

7. CHALLENGES AND RESEARCH GAPS

Implementation barriers include first-cost concerns, limited awareness, fragmented design responsibility, maintenance of shading and roof coatings, and the gap between predicted and actual building operation. Natural ventilation can be limited by traffic pollution, noise, insects, security and hot nights. Vegetation and evaporative techniques require

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careful water management. Retrofitting existing buildings may also be constrained by ownership arrangements, façade restrictions and structural capacity.

Further work in Madhya Pradesh should develop monitored case studies across cities and building types, compare cool-roof products after weathering, assess passive measures during both pre-monsoon and monsoon periods, and examine indoor comfort alongside energy use.

Research should report baseline conditions, weather files, construction details, occupancy, control logic and uncertainty. Field measurements and calibrated simulation would help distinguish the effects of individual strategies from combined packages.

8. CONCLUSION

Passive cooling offers a practical route to reducing building cooling demand in Madhya Pradesh when strategies are matched to local climate, building use and seasonal operation. External shading, cool roofs, suitable insulation, careful glazing, controlled ventilation and efficient fans form a robust starting point for many buildings. Courtyards, vegetation, green roofs and evaporative approaches can add value in appropriate circumstances but require attention to humidity, water, maintenance and site conditions. The strongest results are likely to come from integrated design rather than isolated features. Future studies should use local weather data, measured indoor conditions and transparent energy models to quantify savings for specific buildings and locations.

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