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# Analysis of urban heat island in Kochi, India, using a modified local climate zone classification

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**Abstract**

Urban Heat Island (UHI), a measure of the near surface air temperature contrast between urbanised and adjoining rural areas, is the most pronounced effect of urbanisation. The definition of 'urban' varies in different contexts, which makes it difficult for direct comparison between cities in different regions. Local climate zone (LCZ) classification based method was adopted in Kochi in Southern India to study its UHI. Twelve mobile surveys were carried out from January 2011 to March 2013 to quantify UHI intensity. Pre-dawn UHI there was more intense than early night UHI, and its intensity in winter was stronger than in summer. UHI observed during winter were 4.6 $^{o}$C and 3.7 $^{o}$C in pre- dawn and early night respectively. The study area was classified into ten different local climate zones based on the standard zone properties. Thermal gradient between different zones and cooling rates observed in these zones were computed, which validates the LCZ classification. Maximum intensity was seen in Compact Midrise zones which cover the central part of the city. Most intense cooling was observed in openset and sparsely built regions in all seasons. Standard zone properties alone were inadequate to explain variation of UHI intensity of same classes with different surface area and diverse adjacent zones. Two more zone properties, radial distance to adjacent zone called Zone Boundary Distance, and the Nearest Adjacent Zone, are proposed here to overcome this. The use of these additional parameters gives a better understanding of the intra zone variation of UHI intensity of the same classes with different coverage area and diverse adjacent zones.


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## 1. Introduction

Urban heat islands (UHI) are characterized by "islands" of warm surface air centered on urbanized landscapes and surrounded by progressively cooler air over suburban/rural areas. Urban Heat Island (UHI), a measure of the near surface air temperature contrast between urbanised and adjoining rural areas, is the most pronounced effect of urbanisation. The heat island is an example of unintentional climate modification when urbanization changes the characteristics of the Earth's surface. The nature of the surface is a strong influence on the spatial patterns of surface and air temperature in the city. The microscale heat island intensity can be measured within the urban canopy layer, which refers to the space below the level of the rooftops of buildings [1]. The urban heat island is a result of extensive paved surfaces and the lack of vegetation and surface moisture, a polluted atmosphere, the canyon effects of buildings, and the artificial heating of buildings in the urban areas [2]. The effect of substitution of natural vegetation with construction materials such as those used in buildings and roads which are largely impermeable and which have different thermal properties, are very complex [3]. Buildings also alter the reception of solar radiation casting shadows, and change surface roughness and local wind field. Most of the materials used in the construction provide a low albedo surface, resulting in increased absorption of solar radiation in the day time. The nature of the surface, vegetative fraction, building/ tree height, soil moisture and anthropogenic heat flux etc., have a strong influence on the spatial pattern of surface and air temperature in the city.

The definition of 'urban' varies in different contexts, which makes it difficult for direct comparison between cities in different regions. This discrepancy in the urban definition creates barriers in urban studies, especially in UHI studies, since the definition alone cannot sufficiently describe the site topography and local environment. Local climate zone classification based measurement is a more effective method to quantify the UHI intensity rather than one based on Urban –Rural classification. UHI intensity is computed as the temperature difference between local climate zone classes [4, 5]. This approach gives a better quantification to the UHI intensity interpretation since it reduces the risk in un-quantified comparison between urban and rural temperature [6,7].The present study attempts to give a better understanding of the urban heat island effect in the city of Kochi based on the modified thermal climate zone classification. In this context Local Climate Zone classification is adopted here for thermal differentiation of the Kochi city and adjacent areas. The present study attempts to give a better understanding of the urban heat island effect in the city of Kochi based on the modified thermal climate zone classification.

## 2. Materials and methods

### 2.1 Study site

Kochi is one of the fast growing urban centre located on the southwest coast of India, between $09^0$ 45' N and $10^0$ 20' N latitude and between $76^0$ 10' E and $76^0$ 35' E longitude, has a coastline stretching up to a length of about 48 kilometres. It hosts a number of industries, and a population of 2.2 million [8].The city is interlaced by estuaries fed by perennial rivers. Much of Kochi lies at sea level. Kochi features a tropical monsoon climate. Its proximity to the equator along with its coastal location results in little seasonal temperature variation, with moderate to high levels of humidity. Air temperatures range between 20 – 35 °C (68–95 °F). The highest temperature recorded in Kochi is 38 °C and the lowest is 17 °C. The average annual rainfall is about 3500 mm with an average 132 rainy days annually; the bulk of the rainfall is from the South-West monsoon. The winds are moderate, with slight increase during summer and the monsoon seasons. A sketch map of the study area is shown in the Fig.1.

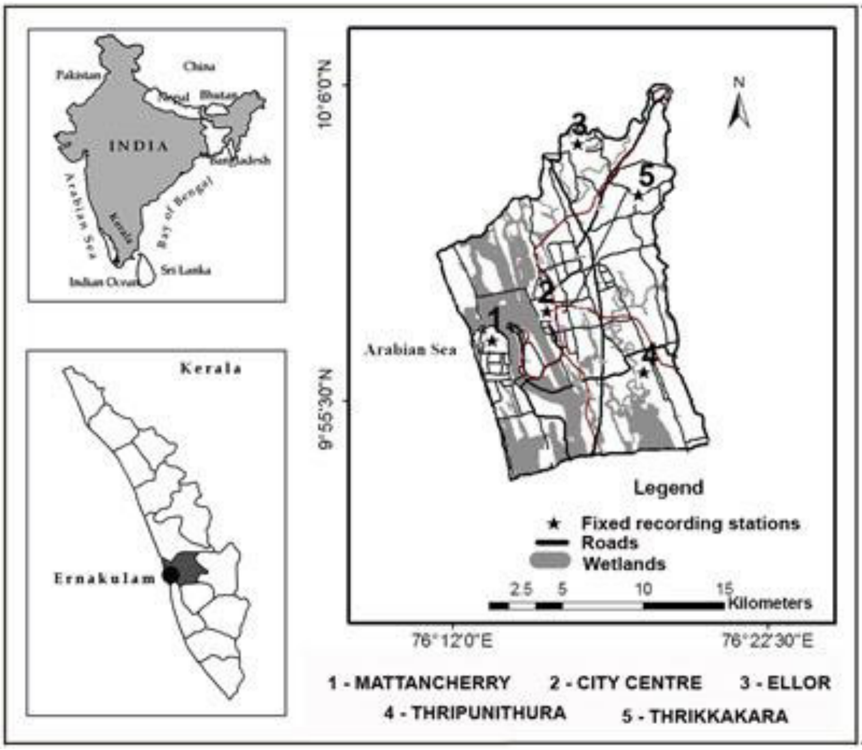


Fig.1. Sketch map of the study area and wider surroundings.

### *2.2. Local climate zone (LCZ) classification*

The study area was classified on the basis of standard zone properties defined in the local climate zone classification system [5]. On site measurements were carried out to record urban parameters which best match with each climate zone. A 100 x 100 m grid measurement regime was carried out within a 2 Km radii around five fixed stations. Then 500 x 500 m grid measurements were carried out at all other locations in the study area. The source area of each field site was parameterized by the differentiating properties of the LCZ classes. Zone properties like Sky view factor (*Proportion of sky hemisphere visible from ground level)*, Canyon or building aspect ratio (*Mean height-to-width ratio of street canyons or building spacing)*, Building surface fraction (*Proportion of zone plan surface covered by buildings)*, Impervious surface fraction (*Proportion of zone plan surface covered by impervious materials*), Pervious surface fraction (*Proportion of zone plan surface covered by pervious materials*), Mean building height (*Geometric average of building heights*) were measured. Zone properties like Canyon or building aspect ratio, building surface fraction, mean building height were manually measured with handheld Electronic Distance Meter and GPS. Sky view factor was derived from height and width of buildings, street width etc. Impervious and pervious surface fraction was computed from physical measurements and google images. On the basis of measurements and with the help of google images, the study area was classified into different thermal or local climate zones.

### *2.3. Mobile traverse to quantify UHI intensity*

Fourteen mobile surveys were carried out during winter and summer from November 2007 to March 2013 to quantify UHI intensity. Measurements were carried out from 07:30 pm to 10:30 pm in evening and from 04:00 am to 06: 00 am before sunrise in pre-dawn during both seasons. Observational points were so chosen as to ensure adequate representation of all local climate zone classifications.

Air temperature was recorded with high resolution RTD probe (MadgTech USA, Model :RTDTemp 101). Automatic temperature recorders with 0.01 K resolution and 0.1 K accuracy were used for reading air temperature. The Temperature recorders were supplied with traceable calibration by the manufacturer. We had further subjected them to inter-calibration / inter-comparison and verified to be within specified limits (± 0.1 K). Relative humidity was recorded with automatic RH-Temperature data logger (MadgTech USA, Model : Temp Retreiver RH). RH was measured with accuracy of ± 3.0% RH and resolution of 0.1%. The RH- Temperature recorder and RTD probe were installed in a radiation screen mounted on a vehicle and kept at adequate distance from engine in order to avoid engine heat. The vehicle was stopped for 1 minute at each observational point along the route to eliminate the error in measurements of RTD probe before reaching the steady state. Temperature and RH were automatically logged along with time stamp at 5 second interval. The coordinates were taken from a hand held GPS and time of observation was noted with a chronometer synchronized with the temperature recorder and GPS, at each point of observation. Observational points were so chosen as to ensure adequate representation of all local climate zone classifications. The reference temperature was taken from a temperature recorder installed at a sparsely built region in the study area. The instantaneous temperature difference between all observational points and the reference site was calculated in order to determine UHI intensity. The average cooling rates at the different locations where fixed temperature recorders were installed were also computed for different periods of the day. The instantaneous temperature difference between all observational points and the reference site was calculated in order to determine UHI intensity.

### *2.4. Fixed Recording Stations*

Fixed recording stations were setup in different Local Climate zones in the study area. The observation point were chosen for representative data from different LCZ of varying levels of urbanisation, land cover, coverage areas, etc., as well as the rural areas [9]. The humidity and temperature recorders were set at a recording interval of 15 minutes. The equipment used in the fixed recording stations and those used for the mobile traverses were of same model and specifications. These were obtained with manufacturer's certification and were further subjected to inter-calibration / inter-comparison exercise and verified to be within specified limits. The average cooling / warming rates at the different locations where fixed temperature recorders were installed were computed for different periods of the day. Recording stations were set up at two Compact Low- rise (CLR), one Heavy Industry (HI), one Open Low- rise (OLR) and one Sparsely Built (SB) zones. The details of the fixed recording stations are given below.

**Mattancherry (CLR 1)** is a typical CLR region which covers an area of 3 $km^2$ of uniform surface and building characteristics. The location is the old city region which includes market place, ware houses, etc., many of which are older than a century. Fixed station was installed at 76:14:59.2 E & 09:57: 59.2N. Mattacherry has overcrowded 1 – 3 storied building with narrow streets. **Ernakulam City Centre (CLR 2)** falls under Compact Mid - rise and Compact Low- rise classes. Fixed station comes under a CLR region at 76: 16: 49.9 E & 09:58: 36.5 N. This station represents dense urban center, with low buildings with uniform surface pattern covers an area of 0.62 $km^2$. This location classified as CLR2 is surrounded by CMR and OMR classes which makes it different from CLR 1. **Eloor (HI)** is a high energy industrial area and the largest industrial belt in the region covering an area of 11 $km^2$. This place is a hub of about 250 chemical industries. The recording station is set up at the southern part of the industrial area. This fixed station installed at 76: 18: 07.6 E & 10: 04: 47.6N represents Heavy industry in LCZ classification. **Thripunithura**

**(OLR)** station is set up in Open Lowrise zone at 76:21: 28.8 E & 09:55: 33.6N. Small 1- 3 storied detached buildings with scattered trees and abundant plant cover are common in this area. This also represents a suburban region in the study area. **Thrikkakara (SB)** recording station is in a Sparsely Built Zone in the north eastern part of the study area at 76:20:23 E & 10:02:46 N. This location is taken as a rural area suitable for setting up reference station. This class has very high natural surface fraction. Impervious surface fraction is negligibly small in this class.

## 2.5 Local Climate Zones classification

Local climate zones (LCZ) are defined as regions of uniform surface-air temperature distribution at horizontal scales of $10^2$ to $10^4$ metres[4, 6]. The classification is mainly based on proportion of sky hemisphere visible from the ground, building mean height, street width, vegetative fraction, anthropogenic heat flux etc. Each region is identified as a particular class only if the surrounding circle of influence is uniform in surface cover, geometry and human activity. The urban and suburban areas are classified in to 10 different climate zones based on the zone properties defined by Stewart and Oke [5]. Measured zone properties of different climate zones in the study area is shown in the Table 1.

Table 1. Standard and observed zone properties of different Local Climate zones

| Zone Properties | Mean Building Height | Canon or Building Aspect Ratio (H/W) | Building Surface Fraction | Impervious Surface Fraction | Pervious Surface Fraction | Sky View Factor | Height of roughness element |
|---|---|---|---|---|---|---|---|
| Compact High - rise (CHR) | > 25 m | > 2 | 40 - 60 % | Class is minor in the study area | | | >25 |
| Compact Midrise (CMR) | 9 -24 m | 0.8 - 2.5 | 40 - 70 % | 30 -50 % | < 20 % | 0.35 - 0.71 | 9 - 24 |
| Compact Low - rise (CLR) | 3- 9 m | 0.6 - 1.9 | 40 - 60 % | 20 - 40% | < 35 % | 0.3 - 0.7 | 3 - 9 |
| Open High - rise (OHR) | 40 -60 m | - | 20 - 40 % | 30 - 40 % | 30 - 40 % | 0.5 - 0.7 | > 25 |
| Open Midrise (OMR) | 10 - 25 m | - | 20 - 35 % | Class is minor in the study area | | | 10 - 25 |
| Open Low - rise (OLR) | 3- 8 m | 0.5 - 0.7 | 20 -50 % | 20 -30 % | 30 - 60 % | 0.7 - 0.8 | 3- 8 |
| Large Low rise (LLR) | 3 -6 m | 0.2 -0.3 | 30 -50 % | - | <25 % | > 0.8 | 3- 6 |
| Light Weight Low - rise (LWLR) | 2 -4 M | Class is minor in the study area | | | - | 0.2 -0.5 | 2 - 4 |
| Heavy Industry (HI) | 6 -10 m | 0.3- 0.5 | 30 - 40 % | 20 - 40 % | < 35 % | 0.5 - 0.8 | 6- 10 |
| Sparsely Build (SB) | 3 - 8 m | 0.1-0.25 | <20 % | <15 % | 60 - 80 % | > 0.8 | 3- 8 |
| Water /Wetlands | - | < 0.1 | < 10% | < 10 % | >90% | > 0.9 | - |

Stewart and Oke [5] classifies the urban –rural build up into a hierarchy of 10 climate zones, namely Compact High – rise (CHR), Compact Midrise (CMR), Compact Low – rise (CLR), Open High – rise (OHR), Open Midrise (OMR), Open Low – rise (OLR), Large Low – rise (LLR), Lightweight Low – rise (LWLR), Heavy Industy (HI), Sparsely Built (SB) and land cover types to dense trees, scattered trees bush, scrub, low plants, bare rock and paved, bare soil and sand etc[5]. The sketch map of Local climate zone classification of the study area is shown in the Fig.2.

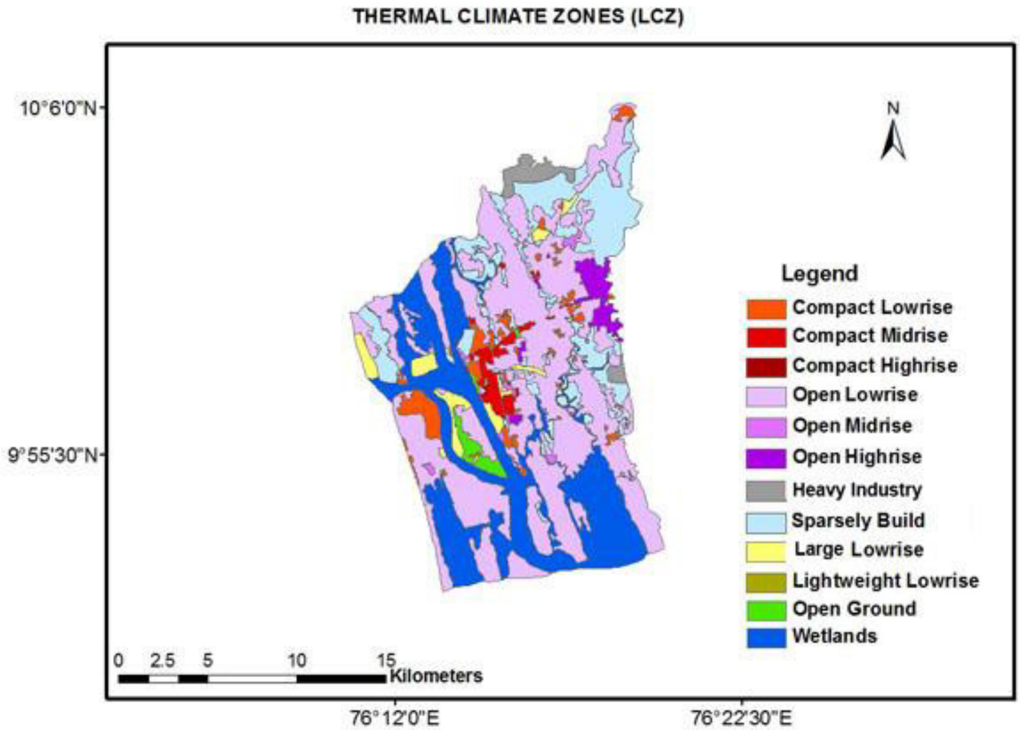


Fig.2.The sketch map of Local climate zone classification of the study area.

## 3. Results and discussion

The Urban Heat Island intensity at Kochi was moderate to high during both winter and summer seasons and is seen to relate well with urbanisation. Highest observed urban heat island intensity in Kochi was 4.6$^{o}$C during winter morning. Maximum observed UHI intensity during summer morning was 3.7$^{o}$C . The spatial distribution of early night and pre-dawn UHI intensity for winter and summer seasons are shown in the Fig.3.

Pre-dawn UHI was more intense than early night UHI, and its intensity in winter was stronger than in summer. Summer season in the region precedes the monsoon rainfall and the sky is partly overcast and humidity is generally high. Occasional pre-monsoon showers raising the humidity are also experienced. This could lead to a weak urban heat island in summer. Higher humidity results in high specific heat capacity of air which in turn increases the heat removing capacity of air. This can also lead to faster cooling and lower UHI intensity. High cooling rates at the rural environment or SB regions reduce the air temperature to a lower level than in city centre. So as night advances the temperature difference between urban and rural environment become more prominent. The overnight temperature variation between the fixed reference station (SB) and two compact zones (CLR 1, CLR 2) during both seasons are shown in the Fig.4.

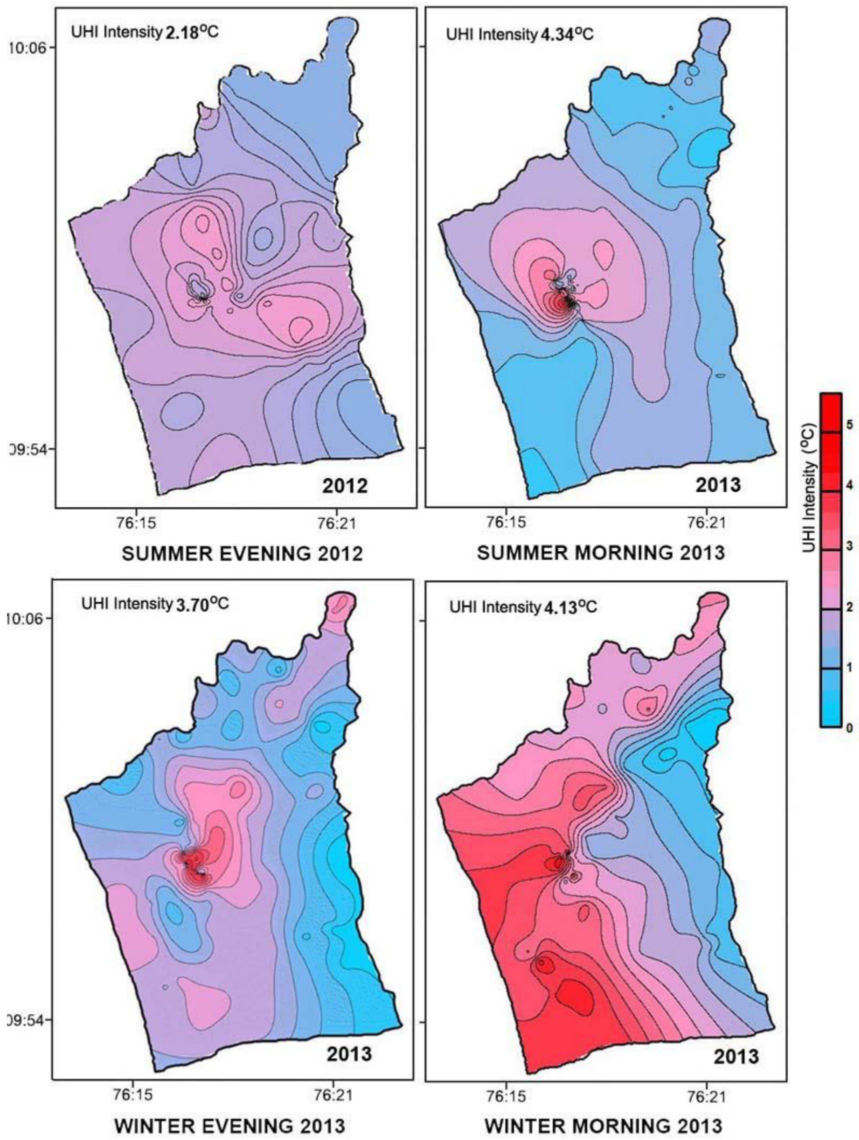


Fig.3.The spatial distribution of UHI intensity for winter and summer seasons.

Thermal gradient between different zones and cooling rates observed in these zones were computed, which validates the LCZ classification. Maximum intensity was seen in Compact Midrise zones which cover the central part of the city. Most intense cooling was observed in open-set and sparsely built regions in all seasons. Zones with higher degree of buildings and impervious materials show a large variation from the sparsely built zone. Temperature difference among zones of lesser thermal separation, like compact midrise and compact lowrise appears to have lesser variation during winter and summer seasons. However, zones with larger separation, like CMR and SB or LWLR show higher degree of variation in temperature. Similar results were reported at Uppsala in Sweden, Nagano in Japan, and Vancouver in Canada [10].

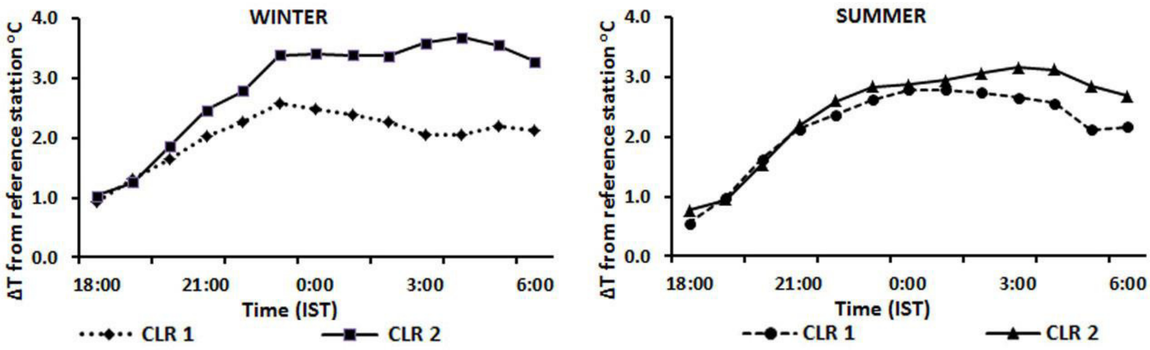


Fig.4. Overnight temperature variation between fixed reference station (SB) and two compact lowrise zones (CLR 1, CLR 2).

The cooling rate also shows significant variation in different LCZ classes. The markedly different thermal properties of the surfaces makes the rates of cooling of urban and rural environs differ widely and growth of the heat island intensity varies with time of the night [11]. The most intense cooling was observed around sunset in Openset and SB regions during both seasons. The average seasonal cooling rate at different fixed stations in the study area after sunset during 2011 is shown in the Fig.5. The most intense cooling was observed around sunset in Openset and SB regions during both seasons. Mattancherry (CLR1) and City centre (CLR2) had the lowest cooling rates irrespective of seasonal variation. In winter, maximum cooling was observed in OLR and SB with 0.74 $^{o}$C/hour and 0.67$^{o}$C/hour respectively. Cooling rates at HI, CLR1 and CLR2 were 0.34 $^{o}$C/hour, 0.44$^{o}$C/hour and 0.55$^{o}$C/hour respectively during the same period. Cooling rates in summer had its maximum value in OLR and SB with a value of 0.71$^{o}$C/hour and 0.83$^{o}$C/hour. Cooling rates observed were 0.62$^{o}$C/hour, 0.59$^{o}$C/hour and 0.48$^{o}$C/hour in HI, CLR 1 and CLR 2 respectively. As night advances cooling rates at all sites reduce, due to the fall in the temperature values, and tend to become uniform. Since the open sites have cooled faster during the earlier part of the night, the temperature difference between the sites increase and attains a maximum value at pre-dawn. This leads to a more intense pre-dawn UHI compared to the evening UHI. However, during dry winter months of 2008, most intense cooling of the order of 1.6K/h was also reported in a different rural location which falls under sparsely built zone in the present study area. It is also reported that the cooling rate at the urban centre is significantly lower than the rural area [12].

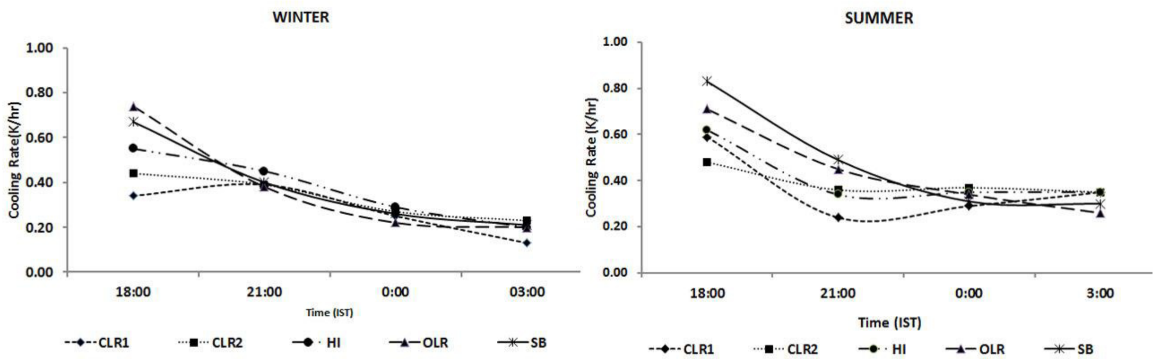


Fig.5. The average seasonal cooling rates at different fixed stations in the study area.

Table.2 The average UHI intensity of major zones in the study area with different adjacent zones

| NEAREST ADJACENT ZONE | AVERAGE UHI INTENSITY (°C) OF MAJOR ZONES IN THE STUDY AREA | | | |
|---|---|---|---|---|
| | **CMR** | **CLR** | **OLR** | **SB** |
| CMR | - | 3.55 | 1.99 | 2.26 |
| CLR | 3.48 | - | 2.24 | 1.72 |
| OLR | 3.01 | 2.47 | - | 0.94 |
| SB | 2.38 | 2.54 | 1.73 | - |
| GROUND | 3.01 | 2.39 | - | - |
| LLR | 2.80 | - | - | - |
| **AVERAGE** | **3.13** | **2.71** | **1.92** | **0.96** |

Standard zone properties alone were inadequate to explain variation of UHI intensity of same classes with different surface area and diverse adjacent zones. The temperature measurements for 12 mobile surveys were standardised for comparison. It is found that average UHI intensity for CMR zone in the entire study period is 3.13°C. However the average UHI intensity of this zone is reduced to 2.38 °C, while considering only the sampling points near LLR zone. UHI intensity of this zone shows a higher value of 3.48 °C, when the adjacent zone to the sampling points was CLR. This variation is observed in all classes when considering different adjacent zones. The average UHI intensity of major zones in the study area with different adjacent zones are given in the Table.2. It is observed that UHI intensity of each zone is highly influenced by type of adjacent zones.

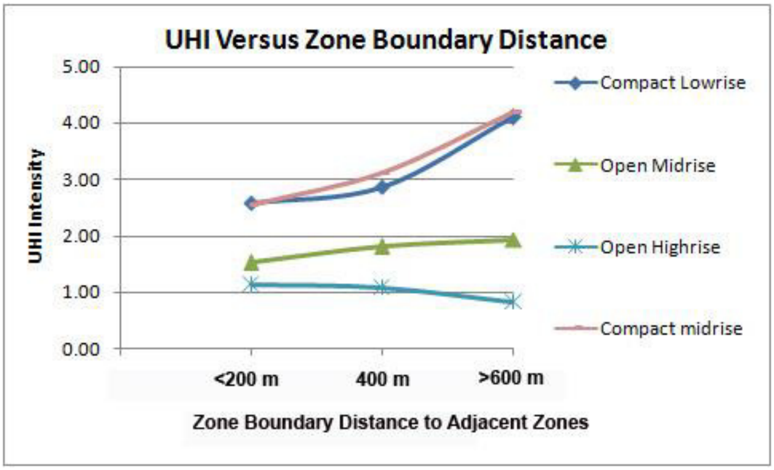


Fig.6. Variation of UHI Intensity with zone boundary distance for different Zones.

It is observed that as the radial distance to adjacent zones or area of the zones increases, the effect of the zone become more pronounced. In other words as the area of the zone under consideration increases the effect of that zone to the UHI intensity also dominates. Table 3 shows the variation of average intensity of different zones in the study area with radial distance to the adjacent zone. UHI intensity of CMR region increases as the radial distance to the adjacent zone increases, ie as area of the zone increases the UHI intensity become more prominent. On the other hand UHI intensity of zones with large pervious surface decreases as the area increases. It is clearly observed from

Table.3 that the UHI intensity decreases from 1.56 °C to 0.62 °C as the area of the SB zone increases.

Table.6 Variation of UHI Intensity with zone boundary distance for different Zones

| ZONE BOUNDARY DISTANCE | AVERAGE UHI INTENSITY (°C) OF MAJOR ZONES IN THE STUDY AREA | | | |
|---|---|---|---|---|
| | CMR | CLR | OLR | SB |
| BELOW 200 m | 2.54 | 2.58 | 1.52 | 1.56 |
| 400 m | 3.12 | 2.87 | 1.80 | 1.08 |
| ABOVE 600 m | 4.18 | 4.10 | 1.92 | 0.62 |

Two more zone properties, radial distance to adjacent zone called Zone Boundary Distance, and the Nearest Adjacent Zone, are proposed here to overcome this discrepancy in the UHI intensity measurements. The use of these additional parameters gives a better understanding of the variation of UHI intensity of the same classes with different surface areas and diverse adjacent zones. Zone boundary distance gives an idea about the area of the zone under consideration. Nearest adjacent zone represent the influence of adjacent zones to the UHI intensity. Hence Zone Boundary Distance represents the influence of each zone and Nearest Adjacent Zone tells the control of adjacent zone on the UHI intensity.

## 4. Conclusions

The Urban heat Island intensity and spatial temperature distribution during summer and winter season observed in Kochi, a coastal city in South West India shows a good correlation with the Local Climate Zone Classification. Maximum intensity was seen in Compact Midrise zones which cover the central part of the city. Most intense cooling was observed in openset and sparsely built regions in all seasons. Standard zone properties alone were inadequate to explain variation of UHI intensity of same classes with different surface area and diverse adjacent zones. Two more zone properties, radial distance to adjacent zone called Zone Boundary Distance, and the Nearest Adjacent Zone, are proposed here to overcome this. The use of these additional parameters gives a better understanding of the variation of UHI intensity of same classes with different coverage area and diverse adjacent zones.

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