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Research Article

# Analysis of a City's Heat Island Effect on the Micro-Climate Parameters within Cities

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**Abstract:** The Urban Heat Island (UHI) is a micro-climatic phenomenon that influences the urban areas by elevating its temperature. UHI not only causes the thermal discomfort but also exert serious health issues along with aggravation of urban microclimate. Although a lot of research has been done on this phenomenon but UHI effect on micro scale is still less explored. This paper attempts to make a contribution in UHI studies of micro-climate. It consists of examination of UHI impact on microclimate of Aligarh city areas using mobile traverse method. This study determined the presence and extent of UHI's microclimate variation within urban communities of different environmental layout and functional uses. The UHI effect started to appear from early afternoon and continue to rise with maximum UHI intensity recorded at early night. The highest recorded UHI intensity was 3.1 °C (at 21:00 hrs.), and the lowest was 0.6 °C (at 09:00 hrs.). A comparison of two districts of the same city located at a distance of 3 km and differing in population density, the number of buildings and landscaping showed that in the L1 area with more dense population and low landscaping, the temperature was consistently higher during the daily period; also the L1 region had less humidity, which combined with the already high temperature, makes it difficult to breathe and control the microclimate. These findings can be used for consideration for the future sustainable development of the affected area in regard of thermal comfort, environmental health and urban planning.

**Keywords:** Urban Heat Island, Urbanization, Temperature Increase, Mobile Traverse Method, Thermal Comfort, Environmental Layout, Urban Planning.

## 1. INTRODUCTION

Rapid urban grain change has an impact on a city's local energy balance and, consequently, its thermal and climatic characteristics [1, 2]. It is predicted that with the growth of cities, the negative impacts on the environment will increase [3]. Urban Heat Island effect is one of the environmental issues that are being caused by such scenarios [4]. The first account of the urban heat phenomenon dates back to 1818 [5] therefore numerous additional research were carried out in numerous places worldwide to better understand the phenomenon [6, 7]. Each city is found to have a unique microclimate that differs from the regional climate pattern and is impacted by the urban form, weather, topography, water features, and greenery [8, 9]. Urban heat island impact is defined by the difference between the temperature of an urban region and that of its surroundings. This difference is often referred to as urban heat island intensity (UHII) or strength [10]. The well-known Intergovernmental Panel on Climate Change [11] report acknowledges the occurrence of UHI brought on by urbanization, loss of plant cover, and

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an increase in anthropogenic heat and discusses the essential mitigation measures. The sixth assessment report [12] acknowledged the significant changes in the climate caused by humans' excessive interventions in their environment.

UHI phenomena generally comes in two flavors. The severity of surface urban heat island (SUHI) varies with the strength of the sun, the weather, and the amount of ground cover. It is often highest during the daytime and can reach temperatures of 10 to 15 °C [13]. Usually, there is a close relationship between the temperatures of near surface air and the ground surface [14]. Warmer air in urban areas than in their surroundings characterizes atmospheric municipal heat island (AUHI), which is divided into two categories based on height as stated: (i) Urban heat island canopy. The air expanse that is below the buildings and trees tops, but above the ground is called the canopy layer. Due to the fact that the majority of activities only take place in the canopy layer, the UHI in this layer immediately influences person functionality [9, 15, 16]. (ii) Heat island in the urban boundary layer. This UHI spreads from rooftops and treetops all the way down to the point where urban environments have no more influence to the atmospheric air. Typically, this vertical spacing from the zone's surface is less than 1.5 km (or one mile) [7] (Figure 1).

Cities have been known to have the UHI effect, preferably in areas that are more populated or densely built up than the surrounding countryside [17]. Solar radiation exposure is influenced by the buildings location orientation and the occupied volume of these buildings, and the aspect ratio of the space between them [18]. The heat produced by human activity and solar radiation congregates as long-wave radiation, which diminishes as a result of the intricate heat transfer betwixt buildings and is trapped betwixt them [19], raising the temperature of the region. Buildings that are close together not only trap heat but also hinder airflow and ventilation, which furthers the phenomenon's intensification [20]. Many studies have demonstrated that air temperature in cities is influenced by surface temperature of municipal superficies materials [14, 21, 22]. The sun frequently heats urban surfaces like pavements and roofs between 27 and 50°C, making them hotter than the air [10, 23]. This heat is progressively released into the environment after being absorbed during the day, which contributes to the UHI effect [24]. All of this occurs because materials' thermal and radiative qualities affect how heat is exchanged in urban environments [9, 18]. Dark-colored materials have a low albedo while white, bright, and reflecting materials have a high albedo [25]. 80 % of the sunlight is absorbed by the pavement and roofs that cover 60 % of urban areas [9]. By evapotranspiration, $CO_2$ absorption, and giving shade to surfaces exposed to the sun, trees and plants are known to keep the environment cool [10]. Greenery's high albedo contributes to its ability to reflect heat back onto itself. The efficiency of this natural cooling drastically decreases with the loss of green space, causing municipal warming [13, 18, 26]. The UHI impact is more pronounced in clear, calm conditions than in cloudy, windy conditions [27]. When the temperature rises, the relative humidity decreases, resulting in drier air, but when the temperature drops, the air gets wet, resulting in a rise in relative humidity [28].

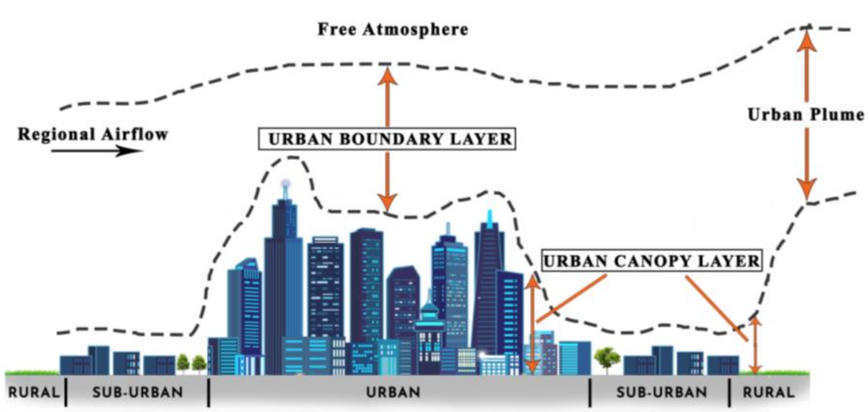


**Fig. 1.** Two-layer representation of atmospheric air thermal alteration in an municipal setting

Source: Redrawn from (Oke, 1976)

In addition to deteriorating the environment, UHI also affects air quality, human comfort, and the demand for cooling energy, which exacerbates problems like global warming. If the air temperature rises even by 1 °C, then in cities electricity consumption increases on average by 2 to 4 %, according to Akbari *et al.* [29], which creates the need to search for alternative energy sources [30, 31, 32]. The study also showed that, in order to make up for the increase between 0.5 and 3.0 °C in municipal temperature, 5–10 % of the power used in cities is used to cool buildings. When the temperature rises, so do the needs for water for cooling, watering plants, and human consumption [33, 34], as well as for power. Those with low thermal tolerance are susceptible to significant illnesses such cardiovascular stress, cardio respiratory diseases, heat cramps, blood clots, and, in some circumstances, death due to the extreme heat [35, 36]. With each degree of temperature increase, those who live in such unfavourable conditions have less sleep, which can amount to up to two weeks of insufficient sleep annually and directly contribute to an increase in health morbidities [37, 38]. Thus, the urban heat island effect has been explored to varying degrees in many scientific papers demonstrating the impact of land use/land cover (LU/LC) and green cover on the air quality index [39]; it is shown that the lack of green spaces is the main problem, and this problem will only be exacerbated due to overpopulation associated with the rapid growth of cities [40]; analyzed the law of spatio-temporal evolution and determined the differences between urban heat islands in winter and summer [41]; impact of urban heat islands on heat-related cardiovascular morbidity [42]; explored nighttime urban heat island intensities during Covid-19 lockdown and ecological habitat [43, 44]; investigated the difference between urban and rural heat [45]. However, the authors did not reveal studies of the comparative nature of two districts of the same city located close to each other, but having different characteristics, such as social activity, population density in the area, the degree of development and landscaping of the territory, etc.

The present study is conducted to investigate and assess the effects of UHI on carefully chosen places, namely: Center Point Chauraha and Staff Club Chauraha, based on local climates for two districts of the city of Aligarh, located close to each other, but have different characteristics. The city of Aligarh is part of the northern Indian state of Uttar Pradesh, around 132 km southeast of New Delhi, and located between the Ganga and Yamuna rivers, in the middle of the doab. Furthermore, to investigate the impact of UHI, this study solely evaluates the relative humidity (%) and ambient dry bulb air temperature in the canopy layer at two specifically chosen locations in Aligarh.

## 2. MATERIALS AND METHODS

For the purpose of gathering data, two places in Aligarh city were carefully chosen. The microclimatic environmental conditions at these two areas are in contrast to one another. Center Point Chauraha is the first location, designated as L1, while Staff Club Chauraha, on the campus of Aligarh Muslim University, is the second location, designated as L2. The two areas are roughly 3 kilometers apart. Since L1 is a Central Business District (CBD), it receives the majority of the city's foot traffic. The area, which is characterized by both commercial and residential land use, is located in the heart of Aligarh City's high density sector. Due to the paucity of urban vegetation relative to the built-up region, the urban grain of the area is poorly preserved. On the spine route of the A.M.U. campus, L2 sees a fair volume of traffic flow. Compared to other locations, the area around has a high level of vegetation and greenery. In close proximity to the place is a public park.

The information is gathered five times a day, from 9:00 to 12:00, 15:00 to 18:00, and 21:00 to 21:00, for a period of 23 days, from April 22 to May 15, 2022. Due to the unfavorable weather, one day from the survey period – May 4, 2022 – was excluded. To capture and comprehend the urban configuration of the research regions, radial buffer zones of 500m were taken into consideration at both locations. To prevent changes in the microclimate, each survey was finished within 30 minutes. Based on the past research procedures, all the precautions and techniques were used [10, 16, 18, 46]. The UHI intensity across the study period, which varied from morning to night and affected micro-climatic factors depending on distinct urban settings, was then depicted in tables and graphs and compared using the temperature and humidity measurements from the two locations.

In order to gain information about the causes of thermal discomfort and evidence of microclimatic variation, data are collected utilizing mobile traverse method-portable equipment. During measurements, the apparatus was fixed to a tripod stand that was 1.3 meters above the ground. The sensor was effectively protected from direct sunlight while still ensuring airflow by having a hard cardboard covering it. Before taking readings, the equipment was left in place for a sufficient amount of time to come into balance with its environment.

## 3. RESULTS AND DISCUSSION

According to analysis of field measurement data, L1 experienced a greater temperature than L2, as indicated in Table 1. The mean temperature difference ranged from 0.87 °C in the morning to 2.23 °C at night (Table 1). As a result, the L1 region exhibits urban warmth, where heat stored during the day is later released into the atmosphere, delaying the cooling of urban space. Given that most past studies have used the same pattern, this UHI pattern justifies the term «urban heat island» [10, 18, 47]. By daybreak, the considerable UHI effect began to show evident, and urban buildings continued to warm up until late in the day. After that, the temperature lowers significantly while the UHII rises, peaking at night. The highest recorded UHI intensity was 3.1 °C when it was seen at 21:00 hours, and the lowest was 0.6 °C when it was seen at 09:00 hrs (Table 2). This is taking place as a result of Location 1's UHI phenomenon, which causes heat to be absorbed during the day and then slowly released after nightfall. The occurrence at L1 may have existed due to human heat, exposed pavement areas, increased traffic volume, decreased vegetation, and strong traffic influx. Several causes of UHI production have been verified in earlier research [10].

This study indicates that microclimatic variables can have a big impact on temperature and humidity over short distances, as the 3 km used in this study. L1's temperature was consistently higher than L2's (Table 1, Table 2). This is taking place as a result of L1, which is a high-density area with artificial surfaces and little vegetation (Figure 2). Due to large asphalt roadways, exposed dense mass, and few pockets of shade, the sun-exposed surfaces are more prevalent in the L1 area. As a result, L1 urban settings absorb more heat throughout the day and have less long wave cooling afterwards,

**Table 1.** The difference between the L1 and L2 mean temperatures (°C) at specific three hours' time intervals between 09:00 to 21:00 hrs. during the survey period of 23 days

| Mean Temperature Difference (°C) | | | |
|---|---|---|---|
| **Time** | **Mean Humidity Center Point Chauraha (L1)** | **Mean Humidity Staffclub Chauraha (L2)** | **Mean Difference** |
| 09:00 | 36.63 | 35.76 | 0.87 |
| 12:00 | 41.80 | 40.43 | 1.37 |
| 15:00 | 42.78 | 41.13 | 1.65 |
| 18:00 | 37.64 | 35.80 | 1.83 |
| 21:00 | 34.00 | 31.77 | 2.23 |
| | | | Average = 1.59 |

**Table 2.** Maximum and minimum UHI Intensity (UHII) at selected three hours' time interval between 09:00 to 21:00 hrs. during the survey period of 23 days at L1 and L2

| Analysis of UHI Intensity (UHII) | | |
|---|---|---|
| **Time** | **Maximum UHI** | **Minimum UHI** |
| 09:00 | 1.4 | 0.6 |
| 12:00 | 1.8 | 1.1 |
| 15:00 | 2 | 1.2 |
| 18:00 | 2.4 | 1.4 |
| 21:00 | 3.1 | 1.6 |

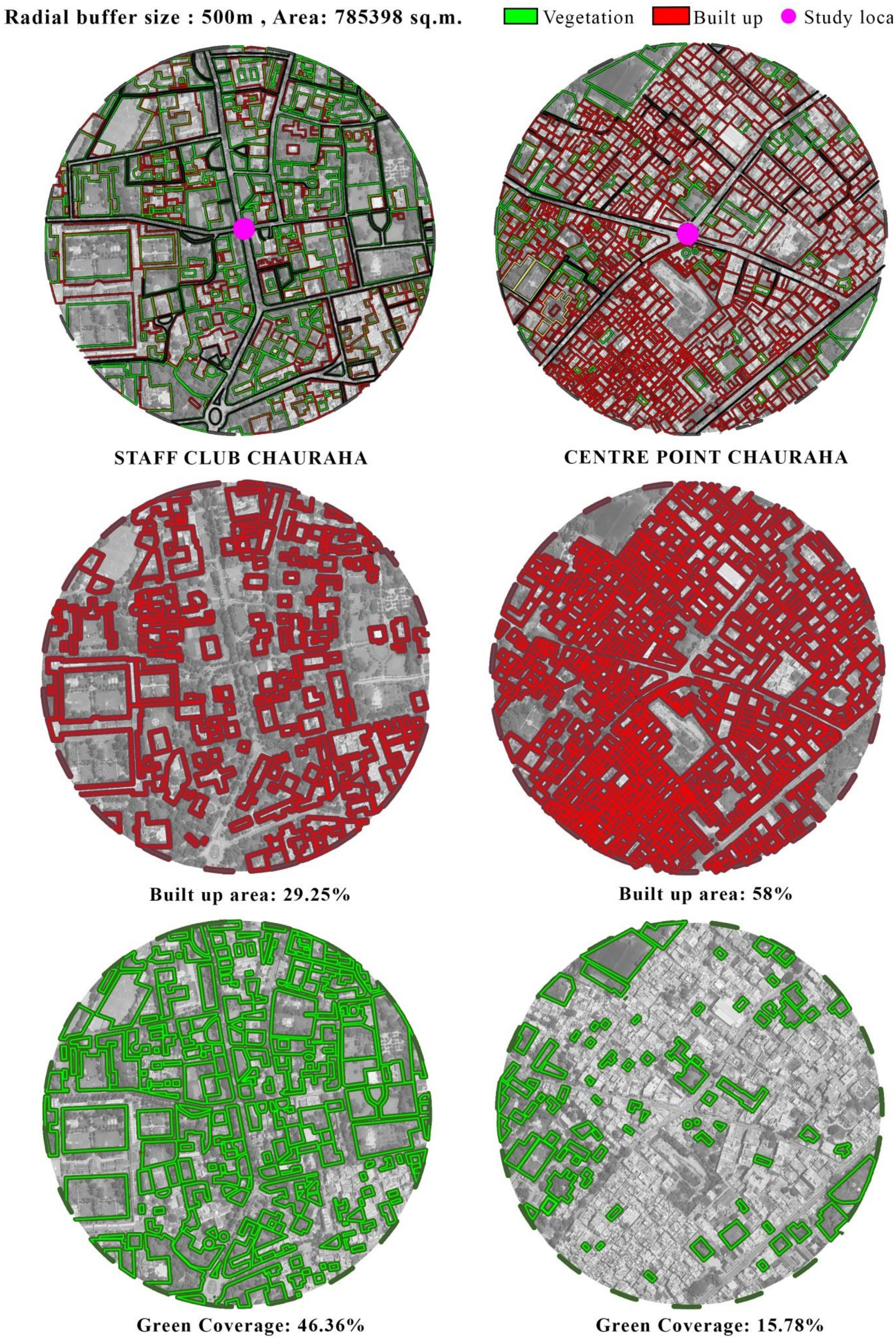


**Fig 2.** Picture depicting the built-up and greenery within the considered 500 meters of the research area

which increases the intensity of UHI. Because it has been proven that asphalt absorbs heat during the day and surface temperatures can reach 67 °C [48] and releases heat at night. However, by adding various color pigments, the temperature of the asphalt pavement can be reduced by 5.4 °C per day [49]. As a result of reduced density and high green cover, L2 temperature increased less than L1 temperature throughout the diurnal period and decreased significantly after sunset (Figure 2). The building density of buildings and the used facing materials significantly increase the air temperature of the urban environment [50, 51]. In other words, depending on the spatial composition and urban features, the urban heat island effect and its amplitude might change at lower scales [15, 52].

As shown in Table 3, the mean relative humidity was seen to be rising starting in the evening and was thought to be the case until early in the morning. It was recorded at its lowest point in the late afternoon, typically about 15:30 when the temperature was at its highest. This explains why temperature and relative humidity have an inversely proportional relationship, meaning that as temperature rises, relative humidity decreases, making the air drier [28]. Because L1 had less humidity than L2 (Table 3), paired with an already high temperature, L1's micro-climate is difficult for urban residents to control. This may be taking place because there are more urban materials at L1 than L2, which are less permeable to water.

## 4. CONCLUSION

The empirical evidence from this study supports the assertion that UHI impact is common in densely populated metropolitan regions. In contrast to L1, which has a high concentration of greenery and is less densely populated, L2 has a lower temperature rise and higher cooling than L1. Furthermore, this study proves that diurnal temperature variations in built environments occur over relatively small distances and are influenced by urban spatial design. The findings of this study indicate that UHII was found to be more severe after sunset. Understanding the relationship between the specified microclimatic measures, such as ambient dry bulb temperature and relative humidity fluctuations, and microclimatic conditions was made easier by the spatial study of urban fabric at selected places. L1 had lower humidity and a higher temperature pattern than L2 because of the location's weak green cover and water-impermeable surfaces (Table 1, Table 3). Similar findings have been drawn by other researchers who have shown how many environmental factors in urban environments can cause 2 °C microclimatic changes that may indicate serious problems with UHI; who substantiated that temperature fluctuations even by 0.69 °C can be considered significant. According to this study, urban dwellers at L1 can experience significant unfavourable microclimatic conditions due to measured mean temperature differences of 1.37 °C at noon and 1.65 °C at 15:00 hours.

A deeper understanding of microclimatic UHI can be produced by such study endeavors. The important component of healthy and energetic public spaces is a microclimate that is thermally comfortable. Good understanding of daily fluctuations in urban temperature can aid authorities and planners in understanding for better existing and future development. This can be done by transforming existing metropolitan areas in a clever and small-scale manner.

**Table 3.** Mean relative humidity (%) at L1 and L2, as well as the difference between them at a certain moment throughout the survey period of 23 days

| Mean Humidity Data (%) | | | |
|---|---|---|---|
| **Time** | **Mean Humidity Center Point Chauraha (L1)** | **Mean Humidity Staffclub Chauraha (L2)** | **Mean Difference** |
| 09:00 | 33.01 | 34.96 | 1.95 |
| 12:00 | 25.73 | 27.21 | 1.49 |
| 15:00 | 23.58 | 26.43 | 2.85 |
| 18:00 | 29.80 | 32.61 | 2.82 |
| 21:00 | 36.08 | 40.70 | 4.63 |

## 5. RECOMMENDATIONS

### 5.1 Altering Roofing Materials – Cool Roofs

Create the idea of cool roofing by replacing heated roof materials with cool materials (high albedo value). According to a National Centre for Atmospheric Research (NCAR) study from 2010, white painted roofs can minimize the UHI effect by 33 %, and if cool roofs can be achieved by changing colour, the cost of the roof is not increased. Engineers at Prude University created a "ultra white" paint in 2021 that can reflect 98.1 % of sunlight, aid in energy conservation, and counteract climate change. This paint can save 10 K.W. of cooling power when applied to a 93 sq.m. roof area.

### 5.2 Bringing Down Anthropogenic Heat

Human activity produces anthropogenic heat, with sources including illumination, building cooling and heating systems, and moving automobiles [53], which creates the need to search for alternative energy sources [30, 31] in the conditions of the energy crisis. The temperature in metropolitan areas may rise by 2 to 3 °C as a result of this heat [54]. Thus, we can observe a vicious circle, since the earlier manuscript emphasized that the consequences of a one degree increase in air temperature is an increase in energy consumption [29], in addition, building-integrated photovoltaic system panels can potentially increase UHI intensity [30]. Encouraging public transit, limiting the use of private motor vehicles, and switching to cleaner fuels can all help reduce the impact of UHI. It may be more energy efficient to switch to an efficient cooling/heating system like VRF (Variant Refrigerant Flow). They operate quietly, consistently give comfort, take up less room, and offer superior control [55].

### 5.3 Increasing the Amount of Greenery

Increasing vegetation cover is one of the most effective ways to reduce the effects of heat on the urban environment [56, 57]. Shade, thermal insulation, and noise and air pollution control are all provided by vegetation [58]. Vegetation is observed to reduce the near-surface air temperature by 1-4.7 %, especially when UHII is significant [59, 60]. Another crucial factor to take into account is the selective planting of trees. For cooling, shade, and evapotranspiration, their healthy growth and type of tree must be taken into consideration. Plantations might benefit from shade trees. They have a large canopy and can shade homes and pedestrians while reducing the amount of direct sunlight that hits urban surfaces, keeping the microclimate cool [61]. A mature tree may evapotranspire up to 450 liters of water per day, which is equal to 20 hours of use of a five-star air conditioner [62]. In their simulation study conducted in Canadian cities, Akbari and Taha [61] found that planting 30 % more trees might result in 10 % energy savings from heating and air conditioning. According to Theeuwes et al. [63], temperature typically drops by 0.6 K for every 10 % increase in vegetation.

### 5.4 More Porous and Permeable Surfaces

Water can percolate through pavement or plant and reach a substrate layer through permeable surfaces, which encourages deep infiltration [64]. These characteristics should reduce temperature to a respectable degree [17]. Turf pavers can be used in place of the typical tiles found on sidewalks, outdoor areas, and parking lots. Further to the water permeability quality, they contribute to the "feel good" quality of green space. Porous concrete paving stones, which not only allow water to get absorbed but also aid trees in consuming nearby water, can be utilized in places where turf tiles are impractical. For pedestrian walkways, porous concrete is advised since it requires less washing for cleaning and maintenance [62].

## 6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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