

FACTORS AFFECTING OUTDOOR THERMAL COMFORT IN HISTORICAL PRECINCTS: A SYNTHESIS OF MICROCLIMATE, MORPHOLOGY, AND HUMAN DIMENSIONS

Ar. Shagufta Irshad¹, Prof. (Dr.) Indrani Chakraborty²

¹Research Scholar (Part-time), Faculty of Architecture & Planning, Dr. A. P. J. Abdul Kalam Technical University, Lucknow, Uttar Pradesh, India., Assistant Professor, Integral University, Lucknow, Uttar Pradesh, India. Email: sirshad@iul.ac.in

²Professor, Faculty of Architecture & Planning, Dr. A. P. J. Abdul Kalam Technical University, Lucknow, Uttar Pradesh, India. Email: Chakraborty.indrani@foaaktu.ac.in

ABSTRACT

Outdoor thermal comfort in historical precincts is shaped by a coupled relationship between climate, urban form, surface materials, vegetation, human characteristics, behavior, and heritage management. Unlike contemporary public spaces, historic precincts often contain fixed geometries, massive masonry, exposed courtyards, irregular streets, archaeological remains, mature vegetation, and conservation restrictions. These conditions can create shade and thermal buffering, but can also increase radiant heat exposure, restrict airflow, and limit the use of conventional mitigation measures. This paper reviews the literature on the principal factors that affects outdoor thermal comfort in historic streets, courtyards, plazas, archaeological parks, monuments, and heritage-tourism environments. The review organizes the evidence into six interacting domains: macroclimate and seasonality; local microclimate; morphology and spatial enclosure; materials and surface properties; vegetation, water, and shade; and human, psychological, social, and cultural dimensions. It also examines thermal comfort indices, field measurement methods, modeling approaches, and heritage-sensitive adaptation strategies. Across the literature, mean radiant temperature, solar exposure, shade availability, sky-view factor, wind, surface temperature, and adaptive opportunity emerge as particularly influential variables. Thermal comfort cannot therefore be represented adequately by air temperature or a single universal comfort threshold. The review proposes an integrated framework in which thermal exposure, spatial form, visitor perception, adaptive capacity, and conservation sensitivity are assessed together. Reversible shading, carefully managed vegetation, route and time management, and locally validated simulation are identified as promising approaches for improving visitor comfort while protecting historic character and fabric.

KEYWORDS: Outdoor thermal comfort, historical precincts, mean radiant temperature, urban morphology, visitor perception

INTRODUCTION

Historical precincts are complex outdoor environments in which cultural value, environmental performance, and visitor experience are closely connected. They include historic streets, courtyards, plazas, temple compounds, fort complexes, archaeological parks, religious squares, and heritage-tourism areas. Their thermal conditions are produced not only by regional weather but also by inherited spatial arrangements, building materials, wall heights, arcades, courtyards, paving, vegetation, water, visitor movement, and management practices.

Outdoor thermal comfort refers to the condition in which people perceive the thermal environment as acceptable and experience little desire for change. In outdoor settings, this perception is influenced by air temperature, humidity, wind, radiation, clothing, activity, physiological condition, thermal history, expectations, and perceived control. Reviews of outdoor thermal comfort research identify physical, physiological, psychological, social, cultural, behavioral, and site-related influences rather than a single controlling variable. [1][2]

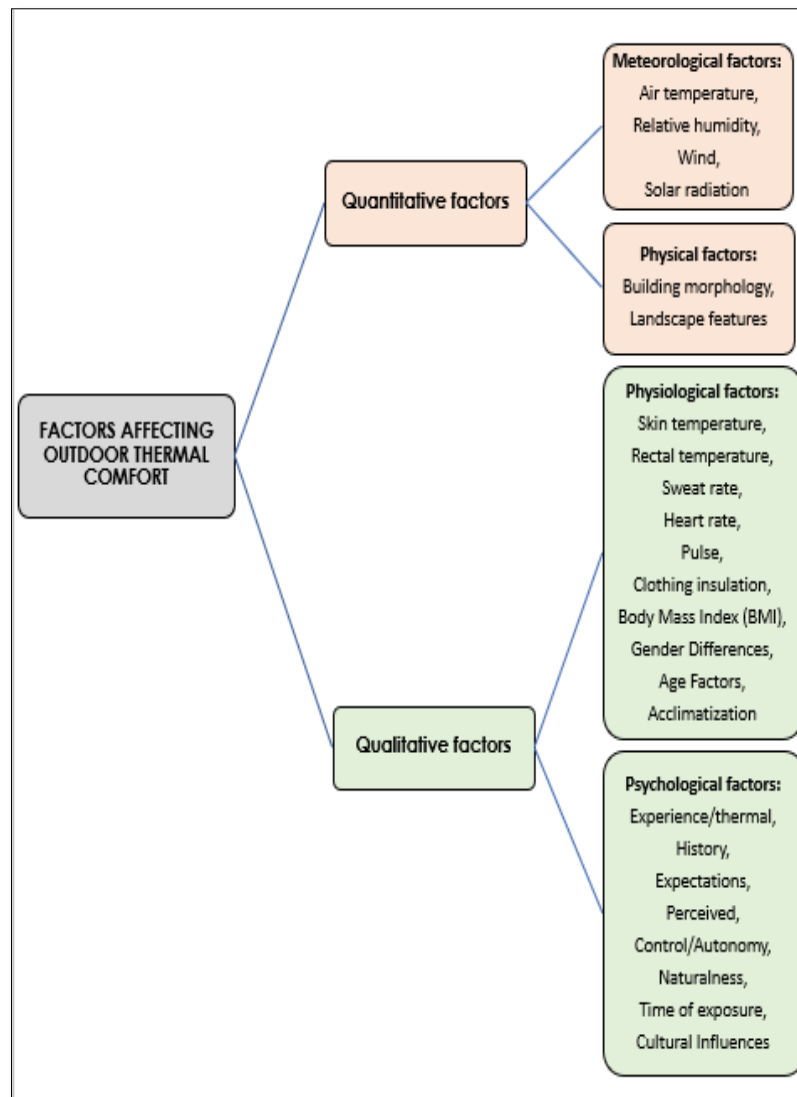


Figure 1: Factors affecting outdoor thermal comfort [3]

Historical precincts require a distinct analytical approach for three reasons. First, their physical form is usually inherited and difficult to alter. Street width, building height, courtyard proportions, wall alignments, paving, and monument locations may be protected as part of the heritage significance. Second, the same element may have both positive and negative thermal effects. Thick masonry can delay heat transfer, but sun-exposed stone can produce high long-wave radiation. Trees can provide shade and evapotranspiration, but roots and moisture may threaten archaeological remains. Third, visitor experience is not determined by physiological exposure alone. Visitors may tolerate heat because of cultural interest, limited time, expectations, or a strong sense of place, while still showing clear behavioral signs of discomfort [4][5].

The purpose of this review is to synthesize the factors that should be considered when assessing outdoor thermal comfort in historical precincts. No individual heritage site is used as the organizing case. Instead, evidence from heritage environments, archaeological areas, historic urban spaces, traditional settlements, and related outdoor-comfort studies is brought together to develop a general framework for research and conservation practice.

2. Review scope and analytical approach

The review draws on research addressing outdoor thermal comfort in urban open spaces, historic urban environments, archaeological parks, heritage-tourism settings, traditional architecture, and Indian climatic contexts. General reviews provide the conceptual and methodological foundation, while site-based studies provide evidence about mechanisms such as radiation, shade, vegetation, morphology, visitor adaptation, and conservation constraints [1][6].

The evidence is organized at three levels:

- Environmental exposure: climatic and microclimatic conditions experienced by visitors.
- Spatial mediation: the way morphology, materials, vegetation, and shade modify that exposure.
- Human response and management: the way visitors perceive, adapt to, and respond to the environment within heritage constraints

This structure avoids treating factors as independent. For example, the effect of wind depends on enclosure and vegetation; the effect of surface materials depends on solar exposure and reflected radiation; and the effect of heat stress depends on clothing, activity, expectations, and access to shade.

3. Conceptual framework

Outdoor thermal comfort in historical precincts can be represented as a coupled system:

Regional climate influences the local microclimate which in turn affects human heat exchange, thermal perception and behavioral responses.

This chain is modified by spatial morphology, materials, vegetation, heritage significance, visitor management, and the availability of adaptive opportunities. A more complete conceptual expression is:

Comfort = f (Ta, RH, Va, Tmrt, S, M, Icl, P, A, H, C)

where Ta is air temperature, RH is relative humidity, Va is wind speed, Tmrt is mean radiant temperature, S represents spatial and surface conditions, M is metabolic activity, Icl is clothing insulation, P represents personal and physiological characteristics, A represents adaptive opportunities and behavior, H represents thermal history and expectations, and C represents cultural and social conditions.

This formulation is not intended as a new comfort equation. It emphasizes that measured comfort results from interactions among variables. The dominant factor can change with season, time of day, climate, morphology, and visitor activity.

4. Factors affecting outdoor thermal comfort

4.1 Regional climate and seasonal conditions

The background climate establishes the range within which a precinct operates. Temperature, humidity, solar intensity, wind regime, cloud cover, rainfall, and seasonal variability influence both the outdoor thermal environment and the adaptation of visitors. Thermal neutrality is not constant across climates. Populations living in hot, humid, arid, temperate, and cold environments often show different comfort ranges because of acclimatization, clothing practices, expectations, and daily routines [1][2]

Seasonality is especially important in historical precincts because a spatial condition that is useful in summer may be harmful in winter. Dense enclosure and low sky exposure can reduce direct solar radiation during hot periods, but may restrict useful winter sunlight and reduce long-wave radiative cooling at night. Conversely, open plazas can provide winter solar access while becoming severe heat-stress locations in summer.

A four-season assessment is therefore preferable to a single summer campaign.

Table 1: Seasonal variations in outdoor thermal comfort and key influencing variables

Seasonal condition	Main comfort concern	Important variables
Hot summer	Direct solar exposure and accumulated heat stress	Solar radiation, T mrt, surface temperature, shade, wind
Pre-monsoon or dry-hot period	Maximum radiant and air-temperature burden	Solar load, humidity, wind, surface heat storage, visitor duration
Post-monsoon or humid transition	High humidity and reduced evaporative cooling	Relative humidity, wind, vegetation moisture, cloud cover
Winter or cool season	Balance between cold exposure and useful solar access	Solar radiation, wind, clothing, activity, shaded duration

Winter should not automatically be considered comfortable. In a World Heritage archaeological setting, visitors experienced strong heat stress during a winter tourist period because of intense solar radiation and limited shade, even though many respondents reported satisfaction.[4] This finding illustrates the difference between season-based assumptions and measured visitor experience.

4.2 Air temperature and relative humidity

Air temperature is a major driver of sensible heat exchange and is frequently correlated with thermal sensation. However, it does not describe the full thermal exposure of a visitor standing near a heated wall or in direct sun. Two locations with similar air temperature may produce very different comfort votes because of differences in radiation, wind, shade, and surface temperature.

Relative humidity becomes particularly important in warm-humid conditions because it limits sweat evaporation. In hot-dry climates, lower humidity can support evaporative cooling but may be accompanied by strong solar radiation and hot surfaces. Humidity also changes near water bodies, irrigated landscapes, dense vegetation, and damp archaeological materials. Its effect should therefore be interpreted together with air temperature and wind rather than as an isolated threshold.

4.3 Solar radiation and mean radiant temperature

Mean radiant temperature is one of the most important variables in outdoor thermal comfort. It represents the combined effect of short-wave and long-wave radiation received from the sun, sky, ground, walls, roofs, trees, and other surrounding

surfaces. In open heritage environments, direct solar radiation and radiation from heated masonry or paving can dominate the visitor heat balance.

Outdoor comfort studies repeatedly show that radiation may influence pedestrian comfort more strongly than air temperature or wind under sunny conditions. [1] Unshaded stone or concrete surfaces can become much hotter than the surrounding air and emit long-wave radiation toward visitors. High sky exposure can also increase direct solar exposure, while the orientation of walls and paths determines when particular locations become exposed.

Mean radiant temperature should therefore be measured or estimated carefully. Common approaches include:

- globe thermometers,
- six-directional short- and long-wave radiation measurements;
- directional radiometers;
- fisheye photographs and sky-view-factor analysis,
- infrared surface-temperature measurements, and
- calibrated microclimate modelling.

The six-directional method can provide detailed information about directional radiation, while globe thermometers are more accessible for field campaigns. Research in humid subtropical conditions shows that globe-based estimates may require local recalibration to agree with directional measurements. ENVI-met modelling at an archaeological site also demonstrated that solar adjustment, cloud conditions, and fine vertical resolution near pedestrian height substantially improved mean radiant temperature prediction. [7]

4.4 Wind and ventilation

Wind affects comfort through convection, evaporation, and the removal of heat accumulated near surfaces. Its effect is beneficial in hot conditions when it increases convective and evaporative heat loss, but it can increase discomfort in cool seasons or in exposed winter locations.

Wind conditions in historical precincts are controlled by building height, street width, courtyard proportions, wall continuity, openings, topography, vegetation, and surrounding urban development. Narrow passages may provide shade but reduce wind speed. Open courts may receive stronger airflow but also greater solar exposure. Arcades and colonnades can create transitional zones in which wind and shade are balanced.

Wind should be measured at pedestrian height and interpreted through spatial variation rather than a single site average. Important variables include mean speed, gusts, direction, turbulence, ventilation paths, and the contrast between enclosed and exposed locations. In vegetated areas, canopy density may reduce wind and improve shade, but excessive density can restrict ventilation and increase humidity.

4.5 Urban morphology and spatial enclosure

Morphology is the physical structure through which climate is filtered at the pedestrian level. The main morphological variables include:

- sky-view factor,
- building height-to-width ratio,
- street and courtyard orientation,
- courtyard aspect ratio,
- building height and continuity:
- arcade and veranda depth,
- wall and path alignment.
- openness of gateways and passages,
- route width and length, and
- distribution of shaded and exposed subspaces.

A low sky-view factor can reduce daytime solar exposure by increasing shade from surrounding buildings, but it may also reduce nighttime long-wave loss and winter solar access. High aspect ratios can be useful in hot periods when they create shade, yet they may reduce air movement. The thermal performance of a form is therefore seasonally dependent.

Research on historic courtyards indicates that aspect ratio and orientation can alter the extent of high mean radiant temperature zones. Smaller or more enclosed courtyards may provide greater shading, while larger courtyards may offer more solar access and ventilation. The effect is time-dependent, changing between morning, noon, afternoon, and night.

Traditional settlements demonstrate that climate-responsive performance often results from combinations of measures. Studies of traditional architecture in Lucknow identify compact form, narrow streets, courtyards, thick walls, shaded openings, projecting upper floors, screens, and ventilation openings as interacting features rather than independent technologies.[8] Similar principles can inform the analysis of historic precincts, but they should not be transferred without measurement because different orientations, materials, vegetation, and visitor routes produce different outcomes.

4.6 Building materials and surface properties

Materials affect outdoor comfort through heat storage, surface temperature, reflectance, emissivity, thermal conductivity, moisture exchange, and long-wave radiation. Historic precincts commonly contain stone, brick, lime plaster, earth, tile, concrete additions, and compacted soil. Each material responds differently to solar exposure and moisture.

Thermal mass can reduce short-term temperature fluctuation by absorbing heat and releasing it later. This may moderate adjacent conditions during some periods, but it can also maintain warm surfaces after sunset. The effect depends on wall thickness, orientation, surface finish, ventilation, and exposure duration. Traditional North Indian buildings, for example,

often combine thick masonry, heavy roofs, shaded courtyards, reflective lime finishes, and natural ventilation to moderate seasonal extremes. [8]

Surface colour and reflectance require careful interpretation. High-reflectance materials can lower surface temperature, but reflected short-wave radiation may be redirected toward pedestrians or nearby walls. A review of outdoor mitigation strategies found that reflective surfaces can sometimes increase PET because of additional reflected solar radiation. Similar research in historical urban canyons showed that material combinations and vertical-surface reflectance can create adverse radiant conditions even when surface temperatures decline. [9]

Material assessment should include:

Table 2: Material characteristics influencing thermal performance and heritage sensitivity

Material property	Thermal relevance	Heritage concern
Albedo or reflectance	Controls absorbed and reflected solar radiation	Visual change and glare
Emissivity	Influences long-wave exchange	Surface finish and compatibility
Thermal conductivity	Controls heat transfer through walls and paving	Moisture and fabric performance
Thermal capacity	Determines heat storage and time lag	Masonry behavior and durability
Moisture response	Affects evaporative cooling and deterioration	Salt, biological growth, and damp
Surface temperature	Directly contributes to radiant load	Material aging and visitor contact

No surface intervention should be judged by albedo or air temperature alone. Mean radiant temperature and pedestrian-level PET or UTCI should be evaluated alongside glare, visual compatibility, maintenance, and conservation risk.

4.7 Vegetation, shade, and water

Vegetation influences outdoor comfort through shading, evapotranspiration, wind modification, humidity, surface moisture, and psychological response. Trees are often the most effective vegetation element at pedestrian level because their canopies block direct solar radiation. The benefit depends on canopy size, leaf density, species, seasonal condition, placement, background wind, and the duration of shade.

A simulation study in Patna found that removing 28% of the tree cover increased mean radiant temperature by approximately 1.9 deg oC and PET by approximately 1.1 deg oC at noon under a lower-wind condition. [10] The cooling effect was related to canopy size and cluster density, while stronger background wind reduced some of the additional benefit. This indicates that the quantity of vegetation is less informative than its spatial arrangement and relation to pedestrian paths.

Vegetation in archaeological areas must be treated as both a thermal resource and a conservation variable. Roots may damage walls, foundations, pavements, or buried remains; leaf litter and moisture may affect surfaces; dense planting may obstruct views; and maintenance may alter the historic landscape. At the same time, indiscriminate removal of vegetation can increase radiant exposure and reduce visitor usability. Research on archaeological areas argues for a balanced assessment of vegetation hazards, biodiversity, conservation value, microclimate, and visitor comfort. [11]

Water bodies can reduce air and surface temperatures through evaporation and heat storage. Their benefits are usually strongest near the water edge and depend on wind, humidity, water temperature, and the size and orientation of the space. In humid conditions, additional moisture may limit sweat evaporation. Water should therefore be considered as a context-dependent strategy rather than a universal cooling solution. [1]

4.8 Shade as a dominant adaptive opportunity

Shade is not only a physical modifier; it is also an adaptive opportunity. Visitors can move into shade, rest below a canopy, use an arcade, change their route, or alter the duration of exposure. Studies comparing shaded and sun-exposed historic streets found that solar exposure was a stronger predictor of thermal sensation than air temperature, and that people were willing to tolerate somewhat higher temperatures in shaded conditions. [12]

The value of shade is determined by continuity, location, depth, visual access, seating, and accessibility. Isolated trees at the edge of a large plaza may provide little benefit if the main movement path remains exposed. Shade should therefore be assessed through pedestrian routes, dwell points, and temporal coverage rather than canopy area alone.

4.9 Human physiological and personal factors

Thermal comfort indices require assumptions about clothing and activity, but these assumptions can be inaccurate in visitor environments. Relevant personal variables include:

- age,

- gender,
- body size and composition:
- health and thermal sensitivity,
- clothing insulation;
- metabolic activity;
- mobility and walking speed;
- origin and climatic acclimatization; and
- previous indoor or outdoor exposure.

Tourists often walk for long periods, carry bags or equipment, pause irregularly, and move between air-conditioned interiors and outdoor spaces. These conditions differ from the sedentary assumptions often used in standard calculations. Research in tourist environments shows that clothing insulation changes with air temperature, age, gender, and cultural background, while activity levels vary with season and sightseeing behavior. [13]

Activity is especially important in large heritage precincts because walking increases metabolic heat production. A person standing in shade and a person walking across an exposed courtyard may experience different thermal sensations under the same weather conditions. Surveys should therefore record posture, activity, walking duration, and resting behavior.

4.10 Psychological, social, and cultural factors

Thermal sensation is not determined solely by physical exposure. Expectations, thermal history, purpose of visit, cultural meaning, perceived control, visual quality, satisfaction, and emotional state can modify responses. Visitors may accept discomfort because the heritage experience is considered valuable or because the visit is short and non-routine. [5][4]

Studies in Indian open spaces show that purpose of visit, gender, kinetic state, landscape elements, perceived color, and the visual environment influence thermal sensation and acceptability. Cultural norms can also affect the adaptive actions available to different groups. Research on historic streets found gendered differences in shade-seeking and clothing adjustment because social practices and religious dress codes constrained behavioral choices.[12]

A visitor survey should therefore avoid treating thermal comfort as a purely physiological response. It should include thermal sensation, preference, acceptability, satisfaction, perceived shade, perceived control, visit purpose, expected weather, origin, clothing, activity, and time spent outdoors.

4.11 Temporal exposure and visitor movement

Thermal stress is often episodic rather than uniform. A visitor may encounter a cool shaded passage, a hot exposed court, a breezy edge, and a warm enclosed gallery within a single route. The duration of exposure and the order of these conditions influence perception and adaptation.

Important temporal variables include:

- time of day;
- duration of stay;
- sequence of shaded and exposed spaces;
- peak solar period;
- waiting time,
- seasonal visitor density.
- opening hours, and
- changes in clothing or behaviour during the visit.

Historical-plaza research shows that preferred visiting periods may shift toward early morning or evening when afternoon heat stress becomes severe [5]. Time management can therefore improve comfort without physically altering the monument.

4.12 Heritage significance and conservation constraints

Heritage status changes the range of acceptable interventions. Historic buildings, archaeological remains, landscapes, views, materials, and spatial relationships may be protected. A thermally effective strategy is not automatically an acceptable conservation strategy.

The main constraints include:

- protection of original fabric and archaeological deposits;
- visual authenticity and historic views,
- reversibility of new elements;
- compatibility of materials;
- root and moisture risks;
- restrictions on fixing or anchoring shade structures,
- maintenance capacity.
- accessibility and visitor safety; and
- the need to preserve intangible cultural practices and public use.

Conservation policies that remove informal shading or traditional adaptive practices may unintentionally increase heat exposure and reduce the social life of a historic area. Research comparing formal and informal shading shows that rigid visual controls can remove locally adapted protection from solar radiation.[12] Heritage management should therefore consider whether temporary awnings, umbrellas, movable shade, shaded seating, and seasonal practices are themselves part of the living character of the precinct.

5. Interactions and trade-offs among factors

The literature does not support a universal hierarchy of interventions. The effect of each factor depends on interactions with other variables.

Table 3: Thermal benefits and potential risks of design urban interventions in heritage precincts

Intervention or condition	Potential benefit	Possible adverse effect
Increased enclosure	Reduces daytime solar exposure	Restricts wind and winter sunlight
High-albedo paving	Reduces absorbed surface heat	Increases reflected radiation and glare
Dense tree canopy	Provides strong shade and lowers T _{mrt} (Mean radiant temperature)	Reduces wind, increases moisture, affects views and roots
Water features	Supports evaporative cooling	Raises humidity and may increase maintenance
Thick masonry	Provides thermal inertia	Stores and re-radiates heat after exposure
Permanent shade structures	Creates reliable protection	May affect authenticity and historic
Vegetation removal	Reduces root or moisture risk	Removes shade and increases visitor heat stress
Open plazas	Supports visibility and ventilation	Increases solar exposure and surface heating

The most important trade-off is between summer shading and winter solar access. A second is between surface cooling and reflected radiation. A third is between vegetation-based comfort and conservation risk. A fourth is between visual openness and visitor protection. These trade-offs support the use of reversible, seasonal, and spatially targeted measures rather than uniform interventions.

6. Assessment methods and thermal comfort indices

6.1 Field measurement

A robust outdoor thermal comfort assessment should combine meteorological measurements, spatial documentation, visitor surveys, and, where appropriate, simulation. The minimum environmental dataset normally includes:

- air temperature,
- relative humidity;
- wind speed and direction.
- globe temperature or radiant fluxes,
- short-wave and long-wave radiation,
- surface temperature;
- sky-view factor,
- shade condition and duration; and
- vegetation and material characteristics.

Measurements should be taken at pedestrian height, with instruments shielded from direct solar exposure where required. The sensor height, sampling interval, calibration, weather conditions, and spatial position should be reported clearly. Standardization remains a persistent issue in outdoor thermal comfort studies because differences in instruments, heights, exposure periods, and calculation procedures reduce comparability.[14]

6.2 Thermal comfort indices

PET and UTCI are widely used because they translate complex meteorological conditions into an equivalent temperature or heat-stress category. PET is based on the human energy balance and is commonly calculated using RayMan. UTCI is based on a dynamic thermophysiological model and is useful for comparing heat and cold stress across outdoor conditions.[2][1]

Other indices include WBGT, heat index, outdoor standard effective temperature, and empirical thermal sensation models. No index should be treated as a direct substitute for perception. Local comfort ranges may differ from standard categories because of acclimatization, clothing, culture, expectations, and adaptive opportunities. Indian studies frequently find site-specific or climate-specific neutral PET values rather than a single national threshold.[6]

The recommended approach is to report:

1. measured environmental variables,

2. the assumptions used for clothing and activity.
3. PET or UTCI results,
4. thermal sensation and preference votes,
5. local comfort or acceptability ranges where the sample permits, and
6. the role of shade, exposure duration, and adaptive behavior.

6.3 Modelling and simulation

ENVI-met, RayMan, SkyHelios, CFD, GIS, and solar-radiation tools can help evaluate spatial variation and test intervention scenarios. Simulation is particularly useful in heritage contexts because it can compare shade, vegetation, surface, and route alternatives before physical changes are made.

However, model outputs depend strongly on geometry, surface properties, vegetation parameters, boundary conditions, cloud cover, radiation settings, and grid resolution. Validation against field measurements is essential. Research at a tropical archaeological site showed that correcting solar radiation inputs and refining vertical resolution near pedestrian height substantially reduced the discrepancy between simulated and measured mean radiant temperature.[7]

Simulation scenarios should therefore be realistic and conservation-aware. Idealized large parks, complete paving replacement, or unrestricted tree planting may not be feasible in protected sites. Models should test reversible shade, existing vegetation management, route changes, temporary structures, and selective material treatments alongside more conventional greening options.

7. Heritage-sensitive strategies for improving comfort

7.1 Reversible and seasonal shading

Shading should generally be prioritized because it directly reduces short-wave radiation and can produce substantial reductions in mean radiant temperature and PET. Suitable options may include movable umbrellas, temporary canopies, potted tree clusters, shaded seating, arcades, fabric devices, and seasonal structures. Their placement should follow visitor routes and dwell points rather than only the edges of open spaces.

Shading systems should be removable, visually subordinate, structurally independent where possible, and evaluated for glare, wind safety, maintenance, and historic-view impacts. Seasonal deployment can provide summer protection while preserving winter solar access.

7.2 Vegetation management

Existing mature trees should be assessed as cultural, ecological, and thermal assets. New planting should be selected according to root behavior, canopy form, water demand, maintenance, biodiversity, seasonal shading, and visual compatibility. Vegetation management should not rely on a simple add-or-remove decision. A combined thermal and conservation assessment is needed to identify which vegetation should be retained, pruned, relocated, or replaced.[11]

7.3 Route and time management

Visitor movement can be managed through shaded routes, rest points, directional information, timed entry, seasonal opening hours, and warnings during peak heat. These strategies are particularly valuable where physical changes are restricted. The aim is not to prevent access but to reduce continuous exposure and increase visitor choice.

7.4 Surface and material management

Surface treatments should be tested for both thermal and visual performance. Candidate materials should be evaluated for surface temperature, reflected radiation, glare, emissivity, ageing, moisture, slip resistance, and compatibility with historic fabric. High-reflectance paving should not be installed solely because it lowers surface temperature: pedestrian-level radiation may increase instead.[15] [9]

7.5 Rest, water, and visitor support

Thermal comfort also depends on access to drinking water, shaded seating, toilets, first aid, and opportunities to pause. These facilities can reduce cumulative exposure and support vulnerable visitors without changing significant structures. Their design and location should be coordinated with conservation, accessibility, and visitor-flow requirements.

8. Research gaps

Several gaps remain in the literature on outdoor thermal comfort in historical precincts.

8.1 Limited multi-season evidence

Many studies focus on summer or a single hot period. More year-round studies are needed to identify seasonal trade-offs and to avoid interventions that solve summer discomfort while worsening winter conditions.[1]

8.2 Weak integration of conservation and comfort

Thermal studies often test interventions without assessing archaeological risk, authenticity, visual impact, material compatibility, or maintenance. Conservation studies may discuss vegetation and visitor management without measuring pedestrian thermal exposure. Integrated evaluation is still limited.[16]

8.3 Insufficient visitor-route analysis

Site averages conceal the thermal sequence experienced by visitors. Future work should map exposure along routes, identify shaded refuges, measure dwell time, and relate thermal conditions to movement and satisfaction.[17]

8.4 Limited attention to cultural adaptation

Comfort models frequently use standard clothing and metabolic assumptions. More work is needed on tourists, local residents, gendered clothing, religious practice, age, disability, social use of shade, and the influence of heritage expectations.[13]

8.5 Need for validated and transferable modelling

Simulation studies often use idealized scenarios and limited validation. Future studies should report uncertainty, validate mean radiant temperature, test realistic intervention options, and compare model outputs with visitor responses. [7]

8.6 Heat-risk assessment under climate change

Rising air temperatures and more frequent heatwaves may increase exposure in open archaeological and historic spaces. [18] Research should combine future climate scenarios with heritage sensitivity, visitor vulnerability, carrying capacity, and operational planning. Comfort assessment should be connected to heat-health risk rather than treated only as a design preference.

9. CONCLUSION

Outdoor thermal comfort in historical precincts is controlled by a network of environmental, spatial, material, human, and management factors. Air temperature is important, but solar radiation and mean radiant temperature often dominate the experience of visitors in exposed heritage settings. Shade, sky-view factor, spatial enclosure, surface temperature, wind access, vegetation, clothing, activity, expectations, and cultural practices determine whether measured heat exposure becomes perceived discomfort.

The most useful analytical approach is therefore integrated rather than reductionist. Environmental measurements should be combined with morphology mapping, material and vegetation assessment, thermal indices, visitor surveys, behavioral observation, and conservation review. PET and UTCI can support comparison, but they should be accompanied by local perception data and transparent assumptions.

Historical precincts cannot be treated as ordinary urban open spaces. Their form and fabric carry cultural meaning, and interventions must protect authenticity, archaeological integrity, views, and living practices. The most promising strategies are likely to be reversible and adaptive: continuous shade along visitor routes, carefully managed vegetation, shaded rest and drinking facilities, seasonal scheduling, route management, and locally validated material or simulation trials. A conservation-sensitive thermal framework should seek not simply to maximize cooling, but to improve visitor safety and comfort while maintaining the historic character that makes the precinct significant.

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