RECLAIMING HEAT-RESILIENT PUBLIC SPACES: A SIMULATION TOOLKIT FOR URBAN HEAT MITIGATION

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Maps in this report are indicative and not to scale.

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1. Introduction

Extreme heat is emerging as one of the most urgent climate-related challenges of our time. Although the earth's climate has varied naturally in the past, scientific evidence shows that the current rate of global warming is unprecedented in at least the last 24,000 years.[1] As temperatures continue to rise and natural systems are pushed beyond their adaptive thresholds, the frequency and severity of extreme heat events are projected to escalate further.[2]

India is already bearing the consequences of this trajectory. Of the 15 warmest years on record, 10 have occurred within the last fifteen years (2011–25), and the decade 2016–25 stands as the warmest ever recorded.[3] Approximately 57 per cent of India's districts, home to 76 per cent of the country's population, are currently classified as facing high to very high risk from extreme heat.[4]

Exposure to extreme heat carries severe public health consequences. One study estimated that an average of 1,116 deaths per year were attributable to heatwaves across just 10 Indian cities,[5] suggesting that the nationwide mortality burden is substantially higher. Beyond mortality, extreme heat elevates the risk of heat stress, dehydration, and a broad spectrum of heat-related illnesses—ranging from relatively mild conditions such as heat rashes and cramps to life-threatening outcomes such as heat stroke.

Rising temperatures also carry significant economic consequences. Diminished work capacity, slower movement, and the need for frequent rest during hot periods translate directly into productivity losses. According to a World Bank report, India could account for 34 million of the projected 80 million global job losses attributable to heat stress-related productivity decline by 2030.[6] Another study found that India lost approximately 259 billion hours of labour annually during 2001–20 due to heat impacts, representing nearly half of total global losses.[7]

As outdoor spaces become increasingly inhospitable, many people are retreating to air-conditioned interiors for relief. Enclosed spaces are now used not only for work and residences but also for shopping, leisure and social interaction, as evidenced by the rapid expansion of malls across the country.

This shift, however, carries a significant environmental cost. Growing reliance on air conditioning drives higher electricity demand,[8] particularly during heatwaves. Simultaneously, air-conditioning systems discharge waste heat into the surrounding urban environment, raising ambient temperatures—especially at night—and intensifying overall heat stress. In Phoenix, USA, for example, waste heat from air conditioners was found to raise mean nighttime temperatures by more than 1°C.[9] This dynamic creates a self-reinforcing cycle in which higher temperatures drive greater demand for cooling, which in turn further amplifies urban heat.

Critically, the impacts of this cycle are deeply uneven. While those with access to air-conditioned homes, offices or commercial spaces can shield themselves from rising temperatures, others—including street vendors, informal construction workers, delivery personnel, traffic police, sanitation workers and daily wage earners—remain exposed to deteriorating outdoor conditions. They face prolonged exposure to heat, often with limited access to alternatives that provide protection from it. For these workers, rising temperatures translate directly into income losses. A study found that informal workers living in Delhi's slums, who face high heat exposure both at home and at work, experience a 19 per cent decline in net earnings for every 1°C rise in temperature. During heatwaves, these income losses escalated to as much as 40 per cent.[10] Thus, as outdoor public spaces lose comfort and vitality, the burden of heat is disproportionately borne by those with the least capacity to avoid it.

Learning climate-responsive urban design from India's past

Historically, Indian cities were shaped by a rich interplay of culture and climate. Streets and public spaces were conceived in response to local climatic conditions, ensuring that outdoor environments remained functional for movement, trade and social life even during periods of intense heat. Rather than serving merely as corridors for movement, streets operated as vibrant public realms that accommodated commerce, worship, exchange and community interaction. Street width, orientation and enclosure were carefully calibrated to balance solar exposure and shade. Built form regularly created sheltered edges through arcades, overhangs and continuous building facades, while trees and waterbodies further tempered temperatures. Together, these elements produced thermally comfortable environments that sustained everyday life across seasons.

Examples of such climate-responsive urban design are found throughout historic Indian cities. In many Rajasthani towns, streets were typically narrow and flanked by continuous row-houses of two to three storeys. This height-to-width ratio ensured that building shadows fell across the street for most of the day, shielding pedestrians from the harsh overhead sun while preserving airflow.[11] In Jaipur,

Chandni Chowk, Delhi, in 1947. A combination of shaded pathways, canopies and fabric-enhanced outdoor thermal comfort.

Source: Wikimedia Commons 1947. 'Chandni Chowk on 15 August 1947'. Available at https://commons.wikimedia.org/wiki/File:Chandni_Chowk_on_15_August_1947.jpg, as accessed on April 20, 2026

commercial activity along major streets was organized within columned arcades that provided continuous shade for pedestrians and shopfronts. These arcades, together with street trees, played a significant role in improving outdoor thermal comfort.[12] Similarly, Shahjahanabad (Old Delhi) was home to Chandni Chowk—a grand avenue lined with pools, fountains and canals for cooling, and shaded pathways that served simultaneously as cultural and commercial thoroughfares.[13,14]

Across these examples, consistent principles emerge: careful control of solar exposure and the deliberate integration of water and vegetation. Over time, however, these climate-responsive principles have progressively receded from urban development practice, eroding the thermal resilience of public spaces.

As cities expanded, design priorities shifted towards maximizing land use and traffic efficiency, often at the expense of environmental performance and human comfort. Open spaces were paved over, tree cover declined, waterbodies were encroached upon, and built surfaces increasingly relied on heat-retaining materials such as asphalt.

Need for this toolkit

Recognizing the urgent need to improve urban public spaces, governments are now investing significantly in upgrading streets and public areas through schemes, missions and redevelopment initiatives.[15,16,17] The focus, however, has largely remained on aesthetics and functionality, with limited attention to how these spaces perform under heat stress. In a warming climate, the success of public space design cannot be measured by appearance alone.

Urban design projects in India need to move beyond place-making through aesthetics and more deliberately integrate local context, culture and materials, with a sharper focus on everyday livability. When these considerations are taken seriously, public spaces become more usable and relevant across different times of day and throughout the year.

This shift also opens the possibility of a more distributed network of active public spaces, reducing dependence on a handful of centralized locations that frequently become overcrowded or overstressed. When thermal comfort and microclimatic conditions are addressed at the neighbourhood level, a wider range of smaller, everyday spaces can remain usable for extended periods. This supports more equitable access to public space—particularly for those with limited mobility—and helps ease pressure on large, formal parks and plazas.

Spaces that reflect local climate and cultural context are more likely to support consistent, everyday use rather than sporadic or seasonal activity. When people find spaces comfortable and familiar, they tend to occupy them for longer durations and at different times of day. This sustained use can strengthen social interactions, reinforce a sense of belonging and deepen people's connection with their surroundings, as the space responds to both environmental conditions and lived practices.

Addressing this challenge requires moving beyond assumptions and broad guidelines towards measurable, site-specific evidence. Urban design decisions must be grounded in an understanding of how built form, materials, vegetation, water and spatial layout influence the localized climatic conditions of a specific

SUGEET GROVER

Chandni Chowk post-redevelopment carried out in 2021


SUGEET GROVER

Paved, unshaded open spaces have a high potential for turning into heat hotspots

space—its temperature, humidity, wind patterns and solar radiation, collectively referred to as its microclimate. Without such assessment, interventions risk reproducing designs that appear improved while continuing to expose users to unsafe thermal conditions.

This toolkit addresses this challenge through microclimate simulation. Using ENVI-met, a three-dimensional modelling tool, this study examines how site-specific design interventions influence surface and ambient air temperatures under heat-stress conditions. By comparing existing conditions with proposed design scenarios, the study generates quantitative insights into how different strategies can improve outdoor thermal comfort. It is intended as a decision-support resource to assist planners, designers, and policymakers in creating urban environments that remain accessible, equitable, and resilient in the face of rising temperatures.

2. Solving for thermal comfort

Rising heat is a global challenge, but its effects are particularly acute in urban areas due to the Urban Heat Island (UHI) effect, a phenomenon whereby cities experience significantly higher temperatures than their rural surroundings. This is driven primarily by the replacement of natural landscapes with heat-absorbing materials, the heat-trapping properties of dense urban layouts and the reduction of vegetation and waterbodies. As cities continue to expand, effective heat mitigation strategies become increasingly critical for maintaining urban resilience and livability. Meeting this challenge requires well-planned, evidence-based solutions that can measurably reduce urban temperatures.

One of the most effective approaches to mitigating urban heat is improving local microclimates. Microclimate refers to the localized climatic conditions within the near-surface atmosphere and surface soil, shaped substantially by the characteristics of the underlying surface.[18] While global and regional climate patterns lie beyond direct human control, urban planning and design can meaningfully shape microclimates at the neighbourhood and block scale. By incorporating targeted cooling interventions, planners can create more thermally comfortable environments that, when implemented at scale, can collectively reduce urban ambient temperatures.

2.1 National missions support and align with heat mitigation measures

Multiple national missions and financing frameworks already provide a strong institutional and financial basis for improving urban microclimates, even where this is not stated as their primary objective. Programmes focused on water management, air quality, urban planning and afforestation collectively support interventions such as waterbody rejuvenation, expansion of green spaces, reduction of impervious surfaces and integration of climate considerations into city planning. These efforts are complemented by emerging financing mechanisms that link funding to climate-responsive planning and infrastructure outcomes. Taken together, this ecosystem of missions and funds creates a clear opportunity to mainstream microclimate improvement within ongoing urban development, rather than treating it as a separate or additional agenda.

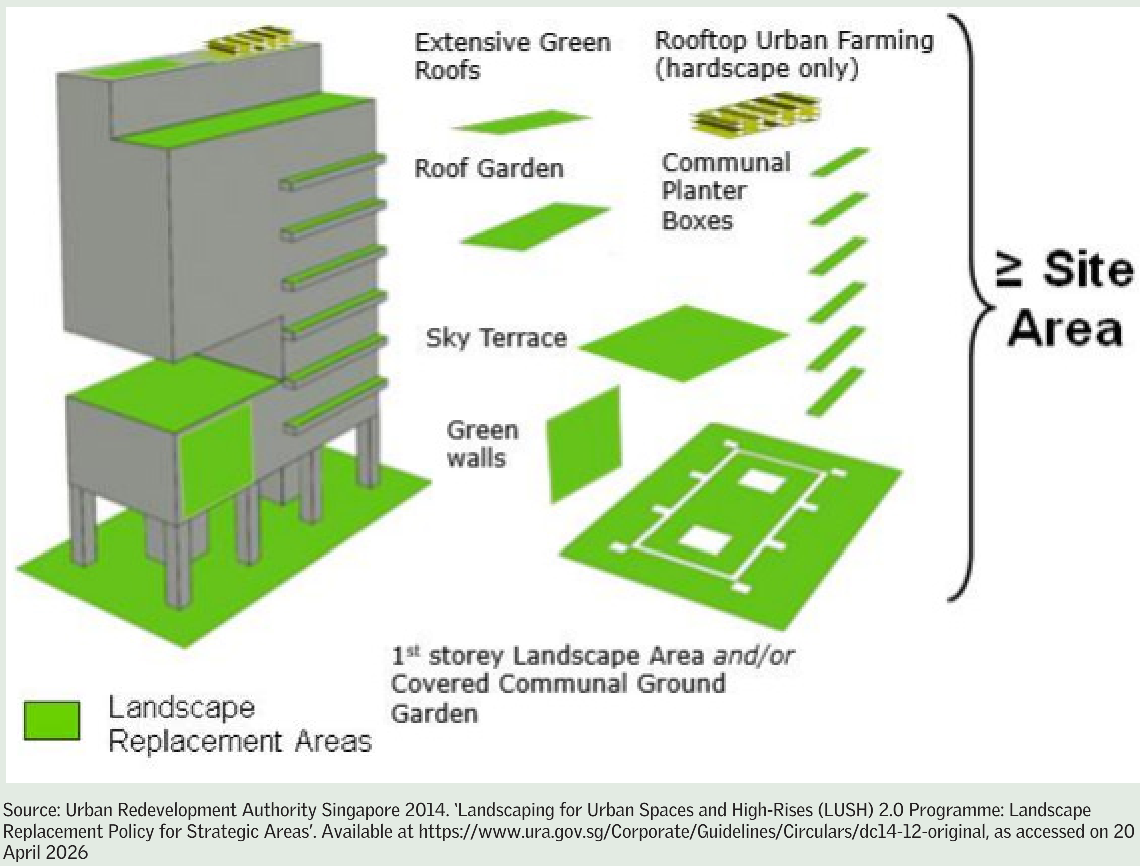
- The Atal Mission for Rejuvenation and Urban Transformation (AMRUT) has actively supported interventions such as water body rejuvenation, along with the development of parks and green spaces. Under AMRUT 2.0, over 2,700

SINGAPORE'S GUIDELINES INTEGRATE SOLUTIONS

Cities such as Singapore integrate microclimate considerations into urban policy and practice. Singapore introduced the Landscaping for Urban Spaces and High-Rises (LUSH) programme, which aims to mitigate the urban heat island effect. Under this policy, developers must replace greenery lost due to construction by adding greenery within the development, such as roof gardens, sky terraces or vertical greening. At least 40 per cent of the required landscape replacement must be permanent planting, while the remainder may include communal spaces such as plazas, water features, or playgrounds.[19] Such measures recognize that heat exposure and thermal discomfort can be reduced through informed urban design decisions at the site scale. Singapore's Urban Redevelopment Authority is developing an environmental simulation planning tool named QUEST, which will help planners understand the city's microclimate and assess how future developments will affect thermal comfort.[20]

Moreover, Singapore's Privately-Owned Public Spaces (POPS) guidelines also define clear, climate-responsive design expectations to support shading of public spaces. These go beyond general intent and define how comfort should be achieved and evaluated. Shade is treated as a critical requirement for all-day usability, with explicit attention to both its extent and performance during peak heat hours. The guidelines recognize multiple ways to create shade, including building form, adjacent structures, vegetation and lightweight elements, while also emphasising that materials used for shading should not contribute to additional heat retention within the space.

Figure 1: Landscape replacement areas under Singapore's Landscaping for Urban Spaces and High-Rises (LUSH) programme



Source: Urban Redevelopment Authority Singapore 2014. 'Landscaping for Urban Spaces and High-Rises (LUSH) 2.0 Programme: Landscape Replacement Policy for Strategic Areas'. Available at https://www.ura.gov.sg/Corporate/Guidelines/Circulars/dc14-12-original, as accessed on 20 April 2026

Shaded pathway in Singapore

Source: Pan Jie 2024. 'Under one roof: How the covered walkway conquered Singapore', RICE. Available at https://www.ricemedia.co/culture-life-one-roof-covered-walkway-conquered-singapore/, as accessed on 20 April 2026

Importantly, they require this to be demonstrated through a sun-shadow study on June 21, the longest day of the year, assessing conditions at 9 a.m., 12 noon, and 4 p.m. The study requires designers to demonstrate that at least 50 per cent of the total public space area and seating remain shaded during these hours, establishing a clear and measurable benchmark for comfort. This requirement shows how climatic response, including material choice, can be embedded into the design process in a verifiable manner, ensuring that public spaces remain usable during the hottest parts of the day rather than being shaped only by visual considerations.[21]

Points covered under the guidelines:[22]

- Public space should be well shaded to encourage public use throughout the day.
- Shade can be provided by integration within the building form, by adjacent buildings, trees, canopies/pergolas, adjustable umbrellas/awnings and/or landscape elements.
- Material used to provide shade must not result in additional heat retention in the public space.
- Sun shadow study should be undertaken to demonstrate that sufficient shade is provided between 9 a.m. and 4 p.m. Shadow diagrams are to be studied for shadow cast on June 21 at 9 a.m., 12 noon and 4 p.m. For each shadow diagram:
    - At least 50 per cent of the total public space area is to be shaded; and
    - At least 50 per cent of public space seating is to be shaded.

waterbody projects and 1,599 parks have been approved at a cost exceeding Rs 7,200 crore, of which 824 waterbodies and 825 parks have already been completed as of March 2026.[23]

- While the National Clean Air Programme (NCAP) is primarily an air quality initiative, its strategies are intrinsically linked to microclimate management. It proposes targeted interventions such as green buffer zones and water fountains along traffic corridors, greening of open areas, gardens and community places, along with extensive urban plantation drives.[24] These interventions, backed with a performance-linked grant of over Rs 13,036 crore provided till 2025,[25] and an additional Rs 1,091 crore allocated for 2026–27[26] under the Control of Pollution scheme, do not just suppress dust but also act as a vital defence against the urban heat Island effect.

- The National Mission on Sustainable Habitat (NMSH), under the National Action Plan on Climate Change (NAPCC), requires million-plus cities to prepare and implement City Climate Action Plans. Within this framework, cities are expected to integrate climate considerations into urban planning, green cover and biodiversity management. This includes mapping eco-sensitive zones, biodiversity hotspots and key natural assets such as waterbodies, wetlands, forests and their catchments. Cities are also required to develop urban heat island maps to guide local mitigation actions, particularly those that improve microclimate conditions and reduce greenhouse gas emissions.

  The mission further emphasizes strengthening urban ecological systems by conserving and rejuvenating waterbodies, increasing green cover and ensuring that 10 to 12 per cent of the developed area is allocated to recreational spaces, including green and blue infrastructure. It also calls for reducing impervious surfaces and promoting permeable materials in sidewalks and pavements to improve groundwater recharge and manage surface runoff. Together, these measures aim to support more climate-responsive and resilient urban habitats.

- Urban plantation at scale is being advanced through dedicated schemes that embed greenery directly within city limits. The Nagar Van Yojana (NVY), launched in 2020 under the Ministry of Environment, Forest and Climate Change, aims to create 1,000 urban forests—Nagar Vans and Nagar Vatikas—by 2027,[27] covering areas ranging from 1 to 50 hectares within or immediately adjacent to municipal limits. The scheme is implemented through State Forest Departments with financial assistance from the National Compensatory Afforestation Fund Management and Planning Authority (National CAMPA).

- Complementing this, the Ek Ped Maa Ke Naam campaign has mobilized urban local bodies to conduct georeferenced tree plantation on public land, extending canopy cover into urban areas where large Nagar Van sites may not be available.

- Broader ecological goals are further supported by the National Mission for a Green India (GIM), which includes a dedicated component for expanding forest and tree cover in urban and peri-urban landscapes to create vital ecological buffers.[28] For FY 2026–27, GIM has been allocated Rs 170 crore to strengthen these green buffers.[29]

- The most recent and significant addition to this financing landscape is the Urban Challenge Fund (UCF), approved by the Union Cabinet in February 2026. It represents a shift toward market-linked urban renewal, moving away from purely grant-based models. Through a dedicated vertical, it incentivizes cities to undertake the 'Creative Redevelopment' of central business districts and heritage cores, and retrofitting of legacy infrastructure (drainage, water, public spaces) while prioritizing climate resilience and disaster mitigation. This initiative provides Rs 1 lakh crore in Central Assistance through 2031 with the aim of catalysing a total investment of Rs 4 lakh crore by mandating that at least 50 per cent of project financing be sourced from the market.[30]

Retrofitting existing urban spaces—potential low-hanging fruit

Most Indian cities are already built up and densely occupied, leaving limited scope for large-scale redesign or reconstruction. In this context, improving thermal comfort cannot depend on new development alone—it must focus on upgrading and retrofitting existing urban spaces.

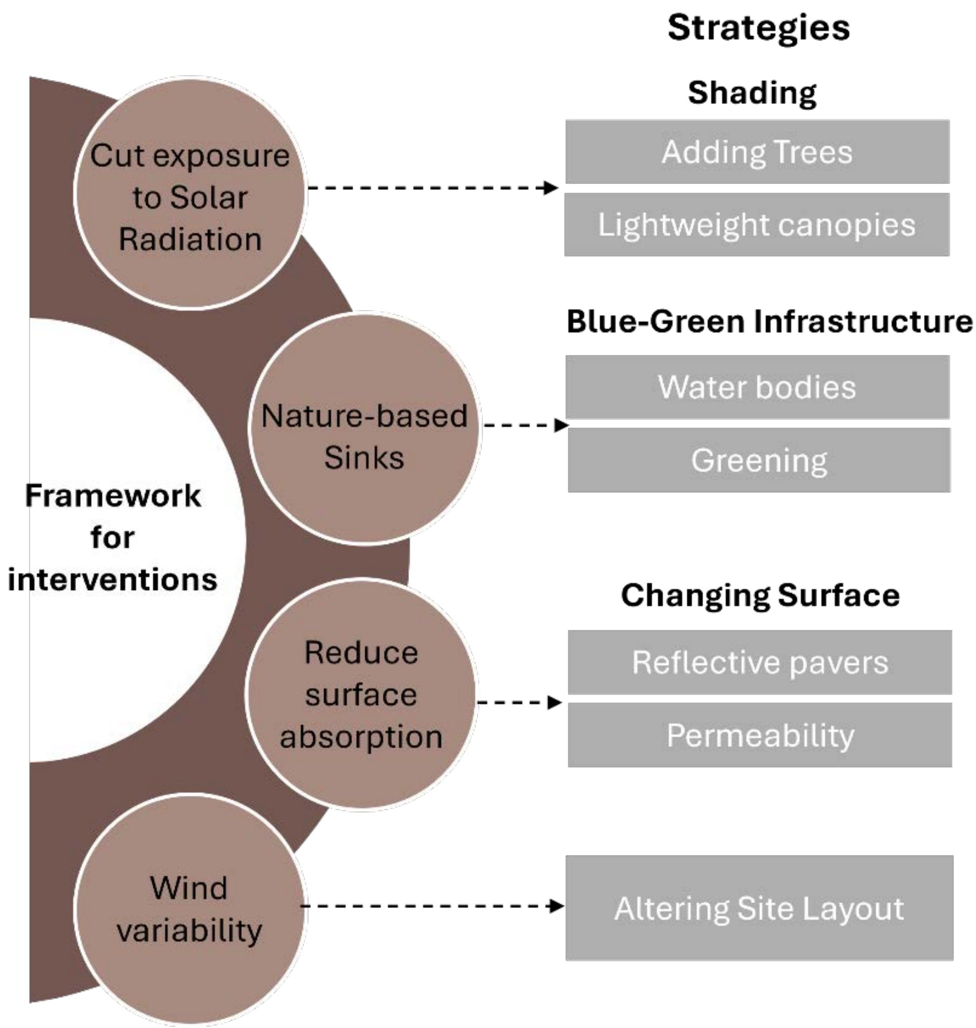
In this context, retrofitting refers to the modification and upgrading of existing streets, open spaces, and built elements to improve thermal performance without altering their fundamental structure or function. This encompasses changes to surface materials, shading structures, greening, water features, and spatial configuration that reduce heat accumulation and enhance outdoor comfort. Unlike large-scale infrastructure projects, retrofitting measures are feasible within existing urban constraints, can be implemented incrementally, and are adaptable to different city contexts. Critically, they allow cities to address rising heat risks without displacing users or disrupting everyday activities—a particularly important consideration in heavily used public spaces.

This toolkit, therefore, focuses on site-scale retrofitting interventions as a practical and scalable approach to improving outdoor thermal comfort. The following sections outline the intervention framework used to identify, evaluate, and simulate these strategies across a range of urban contexts.

2.2 Framework for interventions

This toolkit presents a four-path intervention framework to guide cities in improving outdoor thermal comfort. Interventions are grouped by the physical processes that govern the microclimate: reducing solar exposure, enhancing local cooling through nature-based measures, lowering surface heat absorption, and managing wind variability. Together, these principles help cities prioritise measures that directly influence ambient air and surface temperatures, thereby improving overall outdoor thermal comfort.

Figure 3: Framework for interventions



Cutting solar exposure

Under clear sky conditions, solar radiation at ground level can reach 700–1,000 W/m^2 at midday, with a significant share absorbed by the human body. This heat input can exceed the body's own heat production several times over, making direct

Tensile fabric canopy (top); metal frame with wooden trellis vegetation (bottom)

Sources: Topcu E. 2025. 'Busy street market scene with sunshades', Pexels. Available at https://www.pexels.com/photo/busy-street-market-scene-with-sunshades-33661539/, as accessed on April 20, 2026 (top); Sugeet Grover (bottom) solar exposure a primary driver of outdoor thermal discomfort. Its effect operates largely through mean radiant temperature (MRT), which captures the combined influence of radiation from the sun and surrounding surfaces, as well as heat re-emitted by built materials. Even when air temperature remains unchanged, elevated MRT can make conditions feel substantially hotter and significantly reduce the usability of outdoor spaces.

Shading directly addresses this by intercepting incoming solar radiation and lowering MRT, thereby reducing the heat load on the human body. This effect occurs without significantly altering air temperature, yet results in a marked improvement in comfort. In open urban areas such as streets, parking areas and public squares, shading through trees or built elements can reduce surface temperatures by more than 20°C,[31] further limiting the re-radiation of heat from surface materials. Together, these effects support longer and more consistent use of outdoor spaces, particularly during peak heat hours.

Nature-based sinks

Blue–green infrastructure (BGI)—encompassing trees, parks, gardens, lakes, and ponds—plays a vital role in regulating outdoor heat. Vegetation cools the surrounding environment through evapotranspiration and shading, while waterbodies absorb heat and generate cooler microclimates. A CSE analysis of changes in blue and green cover across several cities found a direct relationship with land surface temperature. In Kolkata, a sharp decline in vegetation and waterbodies between 1999 and 2021 drove average land surface temperatures up by nearly 5°C (37.82–42.65°C). Similar trends were documented in Pune, Jaipur, Nagpur, Delhi and Bhubaneswar, where reductions in BGI were directly associated with hotter outdoor environments.[32] To address this, expanding vegetation cover and introducing water features are key strategies.


Blue–green infrastructure can help reduce local surface temperatures

Sources:
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Trees along the roads provide shade, reducing surface temperatures.

Source: Gowtham A.G.M. 2024. 'Green bus', Pexels. Available at https://rb.gy/hr255m, as accessed on April 20, 2026

Greening through trees

Expanding tree cover is a well-established heat mitigation strategy across diverse climatic conditions, effectively reducing temperatures through shading and evapotranspiration.[33,34] A literature review on the effectiveness of blue–green infrastructure for microclimate regulation found that tree shading can lower surface temperatures by more than 15°C and reduce air temperatures by up to 2.8°C compared to unshaded areas.[35] It is essential, however, to select species that are well-suited to local climatic conditions.

Rooftop greening

Green roofs reduce heat accumulation on building surfaces by replacing conventional roofing materials with a vegetated layer and a growing medium. The vegetation shades the roof surface while the growing medium retains moisture and slows heat transfer through the roof structure. The cooling effect of green roofs arises from three interrelated processes. First, vegetated surfaces generally have a higher albedo than dark roofing materials and therefore reflect a larger proportion of incoming solar radiation. Second, both vegetation and the growing medium cool the surface through evapotranspiration—water evaporates from plant leaves and the growing medium, converting sensible heat into latent heat and reducing the surrounding air temperature. Third, the plant canopy physically shades the roof membrane, limiting direct solar heating of the roof surface.

At larger spatial scales, widespread adoption of green roofs can also influence ambient air temperatures. When many rooftops are vegetated, the combined reduction in heat storage and increase in evaporative cooling can lower local air temperatures and help moderate urban microclimates. Research indicates that green roofs can reduce daytime surface temperatures by an average of 10–17°C, and lower air temperatures by 0.3–3°C when deployed at the city scale, thereby reducing UHI intensity and improving outdoor thermal comfort.[36]

Green roofs help limit heat build-up on building surfaces

Source: Tanvi Deshpande 2023. 'Explained: As indoor heat rises, can India turn to green roofs?', IndiaSpend. Available at https://www.indiaspend.com/explainers/explained-as-indoor-heat-rises-can-india-turn-to-green-roofs-867308, as accessed on April 20, 2026.

Vertical greening

Vertical greening reduces heat accumulation on building façades and other vertical surfaces, which are major contributors to heat storage in dense urban environments. By incorporating climbing plants, modular green wall systems, or vegetated trellises onto building exteriors, vertical greening shields walls from direct solar exposure and reduces the heat absorbed by façade materials. This shading effect lowers surface temperatures and limits the subsequent re-release of stored heat into the surrounding environment.

Vegetated façades can further cool adjacent air through evapotranspiration and by modifying airflow along building surfaces. The plant layer creates a thin buffer zone between the wall and the outdoor environment, reducing façade heating and moderating temperature fluctuations across the building envelope. As a result, less heat is transferred from wall surfaces to the surrounding air.

At the urban scale, vertical greening is especially relevant in urban canyons, where closely spaced buildings restrict air circulation and trap heat between façades. Greening sun-exposed walls and high-solar corridors can reduce surface heating along these vertical planes and introduce evaporative cooling within the street canyon. When applied across multiple buildings in dense areas, these interventions can help moderate local microclimates, reduce heat retention within street corridors, and improve outdoor thermal comfort.

Vertical greening to block direct solar radiation and reduce ambient temperatures through evapotranspiration.

Source: CSE

Studies indicate that vertical greening can reduce surface temperatures by 7–17°C during the day, while lowering ambient air temperatures by up to 3.33°C when irrigated.[37]

Water features

Water features can moderate local microclimates by introducing evaporative cooling. As water evaporates from exposed surfaces such as fountains, ponds, shallow channels or misting installations, it absorbs heat from the surrounding environment, reducing nearby air temperatures and improving thermal comfort in outdoor spaces. Waterbodies also heat and cool more slowly than most urban materials, helping to moderate temperature fluctuations in adjacent areas. When thoughtfully integrated into public spaces such as plazas, courtyards or parks, water features can create localized cooling zones that provide meaningful relief in heat-stressed environments, particularly in dense urban areas with limited vegetation.

Reducing surface absorption by changing surface

Urban surfaces significantly influence heat accumulation, as many commonly used paving and roofing materials absorb large amounts of solar radiation and retain this heat within the urban environment. Dark, impervious materials such as asphalt or dense concrete typically have low reflectance and high heat storage capacity, raising surface temperatures and contributing to the warming of surrounding areas. Modifying these surfaces can reduce heat absorption and limit the release of stored heat into the urban microclimate. One approach is to increase surface reflectance through the use of light-coloured paving materials, high-albedo stones or reflective coatings. Surfaces with higher solar reflectance absorb less incoming radiation and therefore remain significantly cooler than darker alternatives. Field measurements indicate that reflective pavements can achieve surface temperatures up to approximately 19°C lower than conventional dark pavements under comparable solar conditions.[38] Lower surface temperatures reduce heat storage within pavements and limit the transfer of sensible heat to the surrounding air.

Another approach involves increasing surface permeability in areas with little or no pedestrian footfall. Replacing continuous hardscape with planted areas, shrubs or grass allows the ground to retain moisture and supports evaporative cooling from soil and vegetation. Permeable surfaces also reduce heat storage in dense paving materials and improve near-ground thermal conditions. Applied across plazas, courtyards and open spaces, a combination of reflective materials and permeable landscaping can meaningfully moderate surface temperatures and improve outdoor thermal comfort in dense urban environments.

High reflectance stones used for paving in Akshardham temple, Delhi (left); high reflectance paint used over concrete Tirupati Balaji Temple, Delhi (centre and right) for cooler circumambulatory paths

Source: Anon 2012. 'Swaminarayan Akshardham, Delhi, India'. Airpano. Available at https://www.airpano.com/360article/akshardham-india/, as accessed on April 20, 2026; CSE

Permeable pavers (left); grass and shrubs (right) instead of hard surfaces in places with less footfall

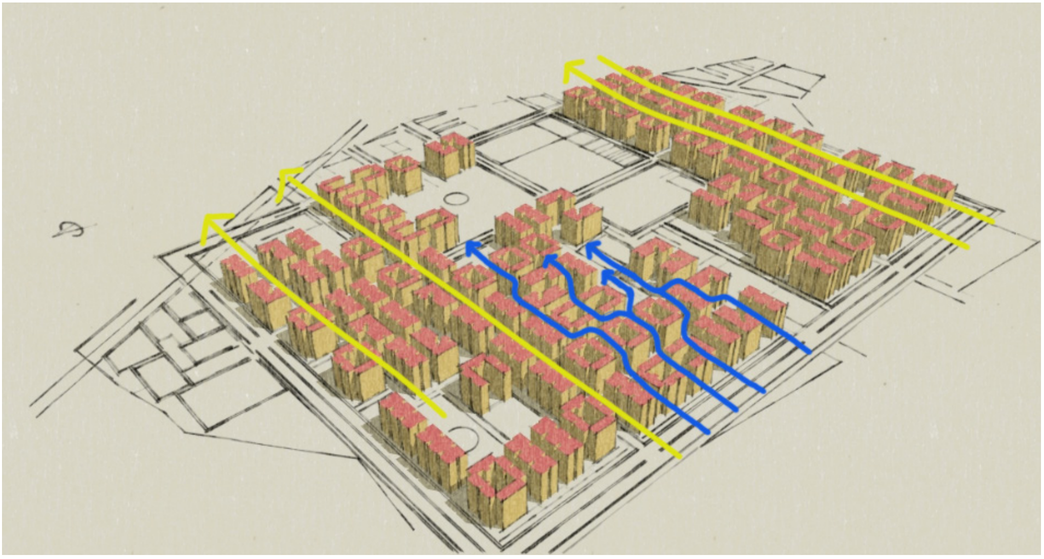
Sources: Mkrndmane 2024. 'Photo detail', WordPress Photo Directory. Available at https://wordpress.org/photos/photo/2726612b0a/, as accessed on April 20, 2026
Anon. 2017. 'DSC-HX200V', Pxhere. Available at https://pxhere.com/en/photo/1002602, as accessed on April 20, 2026

Managing wind variability

Wind movement plays a significant role in determining outdoor thermal comfort, particularly in dense urban environments. The orientation of streets, open spaces and buildings determines how air moves through a site and whether accumulated heat is dispersed or trapped. By aligning site layouts and built form with prevailing wind directions, airflow can be channelled to flush out heat and enhance convective cooling at the pedestrian level.

Effective wind management can also amplify the cooling potential of blue–green infrastructure by dispersing cooler air generated through evapotranspiration across adjacent spaces. Conversely, poorly oriented built forms and unbroken barriers can restrict airflow, creating stagnant heat pockets. Integrating wind considerations into urban design is therefore essential to ensuring that heat mitigation interventions perform effectively under local climatic conditions.

Figure 2: Wind plays a role in trapping or dissipating heat in an urban area



Source: CSE

INDIA'S ECSBC INCORPORATES SITE-LEVEL MEASURES TO MITIGATE HEAT ISLAND EFFECT AND IMPROVE OUTDOOR THERMAL COMFORT

India's Energy Conservation and Sustainability Building Code 2024 (ECSBC 2024) seeks to address heat stress and outdoor thermal comfort not only at the building scale but also at the site level to reduce the heat island effect. By expanding its scope from individual buildings to 'urban layouts', the code incorporates provisions that address the surrounding microclimate and the thermal performance of outdoor spaces.

The code recognizes the role of vegetation and surface treatment in moderating thermal conditions by requiring the preservation of existing mature trees wherever feasible and mandating compensatory tree planting for those that are removed or transplanted. It also limits paved non-roof areas, including uncovered parking spaces and pathways, to a maximum of 30 per cent of the total site area excluding the building footprint, acknowledging the contribution of excessive hardscaping to heat absorption and re-radiation in urban environments.

The code further strengthens these provisions for Super ECSBC buildings by introducing explicit heat island reduction requirements for both roof and non-roof areas. It mandates cool roofs or roof vegetation for at least 95 per cent of the net exposed roof area and requires 100 per cent of paved non-roof areas to be shaded by vegetation or a combination of vegetation and structural shading with high-reflectivity surfaces. By also specifying minimum reflectivity requirements for roofs, the code aims to reduce the heat these surfaces absorb and re-radiate. Together, these provisions signal a broader shift towards integrating microclimate considerations and outdoor thermal comfort into building and site planning practices.

3. Methodology for microclimate simulation

For the strategies outlined above to be truly effective, they must be carefully assessed and optimized for specific urban settings. This is where microclimate simulation becomes essential, providing an evidence-based approach to test and refine heat mitigation strategies before deployment. Simulation tools enable the modelling of different mitigation scenarios to quantify their effectiveness prior to implementation. By evaluating changes in key microclimate parameters—such as temperature, wind flow and humidity—under various intervention scenarios, simulations offer valuable decision-support insights for urban planners and policymakers.

This study employs a simulation-based methodology to assess the effectiveness of urban heat mitigation strategies using the microclimate modelling tool ENVI-met. The approach is designed to evaluate how specific interventions perform under real urban conditions. The methodology begins by identifying urban areas requiring urgent heat mitigation, with these priority sites forming the basis for subsequent analysis and simulation.

3.1 Identification of priority areas for intervention

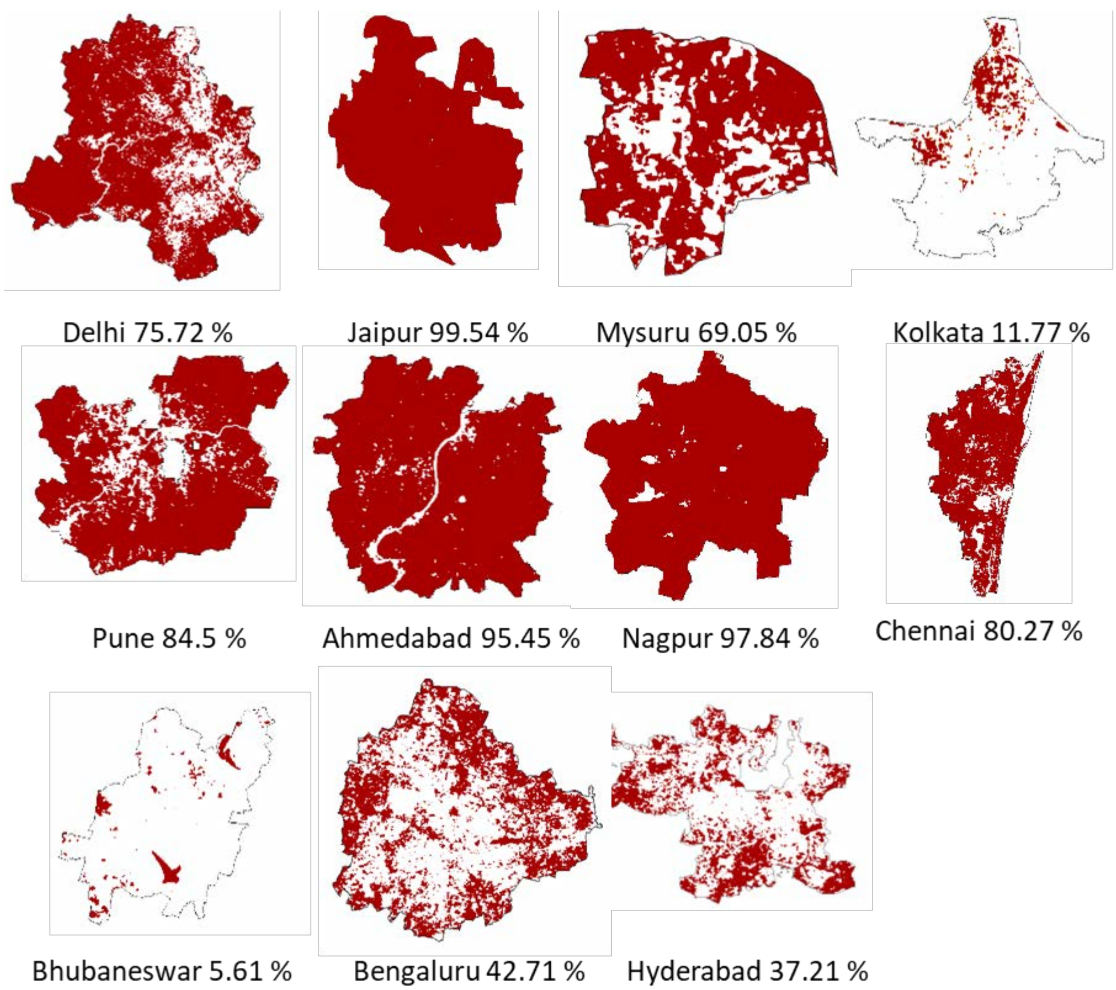
CSE conducted a spatial analysis across eleven Indian cities to identify areas experiencing recurrent heat stress during peak summer months. Satellite-derived Land Surface Temperature (LST) data for the summer period (March–July) were analysed to map spatial patterns of extreme heat. Heat stress thresholds were defined using India Meteorological Department (IMD) heatwave criteria—temperatures exceeding 40°C in inland plains and 37°C in coastal regions.

To account for the difference between surface and ambient conditions, the relationship between air temperature and LST was defined as LST = AT + 5°C, following the findings of Gallo et al.[39] While the referenced study identifies a possible range of 2–7°C between air temperature and LST, a conservative offset of 5°C was adopted to ensure analytical robustness. Areas were classified as heat-stressed when IMD-defined thresholds were exceeded recurrently for six or more years during the decadal period 2014–23.

The analysis revealed that seven of the eleven cities had more than 80 per cent of their urban area under heat stress, indicating widespread and persistent exposure to extreme summer temperatures. From these, Delhi, Jaipur, Mysuru and Pune were selected for detailed simulation-based analysis, representing composite and warm–humid climatic zones. Leh, located in the cold climatic zone, was also included in response to emerging concerns about rising summer temperatures amid rapid urban development.

Within the identified heat-stressed zones, the study focused specifically on outdoor spaces requiring thermal comfort interventions. These included areas with high pedestrian activity—streets, markets, transit nodes and public gathering

Map 1: CSE analysis for 11 cities showing the percentage area under heat stress



Source: CSE analysis

spaces where people not only pass through but also wait, interact, work and eat. Such locations disproportionately expose street vendors, daily-wage workers, commuters and other vulnerable groups to prolonged heat stress, making them critical priority sites for targeted interventions.

Delhi

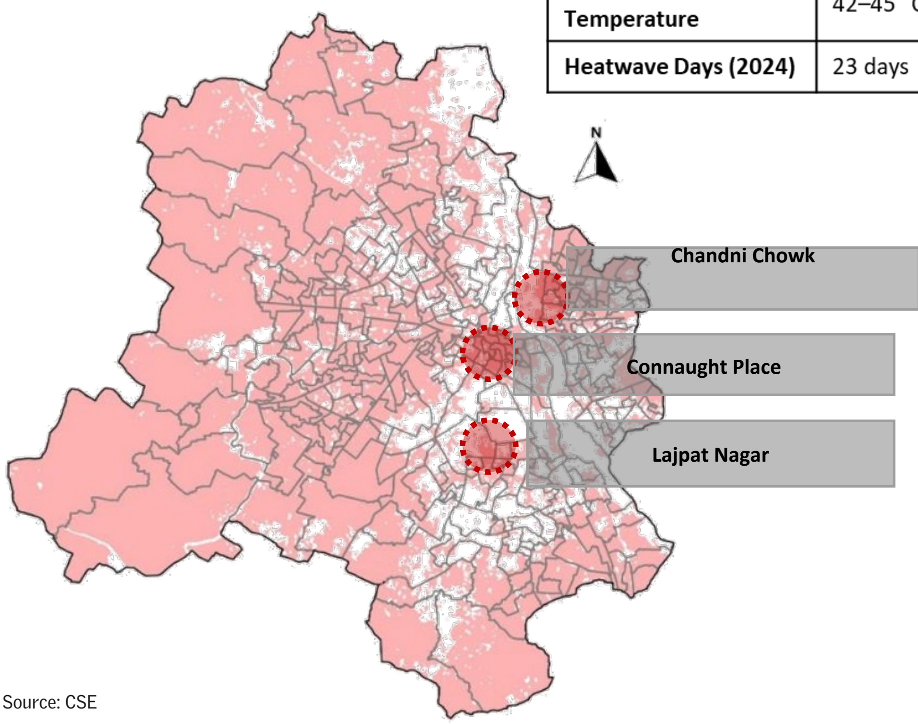
Within Delhi, sites were chosen to reflect a range of urban forms and activity intensities, enabling assessment of heat mitigation strategies across varied public realm conditions.

Connaught Place

Connaught Place was selected as the study site for Delhi due to its role as one of the city's most prominent mixed-use urban precincts. The area supports a wide range of commercial, religious and social activities, resulting in consistently high pedestrian presence across different times of the day. As a major destination for

Map 2: Map of Delhi with study areas

PARAMETERS	DETAILS
Area	~1,484 km²
Climate	Composite
Peak Summer Temperature	42–45 °C
Heatwave Days (2024)	23 days



Source: CSE

commuters, shoppers, workers and visitors, Connaught Place represents a space where outdoor thermal conditions directly influence everyday urban life. The precinct includes formal pedestrian corridors, open plazas and public gathering spaces, making it a suitable location for evaluating interventions aimed at improving outdoor thermal comfort.

Chandni Chowk

Chandni Chowk was selected as a study site due to its role as one of Delhi's oldest and most active mixed-use commercial corridors. The area supports a dense concentration of retail, wholesale trade, religious institutions, food establishments, and informal activities, resulting in very high pedestrian volumes throughout the day. As a key destination for traders, workers, residents, and visitors, Chandni Chowk is an urban space where outdoor thermal conditions directly affect daily livelihoods and mobility. The area comprises narrow streets, continuous building edges, and highly active public realms, making it an appropriate setting for evaluating heat mitigation strategies in historically evolved, high-density urban environments.

Lajpat Nagar

Lajpat Nagar was selected as a study site due to its character as a dense neighbourhood-scale mixed-use area, where commercial activity is interwoven with residential use. The area supports daily retail activity, local services and neighbourhood movement, resulting in sustained pedestrian presence, particularly along market streets and access roads. The precinct consists of active street edges, neighbourhood markets and residential blocks, making it representative of everyday urban environments where outdoor spaces are routinely used by residents, vendors and commuters.

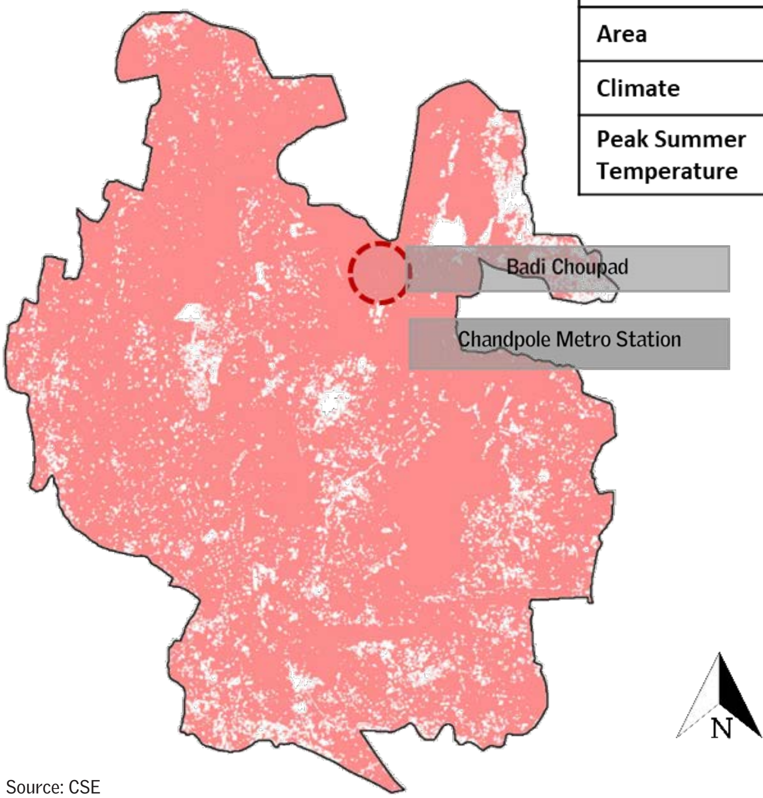
Jaipur

Within Jaipur, sites were chosen to capture different types of outdoor public spaces, i.e. market squares and transit gateways, used intensively during the day.

Badi Chaupad

Badi Chaupad was selected as the study site for Jaipur due to its role as a major public square and market junction with strong cultural and historic significance. The space functions as a key node within the city, supporting a mix of commercial activity, transit movement, and social interaction, and attracting high pedestrian presence throughout the day. As a prominent junction within the historic core, Badi Chaupad accommodates multiple modes of movement, including pedestrians, non-motorized transport and vehicular traffic. Its function as both a movement

Map 3: Map of Jaipur with study areas



Source: CSE

PARAMETERS	DETAILS
Area	~467 km²
Climate	Composite
Peak Summer Temperature	40–47 °C

corridor and a public gathering space makes it a suitable location for examining outdoor thermal comfort in heritage-intensive, high-activity urban settings.

Chandpole Metro Station

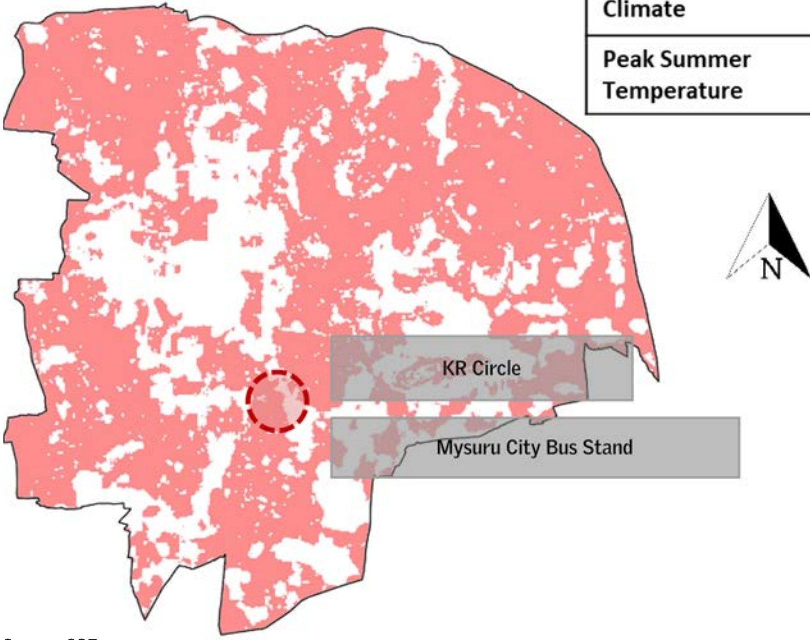
Chandpole Metro Station was selected as a study site due to its role as a major public transport node within Jaipur's historic core. The station serves as an important gateway connecting key heritage landmarks, including Hawa Mahal and City Palace, and provides access to surrounding public spaces such as Chhoti Chaupad and Badi Chaupad. As a result, the area experiences high pedestrian movement from commuters, tourists and local residents throughout the day. The precinct functions primarily as a transit-oriented public space, where pedestrians gather, wait and transfer between modes of movement.

Mysuru

Within Mysuru, sites were chosen to capture public spaces with sustained outdoor use, ranging from civic junctions to transport hubs.

Map 4: Map of Mysuru with study areas

PARAMETERS	DETAILS
Area	~6307 km²
Climate	Warm & Humid
Peak Summer Temperature	24–36 °C



Source: CSE

KR Circle

KR Circle is a central civic and commercial node within the city. The space functions as a focal point for public gatherings, processions and local celebrations, and supports continuous everyday use by residents and visitors. As a major traffic intersection, KR Circle connects key arterial roads and sees heavy pedestrian and vehicular traffic. The presence of shops, banks, and small businesses around the circle contributes to sustained outdoor activity, making it a suitable location for assessing outdoor thermal comfort in active, multifunctional urban junctions.

Mysuru city bus stand

The Mysuru City Bus Stand was selected as the study site due to its role as a primary public transport hub in the city. The facility serves a large number of daily commuters, resulting in consistently high pedestrian movement throughout the day. As a space where people arrive, wait, and transfer between routes, the bus stand is a critical outdoor environment in which thermal conditions directly influence commuter comfort. Its functional importance and continuous use make it a suitable location for evaluating heat mitigation interventions in transit-oriented urban settings.

Pune

Pune's sites were chosen to examine outdoor thermal comfort across formal office precincts and informal market streets.

Margarpatta city car parking

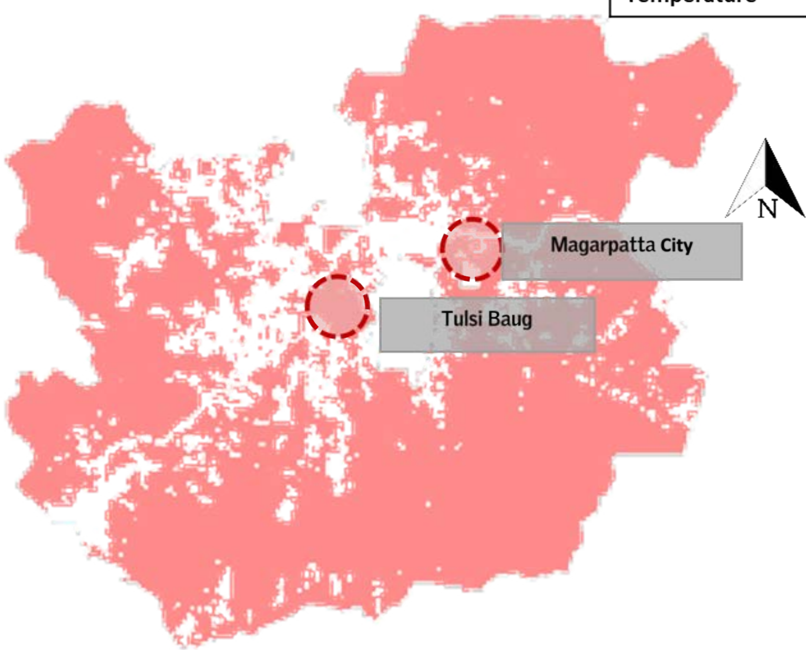
The parking area within Magarpatta City's inner circle was selected as the study site due to its location within a large, planned IT and commercial hub. Magarpatta City accommodates offices, industries and allied services, resulting in high daily commuter activity and extensive use of outdoor spaces associated with work-related travel. The site forms part of a planned urban precinct organised around a central green, with surrounding areas dedicated to circulation and parking.

Tulsi Baug Market

Tulsi Baug Market is one of Pune's most active traditional market areas, catering to heavy pedestrian footfall on a daily basis. The market supports a mix of retail shops, eateries, religious activity, and informal vending, drawing residents and

Map 5: Map of Pune with study areas

PARAMETERS	DETAILS
Area	~331.26 km²
Climate	Temperate
Peak Summer Temperature	23–35°C



Source: CSE

visitors throughout the day. As a space characterised by continuous street-level activity and prolonged outdoor presence, Tulsi Baug Market represents a typical high-intensity public realm where people walk, stop, interact and work. Its functional diversity and dense use make it a suitable location for evaluating outdoor thermal comfort in informal, activity-driven commercial streets.

Leh

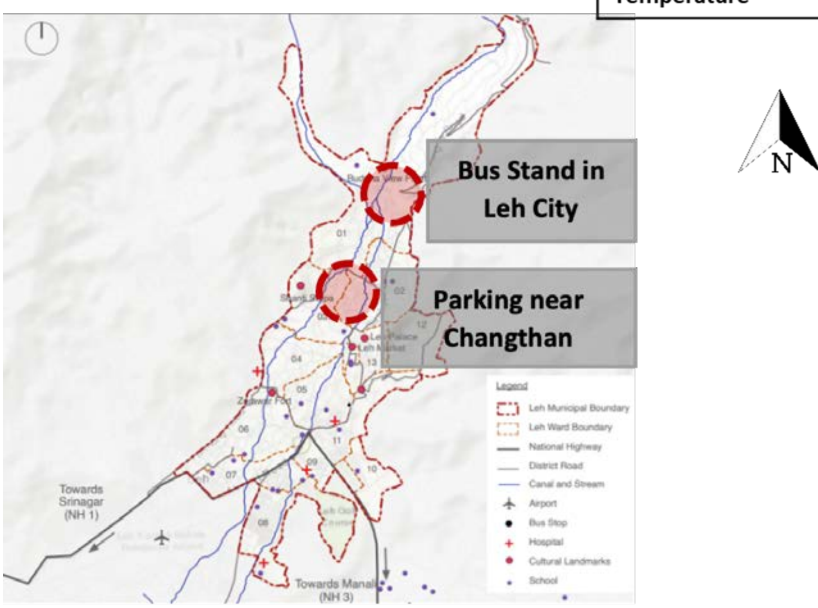
Within Leh, sites were chosen to capture commonly used outdoor spaces such as transport hubs and commercial parking areas.

Leh city bus stand

The Leh City Bus Stand is a key transit hub serving both local commuters and intercity travellers. The facility experiences continuous pedestrian and vehicular movement throughout the day, with people arriving, waiting, and transferring between modes of transport. As one of the most actively used public spaces in

Map 6: Map of Leh with study areas

PARAMETERS	DETAILS
Area	~17 km²
Climate	Cold
Peak Summer Temperature	25–35 °C



Source: CSE

Leh, the bus stand represents an important outdoor environment where thermal conditions directly influence user comfort.

Parking for commercial area near Changthan

The parking area near Changthan is in an active commercial zone that caters to shoppers, tourists and local vendors. The space supports regular movement and short-duration stays associated with commercial activity, resulting in sustained daytime outdoor use. As a functional component of the commercial area, the parking lot represents a common urban space in rapidly developing hill towns, where vehicular access and pedestrian movement overlap.

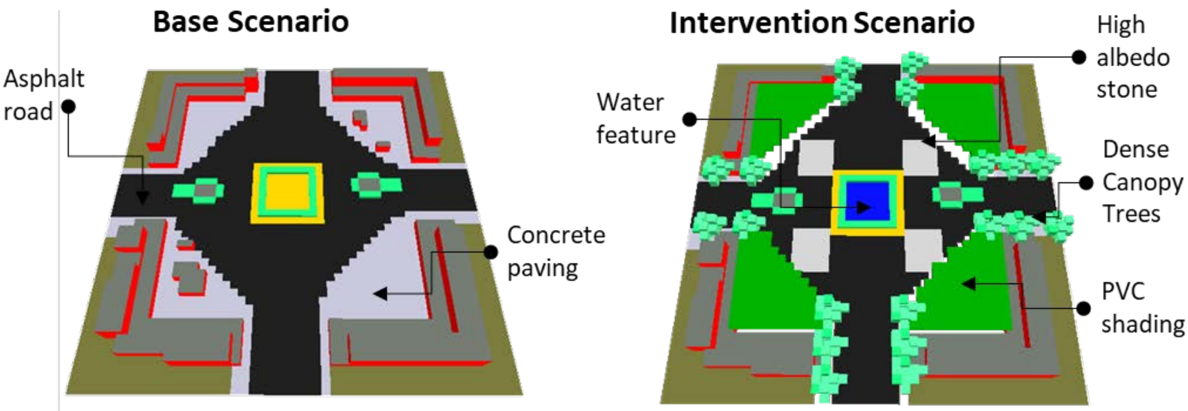
3.2 Developing mitigation scenarios

Following the selection of study areas across the five cities, detailed site visits were conducted to document existing on-ground conditions. These visits were supplemented by systematic visual analysis to understand how the built environment, surface materials, vegetation and spatial configuration influence outdoor thermal conditions at each site. Particular attention was given to areas of active public use—spaces where people walk, wait, gather, work or engage in commercial activity.

The visual assessment focused on identifying patterns of heat accumulation and thermal discomfort, including exposed pedestrian corridors, unshaded paved areas, waiting zones and activity nodes with prolonged outdoor use. Observations also documented missing or inadequate elements that contribute to thermal comfort, such as shading structures, vegetation, surface treatment and ventilation pathways. These observations established a qualitative understanding of how different spatial elements interact to intensify or moderate heat stress at the site level.

Based on this assessment, two simulation scenarios were developed for each site. Both scenarios were run under identical meteorological conditions to ensure comparability. The base scenario represents the existing 'as-is' condition, capturing current built form, surface materials, vegetation cover, and spatial layout. The intervention scenario was developed by introducing context-specific heat- mitigation measures informed by the site observations and aligned with CSE's four-path intervention framework. Model outputs were then analysed to assess changes in key thermal comfort parameters—air temperature and surface temperature—both of which are central to how people experience heat in open spaces. This comparative assessment enables an evaluation of the effectiveness of individual interventions, providing evidence to support climate-responsive urban design and planning.

Figure 4: The base scenario is compared with Intervention scenario



Choosing context-appropriate interventions

The effectiveness of thermal comfort strategies varies considerably across contexts, making site-specific assessment essential. For instance, while tree shading is broadly effective, canopy density significantly influences outcomes—dense-canopy trees deliver the greatest surface temperature reductions, underscoring the importance of prioritizing them in planting plans. Given the time required for trees to mature, a combined approach using both trees and artificial canopies is recommended to ensure immediate shading benefits through built structures while building long-term cooling capacity as tree cover matures.

Similarly, in areas where hard paving is not functionally required—such as spaces without defined pathways or heavy footfall—surfaces can be converted to softscapes. Blue infrastructure, including water features, can provide additional cooling benefits, but their application must be context-sensitive. In high-humidity regions, reduced evaporation limits their effectiveness, while in water-scarce areas, continuous water demand constrains their long-term sustainability.

Applying these principles, site-level observations were used to identify missing heat-mitigation elements and to develop tailored intervention scenarios for each study area. Only feasible and contextually appropriate strategies were selected, reflecting on-ground implementation realities. Shading measures—such as tree planting along medians and lightweight canopies along shopfronts—were prioritized in areas with high pedestrian activity and direct solar exposure. Ambient air temperature reduction measures, including activating existing water features and targeted greening, were proposed for spaces with limited vegetation but high public use. Surface material modifications, such as permeable finishes, were selectively applied in low-footfall zones to reduce heat absorption without disrupting pedestrian circulation. These interventions were integrated into a unified scenario for each site and simulated against the base (as-is) condition using ENVI-met.

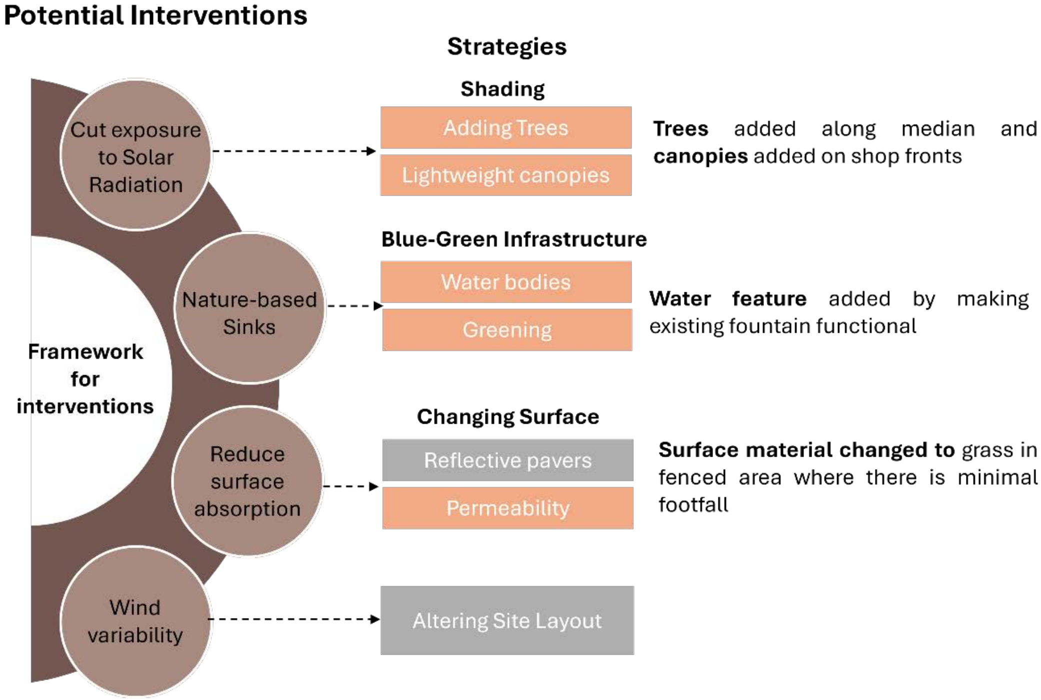
Case example—Chandni Chowk, Delhi: Site-level observations, identification of missing elements and selecting site-specific intervention

The pedestrian zone of Chandni Chowk, while designed to accommodate very high footfall, is dominated by hard, impervious surfaces. Shading is largely absent across key walking and gathering areas, despite sustained pedestrian presence throughout the day.

The fenced area surrounding the central fountain is entirely hardscaped, limiting its potential to contribute to microclimatic cooling. Although a fountain structure is present, it is currently non-functional, eliminating an important opportunity for evaporative cooling within the space. The surface materials used across the plaza and adjoining pedestrian areas further intensify heat absorption during peak hours.

Analysis of the current scenario and missing elements of Chandni Chowk study area

Figure 5: Framework for interventions and highlighted strategies that were used to formulate the intervention scenario for Chandni Chowk study area



3.3 Simulation steps

Once identified, mitigation scenarios must be modelled and simulated for the selected study area to understand and quantify their effect on the microclimate. ENVI-met is the simulation software used for this purpose. It is based on the Reynolds-Averaged Navier–Stokes equations and the Energy Balance equation, which govern heat transfer processes within the simulated environment. The software enables three-dimensional modelling of building–air–vegetation interactions within a defined urban environment. The key components and models used to simulate microclimate parameters are as follows:

1. **Thermal properties:** Thermal properties of each material used, such as reflectance, absorptance, emissivity and thermal conductivity, etc. were included, to accurately simulate the exchange of heat energy between surfaces and the surrounding environment.

MATERIAL PARAMETERS FOR THERMAL PERFORMANCE

Each theme within the database manager consists of material whose thermal performance depends on specific material parameters.

Table 1: Parameters associated with built environment

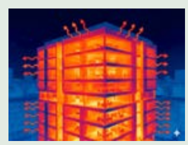
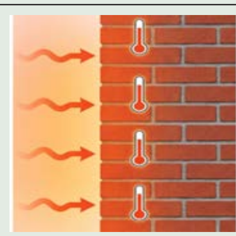
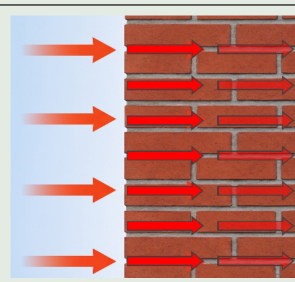
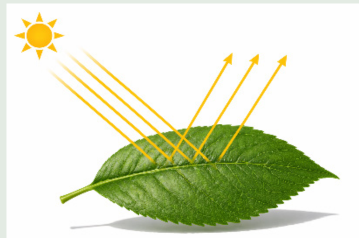
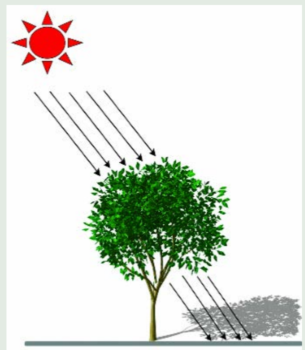
Parameter	Significance	
Absorption (absorption coefficient)	The fraction of short-wave radiation absorbed and is converted to internal heat energy	
Transmission (transmission coefficient)	The fraction of radiation that passes through the material without being absorbed or reflected	
Reflection (reflection coefficient)	The fraction of radiation that bounces off the material	
Emissivity	The effectiveness of a material in emitting heat energy as long-wave thermal radiationv	
Specific heat	The heat required by a body to raise its temperature by a single unit	
Thermal conductivity	Material's ability to transfer heat through itself	

Table 2: Parameters associated with vegetation

Parameter	Significance	
Albedo	The percentage of short-wave radiation reflected from the surface of the plant	
Transmittance	Average amount of short-wave solar radiation that passes through the plant to reach the ground determines the strength of the shadow cast by the plant	

2. **Vegetation model:** The vegetation model calculates the foliage temperature and the energy balance of the leaves, taking into account the physiological and meteorological parameters. The vegetation is characterized by the normalized leaf area density (LAD) and the normalized root area density (RAD). The evaporation rate and turbulence calculations are based on the airflow fields around the vegetation and the tree shape. The evaporation rate at the leaf surface, regulated by the stomata, is affected by the heat exchange between the leaf and its environment. The absorption characteristics of the foliage are calculated as a function of the sun path and the projected shade

Building surfaces: The thermal properties as well as the orientation of building surfaces, including walls and roofs, were considered to simulate their impact on surface temperatures. The simulation process in ENVI-met involves several key steps:

1. **Setting up:** Software installation, creating a workspace for the study area, and creating and managing a material database.

2. **Digitizing the base and intervention scenarios** by modelling the built environment.

3. **Inputting weather parameters** such as temperature, humidity and wind conditions to understand their variation under different scenarios

4. **Running the simulation** to generate microclimate outputs.

5. **Visualizing and analysing results** to study the effectiveness of mitigation strategies in reducing the UHI effect (see *Figure 6: Simulation framework*).

Figure 6: Simulation framework

Set Up
Software Installation
Workspace creation
Project name
Database Management

Digitizing Area File
Location
Geographic properties
Model dimensions
Buildings
Greening- Trees/Plants/Grass
Soil/ Pavement

Microclimate Parameters
Initial Parameters
-Simulation date
-Simulation time (hours)
Weather parameters
-Temperature
-Humidity
-Wind speed
-Wind Direction

Run Simulation
Output Files

Visualize Results
Surface Temperature maps
Potential Air Temperature maps

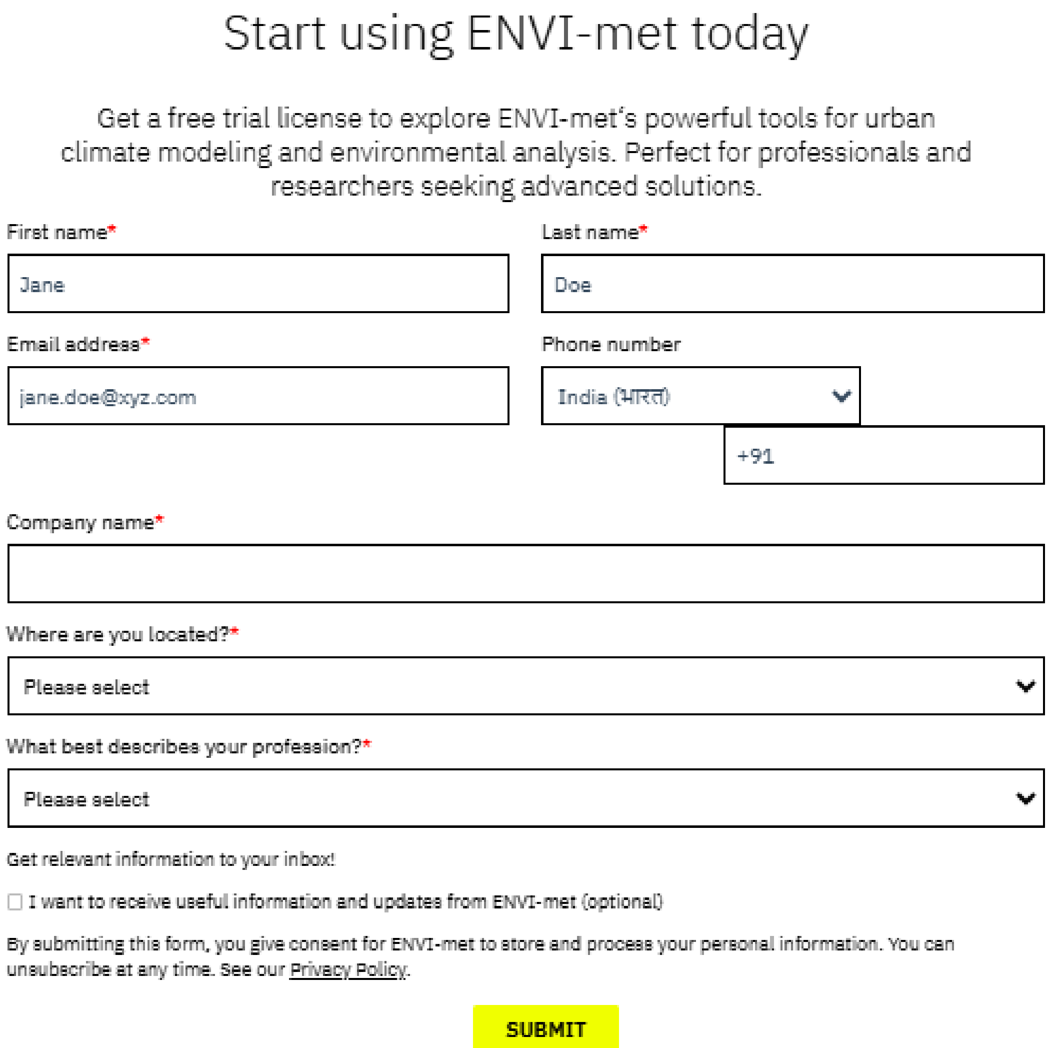
Source: CSE

Set up

Software Installation

Step 1: Download software setup from Envi-met website
- Open website https://envi-met.com/
- Click on 'Free Trial'

- Fill in the details
- Click on 'Submit'



Start using ENVI-met today

Get a free trial license to explore ENVI-met's powerful tools for urban climate modeling and environmental analysis. Perfect for professionals and researchers seeking advanced solutions.

First name*
Jane

Last name*
Doe

Email address*
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Phone number
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+91

Company name*

Where are you located?*
Please select

What best describes your profession?*
Please select

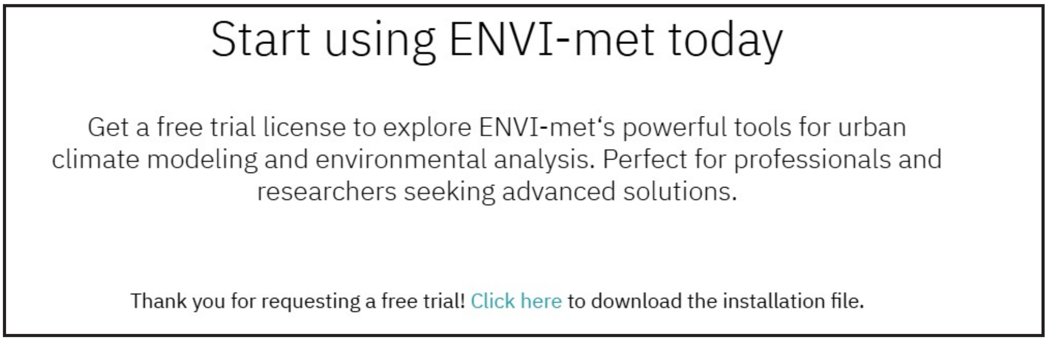
Get relevant information to your inbox!

☐ I want to receive useful information and updates from ENVI-met (optional)

By submitting this form, you give consent for ENVI-met to store and process your personal information. You can unsubscribe at any time. See our Privacy Policy.

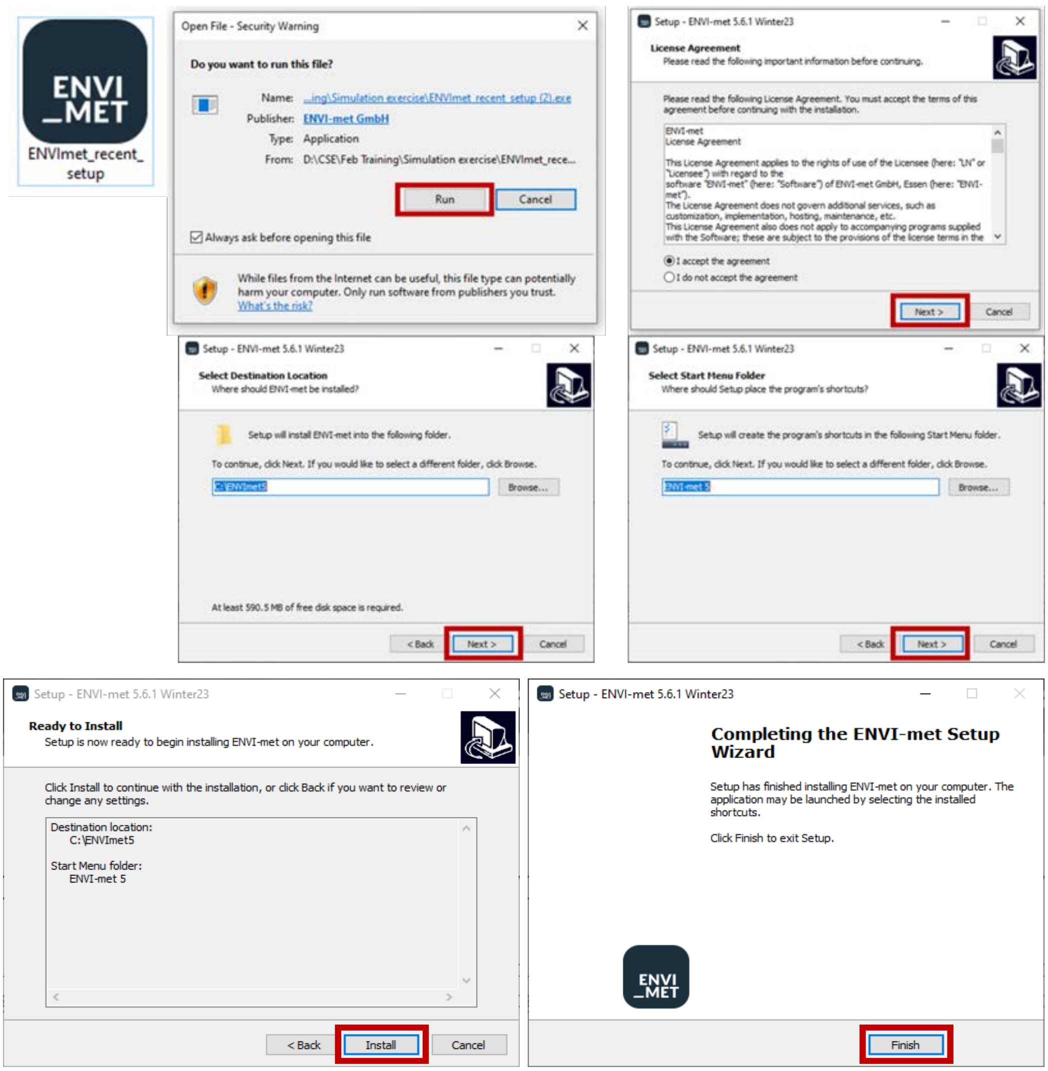
SUBMIT

- Download software set up by clicking on ‘click here’



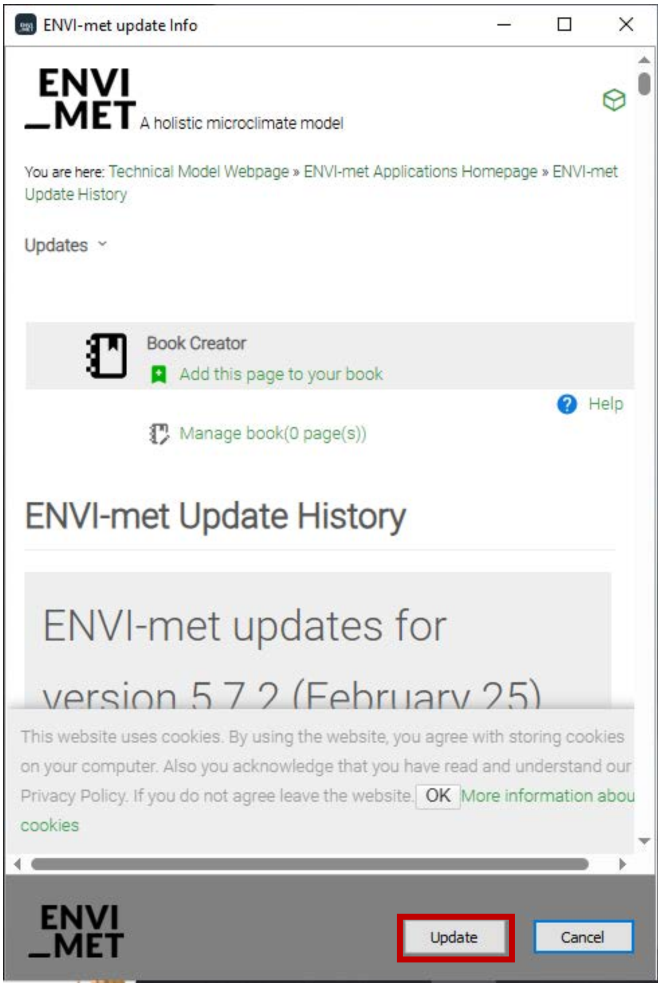
Step 2: Install software

- Locate setup file in *Downloads* folder and run the setup
- Follow the instructions for installation

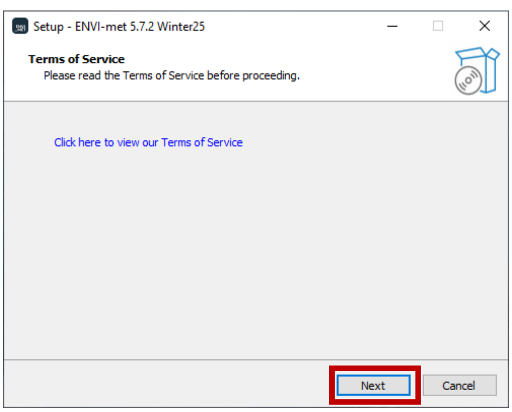


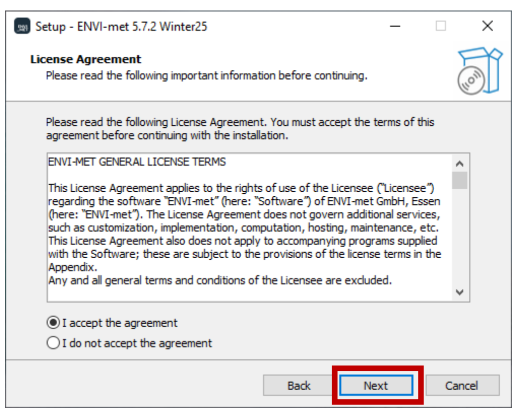
Step 3: Check for update

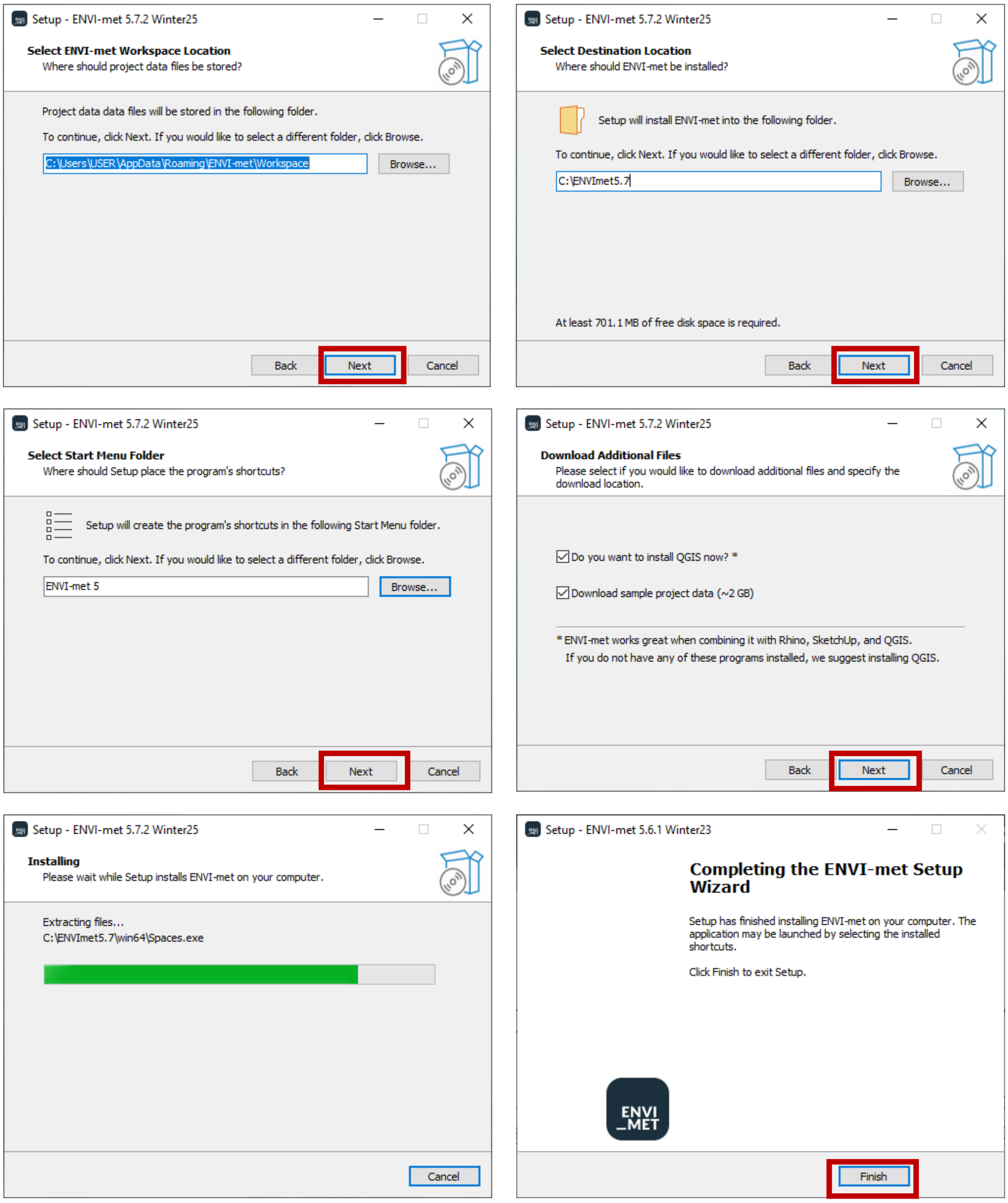
- Click on 'ENVI-met Headquarters 5.6.1' icon on the desktop
- Update pop up will appear
- Click on 'Update'



- Follow instructions for update







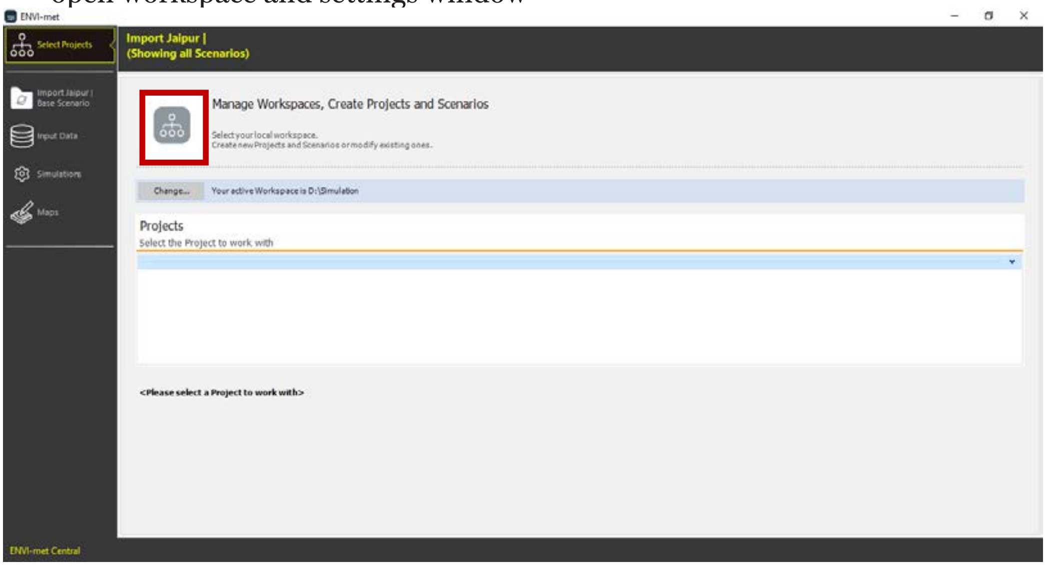
Creating workspace and project

Step 1: Setting up workspace

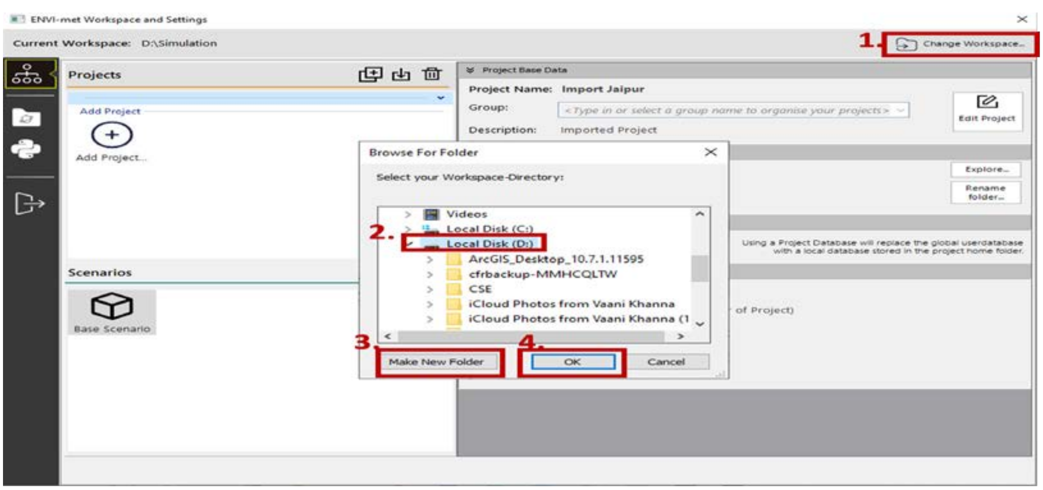
- Click on 'ENVI-met Launcher 5.7.2' icon located on the desktop to open the ENVI-met Headquarter. The ENVI-met Headquarter serves as the central hub for all programs within the ENVI-met Suite. It provides access to essential tools required for the simulation process, including setting up a new project, creating and customizing material databases, digitizing the study area, running the simulation.

- Click on 'Manage Projects' icon on the Headquarter

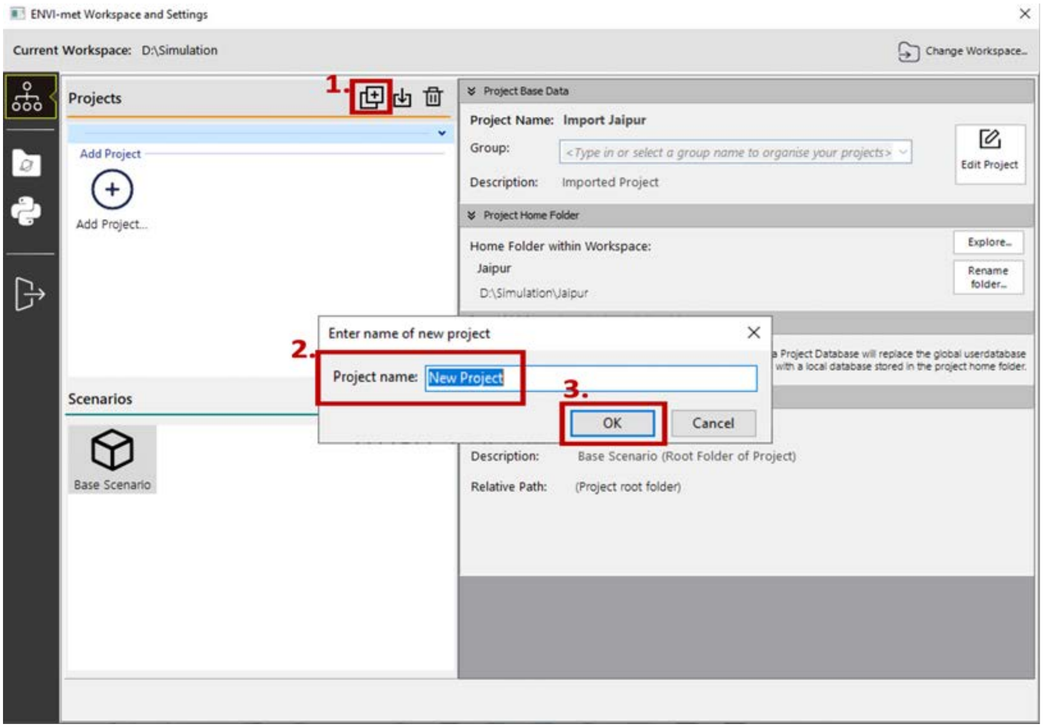
- Click on the icon for 'Manage Workspace, Create Projects and Scenarios' to open workspace and settings window



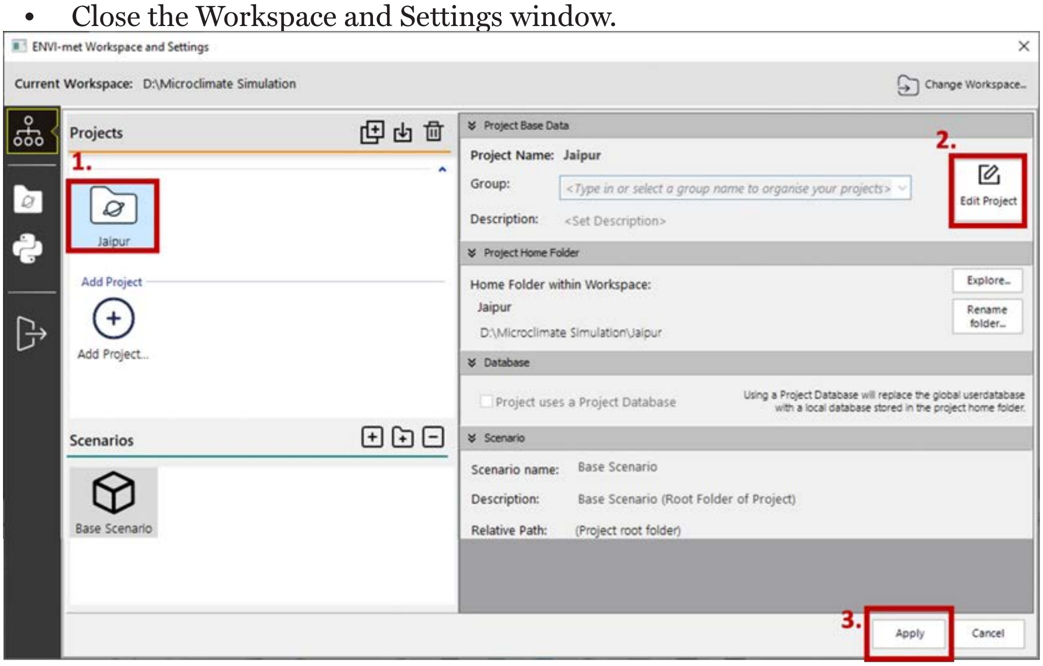
- In the workspace and settings window click on 'Change Workspace' and create new folder in the desired location on the system.
- In the following pop up select the location and then click on 'Make New Folder'.
- Rename the folder accordingly for example, 'Microclimate Simulation' and click on 'ok'



- Click on the 'Add new empty project' icon and name the new project. The name can be based on the study area for example 'Jaipur'.

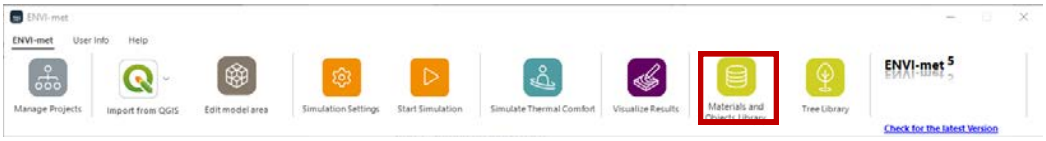


- Click on the project 'Jaipur' so created and then on 'Edit Project' to change project name or home folder within the workspace and click on 'Apply'
- Close the Workspace and Settings window.



Database management

- Reopen ENVI-met headquarters
- To create and modify customized materials and to look up the attributes of the elements within the system database, click on 'Materials and Objects Library' on the ENVI-met Headquarters to open the Database Manager.
- All elements used in the model area, such as materials, walls, soils, simple plants, sources, etc., can be found and adapted here.



- Database Manager contains a list of the different thematic tables stored in the database. For detailed information, click on the items.

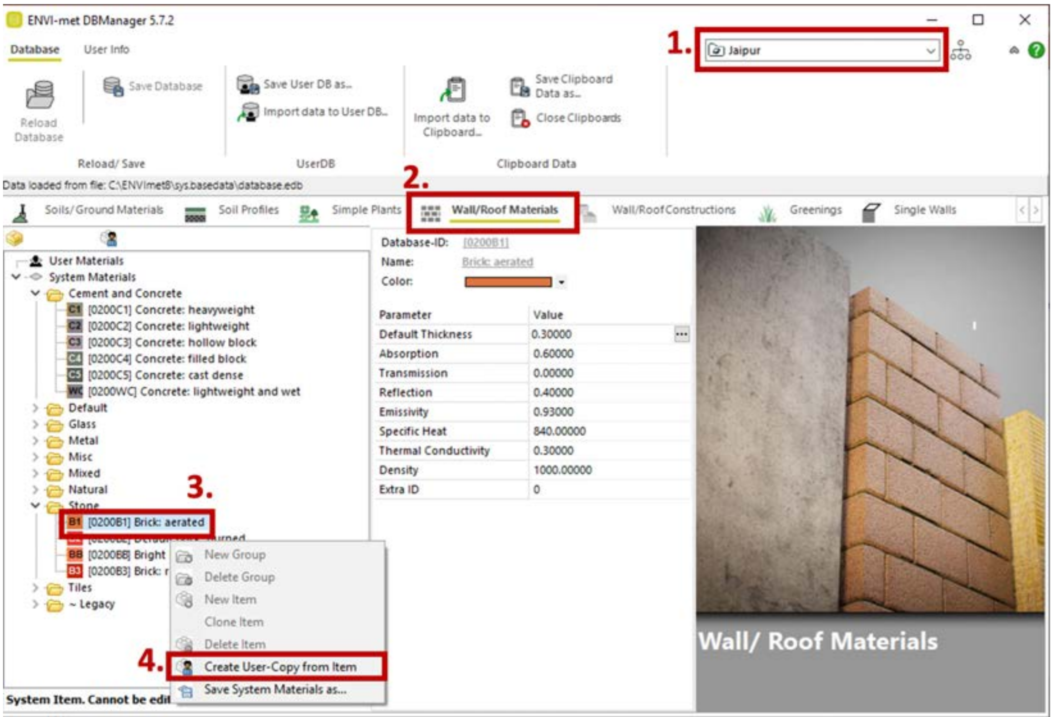
1. Soils: Properties of different natural and artificial soils
2. Soil profiles: Different soil types as vertical sandwiches of soils
3. Materials: Basic collection of different materials that can be used for walls
4. Walls: Sets of building walls and roof composed out of 3 layers of different materials
5. Single walls: Sets of single walls consisting of one material
6. Simple plants: Simple 1D plants such as grass.
7. Sources: Emission profiles for different pollutant sources.

Editing materials in database

Each material in the database is defined by a specific parameter. New materials can be created as needed by modifying these parameters to align with the study's requirements.

Example 1: to create a new material—Fly ash brick

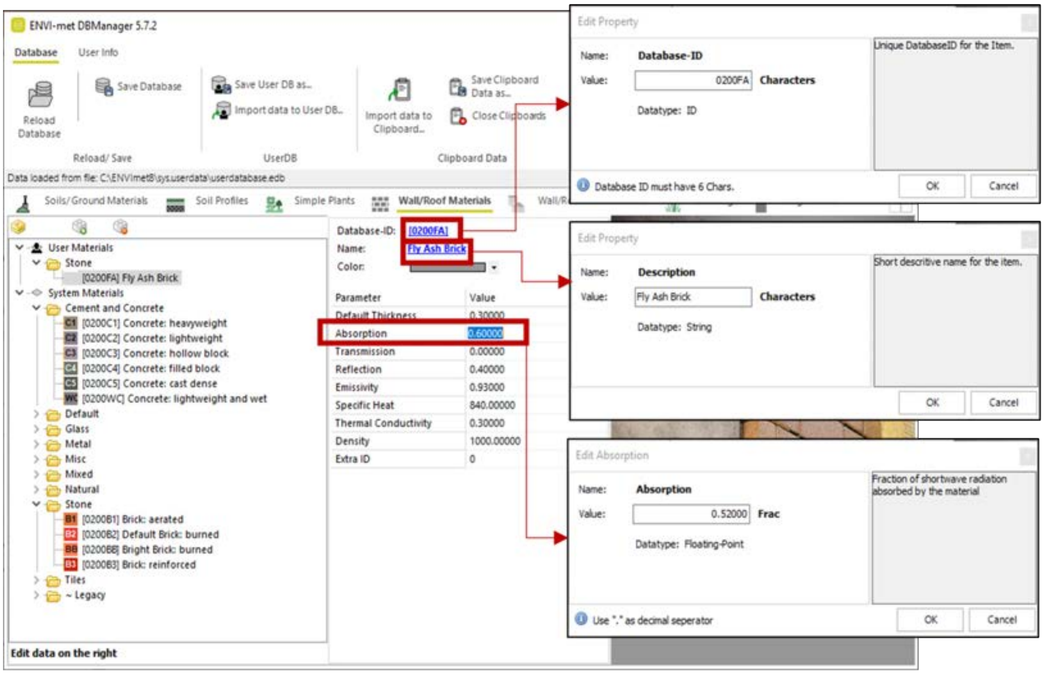
- Select project 'Jaipur' on the top right corner
- Click on 'Wall/Roof Materials' theme
- Right-click on any existing system material and click on 'Create user—Copy from item'



- The user copy will now appear under 'User Materials'
- It can be edited to replace the existing values with the appropriate ones for fly ash brick:

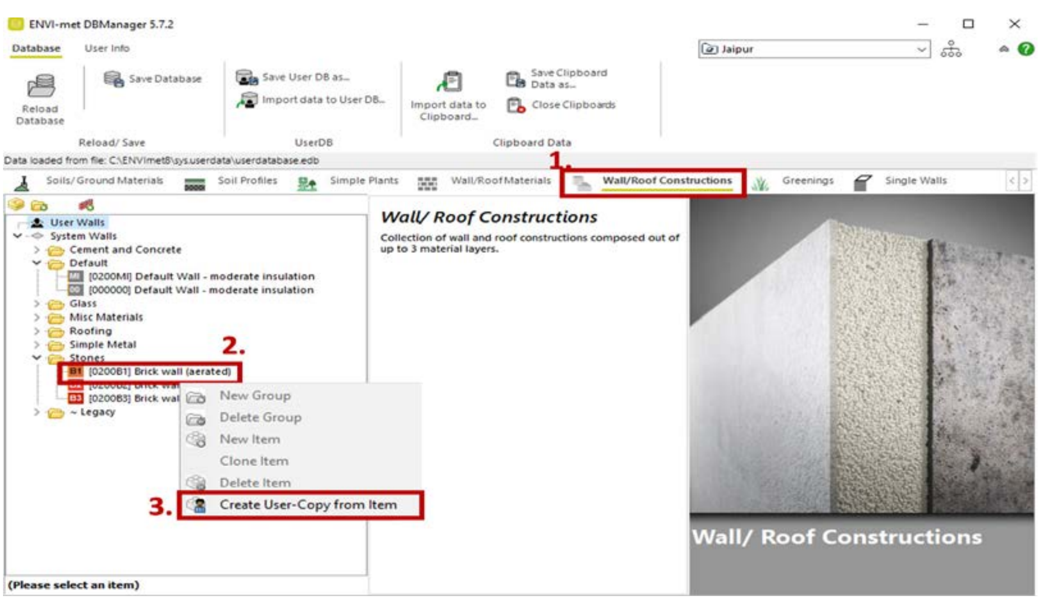
Parameter	Fly ash brick
Absorption coefficient	0.52
Transmission coefficient	0.00
Reflection coefficient	0.48
Emissivity	0.75
Specific heat (J/Kg*K)	950
Thermal conductivity (W/m*K)	0.25

- Click on each field on the right to edit the values accordingly. The database ID for each material in the database must be unique.



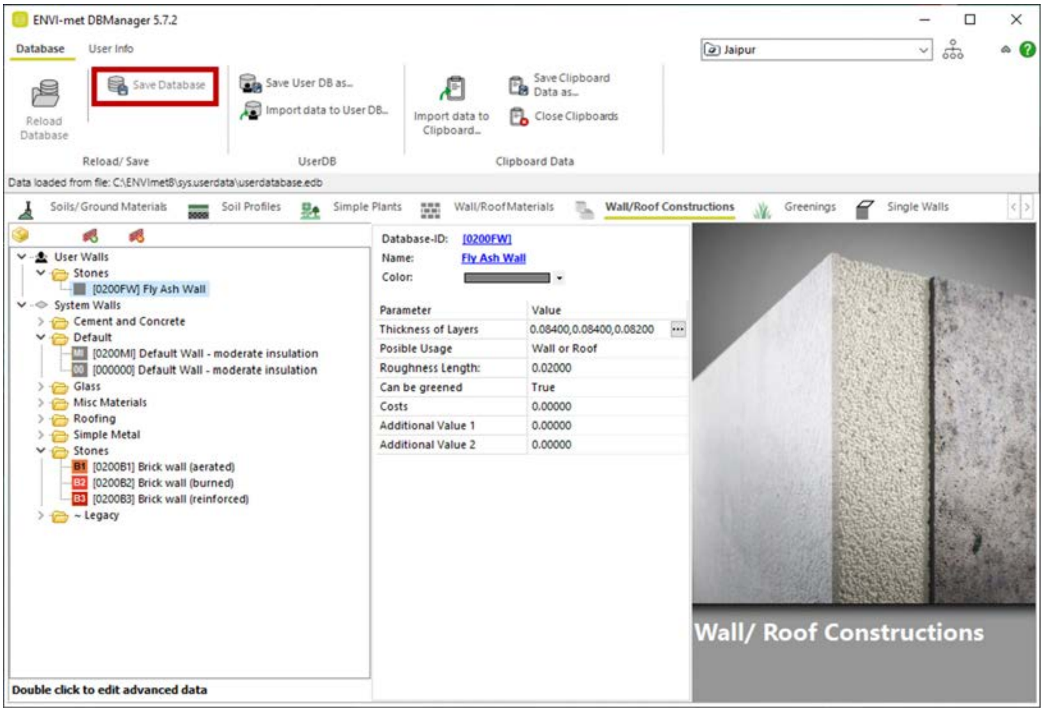
Example 2: Constructing wall/roof from material

- Click on 'Wall/Roof Constructions' theme
- Right click on any existing system wall and click on 'Create user—Copy from item'
- The user copy will now appear under 'User Walls'
- It can be edited to replace the existing values with the appropriate ones for Fly Ash Brick walls.



- Click on the user copy created and edit the parameters such as database ID, name, colour etc.
- Double click on the user copy created to open the Edit Wall window.
- The wall is constructed in three layers. Each layer constitutes a material.
- The required material can be dragged from the list on the right and dropped onto each layer. The list consists of all the 'Wall/Roof Materials' including the user material created- 'Fly Ash brick'
- For Fly ash wall drag 'Fly Ash Brick' material from the list onto the layers
- Edit the width of each layer to achieve the desired wall width.
- Click 'ok'

- Once the database has been edited click on 'Save Database'



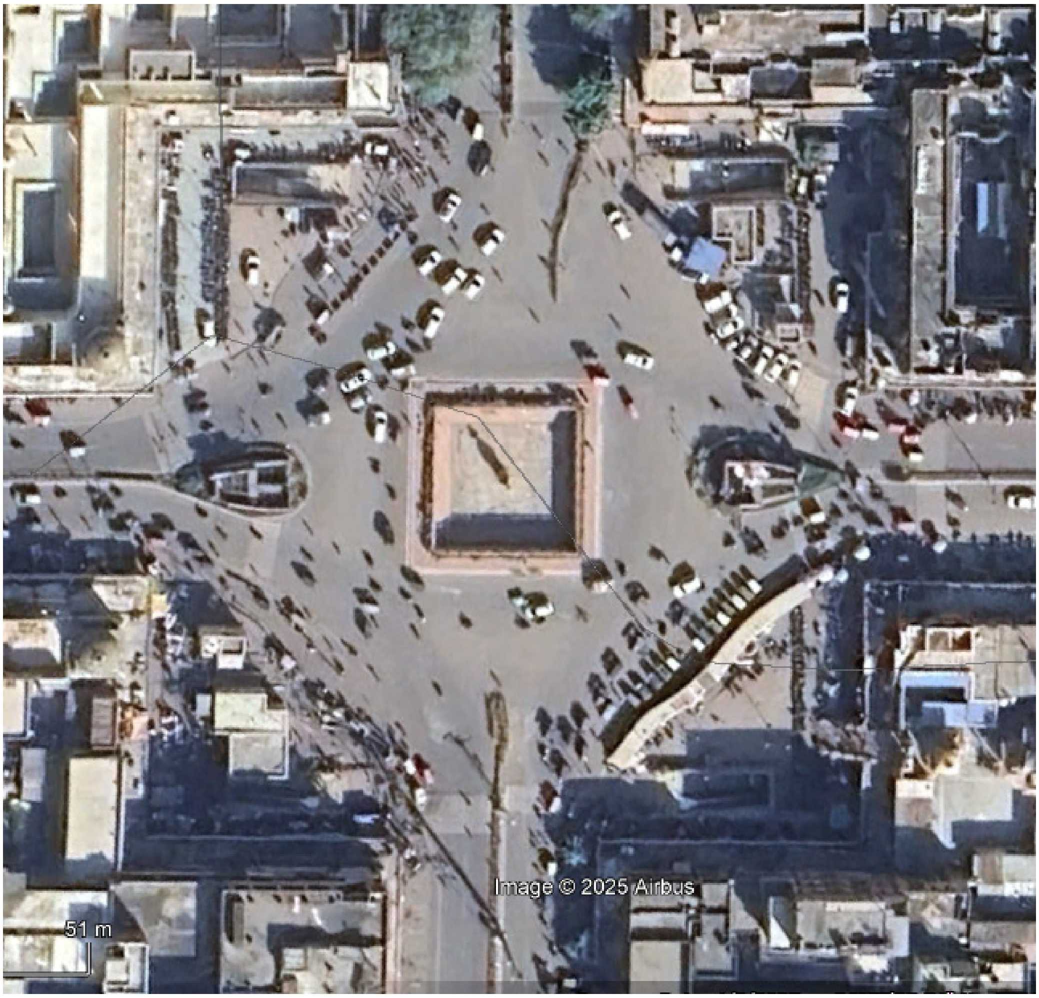
Digitizing area

Volume construction: The building elements can be constructed using building footprints from google earth and heights can be obtained from Google Street view as well as site visits.

Step 1: Study area selection for modelling

Open Google Earth and locate the study area.

- Rotate north to align building boundaries, roads, etc., in right angles as much as possible.
- Save the image as a .jpeg file.



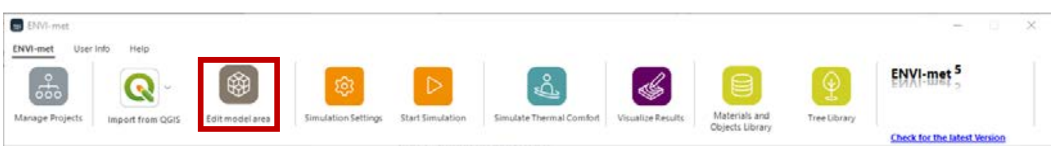
Satellite image of study area as taken from Google Earth

- Open the saved .jpeg with MS Paint and save as a bitmap image (.bmp format)

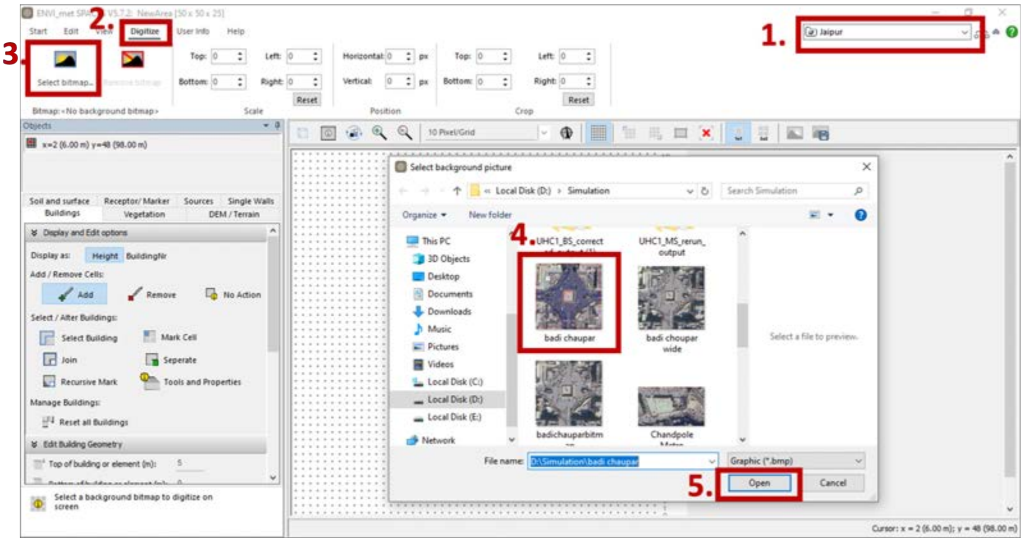
Step 2: Digitizing model area

Opening Bitmap image

- Reopen ENVI-met headquarters and click on 'Edit model area' to open the 'Spaces' window.

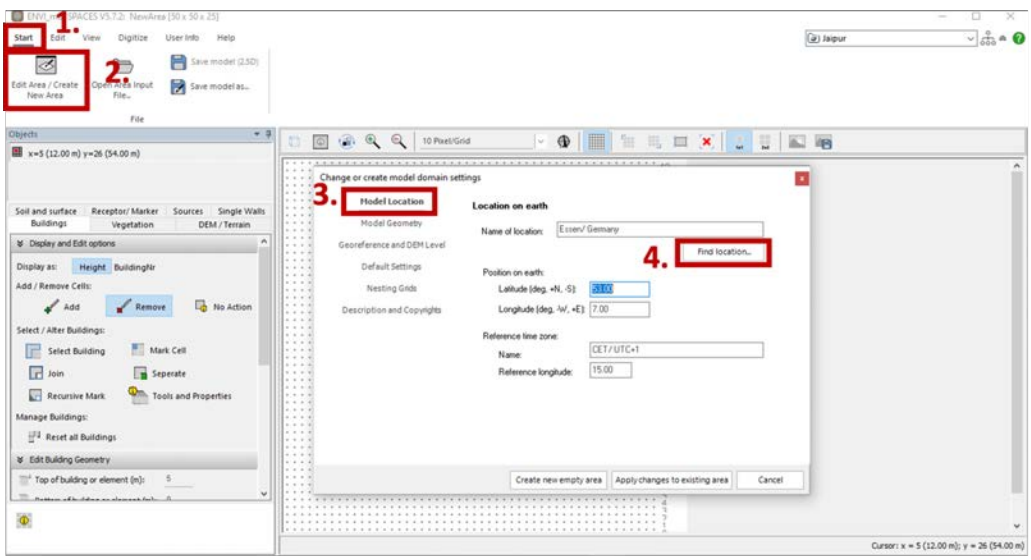


- Select project 'Jaipur' on the top right corner
- Click on 'Digitize' and then on 'Select Bit map image'.
- Select the bit map image of the study area as saved earlier.

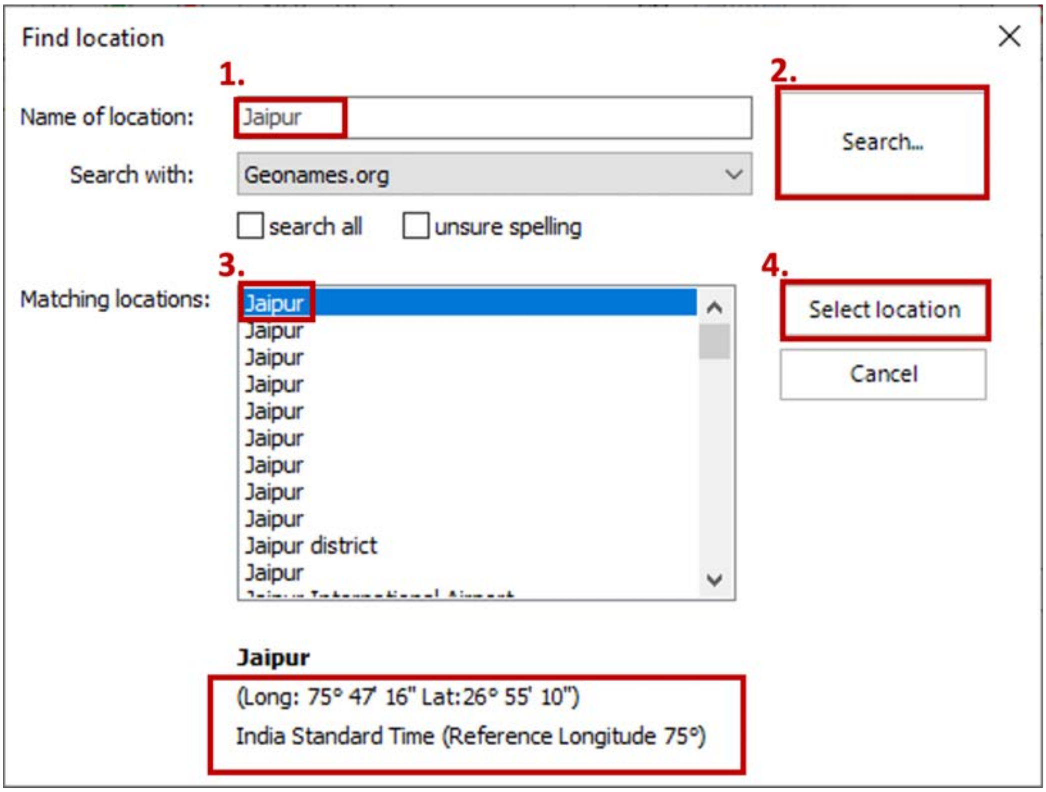


Setting up Model Area

- Click on 'Start' and then on 'Edit Area/Create New Area'
- In the pop-up window click on 'Model Location'
- Under the 'Location on earth' panel click on 'Find Location'



- In the ‘Location’ pop-up, type the name of the city in which the selected study area lies, in this case ‘Jaipur’ and then click on ‘Search’
- From the list of options that appear, select the one with coordinates closest to the chosen study area as seen in Google Earth and click on ‘Select Location’.



- Under ‘Model Geometry’ enter number of grids in the x, y and z axis based on the size of each grid in each direction (x, y, z)

1. Determine Study Area Size:
   - Identify the dimensions of the chosen study area.
   - Example: The selected area is 150m × 150m.

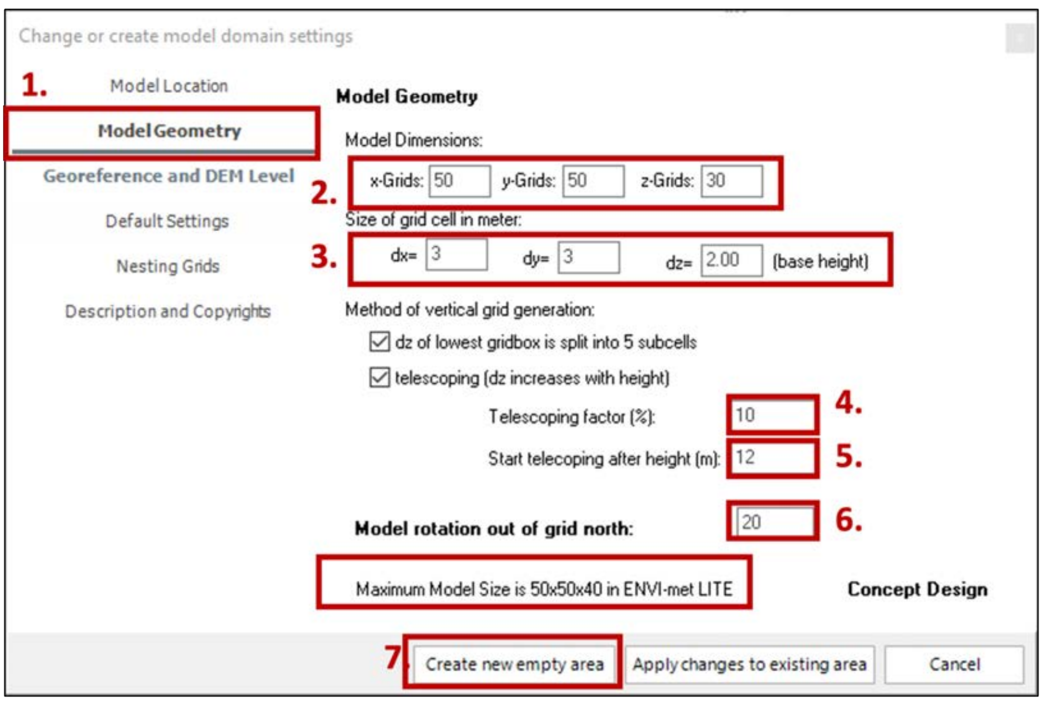
2. Check Grid Limitations:
   - The trial version of ENVI-met allows a maximum grid size of 50 × 50 × 40.

3. Calculate Grid Resolution for X and Y Axes:
   - To use the maximum grid size (50) in both X and Y directions:
     - Resolution = Study area size / Maximum grid count

  - o 150m ÷ 50 = 3m
  - o Final resolution: 3m × 3m for X and Y axes.

4. Determine Model Height (Z-Axis):
   - The height of the model should be twice the tallest building in the area or 60m, whichever is greater.
   - In selected study area, the tallest building is 9m, so:
     - o 9m × 2 = 18m (which is less than 60m)
     - o Final model height: 60m

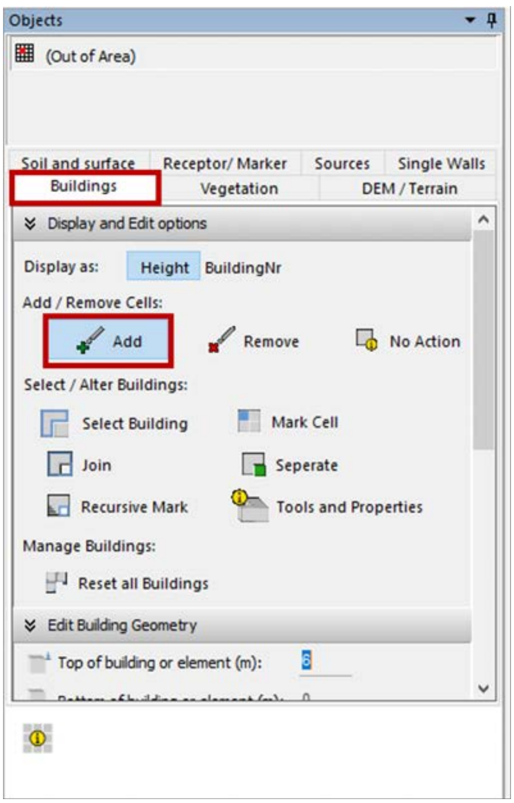
5. Calculate Grid Size for Z-Axis:
   - Choose an appropriate vertical grid resolution.
   - Example: Using a 2m resolution in the Z direction:
   - o 60m ÷ 2m = 30 grids
   - Final grid count in Z-axis: 30.
   - For 'Telescoping factor (%)' enter 10
   - For setting the 'Start Telescoping After Height', first identify the tallest building in the selected study area. In this example, the tallest building is 9m. Add 3m to this height (9m + 3m = 12m) and enter 12m
   - Enter the rotation angle relative to grid north. In this example, the rotation is 20 degrees.
   - Click on 'Create new empty area'.

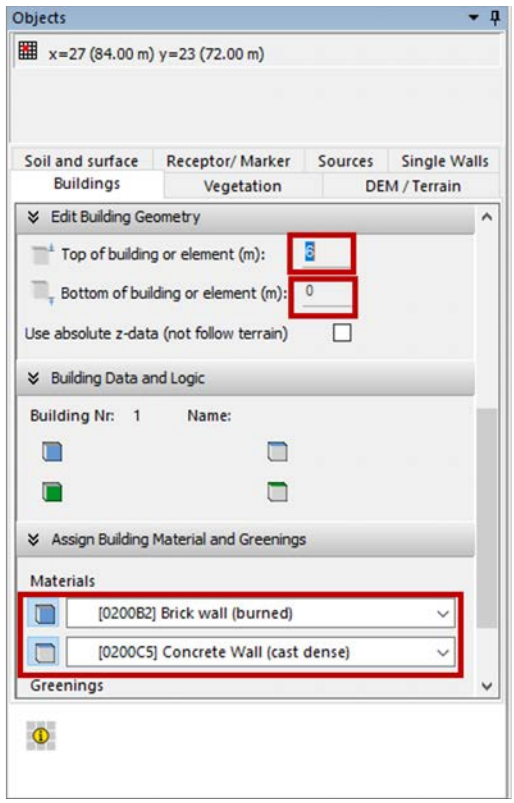


Creating model area—volume construction

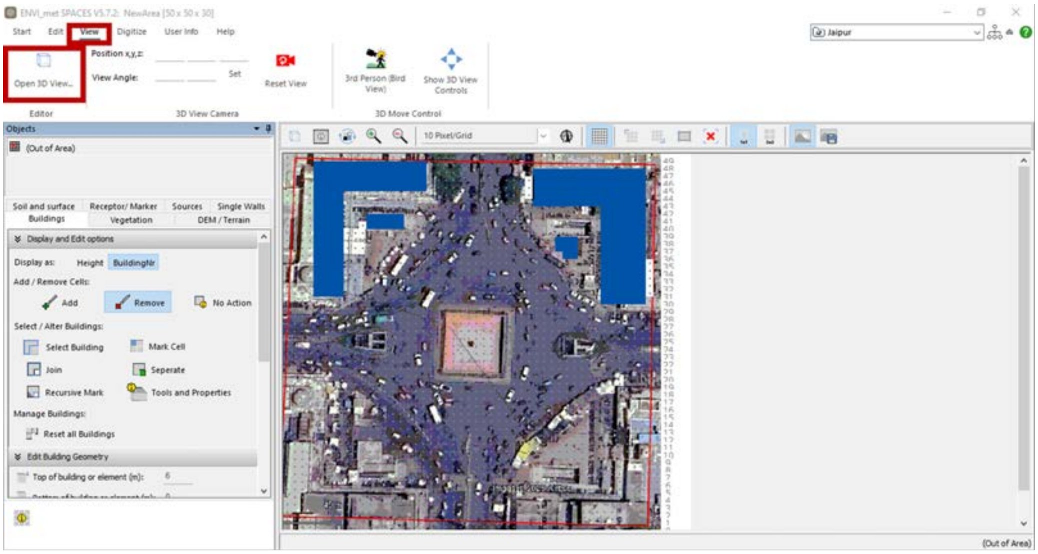
Step 1: Construct buildings

- Click on the 'Buildings' tab on the left-hand side 'Objects' panel
- Click on 'Add' or 'Remove' to build or erase respectively.
- Enter the building height in metres in the 'Top of the building or element (m)'.
- In the 'Bottom of the building or element (m)' enter 0
- Under 'Assign Building Materials and Greenings' select material for building walls and roof. In this example wall material was chosen as 'Brick wall (burned)' and roof material as 'Concrete Wall (cast dense)'.

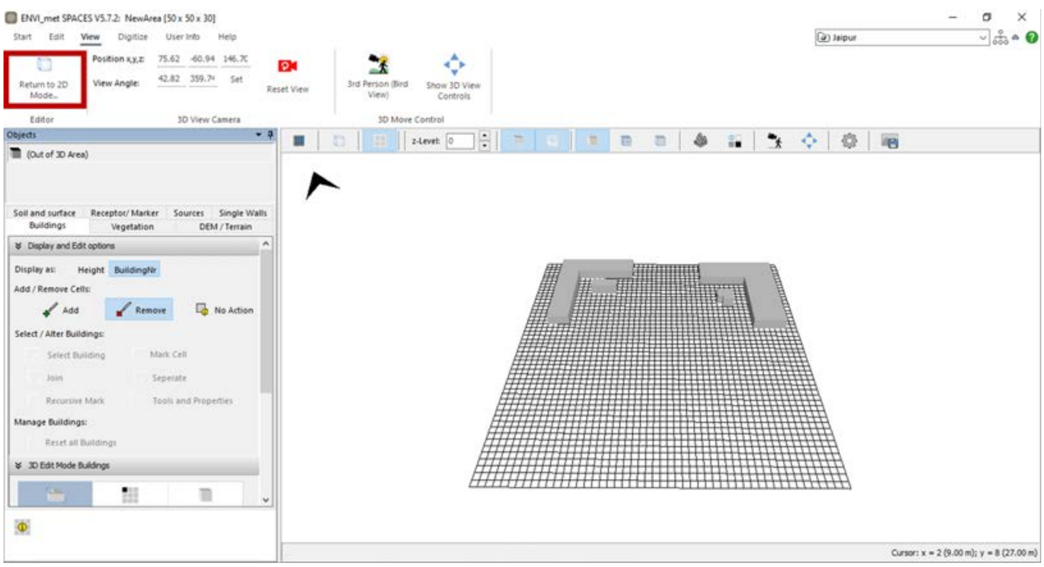




- Use the uploaded bitmap image as reference to digitize buildings by following the boundaries as much as possible

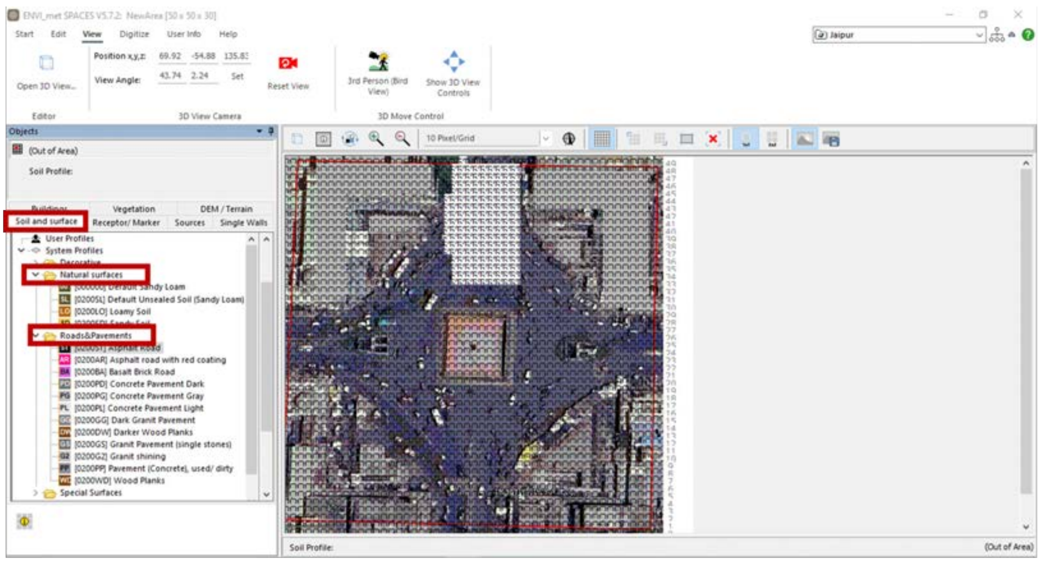


- To view the model in 3D mode, click on 'View' in the toolbar on the top and then on 'Open 3D View'
- Use the mouse scroll button to zoom in or out and hold down the 'Ctrl' key and move the mouse to change visualizing angle
- Click on 'Return to 2D Mode' to go back to 2D view to continue digitizing.

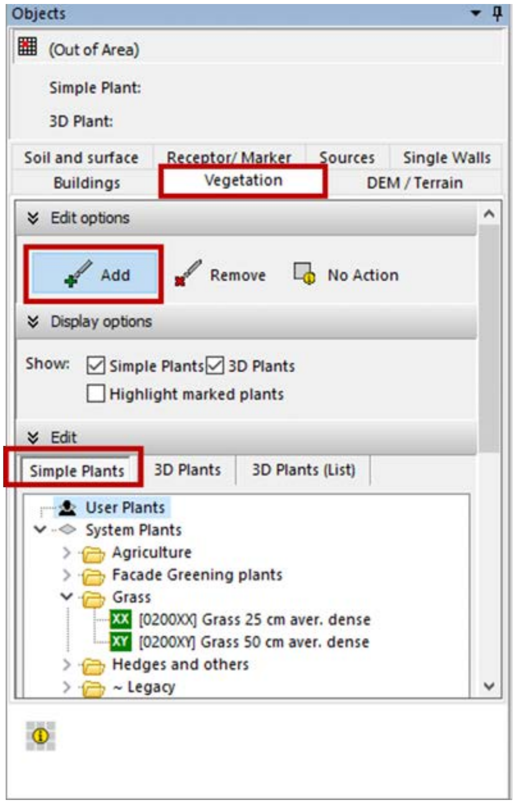


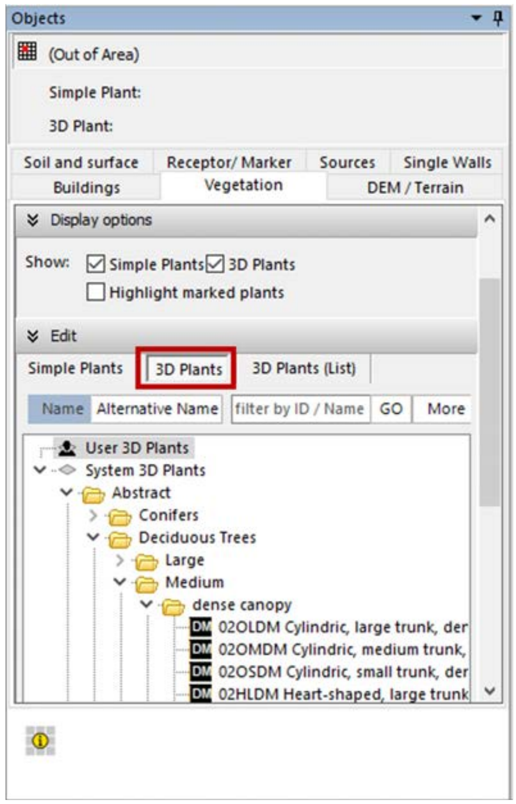
Step 2: Digitizing the surroundings

- Click on 'Soil and surface' to digitize surfaces like roads, pavements, etc.
- From the list of surface materials select the appropriate one and started digitising by clicking on each cell using the bit map image as reference
- For example: for the roads, the material 'Asphalt Road' was selected, for pavement 'Concrete Pavement Gray' was selected

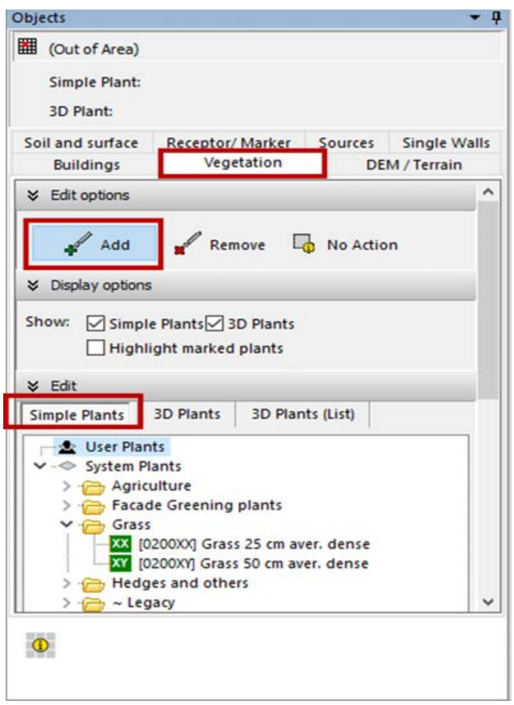


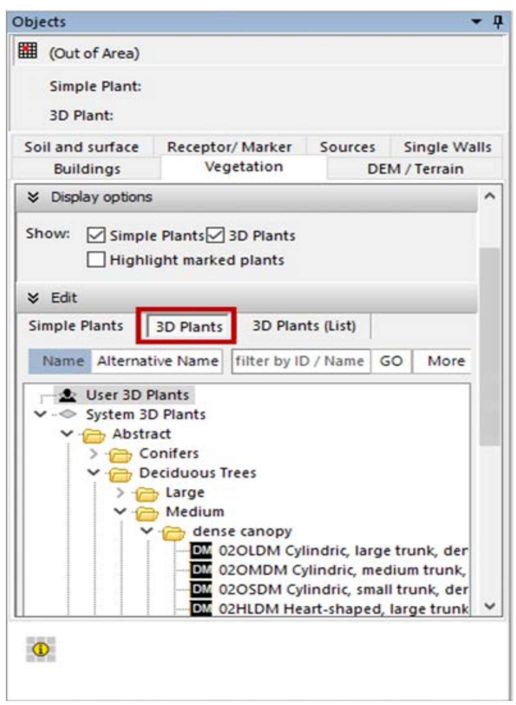
- Click on the 'Vegetation' tab to digitize surrounding trees, hedges, grass, etc.
- Click on 'Add' under the 'Edit options' menu.
- For grass, hedges and smaller plant click on 'Simple plants' tab under the 'Edit' menu.
- Choose from the list of options to digitize greening in the area by selecting it and clicking on model area using the bit map image as reference
- For trees click on '3D plants' tab under the edit menu.
- Choose from the list of options to digitize trees in the area by selecting it and clicking on model area using the bit map image as reference.



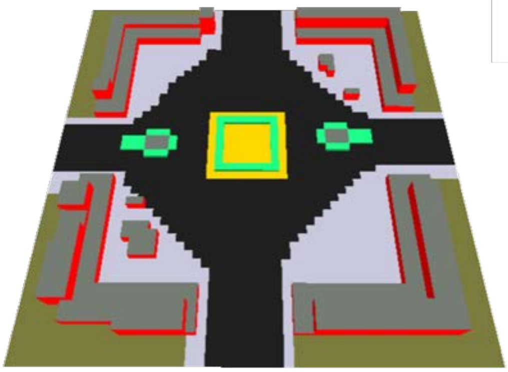


- The study area is thus modelled with all the components namely buildings, soils and surfaces and vegetation.





Study area—Badi Choupar, Jaipur



Digitized model of Badi Choupar, Jaipur

Model Features

- Burnt brick walls
- Concrete roof
- Asphalt road
- Concrete pavements

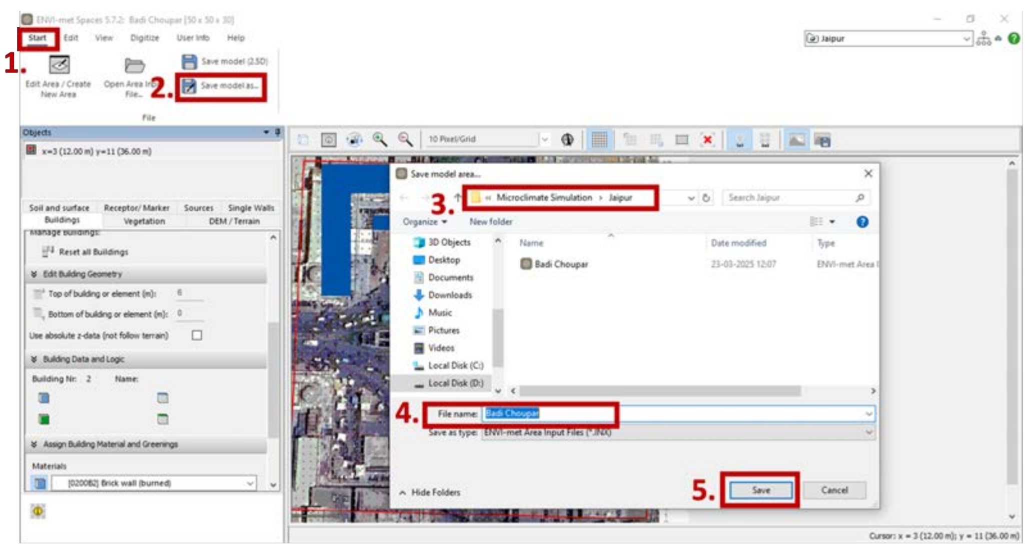
Central water tank red sandstone

Minimal greenery (hedges)

Model Dimensions	
Model Size (m)	150 x 150 x 60
Number of Grids (x-y-z)	50 x 50 x 30
Size of each grid cell (m)	3 x 3 x 2
Location	26°92′ N, 75°79′ E
North	20°

Digitized model of Badi Choupar, Jaipur

- To save the completed area file click on 'Start' on the toolbar on top then click on 'Save model as'
- Save the file in the project folder as created in the first step. For this example, the file location is- D:\Microclimate Simulation\Jaipur\Badi Choupar. 'Microclimate Simulation' is the workspace, 'Jaipur' is the project folder and 'Badi Choupar.INX' is the saved area file.

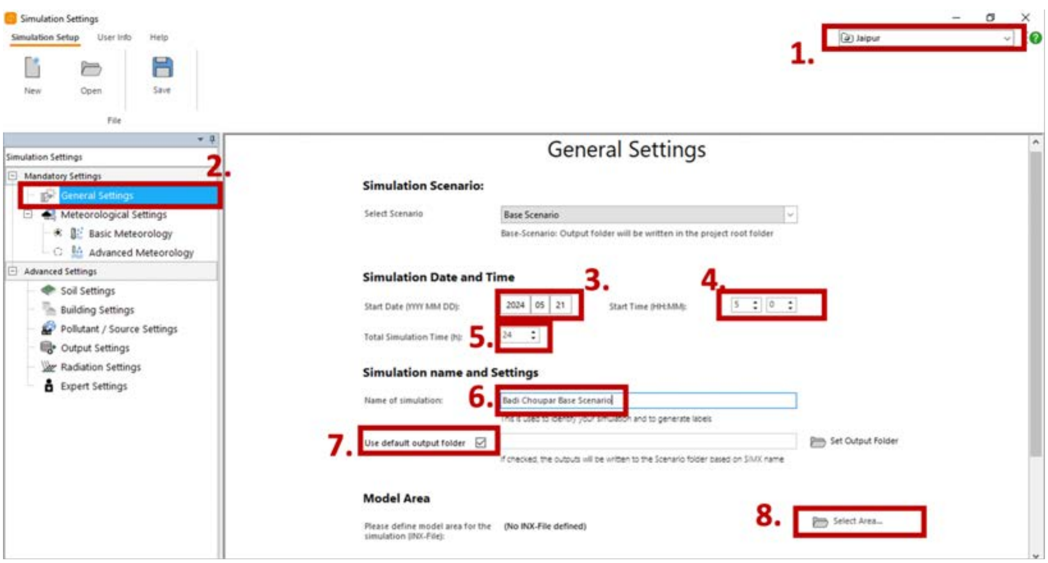


Microclimate parameters

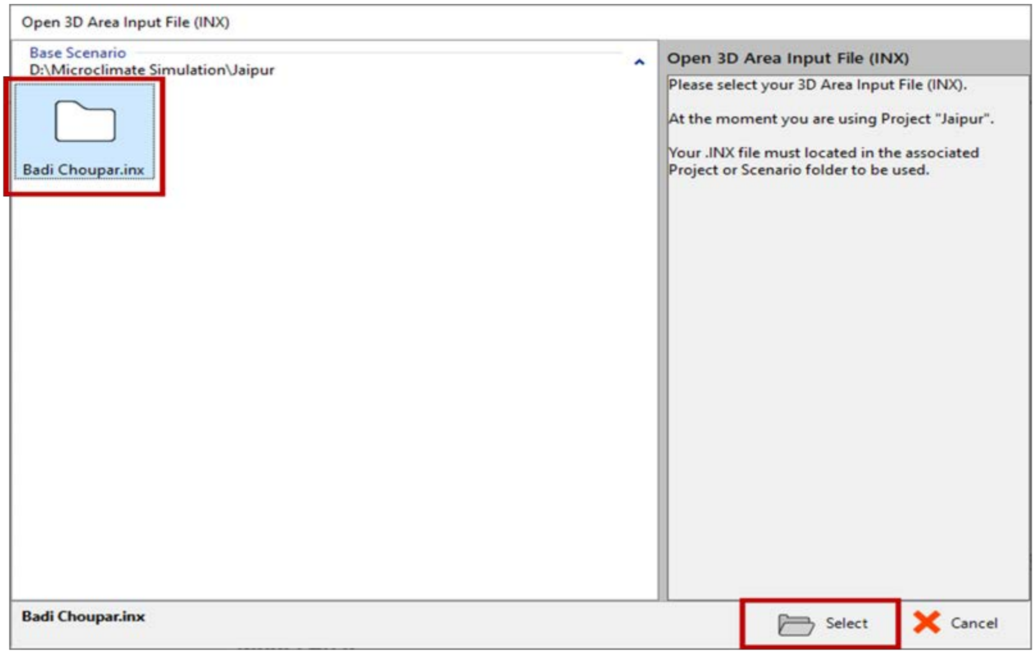
Setting initial parameters

- For setting the simulation parameter, reopen the ENVI met headquarters and click on ‘Simulation Settings’

- Select the project name (‘Jaipur’) on the tab on the top right corner.
- In the ‘Simulation Settings’ panel, click on ‘General Settings’
- Simulation Date and Time-The simulation date and time must be set based on the study requirements. For this example, the simulation was conducted for May 21, 2024, with a start time of 5 AM and a total simulation duration of 24 hours.
- Simulation name and settings—Enter the name of the simulation—‘Badi Choupar Base Scenario’
- Click the check box in front of ‘Use default output folder’
- Click on ‘Select area’ to upload area file saved.

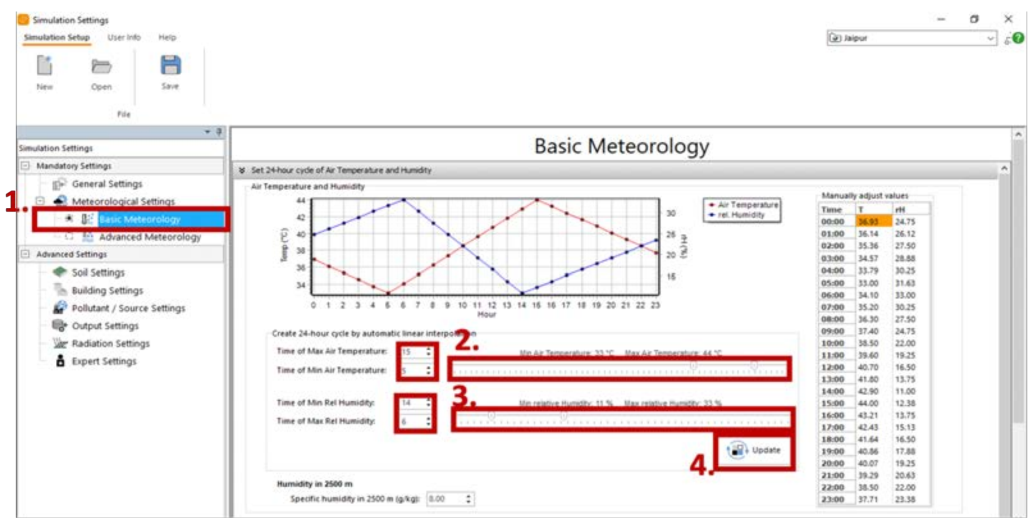


- Click on the area file ‘Badi Choupar’ in this example, appearing in the window and then click on ‘Select’

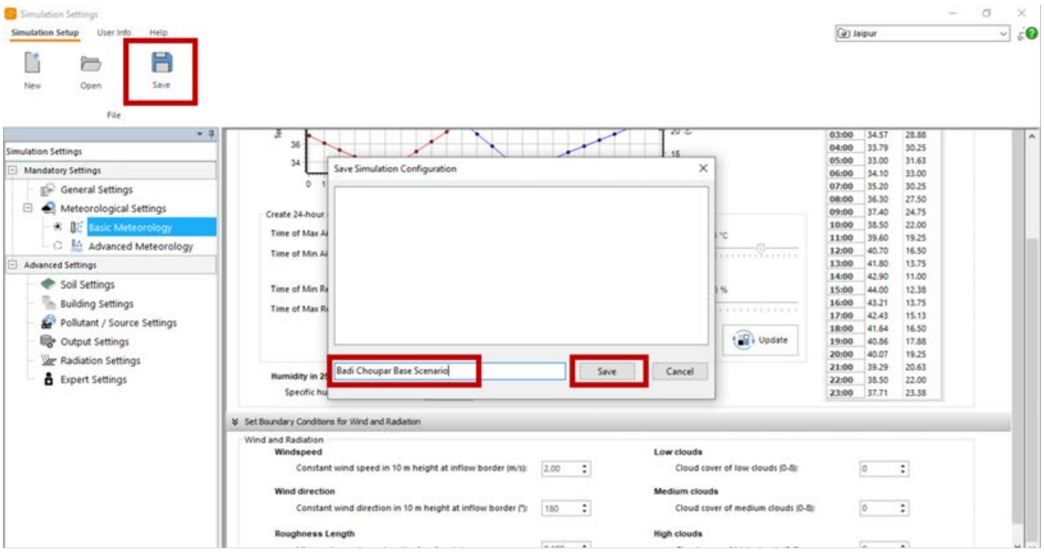


Setting weather parameters

- Click on ‘Basic Meteorology’ under ‘Meteorological Settings’ in the ‘Simulation Settings’ panel on the left.
- In the ‘Basic Meteorology’ window add the maximum and minimum temperature and relative humidity along with their respective time for the selected date of simulation.
- Click on ‘Update’

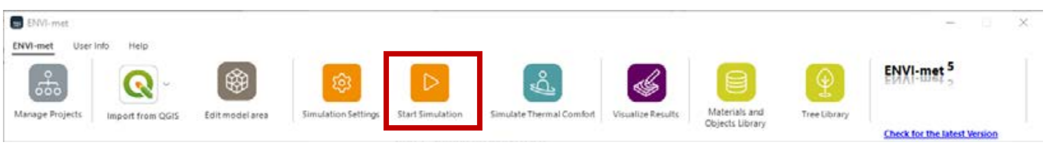


- Also add the wind speed in m/sec and wind direction in degrees for the chosen simulation date.
- Click on 'Save' under the main menu on top and enter a name for the simulation—'Badi Choupar Base Scenario' and click on 'Save'.
- The file will be saved in the project folder 'Jaipur' in the workspace 'Microclimate Simulation' as .SIMX file.

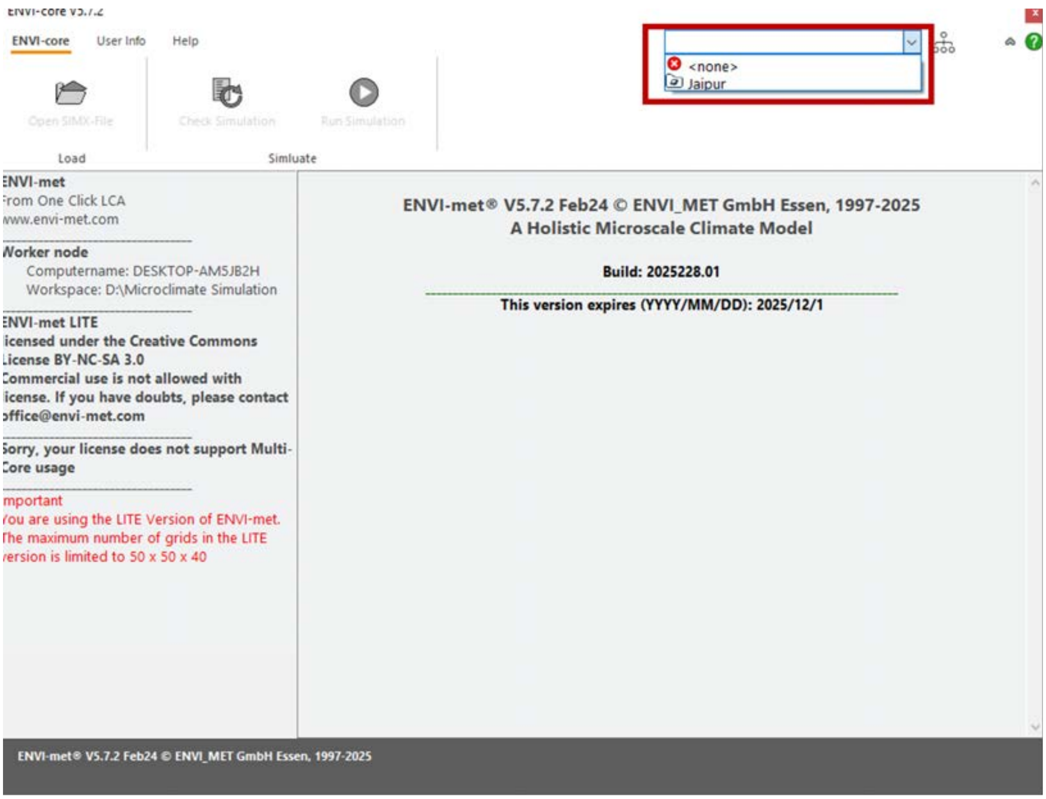


Run simulation

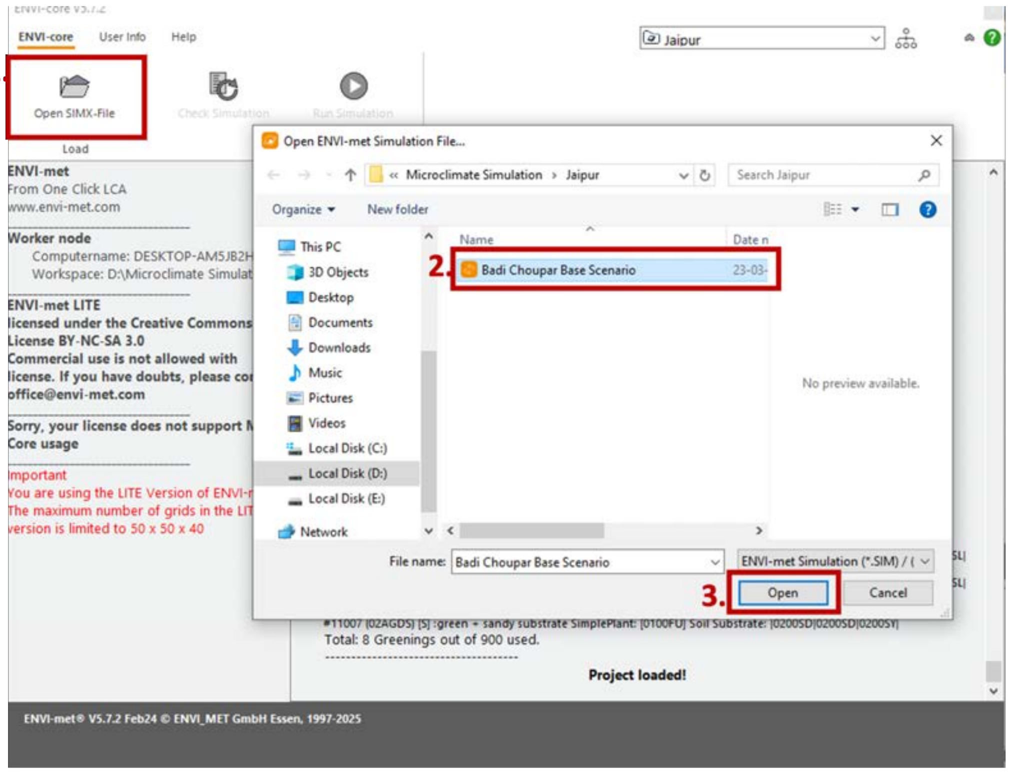
- To run simulation, reopen the ENVI met headquarters and click on 'Start Simulation'



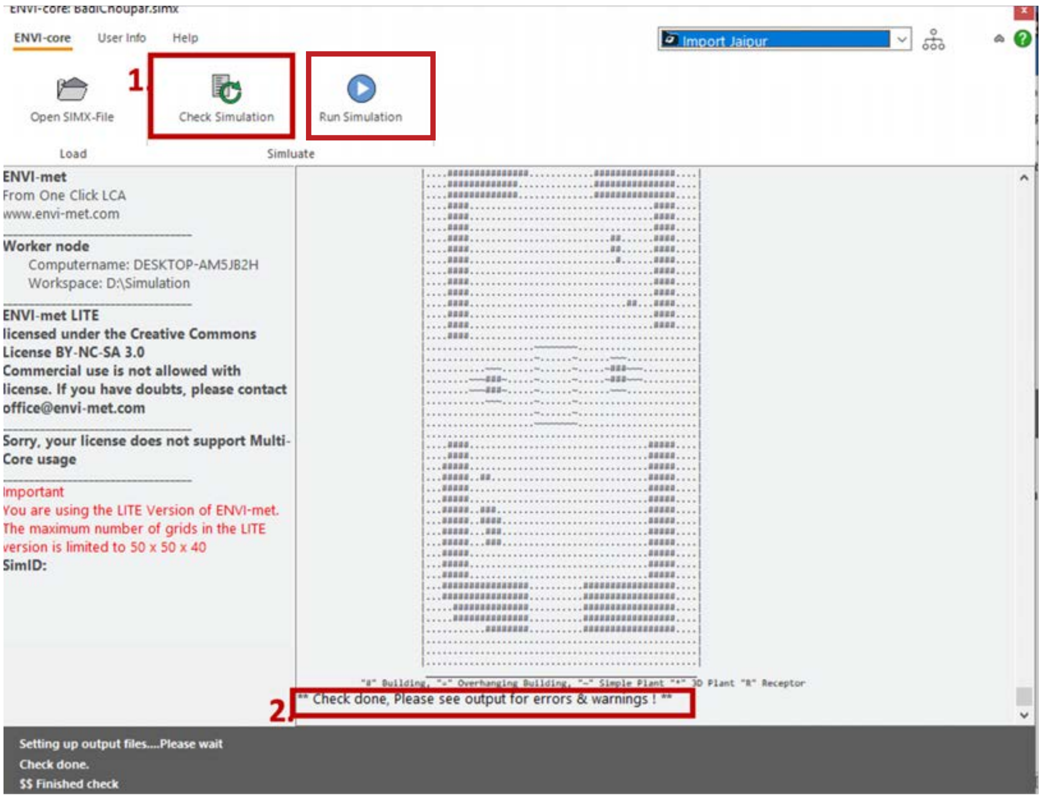
- In the top right corner of the 'Envi Core' window select the desired project—'Jaipur'



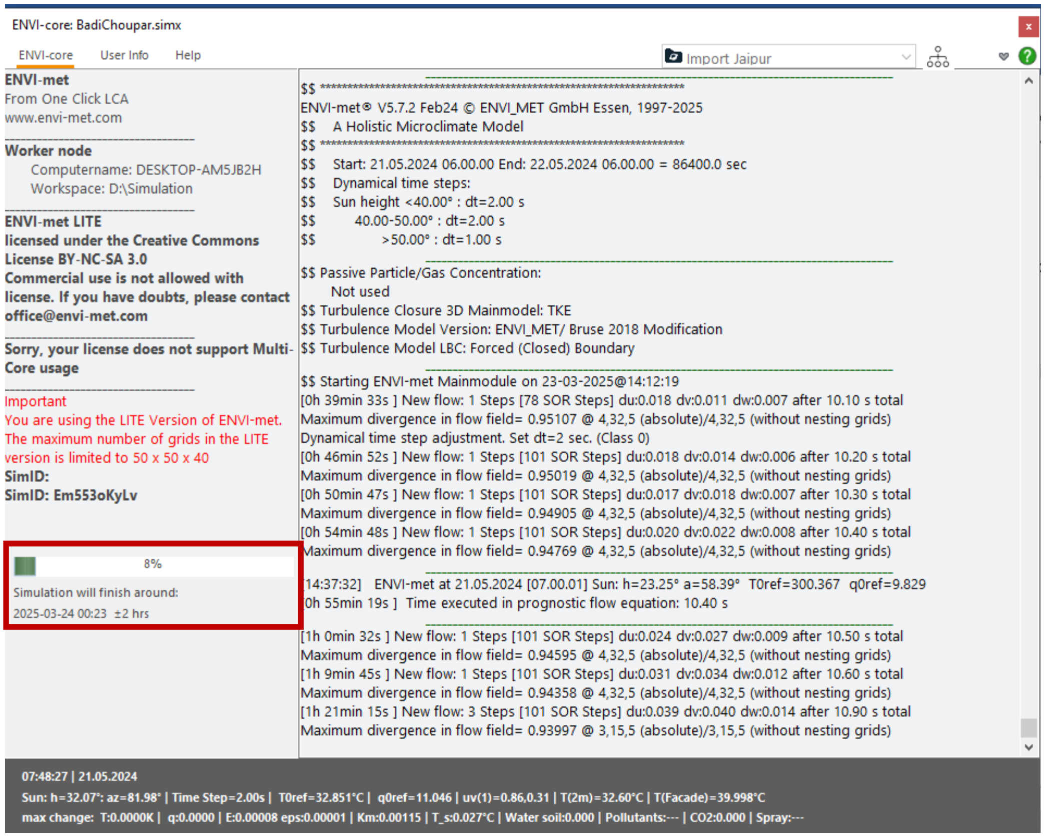
- Once the project is loaded, click on 'Open SIMX file' under the main menu on the top
- Open the .SIMX file saved earlier—'Badi Choupar Base Scenario' from the project folder 'Jaipur' saved in the workspace 'Microclimate Simulation'



- Click on 'Check simulation' under the main menu on the top.
- Click on 'Run Simulation' once the message 'Check done. Please see output for errors and warnings!' appears on the window.

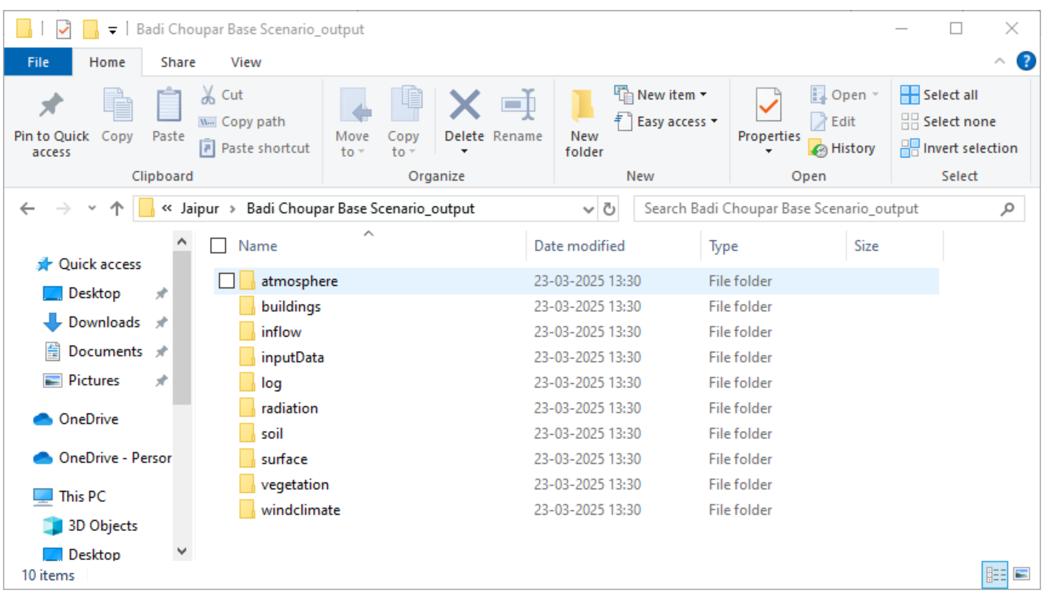


- Once the simulation is running, the progress can be monitored through the bar on the left-hand side, which displays the percentage completed and the estimated time remaining for completion.



Visualize results

- Once the simulation is complete the output is saved in the project folder 'Jaipur' within the workspace 'Microclimate Simulation'.
- The output folder, 'Badi Choupar Base Scenario' will contain subfolders



- All files in one folder are of the same structure and contain the same set of information. The following list summarizes the basic content of the folders.

1. **Input data:** *This folder contains a copy of all relevant simulation files (.INX, .SIMX,...), database files and forcing data used in the simulation.*

2. **Atmosphere:** All information about the state of the atmosphere at different times of model simulation.

3. **Buildings:** Detailed data for the facades and roofs of the buildings. Folder includes static data such as material, albedo (folder STATIC) as well as dynamic data of meteorology along the building and building physics data like temperatures and fluxes (folder DYNAMIC, not in ENVI-met LITE).

4. → **Inflow:** Data about the inflow model of ENVI-met used to represent the surroundings of the model domain that cannot be modelled in the given scale.

5. **Log:** A copy of the ENVI-met outputs generated during the model run.

6. **Pollutants:** Data about pollutant concentration in the model atmosphere (only present if pollutants are used in the model).

7. **Radiation:** Detailed data sets about the different radiation fluxes in the model.

8. → **Receptors:** Time series and profile data at defined receptor points in the model (if defined)

9. **Soil:** State of the ENVI-met soil model

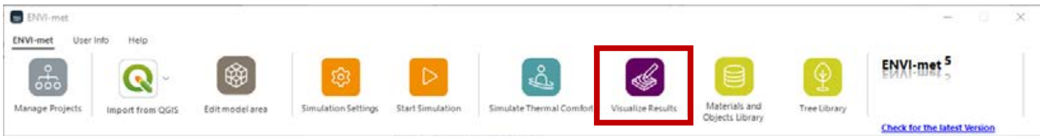
10. **Solar access:** Detailed analysis on solar access data such as solargrams, sun hours, etc (Full versions of ENVI-met only)

11. **Surface:** State of the soil surface as an interface between the atmosphere and the soil model

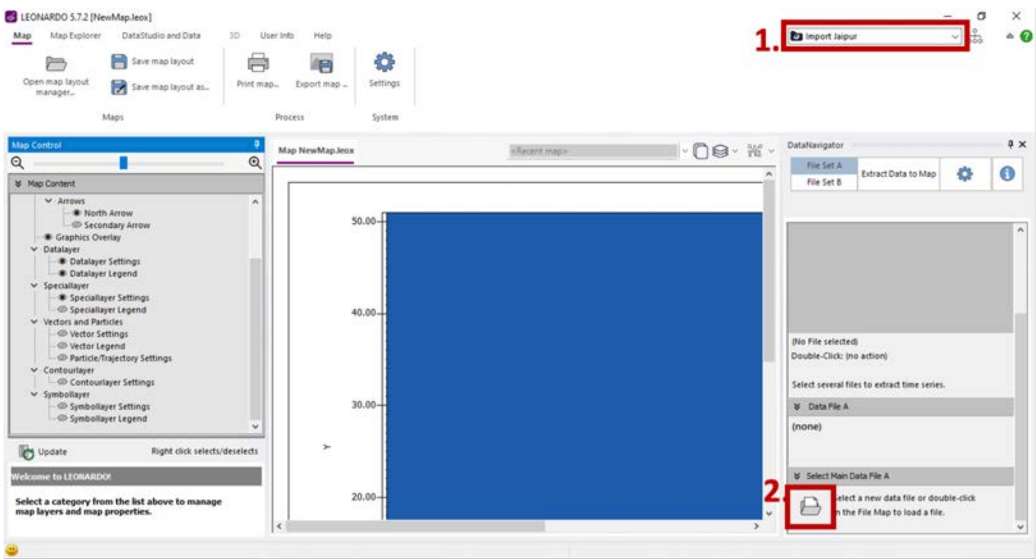
12. **Vegetation:** State of the vegetation including detailed log of observed 3D plants. Contains 3D data and text data for observed plants which are organized in a STATIC folder for constant properties and a DYNAMIC folder with time-dependent properties of the plants.

Generating temperature maps

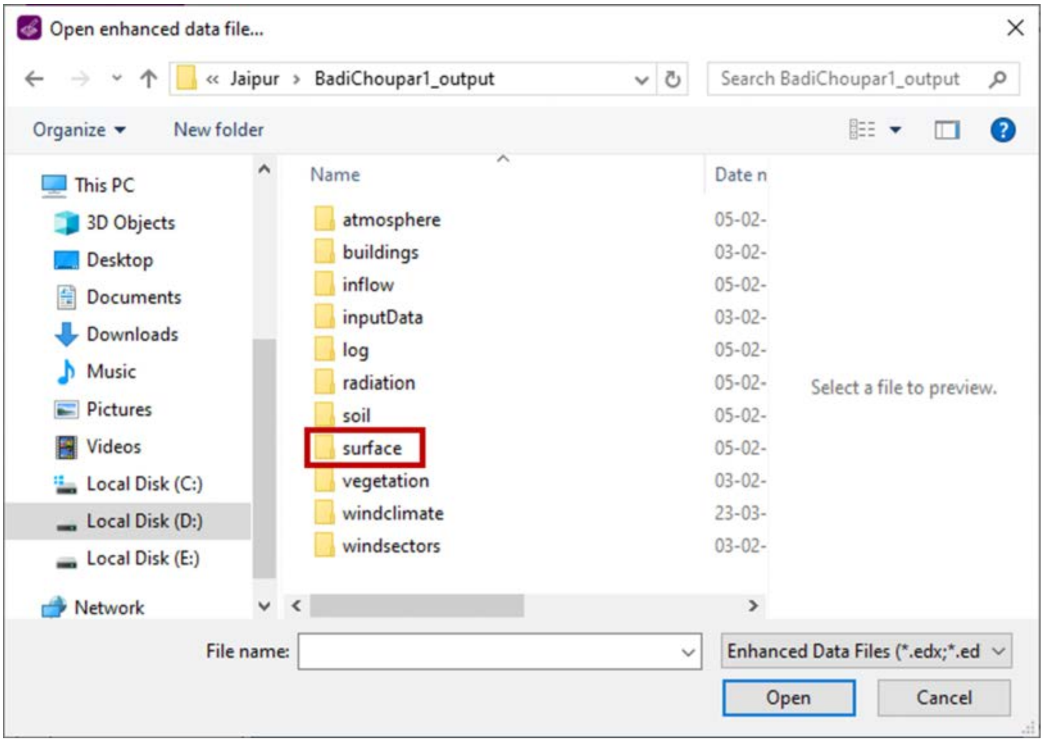
- To visualize the simulation results in the form of maps, reopen the ENVI met headquarters and click on 'Visualize Results' to open 'Leonardo' application



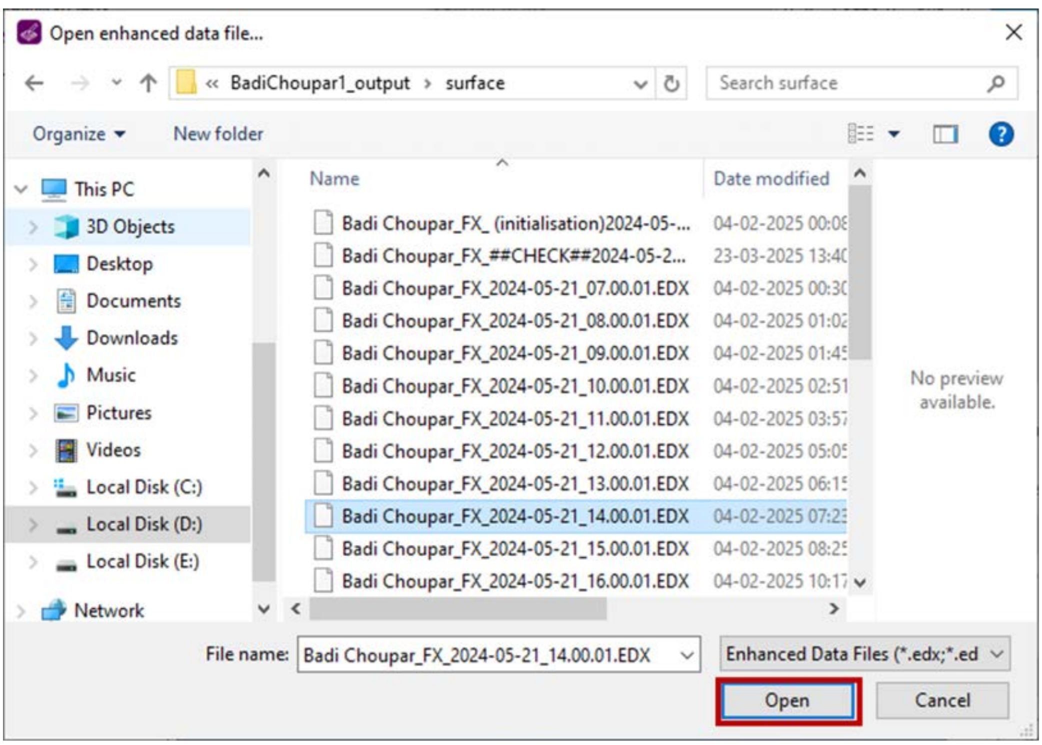
- In the Leonardo window, select project 'Jaipur' on the top right pull down menu.
- To import output files, click on 'Select Main Data File A' in the 'Data Navigation' panel on the right.



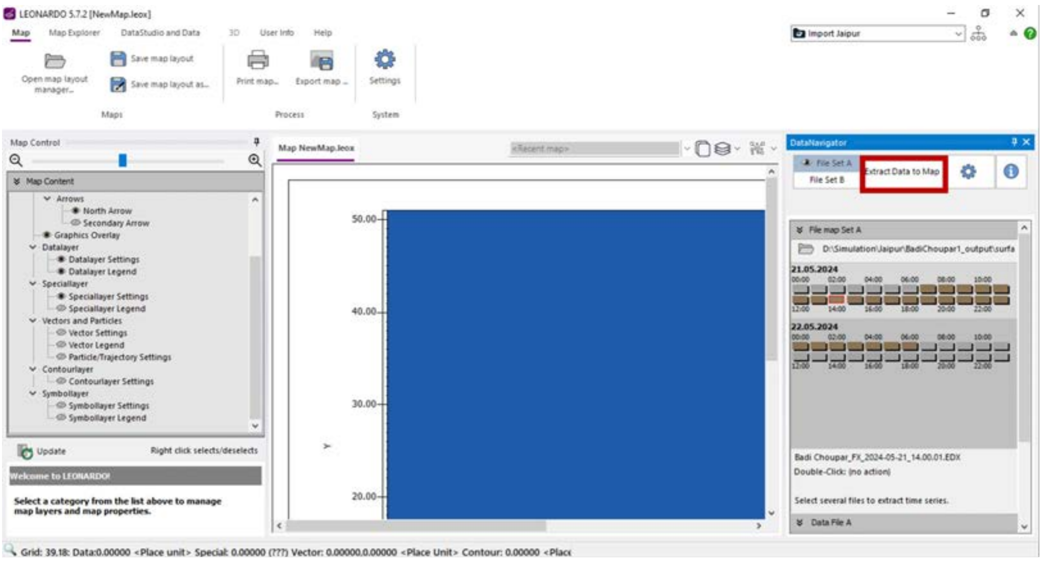
- To analyse surface temperature, select the 'surface folder' within the output folder.



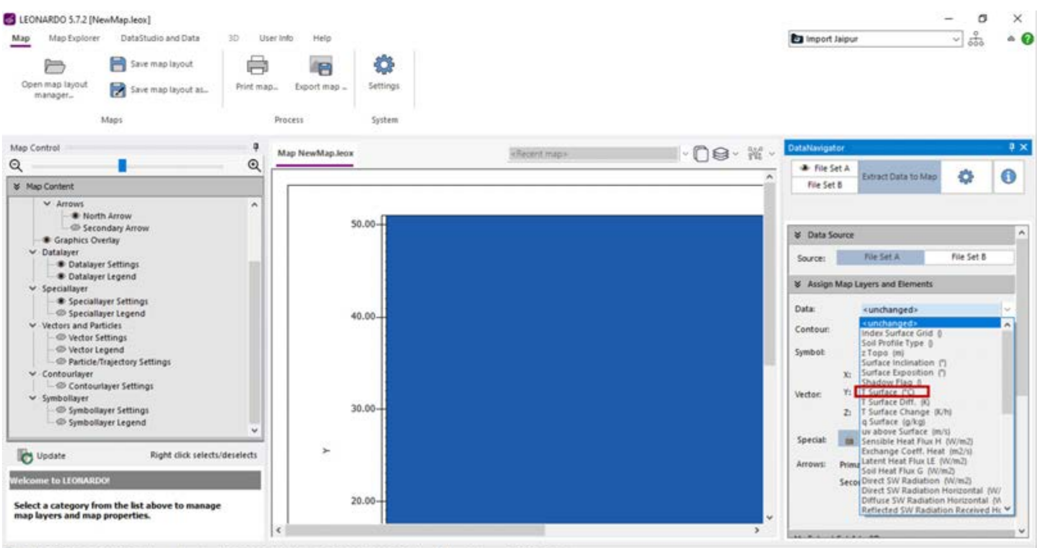
- The surface folder contains the output files for each hour of the simulation time in the form of .EDX file. Click on any one and then on 'Open'



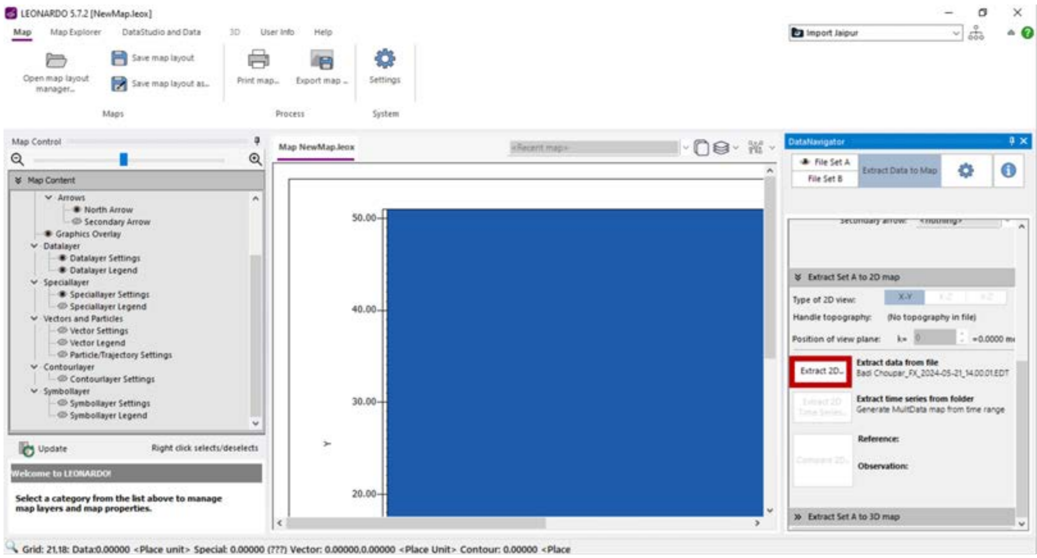
- Once the .EDX file is imported, the tabs depicting each hour of simulation are visible within the 'Data Navigation' panel.
- Select the hour for which the temperature variation needs to be studied, for example- 2 pm and click on 'Extract Data to Map' tab.



- In the 'Extract Data to Map' click on the 'data' pull down menu to select from the list of parameters to visualize.
- To visualize surface temperature, select 'T Surface' from the options.

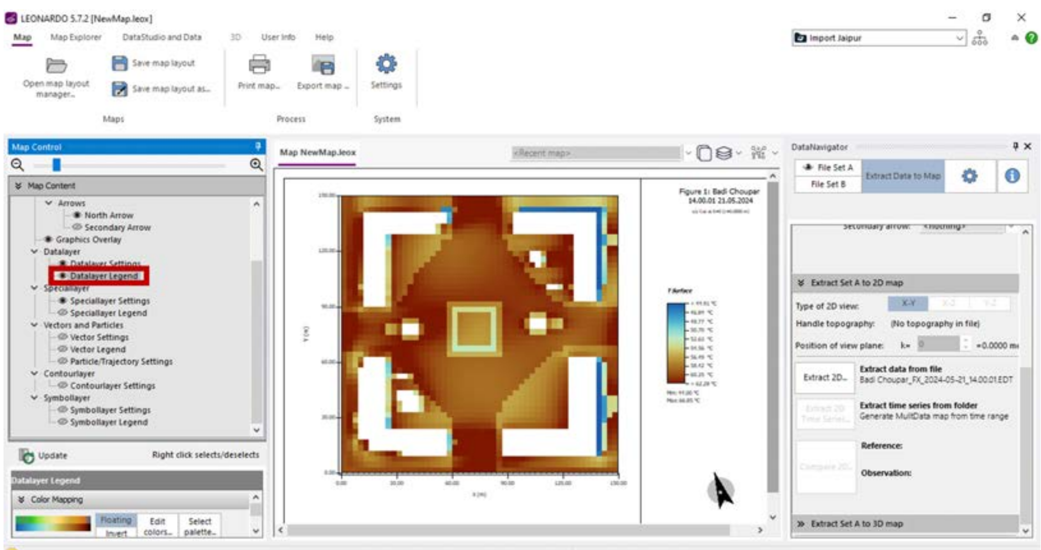


- Under ‘Extract Set A to 2D map’ click on ‘Extract 2D’

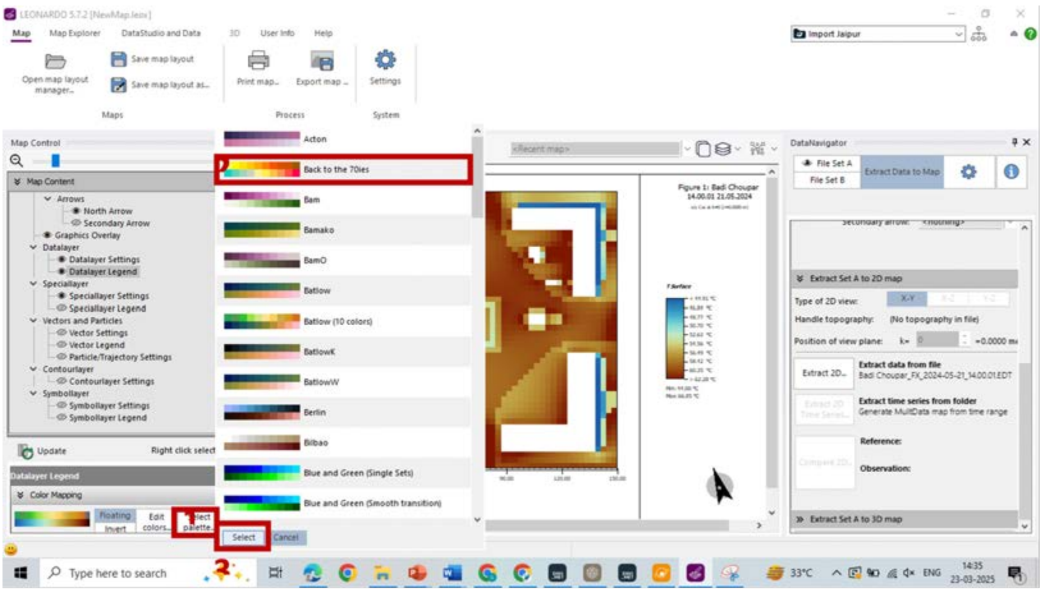


Editing maps

- To edit the map, click on ‘Datalayer Legend’ in the ‘Map Content’ panel on the left.

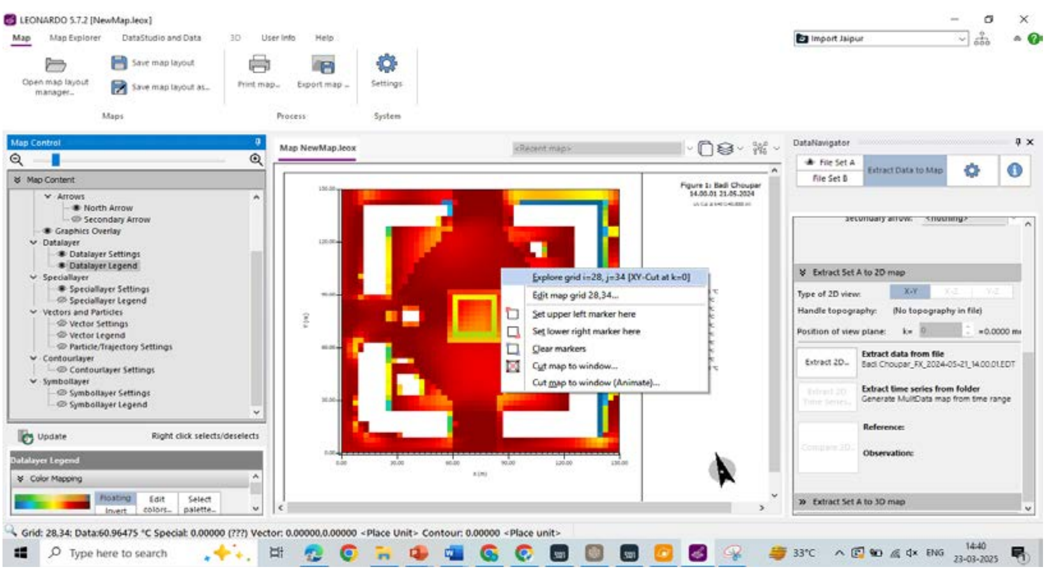


- In the 'Datalayer Legend' panel at the bottom, click on 'Select palette' and choose the desired colour scheme



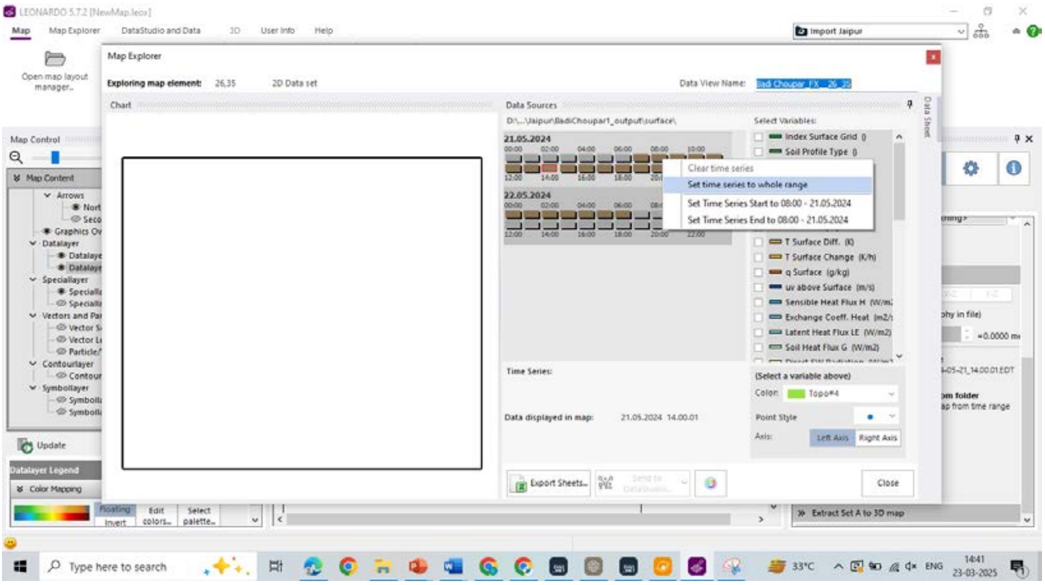
Analysis

- To analyse the temperature at a particular area of interest within the site. Right click on the cell on the map and select 'Explore grid'

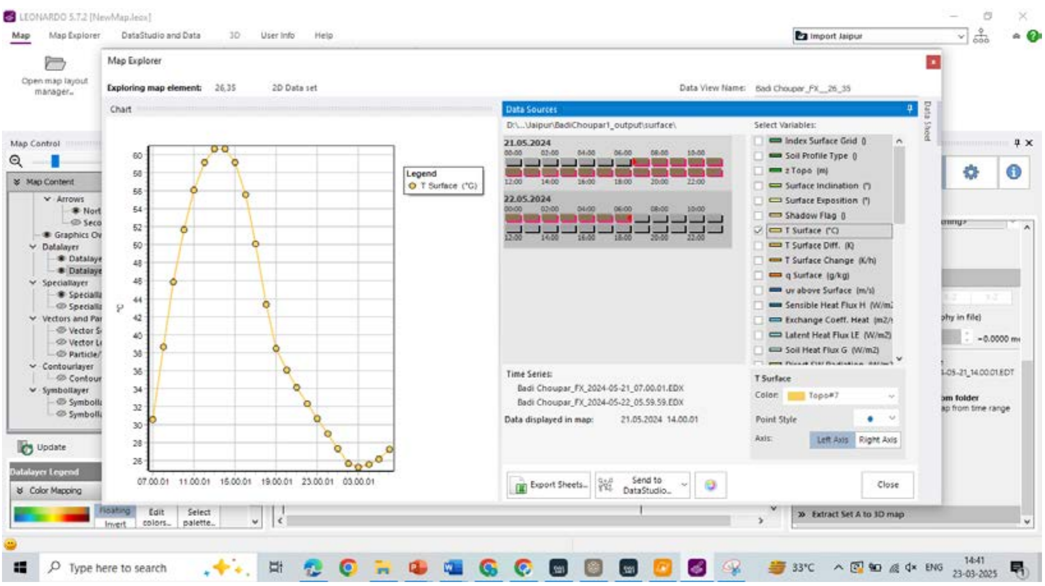


- In the map explorer, right click on one of the tabs depicting the hours of simulation and select 'Set time series to whole range'.

- From the list of variables on the right-hand side, select 'T surface' to visualize the variation of surface temperature for the selected cell through the simulation time of 24 hours for the selected date of 21 May, 2024.



- Click on 'Export Sheets' to export the result for the selected grid cell to excel sheet.



4. Results

Surface and ambient temperature reductions from different interventions

Shading

In the base scenario, surface temperatures of materials such as concrete, granite, sandstone, and dark asphalt ranged between 57–63°C during peak heat hours. The introduction of targeted interventions resulted in significant reductions across these temperatures.

Trees reduced surface temperatures by 6–15°C, with canopy density being the decisive factor. Dense-canopy trees achieved reductions of 9–15°C, while sparser canopies lowered temperatures by 6–9°C.

Trees enhance the microclimate by providing shade. The amount of surface temperature reduction depends on the density and spread of the canopy.

Given the time required for trees to mature, the simulation also evaluated lightweight polyvinyl chloride (PVC) canopies, which reduced surface temperatures by 15–22°C.

Lightweight canopies also bring down surface temperatures by providing shade

These results were obtained by simulating PVC canopies and trees. In practice, however, shading can be achieved through a variety of approaches, including tensile structures using fabrics stretched over steel or cable-supported frames. Wooden frames or trellises covered with climbing vegetation can also be introduced, providing both shade and additional greening.

SUGEET GROVER

Wooden trellis at Anil Agarwal Environment Training Institute, Neemli, Rajasthan

In heritage zones, collapsible or movable canopies—such as retractable frames or inverted umbrella structures—can be deployed to provide shading during peak hours while preserving unobstructed views of the streetscape at other times. Solar panels can also be strategically positioned as shading devices in spaces such as parking areas, combining thermal comfort with renewable energy generation.

Retractable umbrella canopies (left); solar panels used as shading devices (right)

Sources: Omar A. 2010. 'Looking northwest from north side of Al-Masjid al-Nabawi', Flickr. Available at https://www.flickr.com/photos/oansari/4454894880, as accessed on 20 April 2026

Wikimedia Commons 2020. 'File: Solar-Car-Park-PV-Structures.jpg'. Available at https://commons.wikimedia.org/wiki/File:Solar-Car-Park-PV-Structures.jpg, as accessed on 20 April 2026

Changing surface reflectance

The second set of interventions targeted hardscape reflectance. Surfaces prone to heat absorption and retention were replaced with high-reflectance pavers, resulting in reductions in surface temperature of 5–12°C.

Replacing hardscape surfaces with vegetation

The third approach involved replacing hard surfaces with vegetation, including shrubs and grass. Areas away from pathways covered with shrubs were found to be 2.5–5°C cooler than adjacent hardscape, while grass-covered surfaces were approximately 3°C cooler than heat-absorbing materials such as concrete and granite. Together, the combined effect of vegetation and nearby water bodies contributed to an overall reduction of 2–3°C in ambient air temperature.

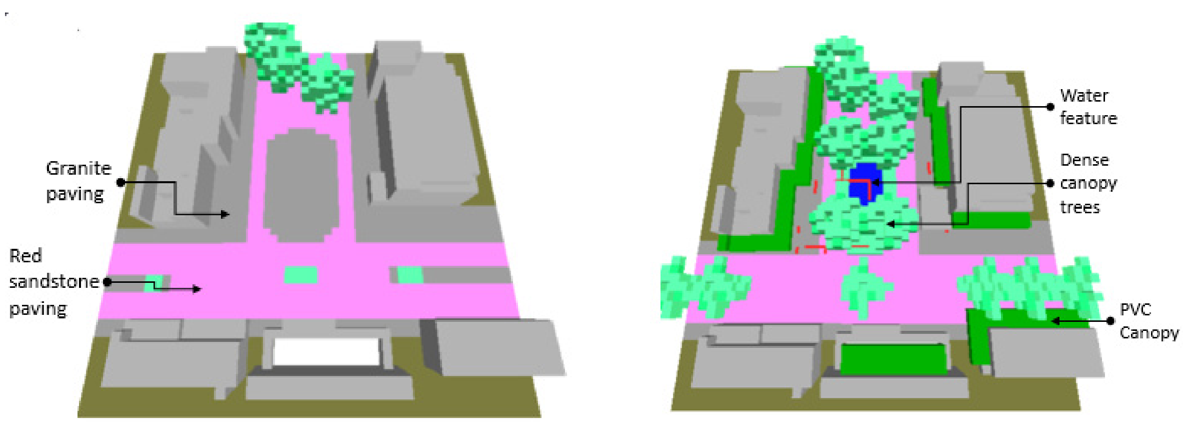
The results also highlight the potential of combining interventions. When strategies were layered—through clusters of canopy trees, or the combined effect of trees and lightweight canopies—the thermal benefits were amplified. Pairing tree

Table 3: Surface temperature (°C) reductions from Intervention

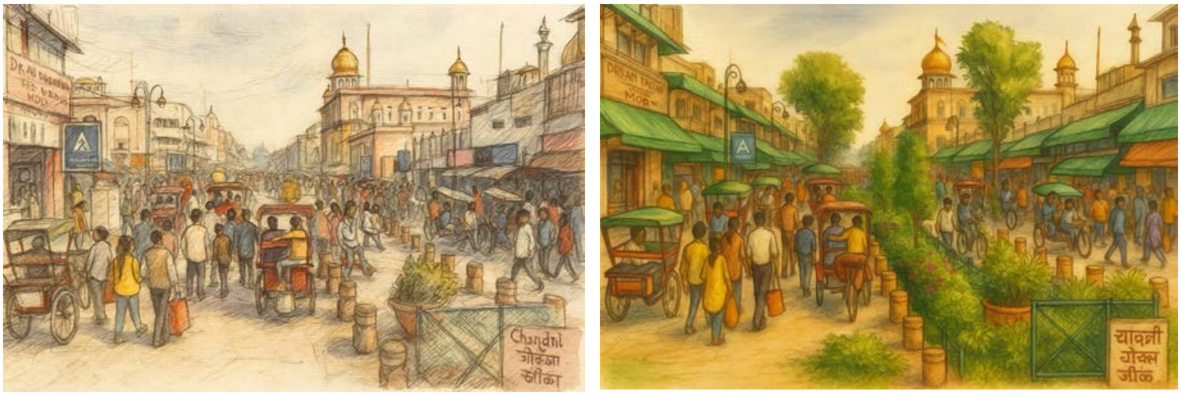
Interventions	Delhi			Jaipur		Mysuru		Pune		Leh	
	Chandni Chowk	Lajpat Nagar	Connaught Place	Badi Choupad	Chandpole Metro Station	KR Circle	Mysore Bus Stand	Magarpatta City	Tulsi Baug Market	Leh Bus/Taxi Stand	Parking in Commercial area
Light weight shading	15-21	12-18	15-21	9-13		13-18	9-12	20-22	18-20	16-20	18-20
Shrub			2.5-3		3-4		4-5		4-5		
Grass	1-2				1-3				1-2		
Dense canopy trees	9-13	10-15	9-14	10-15	9-12		9-11	11-15	9-12		
Sparse canopy tree		6-8				4.5-6	5-8	7-9	5-7		5-8
Reflective material		5-9		9-12	7-9	7-8					

Source: CSE

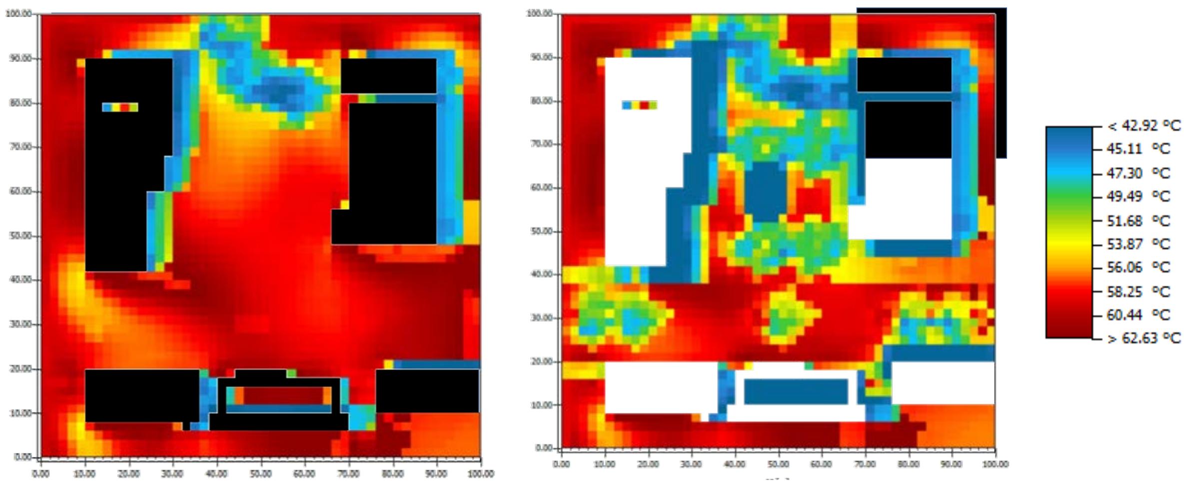
shade with reflective paving proved particularly effective, delivering temperature reductions of up to 15°C compared to single-intervention approaches.



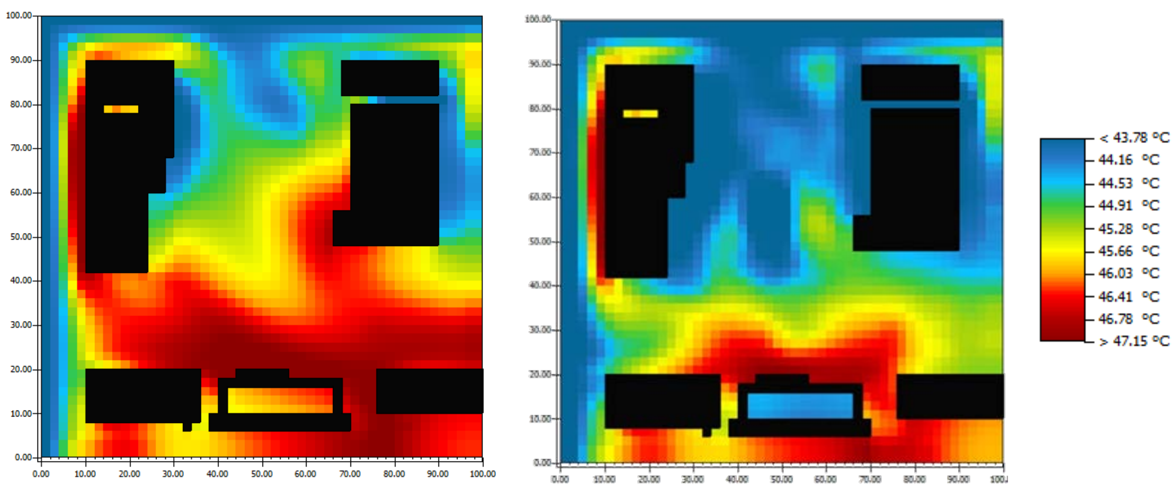
Base scenario (left) vs intervention scenario (right) for Chandni Chowk, New Delhi



View of base scenario (left) vs intervention scenario (right) for Chandni Chowk, New Delhi



Surface temperature distribution across study area, base (left) vs intervention scenario (right) in Chandni Chowk, Delhi



Air temperature distribution across study area, base (left) vs intervention scenario (right) in Chandni Chowk, Delhi

5. The way forward

This study demonstrates that improving outdoor thermal comfort in Indian cities is both necessary and achievable through targeted, site-specific interventions. As extreme heat intensifies, the usability, safety, and inclusivity of public spaces will depend increasingly on how well they perform under high-temperature conditions. The findings clearly show that relatively modest, well-designed changes—such as shading, surface material modification, and the integration of blue–green infrastructure—can yield substantial reductions in surface and ambient temperatures, significantly improving on-ground thermal comfort.

The study also underscores the value of simulation-based approaches in urban design. By enabling planners to test interventions before implementation, tools such as ENVI-met make it possible to quantify impacts, reduce uncertainty, and prioritise investments that deliver measurable outcomes. Embedding such tools within planning and design processes can foster evidence-based decision-making, ensuring that public investments translate into tangible thermal comfort gains. A key insight from the analysis is the importance of tailoring interventions to the specific spatial, functional, and climatic context of each site—what works in a dense historic market may differ considerably from what is effective in a transit hub or open plaza. This reinforces the need to move away from generic design solutions towards context-responsive, evidence-driven planning.

Identify and map urban heat hotspots

Cities should undertake systematic spatial assessments to identify areas experiencing recurrent and sustained heat stress. This can be achieved through satellite-derived land surface temperature data combined with on-ground observations of built form, materials, and activity patterns. Mapping heat hotspots enables cities to prioritise interventions in areas where thermal risks are most acute.

Integrate thermal comfort into urban design

Urban design must move beyond aesthetics and functionality to systematically account for heat exposure and thermal comfort. Planning guidelines, street design standards, and public space redevelopment projects should incorporate heat mitigation as a core performance criterion. Embedding these considerations early in the planning process ensures that both new developments and retrofits are responsive to local climatic conditions and support genuinely usable outdoor environments.

Prioritize high-exposure and vulnerable populations

Interventions should be targeted at spaces with high pedestrian activity, particularly those frequented by vulnerable groups—such as informal workers, street vendors, delivery personnel and daily commuters—who face sustained heat exposure. Prioritizing such spaces can maximise the impact of investments by improving health, productivity and overall livability for those most at risk.

Adopt context-specific mitigation strategies

Heat mitigation measures must be tailored to the specific characteristics of each site, including climatic conditions, urban form, and patterns of use. While this report outlines a range of potential strategies, their effectiveness depends on careful selection and contextual adaptation. A combination of interventions—such as shading, greening and surface material modifications—should be applied on the basis of local feasibility and need, rather than a one-size-fits-all approach.

Implement evidence-based approaches

Cities should make greater use of simulation tools to evaluate the effectiveness of proposed interventions before implementation. An evidence-based approach will help ensure that interventions deliver measurable and lasting improvements in outdoor thermal comfort.

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Extreme heat reshapes the livability of Indian cities. The spaces where people walk, work, wait and gather are becoming increasingly hostile, and the burden falls hardest on those with nowhere else to go.

Reclaiming Heat-Resilient Cities is a rigorous, evidence-based toolkit that uses ENVI-met microclimate simulation to test and quantify targeted interventions—from canopy trees and lightweight shading to reflective pavements and blue-green infrastructure—across ten study sites in Delhi, Jaipur, Mysuru, Pune and Leh. Drawing on spatial heat-stress analysis, on-ground site assessments and comparative scenario modelling, the report demonstrates that well-chosen, context-specific retrofits can reduce surface temperatures by up to 22°C and meaningfully lower ambient air temperatures—transforming unsafe outdoor spaces into thermally comfortable, equitable public realms.

A practical guide for urban planners, designers and policymakers, this report makes the case that heat resilience is not a luxury but a prerequisite for just and liveable cities.

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