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OPTIMUM PERCENTAGE OF TREE COVER TO ACHIEVE THERMAL COMFORT

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Abstract : Urbanization trends worldwide have led to a multitude of challenges, including increased air pollution, rising temperatures, and diminishing green spaces. Trees play a multifaceted role in promoting environmental sustainability by acting as carbon sinks, filtering pollutants, and contributing to urban biodiversity. Their presence contributes to improved air quality, as they absorb pollutants and release oxygen, thereby fostering a healthier living environment. While acknowledging the myriad benefits of urban trees, it is crucial to consider the potential drawbacks associated with dense tree cover. The question which arises here is that what is the optimum tree cover to achieve thermal comfort, avail maximum benefits of the trees and reduce the potential drawbacks. While the integration of trees in urban environments offers a plethora of advantages, this abstract delves into the potential disadvantages associated with dense tree cover in urban areas. While trees contribute significantly to environmental sustainability and human well-being, an excess of tree density may pose challenges to urban infrastructure and management.
This research will help in determining the optimum tree cover to achieve thermal comfort. The study is conducted in four different sites in Lucknow with different tree covers, considering various aspects like temperature, relative humidity, CO2 concentration, air velocity, sky-view factor. The study intends to understand the benefits and drawbacks on each site and provide with the optimum percentage of tree cover to achieve thermal comfort.

IndexTerms* -: wet *bulb temperature, relative humidity, CO2 concentration, air velocity, sky-view factor.

I. INTRODUCTION

1.1.Background

Urban trees support urban sustainability by contributing to the environmental, economic, and social health of urban communities through provision of key ecosystem services. Thus, enhancing and protecting urban trees is necessary to make cities inclusive, safe, and resilient. Trees behave in different ways on microclimate due to mainly distinct features of each species and planting strategies especially in the tropics. Assessing the role of urban green space on the health of city residents is a grand environmental challenge.

Global trends in urbanization have brought about a number of problems, such as a rise in air pollution, an increase in temperature, and a reduction in green space. Trees are important for environmental sustainability because they absorb carbon dioxide, filter pollutants, and increase biodiversity in metropolitan areas. Because they emit oxygen into the atmosphere and absorb contaminants, their presence helps to enhance the quality of the air, making living spaces healthier. Even though urban trees have many advantages, it's important to take into account any potential disadvantages that come with a high canopy of trees. What is the ideal tree cover in this situation to maximize tree benefits, minimize potential negative effects, and attain thermal comfort.

1.2. Aim

The aim of the study is to determine the optimum percentage of tree cover in order to have the impact on reducing the heat island effect and improving the micro-climate of the site.

1.3. Objectives

- Identification of four different sites with different percentage of tree cover in Lucknow.
- Collection of data on WBGT, CO2 concentration, Sky-view factor and air velocity every site with the help of devices.
- Analysis and comparison of data collected on the sites.
- Finding out the optimum percentage of tree cover which helps in reducing the heat island effect on site through the data collected.

1.4. Methodology

In this study, the percentage of tree cover in four different sites were examined by focusing on WBGT, air velocity, sky-view factor, CO2 concentration and humidity. The selected cases represent different percentage of tree cover in different sites in Lucknow. The data was collected using different instruments like Heat Index WBGT meter, Surface Temperature, Multi-functional Air Quality Detector, Digital Anemometer. The data collected was analysed and compared which led to the conclusion.

1.5. Scope and Limitations

- The parameters which will be considered are WBGT, Relative humidity, CO2 concentration, Sky-view factor and air velocity
- The sites were selected on the basis of different % of tree cover in a single neighbourhood.
- The data will be collected on site with the use of devices.
- No survey will be conducted

II. LITERATURE STUDY

2.1. Introduction

This chapter provides a review of the literature and secondary data that already exists in relation to the optimum tree cover in urban area, the various parameters that relate to this, and how they can be applied to obtain optimum thermal comfort in outdoors. Accordingly, this chapter will initially discuss the components associated with urban tree cover, it will then move on to describe and analyse the parameters like air velocity, CO2 concentration Relative Humidity, Temperature, etc. This chapter will also provide an analysis of urban tree cover and its effects on outdoor environmental quality.

2.2.Definitions and Components related to Tree Canopy

Urban open space provides various benefits to citizens, but the thermal environment of this space is impacted by global warming and urban heat islands.(Lai et al., 2019) Tree planting is a powerful ecological restoration method that is frequently used around the world(Cao et al., 2017) to decrease the effect of global warming and reduce urban heat islands. Urban trees ameliorate heat stress for urban dwellers (Chen et al., 2021). However, there are several aspects that contribute to advantages or disadvantages of trees in urban form.

2.2.1. Temperature

Trees effectively reduce thermal radiation in urban open spaces. By reflection and absorption, trees can remove a great amount of incoming short-wave solar radiation.(Lai et al., 2019) Reduction of thermal radiation helps in reduction of air temperature and provide thermal comfort. The air temperature reduction of an unshaded and tree-shaded area in a high SVF domain was found to differ significantly, despite the fact that the differences with medium-low SVF were not statistically significant.(Morakinyo et al., 2020) Surface temperature is also affected by the tree canopy.

Clusters of trees can mitigate temperatures to a greater extent compared with individual trees. Trees release water vapour through a process called transpiration. This evaporative cooling can further lower temperatures in the surrounding area. The combination of shade and evapotranspiration contributes to the creation of cooler microclimates. In urban environments, trees play a crucial role in mitigating the urban heat island effect. They provide shade, absorb solar radiation, and release moisture through transpiration, collectively helping to cool the air and surfaces in built-up areas.

2.2.2. Air Velocity

Urban trees reduce air velocity. The highest outdoor thermal stress is observed during clear sunny days with calm wind in the summer season.(Srivanit & Hokao, 2013)Tree coverage can have a significant impact on air velocity in outdoor environments. Trees act as natural windbreaks, slowing down the speed of the wind as it passes through their leaves and branches. Tree coverage contributes to the creation of microclimates. In sheltered areas with dense tree cover, the air velocity may be lower compared to open areas. Sidewalk trees could reduce wind speed under the canopy by up to 51%(Chen et al., 2021). The more open the urban form, the more exposed it is to wind increasing the velocity. Studies have shown that buildings can enhance or buffer winds, thus changing wind patterns(Gregory McPherson David Nowak Rowan A Rowntree McPherson et al., 1994)

2.2.3. Relative Humidity

Tree cover can influence relative humidity in the outdoor environment through various mechanisms, primarily related to the trees' role in water vapor exchange. Tree canopies provide shade, which helps to cool the surrounding air. Cooler air has a reduced capacity to hold water vapor, leading to an increase in relative humidity. Trees act as windbreaks, reducing wind speed at ground level. Slower-moving air allows for better moisture retention, and as a result, relative humidity can increase. This effect is particularly noticeable in sheltered areas with dense tree cover.

2.2.4. Carbon Dioxide Concentration

The presence of trees can create microclimates, and the effect on CO2 concentration at night can be influenced by factors such as temperature, wind patterns, and the overall density of vegetation. In sheltered areas with dense tree cover, the mixing of air may be reduced, potentially leading to higher localized CO2 concentrations. While trees release CO2 through respiration at night, their overall contribution to nighttime CO2 concentrations needs to be considered in the broader context of their positive impact during the daytime. The balance between daytime carbon sequestration and nighttime respiration is essential for understanding the overall role of tree cover in regulating carbon dioxide concentrations.

2.2.5. Skyview Factor

The sky view factor (SVF) refers to the ratio of the visible sky area to the entire hemisphere above a specific location. It is often used to quantify the openness or obstruction of the sky as perceived from a particular point on the ground. Dense tree cover, with a thick canopy of leaves and branches, obstructs the view of the sky from ground level. The dense foliage limits the visible portion of the sky, leading to a lower sky view factor. In urban environments, dense tree cover in parks or green spaces can influence the SVF. The presence of tall buildings and dense vegetation can create areas with lower SVF, affecting the perception of the sky and sunlight availability.

2.3. Conclusion

Tree coverage can both reduce and enhance air velocity in outdoor environments, depending on various factors. The specific characteristics of the tree cover, local topography, and weather conditions all play a role in determining the impact on air movement. It can significantly influence outdoor temperatures by providing shade, reducing wind speed, releasing moisture, and contributing to the overall thermal regulation of an environment. It's important to note that the impact of tree cover on relative humidity is context-dependent and can vary based on factors such as tree species, local climate, and the overall environmental conditions. While trees contribute to higher humidity levels in some situations, the specific effects may differ across different regions and ecosystems. While trees have a positive impact on reducing CO2 concentrations, the overall balance depends on factors such as tree species, density, and the environmental context. Dense tree cover generally leads to a lower sky view factor due to the obstruction of the sky by the canopy. The extent of this effect depends on factors such as the density of the tree cover, the specific characteristics of the vegetation, and the local microclimate conditions. While dense tree cover may limit the visible sky, it also contributes to various ecological, aesthetic, and microclimatic benefits in outdoor environments.

III.CASE STUDY

In a research study focused on determining the optimum percentage of tree cover to achieve outdoor thermal comfort, incorporating case studies can enhance the depth and applicability of the research.

3.1. Identification and selection criteria

The case studies are selected by considering the following parameters in different papers:

- WBGT
- Relative Humidity
- Sky view factor
- Air velocity
- CO2 concentration

3.2. Case Study 1: Effects of tree plantings and aspect ratios on pedestrian visual and thermal comfort using scaled outdoor experiments

In Guangzhou, large-scale outdoor trials were carried out to look into how planting trees affects pedestrians' thermal and visual comfort in street canyons with different aspect ratios..(Chen et al., 2021)

Measurement site and period

Between October and November 2019, the experimental study was conducted using the SOMUCH platform in Panyu, Guangzhou, P.R. China

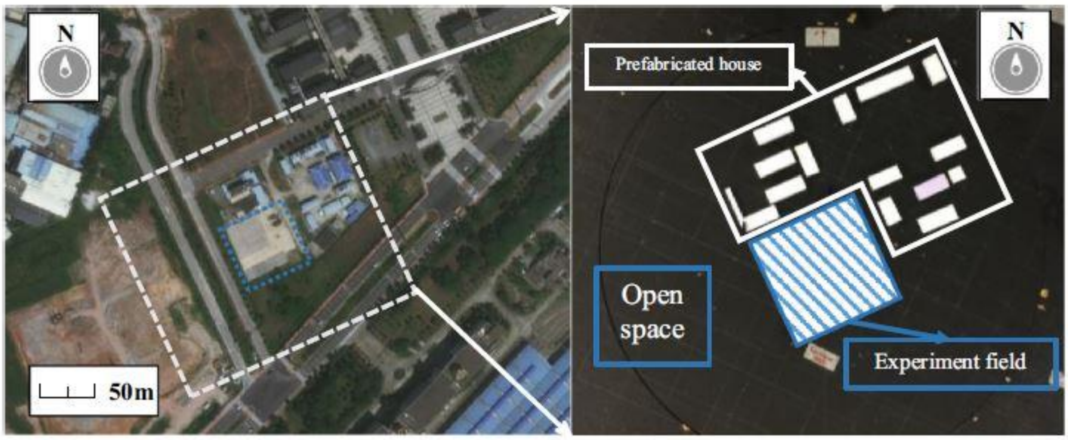


Figure 1.Selected experiment field in the suburb of Guangzhou, showing the surrounding buildings and open space

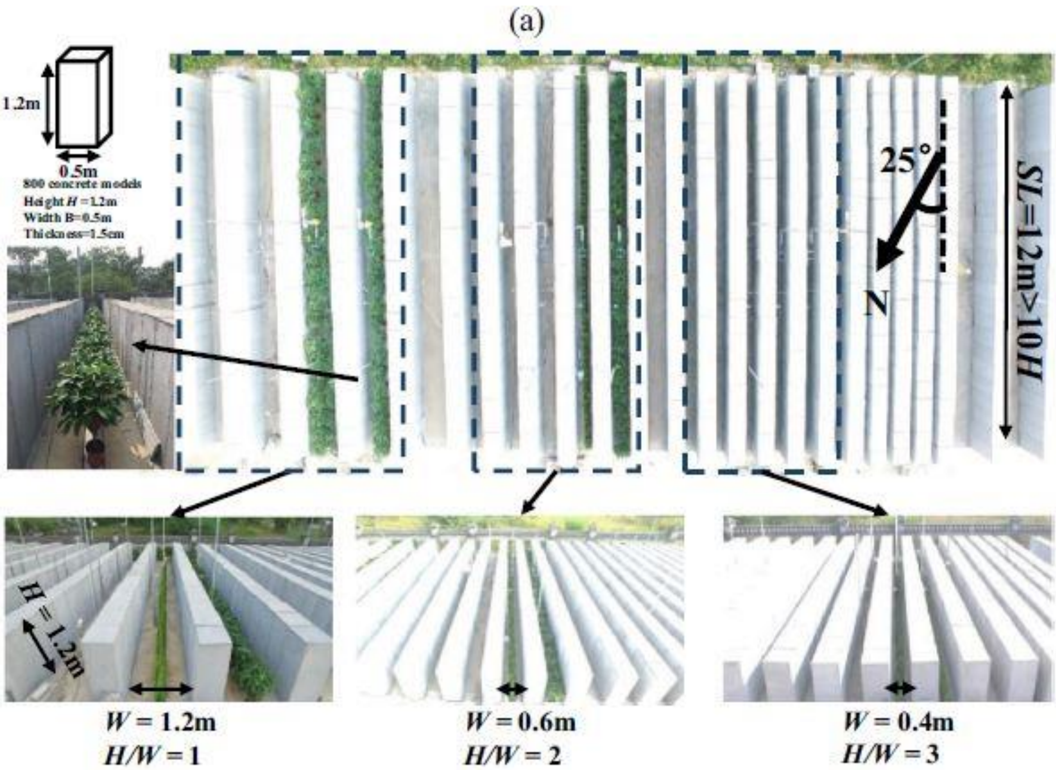


Figure 2.Top view of the experiment site of scaled outdoor field and street canyons with three aspect ratios H/W=1, 2, 3.

Tools used for study

- 3D ultrasonic anemometers,
- omni-direction hot-ball anemometers,
- thermocouples,
- light and humidity sensors,
- a sun tracker to measure the wind speed and turbulence,
- air temperature,
- globe temperature,
- surface temperature,
- illuminance,
- relative humidity,
- background global
- net radiation

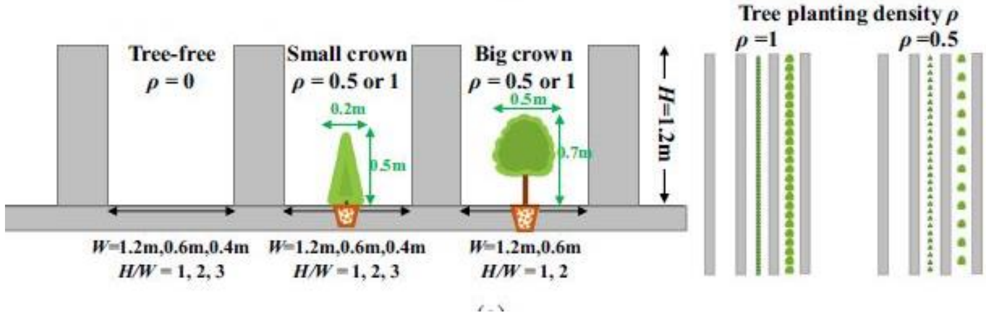


Figure 3.Detailed study on site

Conclusion

This study develops an outdoor experiment at a realistic scale to examine the effects of urban architecture and plants on thermal and visual comfort. According to the results, big crown trees should be planted in streets to efficiently cool the pedestrian area throughout the day, enhancing body and eye comfort. The wider the roadway canyon, the greater the cooling effect. We do not recommend planting trees at a lower density because doing so may decrease their capacity to shade an area. Urban planners may choose to plant little crown trees to provide some shade when giant crown trees are not an option in tight roadway canyons (such H/W = 2, 3).

3.3. Case Study 2: Tree effects on urban microclimate: Diurnal, seasonal, and climatic temperature differences explained by separating radiation, evapotranspiration, and roughness effects

The effects of trees are investigated over a one-year period in four cities with radically different climates: Phoenix, Singapore, Melbourne, and Zurich. To ascertain the background climatic forcing, UT&C requires meteorological input time series above building height, which were accessible in Phoenix, Singapore, and Melbourne. Since the meteorological input forcing in Zurich was measured at 2 m height (10 m for wind speed), there is some degree of uncertainty in the absolute simulated air temperature at 2 m height in the Zurich scenario.(Meili et al., 2021)

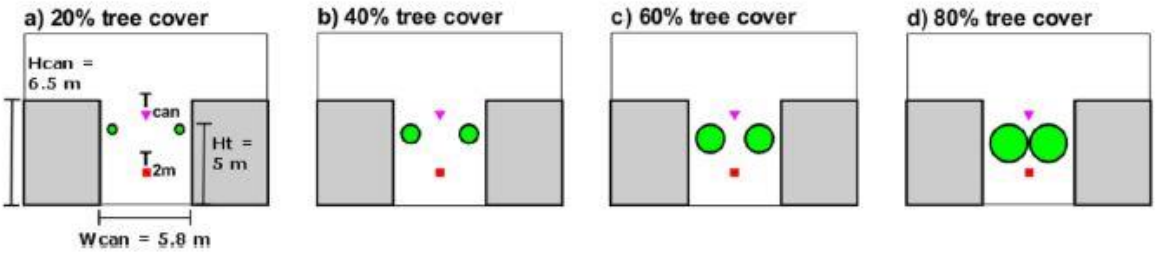


Figure 4.Modelled urban geometry with a) 20 %, b) 40 %, c) 60 %, and d) 80 % tree cover within the urban canyon of a compact low-rise residential neighbourhood

Parameters considered

- Direct and diffuse shortwave radiation,
- Long-wave radiation,
- air temperature,
- humidity,
- wind speed,
- precipitation, and
- air pressure

Conclusion

This study measures the impacts of well-watered urban trees on air temperature below and above the tree canopy, as well as the radiation, evapotranspiration, and aerodynamic urban roughness alteration effects. The effects' partitioning enables the explanation of discrepancies in the air temperature changes that trees are observed to cause for various seasons, times of day, and climatic background circumstances. In all of the climates examined by simulations, tree evapotranspiration has the potential to lower urban canopy layer air temperature. However, this effect is only partially realized during the hottest times of the year, particularly in arid climates where stomatal conductance is significantly decreased at high VPD.

3.4. Case Study 3: Thermal comfort in urban spaces: impact of vegetation growth Case study: Piazza della Scienza, Milan, Italy

This paper describes a study on the effects of plants on evolution in a freshly constructed square in Milan that was designed by V. Gregotti. The work's objective is to assess how consumers' comfort is affected by vegetation growth. The methodology used includes a simplified thermal comfort evaluation using the energy budget method COMFA, a scenario for the growth of vegetation, and sets of field measurements (air and radiant temperature, wind velocity, and relative humidity). As trees reach adulthood, several phenomena become apparent. Even with a high air temperature, the shading effect under an old tree canopy clearly demonstrates a reduction of the absorbed radiation by users, creating an energy budget very close to comfort (around 50 W/m2). (Picot, 2004)

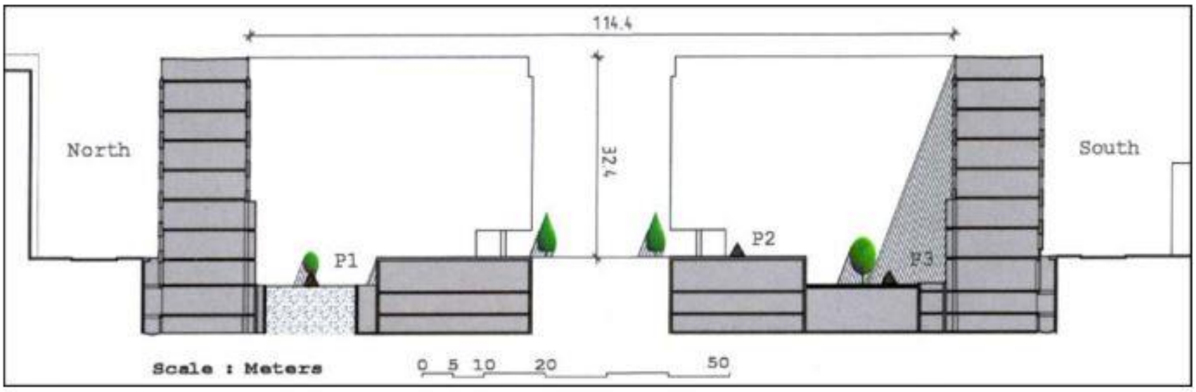


Figure 5.Section of the square: year 2002

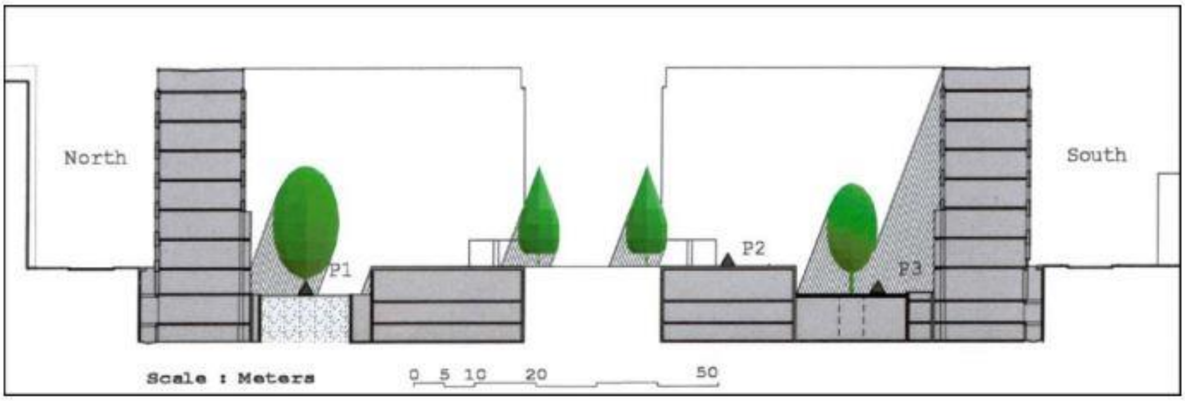


Figure 6.Section of the square: year 2032

Conclusion

The findings demonstrate that vegetation—which in the current case study becomes a reality when trees reach their adult dimensions—should be viewed as a practical instrument for controlling the microclimatic conditions in external spaces. A tree's ability to both absorb and reflect solar energy is greatest. When using vegetation as a tool for microclimatic control, it is important to consider how the vegetation's shading performance evolves over time and ultimately offer temporary and complementary screening solutions. These can be included into the projects in a number of ways, such as using artificial canopies that serve as shade structures, seasonal fabric.

3.5. Conclusion

Tree canopies play a crucial role in providing shade, reducing the direct impact of sunlight on the ground. This leads to a decrease in surface temperatures in shaded areas, creating a more comfortable microclimate. Trees release moisture into the air through transpiration, influencing local humidity levels. This can be particularly beneficial in arid regions where increased humidity contributes to a more balanced and comfortable outdoor environment. The presence of trees can create localized microclimates with higher humidity levels, impacting not only human comfort but also affecting plant and animal life in the vicinity. The arrangement and density of trees can act as natural windbreaks, reducing wind speed at ground level. This is especially important in windy areas where excessive wind can contribute to discomfort and even damage structures. The distance between trees can influence how air flows through a space. A well-designed arrangement of trees can channel and direct air, promoting better air circulation and reducing stagnant areas.

Table 1. Case study table

Case Study	WBGT	Air Velocity	Sky view factor	CO2 Concentration	Humidity
Effects of tree plantings and aspect ratios on pedestrian visual and thermal comfort using scaled outdoor experiments	Big crown trees reduce daytime PET (4.0 °C) and ITS (285 W) to improve thermal comfort.				
Tree effects on urban microclimate: Diurnal, seasonal,	Tree effects on urban microclimate: Diurnal, seasonal,	Air velocity increase with less trees.			Humidity increases with the increased no of trees

and climatic temperature differences explained by separating radiation, evapotranspiration, and roughness effects	and climatic temperature differences explained by separating radiation, evapotranspiration, and roughness effects				
Thermal comfort in urban spaces: impact of vegetation growth Case study: Piazza della Scienza, Milan, Italy	Shading provided with fully grown trees decreases temperature and provide thermal comfort				

IV.SITE SELECTION

4.1. Introduction

Selecting sites for research study, requires a nuanced understanding of the requirements of study. Among these, the percentage of tree cover emerges as a critical factor influencing the overall health and functionality of a site. Trees, with their myriad ecological benefits and impact on microclimates, contribute significantly to the well-being of both natural and urban environments. In this chapter, different four sites have been selected according to the percentage of tree cover on site. By exploring the diverse effects that tree cover can have on factors such as temperature, humidity, and air quality, we aim to underscore the importance of considering this aspect in decision-making processes related to land use and development. As the study navigates through the complexities of site selection, it becomes apparent that trees are not just aesthetic additions to a landscape; they are indispensable components that shape the very fabric of our surroundings.

4.2. Site Selection

In this study four different sites with different percentage of tree cover were identified. In situ experiment was conducted using different instruments on various parameters like wet bulb temperature, air velocity, relative humidity, carbon dioxide concentration and sky-view factor.

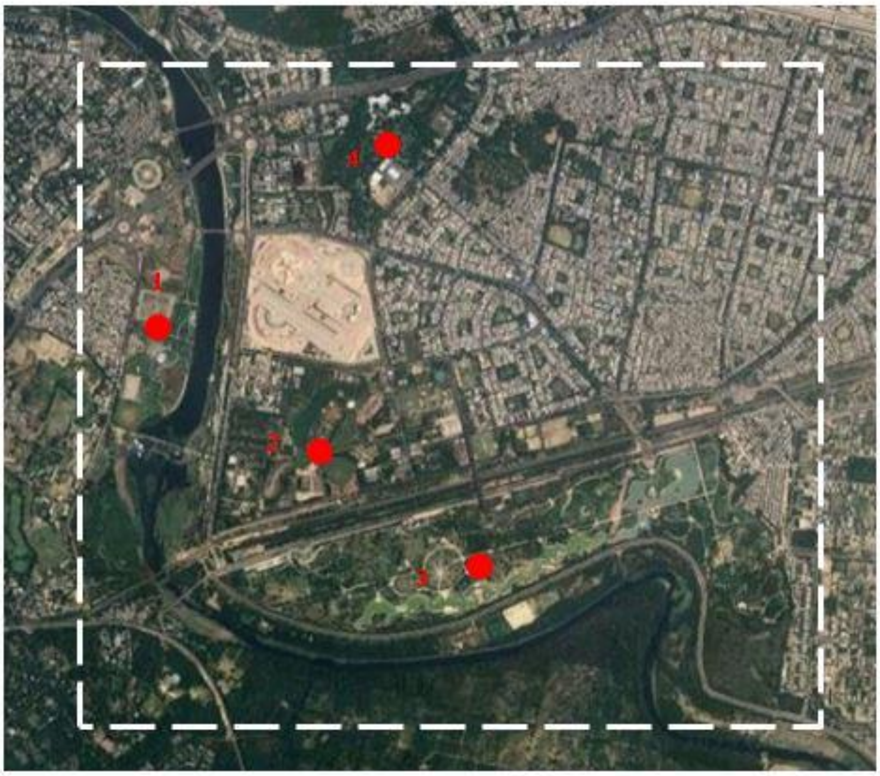


Figure 7. Site Selection

Site 1: With almost 30% of tree cover-Rosia Park, Gomti River Front

Figure 8. Green cover in Rosia Park

First site selected was of Rosia Park, Gomti River Front, it has almost 30% of tree cover. The tree cover is not dense all over the site with native and exotic tree species.

Site 2: With almost 50% of tree cover- Sahara Saher.

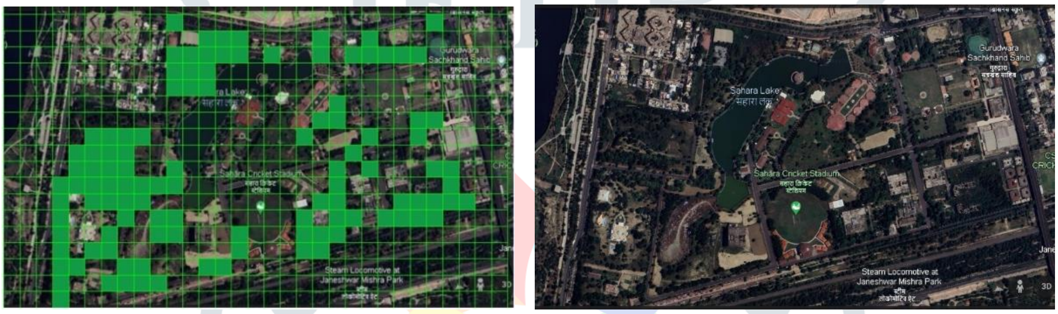


Figure 9. Green cover in Sahara Saher

Second site selected was of Sahara Saher, Lucknow. It has almost 50% of dense tree cover. The trees that are planted all over the site are of native species.

Site 3: With almost 70% of tree cover- Janeshwar Mishra Park

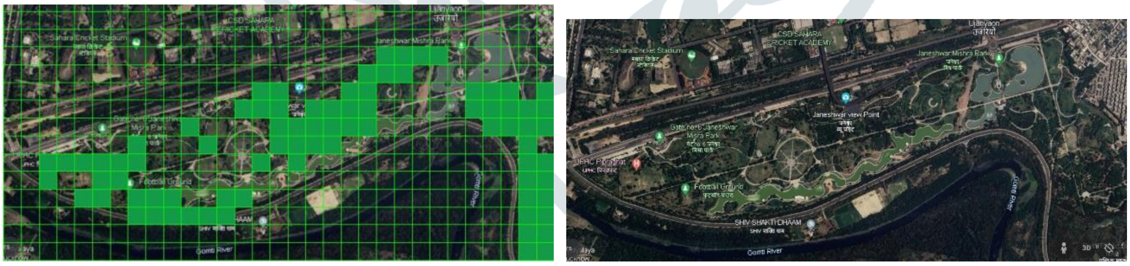


Figure 10. Green Cover in Janeshwar Mishra Park

Third site selected was of Janeshwar Mishra Park. It has almost 70% of dense tree cover. The trees that are planted all over the site are of native species.

Site 4: With almost 90% of tree cover- Dr. Ram Manohar Lohia Park

Figure 11. Green cover in Janeshwar Mishra Park

Fourth site was selected of Dr. Ram Manohar Lohia Park. It has almost 90% of tree cover with native species of trees.

V.DATA COLLECTION

5.1. Introduction

Within the pages that follow, comprehensive measurement of wet bulb temperature, a key indicator of thermal comfort, and relative humidity has been recorded. The narrative unfolds further to encompass carbon dioxide concentration—a vigilant sentinel monitoring air quality and revealing the subtle nuances of natural and anthropogenic influences.

Air velocity, like a rhythmic dance, takes center stage, offering valuable insights into ventilation, air quality, and thermal comfort. As the exploration progresses, the sky view factor, often overshadowed yet undeniably influential, emerges as a critical factor in understanding how the built environment shapes the microclimate and, consequently, the thermal experiences of outdoor spaces.

Throughout this chapter, the focus is not merely on data collection but on fostering a profound comprehension of the intricate relationships between these parameters. Each recorded measurement, conducted with precision, becomes a thread woven into the fabric of knowledge, enriching our understanding of the nuanced environmental conditions at a given site.

Table 2.List of instruments used to record data on site

DEVICE	PICTURE
Heat Index WBGT Meter	
Surface Temperature	
Multi-Functional Air Quality Detector	
Digital Anemometer	

5.2. Site 1: Rosia Park, Gomti River Front

An in-situ experimental study was conducted using different instruments. Temperature data i.e. Wet bulb temperature and relative humidity was recorded on the site using a heat index WBGT meter in two conditions :

1. In the sun
2. In the shade

The data was collected for four days in a month with a weeks interval.

Table 3. Temperature in sun (Day 1)Rosia Park

Temp °C	26.7	26.8	26.7	27.3	27.3	27.3	27.4	28.1	28.2	28.4	28.8	28.9	29	29.2
% RH	21.6	22.6	25.1	26.1	22.7	26.7	27.2	27.5	25.7	27.1	26.7	25.4	25.7	25.5

Table 4.Temperature in shade (Day 1)Rosia Park

Temp °C	28.7	28	27.7	27.2	27.3	26.9	26.5	25.8	25.2	24.8	24.2	24.2	23.9	23.9
% RH	25.5	25.7	25.8	26.1	26.5	26.8	27.3	27.5	28.1	28.3	28.7	28.8	29	29.5

Table 5.Temperature in sun (Day 2) Rosia Park

Temp °C	25.1	25.6	26.2	26.4	26.6	27.1	27.2	26.8	27.2	27.1	27.3	27.5	27	27.1
% RH	26.8	27.5	27.4	27.1	28	27.4	26.1	26.7	26.4	26.9	25.2	25.2	25.3	25.7

Table 6.Temperature in shade (Day 2) Rosia Park

Temp °C	27	26.8	26.4	26.4	25.8	25.4	25.1	24.8	24.5	24	23.9	23.5	23.1	23
% RH	26.8	27.5	27.4	27.1	28	27.4	26.1	26.7	26.4	26.9	25.2	25.2	25.3	25.7

Table 7.Temperature in sun (Day 3) Rosia Park

Temp °C	24	24.5	25.2	25.9	26.2	26.2	26.5	26.9	27	27	27.1	27.2	27.2	27.2
% RH	19	19.5	19.9	20.5	20.8	21.7	22	22.5	22.9	23.2	23.6	23.6	23.9	24

Table 8.Temperature in shade (Day 3) Rosia Park

Temp °C	27.8	27.5	27	27.1	26.9	26.7	26.2	25.9	25.4	25.2	24.9	24.7	24.2	24
% RH	19	19.5	19.9	20.5	20.8	21.7	22	22.5	22.9	23.2	23.6	23.6	23.9	24

Table 9.Temperature in Sun (Day 4) Rosia Park

Temp °C	23.5	24.3	25.9	25.6	26.1	26	25.7	25.3	25.5	25.4	26.4	26.3	27.5	26.9
% RH	29.9	28.5	34.1	30.2	28.1	26.1	26.6	26.8	27.8	25.7	26.9	25.1	25	30.6

Table 10.Temperature in shade (Day 4) Rosia Park

Temp °C	26.9	26.4	25.9	25.3	25.1	25.1	24.9	24.7	24.3	24.1	24	23.8	23.4	23
% RH	29.9	28.5	34.1	30.2	28.1	26.1	26.6	26.8	27.8	25.7	26.9	25.1	25	30.6

CO2 Concentration was recorded using multi-functional air quality detector for 7 days in the evening.

Table 11.Co2 Concentration in rosia park(under tree cover)

CO2 Concentration/ ppm	875	823	857	880	940	920	860

Table 12.CO2 Concentration in Rosia Park

CO2 Concentration/ ppm	871	819	847	870	925	915	852

Air velocity using the digital anemometer was recorded for 7 days on the site.

Table 13.Air Velocity in Rosia Park (under tree cover)

Air Velocity/m/s	0.2	0.2	0.1	0.1	0.0	0.1	0.4

Table 14.Air Velocity in Rosia Park

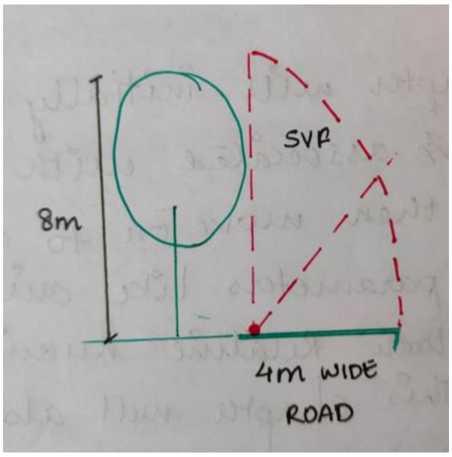
Air Velocity/m/s	0.4	0.4	0.2	0.1	0.0	0.2	0.4

Sky view factor was calculated using the formula $SVF=\pi 1\times\sum i=1n(di2hi)$ for four streets on the site.

- *n* is the number of visible trees,
- *h hi* is the height of each tree,
- *di* is the distance from the observed point to each tree.

Table 15.Sky View factor of different streets in Rosia Park.

Street	Street 1	Street 2	Street 3	Street 4
Sky view factor	0.159	0.032	0.128	0.032



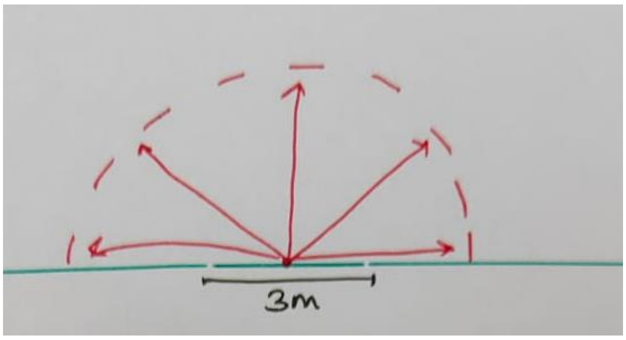
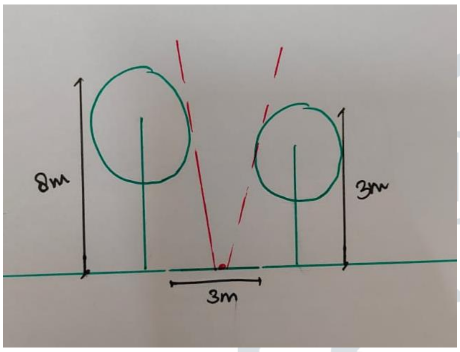


Figure 12.Sky View factor in Rosia Park Figure 13.Sky view factor street 2



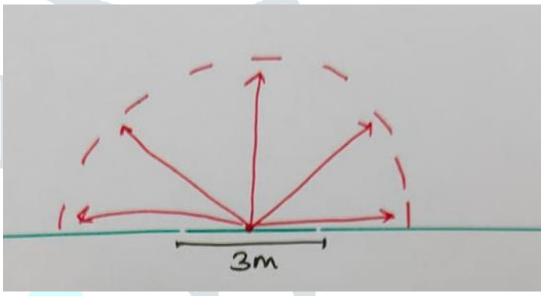


Figure 14.Street 3 Figure 15.Street 4

5.3. Site 2:Sahara Saher, Lucknow

An in-situ experimental study was conducted using different instruments. Temperature data i.e. Wet bulb temperature and relative humidity was recorded on the site using a heat index WBGT meter in two conditions :

1. In the sun
2. In the shade

The data was collected for four days in a month with a weeks interval.

Table 16. Temperature in sun (Day 1) Sahara Saher

Temp °C	25.8	26.3	27.7	26.9	27.4	28.9	27.9	26.5	25.6	27.6	28.7	28	29.1	27.8
% RH	28	30	29	23.4	22.6	21.7	30.6	28.2	29.7	27	23.1	17.3	17	19

Table 17.Temperature in shade (Day 1)Sahara Saher

Temp °C	27.8	27.2	27	26.9	26.7	26.2	25.9	25.4	25.4	24.8	24.8	24.2	24	24
% RH	28	30	29	23.4	22.6	21.7	30.6	28.2	29.7	27	23.1	17.3	17	19

Table 18.Temperature in sun (Day 2)Sahara Saher

Temp °C	24	24.5	25.2	25.9	26.2	26.2	26.5	26.9	27	27	27.1	27.2	27.2	27.2
% RH	19	19.5	19.9	20.5	20.8	21.7	22	22.5	22.9	23.2	23.6	23.6	23.9	24

Table 19.Temperature in shade (Day 2)Sahara Saher

Temp °C	27.8	27.5	27	27.1	26.9	26.7	26.2	25.9	25.4	25.2	24.9	24.7	24.2	24
% RH	19	19.5	19.9	20.5	20.8	21.7	22	22.5	22.9	23.2	23.6	23.6	23.9	24

Table 20.Temperature in sun(Day 3) Sahara Saher

Temp °C	23	23.5	23.9	24.3	24.7	24.9	24.9	25.2	25.6	25.9	26.3	26.9	27	27.3
% RH	23.4	25.3	24.4	26	27.5	27.9	29.3	30.8	29.7	28.9	32.3	30.8	29.8	29.5

Table 21.Temperarture in shade (Day 3) Sahara Saher

Temp °C	25.8	24.8	24.5	23.7	23.1	23.5	22.4	22.4	22.3	22.3	22.9	22.2	22.4	22
% RH	23.4	25.3	24.4	26	27.5	27.9	29.3	30.8	29.7	28.9	32.3	30.8	29.8	29.5

Table 22. Temperature in sun (Day 4) Sahara Saher

Temp °C	23.2	23.5	23.2	24	23.9	24.1	23.9	23.9	23.8	23.7	24.1	25	25.1	25.1
% RH	27.4	27.7	26	26.5	25.9	26.9	27.7	27.6	26.3	27.3	27.1	28.4	28.4	28.3

Table 23.Temperature in shade (Day 4) Sahara Saher

Temp °C	25.1	25.1	24.9	24.6	24.2	23.9	23.5	23.2	23.1	23.1	22.9	22.7	22.5	22.2
% RH	27.4	27.7	26	26.5	25.9	26.9	27.7	27.6	26.3	27.3	27.1	28.4	28.4	28.3

CO2 Concentration was recorded using multi-functional air quality detector for 7 days in the evening.

Table 24.CO2 concentration in Sahara Saher (under tree cover)

CO2 Concentration/ ppm	677	690	595	650	710	670	680

Table 25.CO2 concentration in Sahara Saher

CO2 Concentration/ ppm	671	687	584	638	700	661	675

Air velocity using the digital anemometer was recorded for 7 days on the site.

Table 26.Air velocity in Sahara Saher(under tree)

Air Velocity/m/s	0.0	0.1	0.1	0.1	0.1	0.0	0.0

Table 27.Air velocity in Sahara Saher

Air Velocity/m/s	0.2	0.2	0.1	0.1	0.0	0.1	0.1

Sky view factor was calculated using the formula $SVF=\pi 1\times\sum i=1n(di2hi)$ for four streets on the site.

- n is the number of visible trees,
- $h\ hi$ is the height of each tree,
- di is the distance from the observed point to each tree.

Table 28.Sky view factor in Sahara Saher

Street	**Street 1**	**Street 2**	**Street 3**	**Street 4**
Sky view factor	0.258	0.419	0.438	0.280

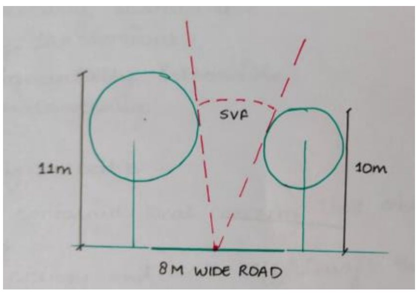


Figure 16. Sky view factor in sahara saher

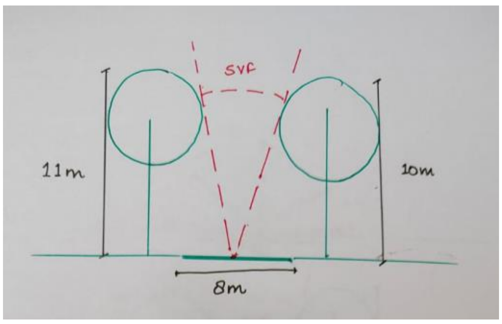


Figure 17.Street 2

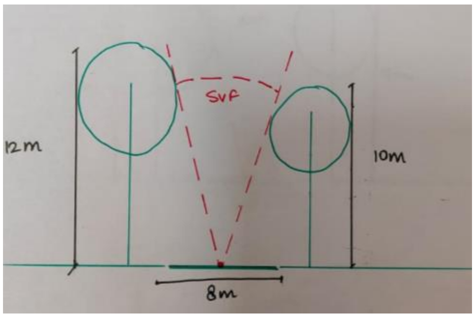


Figure 18.Street 3

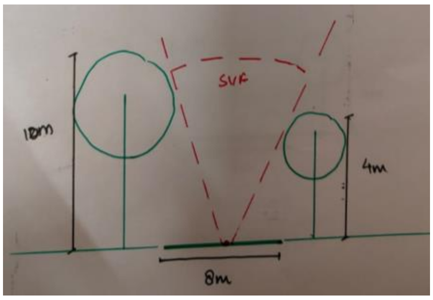


Figure 19.Street 4

5.4. Site 3:Janeshwar Mishra Park, Lucknow

An in-situ experimental study was conducted using different instruments. Temperature data i.e. Wet bulb temperature and relative humidity was recorded on the site using a heat index WBGT meter in two conditions:

1. In the sun
2. In the shade

The data was collected for four days in a month with a week's interval.

Table 29.Temperature in sun (Day 1) Janeshwar Mishra

Temp °C	23.5	24.3	25.9	25.6	26.1	26	25.7	25.3	25.5	25.4	26.4	26.3	27.5	26.9
% RH	29.9	28.5	34.1	30.2	28.1	26.1	26.6	26.8	27.8	25.7	26.9	25.1	25	30.6

Table 30.Temperature in Shade (Day 1) Janeshwar Mishra

Temp °C	26.9	26.4	25.9	25.3	25.1	25.1	24.9	24.7	24.3	24.1	24	23.8	23.4	23
% RH	29.9	28.5	34.1	30.2	28.1	26.1	26.6	26.8	27.8	25.7	26.9	25.1	25	30.6

Table 31.Temperature in sun (Day 2) Janeshwar Mishra

Temp °C	19	19.3	19.7	19.9	20.1	20.1	20.5	20.7	20.9	21.5	21.9	22.3	22.5	23.3
% RH	28.5	28.9	28.8	30.8	34	30.8	32.4	33.1	32.6	34.8	35.4	35.8	35.8	33.2

Table 32.Temperature in Shade (Day 2) Janeshwar Mishra

Temp °C	23.3	23	22.6	22.6	23.1	22.5	22.5	22.5	22.8	23.1	23.1	22.9	23	22.6
% RH	28.5	28.9	28.8	30.8	34	30.8	32.4	33.1	32.6	34.8	35.4	35.8	35.8	33.2

Table 33.Temperature in sun (Day 3)

Temp °C	21.1	21.2	21.3	21.4	21.5	21.6	21.7	22	22	22.2	22.3	22.4	22.5	22.5
% RH	29.7	29.7	29.3	30.2	30	30.2	29.7	29.7	29.7	30.2	31.2	30.3	30.5	30.5

Table 34.Temperature in Shade (Day 3) Janeshwar Mishra

Temp °C	22.5	22.5	22.2	22.1	22.1	21.9	21.8	21.2	20.9	20.5	20.2	19.8	19.5	19.1
% RH	29.7	29.7	29.3	30.2	30	30.2	29.7	29.7	29.7	30.2	31.2	30.3	30.5	30.5

Table 35.Temperature in Sun (Day 4) Janeshwar Mishra

Temp °C	18.6	18.9	20.8	20.2	20.3	19.9	19.6	19.7	19.7	20	21.1	21.2	21.3	21.4
% RH	34.4	33.7	32.5	31.4	31.2	31	32.1	31.8	31.7	32	32.5	32.5	32.6	32.6

Table 36.Temperature in Shade (Day 4) Janeshwar Mishra

Temp °C	22	21.8	21.4	21	21	20.9	20.5	20.1	20.1	19.8	19.7	19.5	19.1	18.5
% RH	34.4	33.7	32.5	31.4	31.2	31	32.1	31.8	31.7	32	32.5	32.5	32.6	32.6

CO_2 Concentration was recorded using multi-functional air quality detector for 7 days in the evening.

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Table 37.CO2 Concentration in Janeshwar Mishra (Under tree)

CO2 Concentration/ ppm	1015	1021	1010	980	1111	1201	999

Table 38.CO2 Concentration in Janeshwar Mishra

CO2 Concentration/ ppm	980	990	984	950	1001	1147	875

Air velocity using the digital anemometer was recorded for 7 days on the site.

Table 39.Air Velocity in Janeshwar Mishra (Under tree)

Air Velocity/m/s	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Table 40.Air Velocity in Janeshwar Mishra

Air Velocity/m/s	0.1	0.1	0.0	0.1	0.1	0.0	0.0

Sky view factor was calculated using the formula $SVF=\pi 1\times\sum i=1n(di2hi)$ for four streets on the site.

- *n* is the number of visible trees,
- *h hi* is the height of each tree,
- *di* is the distance from the observed point to each tree.

Table 41.Sky view factor in Janeshwar Mishra

Street	**Street 1**	**Street 2**	**Street 3**	**Street 4**
Sky view factor	0.419	0.032	0.954	0.530

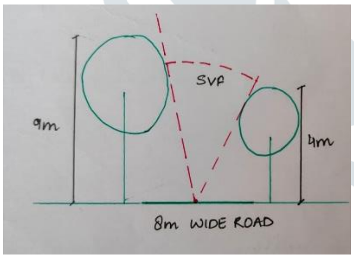


Figure 20.Sky view factor in Janeshwar Mishra

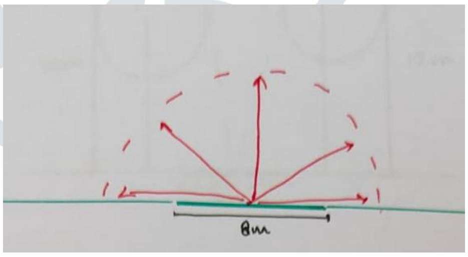


Figure 21.street 2

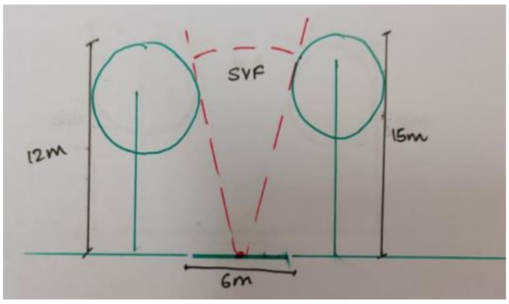


Figure 22.Street 3

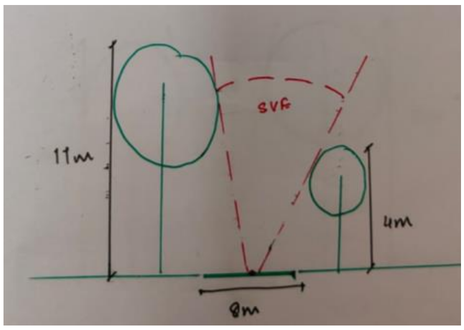


Figure 23.Street 4

5.5. Site 4:Dr. Ram Manohar Lohia Park, Lucknow

An in-situ experimental study was conducted using different instruments. Temperature data i.e. Wet bulb temperature and relative humidity was recorded on the site using a heat index WBGT meter in two conditions :

1. In the sun
2. In the shade

The data was collected for four days in a month with a week's interval.

Table 42. Temperature in sun (Day 1) RML Park

Temp°C	23.5	23.4	25.1	25.6	26.2	26.4	26.6	27.1	27.2	26.8	27.2	27.3	27.5	27.6
% RH	38.2	38.3	37.7	34.7	34	32.3	32	31.8	30.5	29.4	29.9	28.9	27.5	29.1

Table 43.Temperature in shade (Day 1) RML Park

Temp°C	27.6	27.1	26.9	26.4	26.1	26.1	25.9	25.4	25.1	24.8	24.5	24.2	23.8	23.4
% RH	38.2	38.3	37.7	34.7	34	32.3	32	31.8	30.5	29.4	29.9	28.9	27.5	29.1

Table 44.Temperature in sun (Day 2) RML Park

Temp °C	19.5	19.9	20.1	20.6	20.9	21.5	21.9	22.3	22.9	23.1	23.5	23.9	24	24.5
% RH	35.1	36.1	36.5	36.8	37	36.6	36.6	36.4	37	37.5	37.6	37.3	37.7	38.2

Table 45.Temperature in shade (Day 2) RML Park

Temp °C	24.7	24.1	23.9	23.8	23.8	23.9	23.8	23.8	23.6	23.4	23.4	23.5	23.5	23.4
% RH	35.1	36.1	36.5	36.8	37	36.6	36.6	36.4	37	37.5	37.6	37.3	37.7	38.2

Table 46.Temperature in sun (Day 3) RML Park

Temp °C	19.1	19.2	19.2	19.7	19.9	19.8	19.8	19.5	20	19.8	19.8	19.9	19.9	20
% RH	43.8	44.1	39.5	43.4	45.1	43	42	39.5	41.3	38.8	39.6	39.3	39.2	38.2

Table 47.Temperature in shade (Day 3)RML Park

Temp °C	21.2	21.1	20.9	20.5	20.1	19.9	19.5	19.1	18.9	18.7	18.2	18.1	18	18
% RH	43.8	44.1	39.5	43.4	45.1	43	42	39.5	41.3	38.8	39.6	39.3	39.2	38.2

Table 48.Temperature in sun (Day 4) RML Park

Temp °C	18.4	18.1	18	18.2	18.3	18.4	18.5	18.6	18.9	18.9	19	19.1	19.2	19.4
% RH	31.7	31	31	30.6	30.4	30.4	30.5	30.6	30.7	30.7	30.5	30.6	30.3	30.3

Table 49.Temperature in shade (Day 4) RML Park

Temp °C	20	19.9	19.5	19.1	19	18.9	18.5	18.1	17.9	17.5	17.2	17	17	16.9
% RH	31.7	31	31	30.6	30.4	30.4	30.5	30.6	30.7	30.7	30.5	30.6	30.3	30.3

CO2 Concentration was recorded using multi-functional air quality detector for 7 days in the evening.

Table 50.CO2 Concentration in RML Park (Under tree)

CO2 Concentration/ ppm	1817	1627	1780	1720	1801	1627	1556

Table 51.CO2 Concentration in RML Park

CO2 Concentration/ ppm	1750	1548	1652	1587	1754	1548	1244

Air velocity using the digital anemometer was recorded for 7 days on the site.

Table 52.Air velocity in RML Park (under tree)

Air Velocity/m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 53.Air Velocity in RML Park

Air Velocity/m/s	0.0	0.0	0.0	0.1	0.1	0.0	0.0

Sky view factor was calculated using the formula $SVF=\pi 1\times\sum i=1n(di2hi)$ for four streets on the site.

- *n* is the number of visible trees,
- *h hi* is the height of each tree,
- *di* is the distance from the observed point to each tree.

Table 54.Sky view factor in RML Park

Street	Street 1	Street 2	Street 3	Street 4
Sky view factor	0.419	0.032	0.954	0.530

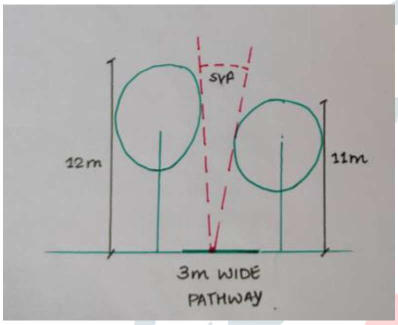


Figure 24. Sky view factor in RML park

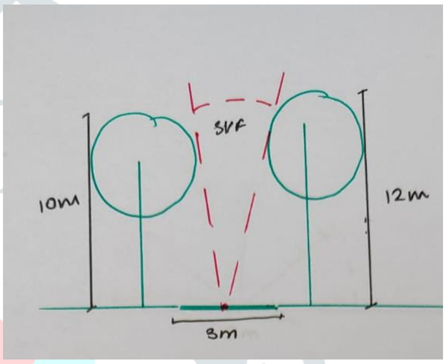


Figure 25.Street 2

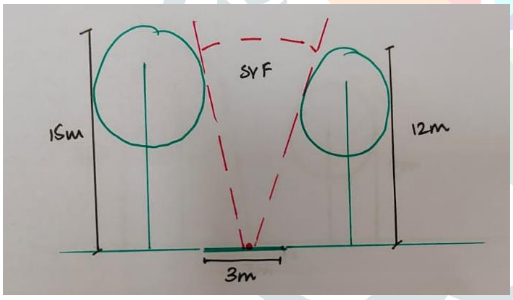


Figure 26.Street 3

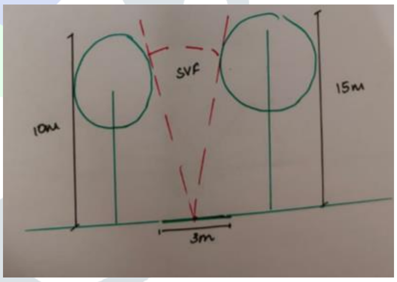


Figure 27.Street 4

V.RESULTS AND DISCUSSION

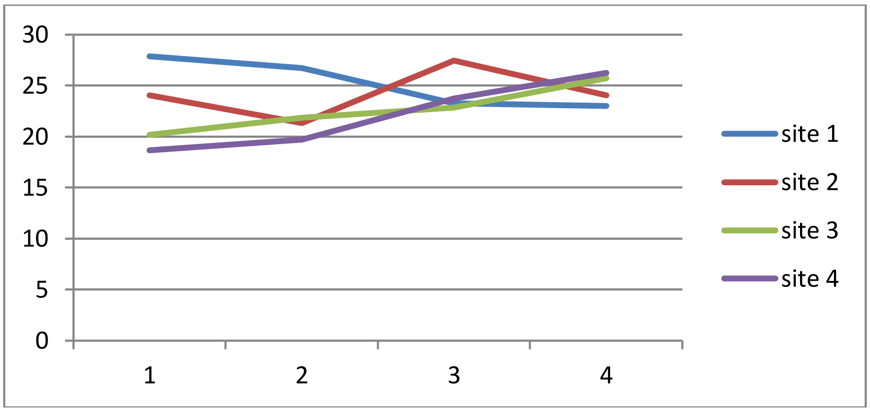
6.1.Introduction

In this chapter, the results and discussions that have emerged from a meticulous study aimed at determining the optimum percentage of tree cover for enhancing thermal comfort within urban environments. The exploration navigates through the delicate balance between the benefits of shading and the potential trade-offs, considering factors such as solar access, wind flow, and overall urban aesthetics. This chapter aims to contribute to the evolving dialogue on sustainable urban planning. The discussions herein not only shed light on the optimal balance of greenery but also consider the broader implications for energy efficiency, air quality, and the overall well-being of urban inhabitants.

6.2. Results and Discussions

6.2.1. Temperature

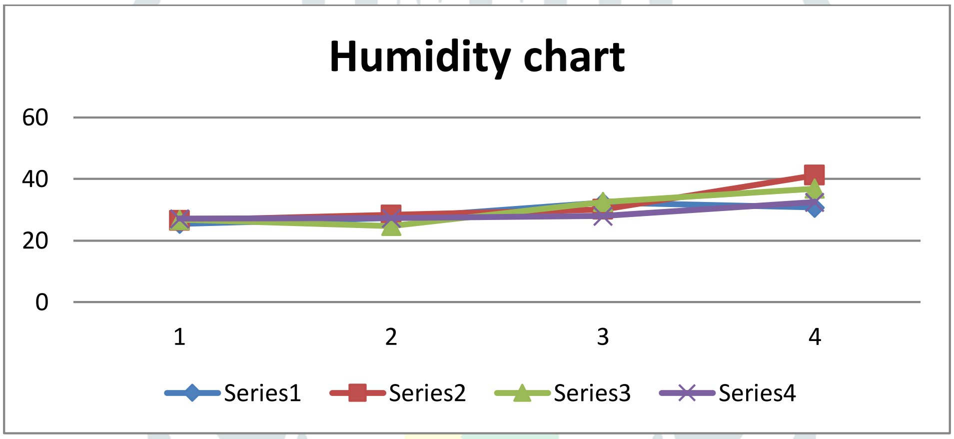
Figure 28. Chart showing the average temperatures of different sites



This chart shows the average of the wet bulb temperature recorded on all the four sites using the Heat Index WBGT meter. As we can see there is not much variations in the temperature recorded on the different sites because the data was collected in the month of October and November.

6.2.2. Relative Humidity

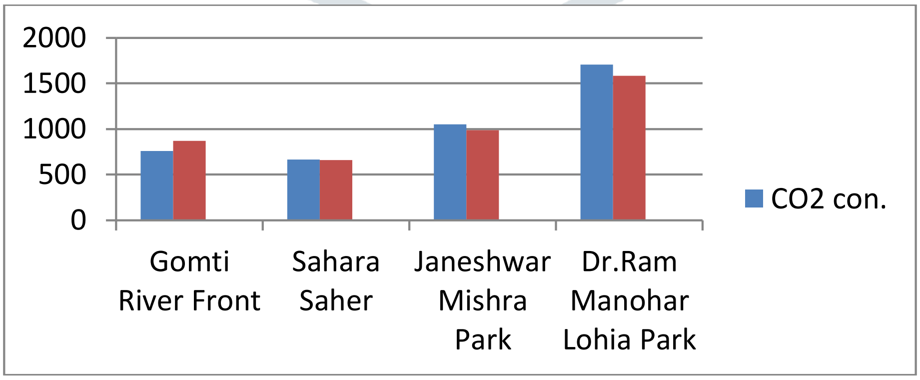
Figure 29.Chart showing the average of Relative Humidity on different sites



This chart shows the average of the relative humidity recorded on all the four sites using the Heat Index WBGT meter. As we can see there is not much variations in the relative humidity recorded on the different sites because the data was collected in the month of October and November.

6.2.3.CO2 Concentration

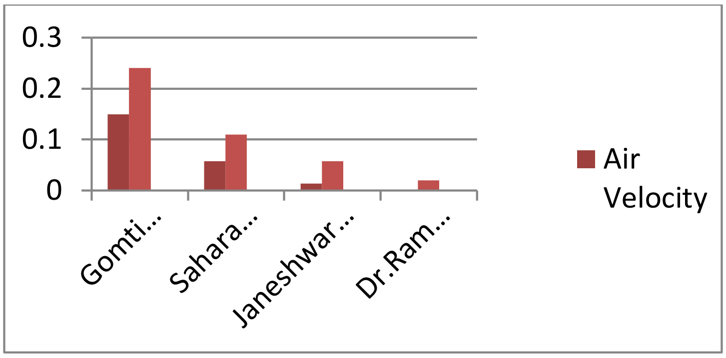
Figure 30. Chart of average of CO2 Concentration



This chart shows the average of CO2 Concentration recorded in all the four sites using a multi-functional air quality detector. It states that Dr Ram Manohar Lohia Park has the most CO2 concentration with is extremely unhealthy, Janeshwar Mishra also has high concentration but less than RML Park which is also unhealthy. Sahara Saher and Gomti River Front have acceptable and healthy amount of concentration.

6.2.4. Air Velocity

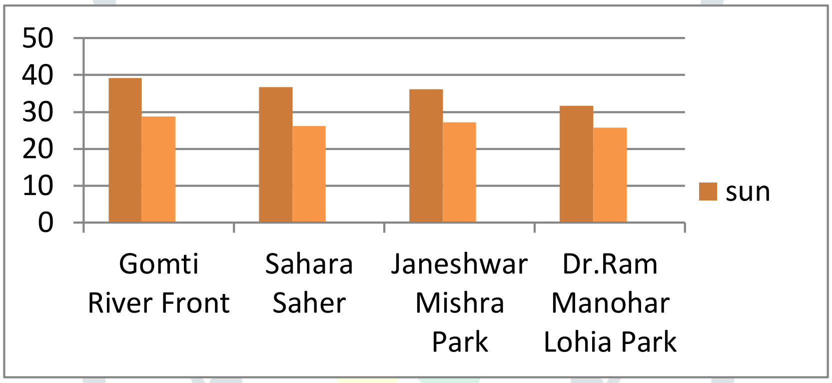
Figure 31. Chart shows the average of air velocity



This chart shows the average of air velocity recorded in all the four sites using a digital anemometer. It states that Dr Ram Manohar Lohia Park has the least air velocity, Janeshwar Mishra also has low air velocity more than RML Park which is also unhealthy. Sahara Saher and Gomti River Front have acceptable and healthy air velocity.

6.2.5. Surface Temperature

Figure 32. Chart Shows the average of surface temperatures



This chart shows the average of surface temperature on grass recorded in all the four sites using a digital anemometer. It states that Dr Ram Manohar Lohia Park has the least surface temperature, Janeshwar Mishra also has low surface temperature more than RML Park . Sahara Saher and Gomti River Front have high surface temperature with Gomti river front the highest.

6.3.Conclusion

From the above data collection and discussion, it can be seen that Sahara Saher which has approx. 50%of tree cover has the most thermally comfortable atmosphere as compared to the other sites with different percentage of tree covers. Therefore it can be concluded that:

1. 50% of tree cover is optimum to achieve thermal comfort.
2. Native trees should be planted to make a site more sustainable.
3. Trees should be planted at a specified distance to achieve more comfort.

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APPENDIX 1: Literature study table

Author	Objective	Climate and Location	Parameters	Analysis	Methodology	Simulation tools	Conclusion
Camilo Ordóñez S. M. Labib Lincoln Chung Tenley M. Conway(Ordóñez et al., 2023)	This research examined whether people's satisfaction with urban trees and satisfaction with the manageme nt of those trees were related to objective measures of greenery such as the Normalize	Continen tal climate. Toronto, Canada,	Calculation of NDVI, canopy cover, and VGVI at three neighbourho od sizes.	We found that canopy cover and VGVI had a positive association with satisfaction with urban trees.	Theoretical framework , Survey, Greenness assessment, Data Analysis.	Rv.4.2.1. Satellite images GVIR Package.	In conclusion, this research examined the relationship between people's satisfaction with urban trees and objective measures of greenness, such as the Normalized Difference Vegetation Index (NDVI), percent tree canopy cover, and the Viewshed Greenness Visibility Index (VGVI). The study found that satisfaction with urban trees was

	d Difference Vegetation Index (NDVI), percent tree canopy cover, and the Viewshed Greenness Visibility Index (VGVI) for trees.						positively associated with canopy cover and VGVI, particularly at larger neighbourhood scales. However, there were no significant associations with NDVI or satisfaction with the management of urban trees.
David J. Nowak, Rowan A. Rowntree, E. Gregory McPherson, Susan M. Sisinni, Esther R. Kerkmann, Jack C. Stevens(Nowak et al., 1996)	This paper reviews several methods for determining urban cover from aerial photographs. Urban tree-cover data are presented from North America and Europe, and relationships among urban tree cover, city, and environmental attributes within US cities are discussed.	United States		Although many factors may influence urban tree cover (Sanders, 19841, two dominant factors affecting the extent and distribution of urban tree cover are the surrounding natural environment and the land use.	Methods for determining urban tree cover: Crown cover scale, transect method, Dot method, scanning method.		Average city tree cover ranges from 55% in Baton Rouge, Louisiana, to 0.4% in Lancaster, California, while percent total green space ranges from 93% in Coachella, California, to 38% in Chicago, Illinois. Percent canopy greenspace also showed wide variation, ranging from 68% in Atherton, California, to 1% in Lancaster, California
Dayi Lai, Wenyu Liu, Tingting Gan, Kuixing Liu, Qingyan Chen(Lai et al., 2019)	The objective of this paper is to conduct a comprehensive and systematic review of the effectiveness of various strategies in improving the urban thermal environment and		air temperature, thermal radiation, wind speed, and humidity, surface temperature, mean radiant temperature, PET, UTCI, long-wave radiation, short-wave radiation.	The paper is a comprehensive and systematic review of the effectiveness of various strategies in improving the urban thermal environment and thermal comfort. The review	The methodology included a literature search to identify related review articles, screening of the studies to ensure the quality of the selected studies, and analysis of the data from the selected studies.		The paper concludes that urban open spaces with a suitable thermal environment attract citizens and boost the vitality of cities. The thermal environment in outdoor spaces can be decomposed into air temperature, thermal radiation, wind speed, and humidity.

	thermal comfort.			analyzes the data from various studies and provides a comparison of the results			
Loyde Vieira de Abreu-Harbich, Lucila Chebel Labaki, Andreas Matzarakis(de Abreu-Harbich et al., 2015)	The objective of this paper is to study the cooling efficiency of urban landscape strategies in a hot dry climate.	Hot and dry climate, city of Campinas, Brazil	The study examined the cooling effects of different tree species and clusters of trees in reducing air temperature.	The study examined the cooling effects of different tree species and clusters of trees in reducing air temperature.	To quantify the thermal comfort provided by shade of trees, meteorological data (air temperature, air humidity, wind speed and global radiation) collected from field measurements were used to calculate PET with the assistance of RayMan software	RayMan software	These results demonstrate that clusters of trees can mitigate temperatures to a greater extent compared with individual trees. Tree shade qualities are also influenced by the individuality of trunks and of leaves, which should be considered.
R.U. Galagoda, G.Y. Jayasinghe, R.U. Halwatura, H.T. Rupasinghe(Galagoda et al., 2018)	The objective of this paper is to evaluate the thermal performance, relative humidity, and CO2 concentration of three types of green infrastructures (living walls, indirect green facades, and direct green facades) in tropical urban environments, and to determine their impact on human thermal comfort	Tropical climate, Colombo metropolitan area in Sri Lanka	thermal performance, relative humidity, and CO2 concentration of three types of green infrastructures (living walls, indirect green facades, and direct green facades) in tropical urban environments.	The study analyzed the data collected from the in-situ experimental study, simulation, and survey to evaluate the effectiveness of the vertical greenery systems on external wall surface temperature reductions and human thermal comfort.	The study consisted of an in-situ experimental study, simulation, and questionnaire survey.	Design Builder version 5.0.3.7	The study concludes that the VGS can be an effective passive cooling strategy for tropical urban buildings to improve the indoor thermal comfort and reduce the energy consumption of air conditioning systems.
Shirisa Timilsina, Jagannath Aryal, Jamie B.	The aim of this research is to effectively map urban		Topographic and climatic variables, such as slope, elevation,	The paper discusses the mapping and monitoring	The paper presents a methodology using object-based convolutional	Remote Sensing Technologies, Object-Based Image Analysis (OBIA), Convolutional	A net tree cover loss was measured in the study area of Greater Hobart between 2005 and

Kirkpatrick(Timilsina et al., 2020)	tree cover changes and model the relationship of such changes with socioeconomic variables.		aspect, solar radiation, geology and precipitation	of urban tree coverage using remote sensing technologies. It highlights the benefits of urban trees and the need for effective management of tree coverage in cities.	neural network (CNN) and object-based image analysis (OBIA) to map and monitor urban tree cover changes between 2005 and 2015/16. The accuracy of the tree cover extraction using this method is reported to be 96% for 2005 images and 98% for 2015/16 images.	Neural Network (CNN),	2015/16. This finding may motivate local councils to make plans and policies to reverse this tendency, such as increasing tree planting on public lands.
Sihan Xue, Xinfeng Chao, Kun Wang, Jingxian Wang, Jingyang Xu, Ming Liu, Yue Ma(Xue et al., 2023)	significance of optimizing the configuration of trees in creating a more comfortable and inviting space for human activities.	temperate continental climate zone,	tree canopy coverage (TCC) and its morphological elements, including leaf area index (LAI), trunk height (TH), and crown diameter (CD)	Results show that the contribution ratio of various elements to the thermal environment vary over time.	This study employed an orthogonal experiment design and ENVI-met software to simulate the microclimate of various multi-factor combination models in the case of a typical urban park in a temperate continental climate zone in China, analysing the simulated result through physiological equivalent temperature (PET).	ENVI-met	The study's findings reveal that TCC and tree morphological elements, including LAI, TH, and CD, all have the potential to improve outdoor thermal comfort during the summer, particularly during the midday period when their impact is most pronounced.
Shixiong Cao, Chenxi Lu, And Hui Yue(Cao et al., 2017)	The objective of the paper is to determine the optimal tree canopy cover for ecological restoration in Changting, China.	Changting, China	Tree canopy cover, soil nutrient content, soil microorganism populations, plant species richness, soil erosion.	In the study, the researchers conducted an analysis to determine whether an ecological threshold existed for the effect of tree canopy cover on soil and site parameters over time.	The researchers used a combination of field measurements and laboratory analysis to determine the relationship between tree canopy cover and various factors such as soil erosion, vegetation cover, and microbial activity.	Steel tape, Auger, Tipping-bucket rain gauges, Sedimentation Pond, Oxidation with potassium dichromate, EViews quantitative analysis software	The study suggests that there may be an ecological threshold for tree canopy cover, and maintaining canopy cover at an optimal level can promote ecosystem sustainability during ecological restoration. The findings highlight the importance of long-term research to monitor the effects of ecological restoration activities.
Viniece Jennings, Richard Schulterb	This project extends prior	Warm climate, City of Tampa	Health data, census data, tree cover data,	The study used adjusted logistic	The methodology of the paper involved the use	**i-Tree Eco Plots, Satellite Imagery,**	The study examined the relationship between tree cover and cardiovascular

randt Gragg III, C. Perry Brown, Dudley Hartel, Eric Kuehler(Jennings et al., 2019)	studies by integrating structural factors of tree cover and exploring their relationship to respiratory and cardiovascular health outcomes across socio-demographic groups.			regression models to assess the relationship between urban tree canopy cover and rates of respiratory and cardiovascular-related hospital admissions.	of i-Tree Eco plots and satellite imagery to assess tree cover and its impact on cardiovascular and respiratory health in Tampa, FL. Two hundred and one plots were distributed across the city using random sampling with a hexagon grid and inventoried. Structural features of the trees, such as tree condition and leaf area index, were assessed.	**Ordinary Kriging, Spatial Analyst Technique, Geographic Information Systems (GIS)**	and respiratory health outcomes in Tampa, FL. The findings suggest that higher tree density is associated with fewer cases of respiratory and cardiovascular admissions. However, the presence of tree cover does not guarantee physical activity that promotes cardiovascular health.