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Study of urban heat Island Effect: A Case of Streets at Pune, India

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ABSTRACT

The increased surface temperature in metropolitan regions relative to surrounding areas is referred to as an Urban Heat Island (UHI). Aim of the study is to find out the relationship of UHI effect (E) factors and temperature on streets of Pune. The objectives include providing a quantitative assessment of outdoor thermal comfort through empirical measurements. The hypothesis of the study was that there will be temperature variations observed in all three seasons of India considering high solar radiations in summer with humidity and rainfall in monsoon and low air temperature in winter. The objectives of the study are to understand factors impacting UHIE and to do comparative analysis of temperature for all three seasons. The methodology includes analysing urban streets of Pune taken as case study and documentation. The outcome of analysis of the two streets has been documented with the help of graphs and factors leading temperature variations are demonstrated.

Key words: *Surface temperature, Factors, Quantitative assessment, Variations.*

Introduction

The urban heat island effect (UHIE) is a recognized phenomenon of heat accumulation, prominently characterized by urban climate resulting from urban expansion and human activity. In the early nineteenth century, researcher Lake Howard quantified and examined the urban heat island effect in London for the first time. Since then, numerous researchers throughout the world have undertaken extensive studies on the features of the UHI effect, concluding that the UHI effect is closely related to urban heat release, underlying surface attributes and structure, plant covering, population density, and meteorological conditions. Meanwhile, as urbanization continues, the extent and severity of the UHI effect will become more severe. The energy balance centre of the urban surface, particularly surface temperature, is one of the most significant variables influencing urban climate, regulating and managing numerous ecological processes. However, rising urbanization has resulted in a continual increase in surface temperature, indefinitely changing urban resource and energy flow. More crucially, the structure and function of the urban ecological system will be altered, harming the health of city dwellers. Furthermore, urban meteorologists have paid close attention to the UHI impact. However, due to the complexity of the research object, few studies on the ecological and environmental implications of UHI have been done from the perspective of the ecosystem. This temperature rise was notably noticeable in Pune's outskirts.

A temperature difference of 4-5 degrees Celsius is feasible between urban and rural locations (Nesarikar, *et al.,* 2012) It has been discovered that

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vegetation, spatial layout to produce visuals indicating the presence of manmade and natural features on roadways impacts the Pune city's UHI. The UHIE causes higher temperatures in cities due to factors like buildings, vehicles, and human activities that produce and retain heat. This has implications for the environment, health, and energy use, so it's important to study and find ways to mitigate its impacts.

Literature Review

Urban Heat Island

The term "urban heat island" refers to the observed temperature difference between urban environments and the surrounding rural areas (Jain, *et al.,* 2017). The Urban Heat Island (UHI) describes the variation in air temperature from suburban regions. Degradation of urban environmental quality is occurring as a result of significant variations in air and surface temperatures as well as an increase in pollutants in the water, air, and soil. (Gupta, *et al.,* 2009). UHI if it is found significantly warmer than its surrounding rural areas. Luke Howard (1810s) was the first to investigate and describe this phenomenon of UHI. Over the past decade, the presence of UHI has been studied and documented in several cities around the world (Heidorn, 1999). A metropolis with a million people or more may have a temperature difference of 1-3°C from the surrounding rural areas, according to Akbari 2005. The climate and habitable environment are negatively impacted by the UHI phenomena (Sharma, *et al.*, 2015). UHI is more significant than the surrounding metropolitan region in terms of space heating. This thermal energy is produced by urban residents, homes, businesses, vehicles, buses, trains, industrial zones, etc. In addition to having a direct and indirect impact on the urban population, the UHI is an essential feature of the urban environment (Gazi, *et.al.,* 2018)

Heat Absorption and Retention

The UHI effect is caused, in part, by the heat that is absorbed and retained by hard urban surfaces like concrete and asphalt (Haddad, *et al.,* 2023). The UHIE is exacerbated by these surfaces because they collect sun energy and reradiate it as heat. The development of mitigation techniques to deal with this issue has been the subject of research. The use of pervious concrete, reflecting pavement, and water-retentive pavement are a few of these tactics that have demonstrated promise in enhancing the hydric and water retention qualities of urban surfaces (Chen, *et al.*, 2023).

An efficient metric for characterizing the possible contribution of paving materials to the creation of UHI is the Solar Reflective Index (SRI). The material stays cooler during the day when the SRI is higher. Based on statistical analysis, which revealed that yellow-colored thin-layer asphalt samples exhibit lower surface temperatures than normal asphalt, the decision to use yellow paint was made. (Maria, *et al.*, 2013). A material's propensity to retain heat and radiate it back into the atmosphere or into the building through its walls and roof decreases with increasing reflectivity (albedo) and emissivity (Paroli, *et al.*, 2008; Synnefa, 2007). To reduce heat accumulation and maintain low surface temperatures, albedo should be raised on roofs and pavements. Higher albedos than typical materials make high-performance roof coating products like elastomeric and polyurea membranes, light-colored tiles, and gravel more appropriate for flat roofs (Akbari *et al*., 2006). Reflective pigments can be added to concrete and asphalt to boost the pavement's albedo. Typically, materials used to make pavement have extremely low albedo or reflection. *Albedo is defined as the fraction of the incident radiation that is reflected from a surface* (Dobos, 2003). Most radiation that comes into contact with surfaces is typically absorbed by them (Calkins, 2012). As a result, the pavement material warms up and radiates the heat, raising the ambient air temperature nearby. The uppermost layer of pavement structures is the only surface that influences albedo.

Sky view factor (SVF)

When describing the urban climatology at scales less than 100 meters, the Sky View Factor (SVF) is crucial. The surrounding obstructions' height affects this proxy for net radiation. A rasterized point cloud height dataset (containing 6/-/10 points per m2) was used to compute the SVF. Grid resolution, search radius, and number of directions all affect the final SVF. Prior studies have linked the diurnal temperature range, solar irradiance, wind speed, vegetation percentage, and SVF to the daily maximum UHI of the canopy layer. A 70 km^2 test area in the Netherlands was chosen, containing urban areas, meadows, and woodlands. Grid resolution has a great sensitivity. According to the results, Utrecht,

the fourth-largest city in the Netherlands, has a mean diurnal maximum UHI of 3.1 °C when utilizing a 1m SVF resolution. However, the UHI is reduced by 0.6 °C on average when using a 3m SVF resolution. The importance of having a fine grid resolution that can catch trees, alleyways, and homes is shown by this (Pagani, *et al*, 2019).

Factors contributing of Urban Heat Island

Urban Sprawl and Loss of Green Cover

Dense built-up regions, more impermeable surfaces (such as roofs, asphalt roads, and paved pavements), a decrease in green and soft areas, and an unparalleled rate of urbanization are all contributing to lower water penetration. In urban areas, the percentage of precipitation that infiltrates the soil is just 15%, while in natural settings, around 50% of precipitation infiltrates the soil and 10% flows off towards watercourses (USEPA, 2007; Cyr *et al.*, 1998). Natural cooling processes like soil moisture evaporation and plant evapo-transpiration are hindered and unable to counteract urban warming when water supply is restricted in metropolitan settings.

Albedo and Thermal Emissivity of Building Materials

Urban surface materials and buildings absorb a lot of heat during the day and release it back into the environment at night, which contributes to the urban heat island effect (UHIE).

Urban Morphology

The three-dimensional shape, placement, and spacing of buildings inside a city are referred to as urban morphology, and they are crucial in the development of UHI (USEPA, 2008). Densely populated areas with tall buildings and winding streets can impede ventilation and air flow by creating urban canyons where heat from the sun and human activity builds up and becomes trapped. As a matter of fact, the SVF decrease restricts the net radiative losses of streets and buildings.

Anthropogenic Heat

The creation of anthropogenic heat, which includes heat released by air conditioners, cars, and industrial processes, is another element that leads to the formation of heat islands, especially in densely populated places where a concentration of activity occurs (USEPA, 2008). Urban activities and infrastructure have an impact on anthropogenic heat generation; more energy-intensive structures and modes of mobility produce more heat.

Geographic Location and Weather

An urban area's geographic location affects the genesis of UHI and dictates its climate and terrain. Winds that carry heat away from cities and lower temperatures are beneficial to metropolitan areas that are close to major bodies of water. Similar to this, mountain ranges in a hilly area can either cause wind patterns to travel through a city or prevent wind from ever reaching it.

Effects of Building Density and Height

The UHIE is influenced by tall buildings and high building densities. Elevated near-surface air temperatures in urban areas, or UHIEs, can cause significant heat stress for city people, particularly during heat waves. The intensity of the UHI is dependent on the size, density, and structure of urban areas. Research has demonstrated that an increase in building height necessitates the use of additional resources per floor space in order to withstand seismic and wind loads, which raises greenhouse gas emissions. Furthermore, higher temperatures, more air pollution, and higher energy consumption are caused by dense structures' surface materials' ability to retain energy. Thus, by magnifying the impact and raising energy consumption and greenhouse gas emissions, both high building density and tall buildings contribute to the UHI (Guldmann, *et al*, 2011). Surface temperature variations across urban surfaces are mostly caused by the influence of urban geometry on radiation with regard to surface energy balance. Numerous earlier research works have examined the connection between street temperature as measured by measurement or numerical modelling and urban geometry as reflected by the SVF or the building height to street width ratio. There are several methods for measuring the surface temperature in the field, such as using airborne infrared thermographs. Since the net loss of longwave radiation decreases with a drop in the SVF, the results indicate that the street geometry alone has a considerable influence on cooling rates (Yang, *et al*, 2015).

Microclimate variability

A microclimate is a collection of meteorological parameters recorded in small regions close to the sur-

face of the planet. These climatic factors, which include humidity, temperature, light, and wind speed, are useful indications for choosing habitats and other biological processes. (Robert J., *et.al*, 2005). Urban heat island effect (UHIE) causes localized increases in air temperature in urban contexts in addition to climate change (Oke, 2002). Because of factors like building density, thermal capacity, and optical qualities of buildings and urban materials, as well as the absence of vegetation and water and human heat generation from HVAC systems and moving vehicles, urban areas absorb and store heat more efficiently than rural ones. This results in an increase in temperature (Giridharan, 2008). The qualities of the urban fabric determine how intense the UHI is in a certain metropolis. Denser urban regions with tall structures and smaller canyons have larger temperature increases because of the high concentration of vertical surfaces that absorb solar radiation, restrict infrared exchange with the sky, and slow down wind and convective heat losses (Young-Hee, *et al.*, 2012) (Yang, *et al.*, 2015). The density of the urban fabric within a city determines the degree of temperature fluctuation, which in turn impacts the energy effect of the UHI. (Xiaoma Li, *et al.*, 2019)

Wind direction and speed are also influenced by urban settings. When travelling from the countryside to the city, the roughness of the urban surface reduces wind speed by 20 to 30% and increases turbulence intensity by 50 to 100% (Ghiaus, *et al.*, 2005), changing the free stream velocity above the buildings. In densely populated locations, the drop in mean wind speed at the pedestrian level might be as high as 60%. Numerous factors, including urban design and geometry, density, vegetation, water levels, and surface characteristics, affect the microclimate of urban open areas.

Traffic-Related Heat Emissions

The UHIE in cities is partly caused by heat emissions from traffic. The degree of pollution in the urban atmosphere, which causes heat transmission and radiation between the air and the soil surface, is mostly determined by weather patterns and automobile exhaust emissions. Heat islands are the outcome of this exchange, which causes an excess of air temperature to form between the city and its surroundings. The intensity and extent of the UHIE are significantly influenced by automobile traffic, with particular locations having vehicular flows that are the primary influencing factor that contribute to the phenomenon's extraordinary nature (Guilbert *et al*, 2017). For urban microclimate models, the pace at which anthropogenic heat, particularly that from motorized traffic, is released is critical. Although it is challenging to quantify, measures of the concentration of urban air pollutants, such as volatile organic compounds, can be used to infer traffic-related anthropogenic heat. The UHIE is exacerbated by the morning and evening peaks shown in daily profiles of traffic-related heat release rates. An urban canyon's thermal profile can change due to vehicular generated heat, depending on variables like wind speed and canyon direction (Rosado, *et al*, 2022).

Impact on Pedestrians and Residents

Because walking is a weather-exposed activity that is heavily influenced by meteorological conditions, UHI has a detrimental effect on how walkable cities are (Böcker *et al.*, 2019). Improved people's physical, social, and mental health has been strongly correlated with higher walkability levels in metropolitan neighbourhoods (Yuxiao 2021). UHI reduction is therefore essential for enhancing thermal comfort and creating more lively, livable, and healthier societies. Mitigation strategies such as urban greening and high-albedo surface materials are crucial for resolving these kinds of environmental problems (Taleghani, 2017). Urban greening is widely seen to be the most effective approach to cool the surrounding region since it creates shade, evaporation, and evapotranspiration (Morakinyo, 2017). The impacts of the UHI-caused temperature rise are numerous and include energy usage, public health, the environment, and pedestrian comfort. The number of fatalities will increase in response to rising air temperatures, as several studies have already shown.

Mitigation and Adaption Strategies

The local and global climates are positively impacted by a variety of UHI mitigation techniques. The four areas that these mitigations fell under were: reduction of anthropogenic heat, stormwater management and soil permeability, greening measures, and measures connected to urban infrastructure. The use of vegetation and cooling, urban greening, planting trees and other vegetation selectively, greening parking lots, vegetation surrounding buildings, green walls, green roofs, sustainable

urban infrastructure, airtightness and insulation of buildings, a variety of shading devices, cooling centers, water and aquatic installations, reflective walls, sustainable stormwater management, etc. are some approaches.

Limitations of the study

The case of UHI is limited only to Pune city. Due to the availability of a smaller number of instruments the readings were taken on three different representative days of summer and monsoon and winter in the months of March April and August, October and January.

Methodology: Selection of Cases

There are Smart city initiatives and beautification done at some streets in Pune, climate response still needs to be given attention. The research utilizes a combination of surveys, interviews, and field trips to gather information. Stratified random sampling is done in Pune city while choosing streets. Two North South and two east west streets are selected. Four different locations from Pune have been chosen for the mapping and analysis. So out of those two Streets have been selected representing one axis as case examples.

The research study includes measuring surface temperatures (LST) and air temperatures of streets in Pune with different orientation has been measured with the help of Infrared Thermometer measurement tool three times a day, as a longitudinal study during summer, monsoon and winter season. Tools used are Infrared Gun and Multifunction altimeter. Selection of streets as per different orientations and measurement protocol for the 1.5 km stretch of the road. The locations seek to investigate the role of trees and materials on the thermal performance of the streets. For easy of representing and documenting readings they are nomenclature as side 'A' and side 'B.' Climate determinants that were analysed were LST, air temperature, air pressure, cloud cover, rainfall, wind direction and wind speed. With change in these climate factors, microclimate determinants responsible for change in UHIE such as material properties (albedo, finishes, colours) presence or absence of trees, type of trees, sky view factor, built to unbuilt ratio.

Tools and Techniques used for study area

Tool Name	Tool Used
IR Gun	
Multifunction Barometer	

Fig. 1. Tools used for measurements (Source: Author)

Objectives of the study are as follows: To understand factors impacting UHIE on streets and to establish a relation with microclimate drivers found out from field data collection. To study three types of surfaces namely, road (vehicular area), concrete paver blocks (pedestrian area) glass, and brickwork (adjacent building facade). To conduct a comparative analysis of LST for three seasons is documented.

Case Studies

Case 01- DP Road, Pune

The street is oriented in an East-West direction and has a width of 21 meters. The typology of buildings includes residential, commercial, recreational, and institutional types, with an average height of 15 meters. The density of vehicles is moderate to elevate. The materials used on vertical surfaces include glass, plastered walls, RCC, and GI sheets. There are various types of horizontal surfaces, including paving blocks, concrete roads, asphalt roads, pedestrian paths, and open ground. The types of vegetation include evergreen trees, deciduous trees, and shrubs.

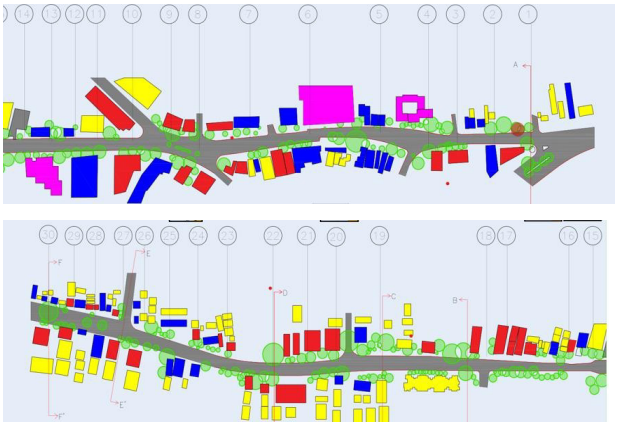

Fig. 2. Landuse plan and points of measurements (Source: Author)

The same colour coding as indicated in the legend has been shown in the tables.

Monsoon readings analysis

Surface Temperature of Façade: Hottest tempera-

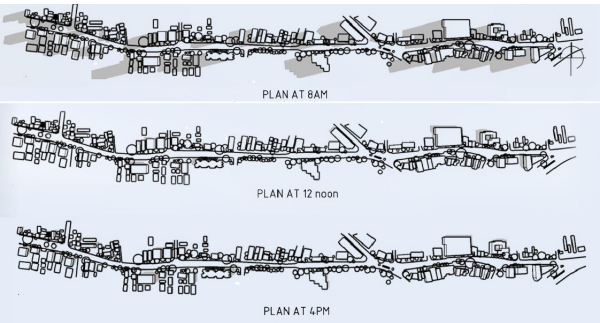

Fig. 3. Shadow analysis of street (Source: Author, Students study Report, 2023)

ture at specific points is seen on only one side due to absence of trees. Least temperature is recorded at the points with presence of trees with good foliage though façade of building is glassed. Generally hottest temperatures were recorded at 12 pm. Fluctuations in the temperature were either due to presence or absence of trees and tall buildings. Though the trees are present but due to less foliage, hottest temperatures are recorded. Temperature at certain points is less due to presence of rainwater puddles. **Surface temperature of footpath:** Overall temperature range is between 20-30 ºC due to very a smaller number of trees. At the junction of two roads pavement material is flexible hence it didn't absorb water. Anthropogenic activities: At the time of signal at the junctions of two or more roads (pt. 26) the gas that vehicles emit mixes in the air which is also one of the reasons for increasing the Air temperature. The temperature is hottest at 4 pm as there is no shading on footpath due to a smaller number of trees and hard paving materials.

Table 1. Summer 4 April 2023 readings DP road

Points	Time											
	8:00				12:00				16:00			
	A		B		A		B		A		B	
	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath
1	36.6	35.0	33.6	31.1	45.5	47.8	45.3	48.0	41.5	40.6	42.6	39.5
2	33.0	28.4	31.1	23.2	40.5	34.8	46.5	29.0	33.5	24.7	37.2	38.2
3	26.2	23.8	35.2	27.3	29.0	26.2	47.6	33.8	24.0	21.1	23.2	20.2
4	30.4	30.4	38.4	37.3	32.1	32.0	40.0	40.0	27.1	24.5	34.4	36.5
5	39.3	26.5	44.5	41.5	32.0	33.0	35.0	35.0	27.6	24.0	31.5	28.3
6	40.7	40.8	41.9	46.9	33.0	32.0	36.0	33.0	29.0	26.9	32.1	31.5
7	30.1	30.2	32.0	32.0	49.0	28.5	35.8	30.0	47.0	43.1	51.9	55.7
8	28.0	28.0	28.1	28.1	40.0	29.0	35.0	28.0	35.0	31.9	35.4	28.6
9	30.1	30.0	31.5	31.5	38.0	29.0	38.0	40.0	36.0	35.9	36.9	3.7
10	26.0	21.0	30.0	30.0	33.0	28.3	45.5	43.5	29.0	27.9	31.7	31.0
11	29.0	20.0	36.0	36.0	33.0	28.0	40.0	41.0	29.0	26.8	27.5	24.5
12	39.0	38.0	40.0	40.0	34.0	25.0	40.0	38.0	28.6	24.0	31.5	26.4
13	41.0	40.0	41.0	42.0	45.0	45.0	46.0	46.0	41.0	39.7	44.9	45.5
14	40.3	40.0	40.0	40.0	45.8	48.0	47.0	46.0	42.8	41.3	44.0	43.5
15	40.0	40.0	40.0	41.0	48.0	48.0	48.0	48.0	43.8	38.5	51.2	48.6
16	40.0	28.0	39.1	39.0	48.2	48.2	48.2	48.0	43.2	43.8	40.6	38.7
17	31.0	31.0	30.1	30.0	28.0	31.3	45.0	45.0	24.0	19.1	27.1	25.9
18	32.0	32.0	36.0	36.2	34.0	33.0	45.2	45.2	32.0	32.3	28.1	20.3
19	30.1	30.0	30.5	30.4	39.0	36.0	46.0	46.0	34.0	30.3	35.4	28.6
20	39.0	39.1	40.1	40.0	48.0	26.7	49.1	49.0	44.0	42.9	42.5	38.3
21	27.0	27.0	30.0	29.0	35.0	33.0	47.6	48.0	30.0	28.0	28.3	24.3
22	30.0	30.0	30.0	31.0	50.0	38.0	52.0	50.0	46.0	44.6	41.5	35.8
23	30.0	30.0	31.0	31.0	50.0	48.0	50.0	48.0	46.0	42.9	53.1	52.1
24	35.0	35.0	36.0	36.0	55.0	53.0	54.0	55.0	49.6	45.6	47.7	44.6
25	58.0	58.0	35.0	35.0	63.0	58.0	61.0	62.0	59.0	56.7	65.5	61.8
26	36.0	36.1	36.0	36.0	62.0	60.0	64.0	62.0	59.0	54.5	56.0	52.5
27	36.0	36.1	36.0	36.0	53.0	55.0	51.0	52.0	48.8	45.6	45.4	44.4
28	30.1	30.0	30.0	30.0	48.0	45.0	48.5	48.0	43.0	38.2	39.5	37.4
29	30.2	30.0	31.0	31.0	40.0	39.0	45.0	45.0	36.0	35.3	36.8	35.4
30	35.0	35.2	31.0	31.0	44.0	38.4	44.0	40.0	40.2	36.1	41.8	39.9

Legend- Temperature ºC

Above 20
Above 25
Above 35
Above 40

Table 2. August 2023 readings DP road

Time																		
Points	8:00						12:00						16:00					
	A			B			A			B			A			B		
	ROAD	FACADE	FOOTPATH	ROAD	FACADE	FOOTPATH	ROAD	FACADE	FOOTPATH	ROAD	FACADE	FOOTHPATH	ROAD	FACADE	FOOTPATH	ROAD	FACADE	FOOTPATH
1	22.7	22.3	22.7	22.9	23.5	22.8	29.4	27.2	28.8	27.7	26.0	27.7	25.7	23.0	23.3	27.0	24.2	24.3
2	22.7	21.9	22.7	23.0	22.8	23.0	30.1	27.4	28.1	31.5	26.5	28.0	26.4	23.3	23.4	25.7	23.9	24.0
3	22.8	21.5	22.7	23.0	23.8	23.1	27.7	24.7	24.4	25.3	24.2	23.6	22.6	22.9	23.0	26.7	24.0	24.9
4	22.7	22.0	22.3	22.5	22.0	22.5	28.3	26.3	27.1	31.0	26.7	27.3	30.6	22.5	22.4	26.2	24.9	26.5
5	22.5	22.4	21.9	22.0	23.5	21.8	28.1	26.3	25.3	26.7	24.2	27.6	27.7	24.2	29.2	27.3	24.3	27.2
6	23.2	22.3	21.9	22.6	27.5	22.5	29.7	24.3	23.7	25.2	22.3	22.7	31.2	22.5	23.2	24.5	23.6	24.4
7	23.8	22.2	21.8	23.1	23.5	23.2	30.5	23.3	26.6	23.8	23.0	22.1	27.3	24.0	24.7	24.6	24.5	25.5
8	23.1	27.0	22.8	23.5	23.5	23.6	26.5	23.4	22.6	23.0	20.8	19.6	28.1	22.0	23.0	25.4	24.3	23.2
9	22.3	31.8	23.8	23.8	25.4	24.0	27.1	23.2	23.7	25.0	22.8	27.5	23.4	21.5	21.9	28.2	25.9	26.7
10	23.9	27.0	23.9	24.5	24.1	23.9	25.3	21.5	21.1	26.2	24.6	29.1	23.4	20.8	21.5	26.6	24.9	27.6
11	25.5	22.2	23.9	25.1	26.5	23.8	24.8	21.6	20.5	22.0	21.5	21.1	24.6	21.9	26.8	25.9	24.7	28.1
12	24.7	22.4	23.7	25.0	23.4	23.9	25.6	23.3	22.4	25.5	21.3	27.7	26.8	21.0	24.9	24.8	23.7	24.4
13	23.9	22.5	23.4	24.8	21.5	24.0	27.0	23.1	22.2	29.0	23.8	22.5	26.6	21.5	30.0	26.6	25.2	25.1
14	23.6	22.5	23.3	24.3	24.4	24.4	32.6	26.8	30.7	28.4	21.4	20.5	29.7	21.2	22.2	25.5	24.0	24.4
15	23.3	22.4	23.1	23.7	25.1	24.8	30.3	24.8	27.7	27.0	28.2	28.8	27.0	21.2	22.2	27.9	24.4	25.8
16	24.4	22.5	23.2	24.1	22.1	23.6	26.0	21.1	20.5	21.7	22.0	27.9	25.5	21.0	21.9	26.0	23.5	25.9
17	25.4	22.5	23.6	24.5	23.2	22.3	26.6	20.3	21.0	20.2	19.3	19.0	24.1	21.1	21.8	26.0	24.3	26.3
18	25.1	22.4	22.8	24.8	21.3	23.6	21.3	21.5	19.7	29.1	21.9	26.8	23.0	21.7	23.0	26.6	25.1	27.3
19	24.8	22.2	22.0	25.0	22.5	24.9	24.6	21.9	22.4	24.4	19.1	19.6	23.2	21.4	24.2	23.2	22.9	22.8
20	24.9	23.1	22.9	25.0	22.6	25.0	26.2	22.5	22.2	29.0	21.8	20.5	23.2	21.3	23.8	25.7	23.6	23.9
21	25.0	23.9	23.8	25.0	22.8	25.0	26.7	22.7	23.9	20.5	20.4	17.7	24.5	21.7	22.5	25.2	23.6	24.3
22	23.7	23.1	23.1	23.7	23.9	23.3	27.2	20.6	23.6	28.3	22.1	21.7	23.9	21.4	22.8	24.4	23.4	23.1
23	22.4	22.2	22.3	22.4	21.6	21.6	26.8	19.7	19.5	28.5	19.4	19.7	24.1	20.3	22.8	25.1	22.9	22.9
24	24.0	24.6	22.7	23.3	24.6	23.0	28.2	20.6	20.9	29.0	21.4	22.8	21.6	20.6	19.7	24.9	22.0	21.8
25	25.5	26.9	23.1	24.2	24.8	24.4	30.2	22.5	24.4	30.5	22.5	26.0	23.0	21.1	22.5	26.1	23.3	23.4
26	26.6	25.8	24.8	25.5	25.6	24.4	27.8	22.2	22.2	24.0	22.5	25.2	22.5	20.0	20.4	26.5	23.0	23.2
27	27.6	24.6	26.4	26.8	22.8	24.4	26.0	23.6	24.1	19.8	22.5	19.6	25.1	21.2	22.0	26.5	21.3	26.3
28	27.6	26.9	23.1	24.2	24.8	24.4	23.2	21.8	23.0	22.4	20.6	21.6	23.9	21.0	21.7	25.7	23.3	25.9
29	27.6	24.6	26.4	26.8	22.8	24.4	26.0	23.6	24.1	19.8	22.5	19.6	24.0	21.0	22.0	24.0	23.3	21.3
30	24.8	22.2	22.0	25.0	22.5	24.9	24.6	21.9	22.4	24.4	19.1	21.6	22.7	21.0	21.1	20.1	20.1	20.3

Table 3. Readings Comparative Analysis DP Road (Source-Author)

Summer (March and April)	Monsoon (August)
Overall temperature fluctuation range is more (20-40 °C) due to clear sky the radiation falls directly on the surface. In summers the foliage of trees is usually less hence shading on surface of road is less Clear sky conditions and direct radiations Shadow of trees and buildings is variable factor	Overall temperature fluctuation range is more (25- 30 °C) as there was sky cover due to rainy season and the moisture in the atmosphere. In monsoon trees have comparatively good foliage and hence provides good shade Sky covers due to monsoon clouds Here due to less sun radiations shadow lengths are very less

Analysis of Winter- January readings

In January, it was noted that the sky conditions were clear. The temperature range for the 8 am observations on the left side was 16-35 °C. The recorded temperature for the façade was 35°C, attributed to the use of galvanized iron sheets and the absence of trees. The lowest recorded temperature at 8 AM was 16.6 °C (road temperature), attributed to the presence of trees with dense foliage. The temperature of the footpath was lower than that of the concrete footpath. The temperature rise of the road and

Table 4. Sample of Readings of Footpath, Road and Facade DP Road (Source-Author)

Typology of built environment	Time	Maximum and Minimum Temperature in August (°C)	Rainfall in August	Reason (August + Rainfall)	Reason (August + No rainfall)
Footpath	8 am	22 – 26	Yes	As there were dense trees with good foliage and it had a cloud cover inmorning.	
	12 pm	20 – 30	No	.	Sky was clear. Less humidity and less number of trees.
	4 pm	19 – 30	No		Less humidity in atmosphere.
Facade	8 am	22 – 25	No		No creepers and material used in façade was glass
	12 pm		No		Clear sky and foreground
	4 pm		No		Clear sky conditions
Road	8 am	22 – 28	Yes	Presence of trees and cloud cover.	

façade was distinctly observed on the opposite side of the façade. The maximum façade temperature recorded was 39.7 °C, but the walkway temperature reached 43.3 °C, attributed to the absence of trees in the vicinity of that measurement location. The unshaded glass registered a temperature of 27.2 °C. The peak temperature for the road, footpath, and façade was documented at 4 PM. The maximum temperature recorded on the footpath was 48.9 °C on concrete, coinciding with increased vehicular traffic during that period.

Case 02 : ITI Road, Pune

The road is oriented in a North-South direction and has a width of 30 meters. The typology of buildings includes commercial, recreational, and institutional categories. Vehicular density ranges from low to medium. The average height of a building is 10

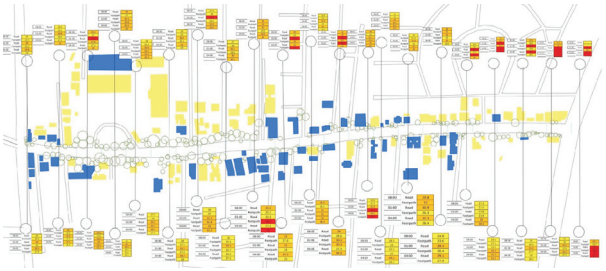

Fig. 5. Plan ITI Road showing temperature of August month
(*Source:* Author, Students study Report, 2023)

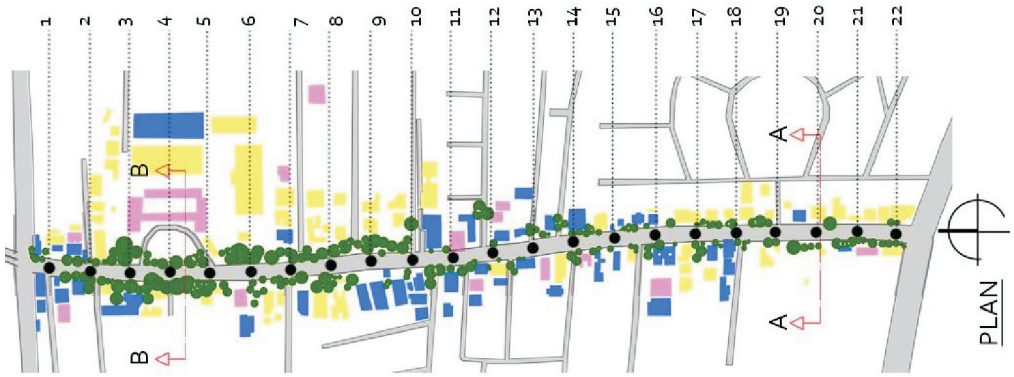

Fig. 4. Plan ITI Road showing land use and points of measurements
(*Source:* Author, Students study Report, 2023)

Table 5. October 2023 Readings DP Road (Source-Author)

	time																	
Poi	8:00						12:00						16:00					
	A			B			A			B			A			B		
	ROAD	FACADE	FOOTPAT	ROAD	FACAD	FOOTPATH	ROAD	FACAD	FOOTPAT	ROAD	FACAD	FOOTHPATH	ROAD	FACAD	FOOTPATH	ROAD	FACADI	FOOTPATH
1.0	23.4	23.9	26.6	37.0	23.3	23.8	30.3	35.8	27.1	45.7	37.0	45.8	26.8	26.4	26.3	25.5	24.2	26.1
2.0	23.3	23.0	22.9	36.9	30.1	35.9	30.4	30.9	28.3	49.0	30.0	34.7	26.5	27.9	27.8	27.8	23.9	29.8
3.0	23.5	23.4	22.4	30.6	26.6	27.5	28.8	29.1	28.5	51.3	51.0	54.0	27.6	24.9	27.4	27.9	24.0	28.5
4.0	23.7	23.4	26.5	38.2	26.9	27.3	29.1	31.3	26.5	43.0	30.1	30.8	32.4	36.7	39.3	32.2	24.9	34.2
5.0	25.5	25.0	24.9	40.5	26.9	27.4	31.3	30.2	27.4	55.0	38.4	52.6	35.9	29.6	30.3	32.1	24.3	24.3
6.0	25.8	23.7	24.5	42.5	24.5	26.9	30.2	28.3	31.7	45.1	36.5	48.0	26.9	27.3	27.4	32.2	23.6	34.2
7.0	23.8	24.1	23.7	39.3	30.3	36.4	28.3	28.5	37.6	46.5	27.4	28.6	48.8	30.0	39.4	35.3	24.5	38.3
8.0	24.2	22.7	22.4	26.8	35.0	34.7	28.5	30.1	26.5	51.7	52.1	47.3	38.4	40.0	25.3	38.1	24.3	32.8
9.0	23.8	22.2	23.1	41.3	27.1	39.0	48.6	31.9	33.4	52.2	42.8	47.6	35.9	29.6	32.3	35.2	25.9	38.1
10.0	24.6	24.2	22.6	41.8	33.5	39.5	39.2	25.6	36.7	48.8	38.3	38.4	48.8	30.0	39.4	40.2	24.9	42.1
11.0	30.8	33.5	33.5	36.8	28.0	29.5	24.6	24.6	28.0	51.3	36.6	53.5	38.4	40.0	35.3	39.9	24.7	38.2
12.0	23.1	25.2	24.5	31.1	30.0	25.8	46.4	36.0	44.0	47.4	39.5	54.0	40.9	37.2	35.1	36.2	23.7	32.6
13.0	31.0	28.0	25.2	37.6	26.4	24.6	43.0	32.1	38.0	53.3	33.1	45.2	32.1	38.3	45.2	32.8	25.2	32.8
14.0	25.2	22.6	24.2	33.6	25.2	30.0	48.9	38.0	48.0	53.5	33.6	48.9	38.3	37.4	32.3	45.2	24.0	38.5
15.0	23.3	28.0	27.7	35.6	38.0	35.5	36.8	29.0	34.0	48.3	27.5	35.6	32.0	32.8	39.1	48.6	24.4	46.1
16.0	32.8	27.4	33.6	36.6	24.0	29.2	41.0	27.0	34.5	41.3	34.5	40.7	31.4	30.1	35.9	32.3	23.5	31.6
17.0	25.8	33.6	26.0	40.1	27.5	38.8	37.0	28.6	32.3	52.3	31.8	51.0	30.0	42.6	32.5	33.4	24.3	32.2
18.0	33.5	26.4	27.7	36.6	37.0	26.0	21.3	25.7	25.5	55.7	35.7	48.2	39.2	29.3	30.1	26.6	38.5	46.1
19.0	28.3	26.6	25.1	36.6	27.2	38.0	46.5	30.4	34.3	55.2	33.8	48.1	40.8	28.6	30.0	23.2	30.4	42.5
20.0	30.0	26.9	25.9	38.8	21.6	39.1	37.5	31.6	34.3	51.2	38.7	37.8	35.3	29.6	36.2	25.7	35.7	33.6
21.0	25.0	30.0	24.4	38.7	27.4	25.9	31.3	30.0	33.7	41.1	34.5	44.6	41.3	46.3	35.0	25.2	30.8	31.8
22.0	26.6	24.6	23.5	39.0	29.6	32.3	36.0	31.3	36.0	43.6	29.0	34.0	38.5	42.9	30.4	24.4	36.5	45.3
23.0	25.0	24.8	22.2	35.9	26.7	39.4	35.0	34.5	31.2	48.0	28.6	36.8	30.4	28.7	36.3	25.1	38.1	43.2
24.0	30.6	25.8	22.2	41.1	23.0	32.7	29.5	29.8	34.0	42.8	31.0	35.1	32.9	29.9	43.4	24.9	35.2	31.0
25.0	25.5	26.9	23.1	24.2	24.8	26.0	25.8	25.0	22.0	45.7	27.4	33.0	30.9	38.4	29.4	26.1	32.8	32.6
26.0	26.6	25.8	24.8	25.5	25.0	24.0	30.0	28.0	27.0	44.0	28.0	34.5	48.9	40.2	45.5	26.5	33.4	43.0
27.0	27.6	24.6	26.4	26.8	24.5	24.8	31.0	29.0	26.0	43.0	29.0	31.0	33.6	33.0	40.0	26.5	38.5	42.5
28.0	27.6	26.9	23.1	24.2	24.5	23.0	32.0	29.8	29.0	38.0	23.0	33.6	34.8	34.6	38.5	25.7	35.4	33.6
29.0	27.6	24.6	26.4	26.8	22.0	26.0	32.5	29.9	28.0	38.9	24.0	36.0	31.0	28.6	38.7	24.0	34.5	35.0
30.0	24.8	22.2	22.0	25.0	24.0	24.9	33.6	30.0	29.5	40.0	26.0	37.2	37.2	29.8	40.0	20.1	35.0	37.0

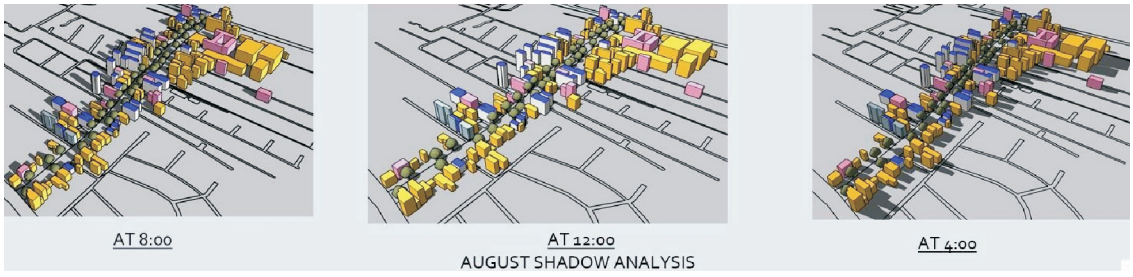

Fig. 6. Shadow pattern in August throughout the day
(*Source:* Author, Students study Report, 2023)

meters. The types of facing materials utilized include glass, plastered walls, reinforced cement concrete (RCC), galvanized iron (GI) sheets, stone walls, and metal installations. Materials utilized on horizontal surfaces include paving stones, asphalt roads, pedestrian pathways, and open ground. The types of vegetation included evergreen trees, deciduous trees, and bushes.

Analysis

Surface wise analysis of ITI road

Analysis of Surface Temperature – Footpath (August 2023)

At 8:00 AM, the surface temperature at Point A18 varies from 23 to 32°C because there are no nearby

Table 6. January 2023 Readings DP Road (Source-Author)

	Time																	
Point	8:00						12:00						16:00					
	A			B			A			B			A			B		
	ROAD	FACA	FOOTP	ROA	FACA	FOOTPA	ROA	ACAD	FOOTHP	ROA	FACA	FOOTHPA	ROA	FACA	FOOTPA	ROA	FACAD	FOOTPATH
1.0	25.8	19.8	19.9	25.8	21.9	26.0	28.1	30.3	31.0	28.1	30.6	29.8	22.5	25.9	19.5	31.0	31.0	31.0
2.0	19.8	18.2	18.0	21.9	23.9	24.0	23.0	23.4	23.3	23	29.2	31.0	22.0	26.6	23.3	30.0	31.5	37.0
3.0	18.3	20.5	18.4	22.4	22.6	27.5	25.5	24.6	24.0	25.5	29.9	32.1	25.3	24.1	20.5	40.2	39.5	39.7
4.0	18.0	20.7	20.7	23.2	23.6	27.3	20.0	19.2	19.6	20.1	26.9	30.1	26.8	25.2	25.7	43.5	30.6	42.3
5.0	19.0	19.3	19.2	23.8	22.4	22.0	20.1	21.6	20.5	22.8	26.9	26.8	23.0	22.3	28.9	46.2	39.5	45.3
6.0	18.9	23.2	19.1	25.8	23.8	23.3	22.8	28.2	22.5	24.9	30.3	23.8	25.6	22.0	20.5	41.0	40.9	48.0
7.0	17.2	19.0	16.9	23.9	23.7	23.7	24.9	25.6	22.9	27.6	25.5	30.2	29.9	23.3	25.3	45.5	43.0	40.4
8.0	17.6	19.7	17.9	23.0	21.8	21.9	27.6	25.2	25.6	26.6	29.5	28.7	28.0	20.6	28.4	44.6	38.5	43.1
9.0	18.0	20.4	20.0	28.3	41.4	23.7	26.5	24.9	23.1	27.8	30.3	28.8	26.5	21.7	23.1	35.5	39.6	41.0
10.0	20.2	19.7	19.9	28.4	29.7	23.7	27.8	27.3	23.0	22.6	27.1	26.9	30.5	20.2	29.3	41.9	41.6	38.5
11.0	19.4	19.3	17.2	26.7	36.7	28.8	22.6	22.3	26.0	22.2	24.2	29.3	23.8	26.2	21.6	35.5	33.3	34.6
12.0	17.2	17.8	17.3	22.9	32.3	25.1	26.6	24.8	21.7	20.8	24.5	33.3	24.9	21.6	22.0	41.8	29.4	38.5
13.0	17.5	19.2	22.8	28.9	22.8	27.5	17.6	25.6	22.0	27.8	38.9	27.9	21.5	21.4	19.3	40.9	38.1	39.1
14.0	19.2	26.3	17.9	25.4	24.8	25.4	22.6	27.2	19.1	24.3	38.7	28.5	21.5	17.6	21.6	43.8	35.7	36.4
15.0	26.3	20.3	18.3	27.4	22.5	28.8	25.2	26.4	20.1	23.2	25.6	28.3	23.3	22.5	22.8	48.9	41.5	45.2
16.0	20.3	19.0	17.8	31.7	23.6	26.5	20.8	18.8	22.8	28.7	29.9	24.6	25.4	20.4	20.2	43.2	40.3	40.2
17.0	19.0	18.3	16.4	30.8	30.2	30.2	20.8	21.7	22.3	28.0	24.6	23.9	33.5	20.8	26.6	34.2	39.3	30.0
18.0	16.6	19.5	17.0	23.4	20.5	24.2	20.7	22.2	22.1	24.2	28.7	29.6	33.8	19.9	26.6	43.2	32.5	40.8
19.0	16.7	19.6	19.0	23.2	35.3	29.9	23.1	20.7	22.2	25.6	23.6	23.8	29.9	20.3	25.3	32.3	38.5	34.3
20.0	16.6	19.4	16.5	21.3	32.6	23.5	24.0	24.3	26.2	26.1	28.2	30.2	21.8	22.3	23.0	34.3	30.8	38.6
21.0	17.0	18.2	17.0	30.2	22.7	23.9	25.7	18.8	25.8	26.2	24.1	28.7	30.0	26.3	25.3	40.8	33.6	44.1
22.0	17.2	20.4	17.8	29.0	28.5	26.4	23.8	24.0	18.8	24.8	30.2	28.8	26.8	25.3	28.5	39.3	40.0	34.2
23.0	18.1	21.6	16.8	29.4	22.8	26.2	23.1	22.6	19.2	35.6	23.1	26.9	25.4	20.3	29.2	41.5	35.3	40.2
24.0	21.5	18.5	21.0	27.3	25.4	29.0	26.2	22.6	20.0	29.2	20.8	29.3	22.1	22.3	28.3	44.0	37.6	35.3
25.0	20.2	19.2	17.6	30.5	29.7	25.3	20.0	29.7	18.6	25.1	29.6	28.6	34.5	21.6	23.8	45.8	38.2	40.3
26.0	18.6	18.0	20.0	23.2	35.6	24.3	20.7	32.1	23.9	30.3	24.2	27.9	20.6	25.5	28.9	43.0	39.2	33.6
27.0	19.5	23.0	23.0	28.4	32.6	27.1	20.1	23.6	18.7	25.6	29.5	28.5	22.5	20.9	21.6	43.3	31.2	33.9
28.0	25.1	21.0	25.0	22.4	22.7	30.6	21.9	22.0	21.0	25.8	28.6	28.3	24.4	20.3	20.0	44.5	36.2	37.5
29.0	24.6	23.9	31.2	27.4	22.0	23.3	24.1	21.5	23.0	22.3	26.3	24.6	22.1	22.1	22.8	44.0	40.3	34.5
30.0	30.0	35.0	22.0	25.0	24.0	25.5	19.1	25.8	28.1	28.8	27.9	23.9	20.6	24.5	28.9	45.6	45.3	36.8

Table 7. ITI road April 2023 readings (Source-Author)

	Time											
points	8:00				1:00				4:00			
	A		B		A		B		A		B	
	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath	Road	Footpath
PT. A1	26	25.1	31	29.1	57.1	57.8	34.2	31.5	38.2	37.5	38.7	36.21
PT. A2	26.1	24	32	30	41.8	54.6	36.4	34.1	34.76	32.5	38.54	35.9
PT. A3	25	24.5	31	30.3	57.4	36.6	39.4	36.8	36.43	35.8	46.34	42.88
PT. A4	27.1	26.2	31	30	58.2	45.2	35.6	34.1	37.9	36	42.1	39.87
PT. A5	28.25	27.6	30	29.4	56.9	55.9	31.5	38.2	46.2	43.54	42.77	41.6
PT. A6	26.9	26.2	30	29	57.5	39.2	40.2	48.8	42.55	39.8	37.9	36.48
PT. A7	27	26	30	29.2	57.4	53.3	40.5	40.5	39.7	35.96	38.64	35.98
PT. A8	28.21	27.1	31	28.5	55.6	57.1	43.1	43.1	43.3	40.2	40.84	37.2
PT. A9	28.5	28	31	29.4	55.1	54.9	43.2	43.2	41.44	39.87	42.6	40.94
PT. A10	27.9	27	35	30.43	49.2	45.3	44.5	44.5	38.97	36.2	42.31	41.2
PT. A11	28.9	28	36	35.23	40.5	35.1	43.6	40.2	37.88	35.4	40.7	36.57
PT. A12	28.2	28.1	39	37	41.1	34.2	34.5	39.5	39.78	36.55	39.68	35.66
PT. A13	28.3	28	35	34.23	35.6	31.7	45.5	45.3	40.7	36.8	43.89	39.5
PT. A14	27.9	27.21	35	33.7	35.5	28.6	41.5	38.1	40.45	34.58	40.63	37.32
PT. A15	30.1	29	32	30.5	38.2	33.7	45.4	45	41.75	33.63	45.68	42.53
PT. A16	30.7	30	30	28.4	33.7	29.7	46	46.5	42.11	36.97	47.9	42.3
PT. A17	29.9	28.4	32	31	46.9	42.2	46	45.3	41.93	35.2	41.4	40.8
PT. A18	30.2	29.2	35	33	48.5	43.4	45.6	41.8	44.6	39.1	48.54	45.21
PT. A19	31	30.2	30	30.1	47.1	37.6	53.5	54.4	46.79	41.54	42.7	40.56
PT. A20	31.3	30	33	32.66	45.8	43.1	36.9	34.8	47.8	43.65	43.83	41.6
PT. A21	31.7	30.21	32	32	42.5	33.7	49.5	47.5	44.35	40.76	45.4	42.92

Table 8. August 2023 readings ITI road (Source-Author)

	Time																	
points	8:00						1:00						4:00					
	A			B			A			B			A			B		
	Road	Footpath	Facade	Road	Footpath	Façade	Road	Footpath	Façade	Road	Footpath	Façade	Road	Footpath	Façade	Road	Footpath	Façade
PT. A1	25	25.4	24.2	26	24.5	24	29	28.5	26.9	29	25	23	29.8	28	26.1	29.1	27.8	26.3
PT. A2	26.4	25.5	25.1	27.5	26	26.1	30.8	28.6	27.4	33.1	30.3	26.9	30	28.6	28	30.4	27.4	27
PT. A3	30.2	27	23.2	31.2	25.7	24.3	35.6	31.8	26.6	25.1	36.4	26	27.1	29	25.2	27.2	35	25.9
PT. A4	29	27	23	28.8	27.1	22.5	34.1	29.8	24.1	32.4	37.6	24	30.2	30	24.1	30.1	38.2	24.3
PT. A5	28	26.4	22	27.1	27.5	24	33.8	29.5	24.5	25.8	23.9	23.9	29.6	30.4	23.1	29	30.1	23.4
PT. A6	26	25	22	27	26	23.2	29.5	26.1	24.5	33.5	27.8	23.9	32	28	25.3	32.1	27.4	25.1
PT. A7	24.9	26	24	33	26.2	22.6	40.5	26.2	26	29.5	24.3	24.1	33.2	29.6	24.6	33.1	28.3	24.3
PT. A8	27	28	26.3	28	27.5	23	30.2	28.6	29.2	32.2	27.4	23.8	30	30.2	30	30.2	28	23.1
PT. A9	30	29	25.2	32	27.6	22.1	34	28.2	28.4	31	24	23.9	30.5	30	25.3	29.5	25	25.4
PT. A10	29	24	24.6	28.5	25	21	35.6	33	26.6	22.1	25	22.2	31	35	24.6	30.1	26.3	23.3
PT. A11	28.9	28	23	28.1	27.1	21.9	32.8	25	25	23.3	32.2	22.1	32	28.2	27	31.1	31.3	27.1
PT. A12	30	29	29	30.1	28.5	22.1	35	32.2	32	38.1	36.9	23.2	36.5	33	30	38	36.4	22
PT. A13	29	24	27	30.2	25.6	22.9	31.7	33.2	30	34.6	30	22.8	32	31	32	34.1	31.1	24
PT. A14	24	23	22.1	28	25	25	30	33.2	32.8	32.3	31.8	25.8	30.2	32.2	34.3	33	32.3	23.6
PT. A15	28	25.12	28.2	29.5	26.1	27.1	31.9	24	30	31	31	29.6	32	30	32.1	30	30.3	30
PT. A16	30	31	23.1	29.8	32	21.5	31	25	26.3	30.9	26.3	22.2	32	28.6	25.3	32.3	28.4	24
PT. A17	28.4	25	24.6	24	26.3	22.2	38.6	27.1	25.6	31.2	27.7	24.3	39	29	24.6	28	28.1	24.3
PT. A18	32	32.5	26.2	25	32	21.9	37.1	34.7	26.1	29.5	26.5	23.6	38	35	23.1	27.2	27.1	24.6
PT. A19	31.5	28.2	29.6	26	27.5	23.5	36.2	26.9	29.1	30.1	26.7	24.3	37.1	28.7	30.3	26.4	27.1	23.3
PT. A20	32.1	30	24.3	29	28.6	21.2	37.1	35.7	26.5	30.5	30.3	22.2	38	36	23.1	27.3	30.2	25.6
PT. A21	33.7	31.5	26.1	24.8	23.6	20.9	36.5	34.1	29.2	29.4	26.4	21.9	38.2	35	31.2	29.1	27.9	24.3

trees. At 1:00 PM, the surface temperature varies between 24 and 37 °C. The highest recorded temperature is 37.6 °C at position B4, which is due to the distance between the buildings and the type of material used for the pathway. At 4:00 PM, the surface temperature varies between 28 and 38 degrees. The highest temperature is recorded at point B4, which can be attributed to the fewer buildings in that vicinity. This leads to less shading and the use of hard paving materials.

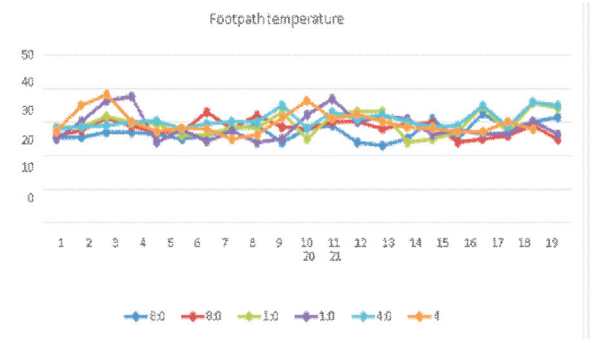

Fig. 7. Graph footpath temperature (Source: Author)

Analysis of surface temperature – Road (August 2023)

At 8:00 AM, the surface temperature at Point A 21 is between 25 and 33 degrees Celsius, which is attributed to the lack of nearby trees. At 1:00 PM, the surface temperature ranges from 29 to 40 °C. At point

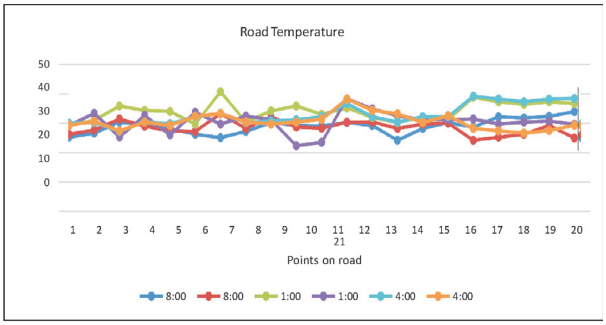

Fig. 8. Graph Road temperature (Source: Author)

A7, it peaks at 40.5 °C due to the fewer buildings in that area, leading to reduced shading. At 4:00 PM, the surface temperature at point A 17 ranges from 27 to 39 °C. This is due to the fewer buildings in that area, leading to reduced shading.

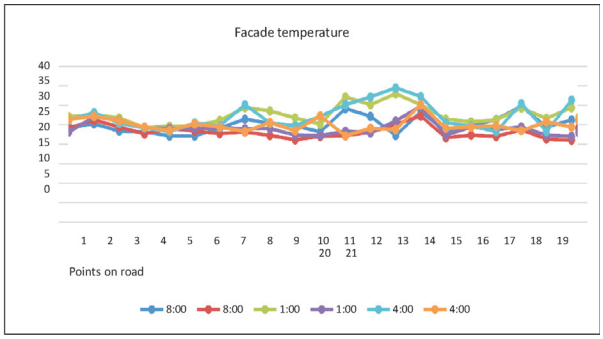

Fig. 9. Graph Façade Temperature (Source: Author)

Analysis of surface temperature – Facade (August 2023)

At 8:00 AM, the surface temperature varies. The temperature at Point A ranges from 21 to 29 degrees Celsius. 19. One o'clock in the afternoon. The surface temperature ranges from 21 to 32 degrees Celsius, with a peak value of 32.6 degrees Celsius observed at point A. Fourteen o'clock, four PM. The surface temperature at point A ranges from 23 to 34 degrees

Table 9. Understanding of factors responsible for temperature variations (Source: Author)

Time	Monsoon [August]	Summer [April]	Temp. Difference	FACTOR- 1	FACTOR- 2
8AM	25 - 35	25-38	0-3	The Surface temperature ranges Between 25- 33 degrees at Point A 21 in august due to absence of trees nearby	In April it is 25-38 degrees because of summer its high temperature.
1PM	29-40	31.5-57.1	2.5 -17.1	The surface temperature between 29 – 40 degrees at some points it reaches at peak value i.e. 40.5 degrees at point A7 because there are less number of density buildings at that point which results in less shading	Comparatively in April 31.5-57.1 degrees due to sun at its highest elevation.
4PM	27-39	34-48.5	7 -9.5	The surface temperature between 27 – 39 degrees at point A 17 because there are less number of buildings at that point which results in less shading and in summer	34 - 48.5 degrees at point B18. density wind flow direction Analysis of Surface Temperature –Footpath
8AM	23-32	24 -37	1-5	The Surface temperature ranges Between 23 – 32 degrees at Point A18, because no treesnearby,	In April it ranges between 24- 37 degrees.
1 PM	24 -37	28 -57	4-20	The surface temperature between 24 – 37 degrees at some points it reaches at peak value i.e. 37.6 degrees at point B4 because Building placed are distant from each other and the footpath material is composite	April 28- 57 degrees due to concrete surfaces as these materials absorb and retain heat leading to significantly high temperature. Values market survey
4PM	28 -38	32 -43.5	4-5.5	The surface temperature between 28-38 degrees the peak value is at point B4 because there are a smaller number of buildings	Paving material, in April it is 32- 43.5 degrees because nearby buildings are providing some relief, but footpaths with concrete and asphalt surfaces may remain hot in evenings.
8 AM	21 -29	28 -48	7-19	The Surface temperature ranges Between 21-29 degrees at Point A 19.	
1 PM	21 -32	30 -40	7 -6	The surface temperature between 21-32 degrees at some points it reaches at peak value i.e. 32.6 at point A 14.	
4 PM	23 -34	36 -42	15 -10	The surface temperature between 23– 34 degrees at point A 14.	

Celsius. Fourteen.

Factors influencing the surface temperature at the facade. The highest temperatures at certain locations are observed solely on one side, specifically side A, because of the lack of trees and the presence of exposed concrete on the façade. The least temperature is observed at specific locations because of the presence of trees with dense foliage, even though the building's façade is glazed.

Inferences

The variations in temperature are also caused by changes in weather conditions. It is observed that the surface temperature and air temperature show lower temperature levels when there is presence of moisture in it. The presence of the river contributes to lower temperature readings along the bridge. Trees along the footpath contribute in reducing the surface temperature of the footpaths. Asphalt roads and rigid materials show higher surface temperatures. Flexible materials show comparatively lower surface temperatures as they reflect more heat. Shaded areas show lower temperatures as direct sunlight does not reach the surface. Surface areas coming under trees with dense foliage have lower surface temperatures as compared to the area under trees with sparse foliage.

Conclusion

The study elaborates the importance of understanding climatic variables and urban morphology to comprehend the factors influencing UHI. Shaded areas with trees had lower temperatures, trees along footpaths reduced surface temperatures, vehicular traffic influenced temperature values, different footpath materials resulted in varying surface temperatures, asphalt had the highest surface temperatures, minor changes in material color had minimal impact on temperature readings, and the presence of a river lowered air temperatures along the bridge. Also, the presence of trees, dry and wet conditions of paver blocks, and patches of vegetation cover on paver blocks were responsible factors. As per the observations in change in temperature nature-based design guidelines for streets is suggested. The research paper can be taken ahead by offering recommendations tailored to specific local streets, highlighting its practical implications for urban planning and mitigation strategies.

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Conflict of Interest - None

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