MITIGATING URBAN HEAT ISLAND EFFECT THROUGH, SUSTAINABLE PLANNING :STRATEGIES FOR RESILIENT CITIES

A Thesis Submitted

in Partial Fulfilment of the Requirements

for the Degree of

MASTER OF PLANNING

by

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Under the Supervision of

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I, MISS.ANSHIKA MEHROTRA , the author of the thesis titled “MITIGATING URBAN HEAT ISLND EFFECT THROUGH SUSTAINABLE PLANNING AND STRATEGIES FOR RESILIENT CITIES”,
hereby declare that this is an independent work of mine, carried out towards fulfilment of the requirements for the award of the Masters in Planning at the Department of Architecture and Planning, BBDU, Lucknow. The work has not been submitted to any other organization / institution for the award of any Degree.

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EXECUTIVE SUMMARY

The built environment is highly vulnerable to the impacts of climate change, with heat waves becoming more frequent and severe. The effects of global warming are intensified in urban areas, where the Urban Heat Island (UHI) phenomenon occurs. The UHI phenomenon is defined as the difference in temperature between the rural environment and inner cities, which is caused by the replacement of the natural landscape with impermeable and man-made surfaces such as concrete, asphalt, and buildings that trap and retain heat. It significantly impacts heat stress, electricity consumption, cooling load, and air pollution.

Although awareness and ambitions to mitigate UHI are strong globally, actions palpably do not match these intentions. Among others, two main reasons for this imbalance stand out: (1) the absence of effective tools needed for developing mitigation strategies, and (2) the lack of insights into different types of UHI and their relationship to mitigation strategies.

The effectiveness of UHI mitigation strategies depends on the ability of decision-makers to assess the impact of their decisions. However, current UHI assessment tools have limitations related to modeling philosophy, modeling scope, and modeling resolution, which can hinder their applicability and accessibility to urban planners. While complex simulation-based models can provide more accurate predictions, they also require extensive data and computational resources. Furthermore, existing UHI modeling tools often require a high level of technical expertise, which can make them less practical for urban planners. Generic UHI mitigation strategies may not be effective due to the specificity of each city's morphology and socioeconomic characteristics, and the interplay between these factors can result in different UHI intensities across a city. Thus, the development of more practical and accessible UHI assessment tools that consider the interplay of multiple factors at a street-level resolution is essential for effective UHI mitigation strategies.

UHI is classified into four types: Surface UHI (SUHI), Canopy UHI (CUHI), Boundary UHI (UHIUBL), and Subsurface UHI (UHISub), each with a unique mix of processes and necessitating distinct monitoring approaches to understand

and mitigate it. However, CUHI and SUHI have the greatest impact on urban temperatures and human health at a micro-scale, making them the focus of this research. SUHI is measured using land surface temperature (LST) data obtained from thermal infrared (TIR) satellite imagery, while CUHI is measured using weather stations with high temporal resolution but limited spatial resolution. The interplay between SUHI and CUHI can either amplify or mitigate the effects of UHI as a whole. Effective UHI mitigation strategies require a deep understanding of how urban design decisions affect both types of UHI, but literature examining their combined effect is limited due to inconsistent data. Therefore, there is a clear need for a more in-depth analysis of the interplay between different types of UHI and mitigation strategies using more consistent data.

Data-driven methods are increasingly used to solve complex problems, including in the study of UHI. These methods can compensate for the complexity of physics-based modeling by identifying patterns in data, which can provide more user-friendly tools for analysis. However, comprehensive datasets are necessary for these methods to be effective. UHI research faces challenges due to limited, fragmented, and varying spatiotemporal resolution datasets, as well as the need to distinguish between different types of UHI. Current UHI mitigation strategies are often based on a one-size-fits-all approach, but recent research has shown that UHI mechanisms can vary depending on the urban context. To develop effective mitigation strategies, a user-friendly UHI simulation tool is essential to capture and reflect this dynamism.

Based on the above, this thesis revolves around the central questions of how a user-friendly UHI simulation tool can be developed based on data-driven methods and how this tool can be used to generate insights into the dynamic nature of the UHI driving mechanism vis-à-vis (1) decision making jurisdiction (urban morphology, socio-economic factors) and (2) different types of UHI. To answer these questions, this research aims to develop an insight into the context-specificity of the interplay between UHI and urban planning decision parameters using data-driven methods. This objective is decomposed into five sub-objectives, each addressed in one chapter of this thesis:

1. to develop a user-friendly urban data collection pipeline, which can be used by urban planners to investigate the impact of their design choices on UHI at the street level;
2. to develop a user-friendly tool for the assessment of the impact of urban planning decisions on UHI at the street level;
3. to investigate the spatiotemporal patterns of CUHI/SUHI and their interplay with a wide range of street level urban planning and socio-economic parameters;
4. to perform a comprehensive generalizability assessment (how far can we go) of data-driven UHI models considering the degrees of similarity between the training and testing datasets;
5. to investigate whether and how CUHI/SUHI is influenced by various street level urban planning parameters when considering different groups of streets as opposed to individual streets.

The research was conducted in four phases to explore the relationship between UHI and urban planning parameters. In the first phase, publicly available urban data were collected to develop a data-driven methodology to explain UHI at a street level. In the second phase, a mobile data collection unit was developed to collect micro-level data on the impact of socio-economic and urban morphological parameters on UHI. The third phase examined the generalizability of the data-driven models developed in the first two phases by assessing their accuracy in five different cities. The fourth phase explored the effectiveness of a disaggregated modeling approach to understand UHI at a street-level. This approach was based on street-level typologies and aimed to provide a more accurate and context-specific understanding of the UHI phenomena.

All in all, the outcomes of this research provide valuable insights into the complex phenomenon of UHI at the street-level and the potential use of data-driven methodologies to support urban planning and the design of heat-resilient strategies. Further, they show that investigating both CUHI and SUHI concurrently, as well as considering the time of day and the socio-economic and morphological features of urban streets, is critical to understanding and addressing UHI. While data-driven UHI models may be accurate for the cities for which they are trained, their generalizability is limited, thereby emphasizing the importance of tailor-made mitigation strategies. The context-specific nature of the phenomenon highlights the singularities of each city, in the sense that what drives the UHI phenomenon in one city is not necessarily the same in another city due to the intrinsic differences in urban morphology and socio- economic parameters of each built environment. Moreover, while general principles and best practices for UHI mitigation exist, it is essential to recognize that the most effective strategies are context-specific and require careful consideration of the unique conditions of each environment at the street-level. Therefore, street-level typologies can provide a more accurate and local-specific understanding of the phenomenon. This research provides a solid foundation for future studies to build upon and offers practical tools to bring data-driven knowledge to the urban planning design table. By doing so, it paves the way for the design of more heat-resilient built environments.

1. INTRODUCTION

Firstly, the background of the Urban Heat Island (UHI) phenomenon and problems related to it will be discussed. Secondly, past efforts to establish models and tools to predict the heat island intensities of urban areas will be discussed. These are categorized in numerical models and empirical models. The Local Climate Zone (LCZ) classification will be briefly discussed as a means to guide heat island studies. Subsequently, the aim of this research will be discussed. This introductory chapter will be concluded with the methodology.

1.1 RESEARCH BACKGROUND

The global average temperature has risen by 1.1 °C compared to pre-industrial levels due to the rapid progression of climate change (Masson-Delmotte et al., 2021). This trend is expected to continue, leading to more frequent and intense heat waves as one of its major impacts (Ranasinghe et al., 2021). Urban areas, where currently nearly 56 out of 100 people live (United Nations, 2019), are particularly vulnerable to heatwaves due to the Urban Heat Island (UHI) effect. The UHI is a phenomenon where urban areas are hotter than rural areas due to the absorption and re-radiation of heat by buildings, pavements, and other urban infrastructure (Oke, 1982). The UHI effect exacerbates the impacts of heatwaves in urban areas (Wamsler et al., 2013, Bednar-Friedl et al., 2022), leading to health problems (Piracha and Chaudhary, 2022, Shahmohamadi et al., 2011, Tan et al., 2010), increased energy demand (Shahmohamadi et al., 2010, Li et al., 2019), and economic losses (Mills, 2005).
Luke Howard was the first to introduce the concept of the urban heat island (UHI) in his 1833 book, “The Climate of London”. One hundred and ninety years later, the UHI phenomenon is well-understood and features prominently in discussions about heat- resilient cities and climate change.

The physical characteristics of urban materials significantly contribute to this phenomenon. Materials like concrete, asphalt, and other construction elements differ in thermal properties from natural surfaces. Such urban materials have higher heat capacities and conductivities, enabling them to absorb and store more heat during the day (Akbari et al., 2009). Conversely, natural surfaces, such as soil and vegetation, usually have lower albedo. This means they can reflect a significant portion of solar radiation, reducing heat absorption. Urban materials on the other hand have higher albedos, which leads them to absorb more solar energy (Taha, 1997).

The “canyon effect” exacerbates this situation in urban areas (Santamouris, 2005). This arises from the dense clustering of buildings, especially high-rises, which trap heat between them and restrict its dispersion. As a result, heat is continuously reflected between structures during the night, resulting in a slower cooling rate compared to that in open, rural settings.

Furthermore, human activities in cities intensify the UHI effect. Processes like traffic, industrial operations, air conditioning, and even human metabolism release heat, further elevating temperatures (Kleerekoper et al., 2012). This anthropogenic heat, when coupled with natural absorption and radiation processes, intensity the UHI phenomenon.

Vegetation also plays a pivotal role in temperature regulation. In natural landscapes, plants and trees not only offer shade but participate in transpiration, a process where water vapor is released into the air, inducing cooling (Gill et al., 2007). Urban regions, however, often lack green spaces, depriving them of this natural cooling effect. Furthermore, coupled dense clustering of buildings vegetation can increase humidity and heat entrapment, worsening the situation.

In response to the challenges posed by UHI, countries globally are devising mitigation strategies to safeguard their citizens from the adverse effects of heatwav 1 Taking the Netherlands as an example, the country, given its low-lying terrain, is highly susceptible to the repercussions of climate change, such as rising sea levels. While the Netherlands has a rich tradition of water management, attention to extreme heat has only gained prominence recently (Pot et al., 2022, Özerol et al., 2020). The increasing frequency and severity of heatwaves in recent years have prompted the Dutch government to initiate the National Heat Plan (RIVM, 2019), offering guidelines to cope with extreme heat events.

1.2 PROBLEM SOLVING

Urbanization has led to a significant increase in impervious surfaces such as roads, buildings, and concrete structures, which absorb and retain heat. This phenomenon, known as the Urban Heat Island (UHI) effect, causes urban areas to become significantly warmer than their rural surroundings. The elevated temperatures have adverse effects, including:

- Increased energy consumption (especially for cooling),
- Higher greenhouse gas emissions,
- Elevated air pollution and health risks,
- Thermal discomfort for urban residents, especially vulnerable populations.

Despite growing awareness, many cities lack integrated sustainable planning strategies to address UHI holistically and equitably.

1.3 NEED OF THE STUDY

- ❖ **Climate Change Context:** With global warming intensifying, urban areas are at higher risk due to the UHI effect.
- ❖ **Public Health Implications:** Rising urban temperatures contribute to heat stress, respiratory illnesses, and mortality.
- ❖ **Energy Demands:** UHI leads to increased demand for air conditioning, straining energy systems and increasing carbon footprints.
- ❖ **Urban Inequities:** Disadvantaged communities often bear the brunt of UHI impacts due to lack of green spaces and poor housing.
- ❖ **Lack of Integrated Strategies:** Current planning approaches often address UHI in a fragmented way without a systems-based or resilient planning framework.

1.4 RESEARCH GAPS

1. Insufficient Integration of UHI Mitigation in Urban Planning Policies
    - Most cities address UHI through isolated environmental or architectural interventions, rather than embedding UHI mitigation into comprehensive land use planning, zoning, and urban design codes.

2. Limited Context-Specific Studies
    - Many existing studies are generalized or based on developed countries with different climates, urban forms, and socioeconomic conditions. There is a lack of region-specific or city-specific research, especially in developing nations.

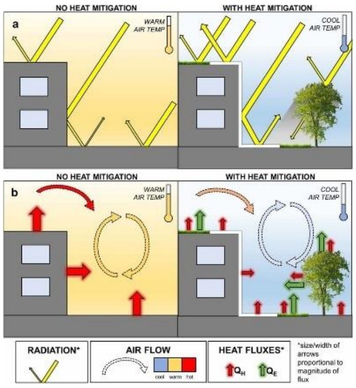
3. Lack of Interdisciplinary Approaches
    - UHI is a complex issue involving climate science, urban planning, public health, and social equity. Few studies adopt a truly interdisciplinary or systems-thinking approach to address these interrelated dimensions.
4. Underrepresentation of Socio-Economic and Equity Factors
    - While environmental aspects of UHI are well-studied, there is limited research on how heat disproportionately affects low-income and vulnerable populations, and how planning strategies can ensure climate justice.
5. Inadequate Use of Smart Technologies and Data Analytics
    - There is a gap in the application of real-time data, GIS, remote sensing, and IoT-based monitoring to track UHI and inform dynamic planning responses.
6. Lack of Performance Evaluation of Existing Strategies
    - Few studies evaluate the long-term effectiveness of green roofs, cool pavements, and other UHI mitigation measures in terms of thermal performance, maintenance, cost-benefit analysis, and scalability.
7. Limited Climate Adaptation Perspective
    - UHI is often studied as an isolated urban challenge rather than within the broader framework of climate resilience and adaptation planning for cities.
8. Absence of Standardized Metrics and Assessment Tools
    - There is a lack of standardized tools to assess UHI intensity, mitigation effectiveness, and progress toward resilient urban development goals.
9. Gap Between Research and Implementation
    - Even where academic research on UHI exists, it is often not translated into actionable policies or design practices by urban local bodies.
10. Neglect of Informal Settlements and Peri-Urban Areas

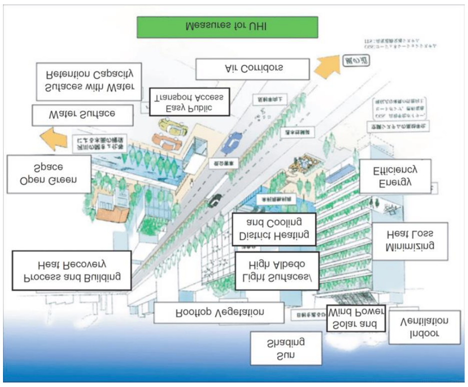
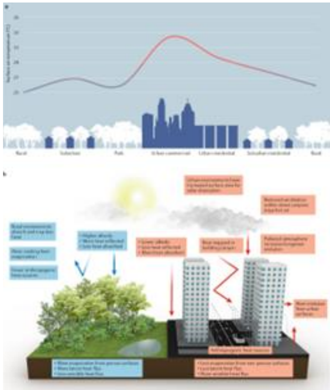
- Most UHI studies focus on formal urban cores, ignoring rapidly urbanizing peri-urban zones and informal settlements that are often more vulnerable.

1.5. AIM & OBJECTIVE

To explore and develop sustainable urban planning strategies that effectively mitigate the Urban Heat Island (UHI) effect, with the goal of enhancing urban resilience, reducing thermal stress, and promoting environmentally and socially sustainable cities.

The aim and objectives of mitigating the Urban Heat Island (UHI) effect through sustainable planning strategies for **Mangalore city**, that multifaceted, focusing on environmental, social, and economic dimensions. Here's an overview:



1. **To Identify Key Contributors to the Urban Heat Island (UHI) Effect**
    - Analyze urban design, materials, and land use patterns that intensify heat retention in urban environments.
    - Examine socio-economic and geographical factors influencing UHI intensity.

2. **To Evaluate the Effectiveness of Existing Mitigation Strategies**
    - Review local and global case studies of green infrastructure, cool roofs, reflective materials, and urban forestry.
    - Assess their applicability and effectiveness in different urban settings.

3. **To Develop Integrated Sustainable Planning Strategies**
    - Propose a set of context-specific sustainable urban design interventions to reduce UHI intensity.
    - Emphasize nature-based solutions, energy-efficient architecture, and climate-sensitive urban planning.

4. **To Promote Urban Resilience Through Policy and Community Engagement**
    - Explore the role of policy frameworks and governance in supporting UHI mitigation.
    - Encourage community-based adaptation strategies and stakeholder participation in sustainable planning.

5. **To Create a Framework for Monitoring and Evaluation**
    - Design a methodology to assess the performance of implemented strategies in reducing urban temperatures and enhancing livability.
    - Utilize GIS, remote sensing, and real-time data for long-term monitoring.

6. **To Support Climate Change Adaptation Goals**
    - Align UHI mitigation strategies with broader climate adaptation and sustainability goals such as the UN SDGs and local climate action plans.

7. **To Identify the Causes and Impacts of the Urban Heat Island (UHI) Effect**
   Understand how urbanization, land use, and built environments contribute to temperature rise in cities and its effects on health, energy use, and ecosystem balance.

8. **To Explore and Evaluate Sustainable Urban Planning Strategies**
   Investigate planning approaches such as green infrastructure, cool materials, urban vegetation, and sustainable mobility that can reduce urban heat accumulation.

9. **To Enhance Urban Resilience to Climate Change**
   Develop strategies that improve a city's ability to adapt to increasing temperatures and extreme weather events through heat-reducing design and infrastructure.

10. **To Promote Integration of UHI Mitigation into Urban Policy and Planning**
    Encourage the adoption of UHI-reducing practices in zoning laws, building codes, and city master plans to support long-term climate resilience.

11. **To Foster Community Awareness and Participation**
    Engage residents, stakeholders, and local authorities in understanding the UHI effect and implementing locally appropriate, sustainable solutions.

12. **To Develop a Framework for Monitoring and Assessment**
    Create tools and indicators to measure the effectiveness of implemented strategies in mitigating UHI and improving urban microclimates.

1.5 SCOPE

This study focuses on exploring and evaluating sustainable urban planning strategies aimed at mitigating the Urban Heat Island (UHI) effect and enhancing the climate resilience of cities. The research encompasses an interdisciplinary approach combining aspects of urban design, environmental science, climate adaptation, and public policy.

Specifically, the scope includes:

1. **Identification of Key UHI Drivers**
   Investigating the primary causes of urban heat islands, including land surface modifications, building materials, lack of vegetation, and anthropogenic heat emissions.
2. **Assessment of UHI Impacts**
   Analyzing the environmental, social, economic, and public health impacts of elevated urban temperatures, particularly in densely populated and vulnerable urban areas.
3. **Evaluation of Sustainable Planning Strategies**
   Reviewing and assessing sustainable urban planning interventions such as:
   - Urban greening (e.g., green roofs, vertical gardens, and urban forests)
   - Cool and reflective roofing and paving materials
   - Sustainable transportation systems
   - Compact and mixed-use development
   - Climate-sensitive zoning and land use policies
4. **Case Studies and Best Practices**
   Examining successful case studies from cities worldwide that have implemented innovative solutions to combat UHI and enhance urban resilience.
5. **Policy and Governance Frameworks**
   Exploring the role of urban governance, community participation, and integrated

planning policies in driving sustainable urban heat mitigation efforts.

6. **Technological and Nature-Based Solutions**
   Investigating the use of smart technologies, data analytics, and nature-based solutions in monitoring and managing urban heat.
7. **Recommendations for Resilient City Planning**
   Providing evidence-based recommendations tailored to different urban contexts for integrating UHI mitigation into broader climate adaptation and sustainability agendas.

1.6 LIMITATIONS

While this study aims to provide valuable insights into sustainable planning strategies for mitigating Urban Heat Island (UHI) effects, several limitations must be acknowledged:

1. Geographic and Climatic Variability
   UHI effects and their solutions vary significantly depending on geographic location, climate zone, and local urban morphology. As a result, findings may not be universally applicable across all urban contexts.
2. Data Availability and Accuracy
   Reliable data on land surface temperatures, vegetation cover, energy usage, and urban materials may be limited or inconsistent, especially in developing regions. This can impact the precision of UHI analysis and evaluation of mitigation strategies.
3. Temporal Scope
   UHI impacts and the effectiveness of mitigation strategies evolve over long periods. Short-term studies may not capture the full effects of sustainable planning interventions, particularly those relying on vegetation growth or urban redesign.
4. Limited Stakeholder Perspectives
   The study may not fully incorporate diverse perspectives from all stakeholders (e.g., local residents, marginalized communities, small businesses), which are essential for understanding the social implications of planning decisions.
5. Policy and Implementation Gaps
   The effectiveness of proposed strategies depends heavily on political will, regulatory frameworks, funding availability, and institutional capacity—factors that vary widely between cities and are often outside the scope of academic research.
6. Technological Constraints
   While emerging technologies offer promise for monitoring and managing UHI, their

integration into urban planning is often limited by costs, expertise, and infrastructure, particularly in low-income settings.

7. Focus on Mitigation Over Adaptation
   This study emphasizes mitigation strategies and may not fully address adaptive measures necessary for populations already experiencing severe UHI impacts.
8. Urban-Rural Interactions
   The complex interactions between urban and surrounding rural or suburban areas are not extensively covered, despite their role in shaping regional temperature patterns.

1.7 METHODOLOGY

1. Research Design

This study adopts a mixed-methods approach, combining both qualitative and quantitative research techniques to assess the impact of sustainable planning strategies on urban heat island (UHI) effects and city resilience.

2. Study Area Selection

Urban centers experiencing significant UHI effects will be selected based on:

- Climate zones (tropical, temperate, arid, etc.)
- Population density
- Rate of urbanization
- Availability of spatial and environmental data

Cities like Los Angeles, Tokyo, Delhi, or Lagos may serve as case studies to ensure global applicability.

3. Data Collection

a. Primary Data

- Field surveys: To assess land surface temperature (LST) using handheld thermal sensors in different urban zones (residential, industrial, green spaces).
- Stakeholder interviews: Urban planners, environmental engineers, municipal officials, and community members will be interviewed to understand current UHI mitigation practices and perceptions.

b. Secondary Data

- Satellite imagery (e.g., Landsat, MODIS) for LST and land use/land cover (LULC) analysis.

- Climate and environmental datasets from sources such as NASA, NOAA, or local meteorological departments.
- Urban planning documents, sustainability frameworks, and resilience strategies from municipal archives.

4. Data Analysis

a. Spatial Analysis

- GIS-based analysis will be conducted to map UHI hotspots and evaluate correlations between land cover types and surface temperature.
- Use of tools like ArcGIS or QGIS for spatial visualization.

b. Statistical Analysis

- Regression models to analyze relationships between variables (e.g., green cover %, built-up area, albedo) and UHI intensity.
- Comparative analysis between cities implementing sustainable strategies and those that do not.

c. Qualitative Analysis

Thematic coding of interview transcripts to extract recurring themes related to challenges, best practices, and perceived benefits of sustainable urban planning.

5. Sustainable Planning Strategies Evaluated

The study will assess the effectiveness of various strategies, including:

- Urban greening (green roofs, vertical gardens, tree canopy expansion)
- Use of cool/reflective building materials
- Sustainable drainage systems (SUDS)
- Zoning and building code reforms
- Compact and mixed-use development

6. Resilience Assessment

The research will use frameworks such as the Urban Resilience Index or UN-Habitat's City Resilience Profiling Tool to evaluate improvements in urban resilience linked to UHI mitigation efforts.

7. Validation and Triangulation

- Triangulation of remote sensing data with ground-level observations.
- Cross-validation of stakeholder insights with policy documents and environmental indicators.

1.8 EXPECTED OUTCOMES

1. Identification of Effective Sustainable Planning Strategies

The study is expected to identify and evaluate sustainable urban planning strategies—such as increased green infrastructure, reflective surfaces, and smart zoning—that significantly reduce Urban Heat Island (UHI) effects across different urban contexts.

2. Improved Understanding of UHI Dynamics

Through spatial and statistical analysis, the research will enhance understanding of how various land use types, surface materials, and urban forms contribute to temperature variations within cities.

3. Evidence-Based Policy Recommendations

The findings will support the development of actionable policy recommendations for urban planners and municipal governments aimed at integrating UHI mitigation strategies into broader climate adaptation and urban resilience plans.

4. Development of a Strategic Framework for Resilient Cities

The study will propose a strategic, replicable framework that cities can adopt to enhance thermal comfort, environmental quality, and resilience through sustainable design and planning.

5. Assessment of Resilience Improvements

By applying resilience assessment tools, the research will demonstrate how UHI mitigation contributes to broader urban resilience—improving public health, reducing energy demand, and enhancing disaster preparedness.

6. Contribution to Sustainable Development Goals (SDGs)

The research will align with and support several UN SDGs, including:

- SDG 11: Sustainable Cities and Communities
- SDG 13: Climate Action
- SDG 3: Good Health and Well-being

7. Creation of GIS-Based Heat Maps

High-resolution GIS maps showing UHI hotspots and the effects of implemented planning interventions will be produced, offering valuable tools for urban management and decision-making.

8. Increased Public Awareness and Stakeholder Engagement

The study will raise awareness among stakeholders (e.g., residents, planners, developers) about the importance of climate-sensitive planning and may lead to increased community participation in UHI mitigation efforts.

2. LITERATURE REVIEW

In order to be able to collect relevant data in Chapter 3, an overview of UHI mitigation measures and their effects will be provided in this chapter. These will be accommodated in the categories vegetation, open water, built form, material and anthropogenic sources. Section 2.6 concludes this chapter by summarizing the mitigation measures that should be included in the analyses.

2.1 Vegetation

Increasing the amount of vegetation in urban areas is considered an important UHI mitigation measure. Vegetation lowers the air temperature through (evapo)transpiration and shading (Dimoudi & Nikolopoulou, 2003). Transpiration describes the water loss of a plant as vapour into the atmosphere. This requires energy, hence cooling the leaves and the air around them. The shading from trees cools the atmosphere by intercepting solar radiation (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013). In addition, green spaces will usually improve the surface porosity, increasing the amount of water available for evaporative cooling (Hathway & Sharples, 2012). Two types of urban greening measures have been identified: urban greenspaces, and green roofs and walls.

A number of studies have investigated the cooling effect of greenspaces. The range of the greenspace influence is usually assumed to be one park-width from the greenspace (Chang & Li, 2014; Spronken- Smith & Oke, 1998), although Doick, Peace, & Hutchings (2014) found it to be much smaller. Chang & Li (2014) found that larger parks and more heavily vegetated parks generally have a larger cooling effect than small parks and parks with more paved surfaces. A review of a number of observational studies by Bowler et al. (2010) also shows that larger parks are cooler.

Chang & Li (2014) note that the cooling effect of parks on park surrounding also differs with vegetation type. Although trees can have a cooling effect during the day, this is offset during the night, when heat exchange between parks and the cooler air above them is obstructed (Chang & Li, 2014; Spronken-Smith & Oke, 1998). Similarly, there is evidence that the air temperature beneath individual trees (e.g. street trees and trees on parking spaces) is lower than the air temperature measured at non-green urban sites during the day (Bowler et al., 2010; Golden, Carlson, Kaloush, & Phelan, 2007). The cooling effect of grass depends largely on the amount of irrigation (Gill, Rahman, Handley, & Ennos, 2013) and shading (Shashua-Bar, Pearlmutter, & Erell, 2009).

As opposed to conventional roofs, green (or 'living') roofs are known to improve building energy performance as well as the environmental conditions of the surroundings (Gago et al., 2013). The effectiveness of green roofs in reducing the energy consumption (Virk et al., 2015) and UHII (Liu & Bass, 2005) is highly dependent on their moisture conditions; dry roofs are less effective than moist roofs. Furthermore, Santamouris (2014) provides a review of several studies and concludes that when green roofs are installed on high or medium rise buildings, their mitigation potential at street level is almost negligible. Green façades and living walls have similar effects on the (thermal) urban environment (Kikegawa, Genchi, Kondo, & Hanaki, 2006; Mazzali, Peron, Romagnoni, Pulselli, & Bastianoni, 2013; Sheweka & Magdy, 2011).

2.2 Open water

The presence of water bodies has the potential to mitigate the UHI effect through evaporation and sensible heat transfer between the air and water (Kim et al., 2008). It is believed that water bodies possess the most efficient UHI reducing effect during summer (Oláh, 2012). Urban rivers, lakes and ponds, and novel water facilities will be discussed below.

Kim et al. (2008) found that a restored stream in Seoul (South-Korea) affects the local thermal environment, including heat mitigation. Hathway & Sharples (2012) found that a small urban river in Sheffield (UK) provides significant cooling both over the river and on the river banks during spring and summer. This cooling effect was largest in the mornings and on highly vegetated banks. The cooling effect increases with greater solar radiation and higher ambient temperatures, and decreases with higher water temperatures. The level of cooling 40 metres from the river was found to be negligible. Murakawa, Sekine, & Narita (1990) however, found that the cooling effects of the Ota River in Hiroshima City (Japan) were discernible at least a few hundred metres. Again, it was found that the cooling effect is virtually absent during the night.

Steeneveld, Koopmans, Heusinkveld, & Theeuwes (2014) found that in Rotterdam (The Netherlands), the harbour is cooler than the city centre during daytime. At night however, the city centre and the harbour have approximately the same temperature and both cool much slower than the rural surroundings.The cooling effect of ponds in courtyards in Oregon (USA) was investigated by Taleghani, Sailor, Tenpierik & van den Dobbelsteen (2014), who observed the cooling effect to be the largest in the afternoon. Sun & Chen (2012) investigated the urban cold island intensity (UCII) and efficiency of 197 ponds and lakes in Beijing. They found that larger water bodies increase the cooling intensity, but reduce the cooling efficiency (UCII per ha). This means that given the same total area of water bodies, more small water bodies can offer more beneficial effects.

While flowing water has a larger cooling effect than stagnant water, dispersed water like from a fountain has the biggest cooling effect (Kleerekoper et al., 2012). Nishimura, Nomura, Iyota & Kimoto (1998) proposed novel water facilities (fountains and waterfalls) to improve thermal comfort. They made measurements around such artificial water facilities in Osaka City (Japan). It was found that the cooling effect of water falls and spray-type water facilities extends to approximately 35 metres on the leeward side, in the afternoon.

2.3 Built form

The building density and geometry are of interest in this category. Futcher (2008) argued that overheating by solar radiation in summer can be reduced with high ratios of street height to street width. Although a dense urban fabric provides shading at street level, it also traps heat resulting from multiple solar reflections and lowered sky-view factor, as was already mentioned in section 1.1.1. Furthermore, it may reduce air flow, impairing ventilation cooling. Kleerekoper et al. (2012) state that these negative effects may be stronger than the positive effects of the measure.

Yang, Lau, & Qian (2010) found that the daytime UHI is closely related to site shading factor. Areas with the highest building density were observed to have the lowest daytime UHII, whereas low density urban morphologies showed the highest UHII during the day. Giridharan, Lau, & Ganesan (2005) state that high density city configurations lead to a rise in nighttime UHII, because of the high thermal capacity of the combined mass of the buildings.

Wide streets and other open spaces encourage air flow which improves the opportunity to ventilate the inner parts of a city and reduce temperatures (Futcher, 2008). The orientation of streets with regard to the main wind directions is also of interest. Hathway & Sharples (2012) found that opening up the streets to a river allows a larger cooling effect than streets that are shut off from the river. Similarly, Nonomura, Uehara, Masuda, & Tadono (2014) noticed that medium to high-rise buildings can block sea breeze during the daytime, thereby inhibiting ventilation cooling.

2.4 Material

The use of ‘cool materials’ has gained interest as an UHI mitigation measure in the past decade. Cool materials are characterized by high solar reflectance (albedo), infrared emissivity (Syneffa, Dandou, Santamouris, Tombrou, & Soulakellis, 2008) and/or porosity (Coseo & Larsen, 2015).

Darker (low albedo) materials absorb more solar radiation than lighter materials (high albedo). This warms the surface, which eventually warms the atmosphere (Pomerantz, Akbari, Chang, Levinson, & Pon, 2003). Various studies have shown that reflective pavements and roofs lower surface and air temperatures during the day (e.g. Pomerantz et al., 2003; Rosenzweig, Solecki, & Slosberg, 2006; Syneffa et al., 2008). Erell, Pearlmutter, Boneh, & Kutiel (2014) also found that high albedo pavements lower the air temperature. However, they note that the increased reflection of solar radiation from pavements can increase heat stress for pedestrians. As a result, these authors suggest using reflective materials on roofs, rather than on pavements and walls. In locations where high vertical walls constrained the release of solar radiation, reflective pavements were found to increase air temperatures during the day (Coseo & Larsen, 2015). No influence on nighttime temperatures was observed.

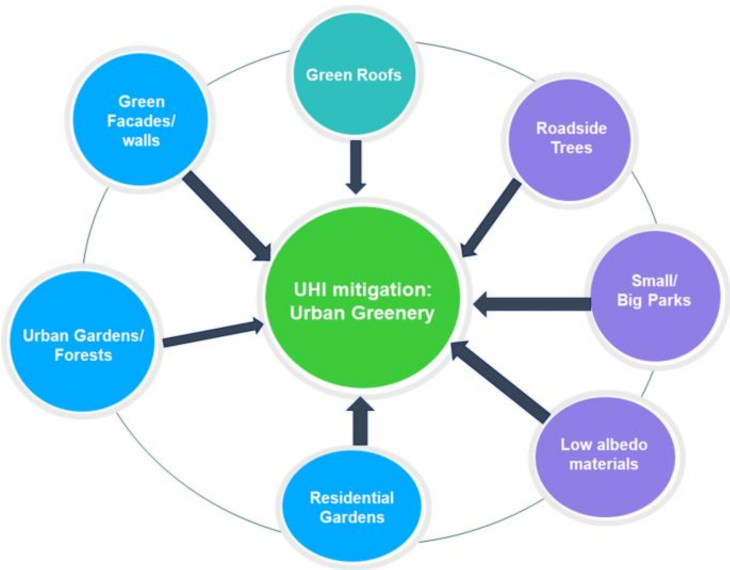
The infrared emissivity specifies how well a surface radiates energy away from itself (Syneffa et al., 2008). Like albedo, emissivity is measured on a scale of 0 to 1.0. Golden & Kaloush (2006) found that conventional pavement materials, such as asphalt, concrete and brick, had emissivity values over 0.90 and therefore effectively stored and released energy. Not much attention has been paid to the emissivity of materials as a means of mitigating the UHI. This is likely caused by the fact that the emissivity is not easily changed; except from a few metals, such as aluminium and silver, most materials, including soil, vegetation and water, have a high emissivity (Brewster, 1992). Coatings to increase the albedo of materials, do not affect the emissivity of the material (Carnielo & Zinzi, 2013).

Whereas impervious surfaces, in combination with efficient drainage, lead to a decrease in surface moisture available for evaporation, the water stored in voids of pervious materials allows cooling through evaporation. The inclusion of porous materials in the urban environment is primarily promoted by two measures: green roofs (section 2.1) and porous paving. Stempihar, Pourshams-Manzouri, Kaloush, & Rodezno (2012) compared the surface temperatures of porous asphalt, traditional dense-graded asphalt and concrete pavements. They found that porous asphalt exhibited higher daytime surface temperatures than the other pavements, but the lowest nighttime temperatures. Coseo & Larsen (2015) found that, when surrounded by high walls, porous asphalt and porous concrete increased maximum daytime air temperatures. In addition, it was found that these porous pavements do not lower nighttime temperatures.

2.5 Anthropogenic sources

As mentioned in section 1.1.1, energy consumption in buildings and motorized vehicles leads to the anthropogenic emissions of heat and water vapour into the urban environment. Improvements in the thermal insulation of buildings can reduce the energy consumption needed for air conditioning during summer, and hence result in a reduction in the anthropogenic heat emissions from buildings (Kikegawa et al., 2006). As mentioned in previous sections, mitigation measures such as green and cool roofs can also lead to a reduction in energy consumption.

In a similar fashion, one could argue that car-free zones would reduce the emission of anthropogenic heat from vehicles. Although no literature has been found to specifically support this, Bagieński (2015) shows that the values of UHI determinants being generated by vehicles are relatively high for high traffic volume streets.



3. CASE STUDY

Among Indian cities, Delhi stands out as one of the most affected by extreme heat, from a study by P.kumar (2022), where four most populous indian cities, Chennai, Kolkata, Mumbai and Delhi, are studied to analyze heat stress on the city. (figure 7).

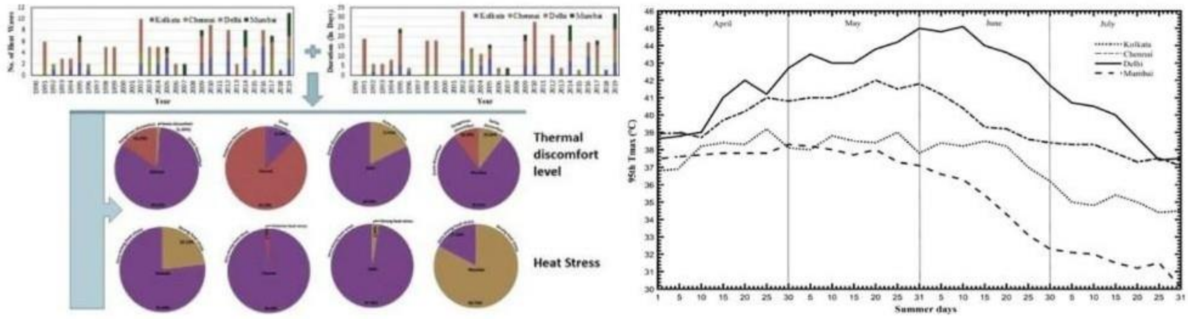
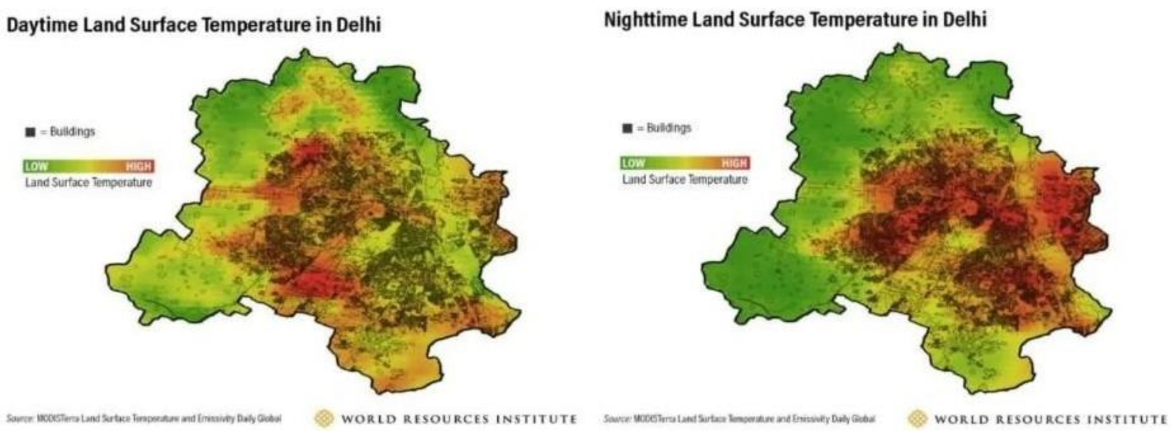


Figure 1- The percentle Me four metrapolitan cities (Kolkata, Chennai, Delhi and Mumbai) by P. Kumar, 2022.

The city's geographic location combined with high levels of vehicular emissions and dense urban fabric, has consistently recorded some of the highest temperatures in India, often exceeding 48°C during peak summer months. The land surface temperature maps of Delhi (figure 8), as highlighted in recent studies, reveal widespread heat hotspots, with temperatures in some areas crossing 50°C (World Resources Institute, 2022). This combination of extreme heat and poor air quality has severe implications for the city's residents, particularly for vulnerable populations and - low income communities.

Figure 8- Land surface temperatures by world resources institute



Growing thermal discomfort in Delhi streets is mapped by Greenpeace India and National Hawkers Federation by capturing real-time condition of street vendors using thermal camera for the summer of 2024. The thermal images (figure 9) show that street vendors are working at 50 °C. to earn their livelihood.

Figure 9- Thermography images captured by Greenspace, 2024

According to the World cities report, Informality is a reality of urbanization especially in developing countries. Cities will not be able to offer a bright urban future if their informal sector workers are perpetually excluded from urban development processes. (UN, 2022).

3.1 DELHI'S WEEKLY STREET MARKETS

Delhi, is renowned for its vibrant street markets that cater to millions of residents and tourists alike. Markets such as Chandni Chowk, Sarojini Nagar, and Karol Bagh have historically been essential to the city's economy and social fabric, offering a diverse range of products, from textiles to street food. Street markets, especially in densely populated cities like Delhi, serve as economic lifelines for various groups, including informal vendors, small traders, and low- to middle-income shoppers.

Moving markets that are set up in different locations on different days of the week provide a source of employment for a large number of vendors in the city as mapped by WEIGo in figure 10.

More than 112,500 vendors in Delhi are associated with weekly markets. These markets operate along footpaths or open grounds of residential neighborhoods and are an important source for everyday essentials for middle and low-income communities.

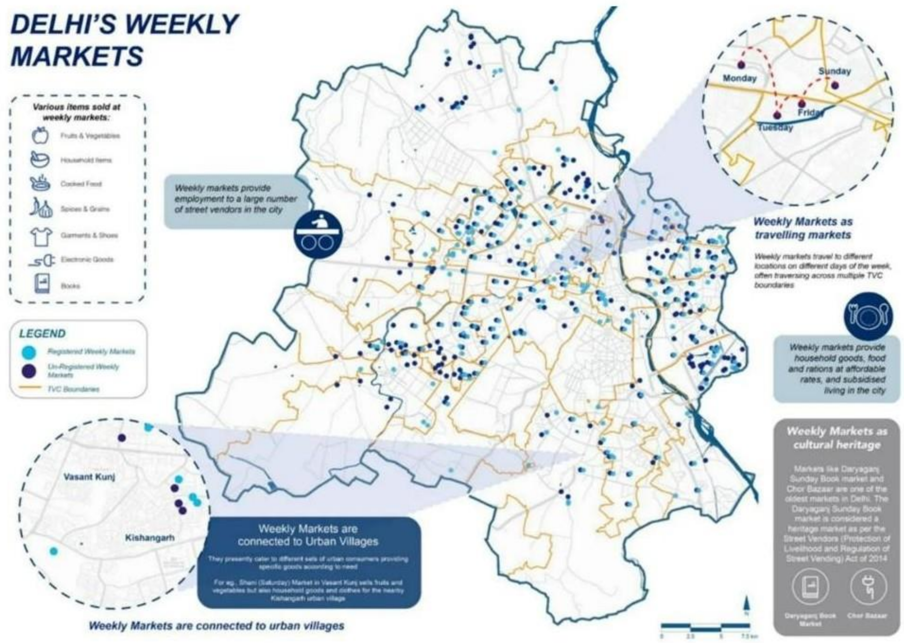


Figure 10- Delhi's weekly markets by WEIGO

3.2 RISKS AND VULNERABILITIES FACED BY STREET VENDORS

As the thermographic images demonstrate (figure 9), vendors work in open environments with little to no shade, leaving them exposed to direct sunlight and extreme surface temperatures. This not only affects their health but also impacts their productivity and overall well-being.

These health risks are exacerbated by the socio-economic vulnerabilities of the vendors. Many come from low-income backgrounds and cannot afford to take time off during heat waves, as their daily earnings are essential for their survival. Additionally, the informal nature of their work means that they often lack access to basic amenities such as drinking water, healthcare, and resting spaces, further increasing their vulnerability to extreme heat.

3.3 POLICY GAPS AND OVERLOOKING URBAN INTERVENTIONS

In recent years, the Indian goverment has implemented various initiatives aimed at improving the working conditions of street vendors. The Street Vendors (Protection of Livelihood and Regulation of Street Vending) Act, 2014 was introduced to provide vendors with legal protections.

More recently, the Prime Minister's Vendors Atma Nirbar Nidhi and initiatives by the National Hawker Federation have sought to formalize the vendor economy by offering financial support and urban design guidelines (figure 11).

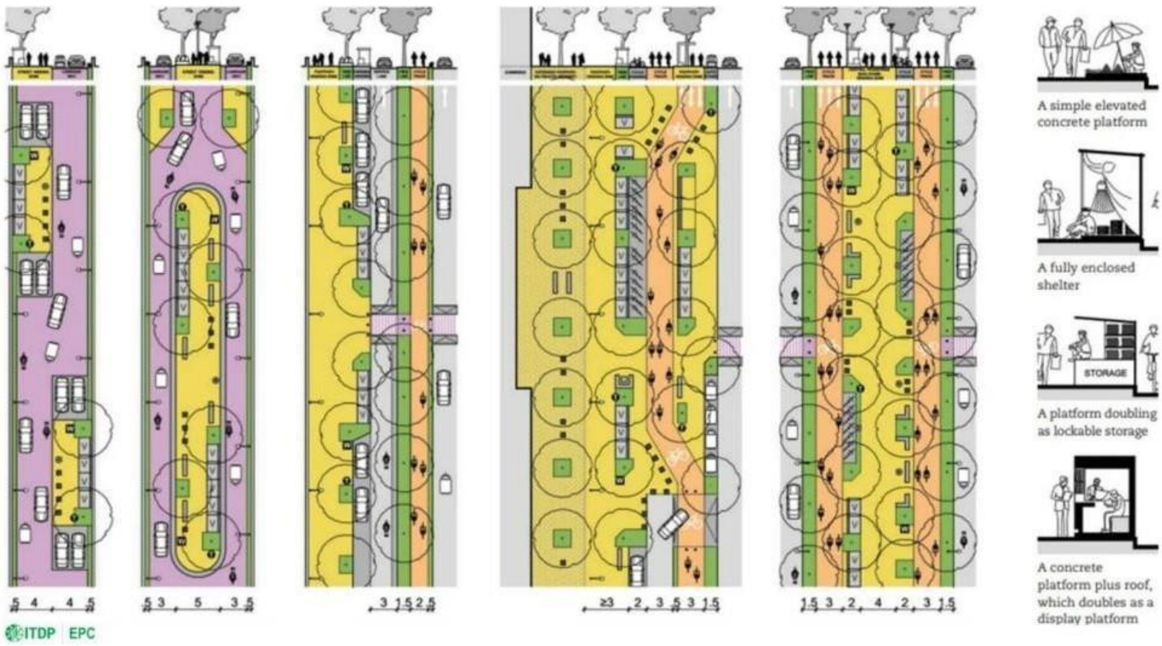


Figure 11- Design for street vendors from urban India street design guide

These design proposals figure, offer little to no consideration for shading or heat mitigation strategies. The design blueprints emphasize the construction of elevated platforms and organized vending spaces but fail to incorporate basic heat mitigation measures such as shaded structures, cooling materials, or vegetation.

This reflects a broader policy gap where urban planning efforts prioritize economic and spatial efficiency over environmental resilience. As Jain and Singh (2022) argue, urban design in India has often neglected the impacts of climate change, with limited attention given to cooling strategies in public spaces.

3.4 SITE OF STUDY: AJMAL KHAN ROAD, KAROL BAGH

Ajmal Khan Road in Karol Bagh, one of Delhi's most bustling shopping districts, presents an ideal case for studying the intersection of urban planning, pedestrianization, and economic resilience.

Figure 12- MCD plan locating Karol Bagh in Delhi map; Figure 13- MCD intervention area highlighting Ajmal Khan road

Before 2019, this road was a chaotic commercial artery marked by heavy vehicular traffic, overcrowded sidewalks, and an informal economy heavily reliant on street vendors. With limited space for pedestrians, the road saw frequent traffic jams and low air quality, further exacerbated by the dense urban heat island effect in summer months (NDMC, 2019).

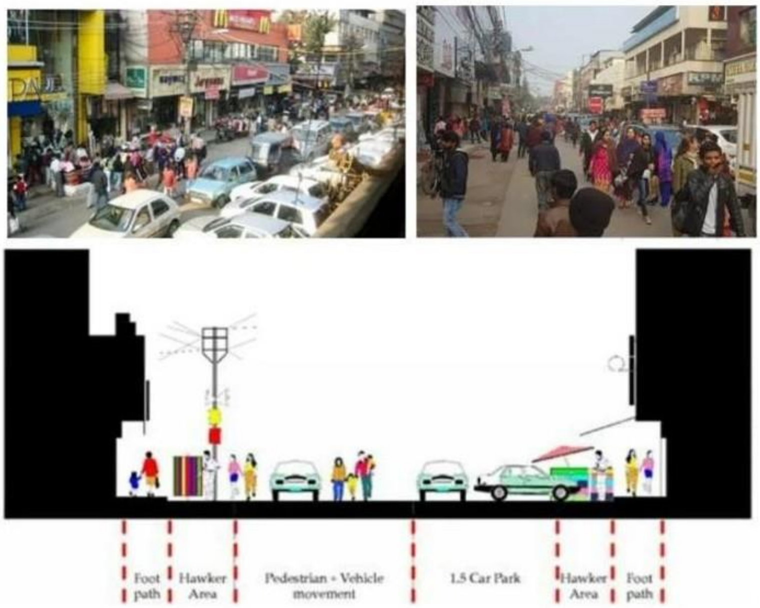


Figure 14a and 14b: Ajmal khan street character mages before 2019; Figure 15- Section of original street (source- MCD submitted to UTTIPEC)

3.4.1 GOVERNMENT INTERVENTION IN 2019

The North Delhi Municipal Corporation (NDMC) launched a pedestrianization project in 2019 to decongest the area. This intervention included transforming 600 meters of the street into a pedestrian only zone, installing benches, adding flower pots. Bollards were placed at entry points to restrict vehicular access, and dedicated spaces were marked for vendors (NDMC, 2019; Business Standard, 2019).

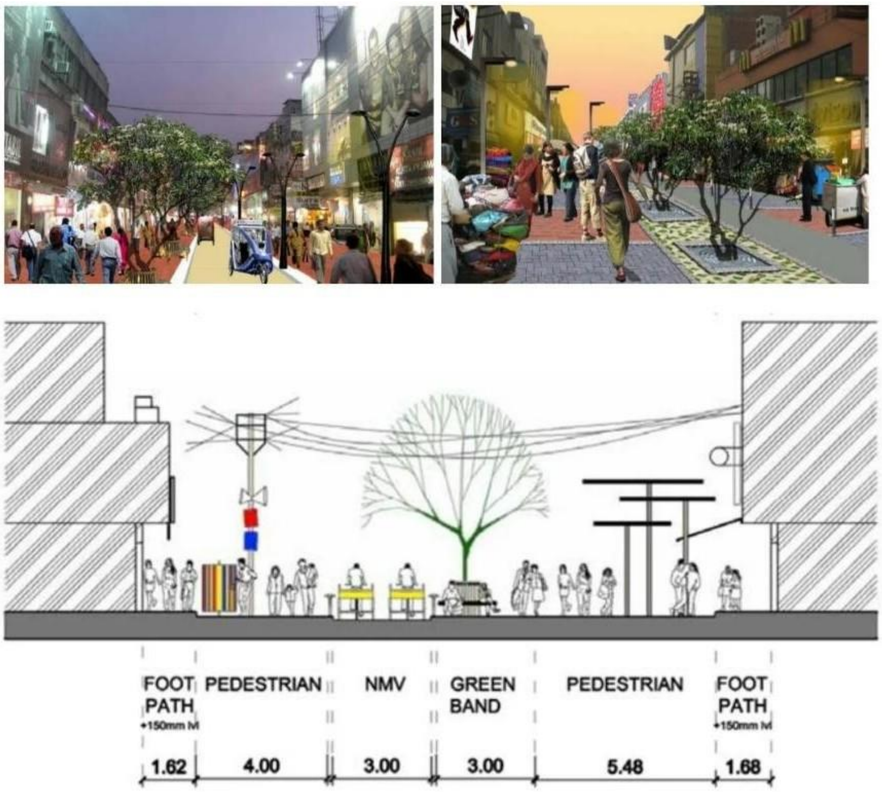


Figure 16a and 16b- nilaA collage illustration for proposal; Figure 17- Section of proposed street (so MCD submitted to UTTIPEC)

The primary goals of this project were to encourage walking, improve the shopping experience, and reduce the overwhelming vehicular congestion. The foot path was widened with sandstone pavers (figure19) The roads were clearly demarcated using paint indicating pedestrian vendor, vehicular, seating and plant lanes. Off-street parking spaces were also created nearby to accommodate vehicles. The intervention was seen as a move towards creating more organized and pedestrian-friendly commercial spaces, similar to efforts seen in other parts of the city (Business Standard, 2019).

Figure 18- nilaA Ajmal khan street design intervention plan

Figure 19a and 19b- Images of Ajmal khan post 2019 intervention (MCD)

3.4.2 IMPACT OF THE PEDESTRIANIZATION

The pedestrianization of Ajmal Khan Road has led to several improvements, including:

• Average reduction of PM 2.5 particles by 35%.

• Increase in pedestrian traffic by 2.7 times.

* Increase in sales by 25% to 30%.

• Basic amenities installed for vendors and shoppers.

• Safer and reduction in crime.

• Demarcation of road removed clutter and chaos.

• Reclaiming spaces lost due to vehicles and parking,

* Overall character of street improved.

This shift is particularly significant given the city's ambitious goals for sustainable urban mobility (NDMC, 2019).

Figure 20- Neighbourhood proposal by MCD for Karol Bagh

3.4.3 LIMITATIONS AND ISSUES

Despite the improvements, the intervention did not adequately address the rising issue of heatwaves in Delhi. The use of traditional asphalt continues to contribute to the urban heat island effect. The intervention completely neglected introducing vegetation on the street due to capital costs and the urgency of the project. The urban planners should know better than just allowing the placement of potted plants.

Although it was a right direction towards managing urban markets, these measures were insufficient to combat the extreme heat waves that regularly affect Delhi. Informal street vendors. who spend long hours on the road, still face significant challenges related to heat stress and exhaustion during peak summer months (Mishra et al., 2015).

The MDC had proposed extending this model of urban interventions in a few other culturally significant markets such as Krishna Nagar market, Lajpat Nagar market and Kamla nagar market.

It is of utmost importance that they realise the pitfalls of this model in addressing the issues of heat vulnerable groups and must incorporate climate adaptation strategies for their future projects.

3.5 CONCLUSION

As global climate change intensifies, extreme heat events in Delhi are projected to increase in both frequency and intensity (Murari K.K, 2015; Rohat, 2020). Delhi's Informal settlements and low-income groups are particularly at risk, as they often lack access to adequate housing, air conditioning, and reliable water supplies. These socio-economic factors, combined with the city's climate, make Delhi one of the most heat-vulnerable megacities in South Asia (Morà C., 2017).

The pedestrianization of Ajmal Khan Road in Karol Bagh represents a significant step toward improving urban liveability in one of Delhi's busiest commercial districts. However, the current design falls short of addressing the rising threat of heatwaves, which continue to affect the health and livelihood of street vendors and shoppers allke.

As a result, there is an urgent need for comprehensive heat action plans and climate-adaptation strategies to mitigate the impacts of extreme heat on Delhi's population (Singh R.P, 2021).

However, the Delhi Heat Action plan like every other HAP in India does not identify these informal sectors of the city who are equally vulnerable. Future urban planning efforts must incorporate climate resilience strategies to fully address the complex needs of all stakeholders involved in the city's bustling street markets.

It is crucial to understand implications of the mitigations strategies proposed to look beyond design. As temperatures continue to rise and urban populations grow, adaptive design approaches that can be tailored to specific site conditions will be crucial for mitigating extreme heat in cities across the world (Santamouris, 2011).

4.1 RESEARCH AIM

To investigate and evaluate context-specific strategies for mitigating extreme heat in heat vulnerable oties, with a focus on street markets of Delhs, and to develop actionable recommendations for enhancing urban resilience among urban informer-sectom

4.2 OBJECTIVES

1. Understanding existing literature on heat mitigation strategies and the its impact on diense urban street markets:

Conduct a comprehensive review of literature and case studies to identify the limitations of current heat mitigation strategies, heat action plans and government design intecventions in urban contexts.

Identity focus group of study, site of study, their key vulnerabilities and limitations in extant terature to disclose research gap

2. Develop and Test existing street conditions to identify context-specific strategies

Analyze meteorological data and street-level data to evaluate the effectiveness of recent

Interventions

Through ENVI-met software, identify required testing parameters and specifications necessary for proposing strategies.

3. Propose mitigation strategies, compare and analyse most effective strategy to present a framework of temperature reductions

Propose and evaluate a range of strategies discussed in literature to quantify their performance in given specific street and for Delhi climate.

Ulize ENVI-met simulation results to conclude the effectiveness of these strategies for the given parameters in conjunction with each other and summanse percentage temperature reductions.

Reviewing and discussing simulation results in concurence with context specific speculations and Implications to recommend the best strategy for the street when environmental, economic, and social challenges are addressed

Proposing an evidence-based recommended strategy by assessing scalability and cost-benefit for policymakers and urban planners to aid them reciprocate the mode in similar settings

5. METHODOLOGY

This section outlines the research approach, underlying principles, and practical methods employed. It also detalls the specific methods and tools used to conduct the research. Furthermore, it explains how the collected information was analyzed and synthesized to draw conclusions that align with the previously outlined aims and objectives.

5.1 RESEARCH METHOD

the research primarily employs a quantitative approach, utilizing literature review, computer modeling and data analysis to investigate the impact of heat mitigation strategies.

5.1.1 Approach:

The methodology for this research follows a systematic approach, starting with an extensive literature review and subsequently data collection. Due to the distant location of the study site, on-site field study was omitted and all data was acquired from verified online sources, Following this, the ENVI-met software model was utilized to execute simulations, from which results were analyzed and compared to draw conclusions and propose a framework.

5.1.2 Specific quantitative methods used include:

Literature Review: A systematic review of existing literature on heat mitigation strategies.

urban heat islands, and the impact of extreme heat on street markets.

Data Collection: Collection of meteorological data (e.g., temperature, humidity, wind speed. solar radiation) from delhi weather station data sources and street-level data (e.g.. building characteristics, vegetation, road infrastructure) using publicly available datasets and existing field surveys.

Computer Modeling: The use of ENVI-met software to create digital models of the study area, simulate microclimatic conditions under different scenarios and extract data on relevant parameters.

Statistical and comparitive Analysis: Graphs were drawn from statistical analysis of the

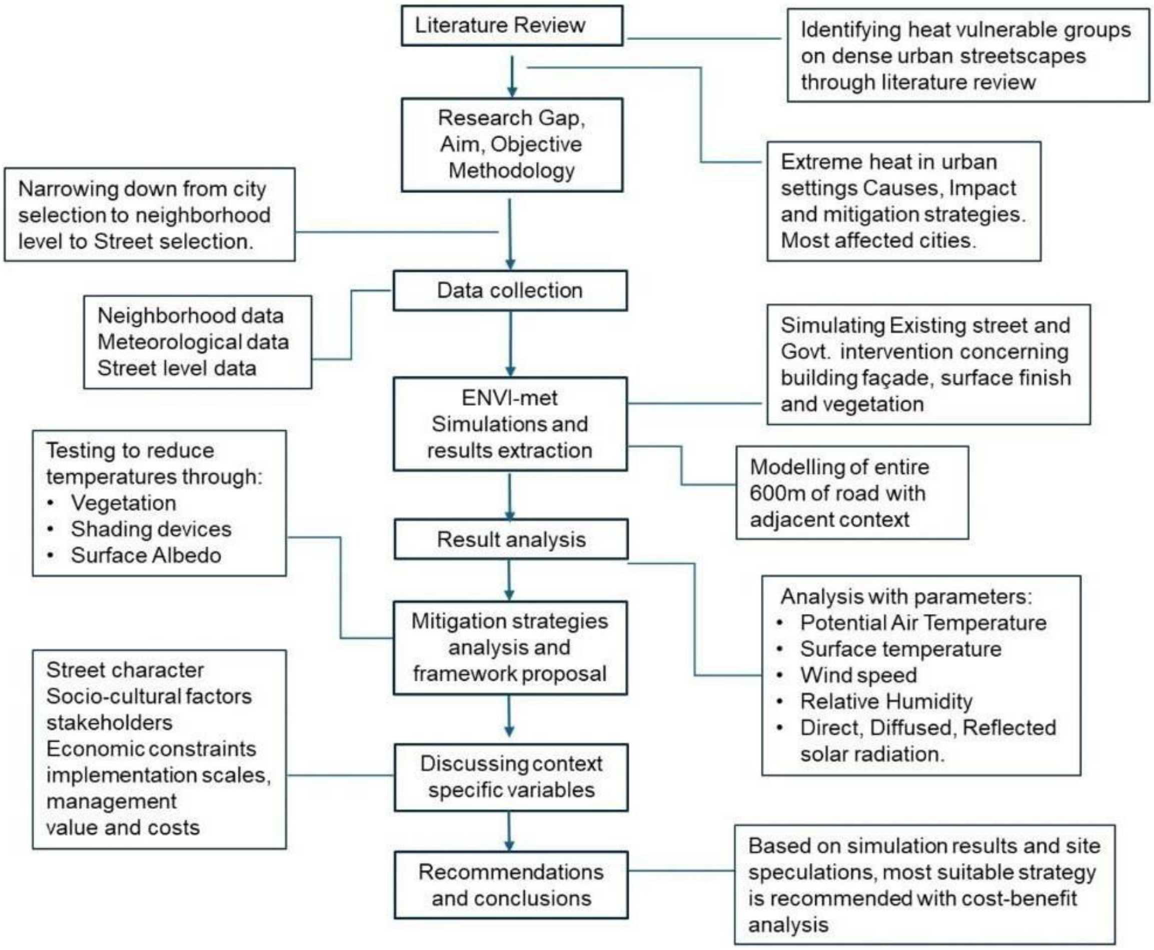


Figure 21- Methodology flowchart

6. SIMULATIONS, RESULTS AND ANALYSIS

6.1 Delhi climate

Delhi's climate is classified as a Tropical, semi-arid (Köppen climate classification: BSh) with distinct seasonal variations marked by extreme temperatures. Situated in northern-India, the city experiences three main seasons: summer, monsoon, and winter.

6.1.1 Weather

Delhi's geographical position subjects it to distinct seasonal extremes, with cold winters influenced by chilling winds blowing down from the Himalayas and extremely hot summers amplified by dry winds from the Thar Desert to the south. These seasonal winds contribute to Delhi's exposure to severe heat waves, particularly during the peak summer months from late April to early July, until the onset of the monsoon season provides some respite (Kumar R., 2017, Singh, 2021).

Summers, which extend from April to June, are characterized by scorching heat, with temperatures often exceeding 40°C placing significant stress on the city's population and infrastructure (Pai et al., 2013).

Monsoon season, from late June to September, brings relief from the heat with heavy rainfall Delhi receives an average of 700-800 mm of rainfall annually, primarily during the monsoon, but recent trends suggest variability in precipitation patterns due to climate change (Ramanathan et al., 2015)

Winters, from November to February, are relatively mild but can witness sharp drops in temperature, with night time lows often reaching around 4°C

6.2 BASE CASE AND EXISTING CASE

From Methodology, simulations were run for each case and are analyzed based on the data generated by ENVI-met for 18th May 2024. The analysis focuses on Potential Air Temperature as primary parameter while additional metrics such as Surface temperature and Reflective solar radiation are studied to understand how the grid cells are reacting to strategies. Other parameters such as Relative Humidity, Wind speed are studied in conjunction.

6.2.1 Base case

The base case simulation reflects the street conditions before the 2019 intervention. The 600-meter stretch of Ajmal Khan Road is modelled in asphalt, a material with a low albedo ranging between 0.12 to 0.15. existing neighbourhood vegetation with no greenery on the street itself, and the primary shading technique used by the shops and hawkers at ground floor being Tarpaulin sheets of varying low quality are modelled for the base case as shown in figure 30,

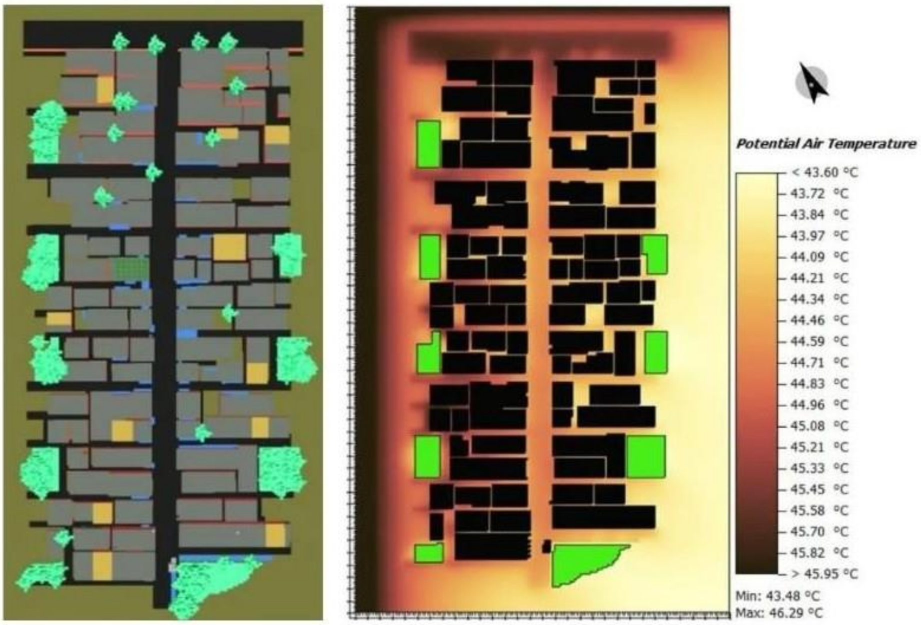


Figure 30- Base case spaces model; Figure 31- Base case temperature visualization chart

The temperature data for this case reveal the significant influence of solar orientation and street alignment, with temperatures peaking in the mid-afternoon. Across the day, there is a noticeable peak around 2:00 to 4:00 PM, with direct solar radiation from South-West. This gives us a picture of the building shadow path falling on street.

6.2.2 Existing Case

For the existing case simulation, the whole 600m of Ajmal Khan road post 2019's intervention is modelled as a part of the MCD intervention, the whole street was partially pedestrianized with sandstone and lime stone pavers along with Asphalt mad. Although the proposal plans proposed tree plantation, only potted plants were placed at 10m apart as seen in figure 195. The same is modelled for this case with no change in shading as seen in figure 32

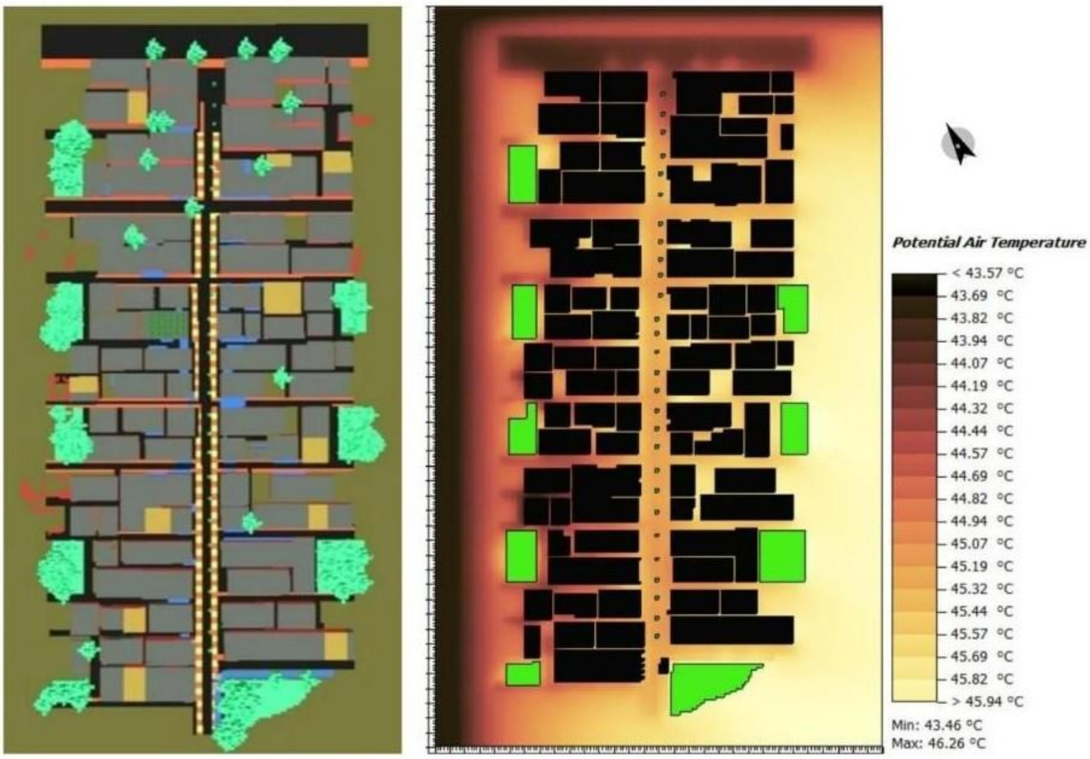


Figure 32- Existing case spaces model; Figure 33- Existing case temperature visualization chart

6.3 STRATEGY TESTING

For the strategy testing, a section of the street junction is considered. This part of the street has buildings, ranging from 4m to 16m in height. The width of the street varles from 18m to 20m. For the modelling of strategies, the existing road with partial pavement and asphalt road is chosen. All the improvements in terms of vegetation, shading and Albedo are implemented to the existing case. The analysis and comparison of their performance is calculated in comparison to this case.

6.3.1 Urban Vegetation

Based on insights from literature reviews and case studies, introducing vegetation along Ajmal Khan Road has the potential to substantially improve the street environment by offering shade, enhancing air quality, and elevating the overall ambiance. To assess the temperature reductions achieved by different types of vegetation, two scenarios are simulated. At ground level, a 4m x 4m patch with 1m tall hedges/grass is modeled, with the following variations:

a) Trees 5m to 10m in height are planted 4m apart.
b) Trees 10m to 20m in height are planted am apart

From Delhi Development Authority (DDA) Urban Greening Guidelines (2021), and Tiwari, P., & Thakur, B. R. (2020), a variety of tree species suitable for urban environments have been identified in the table 7, specific to the site Climate based on their height, leaf type, and recommended plantation distance. These native trees are weil-suited for street plantation in Delhi due to their ability to tolerate high temperatures, limited water availability, and urban pollution (Trane, M. 2024). Deciduous species help in reducing heat during summer by shading streets and shedding leaves during winter to allow sunlight. Evergreen species provide year-round greenery, adding to both the aesthetic and cooling effects

6.3.1.1 Trees 5m to 10m in height planted 4m apart

To the existing case, 5m to 10m tall round and dense follage trees are modelled 4m to 6m apart with 4m X 4m hedges at the foot of the trees that are 1m in height on ENVI-met as illustrated in figure 38.

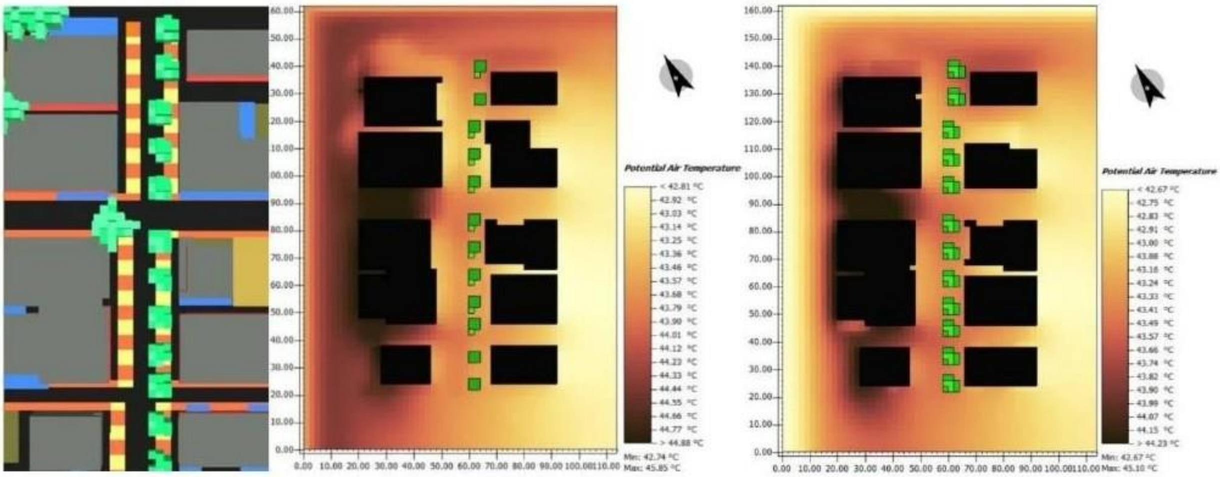


Figure 38- Spaces model with trees at 5m to 10m height

Temperatures at ground level and human height can be observed. The minimum and maximum temperatures averaged from the grid cells is 42.74°C and 45.85°C at 0.1m level and 42.64°C and 45.10°C at 1.5m level. As expected, the Temperatures decrease as we measure It higher from ground level.

6.3.1.2 Trees 10m to 20m in height planted 8m apart

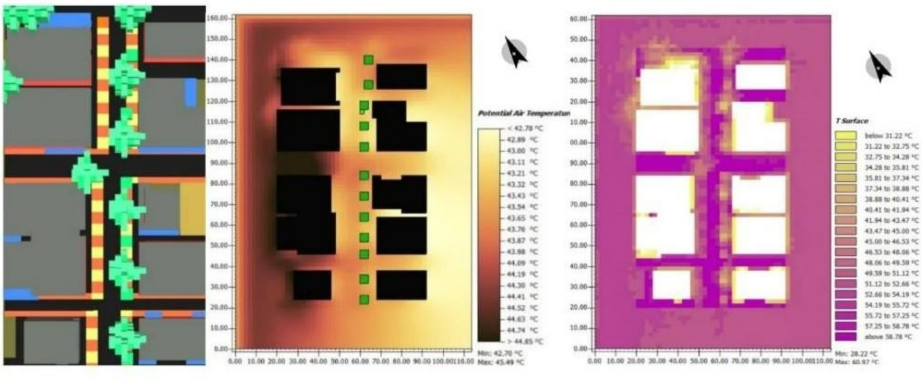


Figure 40- Spaces model with trees at 10m to 20m height

15m tall round and dense foliage trees are modelled 10m to 12m apart with 4m X 4m hedges 4m apart that are im in height on the ground level as seen the figure 40.

From the visualization charts, Maximum and minimum Temperatures at ground level are 42.70°C and 45.49°C. The overall average surface temperature of the modelled street decreased by 2.89°C compared to existing case with maximum temperature of 60.97°C.

6.3.2 Urban Shading

As the Sustainable Cities and society, 2020, suggests, the potential of sun sails as heat mitigation strategy at a street scale is significant. Testing it for Karol Bagh context could be one of the three mitigation strategies explored.

Existing shading modelled for base case and existing case is self-sourced Tarpaulin sheets usually made of Polypropylene or Polyethylene that have high absorption and low reflection values. Table & summarizes different tarpaulin sheet materials from low-grade to high-grade. detailing their properties for heat management gathered from varied sources (Wang, J. 2019,). is important to note that the properties of these materials vary with thickness and if additional coatings are done (Peng. Y, 2016)

Material	Grade	Properties	Reflection	Absorption
Polypropylene (PP)	Low	Lightweight, cheap, low UV resistance	Low	High
Polyethylene (PE)	Medium	Flexible, better UV resistance than PP, waterproof	Medium	Moderate
PVC-Coated Polyester	Medium-Good	Waterproof, UV resistant, fire-retardant, durable	Medium-High	Moderate - Low
Polyester-Cotton Blend	Good	Good breathability, durable, good thermal resistance	Medium	Low-Moderate

Table 8- List of existing Tarpaulin sheet types with properties

For the testing, sunshade salls are proposed along the high pedestrian activity street, to help reduce direct solar radiation exposure and quantify the heat reduction.

Material	Grade	Properties	Reflection	Absorption
High-Density Polyethylene (HDPE)	Medium	Breathable, UV stabilized, allows some air passage	Medium	Low
PVC-Coated Polyester Fabric	Good	Waterproof, strong, UV resistant	High	Low
PVC-Coated Polyester	Very good	Durable, high UV resistance, water-resistant	High	Low

Table 9- List of proposed Sunshade sails with properties

From the table 9, although the PVC coated sails are of best quality, due to their high cost and maintenance, HDPE sunshade sails are chosen for testing as they are cost-effective and are better than existing PP and PE Tarpaulin sheets. Two simulations are modelled at different heights from ground, to understand which level is best suited:

a) Sunshade Sails at 2m

b) Sunshade Sails at 4m

6.3.2.1 Sunshade Sails at 2m

Sunshade sails of 2m X 2m are modelled for 16m2 to 24m2 along the street 4m apart at 2m height. The existing Tarpaulin sheets are replaced with HDPE sails. The sails are proposed on either side of the road above the footpath. Since these sails are low in height, they can be extended from building facades, store fronts or erected as part of hawker stalls. The placement of the sunshade sails can be observed in green color on the ENVI-met model in figure 43.

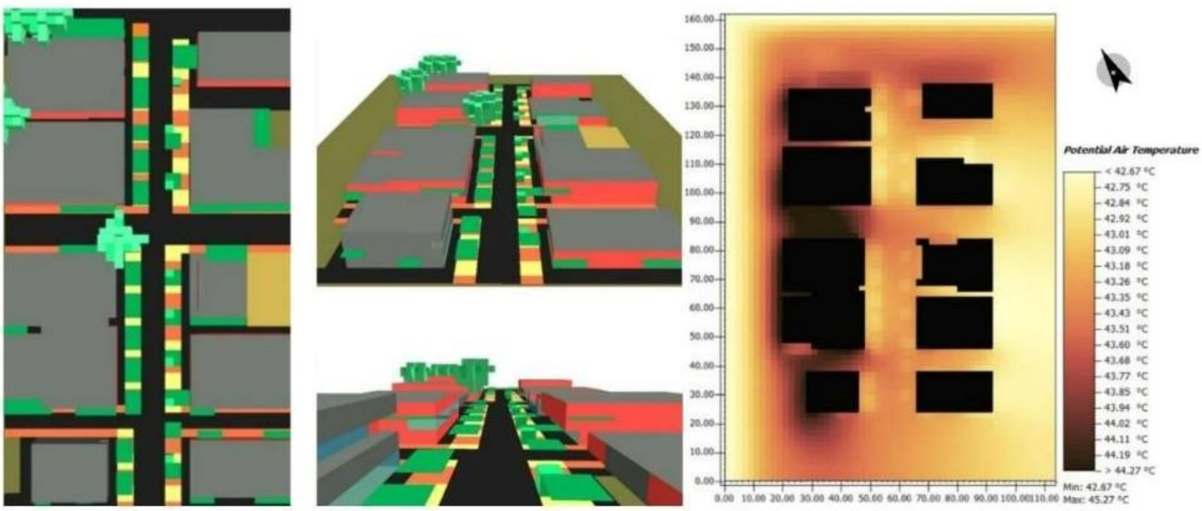


Figure 43a,43b and 43c- Spaces model with sun sails at 2m height

From figure 44, Temperatures at ground level and human height can be observed. The minimum and maximum temperatures averaged from the grid cells is 42. 73°C and 46.07°C at 0.1m level and 42.67°C and 45.27°C at 1.5m level. The results at 2m are similar to 5m to 10m tall trees.

At 2m height, sails are closer to the people and objects beneath them, providing better direct shading and reducing the immediate temperature in the shaded area. But the airflow under the sail is restricted, meaning it could trap some heat even when breathable materials like HDPE are used

6.3.3 Urban Albedo

Improving pavement is an effective strategy to mitigate the impacts of extreme heat in urban settings (Synnefa, A.,2008) as pavements cover a significant portion of the surface in cities.

Albedo is the fraction of light that is reflected by a surface. By incorporating pavers with higher Albedo and those capable of reducing surface temperatures, the temperatures at ground level can be controlled to alleviate heat stress for the targeted vulnerable groups during peak summers,

Material	Albedo	Properties	Reflection	Absorption
Asphalt (Bitumen)	0.1 - 0.15	commonly used for roads, contributes to UHI, Durable	Very Low	Very High
Sandstone / Limestone	0.20 - 0.35	Natural stone, porous, slower heat release, used extensively in Delhi	Low	High
Cement Concrete	0.35 - 0.40	Dense, non-porous, High strength, medium durability	Medium	Moderate-high
Porous concrete	0.35-0.50	Porous structure allows for cooling via water retention and air flow	Medium-High	Moderate
Dark Granite	0.2 - 0.3	Dense, low porosity, slow release, extensively available in Delhi	Low	high
Light Granite	0.45-0.6	Dense, durable, slower absorption due to reflective surface, readily available in Delhi	High	Low

Table 10- List of pavement materials with properties

To assess the impact of different pavement materials on the microclimate, sandstone and light colored granite were selected for simulation, representing the existing and potentially most effective options.

6.3.3.1 Sandstone Pavement

Ajmal Khan Road's existing 4-meter-wide sidewalks on both sides are paved with red and yellow sandstone pavers. To assess the potential impact of replacing the entire street with sandstone pavers, figure 47 is modelled This scenario would create a fully pedestrianized street, potentially enhancing its social value.

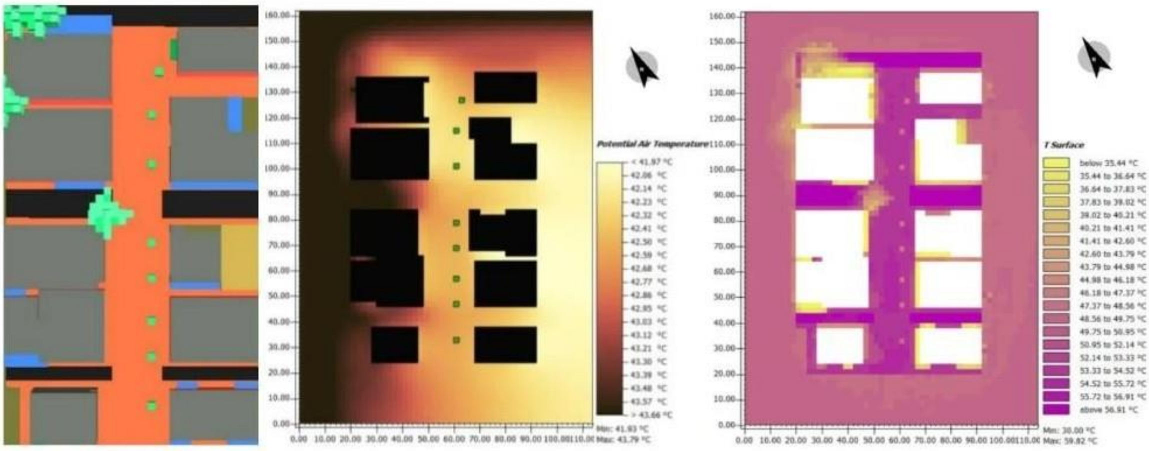


Figure 47- Spaces model with Sandstone pavers

From figure 48. Temperatures at ground level averaged from the grid cells is 41.93°C and 43.79°C. Simulations indicate that replacing the entire street with sandstone pavers could potentially reduce temperatures by nearly 2°C

Sandstone pavers are widely used in Delhi for its availability and aesthetic appeal While it is porous and absorbs heat, it also has the advantage of slowly releasing that heat, which can mitigate the immediate surface temperature rise during peak afternoon hours. However, because sandstone has a relatively low heat reflectivity, it might not be the best.

6.3.3.2 Granite pavement

Granite is highly durable and is extensively used as a building material in India. While Dark coloured granite stone is unsuitable for mitigating heat due to its low albedo and high absorption, light-coloured granite, with an albedo range of 0.4 to 0.6, is one of the best option after concrete pavers for urban footpaths.

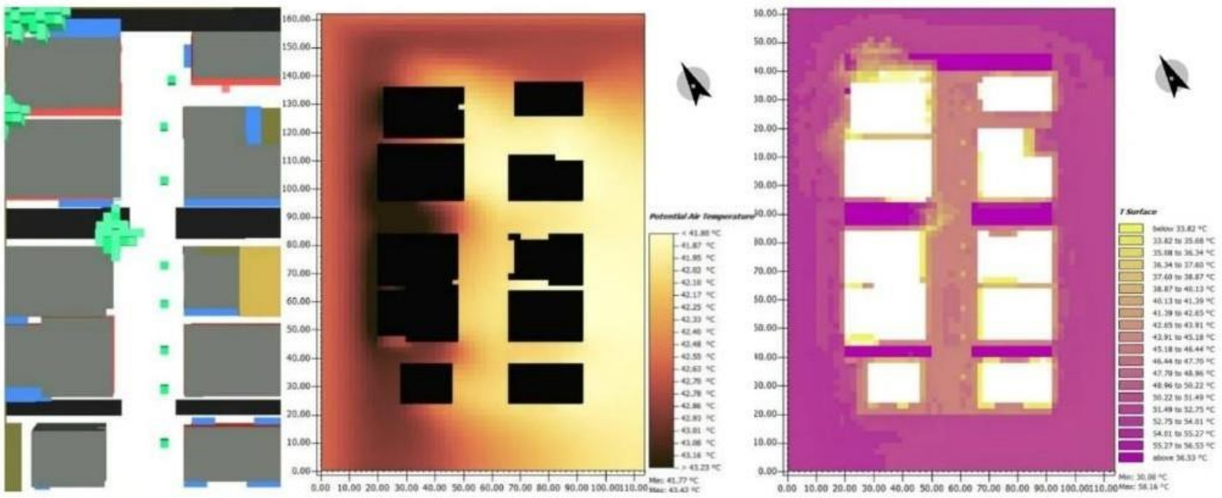


Figure 50- Spaces model with Granite pavers

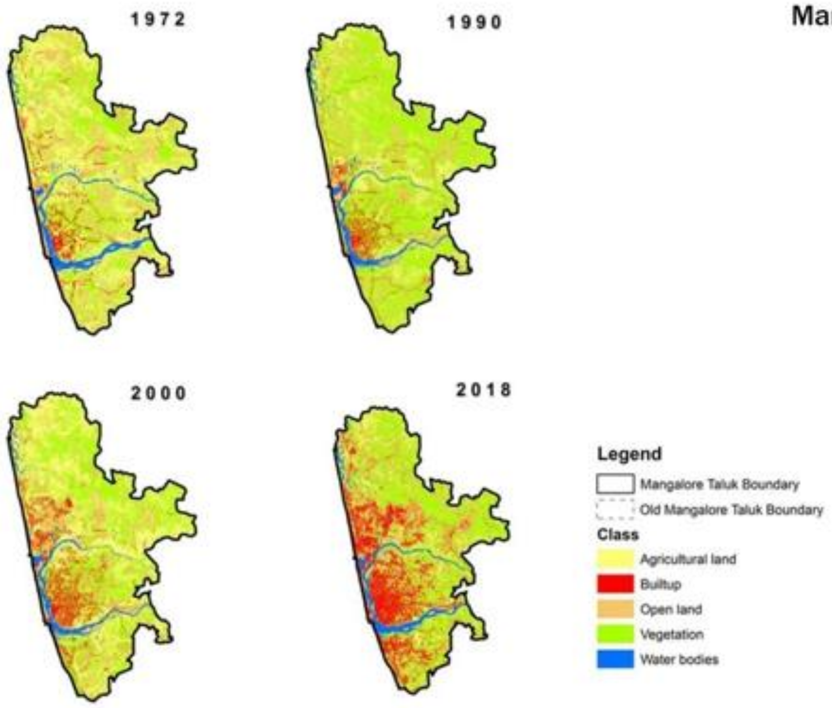
The minimum and maximum temperatures at ground level averaged from the grid cells are 41.78°C and 43.74°C from figure 52. It is the most effective strategy from all the ones discussed in previous sections Also, from Surface Temperature chart in figure 52, maximum average reduced to 56.160°C.

7. SITE STUDY

Mangalore - Site Introduction

Mangalore, officially known as Mangaluru, is the major port city of the Indian state of Karnataka. It is located between the Arabian Sea and the Western Ghats mountain range about 352 km (219 mi) west of Bangalore, the state capital. Mangalore is the only city to have all four modes of transport—air, road, rail and sea. The population of the urban agglomeration was 619,664 according to the 2011 national Census of India.

Mangalore



From the Land Use pattern it was observed that the major hotspots of the city grew over the span of 45years
The study focused on three key areas within the city, namely Lalbagh, Bunder, and Jyothi. These locations were examined through various means, including the analysis of Google Earth images, figure ground mapping to assess density, land use mapping, and on-site visits. These initial observations formed the basis of the study's investigation.

Site Selection

JYOTHI

Satellite Image

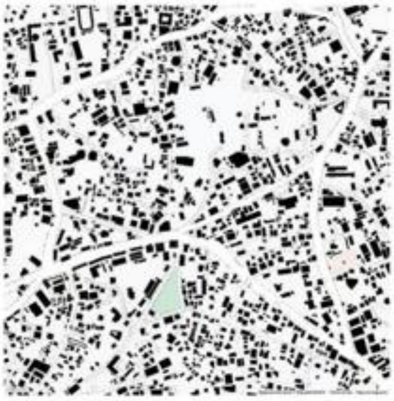


Figure ground Map

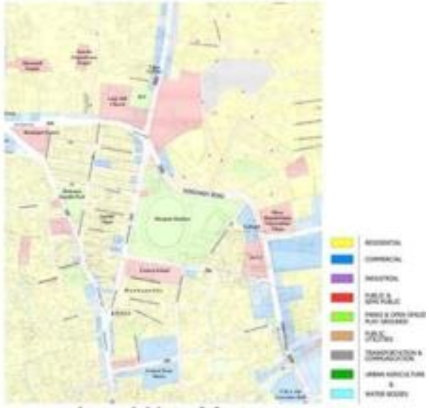
Land Use Map

The first site in Jyothi displays abundant vegetation and low building density. The land use map confirms residential and commercial areas limited to the main roads. Ample public and green spaces are present for the community. The figure ground map shows a modest level of built density.

LALBAGH

Satellite Image

Figure ground Map



Land Use Map

Lalbagh's satellite image reveals abundant vegetation, while the land use map shows fewer commercial buildings, reducing human activity and vehicle movement. The presence of public and green spaces provides the community with ample access to open areas. This is further reflected in the figure ground map, which displays a sparsely built environment in Lalbagh.

BUNDER

Satellite Image

Figure ground Map

Land Use Map

The land use map reveals a scarcity of vegetation and open spaces on the site, with a predominantly commercial land use pattern. This indicates a shortage of green areas and a bustling environment. The figure-ground map strengthens this finding by illustrating a dense concentration of buildings within the site.

Bunder Site Introduction

Mangalore

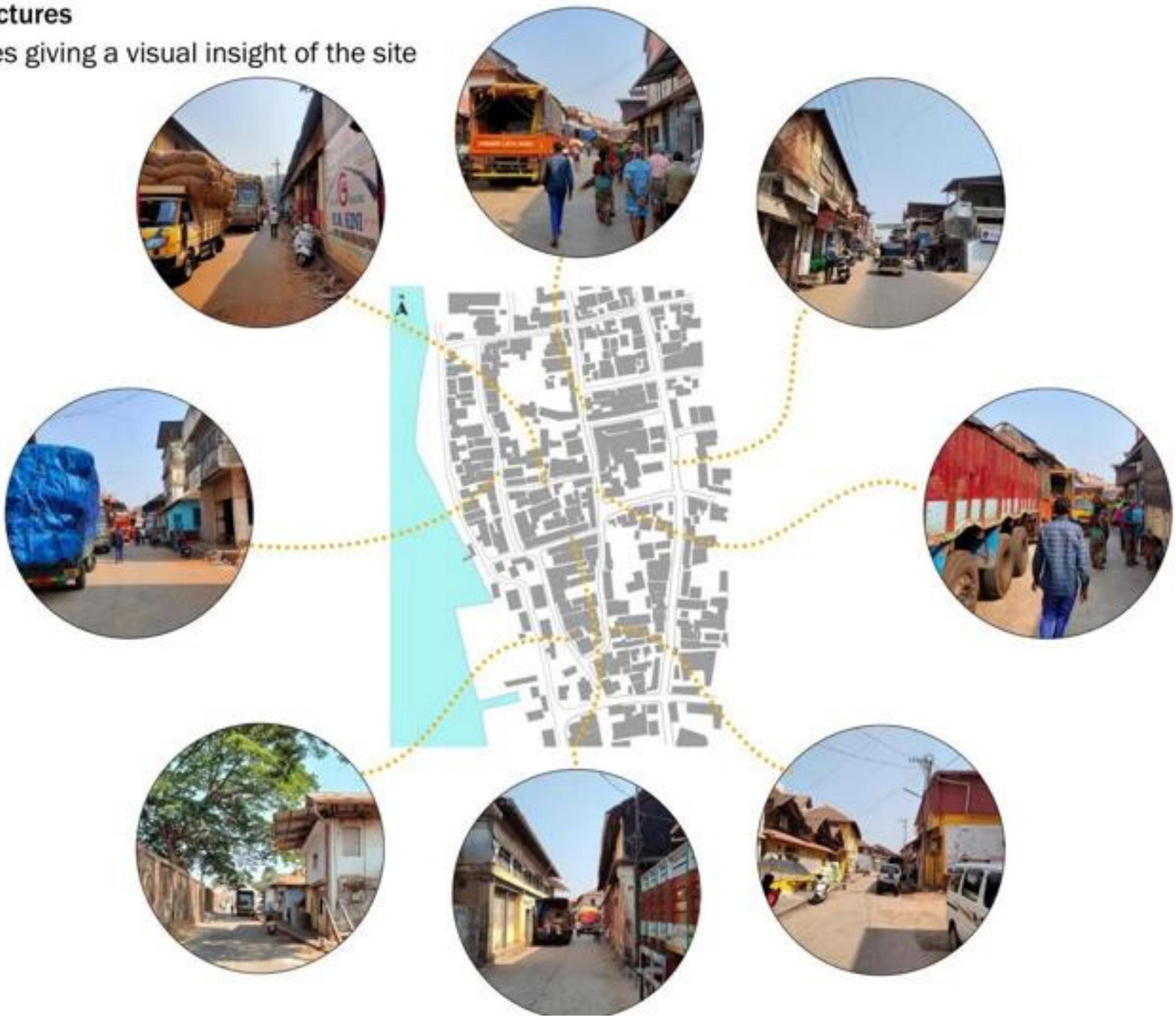
Study Area: Approx.124,900.28 square meters (approximately 0.12 square kilometres).

Bunder

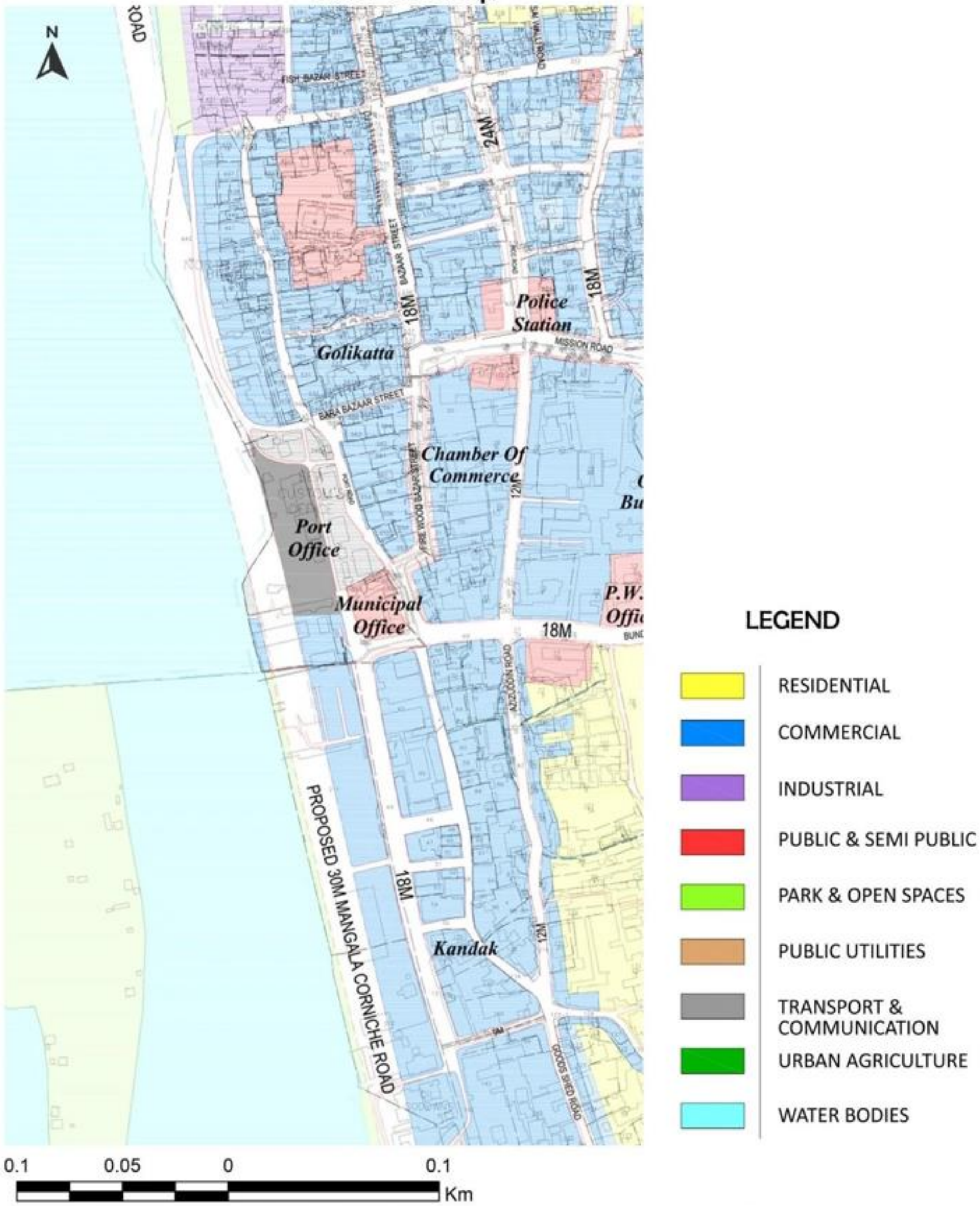
Bunder has emerged as the primary hub for business activities, attracting major trading operations. Consequently, Bunder has transformed into a residential area for various trading communities. The existence of the old port has greatly stimulated the rapid expansion of trade and commerce in this region. The unplanned development of the settlement areas has led to densely packed settlements with narrow lanes, creating a clustered environment. Unfortunately, this unplanned growth has also resulted in increased congestion within the area.

Site Pictures

Pictures giving a visual insight of the site



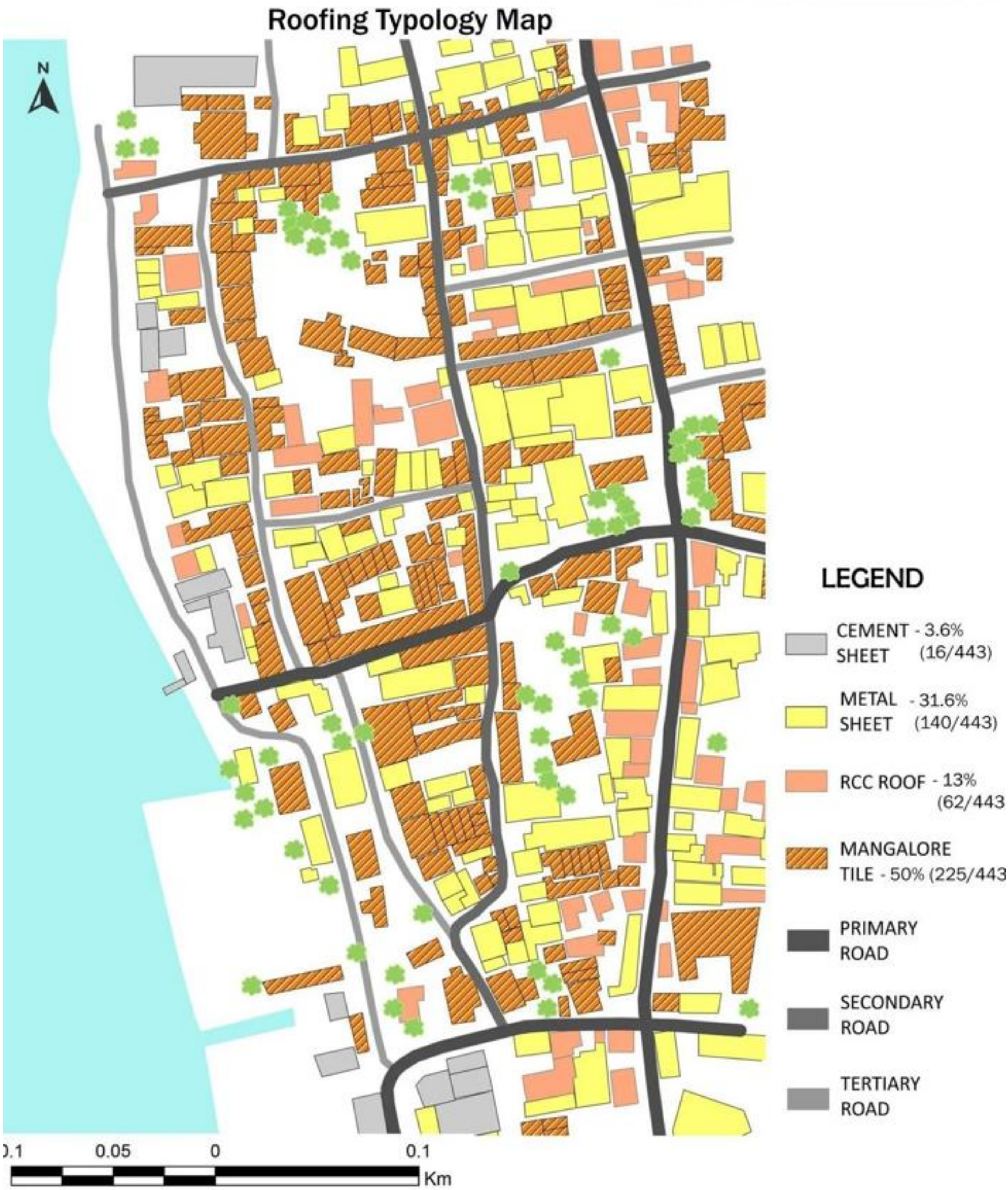
Land Use Map



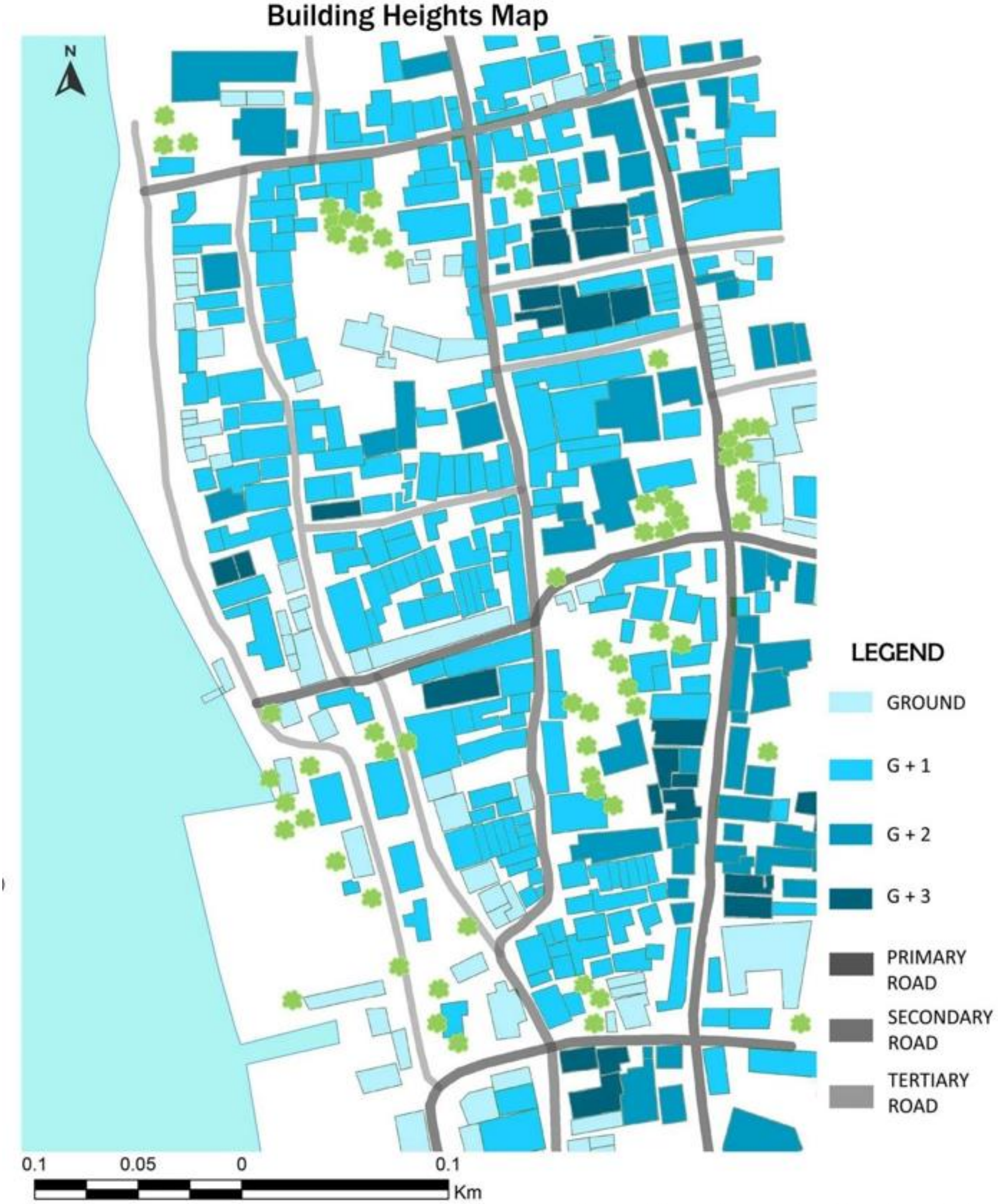
Based on the depicted Land Use Map of the study area, it is apparent that commercial areas dominate the surroundings of the site. This indicates a substantial presence of business and trade activities in the vicinity. Consequently, the site experiences a significant volume of pedestrian traffic and vehicular movement due to the high level of commercial

The Building Typology Map is generated by gathering primary data and conducting on-site documentation. Its purpose is to give an overview of the different types of buildings present in a particular area. By examining this map, one can identify the diverse uses of the buildings on the site, such as instances where specific units have residential spaces on their first floors while the ground floors are allocated for commercial activities and shops.

The figure-ground map of Bunder indicates that 64% of the total area is occupied by built structures, while the remaining 36% consists of open spaces. This suggests high urbanization and a scarcity of trees and vegetation, leading to heat retention and discomfort during peak hours. The lack of greenery worsens the heat island effect, where the urban environment retains and radiates more heat than rural areas. The heterogeneous mixture of buildings further compounds the heat-related challenges by limiting the presence of natural shade and heat mitigation.



This data is crucial for comprehending the roofing typology within the area, enabling us to better understand the implications for the urban heat island effect. Furthermore, it serves as a valuable resource when determining appropriate interventions for each specific roof type. By analysing the prevalence of different roofing materials, we can develop targeted strategies to mitigate heat absorption and optimize energy efficiency.



The map illustrates the varying heights of the buildings on the site, providing insights into the vertical variations of the structures. It aids in understanding the distribution of the population across the buildings and quantifies the contribution of the buildings to the urban heat island effect. The Figure Ground analysis reveals the site's spatial configuration, while the Building Height Map indicates building height variations. Together, these assessments classify the site as LCZ 2 B, denoting densely packed midrise buildings and limited vegetation. This classification assists in understanding the site's urban form and characteristics, informing urban planning and environmental considerations.

Activity Mapping 9:00 AM

During the observed timeframe from 9:00 AM to 9:30 AM, it can be inferred that the site becomes active for trade and other commercial activities. The movement of vehicles towards the designated loading and unloading areas is noticeable. Pedestrians can be seen walking on the streets, engaged in their daily routines, while a specific group of individuals is occupied with work related to loading and unloading. The parked vehicles are predominantly found on the tertiary roads where the shops are present, while private vehicles predominantly utilize the primary road for their movement.

Activity Mapping 12 Noon

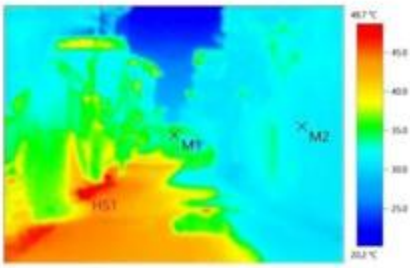
The activity mapping was specifically conducted from 12 noon to 12:30 PM, revealing an ongoing level of commercial activity throughout the site. However, compared to the morning hours, there was a noticeable decrease in the density of commercial vehicles, as well as a reduction in loading and unloading activities taking place on the streets. Despite these changes, significant commercial activities persisted until the peak afternoon period, after which a sense of relaxation and a lunch break from the bustling atmosphere prevailed. The highlighted zones in the site indicate the busy focal points, where eateries are prominently located.

Activity Mapping 4:00 PM

Between 4 PM and 4:30 PM, an observation was made regarding the activity mapping. It was noted that during this time, the site experiences a sense of calmness. The bustling commercial activities that typically occur throughout the day start to wind down, and the streets become less hectic. Loading and unloading operations come to a halt, and vehicles begin to make their way back to the main roads, heading towards their respective homes. Gradually, the site starts to declutter as the day's work concludes. However, the eateries in the area remain lively, as they continue to serve tea, coffee, and snacks to cater to the tired individuals after their busy day.

Sample Thermal Imagery

Actual Image



IR Thermal Image

Testo IR thermal imager was a device utilized to measure the highest and lowest temperatures, as well as identify the materials associated with these temperature readings at 20 different junctions within the site.

The majority of materials that tend to retain heat are metal sheets, concrete pavement, concrete roads, tar roads, parked vehicles, and plastic tarpaulins. On the other hand, vegetation, trees, shaded pavements, and walls generally remain cooler throughout the day. This information will be valuable for further analysis and intervention in the thesis.

Endothermic materials around site

METAL ROOF

MANGALORE TILE

CEMENT SHEET

ASPHALT ROAD

CONCRETE ROAD

CEMENT PAVEMENT

WALL PLASTER

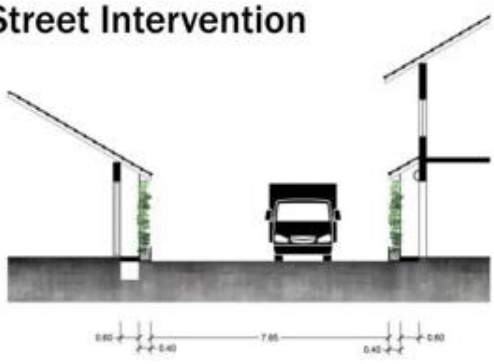
RCC SLAB

8. DESIGN PROPOSAL

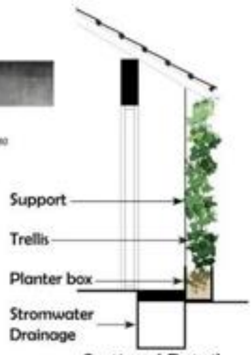
Architectural Intervention

The map displayed above illustrates the roofing intervention conducted. The Mangalore tile, which did not contribute to the Urban Heat Island (UHI) effect, was left untouched. However, the sheet roofing underwent an intervention involving the application of high albedo paint. This paint serves the purpose of reflecting solar radiation, thereby assisting in the reduction of heat at the canopy level. The RCC roof was layered with recycled clay tiles to further reduce the heat.

Street Intervention



Street Section of Green facade

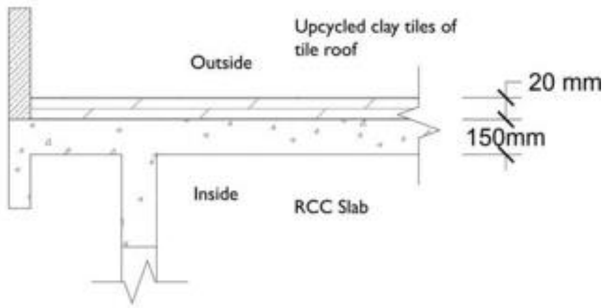


Sectional Detail

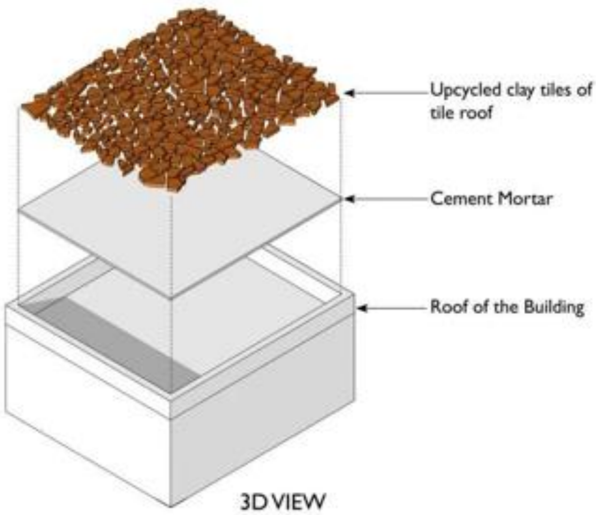
3D View

The street was proposed with 'Green Intervention to reduce the heat. The Green Facade would cater to the reduction of outdoor colling and indoor colling by reducing the solar radiation

Roof Intervention



TYPICAL SECTION



3D VIEW

The existing RCC roof was proposed an innovative method of laying upcycled clay tiles, since there is adundance of tiles. The tiles were laid on RCC roof to reflect off the heat.

Material Intervention Proposals

Cement Pavement
(Existing)

Green Pavement
(Proposed)

Pedestrian Pavement Intervention

Metal Sheet
(Existing)

High Albedo Paint
(Proposed)

Metal roof Intervention

Urban Planning Intervention

For the proposal of Urban Gardens, the intervention areas at the Urban Neighbourhood level, where three distinct sites were identified based on land use and population density. These selected sites overlapped with high concentrations of people. Consequently, these sites were deemed suitable for the implementation of an Urban Green pocket proposal.

Urban Park 1


Walking Path
Food Stalls
'Katte's'
B'
B'
Washroom
Maintenence Room
Store Room
Total area of the Park : 3080m²
N
0 5 10 20 m

Urban Park 2

Urban Planning Intervention

Urban Park 3

Sections

Section AA'

Section BB'

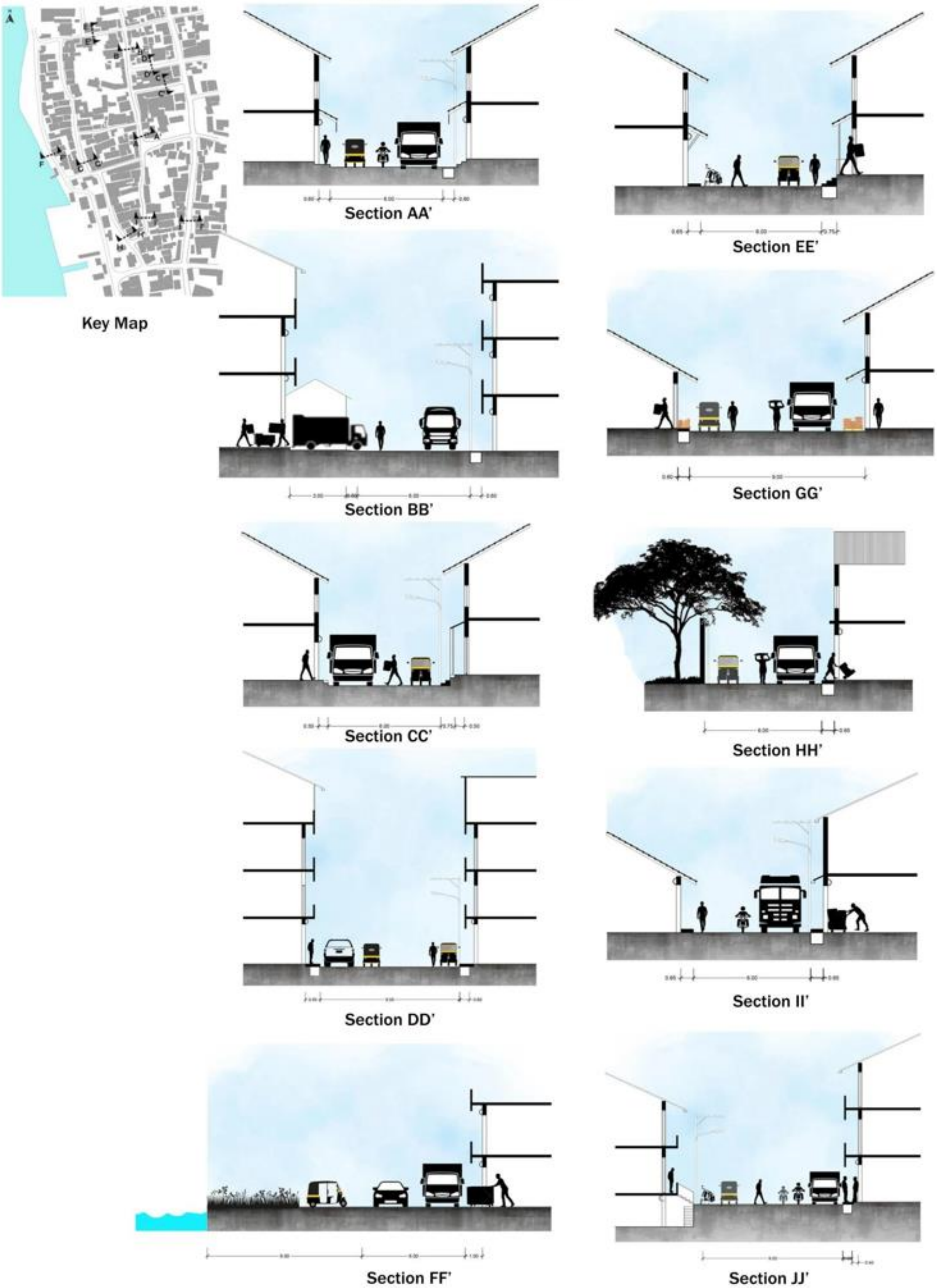
Section CC'

ACTIVITY MAPPING - 9 AM


ACTIVITY MAPPING - 12 NOON
N
LEGEND
- PEOPLE MOVING
- PEOPLE EATING
- PEOPLE WORKING
- MOVING TRUCK
- MOVING PVT. VEHICLE
- PARKED VEHICLE
- LOADING & UNLOADING
- EATERIES
0.1
0.05
0
0.1
Km


ACTIVITY MAPPING - 4 PM
N
LEGEND
- PEOPLE MOVING
- PEOPLE EATING
- MOVING TRUCK
- MOVING PVT. VEHICLE
- EATERIES
0.1
0.05
0
0.1
Km

STREET SECTIONS



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