SPACE
The SPA Journal of Planning and Architecture
Vol. 13 No. 1
2008

AN OVERVIEW OF URBANIZATION AND CLIMATE

Dr. MONSINGH D. DEVADAS
Professor and Chairman, Faculty of Architecture and Planning, Anna University, Chennai

A. LILLY ROSE
Research Scholar, Anna University, Chennai

ABSTRACT

Level of urbanization has been increasing in India since the last five decades. This trend is likely to continue in the near future. More people will become city residents. Increased number of people will have to necessarily live on a limited amount of developed land. In this context, people will demand more housing and everything else associated with urban living including modern physical and social infrastructure. These facilities will be provided with intense use of technology. This urban condition could have devastating climatic and sustainability consequences, if timely mitigating efforts are not made by policy makers and urban planners, managers and designers. This paper attempts to capture the relationship between urbanization and climate by reviewing the existing literature. It has been found that more urbanization without care for the environment could set in motion processes leading to intense clouds of increased urban heat island.

1. INTRODUCTION

Urbanization significantly changes landscape of an urban area and results in distinct climatic conditions termed as the 'urban climate'. Urban climates are distinguished from those of less built up areas by differences of air temperature, humidity, wind speed and direction, and amount of precipitation. These differences occur mainly due to alteration of the natural terrain through construction of artificial structures and surfaces. For example, tall buildings, paved streets, and parking lots affect wind flow, precipitation runoff, and the local energy balance. The alterations owing to urbanization lead to higher temperatures in urban areas when compared to the surrounding rural areas. This difference between urban and rural temperatures is called the 'urban heat island' or the UHI Effect. The primary cause of this phenomenon is faster rate of cooling of open areas around cities compared with the rate of nocturnal cooling of densely built up centers (Givoni, 1998).

According to Oke (1982) causes of the UHI Effect include blocking the view to the night sky by buildings (sky view factor), the thermal properties of surface materials (albedo) and lack of evapotranspiration (vegetation) in urban areas, geometric effects called the 'canyon effect' and anthropogenic heat (vehicular emission, air-conditioning etc). Diminishing diurnal temperatures i.e. variation between maximum and minimum temperatures, in cities are clear indication of the presence of the UHI (Landsberg, 1981; Oke, 1987). The nighttime effects of UHIs are harmful as it deprives urban residents of the cool relief found in rural areas during the night (Clarke, 1972). Therefore, guiding the dynamic 'environment city relationship' towards more sustainable pattern through mitigation of the UHI Effect is essential for comfortable urban living. Ever increasing level of urbanization in India and the world makes the study of the UHI Effect even more important.

2. URBAN HEAT ISLAND

Luke Howard (1833) carried out the first scientific study of urban climate modifications. He compared the temperature of a city weather station with that of a rural weather station and found that the city station was warmer. He found that night was 3.7° warmer and day was 0.34° cooler in the city when compared to the countryside. He attributed this difference to the extensive use of fuel in the city. Heat in cities in contrast to their rural surroundings is termed as the 'Urban Heat Island' as shown in Fig. 1). The term 'Urban Heat Island' was coined by Gordon Manley (1958).

Understanding of alterations to urban climate was further enhanced by Oke's (1976) conception of urban atmosphere into two distinct layers through urban boundary layer and urban canopy layer. The Urban boundary layer (UBL) is the overall atmospheric system that extends for many miles above the cities. The characteristics of the UBL are partially determined by the city below (Oke 1982). The Urban Canyon Layer (UCL) is the layer of atmosphere where most life occurs from

Fig. 1. Urban Heat Island Profile

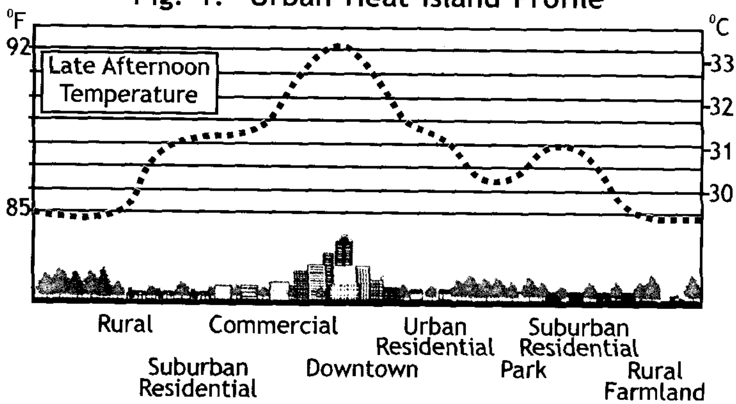
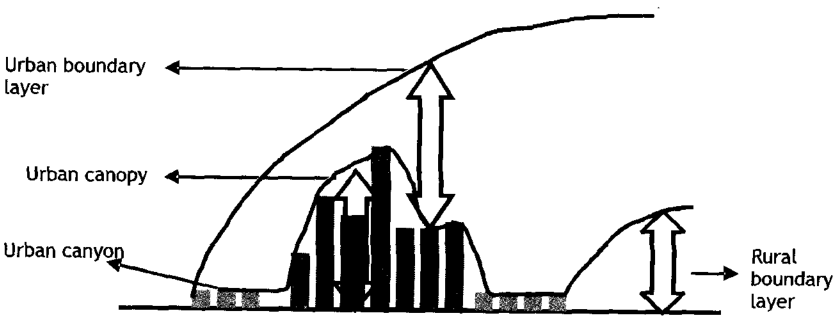


Fig. 2 Urban Boundary Layer



ground up to the mean height of roofs. Thus the climatic effects of urbanization are strongly felt in the UCL (see Fig. 2).

A heat island is a dome of stagnant air over the heavily built up areas of cities (Akbari et al, 1992). The intensity of heat island depends on density, population size (Irving Hoch, Oke, 1982) and morphology (physical structure) of the cities (Jauregui, 1984). It is argued that the rate of cooling in the city depends on two measures of the urban structure (Oke, 1981):

(a) Height width ratio (H/W, street geometry): the ratio of the typical height of the buildings to the typical width of the neighboring streets.

(b) Sky view factor: the fraction of the sky hemisphere visible from a location at street level in an infinitely long Urban Street Canyon.

3. EXAMINATION OF URBAN HEAT ISLAND LITERATURE

According to Oke (1991), the scientific investigations of urban microclimate fall into three categories:

(a) Descriptive studies: Prior to 1930 - Simple studies of individual weather elements. 1930-1965 - description extended to complex spatial and temporal variability and linkage of climate effects to weather and urban structure.

(b) Diagnostic studies: 1965 onwards - the emphasis shifted to the physical basis of the urban climate modifications and to construct models for simulation

(c) Application studies: In the recent past the emphasis has shifted towards mitigation strategies, particularly in light of Kyoto Protocol (Rio De Janerio) and World Summit on Sustainable Development (Johannesburg).

The oldest form of descriptive urban climate research used the city-rural comparison method (historic climate records) or the automobile traverse method (measurements of air temperature and relative humidity across urban areas and comparing it with a reference station). In recent years these approaches have been replaced with extensive use of remote sensing techniques.

The Diagnostic studies resulted in the search for causes of urban climate alterations and creation of the UHI simulation models.

4. URBANIZATION AND CLIMATE

Urbanization alters the climate in and around cities and other built up areas. The effects of urbanization on climatic parameters are presented in Table 1. Many features of the physical structure of the city can affect the urban climate. The microclimatic effects of the city parameters are presented in Table 2. As the structure of a city can be controlled by urban planning and design it is possible to modify the urban climate through urban policies and designs of neighborhoods.

Table 1 Effects of Urbanization on Climatic Parameters

Climatic parameters	Effects of urbanization
Temperature	Rise in daily minimum temperature: some change in maximum temperature
Humidity	Reduction in daytime humidity, but increase in night time values
Precipitation	Larger increases in summer (up to 21 percent) and smaller increases in winter (5 to 8 percent). In the tropics, the increase is attributed more to air pollution than heat emissions.
Wind	Increase in the number of calm periods observed. Up to 20 percent reduction in wind speeds are known. The effect is greater upon weaker winds.
Solar radiation	Although incoming radiation values are not changed, the apparent values are high due to the containment of reflected radiation by the heat dome.

Source: Khemani et al. (1973), Chandler (1976), Landsberg (1981), Oke (1987), Emmanuel (1997).

Table 2 Microclimatic Effects of City Parameters

Phenomenon	Possible effect
Population Size	Urban rural temperature difference is proportional to population size. The effect is pronounced as population increases beyond one million.
Topography	Air drainage caused by elevation differences and secondary wind patterns created by topography tend to reduce the heat island effect.
Rivers and other water bodies	The UHI dissipates at or near water bodies, even if the water body is in the middle of a heat island.
Wind speed	The UHI intensity is inversely proportional to macro level wind speeds. However, urban wind flows are usually weak at macro level.
Anthropogenic heat	The presence of large numbers of heating and cooling equipments can aggravate the heat island effect, though the effect pales in comparison to solar energy trapped by buildings.
Water runoff	The UHI effect is more pronounced if more rainwater is allowed to drain away quickly from cities. Availability of water helps partition more heat by evaporation.
Vegetative cover	The presence of sufficient vegetative cover not only ensures more evaporation, but also helps in reducing radiation received at the earth's surface due to photosynthesis.

Sources: Chandler (1976), Landsberg (1981), Oke (1987).

Population size, topography, rivers and other water bodies, wind speed, water runoff, anthropogenic heat and vegetative cover significantly impact the microclimate of the city.

5. A REVIEW OF THE URBAN CLIMATE STUDIES

Urban climatologists have studied a range of applied problems such as urban climate and the health of city inhabitants, the use of green space and vegetation to improve urban climates, urban climate and urban planning, the use of remote sensing to observe urban climates, etc. Table 3 presents some of the urban climate studies done by various researchers and their important findings.

Table 3 A Review of the Urban Climate Studies

Authors	City	Title of Research	Parameters	Major Findings
Zs. Dezso, J. Bartholy, R. Pongracz and Z. Barcza	Hungary Switzerland	Comparative analysis of urban heat island effects for large Hungarian cities using satellite imagery	Surface temperature, vegetation, cloud charact-eris tics, and temperature and moisture profiles	Intensity of the urban heat island detected in Hungarian cities ranges between 1K and 3K; Most intense periods include the summer season and nighttime.
David J. Sailor	US cities	Streamlined Meso Scale Modeling of air temperature impacts of heat island mitigation strategies	Temperature, city size, albedo and vegetation cover	Modest increases (0.1) in albedo or vegetative cover can result in discernable impacts in local meteorology
David J. Sailor, and 1994	Los Angeles	Simulated urban climate response to modifications in surface albedo and vegetative cover	Urban albedo and vegetation cover	A potential to reduce urban energy demand atmospheric pollution through application of reasonable surface modification strategies
Fazia Ali Toudert, Helmut Mayer	Ghardaia, Algeria,	Street design and thermal comfort in hot and dry climate	Street geometries, architectural details such as galleries and horizontal overhangs and thermal comfort	Dependence of the thermal comfort on the design of the street including geometry, orientation and other design strategies such as galleries, and horizontal overhangs

Authors	City	Title of Research	Parameters	Major Findings
Andreas Matzarakis	---	Estimation and calculation of the mean radiant temperature within urban structures	Calculation of T_{mrt}.	Evaluation of the thermal component of urban and regional climate using Rayman
H. ALPHA, 2003	Adana, Turkey	Land use change and urbanization of Adana, Turkey	Land use and land cover	Remote sensing offers wide scope to determine LULC changes
Michael J. Brown, Austin Ivey, Timothy N. McPherson	Oklahoma City	A study of the Oklahoma City urban heat island using ground measurements and remote sensing	Temperature, thermal infrared image	Distinct variations in temperature across different land use categories exist
Lutz Katzschner, Ulrike Bosch, Mathias Röttgen, 2002	Kassel city centre, Germany	Behavior of people in open spaces independency of thermal comfort conditions	Temperature, meanradiant temperature, wind and Predicted Mean Vote (PMV)	Microclimatic conditions influence the use of open spaces extremely. This was mainly dominated by global radiation (sun and shadow) and ventilation, which could be observed through the parallel measurement of globe temperature and wind speed
A. Matzarakis	—	Assessing urban climate - problems and solutions from the point of View of human biometeorology	Thermal, air quality, activity factor, mobility factor and health factor	Evaluation or coupling of the atmospheric and non-atmospheric factors by the use of mean or multiplication of the values of the ASI and MAF results
B. Bauer, J. Breuste, A. Matzarakis and H. Mayer	Leipzig, Germany	Micrometeorological measurements in small urban structures	Air temperature, vapor pressure, wind velocity, short and long wave radiation	Air temperature and vapor pressure are relatively homogenous in the areas investigated, but wind velocity and radiation fluxes show a high variability depending on the surrounding area; Influence of the vertical building facades on human biometeorological conditions was established
D. Scherer, U. Fehrenbach, H.D. Beha, E. Parlow, 1999	Basel, Switzerland	Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning processes	Land use structures, wind flow and urban ventilation	Climate maps containing the results of the analysis and evaluation of the urban climate of Basel as a valuable tool for planners.

6. MEASURES TO IMPROVE URBAN ENVIRONMENT

Mitigating and reducing the impacts contributed by urban activities is a significant challenge to urban planners, designers, architects and local government and the industry especially in the context of growing population in urban areas and the enhanced access to associated urban infrastructure. By implementing the following measures, it is possible to improve the urban environment.

- Reducing emissions by decongesting the roads through reduced number of vehicles on the roads.
- Use of passive techniques in designs for heating and cooling thereby reducing the anthropogenic heat generated.
- Increasing the vegetation cover by providing more trees to provide shelter and shade.
- Increased use of light colored surfaces thereby reducing the absorption of radiation.

Table 4 Optimal Urban Parameters for Mitigating Negative Impact of the UHI

Urban parameters	Optimal Values
Canyon Geometry	Height width ratio of 0.4 to 0.6 is suggested by Oke (1988b) for minimal heat trapping in summer and enhanced trapping in winter without infringing too much on air quality standards.
Thermal properties	An albedo increase of 0.15 in Sacramento, California, was shown to have reduced the UHI by 2.7° F (Sailor, 1995).
Moisture Availability	Average moisture availability in North American cities is 15 percent of that in rural areas (Montieth, 1973). Its doubling was found to reduce the UHI by 20 percent in a simulation study (Oke et al., 1991).
Anthropogenic heat	Sailor (1995) suggested better building insulation and compact urban planning for a 50 percent reduction in building and urban heat wastes.
Vegetative cover	Average North American cities are about 30 percent tree covered (Moll and Ebenreck, 1989). Sailor (1995) found that doubling of this amount could reduce the UHI by about 2° F.

Source: Rohinton (2005).

In Table 4 we suggest the optimal urban parameters for mitigating the negative impact of urban heat island effect.

7. CONCLUSIONS

Increase in population, population density, reduction in open spaces and green cover and increase in built up spaces have proved to increase the heat island phenomenon. These thermal changes deteriorate the urban environment resulting in adverse climatic changes in the built environment causing health problems. Therefore urban planners, designers, architects and other policy makers need to consider the urban climate while designing and planning cities.

REFERENCES

Givoni, B. (1998) *Climate Considerations in Building and Urban Design*, John Wiley and Sons, London.

Helmut E. Landsberg (1981) *The Urban Climate*, Academic Press, New York.

Oke T.R. (1987) *Boundary Layer Climates*, Methuen London.

Rohinton, E.M. (2005) *An Urban Approach to Climate Sensitive Design, Strategies for the Tropics*, Spon Press, London.

Rohinton, E.M. (2005) Urban Climate Research in Sri Lanka: Efforts towards Mitigation, *IAUC Newsletter*, Vol. 12, pp.11-14.

Ferrar, T.A. (1976) *The Urban Costs of Climate Modification*, John Wiley and Sons, London.

Voogt, J. A. and Oke, T.R. (2003) Thermal Remote Sensing Urban Climates, *Remote Sensing Environment*, Vol. 86, pp. 370-384.

WEB RESOURCES

- Land-Surface Air Temperature - from the IPCC

- Urban Heat Islands and Climate Change - from the University of Melbourne, Australia
- The Surface Temperature Record and the Urban Heat Island From RealClimate.org
- NASA Earth Observatory: The Earth's Big Cities, Urban Heat Islands
- Research and mitigation strategies on UHI - US EPA designated, National Center of Excellence on SMART Innovations at Arizona State University