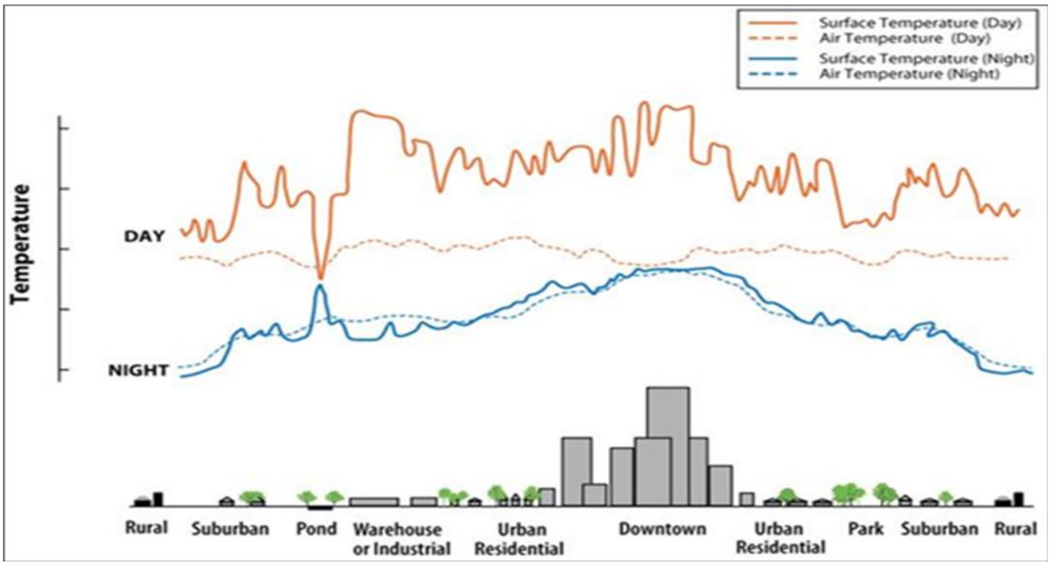
Final Report

# Urban Planning Characteristics to Mitigate Climate Change in context of Urban Heat Island Effect

Prepared for
Environmental Management & Policy
Research Institute (EMPRI)



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*...towards global sustainable development*

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## Project Duration

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## List of Abbreviations

*UHI - Urban Heat Island*
*IPCC - Intergovernmental Panel on Climate Change*
*EPA- Environmental Protection Agency*
*GHG- Green House Gases*
*UCL - Urban canopy layer*
*RSL - Roughness sub-layer*
*ISL - Inertial sub-layer*
*H/W – Height/Width*
*AT - Air Temperature*
*GT - Globe Temperature*
*MRT – Mean Radiant Temperature*
*PET – Physiological Equivalent Temperature*
*SVF - Sky-View Factor*
*HXG – Height/Width x Green Cover*
*GIS – Geographic Information System*
*NDVI – Normalized Difference Vegetation Index*
*TM – Thematic Mapper (Landsat)*
*RH – Relative Humidity*
*IR - Infra-Red*

# 1 Executive Summary

In the last few decades, cities around the world have seen significant urbanization, marked by the increase in building infrastructure and automobiles. Permeable land surfaces which were once covered by vegetation have now been replaced with impermeable and high emissivity surfaces and mostly un-shaded. Such urban surfaces tend to absorb the solar radiation and emit it later, which causes an increase in local temperatures. Consequently, the urban areas observing higher temperatures become ''heat islands'', compared to their rural counterpart.

In a study carried out by TERI in 2014, it was found that Bangalore is one such example of a city where dense urban pockets were found to be about 2 °C warmer than nearby rural area (1). In another study done by IISC, an increase of 2-2.5°C was observed during the last decade owing to 76% decline in vegetation cover and 79% decline in water bodies, which is indisputably due to reckless urban sprawl. (2).

Urban Heat Islands (UHI) can cause deterioration of living environment, elevation of ground level ozone, health disorders and increase in building energy consumptions. Thus the aim of the project includes assessing the impact of urban planning aspects of urban geometry and green cover on the formation of UHI within different zones of Bangalore. The study therefore helped in developing relationship between planning characters and microclimatic influence which will be useful for urban planners to mitigate UHI in newly developing areas of the city.

The building typologies were considered to be residential and commercial (IT or Information Technology) as they are predominant in Bangalore. Three locations were strategically selected for each monitoring based on various urban characteristics such as green cover, open lands, water bodies, height to width (H/W) ratios etc. Continuous monitoring of thermal parameters such as air temperature (AT), globe temperature (GT) and relative humidity (RH) was carried simultaneously in these selected locations.

**Figure 1-1 Satellite Image of Bangalore showing different locations selected for the study (Map Source: Google Maps)**

For residential typology, two monitorings were conducted in three locations: Bellandur, Lalbagh and Basweshwar Nagar areas. The results indicate Basweshwar Nagar recorded highest GT and AT with lowest RH out of all three locations due its lowest green cover, higher H/W ratio, high density and absence of open lands and water bodies. Bellandur although has comparatively higher H/W ratio like in Basweshwar Nagar and low green cover yet recorded lower temperatures due to the mutual shading of buildings and high RH which is because of its close proximity to a large water body. Lalbagh readings also represent similar or slightly lower UHI effect than Bellandur. This is because of its highest green cover out of all three locations including small percentage of open lands and a water body. Therefore it can be concluded that green cover and water bodies with open lands help in reducing temperatures. Locations with higher H/W ratio would not be very effective without sufficient green cover.

From the first monitoring, some errors were observed due to which a second monitoring was performed for same locations during the summer. From both monitorings, impact of H/W ratio was determinable but effectiveness of green cover against open lands and water bodies could not be ascertained. Hence a third monitoring was performed for three different locations:  Koramangala, Jayanagara and HSR layout.

From the third monitored readings, Koramangala showed best performance which has thick green cover as well as open lands with huge water body. HSR layout on other hand has the similar proximity to the open lands and water body as Koramangala but green cover is less. HSR location however recorded better thermal performance than Jayanagar which has thick green cover but less open lands and water bodies. This explains that water body and open lands have greater impact in mitigating UHI effect than green cover.

For commercial/IT typology, three locations were selected for monitoring: Electronic City, Marathahalli and Whitefield. Data from Marathahalli showed lowest GT and AT during daytime, despite having identical RH, in comparison to other locations. This is because of the high H/W ratio. On the other hand Whitefield recorded highest GT and AT during daytime and high diurnal variation due to large and exposed open lands. Electronic city recorded lowest during night and slightly higher than Marathahalli. This is due to its thick green cover and high reflective surface finishing on building enevelops. The comparative analysis could be understood as high H/W ratio, green cover and water bodies can help reducing the local temperatures.

To sum up, analysis of the results helped establishing a relation between the urban characteristics of the locations and their thermal environment.

# 2 Introduction

Urban Heat Island (UHI) is being experienced in developing cities of developing countries, and it is predicted that the magnitude of Urban Heat Island will further intensify with high rise-high density development.

As per United States Environmental Protection Agency "As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape" (1).

Urban structure of a city which includes, land use planning, building morphology, surface characters along with the anthropogenic heat which is generated from vehicles and equipment such as air conditioners are the most crucial factors causing increase in air temperature or urban heat island. These in turn increase air pollution and also energy consumption of buildings in providing thermal comfort inside the buildings by use of refrigeration. This eventually leads to an increase of greenhouse gas emissions and negative impacts on health of citizens of developing cities.

IPCC (Intergovernmental Panel on Climate Change) 2014, had one chapter dedicated on UHI. The report recognizes the presence of UHI due to urban densification, reduction in vegetation cover, and increase in anthropogenic heat. UHI mitigation strategies are seen necessary in order to reduce GHG emissions from urban areas.

In context to the above, it is important that State Governments and urban planning agencies are equipped with tools, guidelines and understanding of impact of buildings and urbanization on climate of the city. The overall objective of the exercise is to look at urban planning as a tool to make urban centres more manageable and liveable.

The focus is on Bangalore city, as the city has gone through rapid urbanization in the last few decades. Bangalore is classified as the third most populous city of India, after Mumbai and Delhi, with a population hitting about 11.5 Million in 2016. Rapid urbanization has seen many negative environmental impacts on the city, which include, diminishing lakes, traffic congestions along with high air pollution levels, urban flooding during heavy rains and increase in summer temperatures. In the summer of 2016, highest air temperature recorded in Bangalore was 39$^{o}$C. All the above environmental impacts are related to Urban Heat Island effect, which is mostly related to the manner urban development takes place. If the current scenario continues, Bangalore could lose its charm of enjoying the salubrious temperate/moderate weather conditions.

Thus, in this project, it is planned to study the effect of urban characteristics on UHI by recording temperatures at strategically identified locations, along with the documentation of physical characteristics of urban planning and anthropogenic heat being emitted in the locations. Based upon the monitored results relation between urban planning characteristics and UHI will be framed. This will provide with important guidelines for urban planners, while carrying out urban planning for new locations/satellite towns around Bangalore.

## 2.1 Objectives

To study the Urban Heat Island effect within different pockets of Bangalore with respect to urban planning and develop relation between planning characteristics and microclimate, which will be useful for urban planners/authorities to mitigate UHI and climate change in newly developing areas of Bangalore.

## 2.2 Need

Urban heat islands can cause deterioration of living environment, increase in energy consumption, elevation in ground-level ozone, and even an increase in mortality rates. In a research by Konopacki and Akbari, it was observed that by mitigating UHI effects in Houston, it was possible to achieve savings of 82 million USD with a reduction of 730MW peak power, leading to an annual decrease of 170000 tonnes of carbon emission. (2). In context of Bangalore, implementing white roofs alone can reduce energy consumption by 1642 MWh/Sqm/yr, which would result in savings of Rs. 10,348 million per year. (3).

In 1998, it was reported that the ozone level could exceed 120 ppbv at 22°C, and could reach 240 ppbv at 32°C. Hence, annual reduction of 25GW of electrical power or potential savings of USD 5 billion by year 2015 can be predicted.

It is apparent that the benefits of mitigation of UHI are vast, and particularly for a developing tropical country like India, study in this field can bring about timely intervention in urban policies to result in energy savings and outdoor thermal comfort.

# 3 Review of Literature

## 3.1 Urban Heat Island

An Urban Heat Island has been best described as a dome of stagnant warm air over the heavily built-up areas of the city (4). Due to this phenomenon, many urban and suburban areas experience a higher temperature than the surrounding rural areas as seen in Figure 3-1. This difference in temperature can be as high as 1 to 3°C for a city with about 1 million people; while on a clear calm night, the difference can be as much as 12°C (1). In New Delhi, the summer time temperature was recorded to be 7-10 °C higher than the temperature of surrounding rural areas.

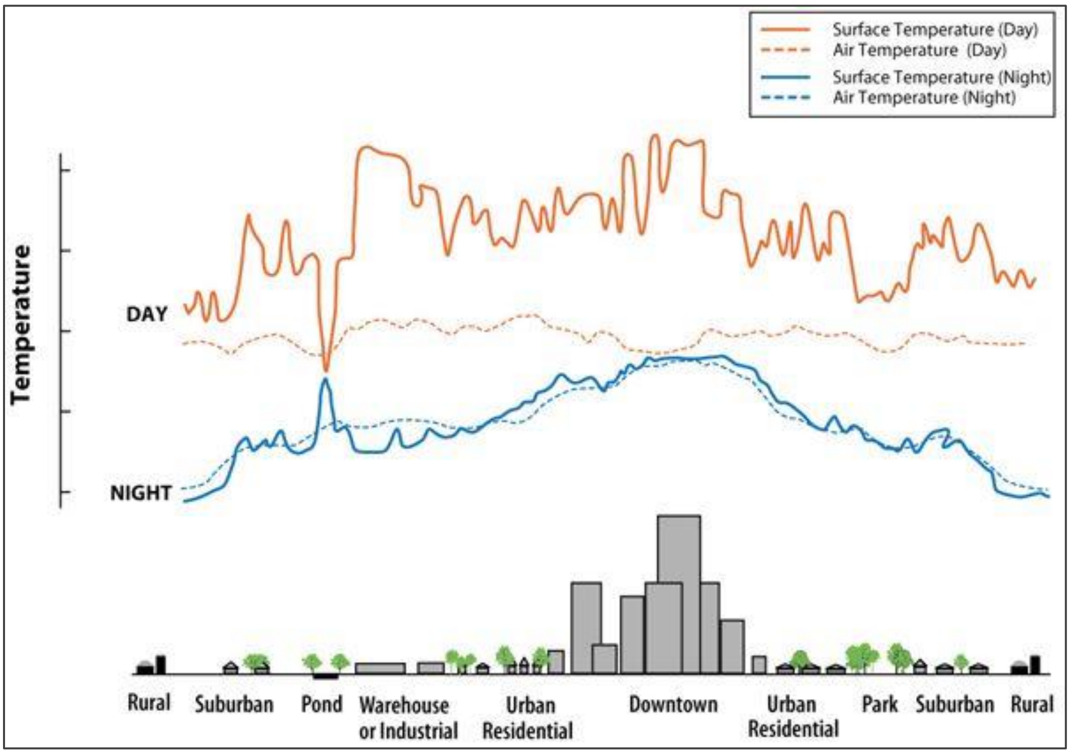

**Figure 3-1 Variations of Surface and Air Temperatures in different types of urban areas compared to rural peripheries. (1)**

It is estimated that for every 0.6°C rise in temperature, there is an increase in electricity consumption of about 2%. (5). Increase in thermal discomfort has led to increase in use of air conditioning appliances, resulting in increased emission of harmful greenhouse gasses which has led to global climate change. Harmful gasses released from power plants cause further increase the air pollution, and in due course, intensify the UHI.

Besides affecting air quality, the surface UHI can also affect water quality, as the temperature of run-off storm water increases after flowing over heated pavements and urban surfaces. When this heated storm water flows into water bodies, it tends to disturb the balance of aquatic ecosystems. In a study carried out in American cities of Atlanta, Dallas, San Antonio and Nashville, NASA researchers have found that urban areas with high concentrations of buildings, roads and other artificial surfaces retain heat and lead to warmer surrounding temperatures. During summer months, the rising heated air creates wind circulation and enhances cloud formation and rainfall. (6)

In areas with tropical climate, increased atmospheric heat can lead to several health hazards such as heat strokes, exhaustion and respiratory problem among the population. In densely urban areas, the suspended and highly flammable particles accumulated in the air, combined with the rise in temperature can trigger fires. In summers, dry trees and vegetation can also catch fire. (7)

The undesirable effects of urban heat islands can be summarized as:

1. Increased heat transfer indoor leading to increased electricity consumption for cooling in tropical countries.
2. Thermal discomfort (both indoor and outdoor) leading to health hazards
3. Increased rainfall intensities over urban areas
4. Increased emission of greenhouse gasses leading to global climate change
5. Risk of fire breakouts

Thus, in the developing countries having tropical climate, the issue of urban heat island has become critical, and is predicted to increase significantly in the near future. With increasing severity of the problem, vast research is being dedicated to this subject and sufficient literature is available.

## 3.2 Urban Heat Island and Climate Change

The effect of Urban Heat Island on Climate change is two-fold. Firstly, the heat build-up caused by urban heat island effect can worsen the effect of global warming in affected urban areas. As the result, these areas may experience more severe heat-waves with very high daytime summer temperature.

Secondly, the increased heat gains in conditioned buildings caused by the heat build-up leads to increased electricity demand for cooling. As developing countries are predominantly dependent on conventional[1] methods of energy generation, the increased electricity demand can cause surge in the rate at which greenhouse gases are released into the atmosphere. For developing countries having limited natural resources and a developing economy, the increased demand of electricity may also lead to economic stress.

Hence employing strategies to mitigate UHI can benefit tropical countries in the mitigation of climate change.

## 3.3 Urban Heat Island and the Built Environment

Urbanization has led to rampant deforestation and construction activities in urban areas. The reduction in urban green cover and the increase of built-up hard surfaces as well as emissions are primary causes of urban heat islands.

Thus UHI mitigation strategies should aim to restrict the excessive heat built up by: 1. Reduction of use of hard and absorptive surfaces, 2. By providing sufficient shading from solar radiation and 3. Reducing anthropogenic GHG emissions. (See Figure 3-2).

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[1] Conventional methods of energy generation refer to those that depend on non-renewable sources of energy and also cause considerable emissions.

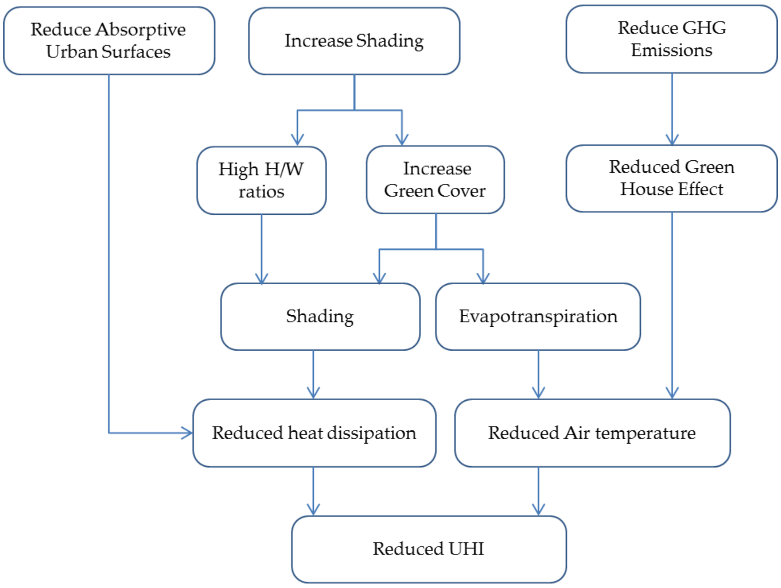


**Figure 3-2 UHI Mitigation Approaches**

### 3.3.1 Green Cover

Trees reduce temperature by means of shading and evapotranspiration. With reducing green cover, there is less shading, hence exposed surface tend to absorb more heat which is later dissipated into the air. With reduced evaporation, the moisture required to cool down the air is not available, hence the air temperature remains increased.

Urban paved surfaces consist of upto 75% impervious surfaces, whereas natural ground cover is about 10% impervious, hence natural ground surface can provide sufficient moisture for cooling the air near the surface. (Figure 3-3)

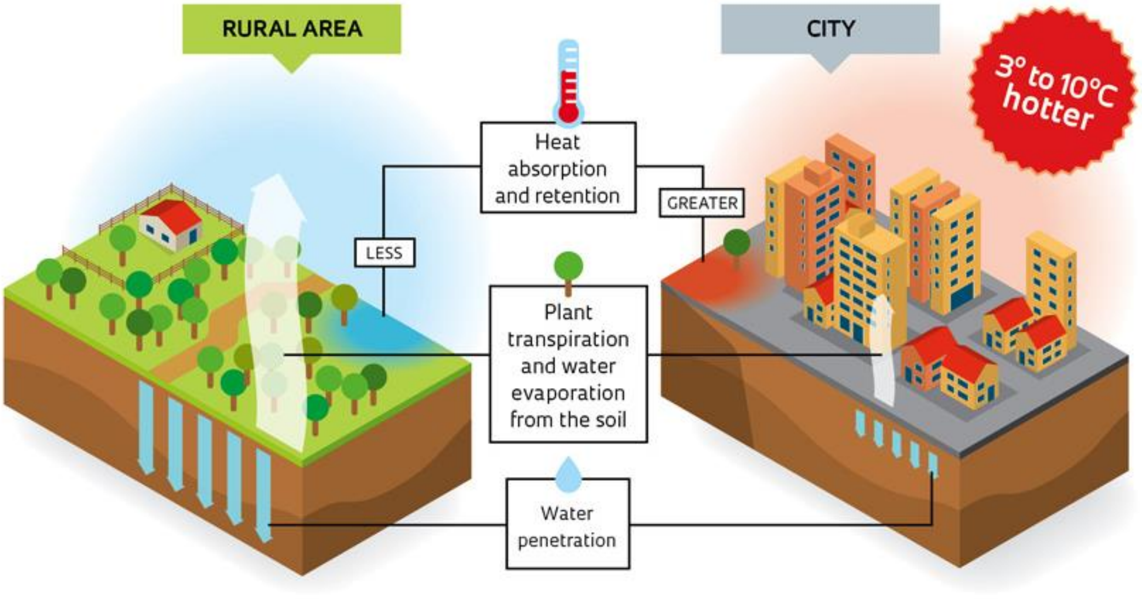


**Figure 3-3 How green cover influences formation of UHI (8)**

### 3.3.2 Urban Geometry

Urban geometry deals with the dimensions of the built environment for a given urban area. It may directly influence wind movement, shading patterns, heat absorption and the ability of a surface to emit long-wave radiation back to the space. (1). The effect or UHI is particularly distinct in urban canyons, which are urban enclosures formed by narrow streets and tall building on both sides. On one hand, during the daytime, the tall buildings can shade the canyon reducing surface temperature, but on the other hand the surfaces of these tall buildings may reflect and absorb the heat leading to increased air temperatures. (See Figure 3-4).

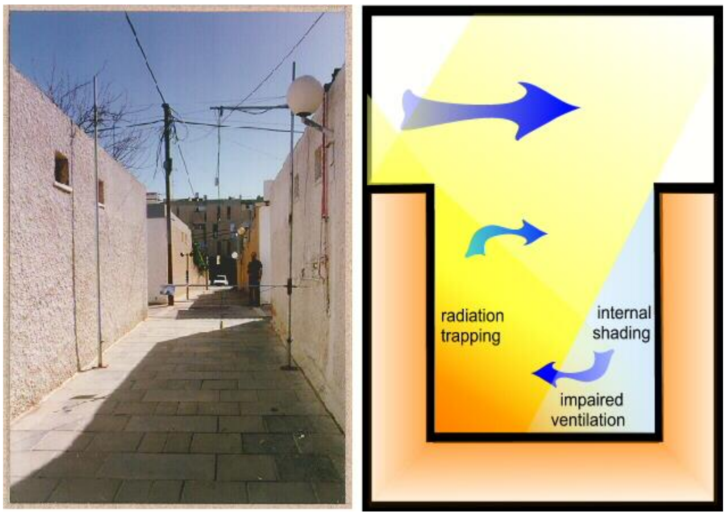


**Figure 3-4 Formation of 'Urban Canyons' based on different heights and widths of urban masses, and their effect on the canyon temperature (9)**

### 3.3.3 Urban Surface Characteristics

Urban surfaces absorb, reflect and re-emit solar energy, thus their characteristics such as thermal capacity, emittance, thermal absorbance and reflectance significantly affect UHI formation.

Urban areas generally exhibit low-albedo surfaces such as roads, rooftops and pavements, which are less capable of reflecting solar heat, compared to rural areas. Hence urban surfaces absorb a lot of heat leading to increased surface temperatures and consequently formation of surface UHI.

Thermal capacity of a material governs the amount of heat that the material can store. Urban surfaces built with materials such as steel and cement are capable of storing more heat compared to rural surfaces such as soil and sand, therefore core urban areas tend to have absorbed more heat than its outskirts, this heat is then emitted back at nights. Due to this phenomenon, diurnal variations are very low in UHI affected urban areas when compared to rural cases.

With interventions such as reflective roofs and green roofs, a reduction of 1.5°C and 1.9°C can be observed, which can facilitate savings of 16.9% and 11.8% respectively. (3).

### 3.3.4 Anthropogenic Heat

Heat caused due to human activity such as manufacturing, heating or cooling, lighting, transportation, heat from human and animal metabolism together constitute the anthropogenic heat, which eventually leads to increased UHI. Urban settings comprise of more energy-intensive buildings that contribute more anthropogenic heat to its surroundings.

Urban climate is associated with the heat and moisture emitted by cities in association with energy consumption of cities. Sensible anthropogenic heat emission into the atmosphere can be directly from chimneys, air conditioners, heaters etc and indirectly from building envelope through convection and radiation into the urban environment. The defined sectors which contribute to the anthropogenic heat generation are: transport, building, industry and human metabolism.

The cooling system of buildings consumes energy to reject heat of the building into the urban environment.

This rejected heat can be quantified as:

$$R = E+P+M+L+AC$$

E-Heat transmitted in building from external environment

P-Plug Loads

M-Human Metabolism

L-Heat generated by lighting

AC-additional energy consumed by cooling systems

Some air conditioning systems use evaporative cooling to exchange heat with the outside environment. In such cases, majority of heat is removed in form of evaporated water.

The largest fraction of anthropogenic heat from buildings comes in the form of heat and moisture rejected by the building through its mechanical heating, cooling and ventilation systems. Data from earlier studies show, city wise anthropogenic heat emissions can vary from 15-150W/m2. (David J. Sailor).

In an urban context, vehicles emit enough heat to considerably add to the increasing heat island intensity. In a research conducted in Beijing, it was found that conventional vehicles would emit $9.85 \times 10^{14}$ J of heat energy per day. And upon replacing conventional vehicles by electrical vehicles, the heat emitted would reduce by $7.9 \times 10^{14}$ J.

## 3.4 Energy Balance of the Earth

The Intergovernmental Panel on Climate Change (IPCC) defines “Energy Balance” of the Earth as the difference between total incoming and outgoing energy. If the balance is positive, warming occurs, and if it is negative, cooling occurs. When averaged over the globe and over long periods of time, this balance must be zero.

Given that the earth receives all its energy from the sun, the zero balance implies that :

Global incoming solar radiation – Reflected solar radiation (from the top of the atmosphere) - Outgoing long-wave radiation (emitted by the earth surface)= 0

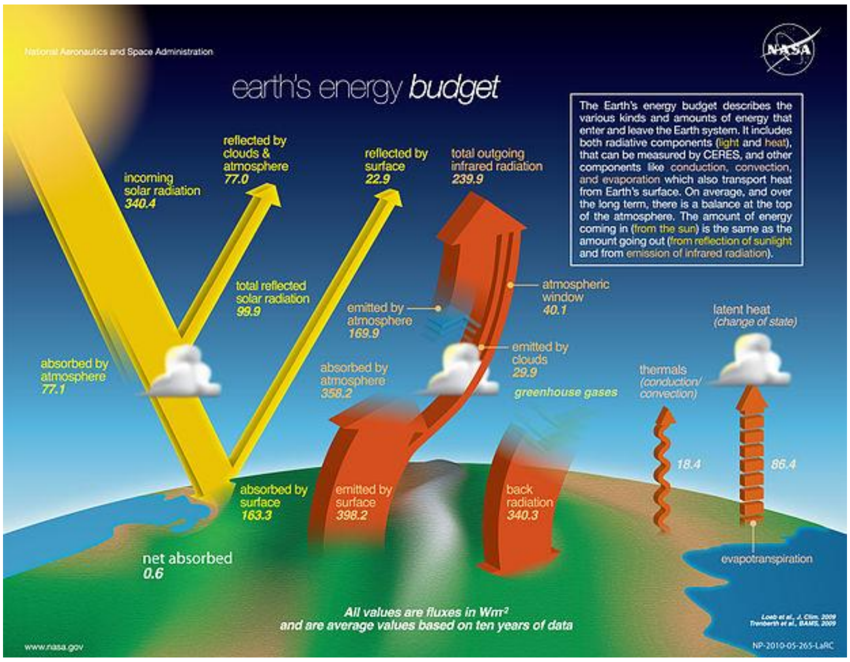


**Figure 3-5 A schematic diagram given by NASA shows the balance between incoming and outgoing energy of the earth (10)**

The earth loses most of its accumulated heat in the form of outgoing long wave radiation, This is the natural cooling mechanism which the earth uses to sustain zero energy balance. The local differences between the radiative heating and cooling provide the energy that drives atmospheric dynamics. The outgoing long-wave radiation component is thus of prime importance when the dynamics of UHI are concerned. (Figure 3-5)

The "energy balance" equation suggested by Oke explains the interactions between anthropogenic heat and the environment:

Net radiation + anthropogenic heat =

Latent heat flux + sensible heat flux + storage heat flux + net heat advection

Where, Net radiation =

Net diffuse short-wave radiation + Net direct short-wave radiation

+ Net long-wave radiation

## 3.5 Surface Energy Balance of Urban and Rural Areas

The urban built environment interacts with the urban climate in many ways. The fluxes of heat, moisture and momentum are significantly altered by the urban landscape.

Also, the anthropogenic input of pollutants in the urban atmosphere changes the net all-wave radiation budget by reducing the incident flux of short-wave solar radiation, by reemitting long-wave radiation to the urban surfaces, and by absorbing long-wave radiation from the urban heated urban surfaces which then warms up the air. (11)

The predominant impervious surfaces in an urban built environment do not absorb rainwater and remain dry. This leads to evaporation deficit in the city. However in rural areas, the natural surfaces retain water and remain moist. These moist surfaces allow evaporative cooling by enhancing the latent heat flux. (12) These exchanges can be seen in Figure 3-6.

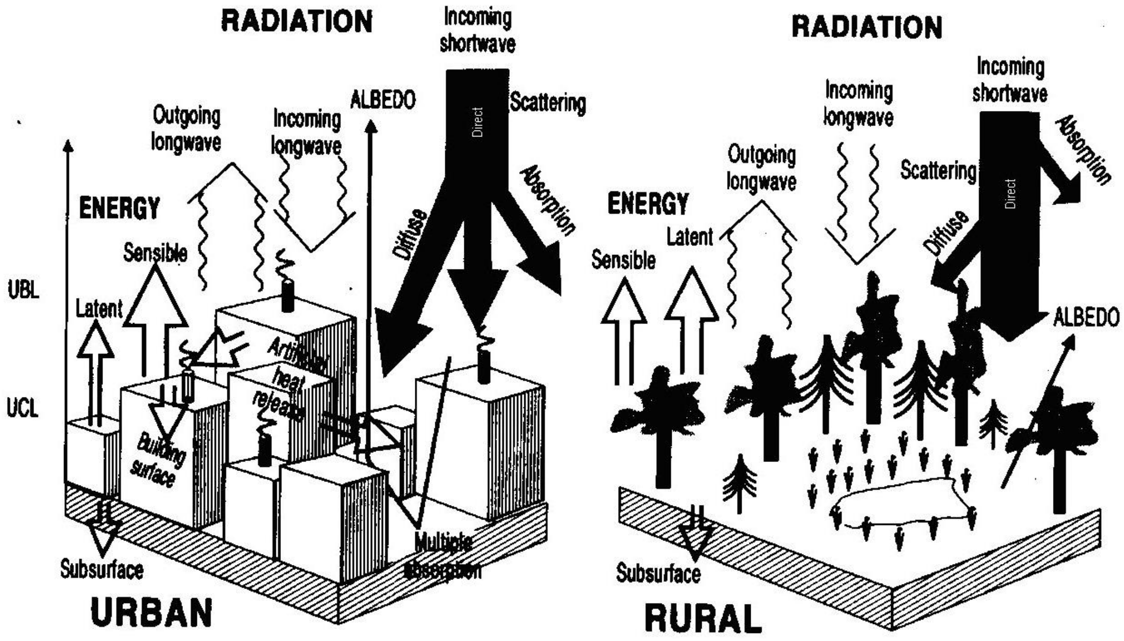


**Figure 3-6 Radiation and energy exchanges in urban and rural built environments on a clear day. (13).**

Urban fabric consisting of materials such as concrete, asphalt and stone has a high thermal capacity and low albedo compared to predominant rural surfaces such as soil and vegetation. Because of this, the urban surfaces absorb a high percentage of short-wave solar radiation and dissipate it to the ambient air in the form of long wave radiation at night. This phenomenon causes higher night-time air temperature in cities in contrast with rural environments that rapidly cool down.

The *roughness* of an urban surface is made up by vertical urban geometry. This roughness of the urban fabric provides undesirable friction to the horizontal air flow through the urban environment. This causes the formation of a stagnant cloud of warm air in the urban canopies. (Figure 3-7)

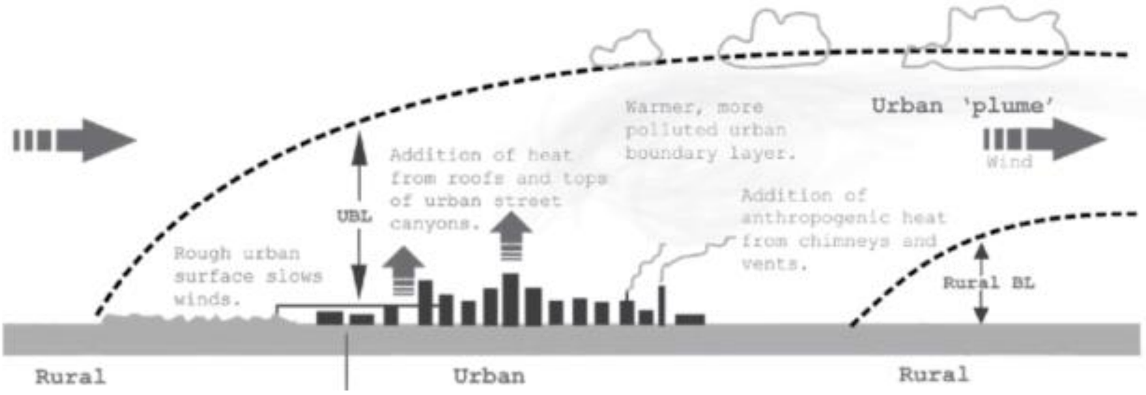


**Figure 3-7 Urban built environment and wind behavior. (5)**

The enclosures formed by tall buildings and streets, known as urban canyons can behave as radiation traps (Figure 3-8). During the day, the canyon surfaces continuously absorb short-wave radiation from the sun and release it slowly to the sky as long wave radiation during the night. Where the canyons are tall and the sky-view factor is less, most of the long-wave radiation remains trapped in the canyon below the canopy level, causing an increase in the urban heat island effect.

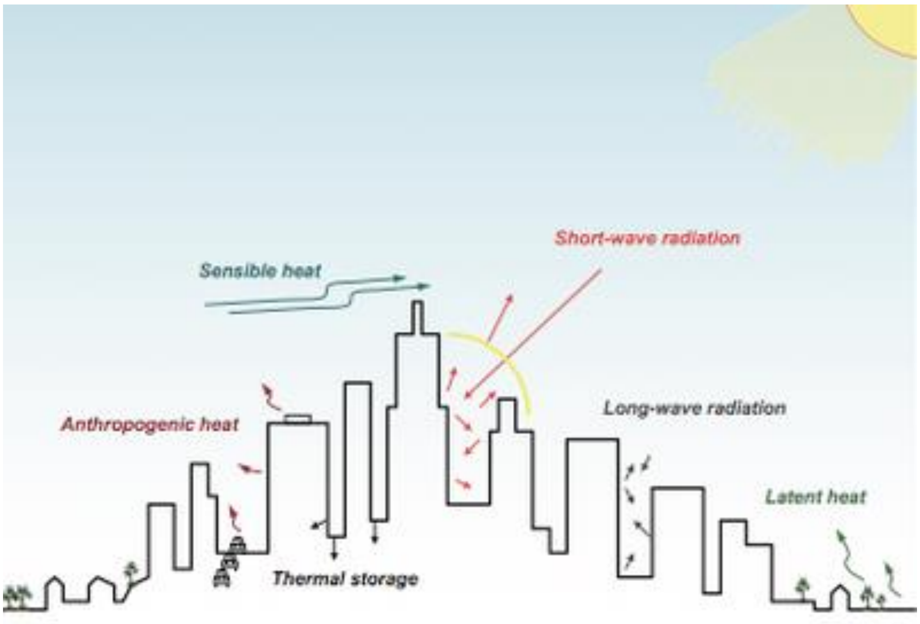


**Figure 3-8 Radiation fluxes and effect of urban canyons (1)**

## 3.6 Urban Climate Scales

Oke in 2006 suggested that the urban processes of heat transfer occur differently at different urban scales namely Micro, Local and Meso (Figure 3-9).

At micro scale, the roughness layer comprises of "urban canopy layer" (UCL). It is the layer where main roughness elements such as buildings and trees exist. It is at this layer that the exchanges of heat and moisture with the built form occur. Typically the height of UCL is equal to the mean height of roughness elements of the given urban area. As the microclimatic effects of individual surfaces blend by turbulence the roughness sub-layer (RSL) is formed. The height of RSL may be as less as 1.5x height of UCL (for dense urban areas) and upto 4x height of UCL (for low-density areas). Instruments located in RSL measure a blended, spatially averaged signal representative of the local scale. Hence, while carrying out measurements at RSL, the individual sources of the heat fluxes are difficult to identify.

At local scale, the surface layer comprises of roughness sub-layer and inertial sub-layer (ISL). Inertial sub-layer is where the atmosphere adjusts to the underlying urban landscape such that the observations of energy, mass and momentum fluxes made at this height are representatives of the amalgam of microclimates created by the urban landscape.

At meso scale, the mixed layer above is where the urban surface exchanges blend together with the wider atmosphere and is then transported downwind in the form of "urban plume", seen in Figure 3-7.

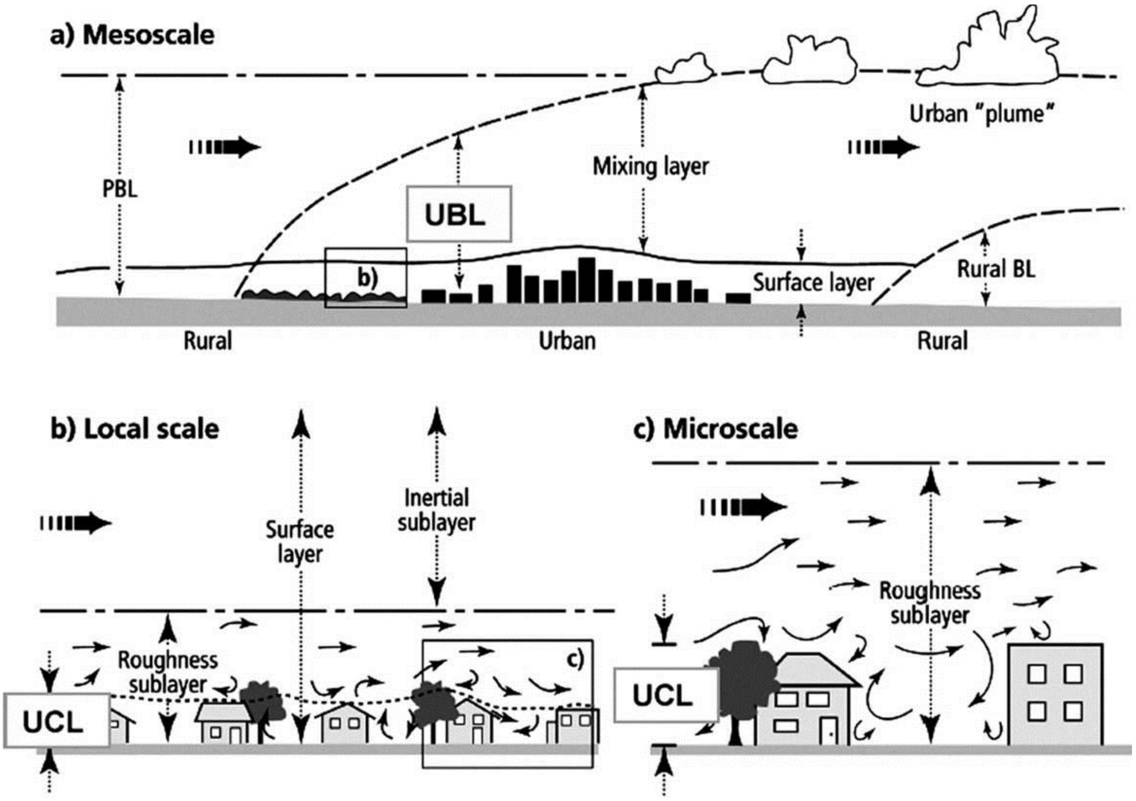


**Figure 3-9 Urban Climate Scales (14)**

## 3.7 Types of UHI

On the basis of its impacts, the urban heat island effect can be of two types: Surface UHI and Atmospheric UHI.

### 3.7.1 Surface-Urban Heat Islands

These are caused when the heat from solar radiation is absorbed by dry and exposed surfaces of the urban set-up. Its magnitude is thus dependent on the intensity of solar radiation, which changes seasonally and diurnally. This is why Surface Urban Heat Islands are highest during summers, especially during the day-time. Another reason why summers characterize high Surface UHI is that: in summers, due to prevalent clear-sky conditions, the solar radiation remains undispersed. Also, the days are calm, with low wind speeds, because of which the mixing of air is minimized.

### 3.7.2 Atmospheric Urban Heat Islands

These are formed where there is a difference between the air temperatures of urban and rural areas. These are further sub-dived into two types:

#### 3.7.2.1 Canopy Layer UHI

They occur close to the ground surface, where people and built environment exists, that is from the ground surface to the topmost level of trees and roofs.

#### 3.7.2.2 Boundary Layer UHI

They occur at a level starting from the rooftops and tree tops, until the point where urban landscapes no longer affect the atmosphere.

Table 3-1 gives a comparison of the two types of Urban Heat Islands.

**Table 3-1 Characteristics of Surface and Atmospheric Urban Heat Islands (1)**

| Feature | Surface UHI | Atmospheric UHI |
|---|---|---|
| **Temporal Development** | Present at all times of the day and night<br>Most intense during the day and in the summer | May be small or non-existent during the day<br>Most intense at night or predawn and in the winter |
| **Peak Intensity** | More spatial and temporal variation:<br>Day: 10 to 15°C<br>Night: 5 to 10°C | Less variation:<br>Day: 1 to 3°C<br>Night: 7 to 12°C |
| **Typical Identification method** | Remote Sensing (Indirect Measurement) | Through fixed weather stations or mobile traverses |

Surface UHI may indirectly affect Canopy Layer UHI, when the heat absorbed by urban surfaces throughout the day gets slowly released to the atmosphere at the end of the day, thus adding to the temperature of the air near the surface.

## 3.8 Determination and Measurement Approaches

The process of measurement and monitoring of UHI is done depending upon the type of UHI. Surface UHI requires measurement of surface temperature for a given area, while atmospheric UHI requires the measurement of air temperature, as described below:

### 3.8.1 Thermal Remote Sensing

Surface Heat islands can be studied using remote sensing techniques. Remote sensing enables us to map the pattern of urban heat island (Surface UHI) for an entire city or region.

Infra-red imagery of a geographical location is provided by satellites such as LANDSAT, or by images captures from thermal cameras mounted on aircrafts made to fly over the given city. In these infra-red images as shown in Figure 3-10, the bright coloured areas indicate hotter surfaces like roads and rooftops, while darker colours indicate cooler surfaces such as green cover, and water bodies. Remote sensing allows us to carry out a temperature study of a large area. (15)

Remote sensing for UHI measurements also has certain limitations. Firstly, they do not capture thermal imagery of vertical surfaces such as external walls of the buildings, Secondly; remotely sensed data represent radiation that has travelled through the atmosphere twice, as wavelengths travel from the sun to the earth as well as from the earth to the atmosphere. Thus, the data must be corrected to accurately estimate surface properties including solar reflectance and temperature. (1) This method is also very expensive and it is very difficult to obtain steady images of the urban surface due to several factors such as atmospheric interactions and operation capability of the apparatus used.

The main disadvantage of this approach is that the remote sensors only capture the upward thermal irradiance patterns, which means that the observed surface temperatures may be significantly different compared to the actual air temperatures inside the urban canopy.

**Figure 3-10 Thermal Image of a city showing temperature of different surfaces. (6)**

## 3.8.2 Small Scale Modelling

A prototype of the urban area is prepared as a small scale model. The prototype is tested using devices such as wind tunnels or in outdoors. Small scale modelling is used in most UHI studies to verify, calibrate and improve mathematical models. Similarity between the model and prototype is necessary to achieve accurate results. However the main drawbacks are the cost and the difficulty of experimentally generating a thermal stratification which resembles the actual atmosphere. (16)

### 3.8.3 Field Measurements

For a study carried over a smaller geographical area, direct measurements can be more convenient and relevant. In this approach the near surface temperature patterns in urban areas are measured and compared against surrounding rural areas Instruments may be used as fixed or mobile stations. The first study of this kind was carried out by Howard in 1818 for London city. This approach also has some limitations. Firstly the development and installation of measurement devices around a city is a very expensive and time consuming task. Secondly, through this type of approach, only limited number of parameters can be simultaneously measured, thus it is very difficult to demonstrate the three dimensional spatial distribution of quantities inside an urban area. It also becomes necessary to carry out the measurements for a long period of time, so that the effect of unpredicted factors can be cancelled out. (16)

#### *Transect Studies*

Transect studies involves continuous measurement of air temperature on a moving vehicle mounted with a weather station. The transect usually comprises of urban and rural areas or areas with different land-use characteristics. They provide high temporal resolution of data and cost effective. Melhuish and Pedder were the first to use and demonstrate this approach using a bicycle in Berkshire in 1998. (17)

The results of such studies are mostly used to find the spatial distribution and intensity of UHI.

In this study, with a similar aim, instruments with data logging capability will be fixed at several locations across Bangalore City inside the Urban Canopy Layer (UCL) with the objective of analysis of spatial and temporal atmospheric UHI in the respective locations.

## 3.9 Essential Thermal Parameters Associated with UHI

### 3.9.1 Air Temperature (AT)

The dry bulb temperature is a direct indicator of "atmospheric" UHI Intensity. When measured throughout the day, highest air temperatures are usually recorded during the night in UHI affected areas against the rural. Measured air temperatures may also indicate the effect of warming occurring due to anthropogenic sources such as vehicular exhaust, air conditioning and refrigeration equipment etc. Hence industrial and commercial locations may show higher air temperatures compared to residential locations during daytime.

It can be measured using a thermometer which is directly exposed to the air but shielded from solar radiation. Field campaigns, transect studies usually involve the measurement of air temperatures at different locations.

In this study, hourly measurements of air temperature are taken for 7 days for selected locations based on different land—use and urban characteristics, using a data logger with air temperature sensor.

### 3.9.2 Black-Globe Temperature (GT)

In urban locations the perceived heat is a combined effect of both air temperature and re radiated heat which comes through building surfaces. Hence, Globe Temperature as an indicator is used to measure Heat Islands.

In this study, the black globe temperature is measured as an indicator of the relative temperature of different urban surfaces in a street canyon. Hard impervious surfaces such as asphalt roads, stone pavements may reach to temperatures as high as 80 °C during hot summer days. Street canyons formed by such materials absorb more heat which is then slowly dissipated through the night. The globe temperature in such street canyons is higher than others. Similarly, a street canyon which is shaded by trees will have low surface temperatures and hence low globe temperatures.

A standard globe thermometer was introduced in 1930 by Vernon. It consists of a hollow copper sphere of diameter of 150mm, painted black matt, with a temperature sensor at the centre.

## 3.10 International Studies on Urban Heat Islands

The study of urban heat islands started receiving profound attention as early as the 18th century. Luke Howard was the first to document this phenomenon in around 1818. His documentation was based on the artificial excess heat building up in the city, compared to its surroundings. Similar studies were carried out by Emilien Renou for the city of Paris during the late 19th century, followed by study of heat islands in Vienna carried out by Schmidt in 1917. This was the first study carried out using instruments mounted on motorized vehicles.

Recent studies have employed several modern technologies such as mobile traverses, thermal imagery through satellites and aircrafts, and use of sophisticated instruments. Various approaches have been use in for the identification of heat islands. These indicators generally depend on the type of UHI to be studied.

In a study done in Fez, Morocco, the old city with narrow pedestrian routes is compared against newly developed part, with wider roads for motor vehicles. In both areas, measurement site were chosen such that they represent different urban geometry (in terms of H/W ratio) and street orientation. Two types of urban canyon are identified: a “deep” canyon with a high H/W ratio, and a “shallow” canyon with a lower H/W ratio.

Continuous measurements were taken for air temperature and humidity, and surface temperature over the period of 1.5 years. Instantaneous measurements were taken over one summer and one winter period three times a day: before sunrise, in the afternoon and after sunset. MRT was calculated using Rayman 1.2 software, while the PET was measured through

It was observed that the urban geometry can directly affect the outdoor thermal comfort of urban canyons and the energy required for cooling the buildings. Compact urban forms, with higher H/W ratios, are better suited to hot climates, since maximum shading can be achieved. There is a strong diurnal variation in the temperature in the shallow urban canyon as compared to the deep canyon; and hence it was concluded that a areas with higher H/W ratios are capable of reducing urban heat islands, as compared to areas with lower H/W. (18).

In a similar study done in the city of Curitiba, Brazil, the impact of urban geometry and street orientation was done using the sky view factor (SVF). The study focuses on a pedestrian street in downtown Curitiba, 19 monitoring points were selected presenting different characteristics with regard to SVF or axis orientation. Fisheye imagery was used to determine the SVF. A pair of identical weather stations was used to simultaneously monitor two different urban locations. Measurements were made for air temperature and humidity, wind speed and direction, solar radiation and globe temperature. Additionally, a comfort survey was carried out with the local population by means of a questionnaire. Relationship between Mean Radiant Temperature and SVF was established and it was suggested that the SVF is a limited parameter to describe the irregularities of urban geometry for the purpose of daytime outdoor comfort studies. Although it was verified that on hotter days, locations with a higher SVF can provide greater discomfort compared to those with lower SVF. (19).

In a study done in the city of Chennai (20), a simple method has been presented to study the effect of physical features of an urban society over its microclimate and the outdoor thermal comfort. Six urban locations with different densities (H/W ratios) have been selected, at each location; three streets with different orientations (N-S, E-W, and NE-SW) are identified for monitoring. The measurements have been done during the hottest months of April, May and June. The ground cover type, as a percentage, is calculated for a region of 200m x 200m for each location.

Daily measurements were made for five clear days at all street orientations, from 9:00 in the morning to 17:00 in the evening, over the interval of 30 minutes. Physiological equivalent temperature (PET) for the six locations was calculated and through regression analysis, it was observed that H/W ratios cannot alone govern the PET of a given location; the effect of green cover also requires consideration. Hence a new scale, called the HXG (Height/Width x Green Cover) scale was developed, which is the product of the H/W ratio and the percentage of green cover of a given area. This HXG scale provided a greater regression coefficient hence proving to be more accurate than H/W ratios alone.

## 3.11Urban Heat Island Studies in India

Various UHI studies have been carried out in the developed and developing cities of India. These are given in Table 3-2. In most of these studies, changing land-use pattern and increasing urban density are the main causes leading to Urban Heat Island Effect.

**Table 3-2 A review of various UHI Studies carried out in different cities of India**

| Sr. No. | Study Location | Focus of the Study | Methods | Issues | Findings | Authors |
|---|---|---|---|---|---|---|
| 1 | Delhi NCR | Study of temperature trends in four cities of the NCR region | Study of seasonal and annual temperature trends and anomalies through trend analysis | Urbanization patterns affecting annual and seasonal temperatures of various cities | Increased night time temperature that indicate contribution of changing land-use pattern and anthropogenic heat | (21) |
| 2 | New Delhi | Summertime UHI over Delhi and its relationship with aerosols | Remote sensing and GIS to measure surface temperature | Thermal contrast between central and surrounding parts of Delhi | Thermal contrast varies from 4-7ºC in April to 7-10ºC in May-June. | (22) |
| 3 | Mumbai | Analysis of UHI in relation to NDVI, comparison between Delhi and Mumbai | Thermal Mapping through LANDSAT Images | Changing land-use patterns and green cover | UHI was found to be strong in Mumbai compared to that in Delhi | (23) |
| 4 | Pune | Structure of heat and moisture islands | Mobile Survey for 170 locations in the City | Influence of topography and morphological variation and kabatic winds | Strong heat and moisture islands at night | (24) |
| 5 | Bangalore | Urban Growth pattern in Bangalore and its impact on UHI | Remote Sensing and Field data through GIS | Increase in built-up area affecting water-bodies and green-cover | Increase of 2-2.5 during the last decade, 76% decline in vegetation cover and 79% decline in water bodies. | (25) |

| Sr. No. | Study Location | Focus of the Study | Methods | Issues | Findings | Authors |
|---|---|---|---|---|---|---|
| 6 | Bangalore | Minimizing UHI and Imperviousness factor | Field measurements and simulation | Effect of urban geometry, water bodies and green cover | 0.8-2°C rise in mean air temperature, higher night temperatures observed in dense commercial areas. Cool roofs and green roofs facilitate 16.9% and 11.8% saving in cooling load | (3) |
| 7 | Guwahati | Summertime UHI in urban and sub-urban pockets | Half-hourly temperature data measurements through fixed weather stations, mobile measurements | Urban sprawl | Urban Heat island intensity of 2.12°C during day-time and 2.29°C during night-time was found | (26) |
| 8. | Chennai | Impact of built geometry and urbanization | Air temperature and relative humidity measurements | Urban density correlation between urban and rural environments | 3.6°C in summer and 4.1°C in winter | (27) |
| 11 | Vishakhapatnam | UHI Intensities and negative impacts | Field Surveys, Measurement of Surface Temperature | Topography and urban morphology | Intensity of heat island varies from 2°C to 4°C and<br>intensity is high during winter season compared to<br>Summer and | (28) |

| Sr. No. | Study Location | Focus of the Study | Methods | Issues | Findings | Authors |
|---|---|---|---|---|---|---|
| | | | | | monsoon seasons. | |
| 12 | Jaipur | Temporal and Spatial variations of UHI | Satellite Data and GIS Technique for assessment of Surface UHI | Changes in Land-use/Land-cover | 13.12% of the city is under moderate UHI potential area and 0.97% is under high UHI potential area | (29) |
| 13 | Bhopal | Mitigation of thermal pollution to enhance urban air quality | Identification of UHI through Landsat TM Band | Increased built up area, reducing green cover. | Old city has very prominent UHI due to heavy pollution and emission of hot gasses | (30) |

## 3.12 Studies done for Bangalore

For the city of Bangalore, the subject of Urban Heat Islands was first discussed in a research conducted by S.G. Gopalakrishnan in the year 2002. This study which also covered two other cities in south India demonstrated the effect of Urban Heat Patches on regional scale meteorology. The study indicated the persistence of distinct urban heat island in the centres of these cities, including Bangalore. In seasons of pre-monsoon, monsoon and winter, a hot pool of 6 degC was observed during sunset. Though the strongest influence was found in Chennai, it was concluded that further expansion of Bangalore could have a stronger influence on the meso-scale climate of this region. (31)

In another study conducted by T.V Ramachandra and Uttam Kumar in the year 2010, it was revealed that in Bangalore, there has been 525% growth in built-up area in the last 40 years, which corresponds to a 78% decline in vegetation and 79% decline in water bodies. The growing built-up area can be seen represented in red in Figure 3-11. (25)

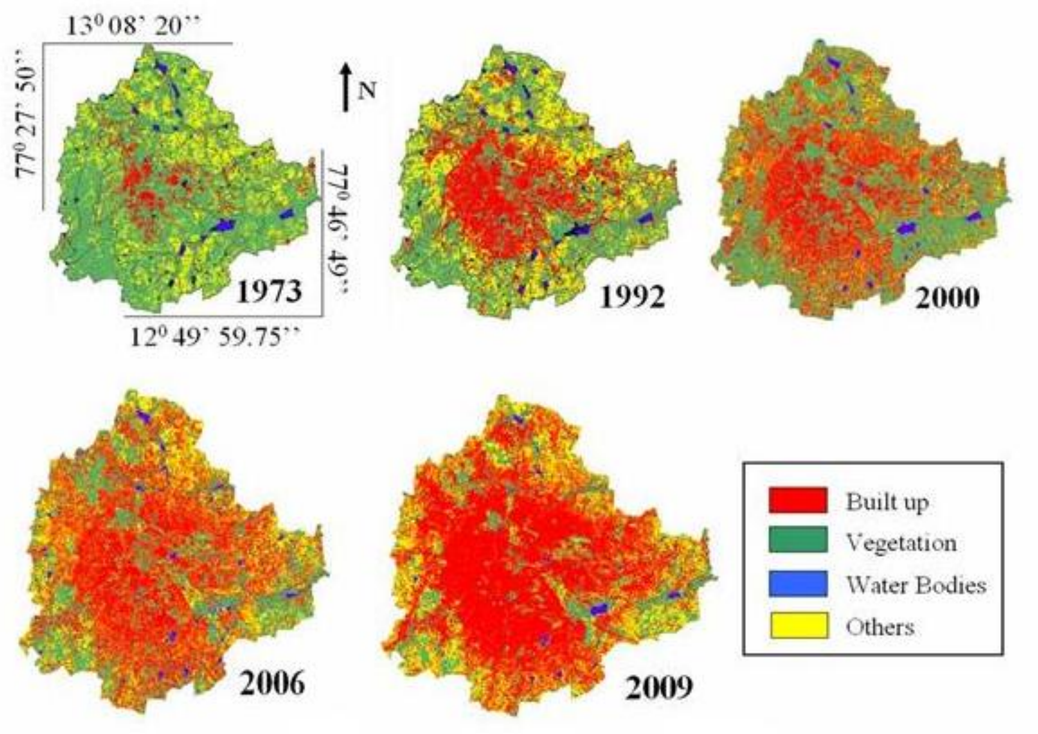


**Figure 3-11 Increasing Built-up area from 1973 to 2009 (32)**

Figure 3-12 below; depict how land surface temperatures have surged from 1992 to 2007.

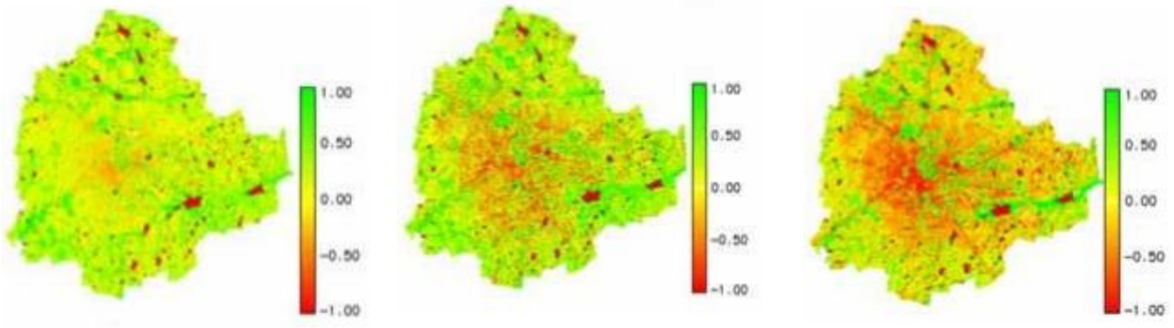


**Figure 3-12 Increased Land Surface Temperatures in 1992, 2002 and 2007 (32)**

It was concluded that increased urbanization has resulted higher population densities in certain wards, which incidentally have higher LST due to high level of anthropogenic activities. Also, in a transect survey carried out in various directions of Bangalore, watre bodies and vegetation patches were found to be helping in lowering temperatures of their surrounding areas.

In a remote sensing based study carried out by Shrinidhi Ambinakudige in 2011, the effects of UHI in Bangalore have been analysed with respect to the relationship betweeen vegetation cover and temperature in context of Bangalore. Results of this study showed that the city core temperatures varied by 1 °C to 7 °C within different land cover classes. However, the city cores were observed to have significantly lower mean temperatures than the city's outgrowth zones. This was because of the presence of water bodies and vegetation in the core city. This can be observed in Figure 3-13. It was concluded that the continued expansion of urban infrastructure and new residential neighborhoods that lack vegetation were the cause of the substantially higher temperatures in the outgrowth zones. (33)

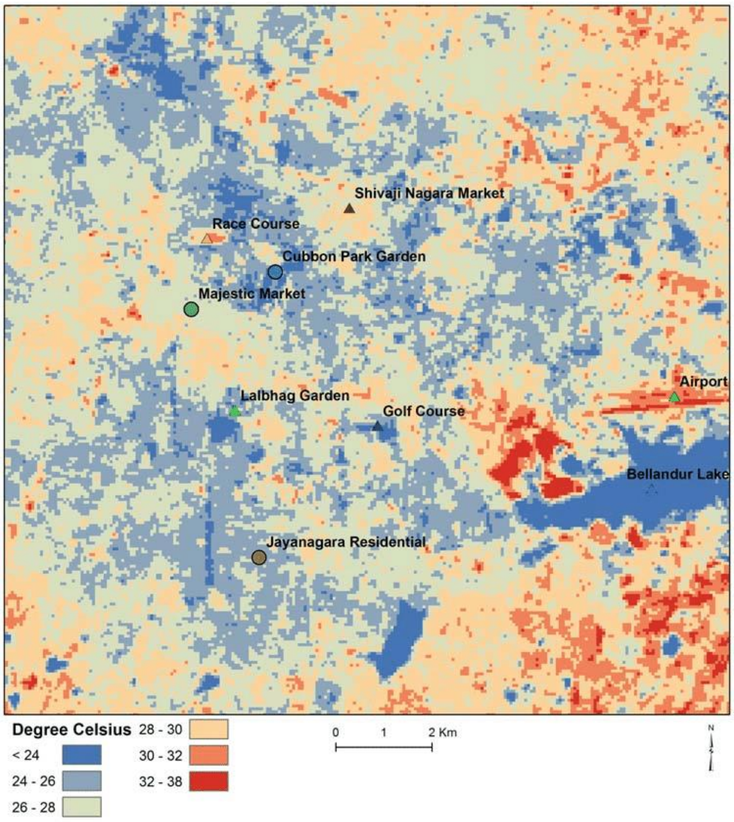


**Figure 3-13 Land Surface Temperatures in Bangalore as observed on March 2003. (33)**

## 3.13 UHI Mitigation Projects Implemented in other countries

Several UHI mitigation projects measures are being implemented across the globe currently. These measures focus in the following broad categories:

1. **Urban afforestation:**
   Strategic Tree Plantation, Urban farming, building new parks and gardens.
   For example: Urban Agriculture Programme (Montreal, Canada), Tokyo Plan 2000 (Tokyo, Japan) etc.

2. **Green Retrofit measures**
   Cool roofs, green roofs and cool pavements.
   For example: Chicago sustainable streets programme, Integration of cool roofs in building codes.

3. **Development of Sustainable Infrastructure** such as energy efficient buildings.
   For example: reflective roofs integrated in energy codes

4. **Anthropogenic heat reduction measures:**
   Promoting pedestrians and cyclists, promoting e-vehicles, strengthening public transportation
   For example: Implementation of safe bicycle paths in Copenhagen, Electric buses in France, Canada, Italy and USA.

Over 172 mitigation projects are being carried out in USA alone since 1998. These projects are being implemented under the Urban Heat Island Pilot Project under US-EPA as well as by various communities. (34) Being a tropical country with hotter climate, India can greatly benefit from UHI mitigation programmes. For example, incorporation of UHI mitigation strategies can be carried out for existing building codes, regulations, and urban planning guidelines. Similarly, retrofit measures for UHI mitigation can also be carried out for existing layouts.

# 4 Methodology for Experimental Studies

It is proposed that the project will be carried out under three activities.

### 4.1.1 Activity 1: Site Selection and Study of Urban Planning Characteristics

The study relies on real time monitoring results of different urban pockets in Bangalore hence the first task was to select nine locations in a such a way that each location presents a unique combination of urban characteristics in terms of built forms, greenery and surface types.

1. *Site Selection*: Bangalore has two predominant building typologies: Residential and commercial. Hence, three locations from each typology were selected for the first session of monitoring. Three more locations were monitored as a part of the final monitoring. The selection criteria are explained in detail in 5.3.
2. *Analysis of Urban Characteristics:* The selected urban areas were analysed in terms of their varying urban characteristics through mapping. The various urban planning parameters such as percentage of built footprint, open spaces, green canopy cover, road areas, paved areas, etc were calculated and documented.

### 4.1.2 Activity 2: Field Measurements and Analysis

1. *Field Measurements*: Continuous hourly measurements of AT, RH and GT were taken for multiple days simultaneously for each location. Multiple sessions of monitoring enabled us to overcome the limitations observed during earlier sessions. During one of the sessions, thermal images of streets were also taken to better understand the surface temperature patterns of the street canyon.
2. *Analysis of Monitored Results:* The measured parameters of AT, GT and RH were averaged out for each location and represented on a 24 hour scale. Each location was first analysed individually to determine the relationship between AT, RH and GT. In the next step, the selected locations in each typology were compared against other locations to observe the differences in similarities in their thermal behavior.

### 4.1.3 Activity 3: Observations and Recommendations

1. *Summary of Observations:* The observed trends of Urban Heat pockets for each location were summarize together to determine a relation between the urban planning characteristics and the observed microclimate of each location.
2. *Recommendation of guidelines for Urban Planners:* Based upon the above relation, guidelines for urban planners will be recommended. Implementation of these guidelines can help prevent the formation of heat islands in newly developing urban areas or satellite towns.

## 4.2 Monitoring Schedule

Monitoring was carried out once during late winter and twice during summer. Parameters were measured hourly for 24 hours over the course of 3-7 days. The monitoring schedule is shown in Table 4-1

**Table 4-1 Monitoring Schedule**

| | Locations monitored | Dates |
|---|---|---|
| **Residential Locations** | | |
| Monitoring I | Jayanagar II Block<br>Basweshwar Nagar<br>Bellandur | 27-January 2017 to 3-February-2017 |
| Monitoring II | Jayanagar II Block<br>Basweshwar Nagar<br>Bellandur | 15-March- 2017 to 22-March-2017 |
| Monitoring III | Koramangala<br>HSR<br>Jayanagar I Block | 31- May -2017 to 10 -June- 2017 |
| **IT Park Locations** | | |
| | Electronic City<br>Marathahalli<br>Whitefield | 15-March- 2017 to 22-March-2017 |

## 4.3 Equipment Used for Monitoring

Air temperature, globe temperature and relative humidity were measured using Heat Stress Meters. The device measures temperatures and RH based on capacitive sensing. The inbuilt black globe (50mm diameter) measures globe temperature.

During Monitoring II, thermal images of the street canyons were also captured using an infra-red thermal imager. A list of the equipment used can be seen in Table 4-2.

**Table 4-2 Monitoring Equipment**

| Sr. no. | Parameter | Monitoring type | Equipment |
|---|---|---|---|
| 1 | Air temperature | Continuous | Heat Stress Meter (Figure 4-2) |
| 2 | Globe Temperature | Continuous | Heat Stress Meter |
| 3 | Relative Humidity | Continuous | Heat Stress Meter |
| 4 | Surface Temperature | Instantaneous | Thermal Gun |
| 5 | Thermal Images | Instantaneous | Infra-red Thermal Imager (Figure 4-3) |

The heat stress meters were enclosed in a metal (grille-type) cage for safety (Figure 4-1). The cage was lined from the inside with a thin polystyrene sheet on 3 sides (top and two longer sides). This ensured protection from direct solar radiation, rainfall and radiation from immediate building surfaces. The two shorter sides were partially covered and the bottom was left exposed to the street canyon. This assembly was mounted at a height of about 3 to 4 meters from the ground level to ensure its safety.

**Figure 4-1 Heat Stress Meter assembly and mounting**

**Figure 4-2 Heat Stress Meter**

**Figure 4-3 Infra-red thermal camera**

# 5 Study Area

The city of Bangalore is the capital of the Indian state of Karnataka. The city has showed massive growth in the last few decades, owing to great influx of business mainly related to information technology, and thus has been nicknamed as the "Silicon Valley of India".

The city is located at 12°58'N and 77°57'E. The altitude varies from 875m to 940m above mean sea level. The city has a number of lakes such as Belladur, Ulsoor, Hebbal, Madiwala, etc. There are no major rivers flowing through this area.

**Figure 5-1 Location of Bangalore in the Indian subcontinent**

## 5.1 Climate

Bangalore lies in moderate climate zone and enjoys salubrious climatic conditions throughout the year.

The months of March, April and May mark the summer season, where temperatures reach as high as 39 °C during April. The summer days are characterised by low relative humidity (20-40%) and high solar radiation (>6000Wh/m$^2$, see Figure 5-2). The sky is usually clear during summer hence un-shaded surfaces receive direct heat and tend to heat up much faster.

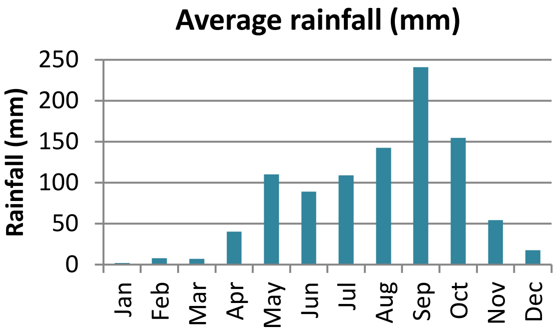
The summer season is followed by monsoon marked by the months of June to October. Monsoon beings relief to the city with lower temperatures (27-28 °C) and higher humidity levels. Annually, Bangalore receives about 900 mm of rainfall. (See Figure 5-2)

Winters are usually pleasant with average temperature of 20-25 °C and slightly lower humidity. The clear sky conditions during this season help maintain comfortable weather conditions.

Table 5-1 shows monthly temperature and humidity data for Bangalore.

**Table 5-1 Monthly Temperature and Humidity data (Bangalore Climatological Table 1971–2000).**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Peak high °C | 32.8 | 35.9 | 37.3 | 39.2 | 38.9 | 38.1 | 33.3 | 33.3 | 33.3 | 32.4 | 31.7 | 31.1 |
| Average °C | 20 | 23 | 26 | 27 | 26 | 23 | 23 | 22 | 23 | 22 | 21 | 20 |
| Peak low °C | 15.3 | 17.2 | 19.6 | 21.8 | 21.5 | 20.2 | 19.8 | 19.6 | 19.7 | 19.4 | 17.7 | 16 |
| RH (%) | 65 | 45 | 51 | 49 | 67 | 77 | 74 | 85 | 77 | 79 | 71 | 71 |



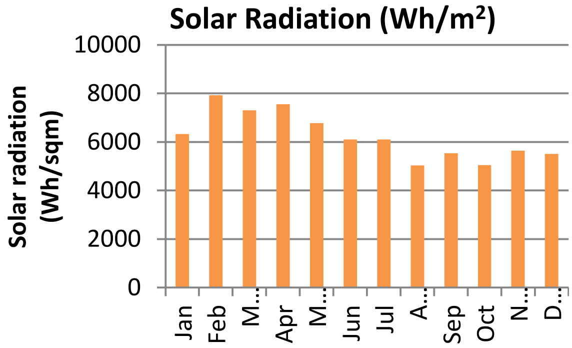


**Figure 5-2 Monthly average rainfall in Bangalore**

**Figure 5-3 Monthly average direct solar-radiation received in Bangalore**

## 5.2 Urban Sprawl

Bangalore has experienced unprecedented growth in past few years due to industrialization and growth of economic activities. It has become the third most populous city in India and the 18th most populous in the world. It has experienced a growth rate of 38% between 1991 and 2001. Roughly 10% of the city population lives in slums.

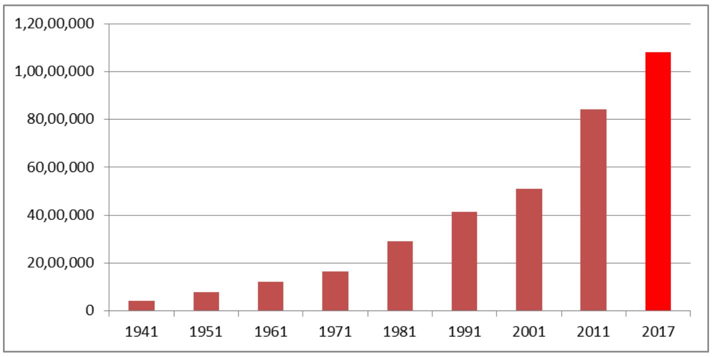


**Figure 5-4 Growing population of Bangalore from 1871 to 2007 (Source: Census of India)**

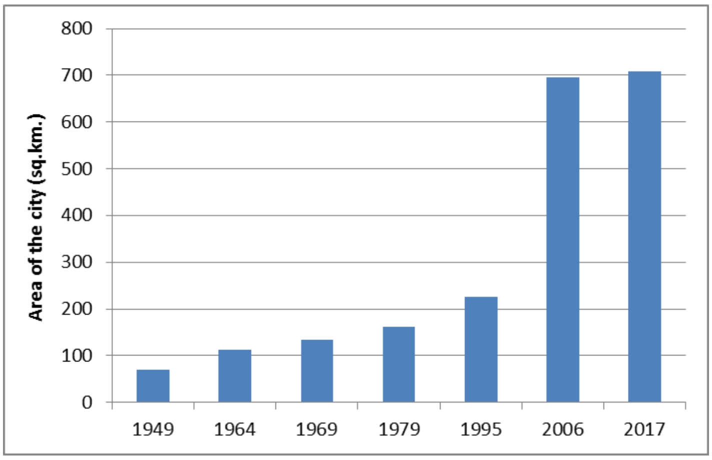


**Figure 5-5 Growing area of the city from 1949 to present. (Source: Census of India)**

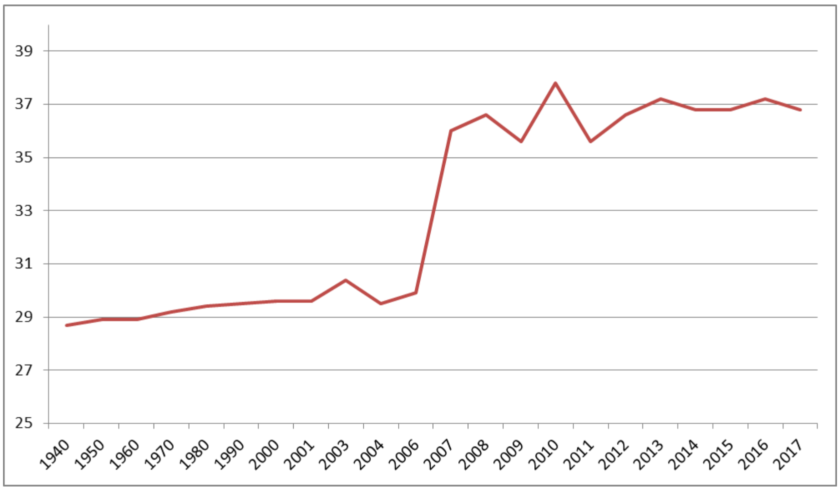


**Figure 5-6 Temperature Trend of Bangalore from 1940 to 2017. (35)**

From the temperature data in Figure 5-6, it can be observed that there is a gradual increase in both maximum and minimum air temperatures from year-1940 to year-2000, which coincides with the growing urbanization and built-up density.

## 5.3 Locations Identified for Study

As seen in Section 3.3, the urban heat islands can be governed by factors such as green cover, urban geometry, urban surface characteristics and anthropogenic heat. Out of these 4 factors, only two can be directly controlled by urban planners: green cover and urban geometry. Hence, the locations identified for this study, are selected based upon different green cover percentages and varied urban geometries that exist in the city. (See Figure 5-7).

### *Study Radius*

The project aims at analysing the local effects of urban planning and green cover on the UHI. Hence, out of the five urban morphological units suggested by Oke, the local scale morphology is apt for the study (13). Accordingly, the diameter of each location has been assumed to be 2 kilometres.

**Figure 5-7 Satellite Image of Bangalore showing different locations selected for the study (Map Source: Google Maps)**

Two typologies of urban areas have been studied: Residential and IT parks, as they are predominant in the land-use of Bangalore. Total nine locations have been selected under residential and commercial typologies based on variation in green cover, different urban geometries, proximity to lakes, gardens, etc. These locations, along with their criteria of study, are listed below:

### 5.3.1 Residential Typology (Monitoring I and II): Selection Criteria

Residential areas in Bangalore are of two types: low rise plotted developments, with 1 to 3 storey houses and mid-rise apartment building clusters. The low-rise residential areas have lower H/W ratios owing to low building heights. One of the greenest low-rise residential developments was identified near Lalbagh Botanical Garden (Figure 5-8). The garden comprising of a small water body, acts as a green lung for the city, hence the area around it may tend to exhibit unique microclimatic characteristics of temperature, humidity and wind.

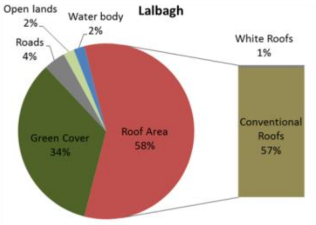
As opposed to the Lalbagh residences, areas in western Bangalore, such as Basweshwar Nagar (Figure 5-9), lack presence of water bodies and green spaces, which is why, they may present a picture much different compared to the previous location. This shall help us recognize the role played by proximate green areas and water bodies in modifying climatic conditions in urban settlements.

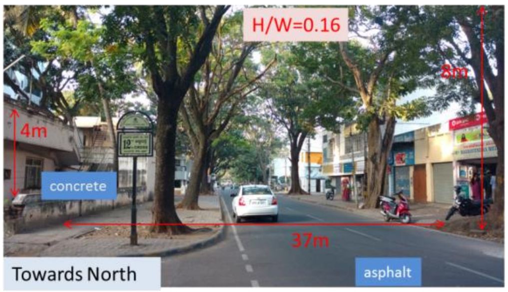
To observe the influence of building density and geometry on microclimate, a cluster of mid-rise apartment buildings (five-six storeys) has been identified in the residential area in the south of Bellandur Lake. Despite having low green cover, the surface of a street tends to remain shaded due to tall buildings. (Figure 5-10).

A summary of the urban characteristics of these locations can be seen in Table 5-2.

## Location 1: Lalbagh
South of Lalbagh Garden

### RESIDENTIAL TYPOLOGY

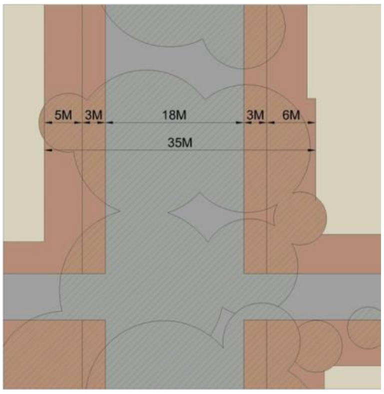




## Jayanagar II Block
South of Lalbagh Garden

| Details at Street Level | |
|---|---|
| Orientation | North-South |
| Typology of Buildings | Residential |
| Green cover (Canopy) % | 80% |
| Vehicular Density | Medium-Low |

| | |
|---|---|
| Width of Street (Building to building) | 35m |
| Average Height of Buildings | 6 m |
| H/W ratio | 0.16 |
| Type of Vertical Surfaces | Concrete, stone cladding |
| Type of Horizontal Surfaces | Asphalt roads, concrete pavements, conventional roofs |
| Type of Vegetation | Wide canopy trees, small leaves |



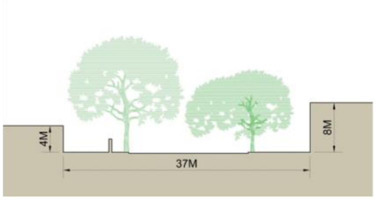
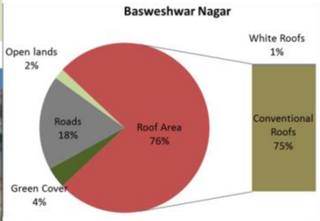


Figure 5-8: Urban Characteristics of Location I: Lalbagh (Jayanagar IV Block)

**Basweshwar Nagar,**
Western Bangalore

**RESIDENTIAL TYPOLOGY**



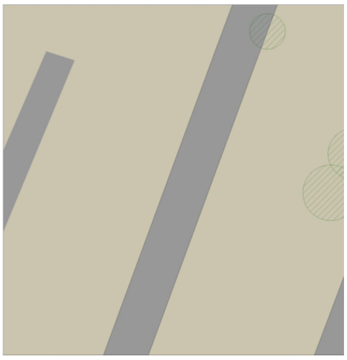
**Surroundings** About 6km radius around this location has a similar development

**Basweshwar Nagar,**
Western Bangalore

| Details at Street Level | |
|---|---|
| Orientation | North-South |
| Typology of Buildings | Residential |
| Green Cover % | 6% |
| Road area % | 18% |
| Vehicular Density | Very Low |

| | |
|---|---|
| Width of Street | 6m |
| Average Height of Buildings | 9-12m |
| H/W ratio | 1.75 |

| | |
|---|---|
| Type of Vertical Surfaces | Concrete |
| Type of Horizontal Surfaces | Concrete |
| Type of Vegetation | Sparse trees of narrow canopy |



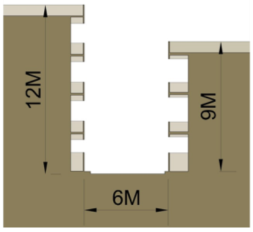
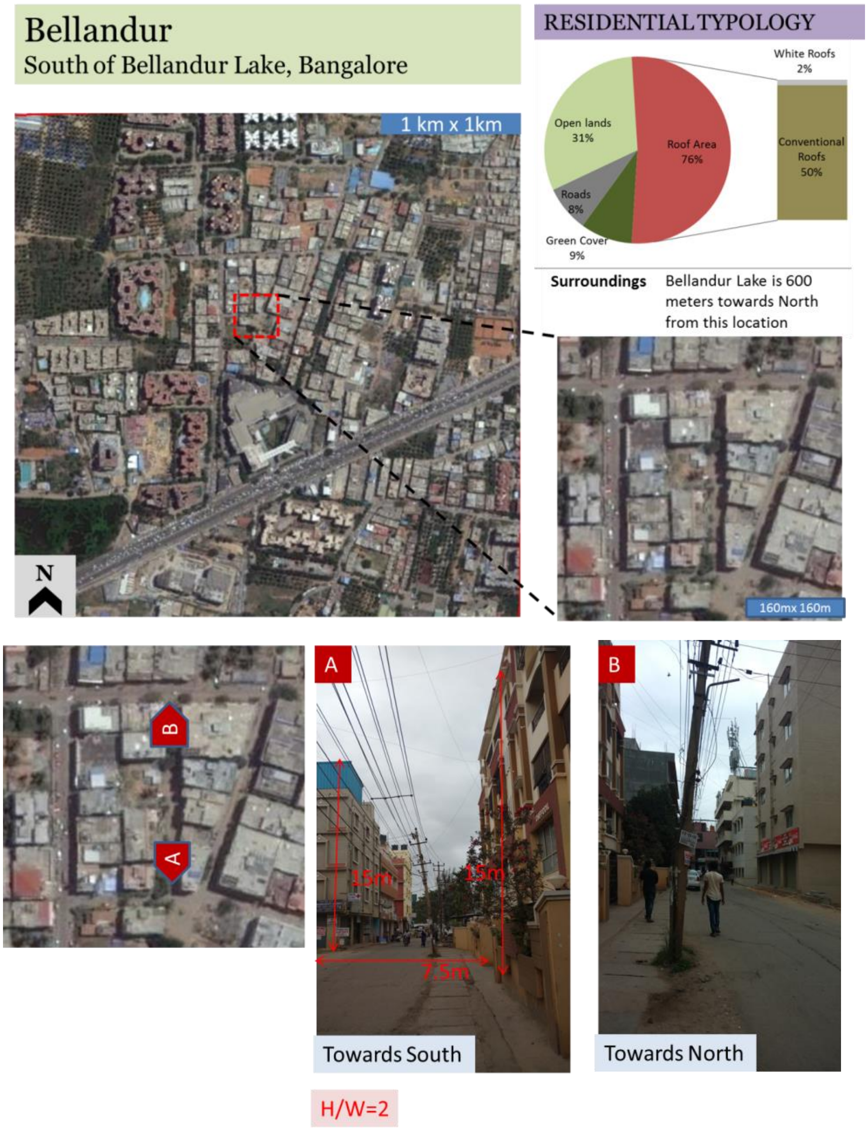


Figure 5-9 Urban Characteristics of Residential Location II: Basweshwar nagar



## Bellandur
South of Bellandur Lake, Bangalore

| | |
|---|---|
| **Details at Street Level** | |
| Orientation | North-South |
| Typology of Buildings | Residential |
| Green canopy Cover % | 14% |
| Built-up density % | 64% |
| Road area % | 28% |
| Vehicular Density | Moderate |
| Width of Street | 7.5 m |
| Average Height of Buildings | 15 m |
| H/W ratio | 2.0 |
| Type of Vertical Surfaces | Concrete |
| Type of Horizontal Surfaces | Asphalt road and concrete paving |
| Type of Vegetation | Low heighted, narrow canopy trees |

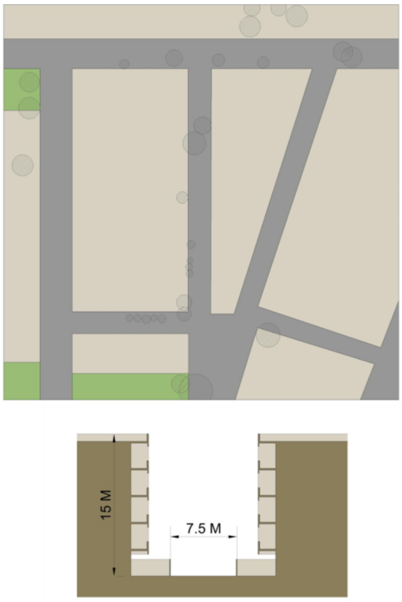
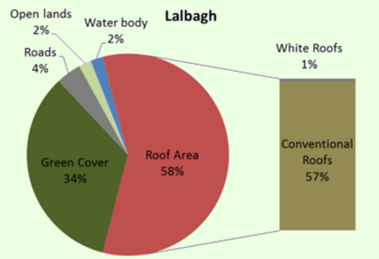
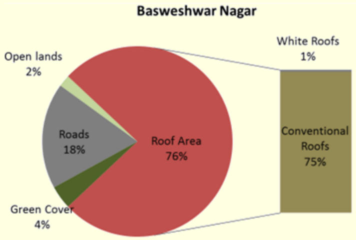
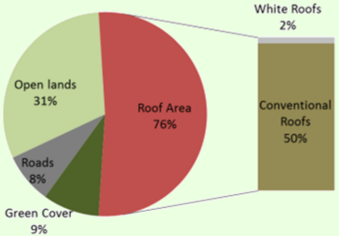


Figure 5-10 Urban Characteristics of residential location III: Bellandur

Table 5-2 Summary of residential locations selected for Monitoring I and II

| | **Location name** | **Development type** | **Characteristics at Area level** (for a radius of 1 kilometre) | **Characteristics at Street level** | | **Significant features** |
|---|---|---|---|---|---|---|
| | | | | H/W Ratio | % Green Cover | |
| 1 | **JAYANAGAR II BLOCK**<br>(South of Lalbagh Botanical Garden) | 1 to 3 storeyed houses & very few commercial |  | 0.16 | 34% | • Presence of lung space<br>• High green cover<br>• Low building heights |
| 2 | **BASWESHWAR NAGAR**<br>(West-Bangalore) | 2 to 3 storeyed houses |  | 1.75 | 4% | • Dense settlement<br>• Very low green cover<br>• Narrow streets |
| 3 | **BELLANDUR**<br>(South of Bellandur Lake) | 4 to 5 storeyed apartment buildings. |  | 2 | 9% | • Proximity to lake (~600m)<br>• Narrow streets<br>• Tall buildings |

### 5.3.2 Residential Locations (Monitoring III): Selection Criteria

From the results of Monitoring I and II, it was possible to determine the impact of H/W ratios in residential streets. It was also found that the impact of greenery and water bodies with open spaces was most effective. To determine which of these factors had a greater impact, a third monitoring session was conducted.

The final monitoring was carried out for three new residential locations selected based on their green cover and proximity to water bodies. By restricting to only one typology, it was easier to keep factors such as urban geometry, anthropogenic heat and surface characteristics constant.

The first location is a residential street in Koramangala. The area is known for its thick green cover. It is located approximately 2.5 kilometres towards west from Bellandur Lake. (Figure 5-11)

The next location selected for study is HSR. It is a relatively new residential development and the green cover is sparse compared to the former location, although the urban geometry is similar. HSR also lies at a similar distance from Bellandur Lake (3 kilometres towards South).

The comparison of HSR with Koramangala can be used to understand the effect of green cover solely, as other factors such as urban geometry, anthropogenic heat; surface materials and proximity to lung spaces are similar. (Figure 5-12 Urban Characteristics of Location selected at HSR Layout)

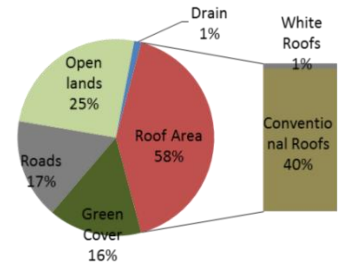
The third location selected for comparison against the first is Jayanagar I Block. This is one of the oldest residential developments in Bangalore, also known for its thick green cover. This location has no major water bodies in its proximity, apart from a relatively small water body situated in Lalbagh Botanical Garden (800 m away). Jayanagar I Block can be compared against Koramangala to understand the effect of water bodies in reducing UHI.

A summary of the urban characteristics of these three locations can be seen in Table 5-3.

The third monitoring was carried out during from 31 May 2017 to 10 Jun 2017. This period falls in the late summer season as per the climate of Bangalore. Temperature during this time generally ranges from 21 degC to 30 degC.

## Koramangala,
Central Bangalore

**RESIDENTIAL TYPOLOGY**



Bellandur lake is 2.5 kms towards East from this point

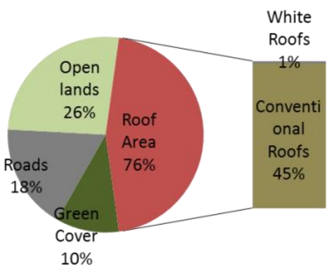
## Koramangala
Central Bangalore

| Details at Street Level | |
|---|---|
| Orientation | North East –South West |
| Typology of Buildings | Residences (bungalows) |
| Green Cover % | 75% |
| Built-up density % | 80% |
| Vehicular Density | Low |
| Width of Street | 7.5 m |
| Dist between Buildings | 9 m |
| Average Height of Buildings | 6 m |
| H/W ratio | 0.66 |
| Type of Vertical Surfaces | Plastered brick and concrete |
| Type of Horizontal Surfaces | Asphalt road |
| Type of Vegetation | Broad canopy trees |

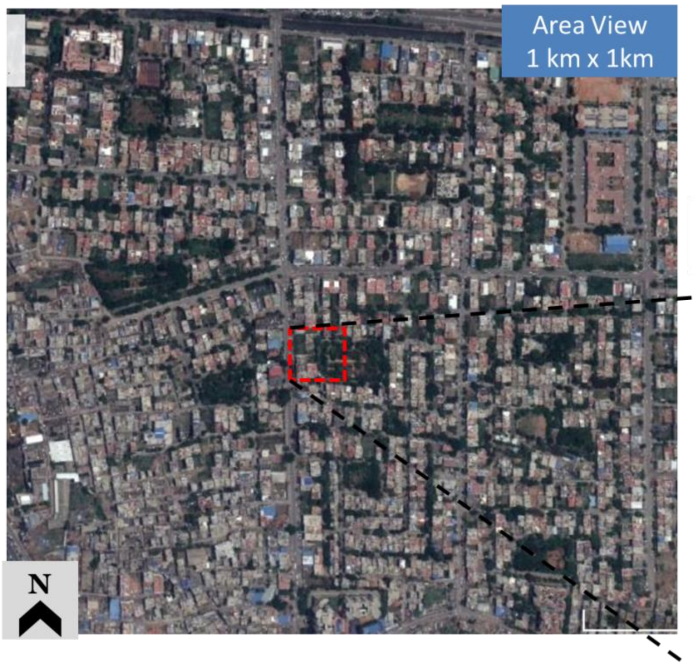
**Figure 5-11 Urban Characteristics of Location selected at Koramangala**

## HSR,
South-East Bangalore

## RESIDENTIAL TYPOLOGY



Bellandur lake is 3 kms towards North from this point



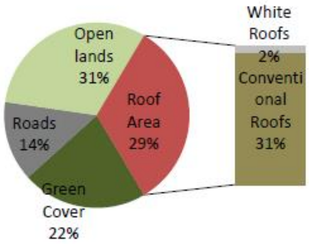
## HSR
South- East Bangalore

| Details at Street Level | |
|---|---|
| Orientation | East-West |
| Typology of Buildings | Residences (bungalows) |
| Green Cover % | 75% |
| Built-up density % | 80% |
| Vehicular Density | Low |
| Width of Street | 7.5 m |
| Dist between Buildings | 7.5 m |
| Average Height of Buildings | 7.5 m |
| H/W ratio | 1 |
| Type of Vertical Surfaces | Plastered brick and concrete |
| Type of Horizontal Surfaces | Asphalt road |
| Type of Vegetation | Moderate canopy trees |

**Figure 5-12 Urban Characteristics of Location selected at HSR Layout**

## Jayanagar 1st block,
South Bangalore

RESIDENTIAL TYPOLOGY



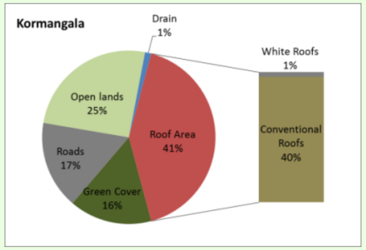
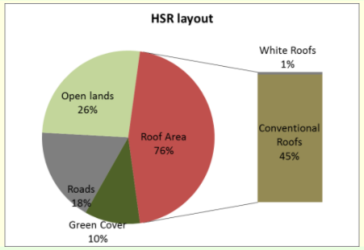
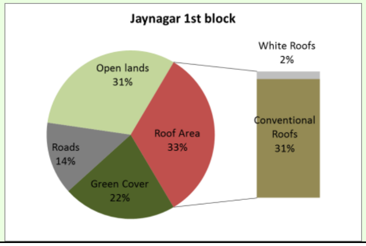
Labagh Garden and lake is 800 meters towards North from this point

## Jayanagar 1st block
South Bangalore

| Details at Street Level | |
|---|---|
| Orientation | North East- South West |
| Typology of Buildings | Residences (bungalows) |
| Green Cover % | 90% |
| Built-up density % | 80% |
| Vehicular Density | Low |
| Width of Street | 7.5 m |
| Dist between Buildings | 9 m |
| Average Height of Buildings | 7.5 m |
| H/W ratio | 0.83 |
| Type of Vertical Surfaces | Plastered brick and concrete |
| Type of Horizontal Surfaces | Asphalt road |
| Type of Vegetation | Moderate and broad canopy trees |

**Figure 5-13 Urban Characteristics of Location selected at Jayanagar I Block**

**Table 5-3 Summary of residential locations selected for Monitoring III**

| | | Location name | Development type | Characteristics at Area level (for a radius of 1 kilometre) | Characteristics at Street level | | Significant features |
|---|---|---|---|---|---|---|---|
| | | | | | H/W Ratio | % Green Cover | |
| **RESIDENTIAL** | 1 | **KORAMANGALA** | 1 to 3 storeyed residential buildings |  | 0.66 | 16% | • Bellandur lake 2.5 km towards East<br>• Large open lands towards north-east<br>• Thick green cover with mature rain trees of wide canopy |
| | 2 | **HSR** | 1 to 3 residential buildings |  | 1 | 10% | • Bellandur lake 3 km towards North<br>• Large open land towards East<br>• Relatively new residential development. |
| | 3 | **JAYANAGAR I BLOCK** | 1 to 3 storeyed residential buildings |  | 0.83 | 22% | • Thick green cover characterised by mature wide-canopy trees<br>• Lalbagh Garden towards north (1 km)<br>• One of the oldest residential layouts of the city. |

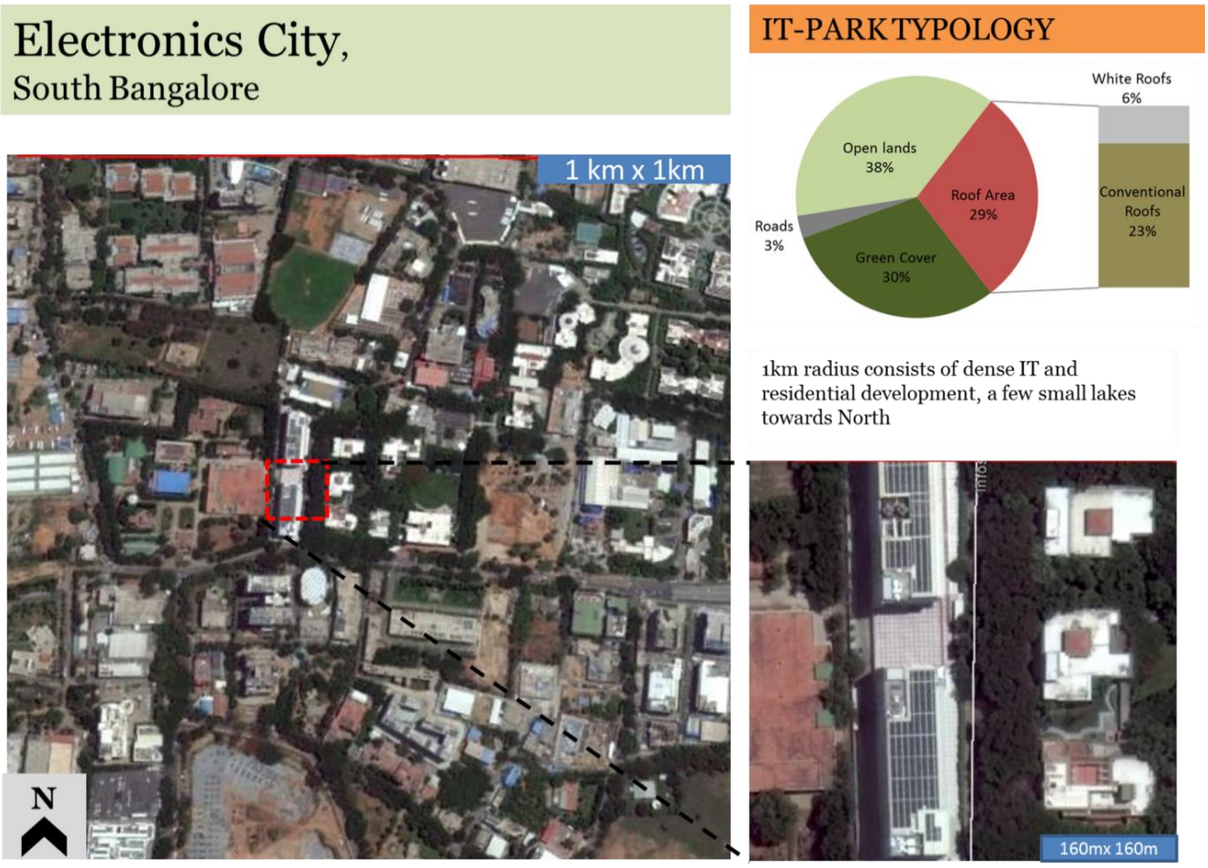
### 5.3.3 IT Park Typology

Owing to its vast IT industry, Bangalore has numerous old and new IT parks in different areas of the city. From the perspective of design, they might differ from one another in terms of road widths, building heights, type of vegetation, etc. The IT-park in Electronic city is one of the greenest in the country. (Figure 5-14 Urban Characteristics of Location Selected at Electronics City).

To assess the impact of green cover in IT developments, the above case can be analysed against another IT-park in Marathahalli, East Bangalore. The 1 kilometre span has a very high percentage of open lands, however the green cover is low. The street selected for study is enclosed by tall buildings (7 storey height) on both sides, leading to a very high H/W ratio (2.33). This case can help study the impact of street geometry in a context of UHI. (See Figure 5-15 Urban Characteristics of Location selected at Marathahalli).

To evaluate the effect of built geometry on local temperatures, it is imperative to consider a third case where the building heights and roads widths differ from the first two. The IT dominated region at Whitefield has buildings of various heights surrounded by large open spaces. The area has moderate green cover (~60%) and roads are predominantly wide (9-18m), thus leading to lower H/W ratios. (Figure 5-16).

A summary of the urban characteristics of these locations is given in Table 5-4.



1km radius consists of dense IT and residential development, a few small lakes towards North

**Electronics City**
South Bangalore

| Details at Street Level | |
|---|---|
| Orientation | North -South |
| Typology of Buildings | Office Buildings |
| Green Cover % | 75% |
| Vehicular Density | Medium |
| Width of Street | 34m |
| Average Height of Buildings | 21m |
| H/W ratio | 0.6 |
| Type of Vertical Surfaces | Aluminium panels, concrete and glass |
| Type of Horizontal Surfaces | Asphalt road and green cover |
| Type of Vegetation | Wide canopy trees |

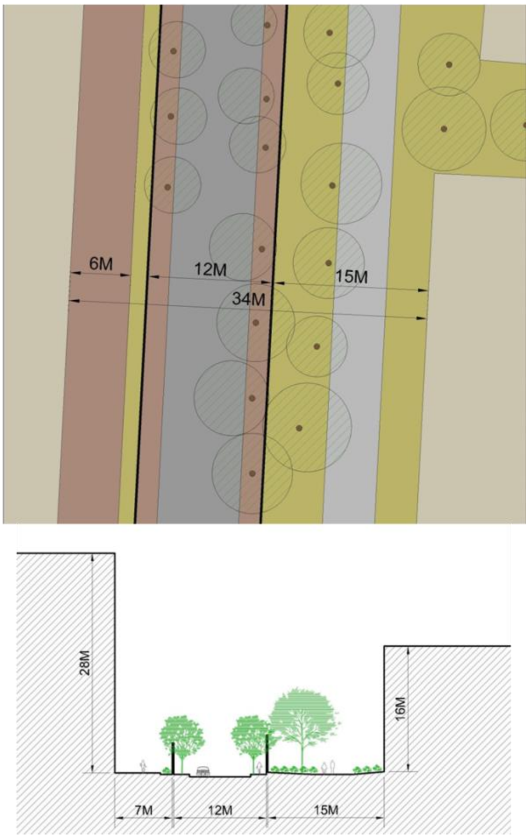
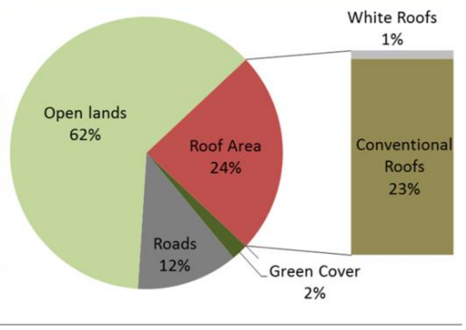


Figure 5-14 Urban Characteristics of Location Selected at Electronics City

# IT Park at Marathahalli,
East Bangalore

## IT-PARK TYPOLOGY



## IT Park 2
Marathahalli, East Bangalore

| Details at Street Level | |
|---|---|
| Orientation | North -South |
| Typology of Buildings | Office Buildings |
| Green Cover % | 16% |
| Built-up density % | 26% |
| Vehicular Density | Medium-High |
| Width of Street | 6m |
| Dist between Buildings | 12m |
| Average Height of Buildings | 28m |
| H/W ratio | 2.33 |
| Type of Vertical Surfaces | Glass, Aluminium panels, concrete |
| Type of Horizontal Surfaces | Concrete roads, concrete pavers and thin grass beds |
| Type of Vegetation | Narrow canopy, low heighted trees |

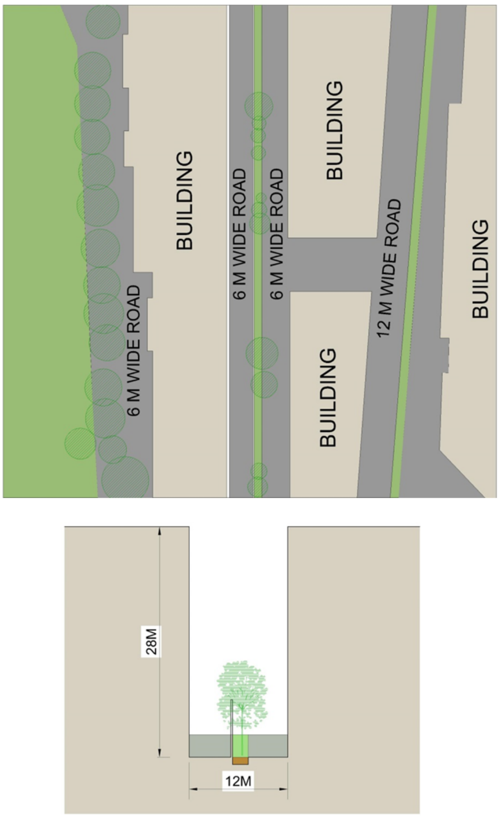
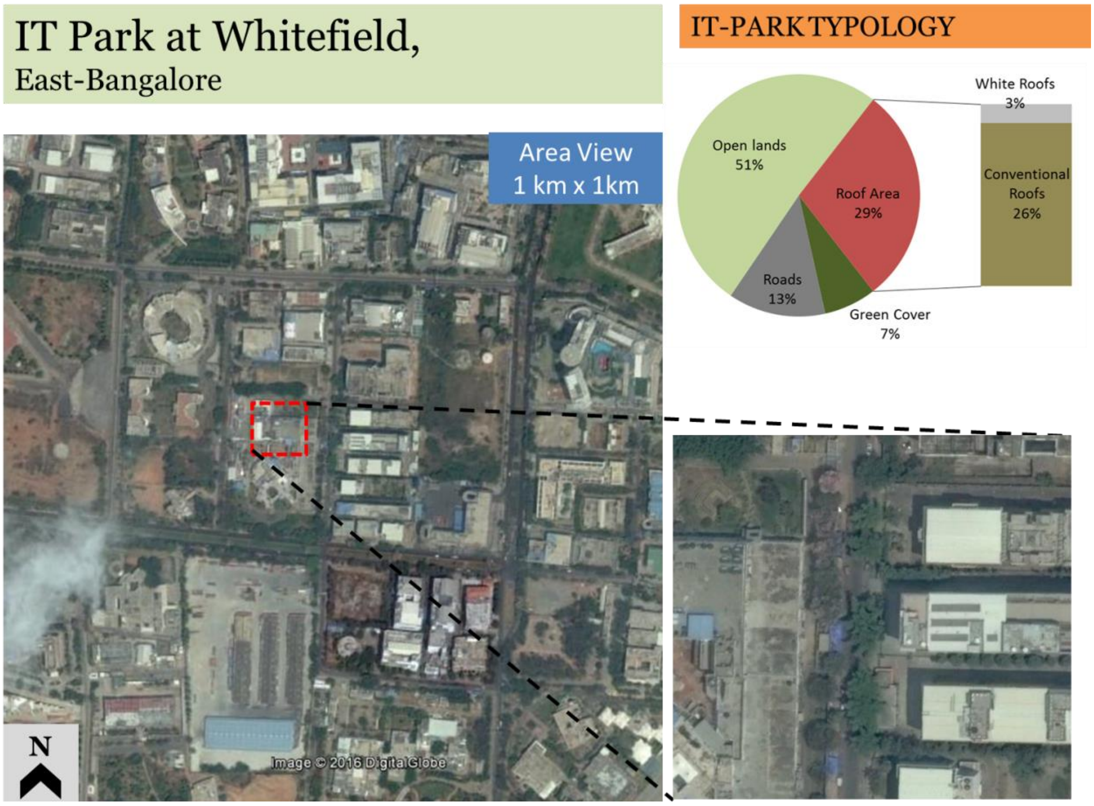
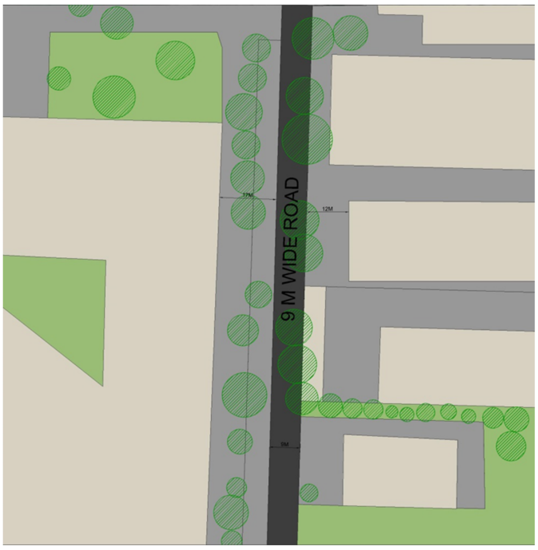


Figure 5-15 Urban Characteristics of Location selected at Marathahalli



## IT Park 3
Whitefield, East-Bangalore

| **Details at Street Level** | |
|---|---|
| Orientation | North -South |
| Typology of Buildings | Office Buildings |
| Green Cover % | 60% |
| Built-up density % | 80% |
| Vehicular Density | Medium-High |
| Width of Street | 9m |
| Dist between Buildings | 39m |
| Average Height of Buildings | 16m |
| H/W ratio | 0.41 |
| Type of Vertical Surfaces | Glass, and concrete, ALCO panels |
| Type of Horizontal Surfaces | Asphalt road, concrete pavers and thin grass beds |
| Type of Vegetation | Narrow and broad trees that shade pathways |



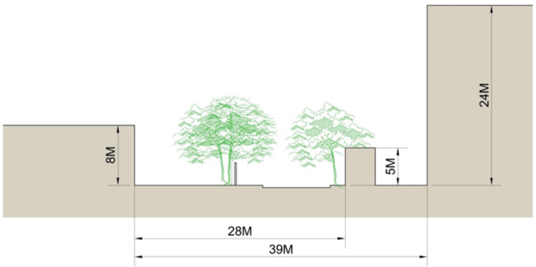
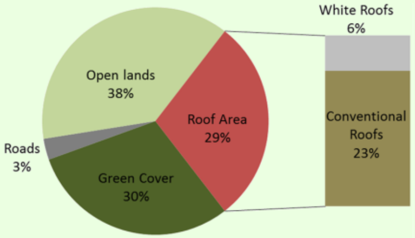
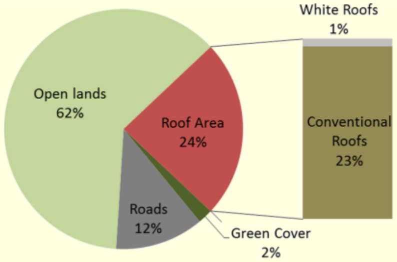
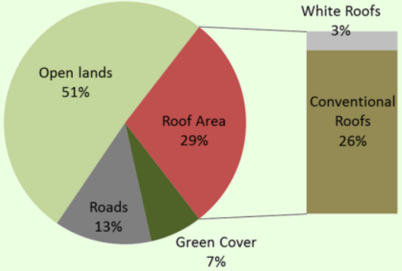


**Figure 5-16 Urban Characteristics of Location selected at Whitefield**

**Table 5-4 Summary of IT locations selected for monitoring**

| | Location name | Development type | Characteristics at Area level (for a radius of 1 kilometre) | Characteristics at Street level | | Significant features |
|---|---|---|---|---|---|---|
| | | | | H/W Ratio | % Green Cover | |
| 1 | **ELECTRONIC CITY**<br>(South Bangalore) | Mid-rise IT offices |  | 0.6 | 30% | • High green cover<br>• Medium density<br>• Moderate traffic |
| 2 | **MARATHAHALLI** | Mid-rise and high-rise IT offices, light commercial |  | 2.33 | 2% | • Very low green cover<br>• Medium density<br>• High traffic<br>• 2 kilometres away from nearest lake. |
| 3 | **WHITEFIELD** | Mid-rise IT buildings |  | 0.49 | 7% | • Wider roads<br>• Moderate green cover<br>• Surrounded by large open spaces |

# 6 Residential Typology: Results and Analysis

## 6.1 Monitoring I Results

The first monitoring was carried out from 27 January 2017 to 3 February 2017. Bangalore usually experiences early spring season during this time of the year. The average temperature reaches about 30 degC during daytime and lowers to about 17 degC during the nights. On an average, there are no rainy days during this time of the year. The wind speed is moderate at 15km/h.

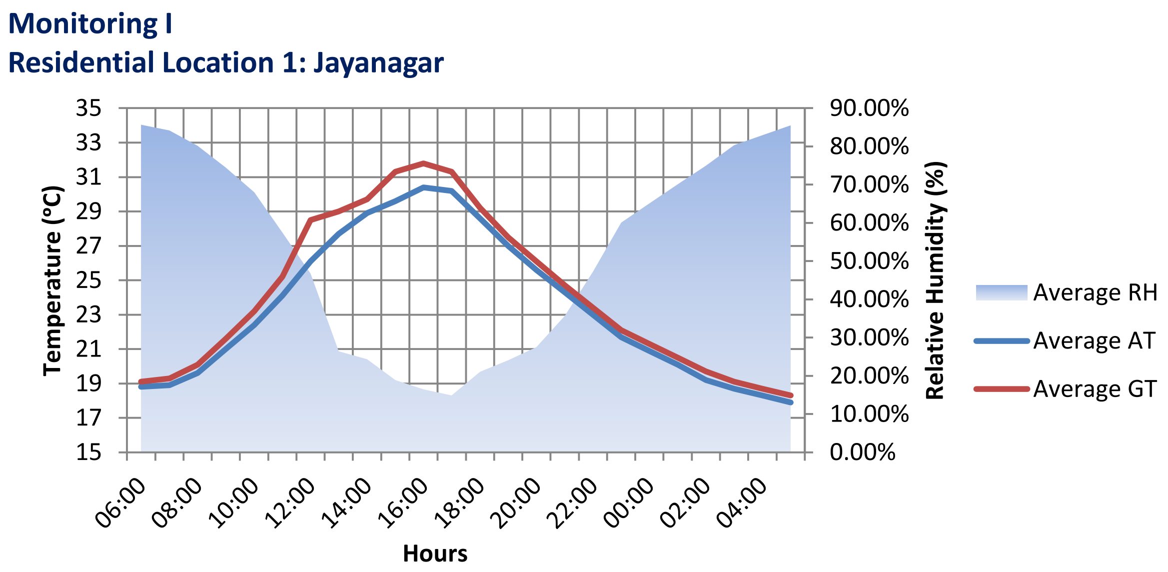


**Figure 6-1 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for Residential location-1: Lalbagh**

Figure 6-1 shows results for the residential area of Jayanagar. The average AT ranges from 18 °C at 5:00 to 30.5 °C at 16:00, whereas the average GT ranges from 18 °C at 5:00 to 31.8 °C at 16:00. The relative humidity ranges from 20% to 85%. The difference between GT and AT is noticeable only at noontime and late afternoon (~1.5 °C to 1.8 °C), after which it is negligible. This suggests that the urban surfaces tend to cool down rapidly due to presence of large open areas, eventually lowering the GT.

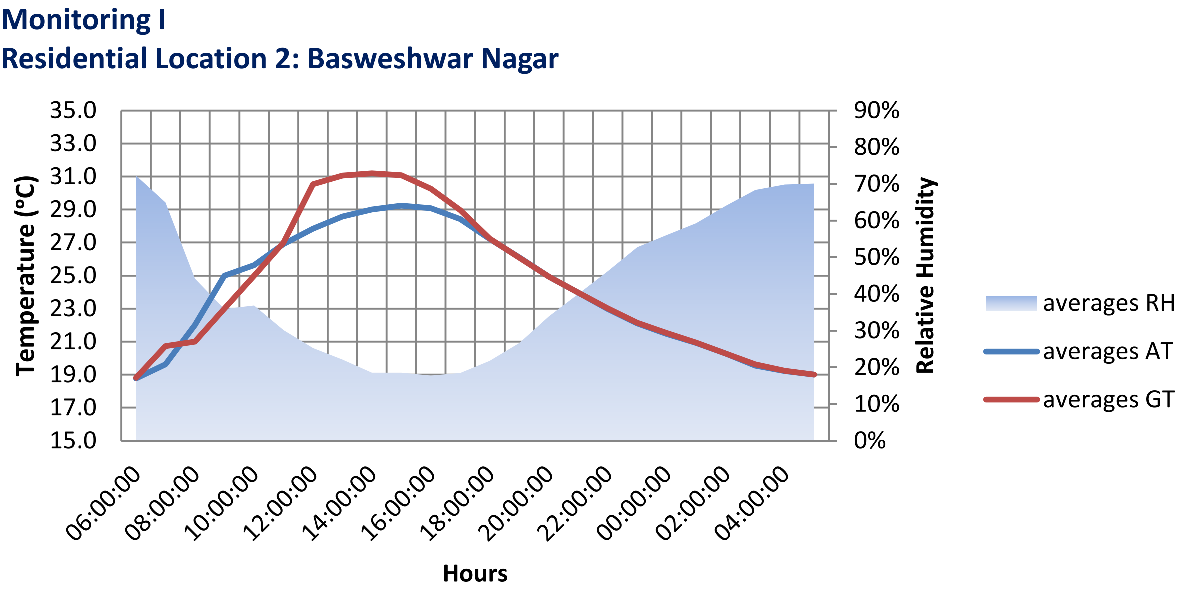


**Figure 6-2 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for Residential location-2: Basweshwar Nagar**

The graph for Basweshwar Nagar (Figure 6-4) shows AT ranging from 19 °C to 29 °C, and GT ranging from 19 °C to 31 °C. The RH falls rapidly in the morning and remains very low until late evening. The GT remains significantly higher than AT for a greater part of the day by approximately 3 °C.

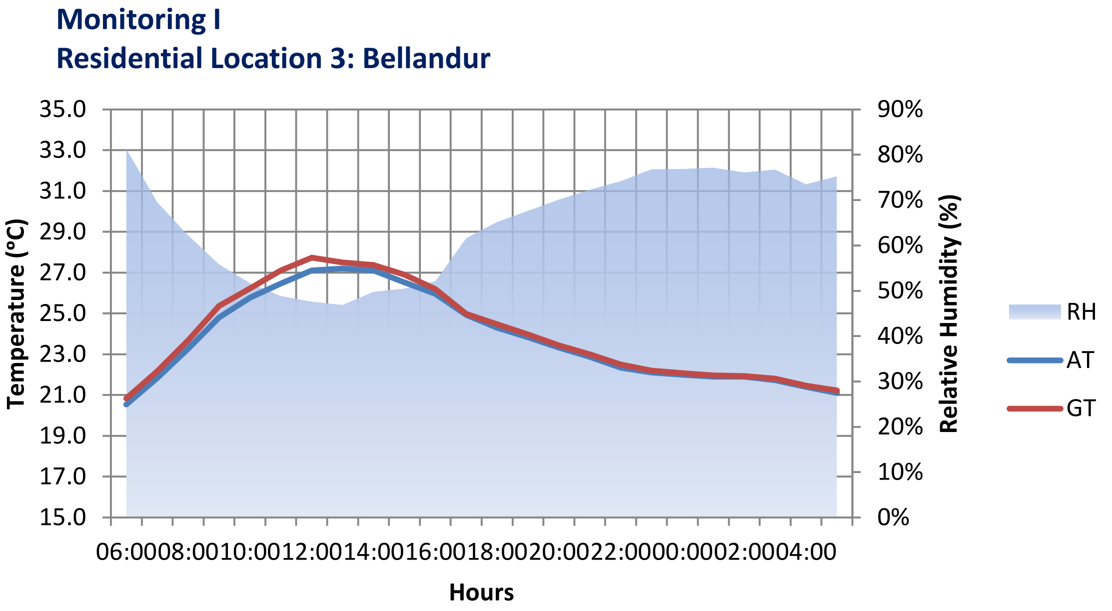


**Figure 6-3 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for Residential location-3: Bellandur**

At Bellandur (Figure 6-3), humidity remains considerably high throughout the day in comparison to previous locations (Range: 45% to 75%) because of its proximity to a large water body. The ATs and GTs range from 21 °C to 28 °C and 21 °C to 30 °C respectively. The building surfaces and the street remain shaded for a greater part of the day because of the high height/width ratio of the street. This is justifiable by the low values of GT. The GT only increases at 13:00, when the sun position n is overhead and the street is unshaded.

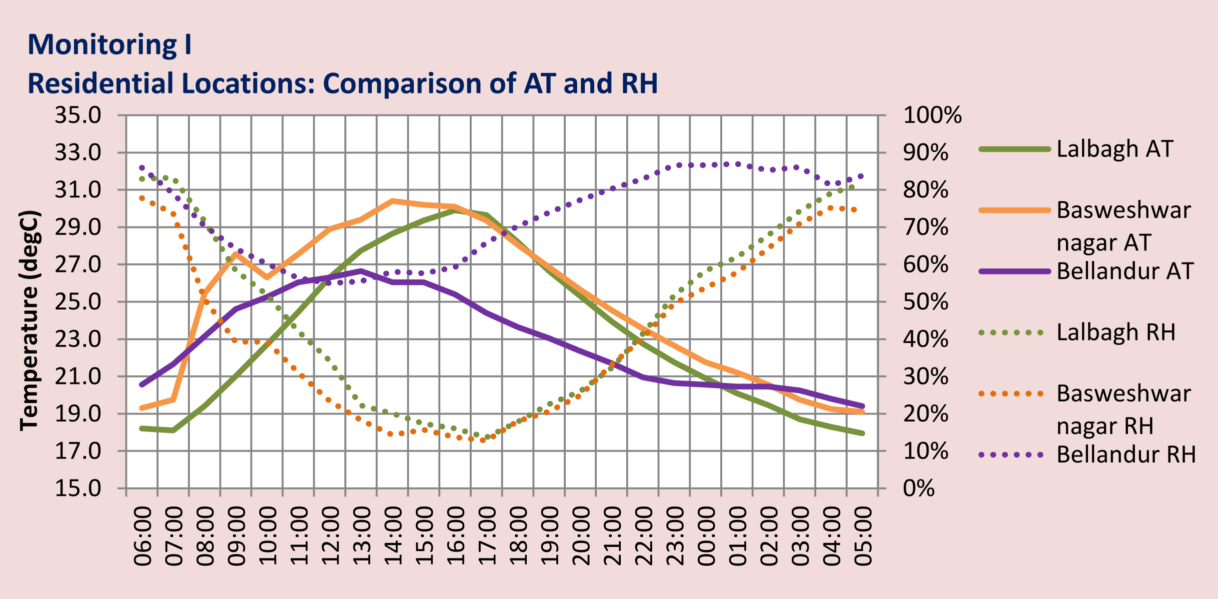


Figure 6-4 Monitoring I Results (Residential locations)- Comparison of AT and RH

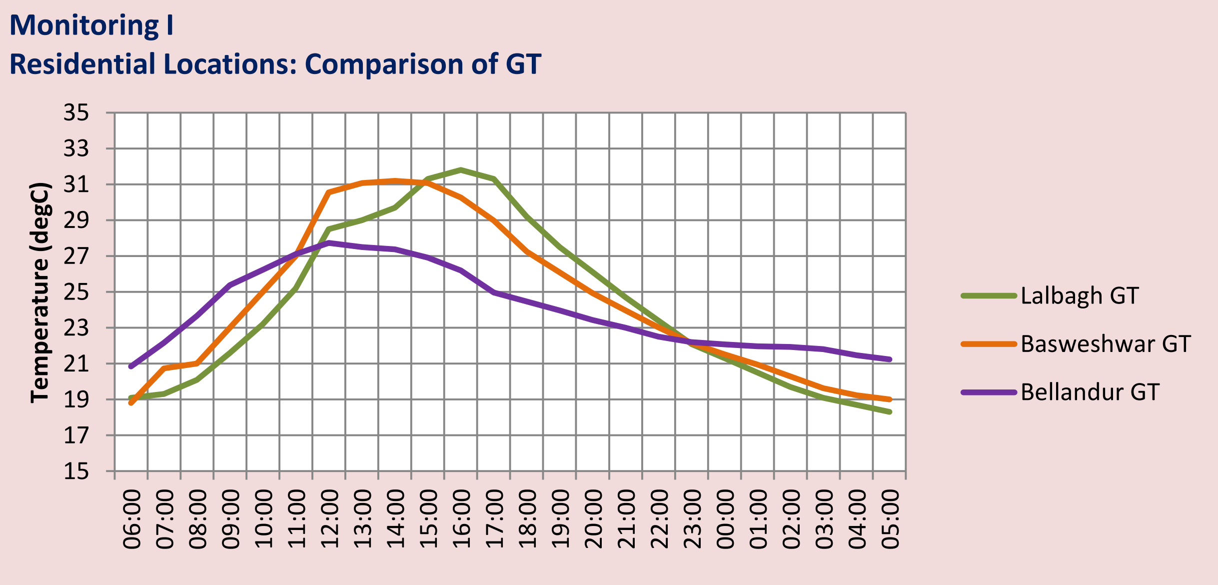


Figure 6-5 Monitoring I Results (Residential locations)- Comparison of GT

## 6.2 Monitoring II Results

Monitoring II was carried out in March. For the climate of Bangalore, the month of March marks the onset of summer. The average temperature during daytime may soar to 35degC and may drop down to 20degC during night-time. The humidity is relatively low. Most of the local trees shed their leaves during this time of the year.

The data recorded at Jayanagar (Figure 6-15) indicates that AT reaches 32 degC by afternoon and drops down to 21 degC at night. The difference between AT and GT is only noticeable 9 am onwards, when the surfaces begin to heat up. However the difference remains low. (<= 1 degC). This implies that the shaded surfaces of Jayanagar do not absorb excessive solar radiation and remain cool. The surfaces cool down considerably fast owing to the wide street canyon and greater sky-view angle.

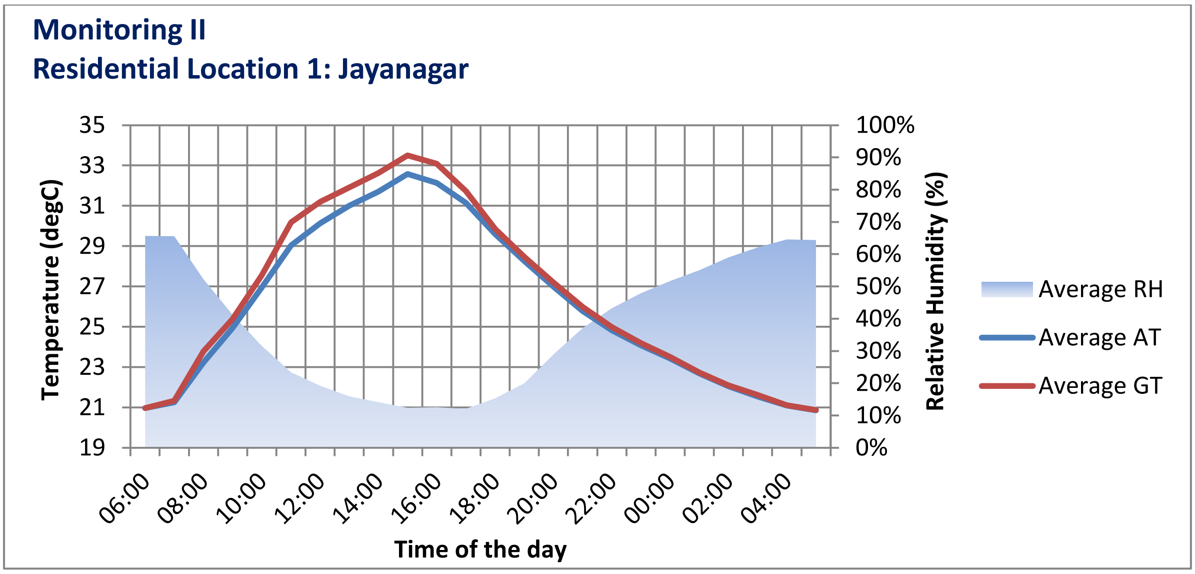


**Figure 6-6 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-1: Lalbagh. (Monitoring Period: 15-March-2017 to 22-March-2017)**

At Basweshwar Nagar (Figure 6-7), the AT reaches 35degC during afternoon and drops down to 23 °C at night. A large difference between air temperature and globe temperature implies that the surfaces absorb enough heat to raise the globe temperature by an average of 2 °C throughout the day. The surfaces dissipate the heat by late evening. At Basweshwar Nagar, AT and GT are higher by 2 °C compared to Jayanagar. The higher globe temperature shows the existence of surface-UHI during the daytime, while the higher night-time air temperatures confirm the presence of atmospheric-UHI at Basweshwar Nagar during night-time.

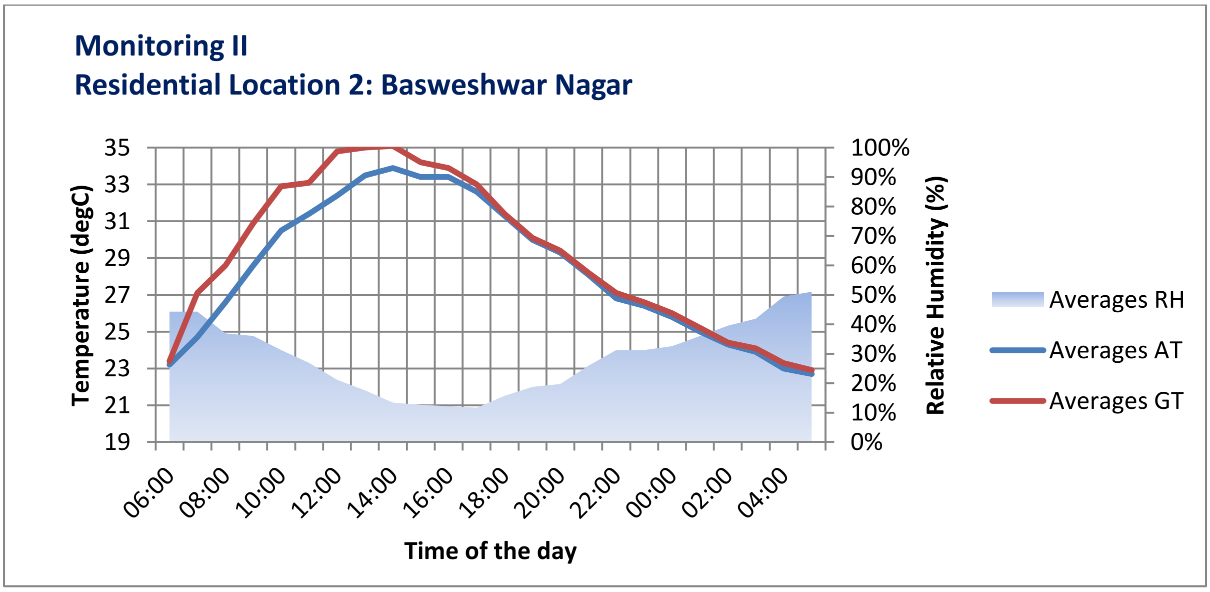


**Figure 6-7 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-2: Basweshwar Nagar. (Monitoring Period: 15-March-2017 to 22-March-2017)**

The AT at Bellandur (Figure 8-3) peaks at 31°C during the daytime. The GT reaches 32.5°C. The tall and narrow street canyon (Figure 6-8) remains shaded for most of the time of the day. Due to its geometry, the street canyon only receives sun from 11 am in the morning to about 2pm in the afternoon. Hence, the GT only rises noticeably for a few hours during the daytime.

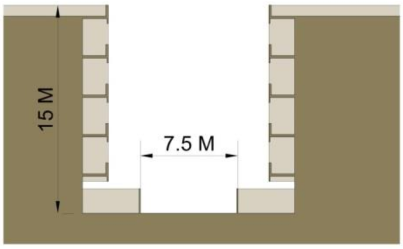


Figure 6-8 The narrow street canyon at Bellandur

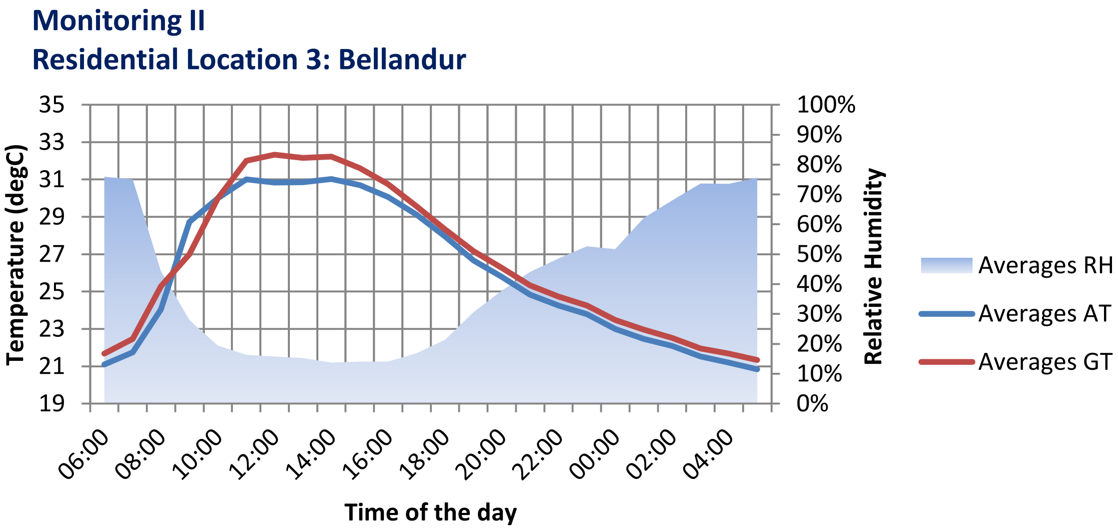


Figure 6-9 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-3: Bellandur. (Monitoring Period: 15-March-2017 to 22-March-2017)

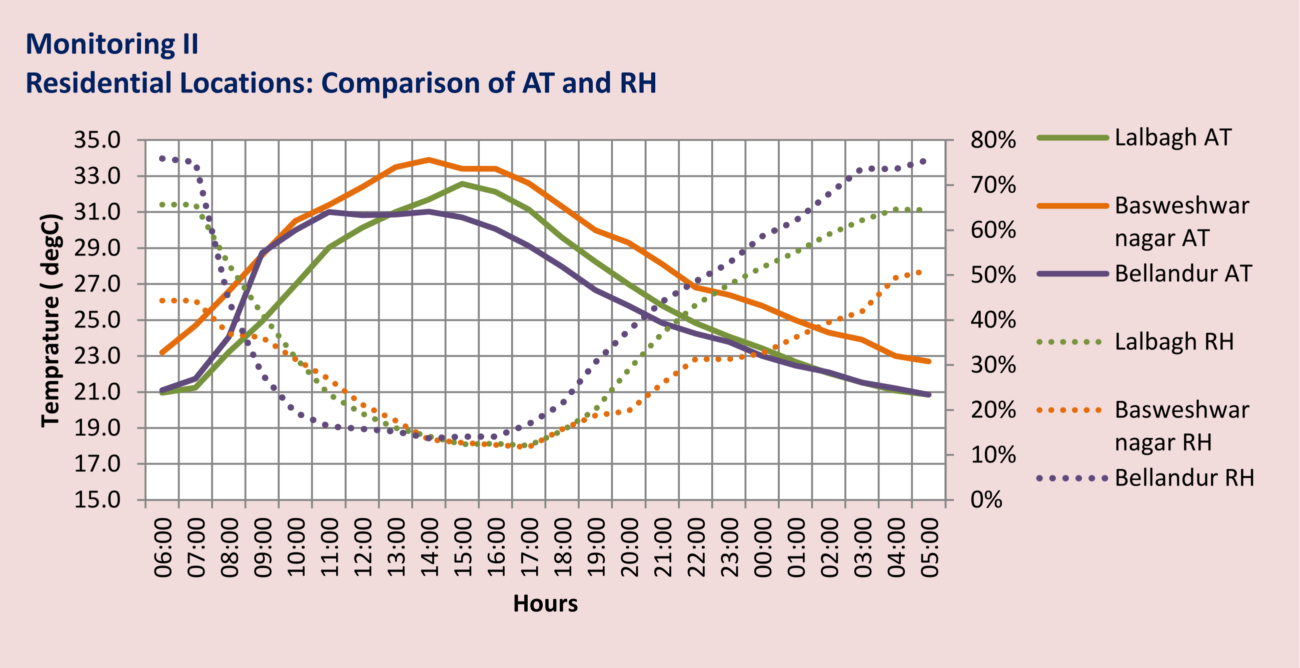


Figure 6-10 Monitoring II Results (Residential locations)- Comparison of AT and RH

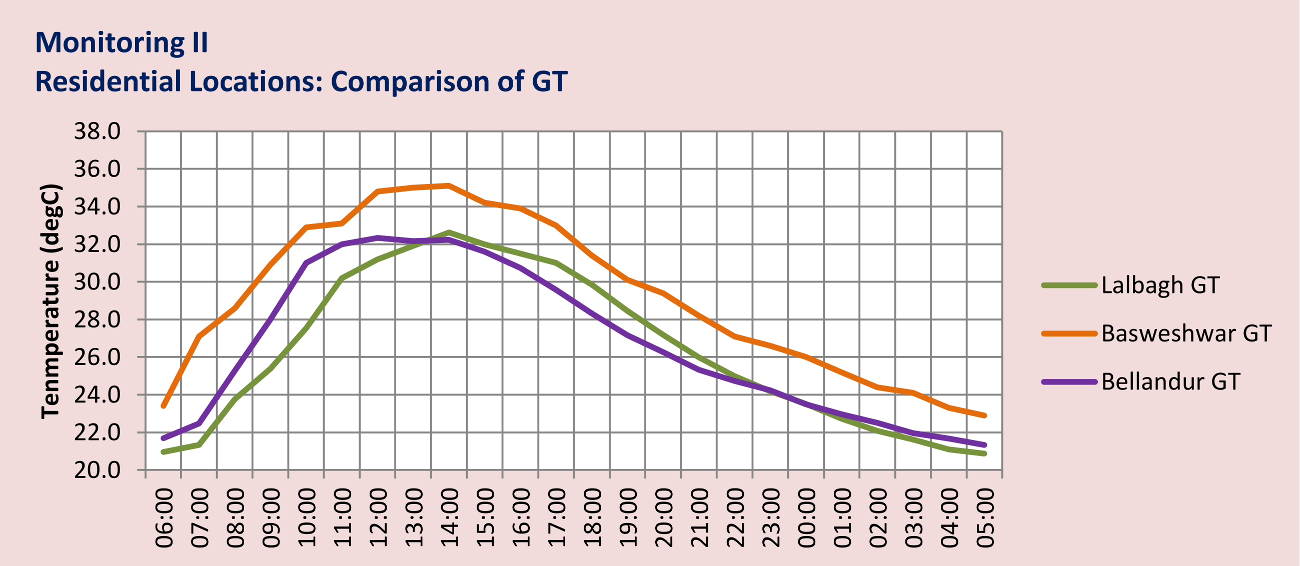


Figure 6-11 Monitoring II Results (Residential locations)- Comparison of GT

## 6.3 Observations from Monitoring I and II

- Basweshwarnagar measures highest air temperature during daytime as well as in the night time. The temperatures are 3deg higher in comparison to other locations. In the night time as well Basweshwar is 2deg C higher than other residential localities monitored under the project. This could be the result of high H/W ratio, dense development, low green cover and no water bodies/lakes in the proximity.
- Bellandur also has high dense development with high H/W ratio; however, the streets in Bellandur are comfortable due to the presence of lake in the proximity.
- Lalbagh has the highest percentage of green cover and lowest H/W ratio (broad roads and low height development), hence in the streets of Lalbagh monitored Globe Temperature (GT) is the lowest during day time as well as in the night time. Thus,

Lalbagh observes minimum UHI effect.GT in Lalbagh is slightly higher than Bellandur during the afternoon, which is due to the low H/W ratio, as horizontal building surface receive solar radiation (as the green cover shades the streets but not roofs). Roofs are not treated with highly reflective materials.

- In residential layouts it is important that the night time temperatures and early morning temperatures are low and comfortable, as this is the time residence are fully occupied. **Hence it is important to analyse and understand H/W ratios for residential layouts, which help in reducing UHI effect.**

## 6.4 Monitoring III Results

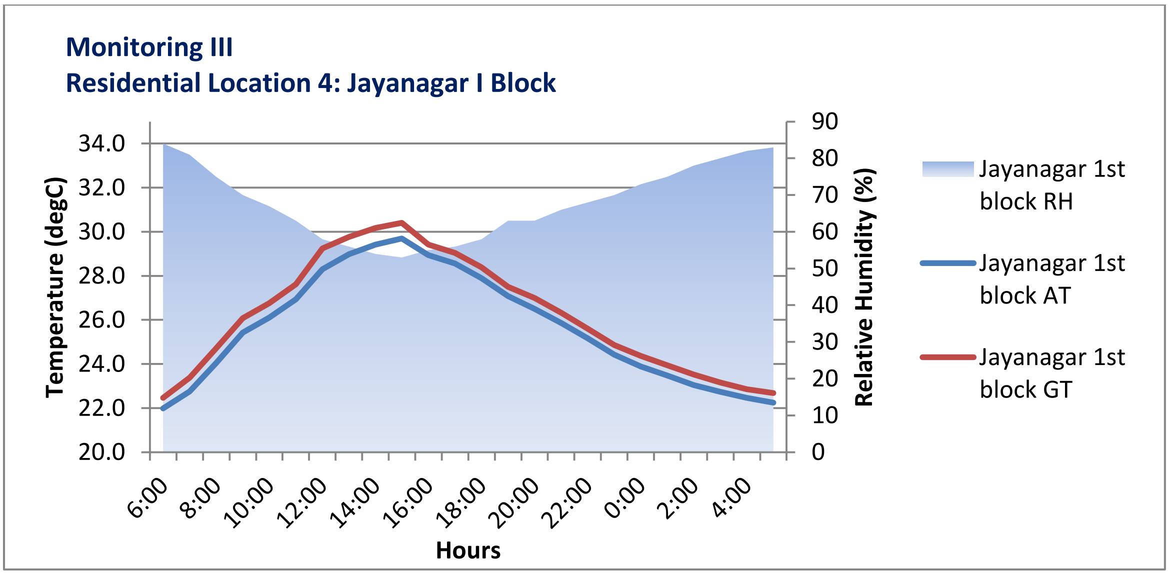


**Figure 6-12 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-4: Jayanagar I Block. (Monitoring Period: 31 May 2017 to 10 Jun 2017).**

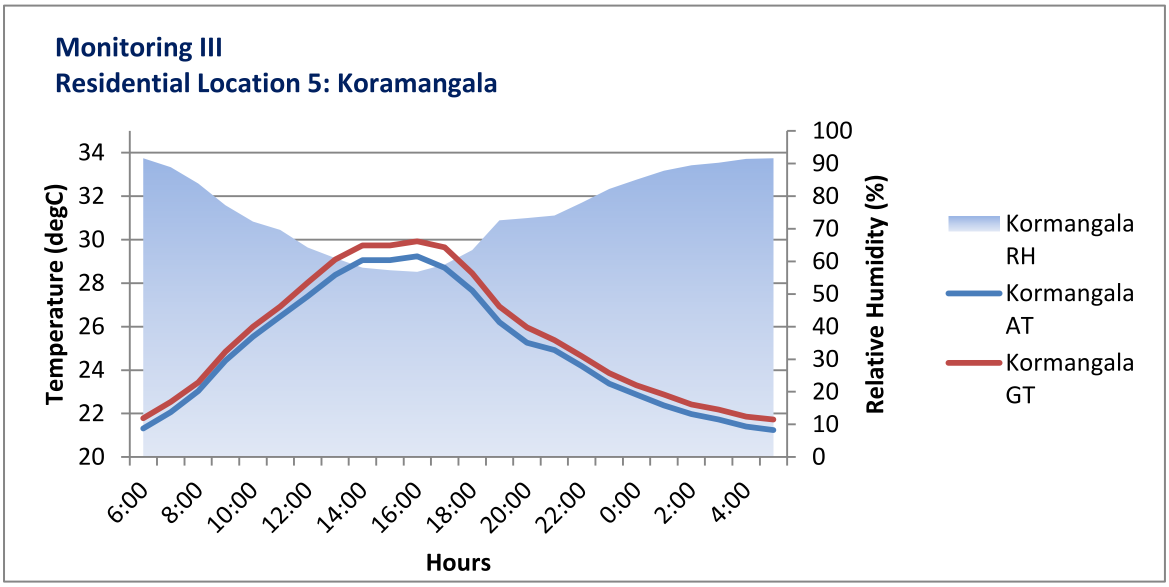


**Figure 6-13 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-5: Koramangala. (Monitoring Period: 31 May 2017 to 10 Jun 2017).**

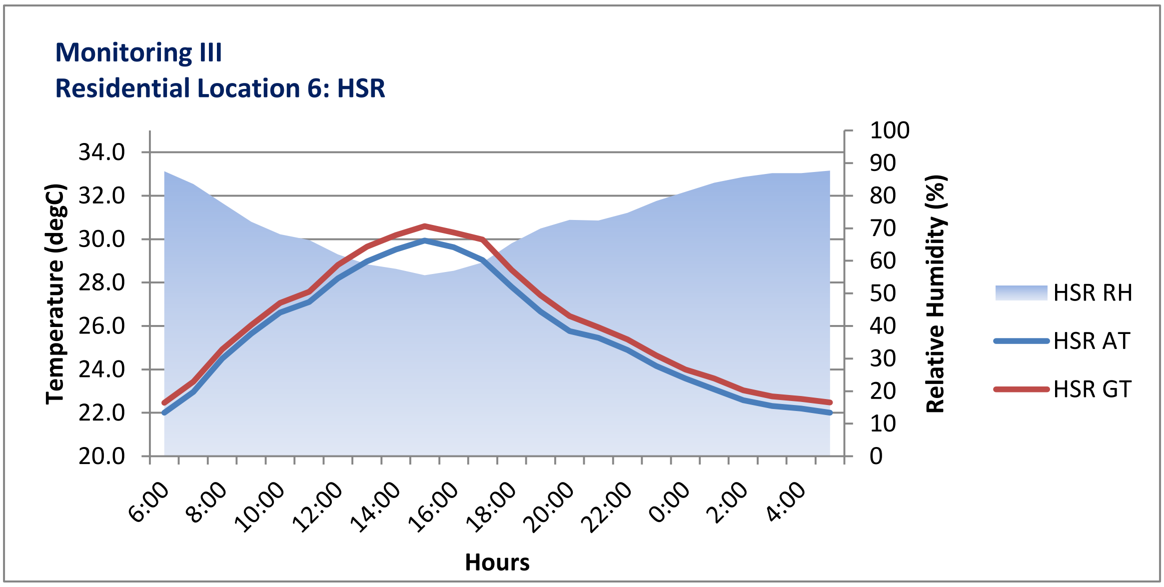


**Figure 6-14 Hourly averages of air temperature (AT), globe temperature (GT) and relative humidity (RH) for Residential location-6: HSR Layout. (Monitoring Period: 31 May 2017 to 10 Jun 2017).**

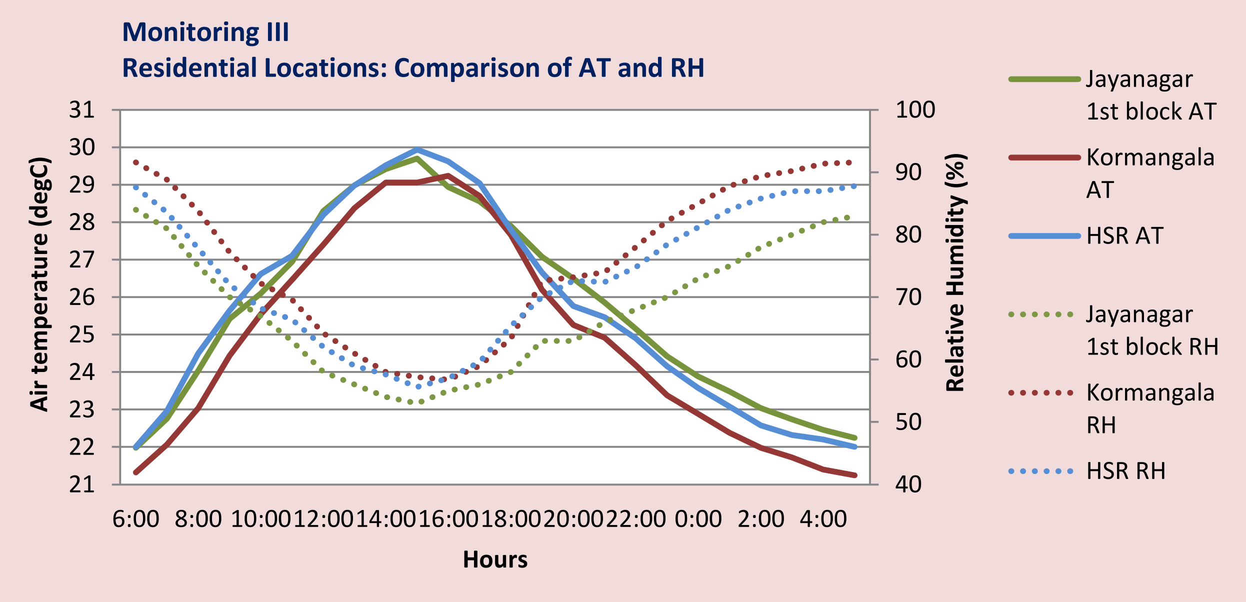


**Figure 6-15 Comparative Analysis of Hourly averages of air temperature (AT)and relative humidity (RH) for Residential location- Monitoring III. (Monitoring Period: 31 May 2017 to 10 Jun 2017).**

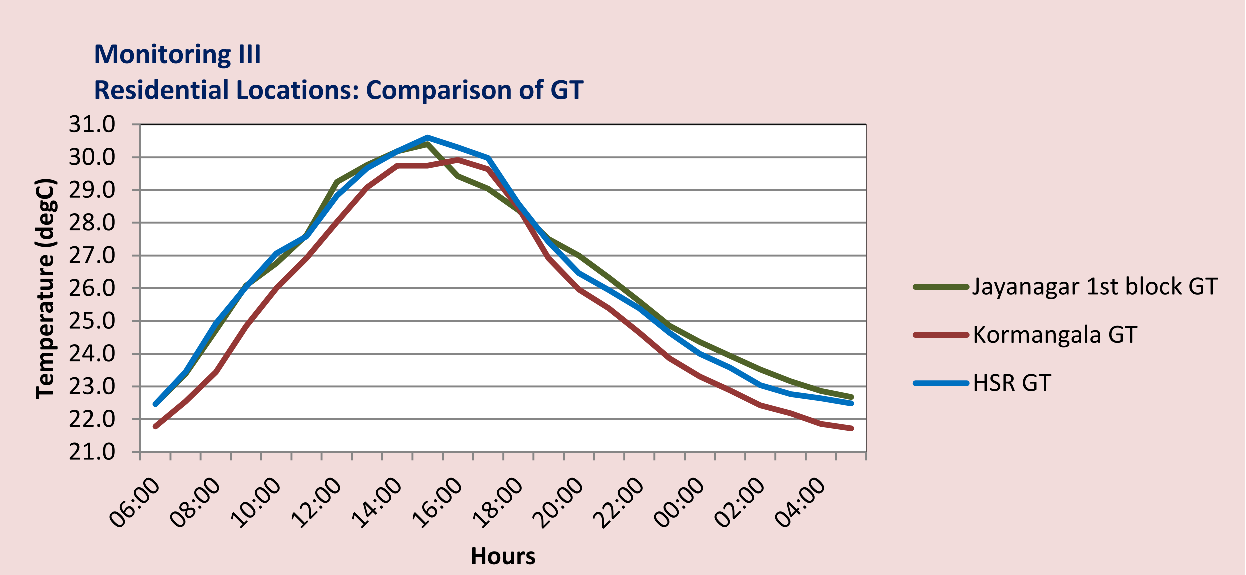


**Figure 6-16 Comparative Analysis of Hourly averages of Globe Temperature (GT) for Residential location- Monitoring III. (Monitoring Period: 31 May 2017 to 10 Jun 2017).**

The difference in temperature amongst the monitored locations is relatively smaller than that observed in previous monitoring sessions. This is due to the fact that all 3 locations belong to the same typology, and are very similar in terms of their geometry and surface characteristics. Koramangala remains 1 degC cooler than the other two locations and has higher humidity almost throughout the day. This can be owed to its proximity to the lake as well as the dense green cover which maintains humidity through evaporation.

Jayanagar I Block and Kormangala are similar in terms of green cover, however, Kormangala lies next to an enormous water body which carries a great potential for microclimate alteration. Jayanagar I Block thus shows lower humidity levels compared to Kormangala and also slightly higher temperatures.

HSR is located at a similar distance from Bellandur Lake as Kormangala. Though it warmer than Kormangala by 0.5 degC to 1 degC. It can be implied that this difference is due to insufficient shading of urban surfaces.

It is interesting to note that HSR remains cooler than Jayanagar I Block, even though Jayanagar has a greater green cover. This could only imply that the presence of a large water body has much more profound impact on reducing UHI compared to shading and green cover.

## 6.5 Observations from Monitoring III

1. When comparing HSR Layout with Koramangala, both locations have similar H/W ratios, proximity from lake, and ratios of open areas to built up. The green cover is higher in Koramangala. The existing tree canopies in Koramangala shade the streets as well as the building surfaces to a much greater extent compared to HSR. As per the results, AT at Koramangala is 1degC lower than that at HSR during the daytime as well as at night.

2. When comparing Kormangala with Jayanagar, both locations have similar green cover and H/W ratios. Koramangala is located near a much larger water body (Bellandur Lake) which helps alter the microclimate of larger urban pockets
3. When comparing Jayanagar with HSR, both locations have similar H/W ratios, however Jayanagar has higher green cover. Despite this factor, Jayanagar is warmer than HSR at night time. This is due to the fact that HSR layout is surrounded by open lands and larger water body.
4. Jayanagar is warmer at night compared to Koramangala and HSR. This is due to the fact that Koramangala and HSR are surrounded by large open spaces, whereas Jayanagar is not.

# 7 IT-office Typology: Results and Observations

## 7.1 Results

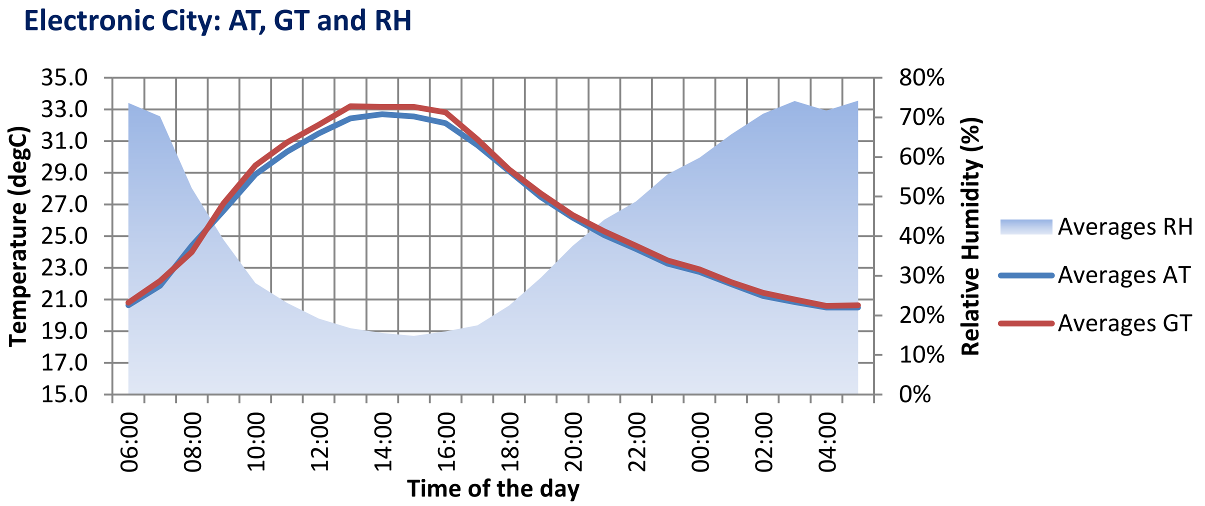


**Figure 7-1 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for IT-1: Electronic City. (Monitoring Period: 15-March-2017 to 22-March-2017)**

Electronic city (Figure 7-1) has high green cover (~32% of the total area in a radius of 1km). Most of the buildings have white roofs, and most of the vertical facades remain shaded with trees. Hence surfaces tend to remain cool and thus there is not much difference between air temperature and globe temperature. At night this difference is negligible. (AT is in the range of 20.8 to 32.2 degC).

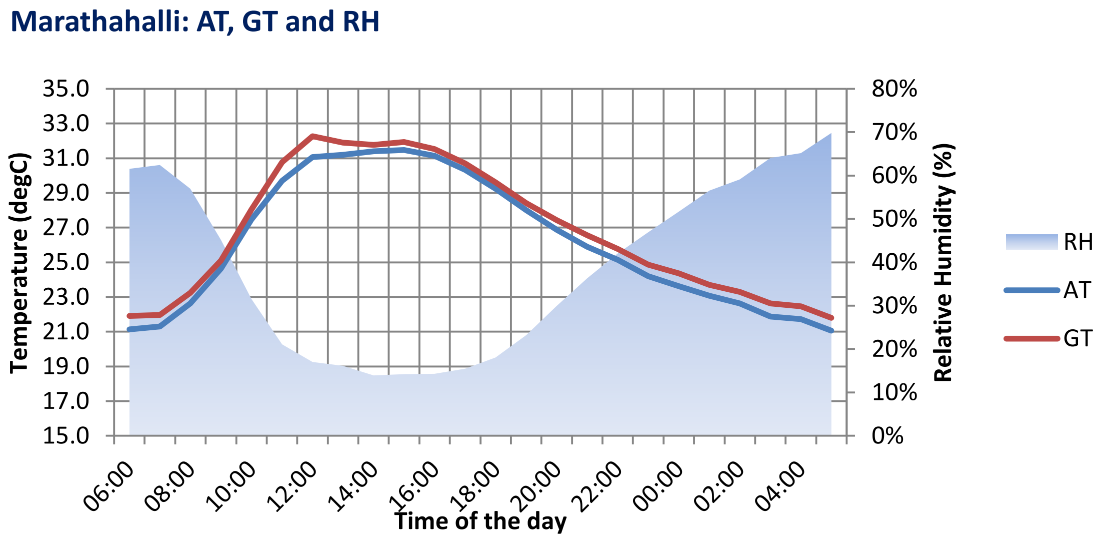


**Figure 7-2 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for IT-2: Marathahalli. (Monitoring Period: 15-March-2017 to 22-March-2017)**

In Marathahalli (Figure 7-2), the green cover is very low (~17%) resulting in lower humidity. The density of traffic is very high on the main traffic corridor, which may lead to increased air temperatures in the abutting areas. However the instrument mounted in an internal road 100 m away from the main road has recorded lower temperature and high humidity than outside(AT between 21.9 to 31.3 degC). This clearly indicates the contribution of a built configuration in controlling and maintaining the microclimate of its adjacent zone against the adverse surroundings.

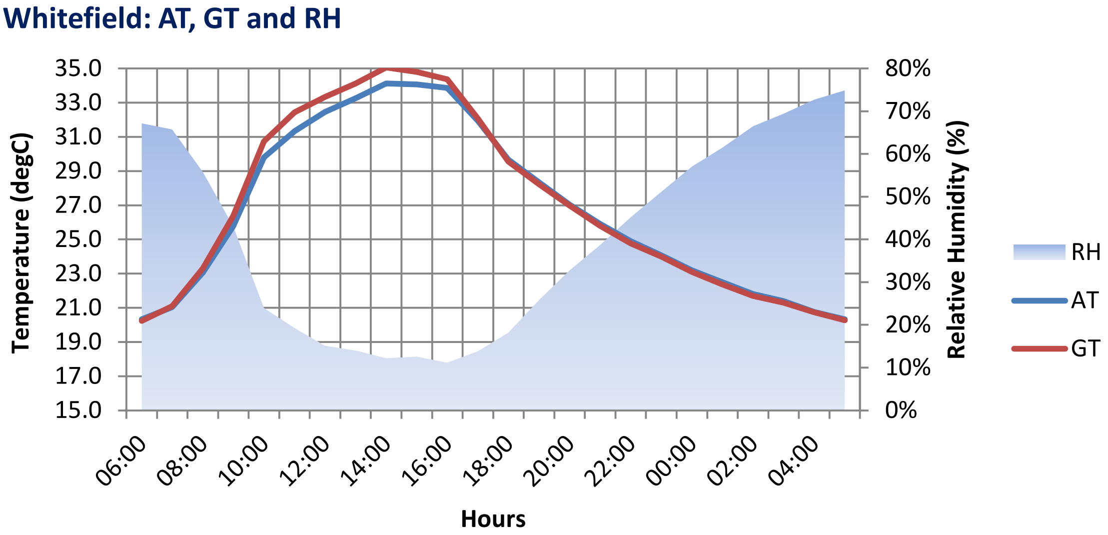


**Figure 7-3 Hourly averages of air temperature (AT), globe temperature (GT), wet-bulb temperature (WBT) and relative humidity (RH) for IT-3: Whitefield. (Monitoring Period: 15-March-2017 to 22-March-2017).**

At Whitefield (Figure 7-3) the highest AT (20.2 to 34.8 degC) and GT ( 20.2 to 35 degC) were recorded.

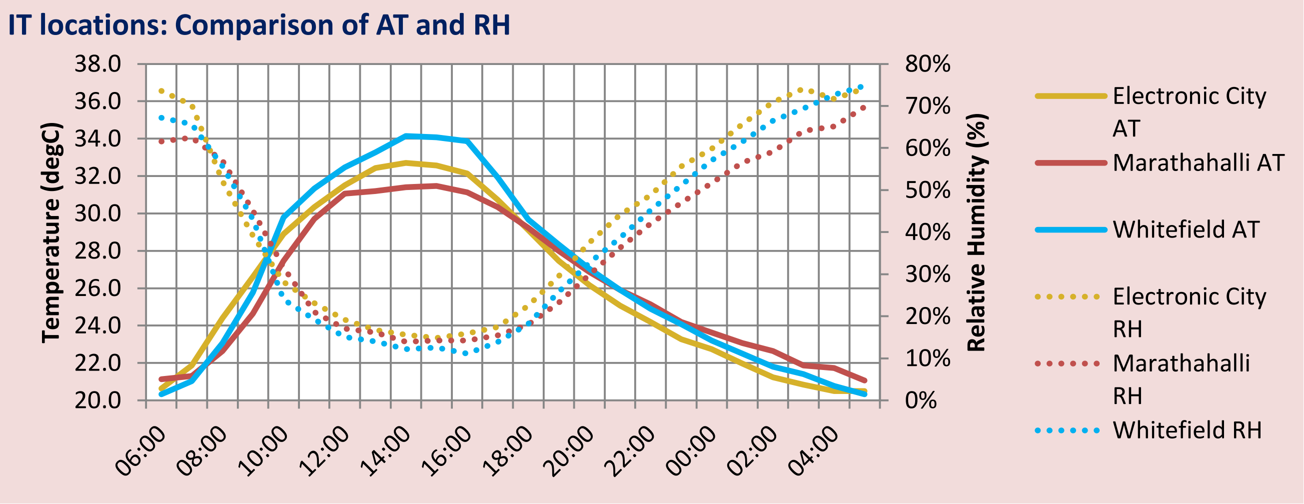


**Figure 7-4 Comparative Analysis of Hourly averages of Air Temperatures (AT) and Relative Humidity (RH) for IT Locations. (Monitoring Period: 15-March-2017 to 22-March-2017).**

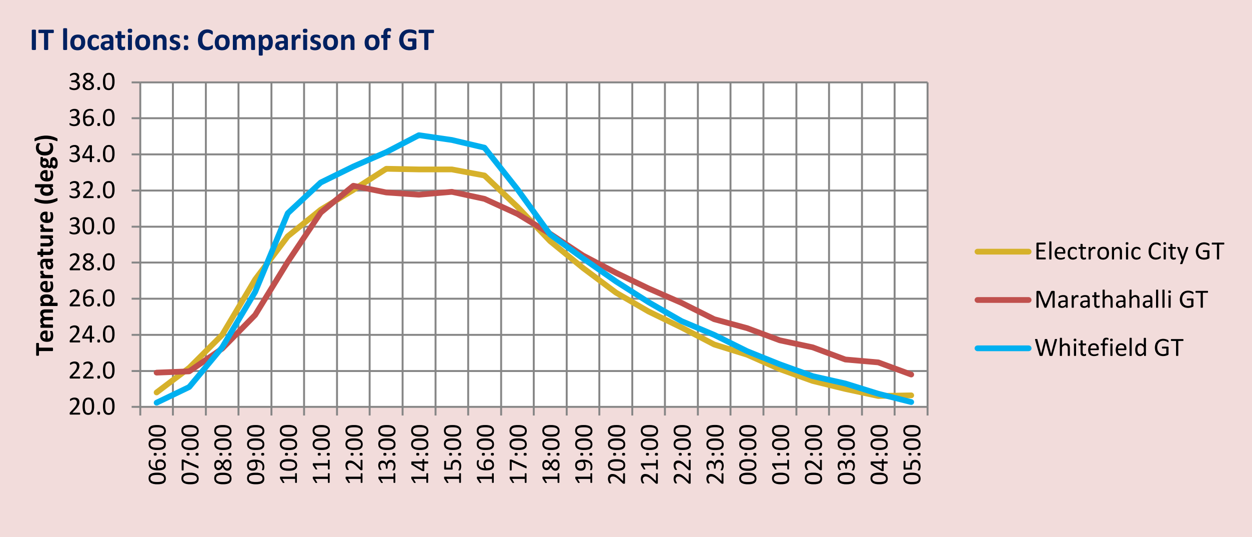


**Figure 7-5 Comparative Analysis of Hourly averages of Globe Temperatures (GT) for IT Locations. (Monitoring Period: 15-March-2017 to 22-March-2017).**

## 7.2 Observations

- Amongst the IT locations, it is observed that Whitefield observes the highest AT as well as GT during daytime. This is due to the fact that Whitefield has a high percentage of open land surfaces with low green cover. Due to a high percentage of open lands, the area shows low temperatures at night and a high diurnal variation.
- It is observed that Marathahalli, has low GT and AT at daytime, despite having identical RH. This ascertains that the lower daytime GT and AT is due to a high H/W ratio. The buildings are tall and space between buildings is narrow as the surfaces are protected from direct solar radiation.
- On comparing commercial zones with residential, it is observed that IT parks planned in commercial areas such as Whitefield, observes 4degC higher temperature during daytime in comparison to residential locations such as Belandur, this is due to high anthropogenic heat emitted by buildings and impervious surfaces which are not covered thus trap heat making the surroundings warmer.
- From the results of Electronic City, it was observed that thick green cover combined with white roofs and light coloured surfaces can be very effective in lowering the daytime as well as the nighttime temperatures. Presence of water bodies can further help reduce the temperature and bring about evaporative cooling.

# 8 Results of Infra-red Thermal Imaging

An Infra-Red (IR) thermal camera was used to capture thermal images of the street canyons during consecutive afternoons on 1st and 2nd March 2017. The thermal images show surface temperatures on a colour scale of dark-blue (coldest) to bright yellow (hottest). Through these images, the behaviour of different surfaces of an urban geometry can be compared on a single scale, thus validating the presence of Surface UHI in the given locations.

From the case of Marathahalli IT Park, it is clear that a tall building canyon (high H/W ratio) tends to remain shaded by tall buildings enclosing the street. This inhibits the solar access for such streets and the surface temperatures remain as low as 20 to 25°C. This led to the lower GT and AT.

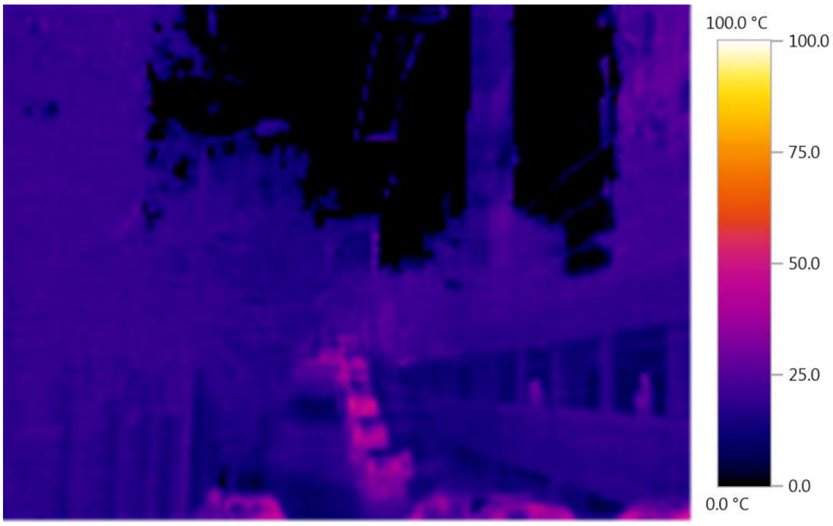


**Figure 8-1 Street Canyon at Marathahalli IT Park**

The north-south oriented road has tall buildings on both sides, and a row of trees in the middle. All the building surfaces are at a uniform low temperature. Towards right, a row of parked cars are visible with warm engines causing bright pink hue.

The behaviour of an unshaded street canyon against a shaded one can be observed from the following thermal images captured at Electronic city.

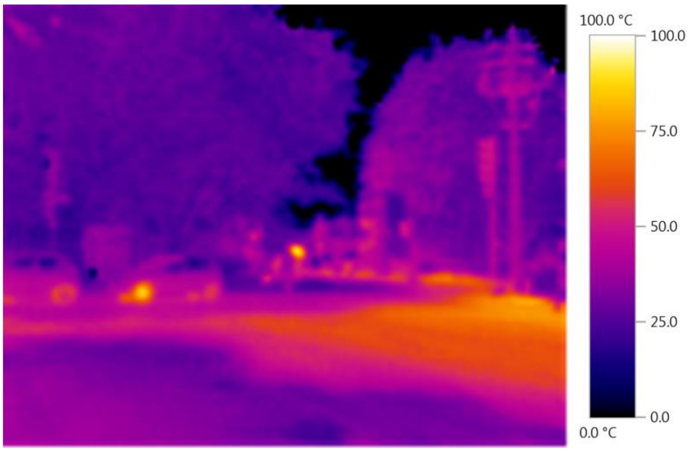


**Figure 8-2 An un-shaded street with low H/W ratio and low green cover**

**Figure 8-3 A street shaded due to tall buildings and trees**

The surfaces of shaded street remain at 25°C, while the un-shaded street surface temperature may reach upto 70 °C. The difference in temperature is significant.

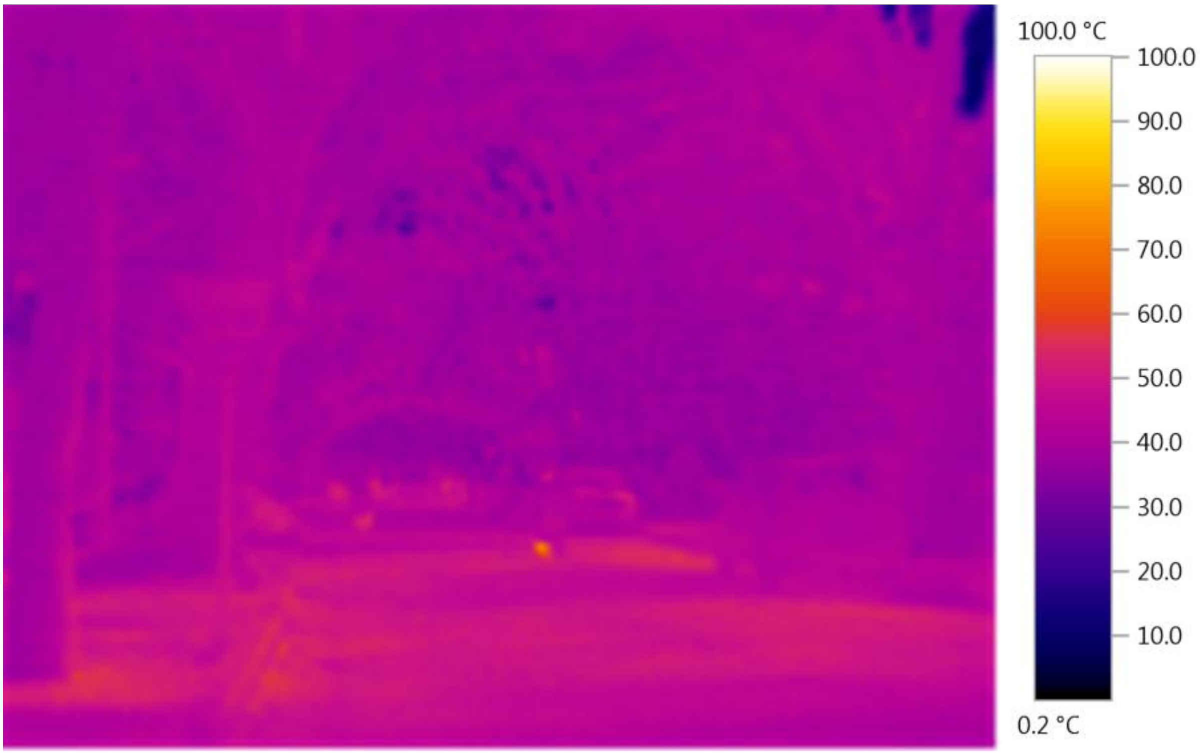
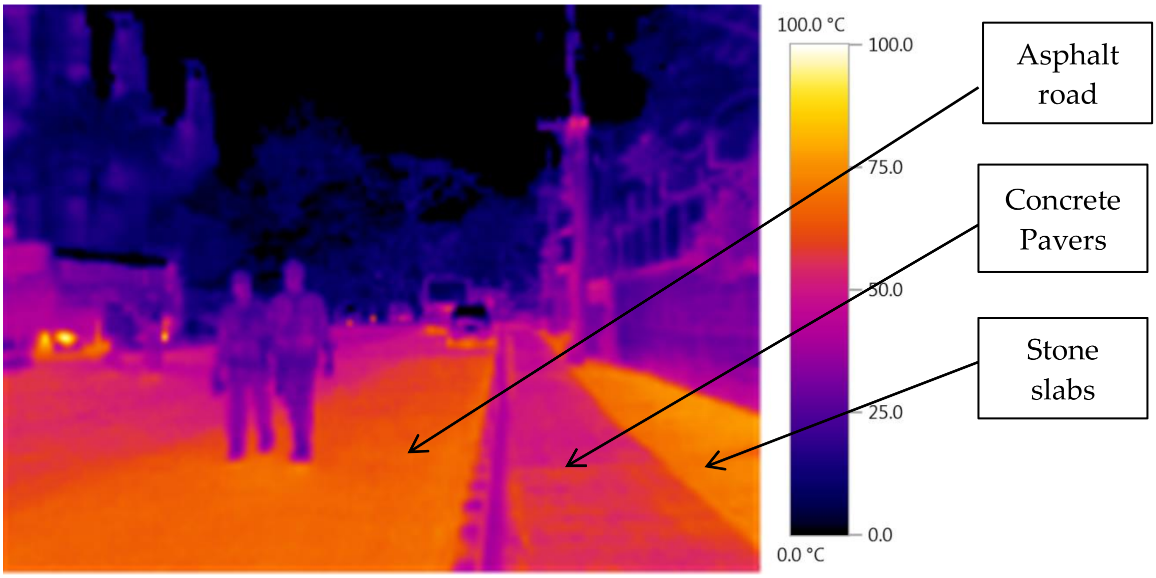


**Figure 8-4 A fully shaded street at Lalbagh: The street is shaded almost throughout the day because of the dense canopy cover**



The materials selected for the urban surfaces also respond differently based on their thermal images as seen in the image above. It can be seen that the asphalt street surface and the stone slabs are at a higher temperature compared to the adjacent band of concrete pavers. This is because of the dark surface of the asphalt road and high thermal capacity of stone.

# 9 Conclusions and Recommendations

The monitored results confirm the presence of urban heat island effect in different pockets of the city. The difference in air temperatures was recorded to be about 4 to 5 deg C. This is due to several reasons including:

1. Reduced Green Cover: low evapotranspiration and reduced shading resulting in low RH, and high AT.
2. Reduced water bodies: reduced evaporative cooling and increased air temperatures.
3. Increased impervious surfaces: greater heat absorption resulting in higher globe temperatures.
4. High density and high H/W ratios, with high-emissivity finishes: increased night time temperatures due to heat trapped in street canyons.
5. Reduced air velocity due to urban surface roughness.
6. High anthropogenic heat rejected from air conditioned buildings and traffic on roads.

Currently most of the existing byelaws and urban planning strategies do not include UHI mitigating aspects. Hence, based on this study, the following urban planning interventions are recommended for future urban growth of Bangalore City which will help prevent Urban Heat Island. The following recommendations have been made for future expansion of satellite towns however they can also be considered for existing cases depending on the feasibility:

**Recommendations for New Residential Locations of Bangalore:**

*Significance of H/W Ratio and its application:* As discussed earlier, the H/W ratio can be of high significance for planning of residential locations in context of UHI mitigation. Currently, for the main residential zone, for the road width of less than 9m, the maximum building height has been limited to 11.5 meters (or Still+ Ground storey+ 2 floors, whichever is less). From this the maximum H/W ratio for a 9m wide street with an 11.5 meter tall building can be calculated as 1.2 meters. However, this study suggested that areas with low H/W ratios (<=1) prove to be effective in combating UHI. Therefore, it is recommended that in intensely dense layouts, in order to maintain the H/W ratio as 1 or below, the maximum height restrictions may be revised.

1. Locations where H/W ratio is higher than 1, it is very important to integrate green cover and water bodies in the planning of the layouts.
2. While designing new layouts, priority should be given to integrate water bodies and open spaces. As observed from the results, a percentage of 14% was found to be effective. In other words, for every 7 sq. kilometres of development, 1 sq. kilometre of water body with open lands is recommended.
3. When designing new layouts, urban planners should ensure that roads are fully shaded by the canopy of planned vegetation.

### Recommendations for New Commercial Locations of Bangalore:

In commercial buildings which are usually air conditioned, the start-up load in the morning has high power consumption, followed by peak load which occurs during the daytime. Hence it is important to reduce outdoor temperatures in commercial areas during the daytime and also in early morning. Following are the lessons from the monitored results:

1. As observed from Whitefield case, In order to reduce the start-up load that occurs early morning it is recommended to have planned open lands that can help dissipate the accumulated heat to the night sky (natural heat sink).
2. A high H/W ratio may be useful in commercial building zones as it is effective in providing necessary shade to the horizontal and vertical surfaces of a street canyon, hence helping reduce the excess daytime heat gains into the buildings.
3. Cool roofs or green roofs can be very effective in lowering the daytime temperatures too. It is also recommended that the light coloured finishes should be selected for external walls of buildings (especially taller buildings) in commercial locations.

### Recommendations for locations covered in this study:

1. Western Bangalore, including Basweshwar Nagar is one of the areas worst affected by UHI. The development is dense and vast and thus not enough space is available for any new tree planation or open spaces and water bodies. Therefore the most viable solution here is to treat all the roofs with reflective finishes. Shading the roof or greening the roof is also an alternative. Existing hard-pavements can be replaced with permeable pavements wherever possible.
2. Areas like Bellandur and HSR are located near water bodies and open spaces that help to bring comfort through evaporation and ventilation. However, including good canopy trees can be planted across all streets to reduce heat further through shading.
3. For Marathahalli and Whitefield cases, more tree plantation in open lands and streets could reduce the temperatures further
4. UHI in areas such as Jayanagar and Kormangala can be further reduced with cool roofs. This can help curb the impact of UHI during peak summer days.
5. In patches of Electronic city where the green cover is sparse, strategic tree plantation can be carried out to improve shading. Low lying areas can be converted to ponds and lakes wherever possible.

Cool roofs, cool pavements and green roofs are a common solution that can be applied to both existing and future developments of the city.

## Additional Recommendations

Meticulous land use planning by incorporation of green cover,), water bodies, good wind circulation, promoting public transit can help countering UHI effect in cities. Some of the building design features to combat UHI are shading of building surfaces, deflecting radiation from the sun.

### Promoting green cover and vegetation

Planting trees and vegetation lowers surface and air temperature by providing shade and cooling through evapotranspiration. Trees and vegetation provide shade there by reducing the direct solar radiation that gets absorbed by urban surfaces. Green cover thus, helps in providing comfort conditions inside out, thereby also reducing energy bills.

### Installation of green roof

Green roof is providing vegetation over the roof top. Green roofs provide shade and also help in cooling air temperature through evapotranspiration. Thus helping in maintaining comfortable outside and inside temperatures.

### Cool Pavements/ Shaded pavements

Light coloured and permeable pavements help in maintaining comfortable temperature as well as reduce storm water run-off.

If light coloured paved areas is not possible, it is important to shade all the paved areas planned in city, to avoid trapping of heat. This should be done by planting trees/vegetation.

### Shaded streets and Parking lots

It is important to ensure that streets carrying heavy vehicle movements and parking lots remain well shaded. Vehicles moving or parked under unshaded streets get overheated inside, which leads to increased and prolonged use of air conditioning inside the vehicle. This would lead to increased fuel consumption as well exhaust emissions. Thus shading of streets and parking lots can be effective in controlling anthropogenic heat which can further intensify UHI.

### Cool Roofs

Cool roofs can help address the problem of urban heat island effect in two ways: firstly, the light surface reflects of a greater share of solar radiation, hence a very less percentage of the solar heat is absorbed and later re-emitted back to the atmosphere; secondly, a cool roofs transfer lesser heat into the building through conduction. Thus, the heat of the building reduces and the air conditioning system can be downsized, resulting in lower anthropogenic emissions.

### Water bodies

Water bodies can also have significant impact in reducing temperatures of the neighbourhood as observed during measurements. The reflective surface of water helps in lowering the solar radiation absorbed and through evaporative cooling, helps in reducing air temperatures.

### Designing of streets

Design of streets is related to FSI, H/W ratio, street widths and orientation of streets.

*Streets oriented North-South*

For such streets, if the building heights are relatively higher and the street widths are lower (resulting in a high H/W ratio), the number of hours for which the street canyon receives direct solar radiation is very less. Thus such street canyons can remain shaded, and due to their narrow width, these streets can function as ideal arterial roads.

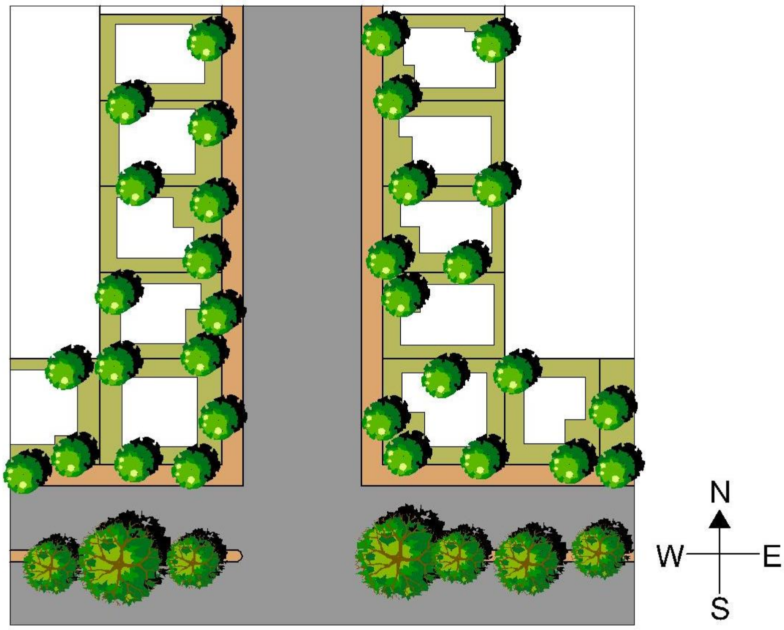


**Figure 9-1 A example of a narrow north-south oriented street**

*Streets oriented East-West*

The axis of such streets coincides with the path travelled by the sun; hence such streets would keep receiving direct solar radiation throughout the day even if they have a high H/W ratio. Therefore a thick green cover with wide-canopy trees is the ideal way to shade the horizontal and vertical surfaces of such street canyons. It is also imperative to ensure that the roofs of the buildings are made reflective.

Since the H/W ratio is not of significant relevance for these streets, wider road widths are possible. These wider streets can form the main traffic corridors given the fact that they are well shaded by tree canopies.

Through literature review, during the project, it is observed that there are regulations and policies drawn by many cities to combat UHI and its impact on climate change through integration of policies such as implementation of green infrastructure, supporting cool roofs, green roofs. There is not much in terms of policies on FSI or H/W ratios to control UHI in cities. Thus in this section of the report, a framework for various H/W ratio to combat UHI have been suggested.

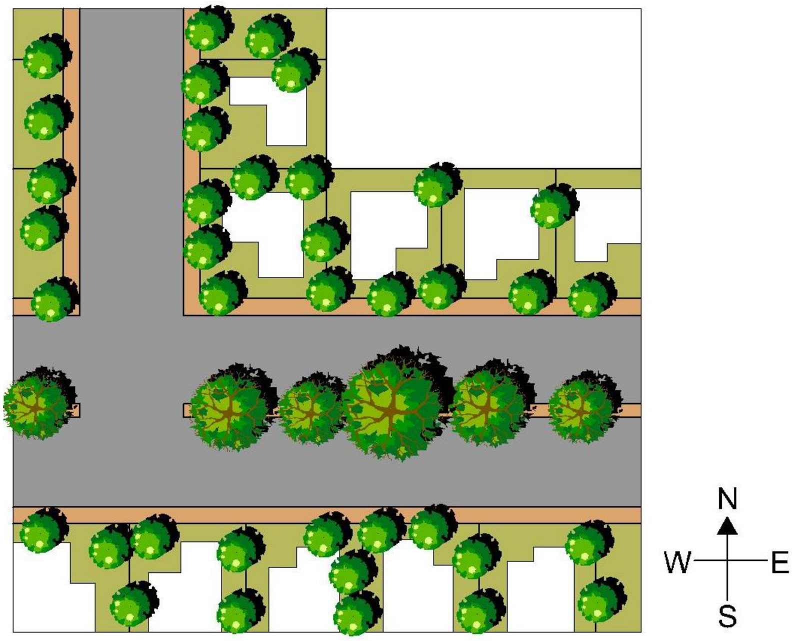


**Figure 9-2 An example of a wide East-West oriented street**

Through literature review, during the project, it is observed that there are regulations and policies drawn by many cities to combat UHI and its impact on climate change through integration of policies such as implementation of green infrastructure, supporting cool roofs, green roofs. There is not much in terms of policies on FSI or H/W ratios to control UHI in cities. Thus in this section of the report, a framework for various H/W ratio to combat UHI have been suggested.

# 10 Way Forward

This study establishes a relation between various urban planning characteristics with Urban Heat Island Effect for the city of Bangalore.

An extensive study based on an urban scale software simulation for multiple parametric analyses of the mitigation measures recommended in this report for a newly developing region of the city.

Demonstration of identified street/ location in Bangalore, to implement UHI and urban flooding adaptation strategies

Percentage contribution of anthropogenic heat (for vehicles and air conditioning equipment) to UHI.

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# 12 Annexures

## Measured Data

### Monitoring I

| Time | Lalbagh | | Basweshwarnagar | | Bellandur | | Electronic City | |
|---|---|---|---|---|---|---|---|---|
| | AT | RH | AT | RH | AT | RH | AT | RH |
| 06:00 | 18.8 | 85.70% | 18.8 | 72% | 20.5 | 81% | 13.925 | 83% |
| 07:00 | 18.9 | 84.20% | 19.6 | 65% | 21.8 | 70% | 13.85 | 79% |
| 08:00 | 19.6 | 80.20% | 22.0 | 44% | 23.3 | 62% | 15.4 | 70% |
| 09:00 | 21 | 74.50% | 25.0 | 36% | 24.8 | 56% | 17.8125 | 54% |
| 10:00 | 22.4 | 68.00% | 25.6 | 37% | 25.8 | 52% | 19.725 | 43% |
| 11:00 | 24.1 | 57.50% | 26.9 | 30% | 26.5 | 49% | 24.4375 | 28% |
| 12:00 | 26.1 | 46.80% | 27.8 | 25% | 27.1 | 48% | 26.725 | 23% |
| 13:00 | 27.7 | 26.40% | 28.6 | 22% | 27.2 | 47% | 27.65 | 19% |
| 14:00 | 28.9 | 24.30% | 29.0 | 19% | 27.1 | 50% | 28.55 | 18% |
| 15:00 | 29.6 | 18.90% | 29.2 | 19% | 26.5 | 50% | 28.3 | 17% |
| 16:00 | 30.4 | 16.50% | 29.1 | 18% | 26.0 | 52% | 28.8625 | 17% |
| 17:00 | 30.2 | 14.90% | 28.4 | 18% | 24.9 | 62% | 27.2625 | 19% |
| 18:00 | 28.6 | 21.10% | 27.2 | 22% | 24.3 | 65% | 21.925 | 30% |
| 19:00 | 27 | 24.10% | 26.1 | 27% | 23.8 | 68% | 20.525 | 36% |
| 20:00 | 25.6 | 27.50% | 24.9 | 34% | 23.3 | 70% | 19.575 | 41% |
| 21:00 | 24.3 | 35.70% | 24.0 | 40% | 22.9 | 72% | 18.675 | 47% |
| 22:00 | 23 | 47.30% | 23.0 | 46% | 22.3 | 74% | 17.675 | 53% |
| 23:00 | 21.7 | 60.10% | 22.1 | 53% | 22.1 | 77% | 17.025 | 58% |
| 00:00 | 20.9 | 65.10% | 21.5 | 56% | 22.0 | 77% | 16.6875 | 61% |
| 01:00 | 20.1 | 70.10% | 20.9 | 59% | 21.9 | 77% | 16.1125 | 65% |
| 02:00 | 19.2 | 75.00% | 20.3 | 64% | 21.9 | 76% | 15.525 | 69% |
| 03:00 | 18.7 | 80.30% | 19.5 | 68% | 21.7 | 77% | 14.8 | 74% |
| 04:00 | 18.3 | 82.90% | 19.2 | 70% | 21.4 | 74% | 14.4875 | 75% |
| 05:00 | 17.9 | 85.50% | 19.0 | 70% | 21.1 | 75% | 14.3125 | 76% |

| Time | Lalbagh | Basweshwar | Bellandur | Electronic City |
|---|---|---|---|---|
| | GT | GT | GT | GT |
| 06:00 | 19.1 | 18.8 | 20.8 | 13.7 |
| 07:00 | 19.3 | 20.7 | 22.2 | 13.7 |
| 08:00 | 20.1 | 21.0 | 23.7 | 16.1125 |
| 09:00 | 21.6 | 23.0 | 25.4 | 18.8875 |
| 10:00 | 23.2 | 25.0 | 26.2 | 20.975 |
| 11:00 | 25.2 | 27.0 | 27.1 | 33.8 |
| 12:00 | 28.5 | 30.5 | 27.7 | 36.8 |
| 13:00 | 29 | 31.1 | 27.5 | 38.3875 |
| 14:00 | 29.7 | 31.2 | 27.4 | 38.5 |
| 15:00 | 31.3 | 31.1 | 26.9 | 40 |

| | | | | |
|---|---|---|---|---|
| 16:00 | 31.8 | 30.3 | 26.2 | 40.3625 |
| 17:00 | 31.3 | 29.0 | 25.0 | 33.725 |
| 18:00 | 29.2 | 27.2 | 24.5 | 21.6125 |
| 19:00 | 27.5 | 26.1 | 24.0 | 20.1125 |
| 20:00 | 26.1 | 24.9 | 23.4 | 19.25 |
| 21:00 | 24.7 | 24.0 | 23.0 | 18.3875 |
| 22:00 | 23.4 | 23.0 | 22.5 | 17.35 |
| 23:00 | 22.1 | 22.1 | 22.2 | 16.6875 |
| 00:00 | 21.3 | 21.5 | 22.1 | 16.3375 |
| 01:00 | 20.5 | 20.9 | 22.0 | 15.8 |
| 02:00 | 19.7 | 20.3 | 21.9 | 15.25 |
| 03:00 | 19.1 | 19.6 | 21.8 | 14.475 |
| 04:00 | 18.7 | 19.2 | 21.5 | 14.175 |
| 05:00 | 18.3 | 19.0 | 21.2 | 14.0375 |

## Monitoring II

| Time | Lalbagh | | Basweshwarnagar | | Bellandur | | Electronic City | | Marathahalli | | Whitefield | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AT | RH | AT | RH | AT | RH | AT | RH | AT | RH | AT | RH |
| 06:00 | 21.0 | 66% | 23.2 | 44.30% | 21.1 | 76% | 20.6 | 74% | 21.1 | 62% | 20.3 | 67% |
| 07:00 | 21.2 | 66% | 24.7 | 44.30% | 21.7 | 75% | 21.9 | 70% | 21.3 | 62% | 21.0 | 66% |
| 08:00 | 23.2 | 52% | 26.6 | 36.90% | 24.0 | 44% | 24.4 | 52% | 22.6 | 57% | 23.1 | 56% |
| 09:00 | 24.9 | 41% | 28.6 | 36.10% | 28.7 | 28% | 26.6 | 39% | 24.6 | 45% | 25.8 | 43% |
| 10:00 | 26.9 | 32% | 30.5 | 31.30% | 30.0 | 19% | 28.9 | 28% | 27.5 | 32% | 29.8 | 24% |
| 11:00 | 29.0 | 23% | 31.4 | 26.90% | 31.0 | 16% | 30.3 | 23% | 29.7 | 21% | 31.3 | 19% |
| 12:00 | 30.1 | 19% | 32.4 | 21.20% | 30.8 | 16% | 31.5 | 19% | 31.1 | 17% | 32.5 | 15% |
| 13:00 | 31.0 | 16% | 33.5 | 17.60% | 30.9 | 15% | 32.4 | 17% | 31.2 | 16% | 33.3 | 14% |
| 14:00 | 31.7 | 14% | 33.9 | 13.40% | 31.0 | 14% | 32.7 | 16% | 31.4 | 14% | 34.1 | 12% |
| 15:00 | 32.6 | 12% | 33.4 | 12.70% | 30.7 | 14% | 32.6 | 15% | 31.5 | 14% | 34.1 | 13% |
| 16:00 | 32.1 | 13% | 33.4 | 12.20% | 30.1 | 14% | 32.1 | 16% | 31.1 | 14% | 33.9 | 11% |
| 17:00 | 31.1 | 12% | 32.6 | 11.70% | 29.1 | 17% | 30.7 | 17% | 30.3 | 15% | 31.9 | 14% |
| 18:00 | 29.6 | 15% | 31.3 | 15.70% | 28.0 | 21% | 29.1 | 23% | 29.2 | 18% | 29.7 | 18% |
| 19:00 | 28.3 | 20% | 30 | 18.80% | 26.7 | 31% | 27.5 | 30% | 28.0 | 23% | 28.3 | 26% |
| 20:00 | 27.0 | 29% | 29.3 | 19.80% | 25.8 | 38% | 26.2 | 38% | 26.9 | 30% | 27.0 | 33% |
| 21:00 | 25.8 | 37% | 28.1 | 25.90% | 24.8 | 44% | 25.1 | 44% | 25.9 | 36% | 25.9 | 39% |
| 22:00 | 24.8 | 43% | 26.8 | 31.30% | 24.2 | 49% | 24.2 | 49% | 25.1 | 42% | 24.9 | 45% |
| 23:00 | 24.1 | 48% | 26.4 | 31.30% | 23.8 | 53% | 23.3 | 56% | 24.2 | 47% | 24.1 | 51% |
| 00:00 | 23.4 | 52% | 25.8 | 32.60% | 23.0 | 59% | 22.7 | 60% | 23.6 | 52% | 23.2 | 57% |
| 01:00 | 22.7 | 55% | 25 | 36.10% | 22.5 | 62% | 22.0 | 66% | 23.1 | 57% | 22.5 | 61% |
| 02:00 | 22.0 | 59% | 24.3 | 39.50% | 22.1 | 68% | 21.2 | 71% | 22.6 | 59% | 21.8 | 66% |
| 03:00 | 21.5 | 62% | 23.9 | 41.90% | 21.5 | 74% | 20.8 | 74% | 21.9 | 64% | 21.4 | 69% |
| 04:00 | 21.1 | 65% | 23 | 49.40% | 21.2 | 74% | 20.5 | 72% | 21.7 | 65% | 20.8 | 73% |
| 05:00 | 20.9 | 64% | 22.7 | 51.10% | 20.8 | 76% | 20.5 | 74% | 21.1 | 70% | 20.3 | 75% |

| Time | Lalbagh | Basweshwar | Bellandur | Electronic City | Marathahalli | Whitefield |
|---|---|---|---|---|---|---|
| | GT | GT | GT | GT | GT | GT |
| 06:00 | 21.0 | 23.4 | 21.7 | 20.8 | 21.9 | 20.2 |
| 07:00 | 21.3 | 27.1 | 22.5 | 22.2 | 22.0 | 21.1 |
| 08:00 | 23.8 | 28.6 | 25.3 | 24.0 | 23.2 | 23.3 |
| 09:00 | 25.4 | 30.9 | 28.0 | 27.1 | 25.1 | 26.4 |
| 10:00 | 27.5 | 32.9 | 31.0 | 29.5 | 28.0 | 30.7 |
| 11:00 | 30.2 | 33.1 | 32.0 | 30.9 | 30.8 | 32.4 |
| 12:00 | 31.2 | 34.8 | 32.3 | 32.0 | 32.3 | 33.3 |
| 13:00 | 31.9 | 35 | 32.2 | 33.2 | 31.9 | 34.1 |
| 14:00 | 32.6 | 35.1 | 32.2 | 33.2 | 31.8 | 35.1 |
| 15:00 | 32.0 | 34.2 | 31.6 | 33.2 | 31.9 | 34.8 |
| 16:00 | 31.5 | 33.9 | 30.7 | 32.8 | 31.5 | 34.4 |
| 17:00 | 31.0 | 33 | 29.6 | 31.1 | 30.7 | 32.1 |
| 18:00 | 29.8 | 31.4 | 28.3 | 29.2 | 29.6 | 29.6 |
| 19:00 | 28.5 | 30.1 | 27.2 | 27.7 | 28.4 | 28.2 |
| 20:00 | 27.2 | 29.4 | 26.3 | 26.3 | 27.4 | 27.0 |
| 21:00 | 26.0 | 28.2 | 25.3 | 25.3 | 26.6 | 25.8 |
| 22:00 | 25.0 | 27.1 | 24.7 | 24.4 | 25.8 | 24.8 |
| 23:00 | 24.2 | 26.6 | 24.2 | 23.5 | 24.9 | 24.0 |
| 00:00 | 23.5 | 26 | 23.5 | 22.9 | 24.4 | 23.1 |
| 01:00 | 22.7 | 25.2 | 23.0 | 22.1 | 23.7 | 22.4 |
| 02:00 | 22.1 | 24.4 | 22.5 | 21.4 | 23.3 | 21.7 |
| 03:00 | 21.6 | 24.1 | 22.0 | 21.0 | 22.6 | 21.3 |
| 04:00 | 21.1 | 23.3 | 21.7 | 20.6 | 22.5 | 20.7 |
| 05:00 | 20.9 | 22.9 | 21.3 | 20.7 | 21.8 | 20.3 |

## Monitoring III

| Jayanagar 1st block | | | | Koramangala | | | HSR | | |
|---|---|---|---|---|---|---|---|---|---|
| | AT | GT | RH | AT | GT | RH | AT | GT | RH |
| 06:00:00 | 22.0 | 22.5 | 84.00 | 21.32 | 21.78 | 91.6 | 22.0 | 22.5 | 87.6 |
| 07:00:00 | 22.8 | 23.4 | 81.00 | 22.06 | 22.54 | 88.8 | 23.0 | 23.4 | 83.6 |
| 08:00:00 | 24.0 | 24.7 | 75.00 | 23.04 | 23.44 | 83.8 | 24.5 | 24.9 | 77.8 |
| 09:00:00 | 25.4 | 26.1 | 70.00 | 24.44 | 24.84 | 77.2 | 25.6 | 26.0 | 72.0 |
| 10:00:00 | 26.1 | 26.8 | 67.00 | 25.54 | 26 | 72.2 | 26.6 | 27.1 | 68.2 |
| 11:00:00 | 26.9 | 27.6 | 63.00 | 26.46 | 26.92 | 69.6 | 27.1 | 27.6 | 66.4 |
| 12:00:00 | 28.3 | 29.2 | 58.00 | 27.4 | 28.02 | 64.2 | 28.2 | 28.8 | 62.0 |
| 13:00:00 | 29.0 | 29.8 | 56.00 | 28.38 | 29.08 | 61 | 29.0 | 29.7 | 59.0 |
| 14:00:00 | 29.4 | 30.2 | 54.00 | 29.06 | 29.74 | 58 | 29.5 | 30.2 | 57.6 |
| 15:00:00 | 29.7 | 30.4 | 53.00 | 29.06 | 29.74 | 57.2 | 29.9 | 30.6 | 55.6 |
| 16:00:00 | 28.9 | 29.4 | 55.00 | 29.24 | 29.92 | 56.8 | 29.6 | 30.3 | 57.0 |
| 17:00:00 | 28.6 | 29.0 | 56.00 | 28.7 | 29.64 | 59 | 29.0 | 30.0 | 59.6 |
| 18:00:00 | 27.9 | 28.4 | 58.00 | 27.66 | 28.46 | 63.4 | 27.8 | 28.6 | 65.4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 19:00:00 | 27.1 | 27.5 | 63.00 | 26.2 | 26.92 | 72.6 | 26.7 | 27.4 | 70.0 |
| 20:00:00 | 26.5 | 27.0 | 63.00 | 25.26 | 25.96 | 73.2 | 25.8 | 26.5 | 72.6 |
| 21:00:00 | 25.9 | 26.3 | 66.00 | 24.92 | 25.38 | 74 | 25.5 | 25.9 | 72.4 |
| 22:00:00 | 25.2 | 25.6 | 68.00 | 24.18 | 24.64 | 78 | 24.9 | 25.4 | 74.8 |
| 23:00:00 | 24.4 | 24.9 | 70.00 | 23.38 | 23.86 | 82.2 | 24.2 | 24.6 | 78.4 |
| 00:00:00 | 23.9 | 24.4 | 73.00 | 22.88 | 23.3 | 85 | 23.6 | 24.0 | 81.2 |
| 01:00:00 | 23.5 | 23.9 | 75.00 | 22.38 | 22.88 | 87.8 | 23.1 | 23.6 | 84.0 |
| 02:00:00 | 23.0 | 23.5 | 78.00 | 21.98 | 22.42 | 89.4 | 22.6 | 23.0 | 85.8 |
| 03:00:00 | 22.7 | 23.2 | 80.00 | 21.72 | 22.18 | 90.2 | 22.3 | 22.8 | 87.0 |
| 04:00:00 | 22.5 | 22.9 | 82.00 | 21.4 | 21.86 | 91.4 | 22.2 | 22.6 | 87.0 |
| 05:00:00 | 22.2 | 22.7 | 83.00 | 21.24 | 21.72 | 91.6 | 22.0 | 22.5 | 87.8 |

## The Energy and Research Institute (TERI)

### *Sustainable Building Science: Overview*

One of the prime areas of activity within the Energy Environment Technology division is adoption of efficient and environment-friendly technologies in new and existing buildings. The activities of this area focus primarily on energy and resource use optimization in existing buildings and design of energy efficient sustainable habitats.

The Centre for Research on Sustainable Building Science (CRSBS) comprising architects , planners, engineers , environmental specialists , specialised in urban and rural planning, low energy architecture and electro-mechanical systems, water and waste management and renewable energy systems has been offering environmental design solutions for habitat and buildings of various complexities and functions for nearly two decades. The group also undertakes LEED facilitation for buildings.

The Green Rating for Integrated Habitat Assessment (GRIHA) cell, also comprising professionals from the above-mentioned fields is actively involved in facilitation of green rating for buildings under the GRIHA framework. Inputs from CRSBS feed into the processes undertaken at GRIHA cell. The different services offered by the Sustainable Building Science (CRSBS and GRIHA) are as follows:

### Environmental design consultancy

- Specialised environmental design consultancy and building performance analysis are conducted. A wide range of computations and simulation tools including DOE2, TRNSYS, ECOTECT, RADIANCE, FLOVENT, AGI32, LUMEN DESIGNER, BLAST, Phoenics, RETScreen are used to assess the environmental and cost impact of the design decisions.

### LEED and GRIHA facilitation

- The team has experience in technically facilitating LEED accreditation [LEED India for New Construction (LEED India NC) and LEED India for Core and Shell (LEED India CS)] for buildings. The group also assists and administers GRIHA, an indigenous green building rating system for buildings, developed at TERI. GRIHA has now been now endorsed by the Ministry of New and Renewable Energy, Government of India, as the national building rating system for India.

### Energy audits and energy management programs

- Energy conservation studies for a large number of buildings are conducted. There exists a vast experience in conducting energy audits and evaluating a whole range of building upgrade options including envelope retrofit and system retrofit or changes in operational patterns. In addition to establishing operating efficiency of electrical, HVAC, lighting and thermal systems, recommendations to improve upon the same by suitable retrofit measures or by refinement of operational practices are also offered. The group also has expertise in development of energy management programs for service industries like hotels and the corporate sector.

### Capacity building

- Capacity building for architects, building developers and service engineers on issues such as energy efficiency in building envelopes and systems has been undertaken. Over 1000 architects, developers and engineers in the area of green buildings, energy efficiency and sustainability aspects of built environment have been trained through training programmes, refresher courses, seminars and workshops.

### Policy inputs

- Several policy initiatives at central and state governments' level towards mainstreaming high performance buildings in India have been successfully completed. Senior members of the group are members of the Committee of experts for development of the Energy Conservation Building Code (ECBC) of India (2007). The manual for environmental clearance of large construction for the Ministry of Environment and Forests, Government of India has also been developed at CRSBS.

### Climate Change related projects

- Climate change is increasingly being recognized as a major global challenge. The group has provided inputs to the National Mission on Sustainable Habitat (a part of the recently released India's National Action Plan on Climate Change). Project Design Documents (PDD) are prepared in order to facilitate trading in carbon through the Clean Development Mechanism (CDM).

The Energy and Resources Institute

www. teriin.org