Indian Journal of Science and Technology, Vol 9(5), DOI: 10.17485/ijst/2016/v9i5/87201, February 2016
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Urbanization and its impact on Urban Heat Island Intensity in Chennai Metropolitan Area, India

Lilly Rose Amirtham*

Sathyabama University, Chennai – 600119, Tamil Nadu, India; lillyini@gmail.com

Abstract

Background: Urbanization results in the formation of heat pockets termed as "Urban Heat Island" (UHI) and their intensities depend on urban built geometry. This study attempts to assess the impact of urbanization on urban heat island intensity in Chennai Metropolitan Area (CMA). **Methods/Analysis:** Air temperature and relative humidity were measured at one hour interval at 30 fixed locations covering urban, suburban and rural locations in and around CMA. HOBO data logger (HOBO U10 Temp/RH), enclosed within a white perforated plastic box to shield the instrument from direct solar radiation were deployed for the study. UHI intensity was computed based on the reference data from Numgambakkam Meteorological station. Day time and night time temperature isopleths of CMA were derived using ArcGIS, including the isopleths at maximum and minimum temperature occurrences at 14.00 hrs and 06.00 hrs respectively. The temperature isopleths at 10:00 hrs, 14:00 hrs and 18:00 hrs were analyzed for daytime intensity of UHI and their temperature distribution pattern. **Findings:** Maximum daytime temperatures were recorded between 11:00 hrs and 15:00 hrs which varied between locations based on urban morphology and the time at which the measurement location is exposed to incident solar radiation. The daytime temperature isopleths at 14.00 hrs revealed the existence of a cool island in the urban core of CMA with a temperature difference of 10.4ºC in summer and 3.7ºC in winter. The night time UHI in the CMA was analysed with the temperature isopleths of 22:00 hrs, 02:00hrs and 06:00hrs. The night time temperature isopleths reveal the significant existence of positive UHI in the CMA. The isotherms at 06.00 hrs revealed a significant positive UHI ranging from 3.6ºC in summer to 4.1ºC in winter. The results of the study indicate a maximum nocturnal UHI during the calm, clear, winter periods in the CMA. The urban rural differences also revealed a significant cool island during the day with the maximum cool island intensity during summer. **Applications/Improvements:** A significant correlation between urban-rural differences and density of urban built form was established; indicating the significance of building regulations that define urban built geometry, in designing comfortable urban environments.

Keywords: Built Geometry, Cool Islands, Chennai, Urbanization, Urban Heat Island Intensity

1. Introduction

Urban areas experience a distinct climate due to the transformation of natural ground cover into hard impervious land parcels. When compared to rural surroundings, urban activities associated with increased anthropogenic emission, increases air temperatures significantly. The urban areas experience higher temperature than the rural areas as the built fabric stores the absorbed incident solar radiation and anthropogenic heat released from vehicles and equipments[1], resulting in the formation of heat pockets that are termed as "Urban Heat Island" (UHI)[2]. And the intensity of heat island is determined by the temperature difference between urban and rural areas. The intensity of heat islands depends on the density, population and size of a city[3] and the morphology of cities[4]. The urban heat island measured through the differences in ambient air temperature at the canyon layer (between buildings at street level) is termed as the Canyon Layer Urban Heat Island. Urban geometry and capacity of urban fabric to absorb heat determines the intensity of UHI predominantly[5].

*Author for correspondence

Oke found that the maximum UHI occurs during the night, under calm and clear nights[4]. Studies found that small green areas, trees and urban parks reduced the ambient air temperatures significantly[6,7]. A study at Szeged, Hungary, established a strong relationship between increased air temperatures and urban land use and built density, indicating an increasing trend of isotherms from suburbs to city core with distinct seasonal variation in UHI intensity[8,9]. Also, envelope ratio determined by built geometry, vegetation and open verandahs greatly contributes to thermal variation[10].

The earliest UHI study in tropical cities was conducted by Nieuwolt in Singapore[11]. Air temperature and relative humidity measurements from nine urban and suburban locations were compared with the data from the airport region representing rural characteristics. The study found that the city was 3.51ºC warmer than the airport area. Subsequent UHI study in Singapore found the severity of UHI with 4.01ºC intensity during night time with higher temperatures at Central Business District area[12]. Also the night time UHI study at Singapore found that the commercial and business areas experienced higher ambient temperatures than industrial and airport areas[13].

Urban heat island studies were also studied in some Indian cities. The UHI study in Delhi revealed the existence of UHI ranging from 5°C to 7°C from December to March[14]. UHI study in Mumbai revealed that the urbanization contributes significantly to the formation of heat islands when compared to the coastal influence[15]. The UHI study in Bangalore identified the reduction in diurnal temperatures especially in the city core during winter months[16]. Intensity of UHI vaiedy from 2°C to 4°C based on the topography and urban morphology with the occurrence of higher intensities during winter months[17,18].

Jayanthi conducted the first UHI study in Chennai through vehicle traverse and found that 4°C of UHI exists during night time[19]. Also the urbanization effects of Chennai from 1991 to 2000 revealed an increase in heat pockets in the city that corresponds to the increase in urban built up[20]. Also urbanization resulted in an increasing discomfort in Chennai city[21]. Through literature it is evident that urban built fabric contributes to the intensity of UHI effect. Therefore, this study attempts to assess the impact of urbanization on intensity of urban heat island in Chennai Metropolitan Area (CMA).

2. Methodology

The Urban Heat Island (UHI) in the CMA is studied through temperature isopleths derived from in-situ field measurements. Air temperature and relative humidity were measured at one hour interval in 30 fixed locations in and around CMA using HOBO data logger (HOBO U10 Temp/ RH). The data loggers were enclosed within a white perforated plastic box, which in turn, was covered by a white painted PVC vent cap (115 mm diameter) in order to shield the instrument from direct solar radiation. The instruments were fixed on utility poles in the canyons at 2.0 m to 3 m height, in order to keep away from the pedestrian traffic and to avoid the risk of theft. The deviation in heights at some of the urban sites, as compared to the standard heights at the non-urban station (1.25 m–2 m), has been acceptable as observations in dense urban canyons show little variations in air temperatures[22]. Also, the instruments were placed at least 1m away from dense built surfaces to avoid reflectance of radiation from surrounding surfaces. Data from Nungambakkam meteorological station were used as reference weather data for the study. Figure 1 show the typical instrument setup used in the in-situ field measurements.

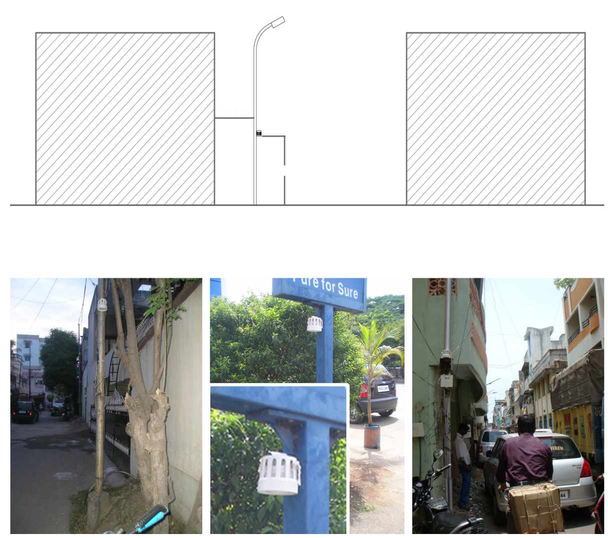

Figure 1. Typical instrument setup used in the in-situ measurements.

To investigate the spatial and temporal change in the temperatures of the CMA, 29 measurement stations within the CMA and one rural station (located at a distance of 57 km in the southwest of the city core) have been selected based on Oke's local climate zone classification[23]. The stations chosen were as far as possible homogenous in nature. Figure 2 shows the measurement locations and meteorological stations in the CMA and Table 1 shows the characteristics of the measurement sites in CMA. The in-situ field measurements were conducted from May 2008 to January 2009 to cover the various seasons typically experienced in the city of Chennai. The measurements from 4th to 29th May 2008 represent the hottest period; 20th July to 8th September 2008 represents the period between the hottest and the coldest, and 16th December 2008 to 31st January 2009 represents the coldest period. The climate data collected on the rainy days (unstable weather conditions) were not included in the analysis of the study.

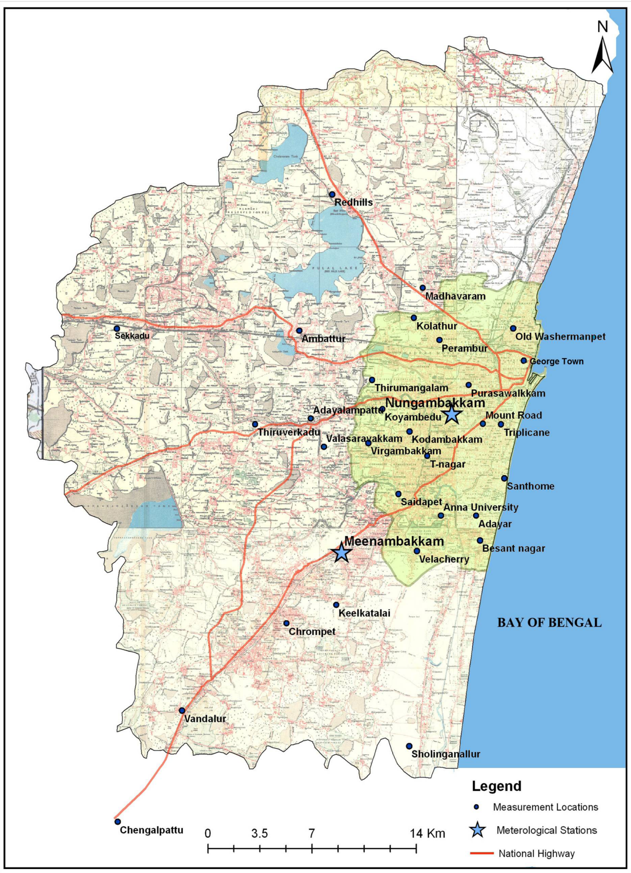

Figure 2. Location of the measurement site and the meteorological stations in the CMA.

3. Results and Discussions

The intensity of the Urban Heat Island (UHI) in the CMA is assessed with the day and night time temperature isopleths of Chennai Metropolitan Area (CMA) derived from the field measurements using ArcGIS. Figures 3 to 8 show the temperature isopleths of the six measurement periods at 02:00 hrs, 06:00 hrs, 10:00 hrs, 14:00 hrs, 18:00 hrs and 22:00 hrs, to cover the 24 hour duration of the day and includes the maximum and minimum temperature occurrences (14:00 hrs and 06:00 hrs).

4. Analysis of Daytime CLUHI Intensity

The air temperatures at the canyons between high rise buildings will be lesser than those of the surrounding low rise areas during daytime and acts as a "heat sink". Oke attributes the daytime heat sinks to shading and the thermal inertia of tall buildings[1]. The intensity of the heat island effect varies from day to day and with the time of the day, depending on the synoptic weather conditions[24,25]. The temperature isopleths at 10:00 hrs, 14:00 hrs and 18:00 hrs were analysed for the daytime intensity of the UHI and the temperature distribution of the CMA during daytime. The analysis of the daytime temperature isopleths reveal that the urban areas act as a heat sink. The maximum daytime temperatures were recorded between 11:00 hrs and 15:00 hrs and it varied between locations based on the urban morphology and the time at which the measurement location is exposed to incident solar radiation.

Therefore, the analysis of the temperature isopleths at 14:00 hrs (period of intense solar radiation) of the three measurement periods reveals the nature of the UHI intensity in the CMA.

4.1 Temperature Distribution of the CMA during Daytime

The warming up of the urban built up commences with the sunrise and the temperature distribution pattern of the city structure depends on the capacity of the materials to absorb and reradiate the solar radiation. The daytime temperature isopleths of the three measurement periods at 10:00hrs, 14:00hrs and 18:00hrs are shown in Figures 3 to 5. Table 2 shows the daytime intensity of UHI during the different measurement periods. The analysis of the daytime temperature isopleths of the three measurement periods reveals the following:

- During daytime, minimum temperatures were recorded in narrow streets with high density urban

Table 1. Characteristics of the measurement sites in the CMA

S. No	Urban Climate Zone*	Location	Description
1	2	Triplicane	Coastal traditional settlement in the east with high density and high traffic
2	2	George Town	A mixed residential area in the old city with very high density and very high traffic with no vegetation
3	2	Old Washermanpet	Old settlement with high density, medium traffic and no vegetation
4	2	Purasawakkam	A perfect mixture of commercial and residential hub with very high density and very high traffic
5	2	Mount Road	Central Business district with high density and very high traffic
6	3	Santhome	A fishing settlement close to the sea in the east with medium density and medium traffic
7	3	T. Nagar	A medium density residential area with few parks and very high traffic.
8	3	Kodambakkam	Residential zone with medium density, medium dense vegetation, high traffic
9	3	Koyambedu	A major hub of activity zone with one of Asia's largest perishable goods market complex and Asia's largest mofussil bus terminus accompanied by medium density and very high traffic.
10	3	Perambur	Suburb in North Chennai with medium density and medium traffic
11	3	Thiruman-galam	Primarily a residential neighbourhood with medium dense vegetation, medium density and heavy traffic
12	3	Virugambak-kam	One of the fastest growing residential neighbourhoods with medium density and medium traffic
13	3	Saidapet	Largely a residential area with medium density and medium traffic
14	3	Adayar	A residential neighbourhood in the south with medium density, dense vegetation and high traffic
15	3	Besant Nagar	Primarily residential neighbourhood adjoining the theosophical society and Kalakshetra academy with medium vegetation, medium density and medium traffic
16	3	Velachery	A fast developing residential area in south west Chennai with medium density and medium traffic.
17	4	Madhavaram	An low density industrial zone with medium traffic
18	5	Chrompet	A fast growing residential neighbourhood in the suburbs, with medium density, medium traffic and medium dense vegetation
19	5	Kolathur	Newly developing low density residential area with low traffic
20	5	Valsarawakkam	Low density residential area with medium traffic and more open areas
21	5	Ambattur	A low density residential neighbourhood with low traffic, and medium dense vegetation
22	5	Redhills	A low density suburban area with low traffic close to Puzhal lake
23	5	Thiruverkadu	Low density, low traffic with more open spaces and medium vegetation
24	5	Kilkattalai	A newly developing residential neighbourhood with low density and medium traffic
25	6	Anna University	An institutional zone close to the Guindy National Park and Raj Bhavan with high dense vegetation, low density and medium traffic
26	6	Adayalampattu	A suburban low density institutional zone with more open spaces
27	6	Sholinganallur	A suburban institutional zone with low density, medium traffic and more open space with less vegetation
28	7	Sekkadu	A rural agricultural area with low density and low traffic
29	7	Vandalur	A rural area adjoining Anna Zoological park with dense vegetation, low density and medium traffic
30	7	Chengalpet	A rural low density residential zone with less traffic

* Oke's Urban Climate zone classification[23].

Table 2. Intensity of urban heat islands during day time in the CMA

Measurement period	10:00hrs			14:00hrs			18:00hrs		
	Max. Temp recorded in the rural Measurement site	**Min. Temp recorded in the urban Measurement site**	**Intensity of Heat island**	**Max. Temp recorded in the rural Measurement site**	**Min. Temp recorded in the urban Measurement site**	**Intensity of Heat island**	**Max. Temp recorded in the rural Measurement site**	**Min. Temp recorded in the urban Measurement site**	**Intensity of Heat island**
May	37.0°C Chengalpet	33.0°C Besant Nagar Kodambakkam	- 4.0°C	43.2°C Sekkadu, Chengalpet	32.8°C Santhome	-10.4°C	33.7°C Chengalpet	30.7°C Besant Nagar	-3.0°C
July-Aug-Sept	32.3°C Chengalpet	29.5°C Adayar	-2.8°C	35.8°C Chengalpet	31.9°C Adayar	-3.9°C	32.2°C Chengalpet Vandalur	29.2°C Besant Nagar	-3.0°C
Dec-Jan-Feb	All the urban and suburban sites were warmer than the rural location and ranged up to 4.7°C			31.4°C Chengalpet	27.7°C Adayar	-3.7°C	All the urban and suburban sites were warmer than the rural location and ranged up to 2.7°C		

built up (George Town, Old Washermanpet, Saidapet) and at locations characterized by dense vegetation (Anna University, Adayar, Besantnagar). In the urban areas the shading effects of the buildings and vegetation reduced the daytime temperatures significantly, thereby resulting in the negative intensity of CLUHI in the CMA. The sea breeze along the coastal areas in the afternoons also reduced the air temperatures significantly (Santhome, Triplicane). The intensity of the cool pockets observed during daytime in the urban areas becomes prominent with daybreak and reaches its peak around 14:00 hrs and fades off with nightfall.

- The maximum temperatures during daytime were recorded at locations with rural characteristics (Sekkadu, Chengalpet and Vandalur). A few sites within urban areas also experienced similar temperatures as those of the rural areas, thereby nullifying the UHI effect during daytime. The sites characterized by wider streets where the shading effects of buildings and vegetation is either absent or negligible (Thirumangalam) and with low rise urban built up, recorded temperatures almost similar to those of the rural areas during daytime (Ambattur, Virugambakkam). This increase in the ambient air temperatures can be attributed to

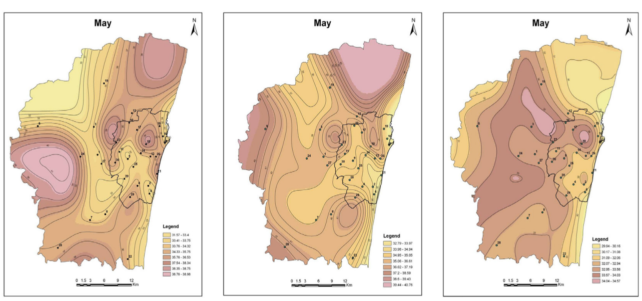

Figure 3. **Daytime temperature isopleths of the CMA during May at 10.00hrs, 14.00hrs and 18.00hrs**

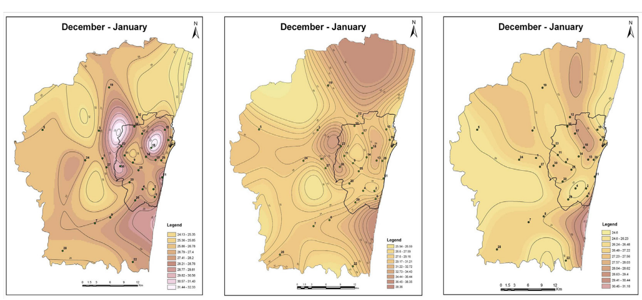

Figure 4. **Daytime temperature isopleths of the CMA during July-August-September at 10.00hrs, 14.00hrs and 18.00hrs**

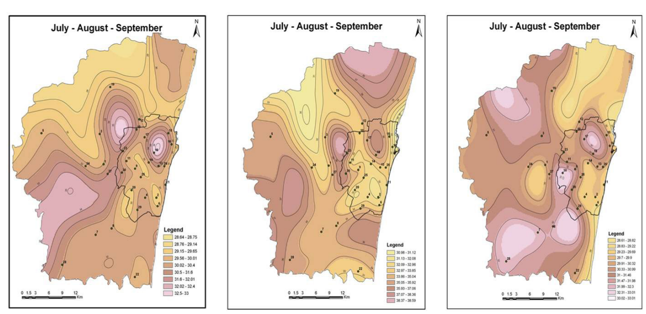

Figure 5. **Daytime temperature isopleths of the CMA during December-January at 10.00hrs, 14.00hrs and 18.00hrs**

the heating up of the hard surfaces of the urban built up areas, characterized by low rise and wide road network with direct solar radiation.

- Anthropogenic heat and the material properties (albedo) have also been found to affect the urban air temperatures significantly (Purasawakkam).
- The daytime temperature isopleths of the summer period (May) revealed that the urban areas shaded by vegetation and dense urban built up were cooler than the rural areas by up to 4.^{0o}C at 10:00 hrs, 10.4°C at 14:00 hrs and 3.0°C at 18:00 hrs.
- The July-August-September temperature isopleths reveal that the difference between the cooler pockets in the urban areas and warmer rural areas varied from 2.8°C at 10:00hrs, to 3.9°C at 14:00 hrs and 3.0°C at 18:00 hrs.
- The cooler pockets in urban areas were witnessed only at 14:00 hrs in the temperature isopleths of the winter period (December-January), and they were cooler up to 3.7°C, whereas at 10:00 hrs and 18:00 hrs, all the sites remained warmer than the rural location. The warmth of the urban areas ranged up to 4.7°C at 10:00 hrs and 2.7°C at 18:00 hrs and can be attributed to the formation of smog during the winter periods.

The daytime temperature isopleths at 14.00 hrs revealed that a cool island exists in the urban core of CMA with a temperature difference of 10.4°C in the summer months and 3.7°C in the winter months.

5. Analysis of Night time UHI Intensity

UHI is measurable during daytime in an urban area but significant positive UHI can be measured only during night time when the temperatures are minimum (Landsberg 1981). The heat absorbed by the built geometry, asphalt roads, parking lots and other hard urban built fabric during the daytime are re-radiate back to the atmosphere after sunset. The night time UHI in the CMA was analysed with the temperature isopleths of 22:00 hrs, 02:00 hrs and 06:00 hrs at different measurement periods. The night time temperature isopleths reveal the significant existence of positive UHI in the CMA. All the measurement locations in the CMA recorded the minimum temperatures at 06:00hrs during the three measurement periods with minor deviations. Figures 6, 7 and 8 show the night time temperature isopleths of the three measurement periods at 22:00 hrs, 02:00 hrs and 06:00 hrs. Table 3 shows the night time intensity of UHI during the different measurement periods.

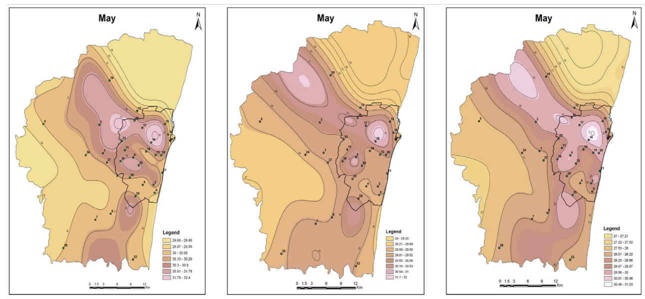

Figure 6. **Night time temperature isopleths of the CMA during May at 22.00hrs, 02.00hrs and 06.00hrs**

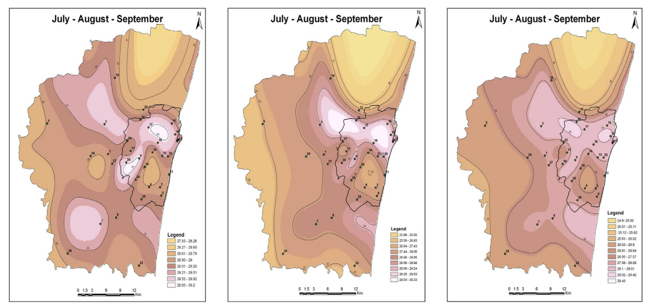

Figure 7. **Night time temperature isopleths of the CMA during July-August-September at 22.00hrs, 02.00hrs and 06.00hrs**

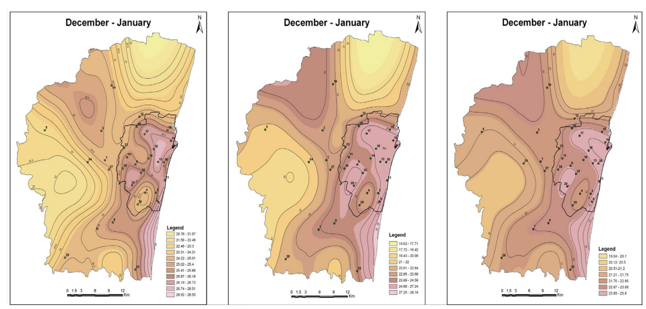

Figure 8. Night time temperature isopleths of the CMA during December-January at 22.00 hrs, 02.00 hrs and 06.00 hrs.

5.1 Temperature Distribution of the CMA during Night Time

An analysis of the temperature isopleths of 22:00 hrs, 02:00 hrs and 06:00 hrs of the three measurement periods reveals the pattern of temperature distribution of the CMA during night time. During the measurement

Table 3. Intensity of heat islands during night time in the CMA

Measurement period	22:00hrs			02:00hrs			06:00hrs		
	Max. Temp recorded in the urban Measurement site	Min. Temp recorded in the rural Measurement site	Intensity of Heat island	Max. Temp recorded in the urban Measurement site	Min. Temp recorded in the rural Measurement site	Intensity of Heat island	Max. Temp recorded in the urban Measurement site	Min. Temp recorded in the rural Measurement site	Intensity of Heat island
May	33.3°C Purasawakkam	30.0°C Chengalpet Sekkadu Vandalur	3.3°C	31.6°C Purasawakkam	28.2°C Sekkadu	3.4°C	30.4°C Purasawakkam	26.8°C Sekkadu Chengalpet	3.6°C
July-Aug-Sept	30.0°C Kodambakkam	28.0°C Sekkadu Chengalpet	2.0°C	29.4°C George Town	26.9°C Chengalpet Sekkadu	2.5°C	29.0°C George Town	26.4°C Chengalpet	2.6°C
Dec-Jan-Feb	26.8°C Mount Road	22.9°C Chengalpet	3.9°C	25.7°C Triplicane	21.7°C Chengalpet	4.0°C	24.9°C George Town	20.8°C Sekkadu	4.1°C

periods, the nights were generally characterized by either very few or no clouds, and calm or very low wind speeds. It is clearly evident from Figures 6, 7 and 8, that the urban built up areas of the CMA are warmer during night time. The analysis of the night time temperature isopleths of the three measurement periods reveal the following:

- At 06:00 hrs, the measurement locations with rural characteristics (Sekkadu, Chengalpet, and Vandalur) recorded the lowest temperatures, and ranged from 20.8°C to 27.2°C. Due to the open nature of the measurement sites with rural characteristics, the heat absorbed during the daytime is reradiated back to the night sky at a much faster rate when compared to the dense urban areas. The maximum temperatures were recorded at locations with narrow streets and high density urban built up (George Town, Kodambakkam, Perambur, Purasawakkam) and varied between 23.8°C to 30.4°C. The narrow streets block the night sky for re-radiation and reduce the cooling rates in the urban areas. The intensity of CLUHI identified at 06:00 hrs ranged from 3.6°C (hottest months) to 4.1°C (coldest months).
- The night time temperature isopleths of the summer period (May) revealed that all the urban and suburban locations were up to 3.3°C, 3.4°C and 3.6°C warmer than the rural locations at 22:00 hrs, 02:00 hrs and 06:00 hrs respectively.
- The July-August-September temperature isopleths shown in Figure 7 also confirmed the existence of urban heat island pockets in urban areas. The urban areas were warmer than the rural areas by up to 2.0°C at 22:00 hrs, 2.5°C at 02:00 hrs and 2.6°C at 06:00 hrs
- The maximum intensity of CLUHI is witnessed in the night time temperature isopleths of the winter (December-January) period. The CLUHI intensity ranged up to 3.9°C at 22:00 hrs, 4.0°C at 02:00 hrs and 4.1°C at 06:00 hrs. The night time temperature isopleths of the winter period revealed that the entire city core remains warmer than the surrounding suburban and rural areas with a distinct cool island visible at the Guindy National park.

The temperature differences are greatest on calm, clear nights, and grow with time after sunset, and the minimum temperatures were recorded at 06.00 hrs in CMA. The temperature isopleths at 06.00 hrs reveal a significant positive CLUHI ranging from 3.6°C in summer to 4.1°C in winter months.

6. Conclusion

The significant existence of an urban heat island is evident from the urban-rural temperature differences in the CMA, during both day and night. During the night, all the urban and suburban locations within the CMA were warmer than the rural locations, whereas during the day, some locations were warmer and others cooler. Also, the results of the study indicate a maximum nocturnal UHI during the calm, clear, winter periods in the CMA. The urban rural differences also revealed a significant cool island during the day with the maximum intensity during summer. The study also found a significant correlation between urban-rural differences and the density of urban built form, built geometry and vegetation; indicating the significance of the building regulations that define the urban built geometry, in designing comfortable urban environments.

7. References

1. Oke T R. Boundary Layer Climate. 2nd ed. Routledge: Methuen; 1987.
2. Landsberg HE. The Urban Climate. New York: Academic Press; 1981.
3. Ferrar TA. The Urban Costs of Climate Modification. New York: John Wiley & Sons; 1976.
4. Oke TR. The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society. 1982; 108(455):1-24.
5. Arnfield AJ. Canyon geometry the urban fabric and nocturnal cooling: A simulation approach. Physical Geography. 1990; 11(3):220-39.
6. Saito I, Ishihara O, Katayama T. Study of the effect of green areas on the thermal environment in an urban area. Energy and Buildings. 1990; 15-16(3-4):443-6.
7. Akbari H, Davis S, Dorsano S, Huang J, Winnett S. Cooling Our Communities: A Guidebook to Tree Planting and Light-Colored Surfacing. US Environmental Protection Agency, Climate Change Division, Washington DC. 1992.
8. Unger J, Sumeghy Z, Gulyas A, Bottyan Z, Mucsi L. Modelling of the maximum urban heat island. ICB-ICUC'99; Sydney. 1999. p. 1-7.
9. Unger J, Sumeghy Z, Mucsi L, Pal V, Kadar E, Barany IK. Urban temperature excess as a function of urban parameters in Szeged. Part 1: Seasonal patterns. Acta Climatologica Et Chorologica Universitatis Szegediensis. 2001. p. 5-14.
10. Shashua-Bar L, Hoffman ME, Tzamir Y. Integrated thermal effects of genesis built forms and vegetation on the UCL microclimate. Building and Environment. 2006; 41(3):343-54.
11. Nieuwolt S. The urban microclimate of Singapore. Journal of Tropical geography. 1966; 22(1):30-7.
12. Wong NH, Chen Y. The urban heat island effect in Singapore. In: Bay J-H, Ong BL, editors. Tropical Sustainable Architecture. 1st ed. Routledge: Architectural Press; 2006. p. 181-99.
13. Jusuf SK, Wong NH, Emlyn H, Roni A, Yan H. The influence of land use on the urban heat island in Singapore. Habitat International. 2007; 31(2):232-42.
14. Bahl H D, Padmanabhamurthy B. Heat island studies at Delhi. Mausam. 1979, 30(1), pp. 119-22.
15. Shravankumar P, Thakur, Sashidharan NV. Heat island intensities over Brihan Mumbai on a cold winter and hot summer night. Mausam. 2001; 52(4):703-8.
16. Mohapatra M. Recent trends in climate of Bangalore. Mausam. 2002; 53(4):425-38.
17. Devi SS. Urban heat island and environmental impact. J3.8. 2006. Available from: http://ams.confex.com/ams/Annual2006/techprogram/paper_104770.htm
18. Kim HM, Zhou Y, Wang T. Measuring ground-level urban temperature: A case study of Suzhou, China. Indian Journal of Science and Technology. 2015; 8(S8):607-13.
19. Jayanthi N. Heat island study over Madras city and neighbourhood. Madras: Regional Meteorological Centre; 1988.
20. Amirtham LR, Devadas MD, Mohana P. Mapping of micro-urban heat islands and land cover changes: A case in Chennai City, India. The International Journal of Climate Change, Impacts and Responses. 2009; 1(2):71-84.
21. Rose AL. Impact of urbanization on the thermal comfort conditions in the hot humid city of Chennai, India. International Conference on Recent Advances in Space Technology Services and Climate Change (RSTSCC); Chennai. 2010. p. 262-7.
22. Nakamura Y, Oke TR. Wind, temperature and stability conditions in an E-W oriented urban canyon. Atmospheric Environment. 1988; 22(12):2691-700.
23. Oke TR. Siting and exposure of meteorological instruments at urban sites. 27th NATO/CCMS International Technical Meeting on Air Pollution Modeling and Its Application XVI. US: Springer; 2004. p. 615-31.
24. Todhunter PE. Microclimatic variations attributable to urban canyon asymmetry and orientation. Physical Geography. 1990; 11(2):131-41.
25. Al-sharif AAA, Pradhan B, Shafri HZM, Mansor S. Spatio-temporal analysis of urban and population growths in Tripoli using remotely sensed data and GIS. Indian Journal of Science and Technology. 2013; 6(8):5134-42.