An initiative supported by

SCOPING STUDY FOR POLICY INITIATIVES TO MINIMISE URBAN HEAT ISLAND EFFECT FOR LOW CARBON URBAN GROWTH

OCTOBER 2014

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EXECUTIVE SUMMARY

The current rapid rate urbanisation in India calls for a need to address an observed consequent issue of the Urban Heat Island effect (UHI). It is now recognized that factors related to an increase in built up area in urban environments cause an increase in the microclimatic temperatures of the city regions compared to the surrounding landscape, characterising the UHI effect. It is speculated that this effect is amplified as we move towards a high-rise high-density model for urban development, and has significant effects in turn on urban energy use and the environment at large. Addressing this Urban Heat Island effect is, therefore, essential for inclusion in a comprehensive strategy for low-carbon urban growth in the country. This project on the 'Scoping Study for Policy Initiatives to Minimize Urban Heat Island Effect for Low Carbon Urban Growth' seeks to review the current status of research and policy on the Urban Heat Island effect, and identify potential initiative areas for incorporation in developmental directives, to help facilitate Urban Heat Island mitigation.

In keeping with the objective of the study there are three main Parts to this report.

Part 1 of the study looks at: firstly a review of the current literature on the global research on the Urban Heat Island effect; secondly an appraisal of international policy documents for their dealing of the Urban Heat Island effect ; thirdly an examination of national government documents for their extent of coverage of the Urban Heat Island effect and mitigation.

The first task, a review of the current literature on the global research on the Urban Heat Island effect was conducted with the view to identifying critical impacting parameters and the extent of their impacts. It was found that the research in this field internationally was comprehensive in identifying the causal factors, impacts, and mitigation effects, however, research in India has been very limited, although the issue has received recognition and the UHI effect documented at places. The international studies have focussed on land planning, building morphology and surface characteristics of the built environment, while lifestyle choices relating to transportation and buildings have largely been overlooked. Further, international research has also verified, increased ambient temperatures, increased air pollution as well as higher energy consumption and health and economic effects, as the major impacts of the Urban Heat Island effect. Effects of mitigation measures too have been mostly well documented internationally, although largely focussed on surface characteristics of buildings and open spaces.. Indian research has primarily highlighted only the temperature impacts of UHI and has only just begun to look at the relative effectiveness of mitigation measures.

The second task, an appraisal of international policy documents sections for their dealing of the Urban Heat Island effect had the objective of examining the operational framework for addressing the UHI effect globally, identifying mitigation measures that were found to be workable and scalable as developmental instruments, as well as noting challenges and issues with their implementation. The study found that: policy recommendations for mitigation of Urban Heat Islands are closely tied to national and international research that was followed up by the governments of these nations, has been often addressed under the larger umbrella of Global Warming based on the outlines laid down by the United Nations; generally, the phenomenon is more thoroughly researched and addressed over a longer period of time by Developed Nations; countries working toward UHI mitigation tend to concentrate their implementation on short term programs such as building energy efficiency, cool roofs, and street surface improvements; in many countries the agenda was incorporated the central level and its implementation structured at state, regional and city levels. It was also noted that the potential for addressing UHI at the town planning and urban design level is receiving greater

attention. Global and trans- national institutions and bodies have emphasised the criticality of health and environmental stress that is attendant on the growing urban populations due to the UHI effect, especially in the developing nations who are located predominantly in the hot climate belts. They also point out the need for further research to develop tools for urban microclimate assessment , integrating the UHI effect, that would inform urban planning and development toward optimal low-carbon futures.

The third task, an examination of national government documents for their extent of coverage of the Urban Heat Island effect and mitigation, was aimed at examining the current legislative structure and identifying instruments addressing the UHI in the Indian context. Through the hierarchy of centre, state, and city, it is evident that there are efforts to address the UHI effect through visionary policy documents tied to the National Action Plan on Climate Change, the ministries of MoUD, MoP, MNRE, and MoEF, while ULBs offer channels for implementation. Apart from governmental institutions there are some non-governmental organisations as well that takes into account the UHI and have given implementation to mitigation strategies. The existing structure of policies, guidelines, and recommendations do recognize causal factors related to city form, building materials, and gaseous pollution and provide for mitigation measures related to surface treatment and building-street orientation. However, a substantive and assertive inclusion of UHI mitigation strategies is as yet lacking.

Part II of the study has attempted to develop the working theories for future action on addressing the UHI effect in the Indian context. This included: Presentation of a reference theoretical guiding framework of UHI influencing parameters and their synergistic effects; Identification of the policy sections, sectors, and scales where UHI mitigation may be addressed throwing light on the nature of mitigation measures that may be feasible and successful.

Further, a consultation meeting was held to confirm the study findings and discuss avenues for further work. The salient points from this Part III, the Stakeholder Consultation include the following:

- Urban Heat Island was agreed to be a real phenomenon that needed to be addressed in both extended research and efficient policy initiatives in the Indian context.
- It was pointed out that there was a need to disaggregate the relative impacts of the causal factors in a context specific way to be able to work out the most effective mitigation strategies.
- Concepts such as those of ‘anthropogenic heat intensity’ were put forth as a way of understanding the combined effects of lifestyle and design factors and examples of such policy.
- The Ministry of Urban Development and the Ministry of Power were identified as the operational ministries for the implementation of UHI mitigation policy.

Finally, directions for future research have been put forth for addressing these salient points using a combination of empirical and numerical methods and covering the different climactic and regional contexts of urbanizing India.

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NEED FOR STUDY

The next couple of decades expect to see a manifold increase in urbanization in the country with an anticipated 3-4 times growth of urban areas. One of the consequences of such increase in urban development may be the empirically observed phenomenon of the Urban Heat Island (UHI). In this phenomenon an increase in the area of buildings and roads, and reduction in green cover, causes the microclimate in cities to become warmer than regional temperatures. Observed microclimatic temperature increases have been recorded in the range of 1-3°C in the daytime and up to 12°C at night in cities. Such changes can also have considerable impacts beyond that on the microclimate, including those on energy use, health, and economics, and can become a cause for national concern.

The trend for urbanization in India has shown an expansion in the geographic area of the cities as well as a progressive intensification of the existing city areas. Due to the pressure on the availability of land on the one hand, and the desire to curtail suburban spread on the other, the trend towards a rise in the density of urban development is becoming inevitable. This trend is most prominent in the large metropolises, which are quickly getting saturated, and is also being observed in second and third tier cities that seem to be quickly following suit. It is now common for planning authorities to encourage a Floor Area Ratio (FAR)(the ratio of built up area to plot area) of up to 4, whereas FAR of 1.5 to 2 are already commonplace.

It has been noted that this increasing urban development may be strongly related to the noticeable heating up of the urban environment. Research on the subject of Urban Heat Islands has identified several distinct factors that contribute to the phenomenon. These are – absorption of radiation by ground surfaces as well as roof and wall surfaces of buildings; reduction of ground moisture content from reduced vegetative cover and evapo-transpiration; reduction of air flow due to increased built obstructions; heat input from anthropogenic sources such as motor vehicles and air conditioners; and the retention of the heat by the building mass. A previous investigation by the authoring research team on impacts of housing densities on urban microclimates in the composite climate zone of India had also noted microclimatic temperature increases with density to be compounded by vegetation effects, the summer season, and possibly building spacing and anthropogenic heat; the total effect being attributed to an interplay of radiant temperatures and air flow.

These increased ambient temperatures of the Urban Heat Island effect, it is speculated, further impact the temperatures inside buildings as well, and compel the use of electromechanical systems to obtain comfort, especially in warm climates. In parallel, as income levels of the urban population rises, the middle classes who occupy these new high density developments, are further encouraged to adopt these refrigerant based air-conditioning systems. This trend toward a desire for “air conditioned comfort” is of major significance from the point of view of energy conservation as air conditioning is a high-energy consuming means of achieving comfort. The process of air-conditioning further pumps out heat from building interiors adding to the ambient heating effect.

Furthermore, it is observed that the increasing affordability of the middle income classes also promotes motorcar dependency, which is encouraged by current planning regulations that require developments to provide parking for personal motor vehicles. The increased concentration of motor vehicle ownership has consequences at two levels. More land area is dedicated to hard paving for roads and parking lots and secondly there is concentrated slow movement of vehicles in the spaces adjacent to residential buildings. These two factors, together, cause an appreciable increase in heat inputs to the atmosphere and a consequent rise in ambient temperatures and formation of heat islands.

This rise in outdoor temperatures has a rebound effect as it discourages pedestrian mobility and further encourages motorized vehicle dependency.

Lastly, most urbanizing areas in India fall predominantly in the warm and hot regions of the country, which may be especially prone to the impacts and rebound impacts of the UHI effect.
In sum, the Urban Heat Island phenomenon poses a major environmental threat. Recent satellite data of surface temperatures in and around cities like Delhi have shown an elevation of temperatures in dense urban centers of up to 8-10degrees above the outlying countryside temperatures. It is possible that the benefits of compact city growth from the point of view of reducing transportation distances, therefore, may have unintended consequences of increasing energy demand by encouraging the Urban Heat Island effect instead. This relationship has, hitherto, been largely been unexamined, especially in the Indian context. The expected large scale urbanization, particular cultural and climatic context of the country, and the vicious cycles that can be set up by the Urban Heat Island effect, make it critical to address this aspect with immediacy. A comprehensive strategy for tackling the Urban Heat Island effect needs to be factored into the overall approach for low-carbon urban growth in cities. This project seeks to, therefore, document the current status of research and monitoring of the effect both globally and nationally, and thereafter assesses the status of policy level recommendations at the national level alongside a comparison with the international coverage of the subject, with a view to contributing to this larger objective.

STUDY METHODOLOGY

The project on 'Scoping Study for Policy Initiatives to Minimize Urban Heat Island Effect for Low Carbon Urban Growth' is divided into 3 parts as noted below.

Part I of the study has involved the following objectives:

1. **Summary of the global state of knowledge on UHI effect and estimates of its implication on energy demand in urban areas.**
   This includes a collection, review, and analysis of the international and national UHI literature published in the past decades, with the scope of identifying the key parameters affecting the Urban Heat Island effect.

   Global knowledge on the subject is available in published reports and papers of international organizations and peer reviewed journals. Research on the subject is also being conducted at a number of international and national universities and institutions. This study has included desk based research reviewing a total of 49 key papers These sources have been cited and their findings summarised with inferences relevant to the context of this study.

   The structure for the review draws on a classification of Causal Factors, Measured Impacts, and Mitigation Measures, relevant to the Urban Heat Island,. The Indian cities citied with respect to empirical UHI studies include: Delhi, Bangalore, Pune, Chennai, Thiruvananthapuram, Guwahati, Ahmedabad, Bhopal, Nagpur and Visakhapatnam.

2. **Secondary research on initiatives and policies with respect to the UHI effect being implemented in other countries**
   This includes a documentation and appraisal of policies across global cities addressing the UHI effect, with a view to understanding the incorporation of UHI strategies into planning and developmental guidelines and regulations, budgetary impacts, and implementation issues in the deployment of the countermeasures.

   Policy documents and developmental guidelines across international cities are examined through an internet review. Secondary data through a literature review of institutional papers and journal articles is also covered to bring out the global best practices.

   The structure for review considers the level of intervention, policy instruments, and the mitigation measures addressed, to report findings at the global level represented by international countries including the USA, Japan, and entities of the EU, covering the major climate zones of the world.

3. **Analysis of UHI effect related parameters in environmental assessments of large developments in India through voluntary environmental assessment instruments as well as mandatory environmental clearances .**
   This includes an examination of the ministerial instruments guiding urban development as well as voluntary environmental certifications, for initiatives on the mitigation of the UHI effect. These instruments are reviewed to see how they help in sector level provisions of city development and the level to which they incorporate efforts to mitigate the UHI effect. Based on this the direction and means of Indian policy interventions will be recommended.

The review incorporates the consideration of UHI effect in the National Action Plan on Climate Change as well as the related and relevant ministerial instruments that guide and regulate urban development. Alongside, non-governmental as well as collaborative initiatives like Leadership in Energy and Environmental Design (LEED) and Green Rating of Integrated Habitat Assessment (GRIHA) are also evaluated for the weightage they give to the cause of UHI mitigation.

The structure for the review adopts a framework of Central Government ministries and State/City Government legislation and their interrelationships to examine the current recognition of and recommendations for mitigation of the UHI effect.

Part II of the report is based on the following objectives:

4. **Development of a descriptive model of the interrelationships between various parameters of urban development such as ground coverage, building density, building setbacks, as well as parking allowances and transportation provisions, and their impact on the UHI effect in cities**
   City development and planning is guided by parameters like land use zoning, building morphology including ground coverage, floor space index, set back provisions, as well as infrastructure such as parking, utilities, and green area requirements. A theoretical model is developed as an attempt to describe the dynamic relationship between these parameters, interactions with lifestyle factors and associated contributions to the heat island effect as well as rebound impacts on energy demand and exacerbation of the effect.
   The structure of the framework derives from the literature review of the causal factors, and environmental impacts related to the UHI. Besides describing the interrelationships, the intention of the framework is also to depict the impact of the present trends of development and identify key levers for mitigating negative trends.

5. **Based on the descriptive model, identification of possible policy instruments within the existing governmental framework of the country ,for UHI related interventions.**
   There are various initiatives at national, state, and city level governance, for addressing urban development, environment, and energy related issues in India. Some policies and guidelines are under preparation while others are already instituted. Based on the understandings gained from the descriptive framework, the policy instruments and sectors and scales at which they can operate, can be identified for incorporating UHI mitigation.

The final Part III of the report covers of the following objectives:

6. **Conducting a stakeholder consultation and presentation of findings with subject experts and concerned relevant government department officials.**
   The consultation process had a threefold objective: first, to obtain a confirmation over Urban Heat Island issues, second, to communicate the necessity of the Urban Heat Island issues being addressed in urban development guidelines, and third to invite opinion on the appropriate approach for incorporation of UHI mitigation in Indian policy. The process was intended to help in developing a road map for next steps in India-specific empirical research to provide a comprehensive basis for the development of urban guidelines concerning the Urban Heat Island effect.

   This consultation process also involved two empanelled scientific leaders in the field of UHI internationally:

1. Dr. Koen Steemers of the University of Cambridge, UK
2. Dr. Ronnen Levison at the Lawrence Berkeley National Laboratory, California.

These experts jointly validated the proposals of the project and reviewed findings in Part I of the report and contributed their perspectives and comments relevant to urbanization in India for the Stakeholder consultation meeting.

The consultation meeting included presentation of the review on research and policy followed by two open sessions covering discussion points laid out to consider aspects of research and policy respectively.

7. Formulation of a proposal to establish an empirical data base from cities in India to enable a quantitative assessment of the impact of UHI effect and consequent guidelines for low-carbon urban development.

The impact of UHI is considered to be influenced by a set of uncontrollable and controllable measures. The former includes regional and local climatic patterns diurnally and seasonally, as well as topographical influenced -. The latter includes aspects of urban structure and urban lifestyle that can be influenced to affect the impacts of UHIs.

This implies that it is not only significant to identify the key mitigating measures by affecting the influencing factors and assess their relative impacts, but also to do this in view of the to the location of the urban environment under consideration by developing a data base across cities in different regions.

An outline proposal for further work on assessment of parameters, collection of data, and deriving UHI mitigating guidelines is presented.

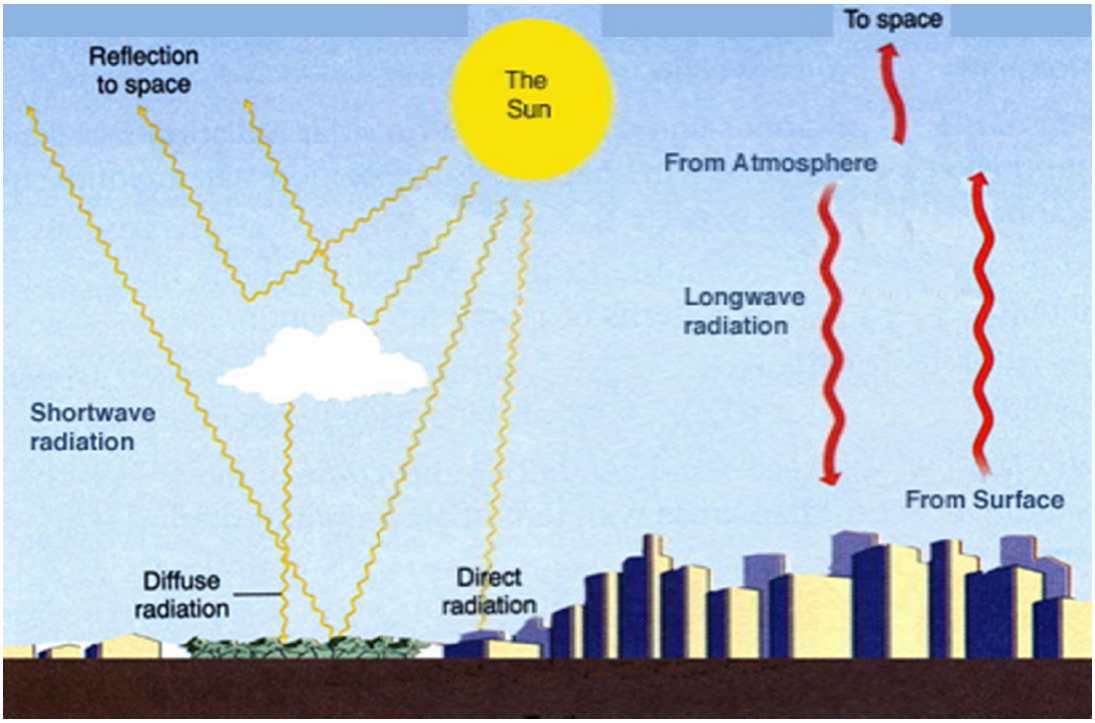
PART I
LITERATURE REVIEW

1. Overview of UHI

"Heat island" is an area specific phenomenon where the temperature of one area is higher than that of the surrounding areas. The physical extent of this island of heat can vary from a few metres to several kilometres across.

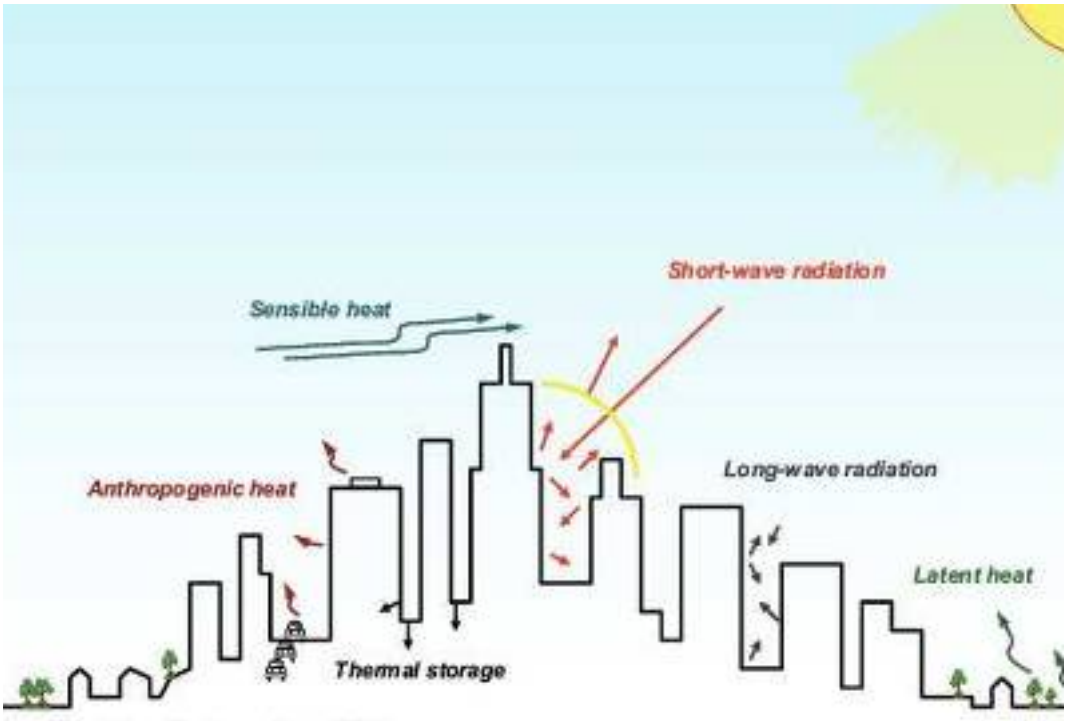
As per United States Environmental Protection Agency "As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry. These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape" (EPA, 2013).

During the day time buildings, roads, pavement, and open ground absorb heat that is then released in the evening and night time. However, due to the nature of urban morphology, that these elements form part of, this released heat is restricted from escaping into the higher atmosphere, resulting in the formation of heat islands. This phenomenon is referred to as the 'Urban Heat Island' effect or UHI effect. The phenomenon of the UHI has been observed in many urban areas around the world.



Source: (Rice Uniersity)

Figure 1: Natural Radiance Balance

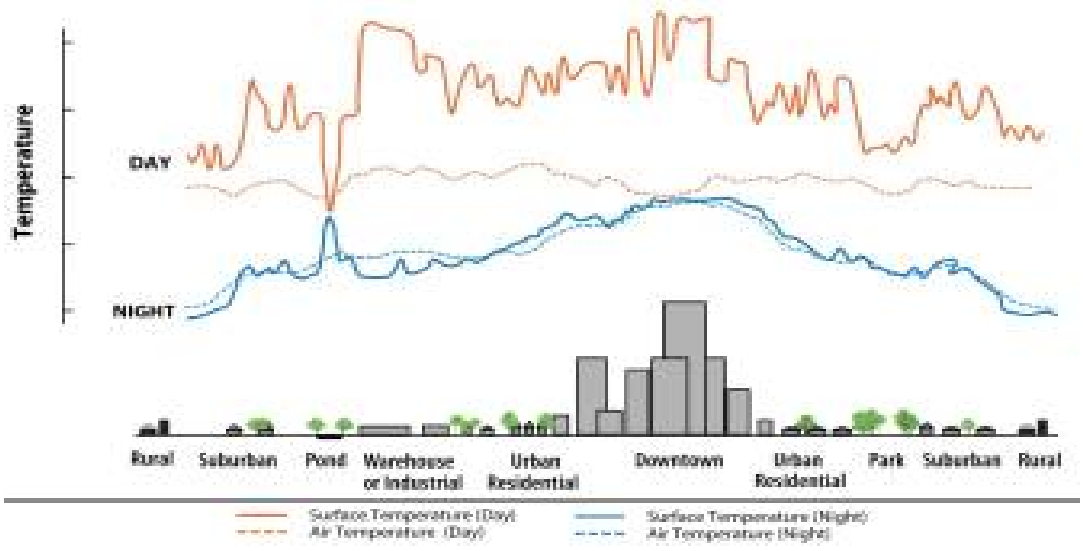


Source: (EPA, 2008)

Figure 2: Radiation balance affected by Urban Interventions

It is interesting to observe the Heat Island as a local level phenomenon (in contrast to global warming which is a global level phenomenon), where only a patch or several patches within a city have higher temperature with respect to their surroundings. Also global warming is driven by emission of greenhouse gases whereas the UHI effect is a resultant of physical alteration of the natural landscape and the release of waste heat (Stone R., 2007). Urban Heat Islands, however, can impact global climate and can also affect the long term temperature record which is used for detecting global climate change as many temperature recording stations are located in urban areas (Douglas, 2002).

The image given delineates the intensity of heat island in downtown areas with respect to rural and suburban areas.



Source: (Douglas, 2002)

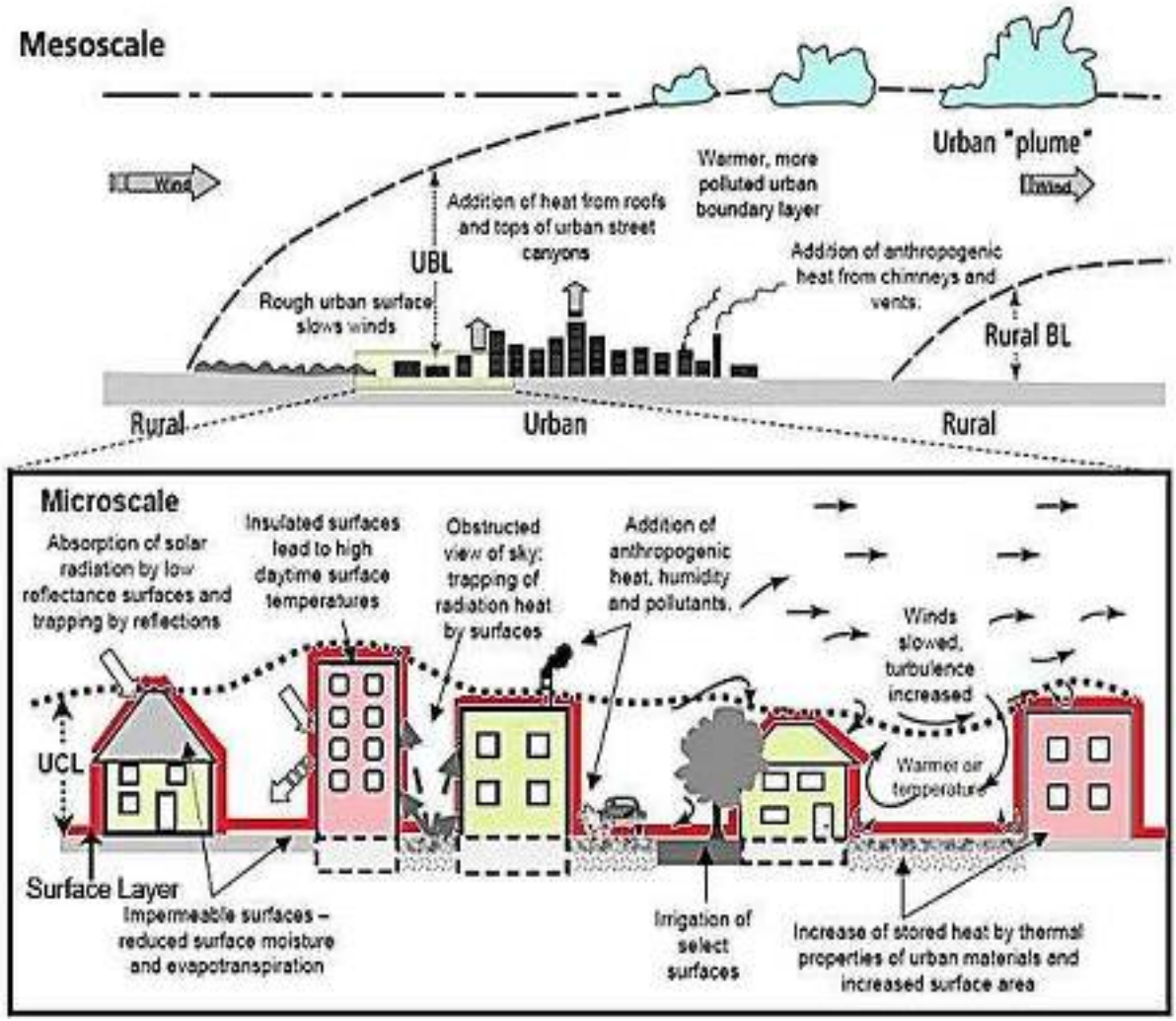
Figure 3: Urban heat island intensity

Urban Heat Island types

The UHI is categorized into three distinct types: Surface Urban Heat Island (SUHI), Canopy Layer Urban Heat Island (CLUHI) and Boundary Layer Urban Heat Island (BLUHI).

- SUHI is the heat island formed by heating of urban surfaces like buildings, roads, pavements, open space, water bodies and vegetation.
- CLUHI is the heat island formed in the Canopy Layer or the layer of air closest to the different surfaces in a city after surface layer and extends upwards to approximately the mean building height of a particular area. It is the air layer where we live – from ground level to top of trees and buildings. There is also a heat island layer described for 1-2m of the layer of air next to the urban surfaces referred to as the Near Surface Urban Heat Island or the NSUHI which is most relevant to the occupied zone of the urban environment.
- BLUHI is the heat island formed in the Boundary Layer or the layer above Canopy Layer that extends up to 1 km or slightly more above during daytime and to hundreds of meters or less during the night. The heat island dome extends downwind of the city and is often changed to plume shape due to wind (Voogt J. A., 2004)(HARC, 2009).

The image below depicts the aforementioned three types of heat island.



Source: (Voogt J. , 2007)

Figure 4: Types of UHI

CLUHI and BLUHI are together also referred to as Atmospheric Heat Islands. These together with SUHI have a bearing on the ambient temperatures surrounding buildings in urban areas. The specific differences between Atmospheric heat island and Surface heat island are summarised in table below.

Feature	Surface UHI	Atmospheric UHI
Timing	Present at all time during day and night. Most intense during daytime and summers.	Small or absent during day. Most intense at night or just before dawn and in winters.
Peak Intensity	More variations during daytime.	More variations during night time.
Measurement	Indirect measurements using remote sensing	Direct measurements with weather stations or mobile measurements
Typical Illustration	Thermal image	Isotherm maps & temperature graphs

Source: (EPA, 2008)

Table 1: Surface and Atmospheric UHI difference

Heat Island Measurement

The UHI intensity is the difference in air/surface temperature between urban and rural areas. There is very good recognition and documentation of UHI intensity globally. UHI intensity was first documented by Luke Howard's study of London's climate in 1818 when hefound 'an artificial excess of heat' in the city compared to the country (Gartland, 2008).

It has been seen that the annual mean air temperature of a city with 1 million people or more can be 1–3°C warmer than its surroundings and as high as 12°C at night(EPA, 2008).

The study conducted across the globe for 419 big cities having population of more than 1 million indicated that the average annual day time SUHI intensity is higher as compared to the average annual night time SUHI intensity.. (Peng, et al., 2012). These 419 cities were divided into developed and developing countries and its was then noticed that annual daytime SUHI intensity over developed nations (2.1 ± 1.1°C) was much higher than the SUHI intensity over developing countries (1.3 ± 1.1°C), (Peng, et al., 2012).

An ideal way to measure an intensity of heat island is to examine regional weather patterns, both with and without the city in place. As it is impossible to remove and replace cities, different approaches have been identified for the measurement of heat island intensity (Gartland, 2008). Mirzaei and Haghighat (2010) in their research have mentioned two types of approaches to measure heat island intensity i.e.: Observational approaches and Simulation approaches.

Observational approach

The observational approach measurement of UHI intensity is divided as follows:

Field Measurement

This involves the measurement of temperature by the following methods:

a. Fixed Station

It is the simplest and most commonly used method for analysing the intensity of heat island for any given area. Weather data, specifically temperature data from two or more fixed locations is compared for a defined period to get the temperature difference(Gartland, 2008).

b. Mobile traverses

It is difficult to find many fixed stations at right locations in any city to yield a clear two-dimensional picture of the heat island. Setting up a temporary fixed station for study purpose can be difficult as well as very expensive. Taking a mobile transverse is an economical way to study the intensity of heat island for an area. Mobile transverse involves taking readings using a single set of weather instrument by travelling on a pre-set path throughout a region stopping at representative location(Gartland, 2008).

c. Vertical sensing

Vertical sensing helps especially in identification of BLUHIs. Methods taken up to measure the heat island intensity includes sending instrumented balloons aloft, installing monitoring equipment on radio towers, or flying at different altitudes in an instrumented helicopter or airplane(Gartland, 2008).

Thermal remote sensing

Fixed station and mobile transverses are used for monitoring temperatures of both the atmospheric and surface layers, whereas remote sensing is used to find temperatures and other characteristics of mainly the surface. Remote sensing data helps to visualise temperatures over large areas, however, it is only the birde birds are used for monitoring temperatures of both the atmospheric and surface layers, whereas remote sensing is used to find temperatures and other characteristics of mainly the surface. Remote satelites are continuously circling the earth (Gartland, 2008).

Small-scale modelling

A small scale model of an urban area is developed to study the UHI effect. The prototypes are tested either using wind tunnels or outdoor spaces, tough it is sometimes hard and unfeasible to ensure similarity between real case and prototype. Small scale model can help to study the impact of limited number of parameters of a small region or a building on its environment(Mirzaei & Haghighat, 2010).

Simulation approach

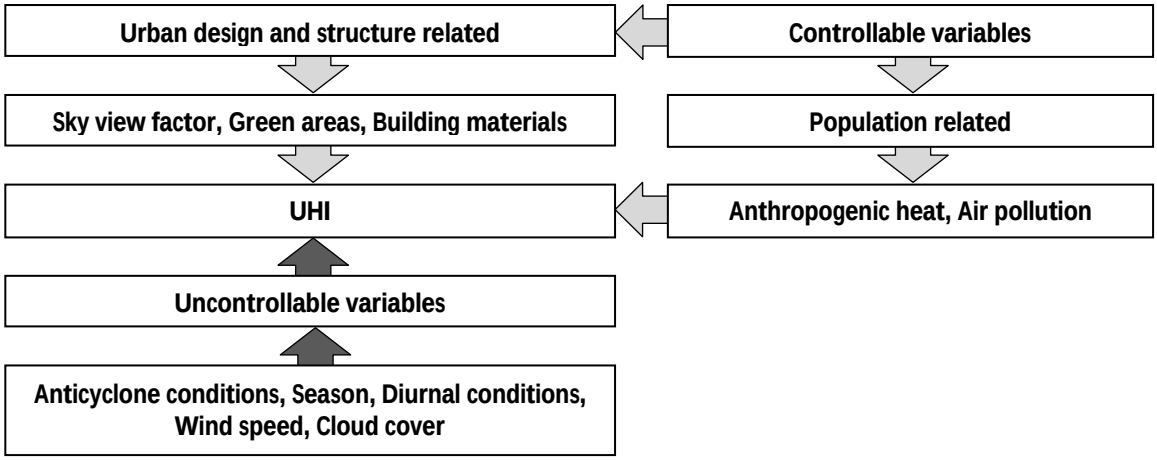
In this approach mathematical models have been developed to address the large scale UHI problems. However, due to the complexity of UHI, major simplifications are generally required nevertheless the advancement in computational techniques has helped researchers to address the urban climate problems. Among the models worked upon energy balance showed the most reliable and satisfactory outcome (Mirzaei & Haghighat, 2010).

Energy balance model (simplified model)

The energy balance equation is based on the first law of thermodynamics, which states that the energy in and out of any surface must be conserved. In that case of a surface on the earth, the equation is generally written as: Convection+ Evaporation+ Heat storage = Anthropogenic heat + Net radiation (Gartland, 2008). This model considers the atmospheric phenomena, turbulence fluctuations and velocity field as heat fluxes (Mirzaei & Haghighat, 2010).

Causal factors

Several factors have been identified which contribute to the heat island effect in urban areas. Memon, Leung and Liu divided the heat island causal factors into uncontrollable and controllable variables (Memon, Leung, & LIU, 2007) as below:



Source: (Memon, Leung, & LIU, 2007)

Figure 5: Urban heat island causal factors

The uncontrollable factors include anticyclone conditions, seasonal changes, wind speed, cloud cover and diurnal conditions. Amongst these uncontrollable variables it has been indicated heat island effect is highest during calm and composed weather (Gartland, 2008). One study indicated that with wind speeds of greater than 0.8m/s there could be a visible decrease in maximum UHI and with wind speeds of more than 7m/s UHI of 0.3°C or less could vanish (Kim & Baik, 2002). Another study, found that with a city average wind speed of 4m/s during night time and 2m/s during day time heat island of higher than 1°C could still be observed (Kłysik & Fortuniak, 1999). Similarly, a study by Oke (Oke, 1982) a established negative correlation of UHI with cloud cover and wind speed and another by Morris indicated that the UHI intensity is approximately the fourth root of both the wind speed and cloud cover (Morris, Simmonds, & Plummer, 2001). A previous study by the research team for this project on urban microclimate studies also pointed to the possible reduction of ambient urban temperatures with increasing wind speeds. On the whole the degree of influence of uncontrollable variables on heat island effect indicated by various research works is region specific and much more work is required in this area.

With regards the controllable variables these are branched by the Memon study into urban design and structure related and population related variables (Memon, Leung, & LIU, 2007). Here, urban design and structure related variables are posited to include sky view factor, green areas, and building materials; and population related variables anthropogenic heat and air pollution. The degree of influence by controllable factors has been widely researched around the world. A U.S. Department of Energy report identifies numerous research studies establishing the relation between controllable factors and urban heat island (EPA, 2008).

At present the study examines the controllable variables within the broader structure proposed by Memon et al. (2007) with some modifications. Parameters falling under the controllable variables are therefore delineated as:

Urban Lifestyle

- **Transportation Mode**(public, private) arising from preferences for mobility
- **Cooking & Appliances**(burners & stoves, fridge &ovens, washers & dryers) arising from conveniences for the home

- **Building Equipment**(air-conditioners, lights, lifts & pumps) arising from aspirations of comfort

Urban Structure

- **Landuse Planning** (buildings, infrastructure, industry, park, roads)
- **Building Morphology** (ground coverage/open space, FSI/building heights, H:W ratio/skyview)
- **Surface Character** (ground cover, building material, water bodies)

These above mentioned variables contribute to the formation of heat islands in the following ways:

Cities have a larger surface area as built up area (land use and land cover) compared to rural areas and therefore more heat is stored. Low albedo materials (surface and building thermal properties) absorb the short-wave radiation from the sun and emit it slowly even after sunset. Reduced usage of permeable materials and reduced vegetation cover as well as fewer water bodies further reduces evaporation from urban areas as well, reducing energy absorption as latent heat. The emitted radiation, moreover, gets trapped by multiple reflections between buildings and street surface, the obstruction of the sky by buildings (sky view factor) resulting in a decreased long-wave radiated heat loss from street canyons. The turbulent heat transfer within streets is also decreased by a reduction of wind speed due to buildings. Furthermore, air pollution adds to effect by absorbing and re-emitting long-wave radiation to the urban environment. Anthropogenic heat is also released by combustion processes such as traffic, space cooling and industries further adding to the heat balance contributing to UHI.

Measured Impacts

UHIs can affect a community's environment and its quality of life. There are some positive impacts: lengthening the plant growing season or improving thermal conditions in winters and in cold climates, however, the impacts can often be negative, including and not limited to: worsening summertime discomfort, increase in energy consumption, higher emissions of air pollutants and greenhouse gases, compromised human health, impaired water quality etc. The prime impact is of increased temperatures referred to as UHI intensity in patterns described above.

The higher temperatures, however, also speed up the chemical reactions that lead to ozone formation. Ozone is a result of nitrogen oxide reacting with volatile organic compounds in sunlight and at surface level, is a harmful pollutant. It was calculated that for every 0.03°C rise in temperature, polluted days may increase by 10%. It is however, not just air temperature that affects air pollution, other contributing factors include changes in the air's dew point, air pressure, cloud cover and wind speed. The rebound effects of each of the above mentioned affects the UHI intensity. (Akbari, 2009).

With the increase in summertime temperatures, the heat island effect increases the use of energy in terms of air conditioning usage and adds pressure onto the electricity grid during peak hours, which further increases the emissions of greenhouse gases. The peak hour electricity demands increase 1.5 to 2% for every 0.6 °C increase in summertime temperature (Voogt J. A., 2004). The increase in temperature and thus the energy demand also causes health and economic impacts. It can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality (EPA, 2013). Phenomenon such as heat waves put vulnerable groups such as young children, adults with health conditions and the elderly particularly at risk from heat related illness.

Mitigation Strategies

The intensity of urban heat island can be reduced by adopting various mitigation strategies. UHI mitigation will help in reducing the local temperature, energy demand, and CO^2 emissions, will improve air quality and human health and overall improve human comfort especially in cities having warm climates. Various strategies linked to causal factors like mutual shading, increasing surface permeability, cool roofs, green roofs, cool pavements, increasing urban green areas, and application of high albedo material and finishes have been acknowledged and implemented around the globe.

1. Status of Research

This section critically examines the research work carried out internationally and in India on the subject of UHI.

International Research

This section reviews the key international papers examining the causal factors, measured impacts and mitigation strategies related to UHI.

The attached table summarizes the UHI causal factors and significant findings of specific studies.

	Some Significant Findings	No
Landuse Planning	UHI obvious manifestation of urbanization observed in every city (Landsberg, , 1981) UHI intensity directly proportional to population size & density (Oke, 1987)	5
Building Morphology	Low SVF directly related to UHI intensity esp. in the day (Yamashita, et al., 1986) UHI increase by 3% with decrease in SVF by 1% in Hongkong (Giridharan, et al., 2004) Densely arranged buildings lower wind speeds and heat dispersion (Akbari, 2009) High rise high density areas have higher temperature for longer (Wong & Yu, 2004)	7
Surface Character	5-10 % lower albedos in urban areas results in more short wave radiation absorption (Shahmohamadia, et al., 2011) Exposed surfaces have up to 27–50°C higher temperatures than air (Berdahl & Bretz, 1997). Lower evapotranspiration rates major factor in increasing urban daytime temperatures (Taha H. , 1997)	7
URBAN LIFESTYLE	Anthropogenic heat increases the near surface air temperature (Taha H. , 1997) Transportation use directly related to city size and role of the public transportation (Shahmohamadia, et al.,2011).	2

Table 2: UHI causal factors summary sheet

Landuse planning can affect the proportion of built and unbuilt spaces in a region. Landsberg (1981) stated UHI as an obvious climatic manifestation of urbanisation which can be observed in every town and city. As per the United Nations World Population Prospects Revision Report of 2011, in 1950 30% of the world's population lived in urban areas and by 2030 this number is expected to reach to 60%. This rapid increase in the rate of urbanisation is one of the main reasons which has lead to a brisk transition of natural vegetation to manmade engineered structures. In the years to come, most of the world's urban population growth is expected to occur in the hot and arid regions of the world (Baker, Brazel, & Westerhoff, 2004).

In urban areas, also, because of the use of massive construction materials within a very small space the ability to release heat by long wave radiation is decreased resulting in heat storage in building structures and thus warming of the space (Memon, Leung, & LIU, 2007). A study conducted in Singapore indicated that areas having high rise high density (low sky view factor) result in longer retention of heat and thus higher temperatures for longer periods even after the sunset as compared to sparsely dense areas having high sky view factor (Wong & Yu, 2004). Research by Yamashita et al.(1986), through controlled sky view factor (SVF) (Sky View Factor: defined as the ratio of the area occupying the sky view to the whole sky area) readings established increase in air temperatures as the SVF decreased. The study also noted that the daytime air temperatures showed stronger correlation to lower SVF. Research done by Blankenstein and Kuttleron (2004) the other hand, found a strong

interrelation between long-wave radiation and SVF but weak between SVF and air temperature, concluding that the air temperature was influenced by many other factors and thus was challenging to predict using SVF alone. A study conducted at high rise high density developments of Hong Kong indicated an increase in UHI by 3% when SVF decreased by 1% (Giridharan, Ganesan, & Lau, 2004). Moreover, in case buildings are densely arranged, only low winds are allowed which hampers the dispersion of air and heat pollutant (EPA, 2008)(Akbari,2009).

Rapid urbanisation has also led to changes in the earth's surface characteristics. Green cover has been largely replaced by impervious cover in cities that store radiation in form of heat energy. On an average the urban albedos are 5-10 % lower than the rural value which contributes to the greater diurnal absorption of short-wave radiation in urban areas (Shahmohamadia et al.2011). A study by Hamdi and Schayes (2008) highlighted that increasing thermal diffusivity, surface albedo, heat capacity, and fraction of vegetation and roof planting, decreases summer peak temperature during daytime. Another study highlighted that lower evapotranspiration rates in urban areas are a major factor in increasing daytime temperatures (Taha H. , 1997). Berdahl (1997) established that on a hot sunny summer day the exposed urban surfaces such as roofs, pavements etc. can have 27–50°C higher temperatures than the air.

The anthropogenic heat in urban areas affects the near-surface air temperature the most and plays a role in creating urban heat islands (Taha H., 1997). In some high density areas, total anthropogenic heat release may be greater than or equal to the solar input. This is owing to the excessive use of air conditioning/ heating systems as well as urban transport operations.

Air pollution is largely contributed to by transportation use as well. Transportation use is a directly related to city size and the relative role of the public transportation in it. In terms of vehicle emissions in urban canyons, studies showed that pollutants followed the traffic flow rate. Also in urban canyons pollutants were up to 16% higher on the leeward side compared to the windward side, pollutants can be up to 107% higher when wind speeds are low, i.e. between 2 and 4 m/s (Tsai & Chen, 2004)

With regards the impacts of UHI studied by research works internationally, these are broadly given in the table below.

	Some Significant Findings	No
TEMPERATURE INCREASE	• Upto 12°C UHI intensity recorded during evening/ night time (EPA, 2008) • City with population of more than 1 million may have the annual mean air temperature difference ranging from anywhere from 1–3°C (EPA, 2008)	8
ENERG USE & EMISSIONS	• Increase in temperature by 2.5°C causes 1500 MW increase in energy (Akbari, 2002) • Cities with populations over 1 million use approximately 1billion KWH per year with each KWH creating half a pound of carbon as CO2 (Akbari, 2009)	7
AIR QUALITY	• Positive correlation between air pollutants and urban density (Lai & Cheng , 2009) • CO^2 dome existence was confirmed and identified as being 75% stronger than the surrounding rural area (Idso, et al., 2001)	5
HEALTH IMPACTS	• Mortality rates increases 9% with 0.3°C increase in temperature (Ostro , Roth, Green, & Basu, 2009)	4
ECONOMIC IMPACTS	• UHI annually costs Los Angeles $100 million in energy (Heat Island Group, 2013)	3

Table 3 UHI measured impacts summary sheet

The Urban Heat Island effect is characterised by an increase in air and surface temperature in urban areas with respect to rural areas. Studies have indicated varying range of UHI intensity. A city with population of more than 1 million may have the annual mean air temperature difference ranging from anywhere from 1–3°C to 12°C more that its surroundings (EPA, 2008). Often temperatures in the urban areas can be up to 4.7°C more than the rural surroundings (Weng & Yang, 2004)(Wong & Yu, 2004). A study in Tokyo has indicated that in past 20 years the total duration of time with air temperature above 30°C has about doubled.

Rising temperatures increases the demand for cooling which results in increased usage of air-conditioning units and fans. In USA a sixth of all electricity generated is used to cool buildings using air conditioners, and of this, 50% consumption occurs in cities that have been classed as urban heat islands (Akbari, 2002). Increasing local downtown temperatures of a city have also been noted to increase the community-wide demand for electricity by 5- 10%, often to counter the heat island effect (Douglas, 2002). It is estimated that the temperature of Los Angeles has increased by 2.5°C since 1920 adding to 1500 MW increase in energy demand. Cities with populations over 1 million use approximately one billion kilowatt hours per year with each kilowatt hour of electricity creating half a pound of carbon in form of CO2 (Akbari, 2009). Further in a two week intense study of the "CO2 dome" its existence was confirmed and identified as being 75% stronger than the surrounding rural area (Idso, Idso, & Balling Jr., 2001).

Studies have also indicated a positive correlation between UHI and air pollutants. Lai studied air quality and its association with urban heat islands using statistical analysis of real data and simulations, he found that certain weather patterns deteriorate air quality. He found that high UHI

intensity is correlated with the increased concentrations of air pollutants that gathered at night and affect the air quality the following day (Lai & Cheng , 2009) (Yoshikado & Tsuchida, 1996).

In addition, various heat-related health conditions have been associated with Urban Heat Islands. It has been found that people in homes with dark roofs, on upper floors, with windows on two sides, and of brick construction, may be particularly at risk from extreme heat during heat waves (EPA, 2008). The heat wave of 2003 in Europe caused 35,000 deaths (Treasury, 2006). A study on the July 2006 heat-wave in California showed a daily mortality rate increase of 9% per 0.3°C increase in temperature, about 3 times greater than for full summer non heat-wave seasons (Ostro , Roth, Green, & Basu, 2009). McMichael and Beaglehole (2000) have highlighted that heat waves claim more lives each year than hurricanes, floods & tornadoes combined.

Energy use and health impacts both result in increased economic implications. In the US electricity used to air-condition buildings equates to approximately $40 billion a year in energy bills (Akbari, 2002). If half the air-conditioning usage is attributable to Urban Heat Islands then possible UHis account for about nearly $20billion a year for energy. The 2003 heat wave of Europe caused agricultural losses of $15bn across three countries. Heat island formation around Los Angeles annually costs the city $100 million in energy (Heat Island Group, 2013). Such losses incurred by extreme weather events are rising, according to the Stern Review: Economics of Climate Change (Treasury, 2006).
To mitigate the above cited largely negative effects of Urban Heat Islands, various measures have been recommended and applied internationally, the types and broad effectiveness of some of which are documented in the table given below.

	Some Significant Findings	No
Landuse Planning	• Specific land use planning policies can reduce SUHI by almost 40% (Stone & Norman, 2006) • Meticulous land use planning by incorporation of good wind circulation, combining vegetation and water installations, proper distribution of green spaces, promoting public transit can help in countering the UHI effect (Giguère, 2009).	4
Building Morphology		0
Surface Character	• 25%-40% increase in albedo value temperature drops by 1–4°C (Taha, Rosenfeld, Akbari, & Huang, 1988) • Raising roof reflectivity by 40-50% decreases building cooling demand by 20% (Akbari, 2005) • Water has an average cooling effect of 1–3°C to an extent of about 30–35 m (Robitu et al., 2004)	11
URBAN LIFESTYLE		0

Table 4: UHI proposed mitigation summary sheet

Mitigation strategies relating to urban planning and the built form have been somewhat limited. One study suggests that the contribution of individual land parcels to regional surface heat island formation could be reduced by approximately 40% through the adoption of specific land use planning policies, such as zoning and subdivision regulations, and with no modifications to the size or albedo of the residential structure (Stone & Norman, 2006). A report by Giguère (2009) highlights that

meticulous land use planning by incorporation of good wind circulation, combining vegetation and water installations, proper distribution of green spaces, promoting public transit can help in countering the UHI effect.

With regards to built morphology, one reference by Futcher (2008) indicated that overheating by solar radiation in summer may be reduced with high ratios of street height to street width. However, this may also reduce air flow, lower the SVF and promote multiple solar reflections leading to the trapping of heat. Shading buildings with trees and green walls, which are green in summer and transparent in winter, may be a better alternative. Another study suggested that the orientation of streets taking into account the solar and wind orientation could also be helpful but could bring some design challenges (Kleerekoper, Escha, & Salcedob, 2012). Brian (Stone R., 2007) in his report outlines a set of design strategies which have proven successful in mitigating urban heat effect.

Surface character, however, has received the largest coverage amongst the mitigation strategies. Taha et al.(1988) established that a 25% to 40% increment in albedo values in a city will result in a temperature drop of 1–4°C. Simulation results also indicated there can be a reduction of 62% in cooling energy demand when both the city-wide albedo and building albedo are increased. Akbari (2005) identified that there can be 10%-40% reduction in energy use by application of reflective coating on building roofs and pavements. Another research project in Singapore focussed on the difference in temperature on building facades due to dark or light colours. A maximum temperature difference of 8 ℃ to 10 ℃ on the external wall was measured during 13.00 and 16.00h (Kleerekoper, Escha, & Salcedob, 2012). Reports on strategies to mitigate UHI in London and in Quebec highlight the use of high albedo materials to curtail the UHI effect (Greater London Authority, 2006)(Giguère, 2009). The application of cool roofs/ green roof therefore has huge potential of lowering the surface temperature as well air temperature and thus also translates to large energy savings. UHI mitigation strategies adopted by London, Quebec, and California highlight the use of cool roofs (Greater London Authority, 2006)(Giguère, 2009) (USEPA, 2009).

Vegetation cover has been identified as an important mitigation strategy. One study highlighted that on a sunny day the evapotranspiration of a tree cools with a power equal to 20–30 kW, a power comparable to that of more than 10 air-conditioning units (Kravcík et al., 2007). Another research study suggested that a 25% reduction in the impervious cover of an average single-family parcel is associated with a 16% reduction in the net black body flux. It also indicated that for the average single-family parcel, an increase in tree canopy cover from 45% to 60% reduced the parcel net black body flux by 14% (Stone & Norman, 2006). It has been found that vegetation cover spread over an urban area of 100-1000sqm has an average cooling effect of 1–4.7 ℃, although this is dependent on the amount of water the plant or tree has available or the emissivity value of the green cover (Schmidt, 2006). Another study found that greening leads to an average decrease of 0.2–1.2 ℃ in the near-ground temperature and cooling energy savings of 4–40% (Yukihiro et al., 2006). According to a study, a park of 0.15 ha had an average cooling effect of 1.5 ℃ with noon-time difference reaching 3 ℃ (Shashua-Bar and Hoffman, 2000). Another study in Göteborg established that a large cooling effect is produced by a larger green area and measured a maximum difference of 5.9°Cin summer by 156ha green area (Upmanis , Eliasson, & Lindqvist , 1998).Research has highlighted that incorporating green areas within London city may cool the city by as much as 2 or 3°C (Barlow, 2010).

The use of water itself has also been identified as an effective strategy. It has been established that water has an average cooling effect of 1–3 ℃ to an extent of about 30–35 m. A study conducted to

examine the cooling effect of a pond of 4m × 4m indicated that the cooling effect was about 1 ℃ at a height of 1 m, measured at a 30 m distance from the pond (Robitu et al., 2004). The effect of the water system can be felt (from 14.00 to 15.00 h) up to a 35 m distance (Nishimura et al., 1998).

Overall strategies such as increasing vegetation cover by planting trees for shading, providing evaporative cooling, and increasing reflectivity of the exposed surfaces such as roofs in order to reduce the amount of radiation absorbed, have received the most attention worldwide (Rosenfeld, et al., 1995).

Research in India

A fair amount of research has been conducted in India on building energy demand, vehicular increase, as well as climate change related to urbanisation. The Urban Heat Island has, however, remained among the less researched issues. Dedicated research on the heat island effect in India has primarily covered the observation and documentation of the effect city-wise in the country

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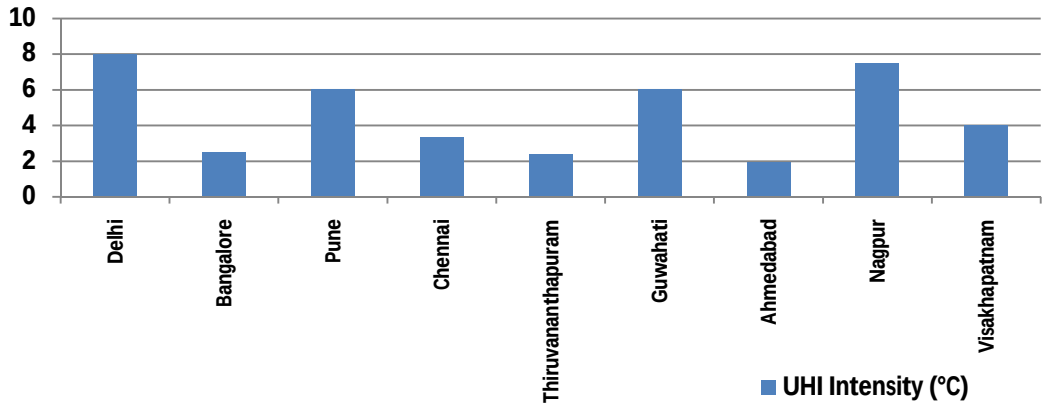


Figure 6: Observed UHI intensity by various research works.

This section reviews the causal factors, measured impacts, and mitigation strategies related to UHI identified by the research efforts in India is summarized in the table below.

City	Delhi	Bangalore	Pune	Chennai	Thiruvananthapuram	Guwahati	Ahmedabad	Bhopal	Nagpur	Visakhapatnam
CAUSAL FACTORS										
Landuse Planning	■	■	■		■	■	■			■
Building Morphology	■	■	■	■		■	■	■	■	■
Surface Characteristics								■		
URBAN LIFESTYLE				■						
MEASURED IMPACTS										
Temperature Increase	■	■	■	■	■	■	■	■	■	■
Energy Use& CO2 Emissions										
Air Quality										
Health Impacts										
Economic Impacts										
MITIGATION MEASURES										
Landuse Planning									■	
Building Morphology										
Surface Characteristic		■						■		
URBAN LIFESTYLE										

■ Identified factors in particular study.

Table 5: Status of research conducted in India

Studies carried out in the some of the major cities in India have shown that urbanisation has had an extreme effect on the climate of these cities and UHI intensity(Deosthali, 1999) establishing increasing urbanisation and associated characteristics to be closely linked to the formation and extent of heat islands.

DELHI

A study conducted by IIT Delhi in Delhi has found the maximum and minimum heat island intensity to reach temperatures of 8.3°C and 4.7°C respectively. Also it has been exhibited that the UHI intensity tends to be maximum at night around 9 PM when the temperature increases range from 2.8 °C to 8.3 °C, and in the afternoon hours around 3 PM with temperature increases of 3.8 °C to 7.6 °C compared to early morning hours. Considering that the period of temperature measurement was moderate temperature condition the heat island intensity obtained was very high at different time intervals of the day (Mohan et al., 2012).

BANGALORE

A study carried out by IISC Bangalore at Greater Bangalore shows an increase of ~2°C to 2.5°C in air temperatures in the past decade. The study also shows a growth of 632% in urban area of Bangalore from 1973 to 2009 and a 76% and 79% decline in vegetation cover and water bodies respectively in Greater Bangalore (Ramachandra & Kumar, 2010). Another study conducted by TERI for the city of Bangalore highlights 1.5°C higher temperature in Commercial Street, a high density area as compared to city outskirts having low density. The study also highlights a 1.5°C- 1.9°C reduction in peak air

temperature by use of reflective roof or green roof and by the use of reflective roof material for commercial buildings and suggests that by improving micro climate there can be an expected saving of 1642MWh/yr (SANEI, 2012-2013).

PUNE

Studies conducted in Pune have showed the formation of large high intensity urban heat islands in the core of Pune city covering 8% of the total city area (146 sqkm) and accommodating 33% of the city population (1.5 million), including isolated warm pockets distributed over the city (Deosthali, 1999). Another study highlighted a 32.68% per cent increase in built up area, 10% decrease in agriculture land, and 21.91% decrease in barren land from 1999 to 2009. Also a rise of 1°C-6°C has been shown in land surface temperatures from the year 1999 to 2006 (Patki & Alange) . These studies cited for the context of Pune city, again point to the elsewhere noted relation between increasing urbanization and the heating up of the city environment.

CHENNAI

The existence of heat islands has also been observed for the city of Chennai. Increasing temperatures have been noted from the suburbs towards the city centre in a radial pattern indicating the existence of heat island/ dome. The mean maximum heat island intensity observed has been 2.48°C during summers and 3.35°C during winters (Devadas & Rose A, 2009).

THIRUVANANTHAPURAM

At Thiruvananthapuram, a maximum UHI intensity of2.4°C was recorded for the city centre, in comparison to the city suburbs. In this case, as well, the regions exhibiting the higher temperatures fell under high density categories of the built environment, including compact low rise and compact midrise developments. The major physical characteristics of these developments include densely packed buildings of 1-3 stories (low rise) or 3-8 stories (mid-rise) with narrow streets. The study identified that due to the parameters of sky view factor and building height to street width ratio offered by the above typologies, the city demonstrates a cooling rate of about 1.5°C/hr at the maximum as compared to 3.4°C/hr in the rural areas (Ansar, et al., 2012), indicating impacts of the built form aspects of urban structure as implications on the city heat islands.

GUWAHATI

The study conducted at Guwahati shows areas of human intervention, such as towns and cities to be characterized by closed isotherms indicating pockets of surface warming. Studies have also documented a decrease of 26% in dense vegetation over the years from 2000 to 2009, a 23% increase in high density settlements, and a 16% decrease in open space. These have found that as the low density area converted to a high density over a period of 10 years area, there has been a corresponding recorded temperature increase of 6°C. In addition the massive decrease of vegetation cover in the hills and reserve forest areas have caused a temperature increase of 3°C and more in the surrounding city (Borthakur & Nath, 2012).

AHMEDABAD

Surface temperature images of Ahmadabad for the years 2000, 2007 and 2010 have clearly shown Urban Heat Island formations over the city as well. These have also indicated an increase in temperatures from the outskirts of the city to the core of the urban area and have attributed these to an increase in densification and reduction in open spaces towards this area. The study further also implicates the increase in the extent of the UHI on the increase in urbanization. UHI intensity has been indicated as 1.51°C, 1.62°C & 1.95°C for the year 2000, 2007 & 2011 respectively highlighting the increasing UHI intensity with increasing urbanisation (R.S & Raoa, 2012)

BHOPAL

Areas in old Bhopal have also been found to have prominent Urban Heat Islands of high intensity with areas of high green cover or light surfaces with high albedo material with reduced intensities. The study highlights vegetation effects in temperature reductions of about 2°C-3°C (Gupta, Dey, & Goel, 2009) implying its possible role in mitigating the impacts of heat islands.

NAGPUR

Studies carried out at Nagpur have indicated the influence of landuse and landcover of an urban area on the air temperature of the city and this Urban Heat Island formation. The temperature difference of 7.5°C is highlighted by mapping the air-temperature contours within the city. landcover types like water and vegetation were identified to have lower temperatures and high density areas to have higher temperatures (Katpatal, Kute, & Satapathy, 2008), again implying possible roles in reducing heat islands.

VISAKHAPATNAM

A study conducted for Visakhapatnam region revealed that urban heat islands could be complicated zones with multiple cores corresponding to the urban morphology. It was observed also that heat islands were noticed over the thickly built up areas with intensities varying from 2°C to 4°C. It was also observed that the rate of decrease of temperature during winter nights was 0.30C/hr in urban areas compared to 0.50C/hr in rural areas (Devi, 2006), possibly contributing to the observed high intensities in the former areas.

SUMMARY

The research internationally has taken into account the various factors involved in the formation of UHI, the impacts of UHI and how to mitigate the effect, however, research conducted in India has not as extensive.

Internationally the maximum UHI intensity is recorded as high as 12°C, and landuse and landcover, building density as well as morphology, and lifestyle related anthropogenic emissions are considered as the prime contributing factors. In India the maximum observed UHI intensity is of 8°C and the research conducted for highlights city density and landuse type (residential, commercial, green cover, etc) as the major causes of UHI intensity. Lifestyle related anthropogenic emissions (heat & pollution) have not really been focused upon in the Indian studies.

With respect to a documentation of the impacts of the UHI, while International research indicates higher energy consumption, increased temperature, increased air pollution and health and economic impact, Indian research largely highlights only temperature increase as a UHI impact. Studies conducted in different Indian cities highlight the intensity of heat island varying with the city pattern and its impact on energy demand, air quality, health and economy is missing.

Moreover, internationally strategies proposed to mitigate UHI are incorporated into urban planning guidelines, building construction codes, etc., whereas India is still on the stage of discovering the urban heat island phenomenon. Only a couple of studies have even begun to consider the relative mitigation impacts of strategies. That said, the mitigation strategies internationally have primarily focussed on surface character changes while aspects of planning and built form get less emphasis and those of urban lifestyle are mostly taken as given This probably derives from the status of research and empirical evidence on each of aspects and their combined effects as well as implementation feasibilities.

Overall, although globally there is good coverage of the Urban Heat Island parameters, the relative degree of influence of the various parameters and their combined effects is still unclear. It is apparent that UHI intensity varies with the climate type, city density, and city energy consumption and the region/ area specific degree of influence by various factors will need to be considered. In India while the studies indicate the presence of UHI and also consider it as an environmental issue the degree of influence of various factors will have to be established. Besides, increasing energy demand, increasing air pollution, deteriorating health, and such aspects need also to be researched and their empirical relation with UHI needs to be established in order to propose mitigation strategies

INITIATIVES AND POLICIES

1. International Policy Framework

This survey looks at policies with respect to UHI developed by transnational, global institutions or multinational, regional institutions and by national bodies and governments in different parts of the world.

1.1 General

The recommendations and programs of all international institutions flow from the mandates adopted from the United Nations Framework Convention on Climate Change (UNFCC), the most recent being the Durban Platform for Enhanced Action (2012). Rapid urbanization in the developing economies is identified as the emerging arena for mitigating environmental impacts, especially with respect to an anticipated increase in GHG emissions by a multiplier effect of growing global populations shifting to urban habitations. The institutional framework for adoption of UHI related policies at regional and national levels follows varied models. The European Union, under its European Environment Agency has a program with a special focus on UHI, which supports implementation of pilot projects backed by research and documentation. In the United States of America, implementation initiatives are under the purview of state governments and urban local bodies. Some local bodies have instituted by-laws with regard to UHI mitigation. The federal government may adopt policies based on research and recommendations of the Environment Protection Agency and make financial provisions or give fiscal incentives. Japan has established a comprehensive integrated model to address UHI specifically. Similarly, Israel has instituted a broad based research group on UHI.

All voluntary environmental certification programs such as LEED and BREAM, and similar programs which are used in many parts of the world, do address UHI. Their limitation, however, is that they are limited to discrete projects and do not address town planning strategies or development controls which have a determining influence on urban microclimates.

1.2 United Nations

Under the UNFCC the Parties to the Convention (COP) established the Global Environment Facility (GEF) as an entity entrusted with the financial mechanism of the Convention, on policies, programme priorities and eligibility criteria for funding projects. Amongst other environmental issues, the GEF also supports projects to reduce GHG emissions. It is of interest to note the GEF has supported a 30-year project toward reduction of Urban Heat Island effect in the city of Delhi by measures of afforestation in the surrounding areas of the National Capital Region. This project was taken up though the Department of Forests and Wildlife in India. The project recognizes the impact of loss of vegetation on the Urban Heat Island effect in the city, and the need to increase green cover to address the same. However it remains to be seen if afforestation in surrounding areas helps mitigation within the city.

Intergovernmental Panel on Climate Change (IPCC) 2014

The IPCC, which is constituted under the United Nations Environment Programme, brings out an annual report on Climate Change. The latest report has a chapter dedicated to UHI**.** The report recognizes research that confirms the coincidence of UHI with urban densification due to changes in surface characteristics, reduction in vegetative cover and increase in anthropogenic heat. UHI mitigation is seen as a necessary strategy toward limiting GHG emissions in urban areas. Interestingly, focus is seen to shift from mitigation measures at the level of buildings towards urban design and urban development controls. Urban morphology that allows flushing breezes and

distributes soft ground, biomass and water bodies would produce cooler urban microclimates. This would be particularly applicable for rapidly urbanizing economies where urban extensions and new towns are being built. Also, it is noted that design and environmental strategies that mitigate UHI have parallel benefits in safeguarding health and protecting biodiversity. The report also flags the need for further research regarding urban systems and their cumulative impact on GHG emissions in order to establish reference baselines and have measurable targets for GHG reductions.

World Bank

The implications of Climate Change and Global Warming are sought to be addressed in the World Bank's development programmes. In the Bank's literature discussing development challenges UHI is considered as one of the risk factors that are to be anticipated with urbanisation and increasing densities. Rising temperatures in urban areas due to UHI are identified as a health risk for poor populations, and especially the young and the elderly.

The report '*Turn Down the Heat, Climate Extremes, Regional Impacts, and the Case for Resilience*', brought out by the Bank in 2013 assesses the vulnerability of Africa, South East Asia and South Asia to Climate Change. It points out that "*high levels of growth both urban population and GDP (further) increase exposure to climate change impacts in these areas . Further, the effect of heat extremes are also particularly pronounced in urban areas due to the Urban Heat Island Effect, caused in large part by the density of the buildings and the size of the cities*" (Postdam Institute for Climate Impact Research and Climate Analytics, 2013)

The report of the 5th Urban Research Symposium on Cities and Climate Change – Responding to an Urban Agenda (2009) highlights how '*Climate Change and Urbanization are converging to create one of the greatest challenges of our time*'. In their paper 'Urban *Heat Islands: Sensitivity of Urban Temperatures to Climate Change and Heat Release in Four European Cities*' presented at the symposium, McCarthy and Sanderson focus on the urban heat island effect, pointing out that the effect is created by heat released through human activity, such as heating and cooling of buildings, traffic exhaust and even human metabolism and further caution that:

> "*Some mitigation options may exacerbate urban vulnerability to climate change. For example, although increasing urban density may contribute toward reducing emissions from transport, this will have negative implications for adaptation, such as intensifying the urban heat island effect and posing problems for urban drainage. Improving our understanding of the synergies, conflicts, and trade-off s between mitigation and adaptation measures would enable more integrated and effective urban climate policy" It further states that due to UHI urban populations "are therefore exposed to both urban-induced climate modification and larger-scale climate change resulting from increasing greenhouse gas concentrations. An understanding of current and possible future changes in the magnitude of the UHI is therefore necessary for planning and developing of adaptation and mitigation strategies. Future heat waves may be underestimated if finer features are not included in model simulations" (Hoornwig, Freire, Lee, Bhada-Tata, & Yuen, 2011)*

1.3 European Union

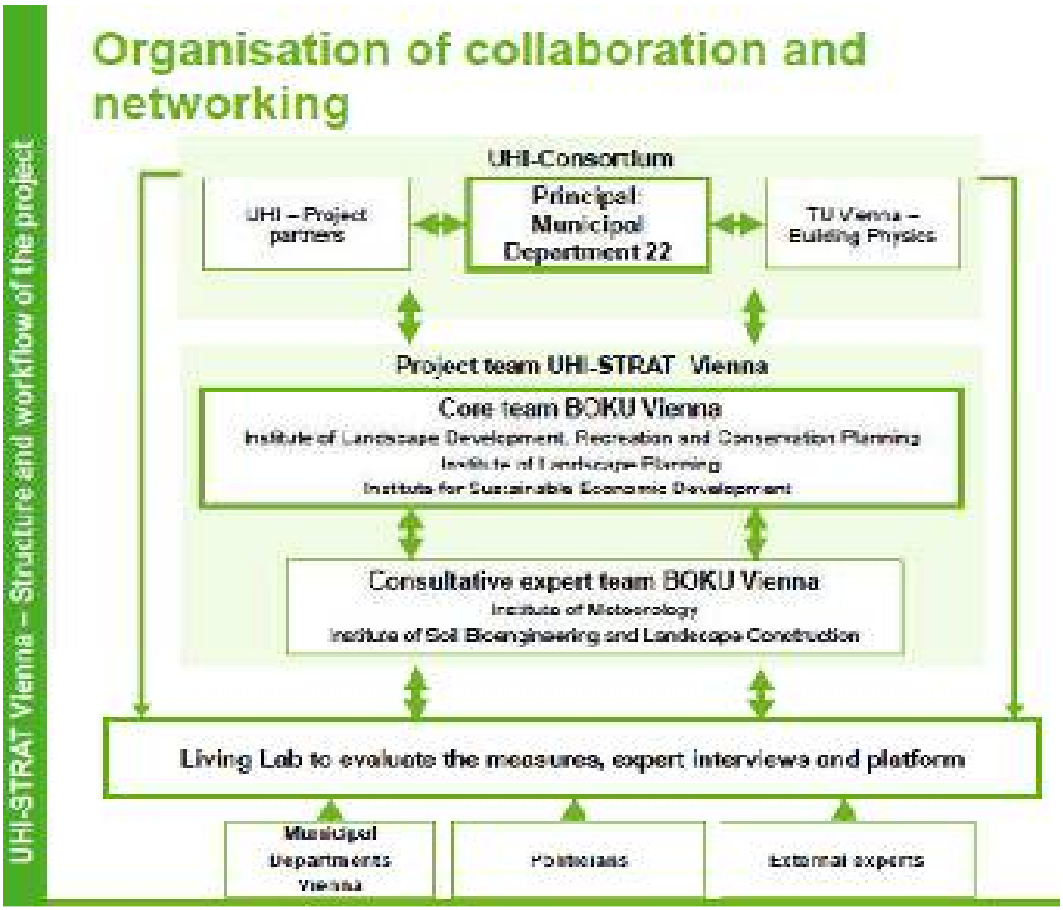
In Europe, the State of the Environment report – The European Environment (SOER-2010) published by the European Environment Agency (EEA) covers the entire European Union. At the regional level, the European Commission and EEA provide guidelines covering overarching topics such as Sustainable Cities and Air Pollution. UHI is again seen as one of the factors of climate change and

mitigation strategies are integrated with more holistic assessments and strategies for improvement of environmental quality and addressing Climate Change.

Europe had adopted the mitigation of UHI whole heartedly in response to increasing mortality and health concerns and a perceived reduction in the quality of life in urban centres due to temperature rise and pollution, particularly during warm and calm seasons. These are the main concerns that have propelled the European Government to action.

The Central Europe Programme co-funded by the European Regional Development Fund (ERDF) which is set up to strengthen ties between some central countries of the European Union, creates opportunities for collaboration between public authorities, institutions and private businesses, by co-financing projects and initiatives under six different mandates, one of which is 'Environmental Risk Management and Climate Change'. There are twenty five projects listed for funding on the Central Europe website. Under this mandate, one project that is focussed on UHI : '*UHI - Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Islands phenomenon*'. The project is led by the Regional Agency for Environmental Protection (RAEP) in Emilia-Romagna, Italy. This project aims to provide a virtual tool for dealing with UHI by raising awareness about the factors and mitigation of the same. The virtual tool is supported by eight pilot projects that have been initiated at different locations in the region to investigate and propose policy and measures to be taken to "*...developing policies and actions for preventing, adapting and mitigating the natural and man- made risks arising from the UHI phenomenon*" (UHI Project, 2014) The projects are distributed over a wide region ensuring different climate types as well as a range of urban configurations on which to study the phenomenon of urban heat islands.

Europe had adopted the mitigation of UHI whole heartedly in lieu of increasing mortality and health concerns and a perceived reduction in the quality of life in urban centres. These are the main concerns that have propelled the European government to action. Centrally motivated action has been taken through pilot projects as well as funding toward innovation. The management is on the central level, but the action has been taken by involving stakeholders on a participatory and local scale. Because of this, the mitigation strategies address various scales of planning and design – as well as lifestyle changes including alternative mobility. Also the pilot suggests that the existing structure of governance be revisited to include environmental concerns such as UHI in its processes.



Source (UHI Project, 2014)

Figure 7 - Regional Agency for Environment Protection project in Vienna- Organisation Chart

Source (UHI Project, 2014)

Figure 8 - Regional Agency for Environment Protection project in Vienna - Master Plan concepts

Source (UHI Project, 2014)

Figure 9 - Regional Agency for Environment Protection project in Venice - Proposal for Building Envelope

<table>
<tr><th rowspan="2">AGENCY</th><th rowspan="2">ACKNOWLEDGEMENT & INSTRUMENT</th><th colspan="4">MITIGATION MEASURES</th><th>PROPOSED INTERVENTION</th></tr>
<tr><th>LAND USE PLANNING</th><th>BUILDING MORPHOLOGY</th><th>SURFACE CHARACTERISTICS</th><th>URBAN LIFESTYLE</th><th></th></tr>
<tr><td colspan="7">EUROPE</td></tr>
<tr><td rowspan="6">CENTRAL EUROPE</td><td rowspan="6">UHI - PILOT PROJECTS IN 8 CITIES SPANNING THE REGION</td><td rowspan="2">GREEN SPACES</td><td rowspan="2">SHADING</td><td>GREEN SPACES</td><td rowspan="2">MOBILITY</td><td>STRATEGIS TOOLS AND LEGAL BASIS</td></tr>
<tr><td>ALBEDO</td><td>MASTERPLAN AND URBAN PLANNING CONCEPTS</td></tr>
<tr><td rowspan="2">MOBILITY</td><td rowspan="2">BUILDINGS</td><td rowspan="2">DE-SEALING</td><td rowspan="2">GUIDELINES</td><td>ZONING AND DEVELOPMENT PLANS</td></tr>
<tr><td>DEVELOPER COMPETITIONS, HOUSING INITIATIVES AND HOUSING PLANS</td></tr>
<tr><td>SHADING</td><td>WEB TOOLS</td><td>PUBLIC UTILITY BUILDINGS</td></tr>
<tr><td>SUBSIDIES</td></tr>
<tr><td rowspan="3">SEVENTH FRAMEWORK</td><td>FUNDING FOR RESEARCH - ENVIRONMENT, ENERGY USE REDUCTION</td><td></td><td></td><td>INNOVATION: HEAT REFLECTIVE TECHNOLOGY</td><td></td><td></td></tr>
<tr><td>Research Technological Development and Demonstration under grant agreement no. 282834</td><td>LIMITING URBAN SPRAWL
Climate change resilient city planning and Climate Neutral Infrastructure</td><td>Climate change resilient city planning and Climate Neutral Infrastructure</td><td>Greening public and private green infrastructure</td><td></td><td></td></tr>
<tr><td>The "TURAS" initiative: communities, businesses, local authorities and researchers for new solutions.9 "work packages" in 12 regions</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 6: -Review of UHI mitigation and intervention in Policies in Europe

1.4 Other Developed Nations

Some developed nations have been working on UHI mitigation for more than two decades now. The factors that contribute to UHI, and the effects of UHI are manifold and interrelated. Due to such an interrelated nature of environmental issues the strategies for UHI are often subsumed under other objectives such as green roofs to reduce energy demand or pervious pavements to reduce flooding. Programmes for addressing UHI directly are few.

In nations where there are programmes to deal with UHI as a primary concern the policy framework is , as one would expect, based on their respective governmental structures. This is brought out in the tables describing policy frameworks discussed below.

Japan

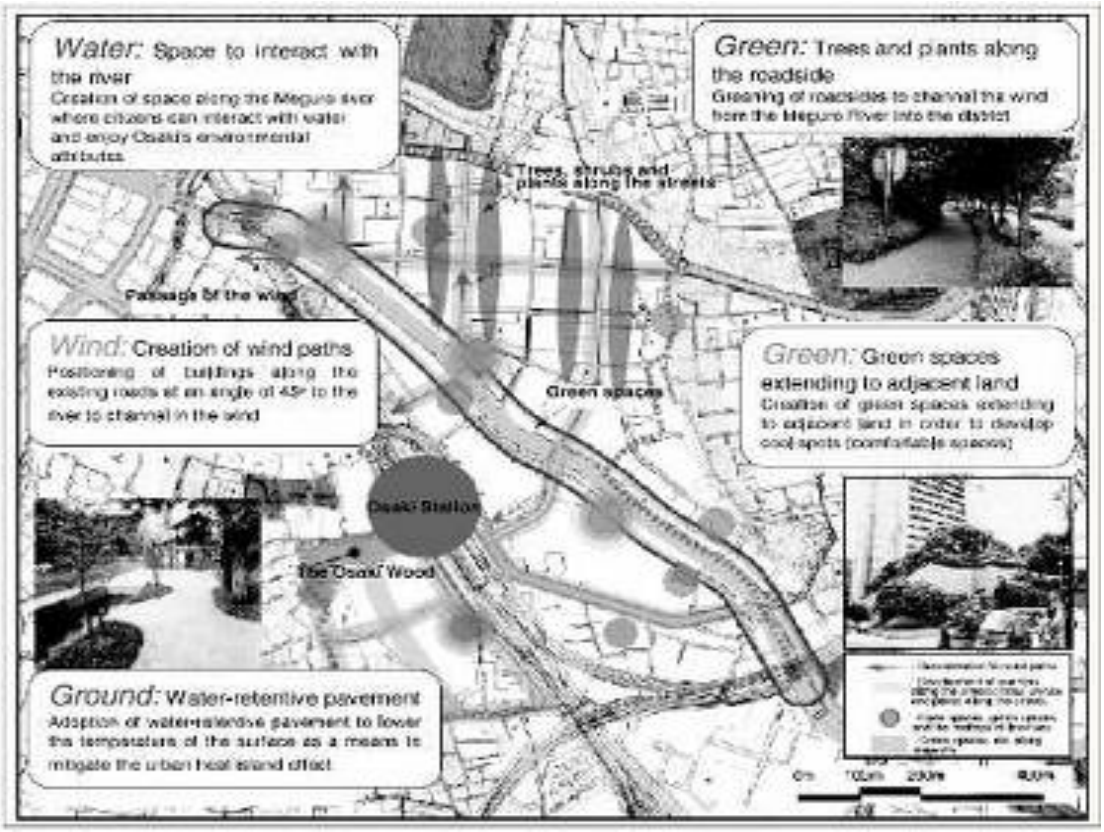
In Japan, the first step in the direction of UHI mitigation was taken with the identification of UHI with air pollution and increased mortality. Since then, over a period of five years, eight model areas for development have been selected where UHI has been studied.

The action toward the formation of policy framework that dealt with UHI mitigation was taken by The Ministry of Environment and the Cabinet Secretariat– which set up an inter ministry coordination committee known as 'The Liaison Council' to mitigate heat islands. The result of these actions and the subsequent policy framework established, included:

1. Anthropogenic heat reduction
2. Improvement of urban surface covers
3. Improvement of Urban Structure
4. Enhancement of Lifestyle

This chart shows the different agencies involved in the formation of Japan's policy related to UHI. As can be seen from the chart, in a very top- down approach, the Japanese Central Government has been proactive in setting up the governance infrastructure for research and mitigation of UHI in Japanese cities. Pollution and mortality have been the greatest concerns and motivators toward central involvement through Projects and Schemes.

The proposed mitigation measures address all scales of intervention – from the use of appliances and energy efficiency in buildings, to street design and Urban Planning. Also important to note is the recognition of lifestyle changes, e.g. preference for public transport over individual motorized transport and clothing styles for comfort, as an important factor of UHI mitigation strategy.



Source (Shinagawa City)

Figure 10 - Proposed measures to mitigate the UHI effect in Shinagawa

AGENCY	ACKNOWLEDGEMENT & INSTRUMENT	MITIGATION MEASURES				PROPOSED INTERVENTION
		LAND USE PLANNING	BUILDING MORPHOLOGY	SURFACE CHARACTERISTICS	URBAN LIFESTYLE	
The Ministry of the Environment defined UHI as Air Pollution						
The Cabinet Secretariat	"Three-Year Program for Promoting Deregulation"					"promotion of comprehensive approaches to the Urban Heat Island effect"
	July 2002: "Basic policies for Urban Renaissance" are framed					UHI mitigation - A means to revitalize urban areas
The Ministry of Land, Infrastructure and Transport, The Ministry of Economy, Trade and Industry and the Cabinet Secretariat	Established Inter-Ministry Co-ordination Committee known as **"The Liason Council"** to Mitigate Urban Heat Islands	urban structure: placement and orientation of buildings, with respect to water bodies	urban structure: placement and orientation of buildings	artificial urban surface covers	1. anthropogenic heat release 2. light clothing ,Idling of automobile engines	"Outline of the Policy Framework to Reduce Urban Heat Island Effects"
Ministry of Land, Infrastructure and Transport	"Guidelines for Architectural Design to Mitigate the UHI Effect"					
Urban Renaissance Headquarters of the Cabinet Secretariat (headed by the Prime Minister)	Eighth Urban Renaissance Project adopted					
The Kyoto Protocol is adopted by the Japanese Govt.	**"CO2 emissions must be reduced by improving the thermal environment through urban heat island mitigation measures such as greening."**					
	MODEL AREAS					
	CASBEE-HI EVALUATION TOOL					

Table 7 -Review of UHI mitigation and intervention in Policies in Japan

United States of America

The United States Environmental Protection Agency (EPA) is the central agency for federal research, monitoring, standard-setting and enforcement activities to ensure environmental protection. In its standard setting and enforcement activities it does not deal with urban development and buildings. However, EPA hosts an informative website on Heat Island effect and also runs a Heat Island Reduction Program. It has undertaken an Urban Heat Island Pilot Project (UHIPP) in which five cities have participated. The purpose of UHIPP was to: *Assist cities in efforts to adopt and evaluate heat island reduction strategies and programs*;

- Encourage research, education, and communication;
- Demonstrate and document successful heat island reduction projects that may be adopted in other communities; and
- Build community support and understanding of heat island reduction strategies.

EPA selected these cities based on the magnitude of the local ground-level ozone problem, the likelihood that the city could benefit from heat island reduction measures, data availability, and local interest in advancing heat island reduction strategies.

EPA has played an active catalytic role in promoting research and disseminating information and knowledge about UHI. "*Reducing Heat Island: A Compendium of Strategies*" published by EPA brings together the examples and experiences of many local urban bodies in their voluntary and regulatory programmes for UHI mitigation and also discusses the potential of zoning and planning regulations, in addition to building codes to reduce heat islands. (EPA, 2008)

Many cities have initiated awareness programmes and instituted policies related to reducing heat island intensities. These cities are principally in the south-western and central regions of United States of America where the rise in summertime temperatures is a concern. Strategies that reduce heat island intensities are seen to have the benefit of reduction in negative health impacts by reducing air pollution and heat stress on vulnerable populations, in addition to avoiding increases in electricity consumption and peak electricity demand for air conditioning. There is an awareness that issues such as air pollution cannot be handled at a micro/ city level alone and are dealt with through State Implementation Plans. These plans are federally approved and enforceable by the state. This is a promising example of how policy structures can play at various levels of governance; city, state and region to achieve positive results. Although some of these policy instruments are not directly focused on UHI mitigation, their implementation has a direct impact on temperature reduction. Because of the city authorities' involvement in the mitigation strategies, the policies are well integrated into the governance system and city level building codes. However the mitigation strategies tend to lean toward the smaller - building design and street design scales. City planning and design do not seem to reflect any other strategies, other than tree plantation, toward heat island reduction specifically.

AGENCY	ACKNOWLEDGEMENT & INSTRUMENT	MITIGATION MEASURES				PROPOSED INTERVENTION
		LAND USE PLANNING	BUILDING MORPHOLOGY	SURFACE CHARACTERISTIC	URBAN LIFE-STYLE	
USA						
CITY GENERAL BID CRITERIA	**PROCUREMENT:**		COOL ROOFING	COOL ROOFING		
CITY DEPARTMENT TRANSPORTATION PROGRAMS				**STREET RENOVATION**		
	RESOLUTIONS:	**TREE PLANTING**	COOL ROOFING	COOL ROOFING, TREE PLANTING		
		TREE SHADING		TREE SHADING		
	TREE AND LANDSCAPE ORDINANCES	TREE PROTECTION		**TREE PLANTING**		
		TREE PROTECTION		**TREE PLANTING**		
		STREET TREE PLANTING		TREE SHADING		
		TREE SHADING		TREE SHADING		
		TREE SHADING				
	COMPREHENSIVE PLANS AND DESIGN GUIDELINES:	TREE PLANTING	COOL ROOFS	COOL ROOF , TREE PLANTING		EDUCATION
	ZONING CODES:		GREEN ROOF INCENTIVES	GREEN ROOF INCENTIVES		
	GREEN BUILDING PROGRAMS AND CODES:	PAVEMENT DESIGN, GREEN COVER	ROOF DESIGN	ROOF DESIGN, GREEN COVER, PAVEMENT DESIGN		
		HOMEOWER, PRESERVE TREES				
	BUILDING CODES:			SOLAR REFLECTANCE		
				SOLAR REFLECTANCE		
FEDERAL GOVERNMENT: CLEAN AIR ACT	**AIR QUALITY REQUIREMENTS:** State Implementation Plans (SIPs	URBAN FORESTRY				
	The Emerging and Voluntary Measures Policy					
	(SIP) Credits for Emissions Reductions					
	The Bundled Measures Policy:					

Table 8 Review of UHI mitigation and intervention of Policies in America

Israel

Israel has set up ICCIC – Israel Climate Change Information Centre by the Ministry of Environmental Protection. The work of the ICCIC will serve as a platform for developing a national plan for climate change adaptation, in accordance with a Government Resolution which was adopted in June 2009. The ICCIC team consists of academic experts in disciplines ranging for, economics, town planning and architecture, geography, ecology and environmental studies to public health, each leading a research group. In the recommendations of their second report of June 2012 the Climate Team calls for *"Enhancement of pollution monitoring in urban centers" and monitoring and mapping of the urban heat island annually, with particular focus on the function of urban parks in the mitigation of heat and pollution concentrations."* (Israel Adaptation to Climate Change Information Center, 2012)

London

In the wake of heat wave of 2003 the Mayor of London commissioned a technical study to investigate London's Urban Heat Island. The Mayor, Ken Livingstone, considers the report to be

"*an important first step in understanding the relationship between London's microclimate, development and the predicted changes to our climate……. It is essential that we address the Urban Heat Island through better planning and design – new development should not intensify the problem, opportunities to offset the Urban Heat Island should be taken, and our vulnerable communities should be safeguarded*." (Greater London Authority, 2006)

The report '*London's Urban Heat Island : A Summary for Decision Makers*' was prepared by an inter-disciplinary team of climatologists, meteorologists, geographers, engineers and public health experts have contributed to the study. The report is aimed at 'decision makers' - planners, architects, urban designers, developers and public health care professionals. The report brings two important perspectives that have not been addressed as coherently in the other examples. The first is the differentiation between existing urban contexts and new developments with an eye to developing strategies appropriate to each. Secondly, it recommends improving available data about the UHI phenomenon, and developing modelling tools to enable urban planners to evaluate plans to enhance urban micro-climates. Nations situated in hotter climates – which also tend to be developing nations, show very little activity in the area of Urban Heat Island identification and mitigation. (Greater London Authority, 2006)

1.5 International Alliances for exchange and collaboration between City Governments

Although developing nations, which are also predominantly located in the warm climatic regions, have paid little attention to Urban Heat Island identification and mitigation, in recent years intercity alliances have provided a platform for mutual exchange of knowledge and practice between city governments. The C40 Cities Climate leadership Group and ICLEI- Local Governments for Sustainability and Global Cool Cities Alliance are a couple of such alliances.

C40 is a global network of large cities taking action to address climate change and has partnered with Global Cool Cities Alliance specifically for tackling UHI. (About Us: C40 , 2014) Membership is across the globe from all continents with New Delhi being a member.

ICLEI is a network of local governments with a membership of over 1000 municipalities representing all continents and cities of all sizes. ICLEI India has membership of 50 cities.
ICLEI conducts an annual global forum *'Resilient Cities'*. UHI was a focus area for discussion at the 2010 forum. In its work with local governments it has it has promoted collaboration with institutions such as the Lawrence Berkley Lab and EPA. However it does not have a programme dedicated to UHI.

UHI in International Green Rating Systems

Voluntary green building rating systems have acknowledged UHI. The importnce given to UHI in the various rating systems varies. It is to be noted that since such rating systems are intended to rate discrete projects, they accept the pre-eminence of the dictates of town planning and development control provisions as a given. They, therefore, do not address the fundamental causative factors of UHI attributable to rising urban densities and motorized traffic intensity. They restrict their rating credits to palliative measures such as, green roofs and permeable pavements.

(USGBC) Leadership in Energy and Environmental Design (LEED) Green Building Rating System offers two points for action taken toward reduction of heat islands by minimizing impacts on microclimates and human and wildlife habitats. Credits associated with reflective roofing or planted roofs can help a building achieve LEED certification. Buildings also receive credits by providing shade. Also in its Neighbourhood Development Rating system it offers one point toward heat island reduction. The Green Building Initiative (GBI)'s Green Globes program, which is active in both the United States of America as well as in Canada awards points to sites that take measures to decrease a building's energy consumption to reduce the heat island effect. As many as ten points may be awarded to sites with roof coverage from vegetation, highly reflective materials, or a combination of the two.

The German DGNB rating system, which is now active in several countries around the globe has included '*Changing Urban Microclimate*' as a criteria under Global and Local Environmental Impact for rating Urban Districts. The Green Star rating system developed in Australia has separate rating systems over various scales of development. Under the Communities rating, Heat Island Effect is a separate credit, on meeting which one point is awarded to the project

SUMMARY

While UHI is a localised phenomenon, it is becoming a significant aspect of Climate Change mitigation and adaptation as global populations urbanise, especially in the developing countries that lie in the warm climatic belts. The global institutions - UNFCC, UNEP,IPCC and the Word Bank, all draw attention to the challenge of urbanisation and to the environmental stresses in cities, including UHI, impacting the urban poor the most. They also emphasise the need for further research on urban systems and climate change to enable integrated urban planning for mitigation. The UNFCC provides the impetus for most policy action while UNEP and IPCC lays out the frameworks and an informed basis for policy design. Research by various institutions and researchers is brought together to indicate strategies.

European Union and America, backed by substantial research, have made a head start towards UHI mitigation. Programmes for UHI research and pilot projects are instituted through the European Union. This is a largely '*federal*' initiative. The EPA in America plays a similar umbrella role. Policy and legislation, however devolve to state governments and city authorities and some building and

planning codes have included UHI mitigation palliative measures. In Europe, though, the policy thrust is more strategic as it seeks to develop town planning and urban design principles to minimise UHI.

The example of Japan, which has comprehensive programme devoted to minimising UHI effects, is instructive. It brings together various ministries, levels of government and research institutions to build the policy and implementation programs. It is significant that both in Europe and in Japan the critical driver for UHI mitigation is risk to health due to high temperatures and pollution during calm seasons. In America, as UHI is a greater issue in the warmer cities of the subcontinent, the concern for increasing energy demand due to UHI is also important. This is beginning to be counted in Europe too where air conditioning is being resorted to progressively. The recommendation of the ICCIC of Israel for a policy to monitor and map UHI annually so as to inform mitigation policy is particularly instructive. Although UHI is mentioned as a concern for the rapidly urbanising developing countries, there do not appear to be governmental programmes that address UHI. A window of opportunity is provided by global inter- city alliances such as C40 and ICLEI.

All Green Certification Programmes, irrespective of their origin address UHI, but this remains confined to the level of discrete projects and does not address the potential of town planning strategies. Ironically it is through the growing acceptance and spread of these certification programmes that UHI is being introduced to the architects and planners in the developing world. The criticality of doing systematic research on UHI and integrating it into town planning and urban management of the rapid urbanisation in developing countries is succinctly expressed by Mc Carthy and Sanderson in their paper presented at 5th Urban Research Symposium on Cities and Climate Change:

"Some mitigation options may exacerbate urban vulnerability to climate change. For example, although increasing urban density may contribute toward reducing emissions from transport, this will have negative implications for adaptation, such as intensifying the urban heat island effect and posing problems for urban drainage. Improving our understanding of the synergies, conflicts, and trade-off s between mitigation and adaptation measures would enable more integrated and effective urban climate policy …..." (Hoornwig, Freire, Lee, Bhada-Tata, & Yuen, 2011)

An understanding of current and possible future changes in the magnitude of the UHI is therefore necessary for planning and developing of adaptation and mitigation strategies.

Policies in India

Organizational Structure

Under the Indian governmental structure, along with various other functions, organizations are set up under the purview of Acts and Ministries at the Central Governmental level to oversee specific aspects and ensure their smooth functioning. Besides setting up organizations, ministries also formulate or undertake policies to provide for future vision and direction as well as guidelines which may be followed by the States. In addition, the Ministries establish mandatory provisions that all states and cities are bound to follow.

The State Authorities are empowered through the federal structure of the constitution to work on subjects under the state list. The guidelines and policies formulated by the Central Government Ministries provide for direction to State Authorities to formulate the state specific actions. Further, the mandatory provisions ensure implementation as envisioned at the central level.

Non-governmental organizations (NGOs), through the channel of governmental policies and their visions, collaborate with the authorities at all levels of governance to provide assistance in making action plans, capacity building, research activities etc.

The figure below delineates the basic organisational structure of Government, relevant for the purpose of this study

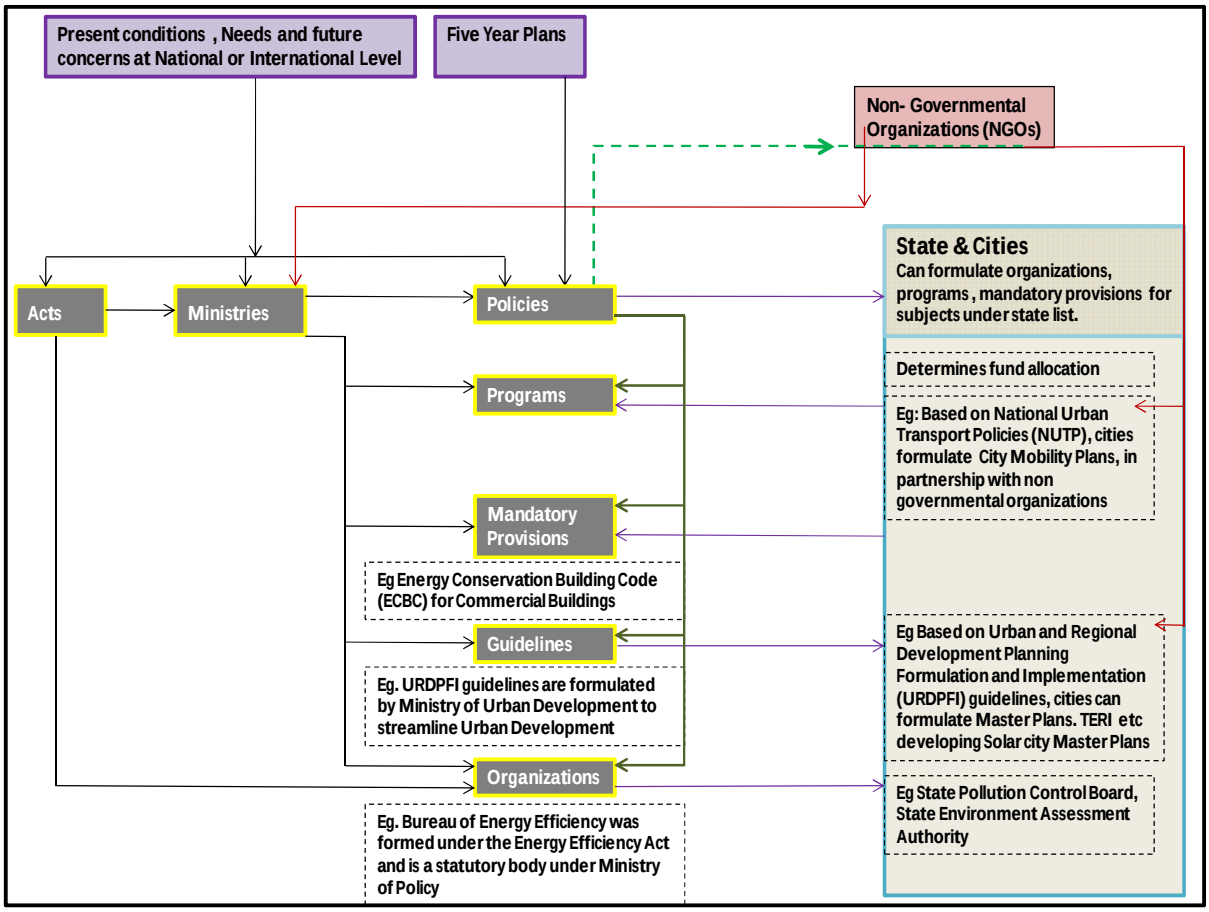


Table 9 Governmental and Non-Governmental organisational structure and Legislative Framework

There are numerous acts and ministries in India's governmental setup, but here we will focus on the acts dealing with and the ministries of Environment and Urban Planning in particular.

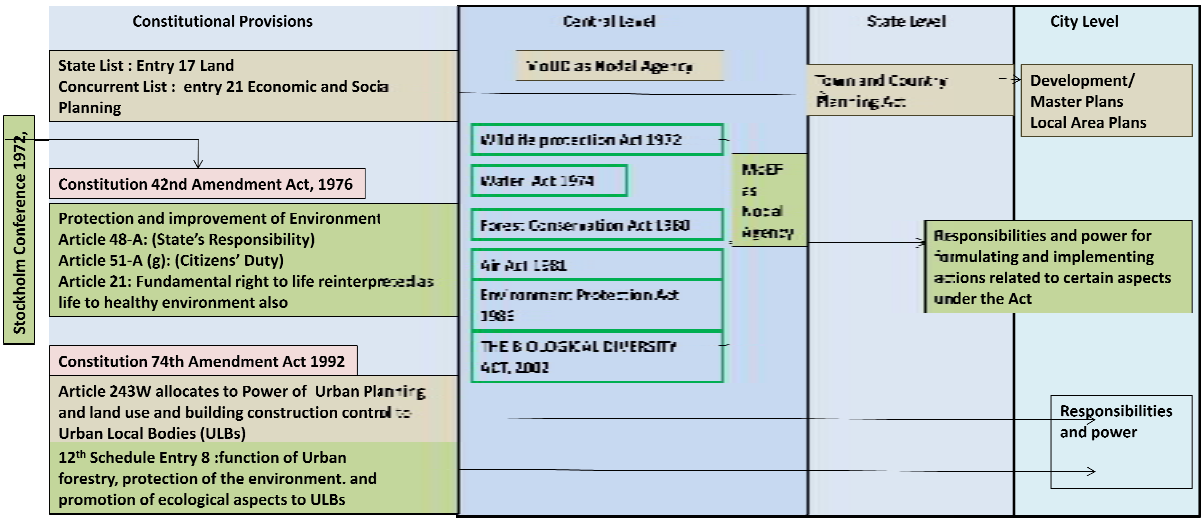


Table 10 : Legislative framework for Environmental and Urban Planning

The approach of sustainable development has traditionally been an integral part of India's culture. Changing times have, however, brought forth many facets of environmental issues globally which need addressing at the national level as well. To address these emerging issues the United Nations Conference on Human Environment (Stockholm 1972) brought forward the issues related to environment in the process of development and India's participation in the event was a stepping stone towards inclusion of environmental concerns in a concrete manner at the national level.

In 1976, in the wake of Stockholm conference and the adoption of its principles in UN-Conference on Human Settlements, the Indian constitution underwent its 42nd Amendment. This introduced Article 48-A and 51- A(g), that form part of the Directive Principles of State Policy and Fundamental Duties respectively.

Article 48-A: By Constitution (42nd Amend) Act, Sec.10 (w.e.f. 3.1.1977) Protection and Improvement of Environment and Safeguarding of Forests and Wild life: "*The State shall endeavour to protect and improve the environment and to safeguard the forest and wildlife of the country*". Article 51-A (g): By Constitution (42nd Amend) Act, Sec.11 (w.e.f. 3.1.1977) "*It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife and to have compassion for living creatures*". (R. Balamurugan).

The Environmental Protection Act of 1986 further laid down the definition of the term "*Environment*" to include water, air and land and the inter- relationships which exists among and between them and human beings, as well as other living creatures, plants, micro-organism and property. This definition through legislation has given wide coverage to environmental concerns and enabled the functioning and origin of various programs, policies and institutions. In addition to the environment, urban planning concerns obtain statuary status from two entries i.e. Entry 7- Land and Entry 21 –Economic & Social Planning, mentioned n the state and concurrent lists, respectively. Further, the 74th Amendment Act strengthened the importance of environmental concerns in urban development through Entry 8 (Urban Forestry, Protection of the Environment and Promotion of Ecological Aspects) and gave power of planning and environmental safeguard to Urban Local Bodies. The complete implementation of the provisions, though in process, is yet to be seen.

Framework Review of Central Government Ministries

The framework of the Central Government Ministries of Environment and Forest (MoEF), Urban Development (MoUD), New and Renewable Energy (MNRE) and Power (MoP) are reviewed below from the perspective of the inclusion of UHI effect in their programmes and policies.

UHI is understood to be a causal factor of air pollution and research has pointed out connections between UHI and climate change. Since MoEF is the nodal agency for dealing with environmental issues, we look at MoEF's policy and programs. Since UHI is an urban phenomenon caused by the nature of urban structure, the MoUD becomes, perhaps, the ministry most concerned with the UHI effected , as this ministry is responsible for the policy for growth and development of future and present cities. UHI has been proven to impact not only temperatures but also lead to higher energy consumption by virtue of rising temperatures in cities, thus it becomes relevant to look at policy framework of MNRE and MoP as they have a stake in devising policies and programs for energy conservation, especially in the context of developing low carbon cities.

1. Ministry of Environment and Forest (MoEF)

The Ministry of Environment & Forest is the nodal agency in the administrative structure of the Central Government for the planning, promotion, co-ordination, and overseeing the implementation of environmental and forestry programmes and policies. The Ministry's main activities include conservation and survey of flora, fauna, forests and wildlife, prevention and control of pollution, afforestation and re-generation of degraded areas, protection of the environment, ensuring welfare of animals, as well as research related to these activities, collection and dissemination of environmental information and creation of environmental awareness.

1.1National Environment Policy (NEP)

The National Environment Policy 2006 was formulated as a response to the national commitment to a clean environment mandated in the Constitution, as well as to various international commitments to mainstream environmental concerns in the developmental processes.

The policy considers environmental protection and setting up of environmental standards as its main principles and works towards streamlining and co-ordination of multiple agencies involved in this process. It covers almost all aspects of environment like ecosystems, biodiversity, heritage, pollution, climate change and lists strategies for each. Its stress is on preparation of action plans and capacity building.. In the context of the urban environment, the policy targets pollution relating to water, air, land, and noise, resulting from increasing urbanization and urges monitoring , setting up of standards, and city level action plans through public- private partnerships, (Ministry of Environment & Forest, 2006)

The Ministry has mandated Environmental Clearance for Large Development Projects through an environment impact assessment process as one of the substantive reforms for protection against the degradation of the environment (both Rural and Urban).Although this does not take into account the component of UHI directly, but being a far-reaching policy for prevention of environmental degradation, it provides us with an umbrella to introduce UHI effect as a degrader of urban environment in the implementation measures and to propose more research on the subject.

1.2 National Mission on Green India (NMGI)

The National Mission on Green India is one of the eight missions under the National Action Plan on Climate Change, an initiative in the wake of global thrust on addressing climate change endorsed by the Intergovernmental Panel on Climate Change (IPCC). The mission talks about increasing green cover for climate change adaptation and mitigation and sets targets for the same. In context of urban areas it talks about increasing urban forest cover, developing parks, and greening of institutional lands. (Ministry of Environment & forest, 2010)

Though it does not mention UHI effect directly but the objective to enhance green cover (in Urban Areas in particular) is an indirect mitigation strategy, which will be beneficial in case of addressing UHI The mission is important from the UHI perspective as it provides for a quantum of open space required; it can be integrated in the Master plan for cities and distributed according to the built mass to counter the UHI effect.

1.3 National Conservation Strategy and Policy Statement on Environment and Development

This policy document formulates guidelines with a vision to direct development that incorporates environmental considerations, and stresses the integration of environmental safeguards in development policies. It states that the process of development, the status of being under-developed combined with poverty as major environmental problems. It suggests various legal provisions and institutional arrangements. The legal instrument directly relevant to urban development is the Environmental Clearance for Large Development Projects, enforced through the Environment Protection Act. (Ministry of Environment and Forest, 1992)

In general the policy talks about pollution abatement through setting standards, monitoring levels, safeguarding of forests, wildlife and ecosystems. But there is no specific mention of urban microclimate or UHI.

1.4 Environment Clearance (EC/EIA)

The process of Environment Clearance implemented through Environment Impact Assessment (EIA) Notification 2006 for various projects, assesses likely impacts of a development on the components of environment, where the primary concern is the suitability of the site and its surrounding environment for the proposed activity.

Environment Impact Assessment for building & construction projects and township &area development projects are of specific concern with reference to UHI as a phenomenon of the urban environment. The EIA Manual on Norms and Standards for Environment Clearance of Large Construction Projects is a guideline that indicates the aspects of importance which should be taken care of with respect to environmental protection in the implementation of such projects. In the manual UHI is directly acknowledged (through stating temperature variation between urban and surrounding rural areas) as a contributor of air pollution. Surface material properties and built up density are stated as causes of UHI. Mitigation measures for UHI effect are stated under ‘Mitigation measures for dust control’ and suggested in terms of reducing heat gain by increasing reflectiveness of exposed surfaces, increased vegetative cover and through considering other design methodologies that address the UHI effect.

The Environment Impact Assessment under Environment Clearance incorporates steps to address the UHI effect indirectly by encouraging open spaces, pervious surfaces and tree cover. It acknowledges that current development patterns are tending towards a more energy intensive lifestyle and

recommends increasing green areas and green cover through parks and urban forestry, decentralization of urban centres, and proper sitting of industries.

Under the columns for Air Pollution of form 1A (mandatory for EC of Large Projects) the following clarifications are sought:: *"Will the Project increase atmospheric concentration of gases and result in heat island'* Give details of background air quality levels with predicted values based on dispersion models taking into account the increased traffic generation as a result of the proposed constructions."

The point of observation is that although this requires the prediction of heat island due to the proposed development, the empirical data it asks for concerns air pollution which cannot be used to predict the UHI effect of the said development.

Nevertheless, on the whole the EIA is one of the mandatory provisions in the governmental framework addressing urban environmental issues which covers UHI effect in some detail..

1.5 Central Pollution Control Board (CPCB)

The board set up though the provisions of Air Act (1981) and Water Act (1974) provides technical help to Ministry of Environment and Forest. The focus areas of the Board are the prevention, control and abatement of water pollution and air pollution. It has also worked towards safeguard of land resource through its 'Zoning atlas for siting of Industries'. . The compatibility of industrial development sites is determined on the basis of a combination matrix of environmental factors like slope, proximity to national park/sanctuary, proximity to eco sensitive zones, existing air and water pollution levels, agricultural suitability of site, watershed suitability etc.

From UHI perspective- it does not deal with phenomenon directly but its focus area of monitoring pollution levels, suggests a possibility of the organization's role in monitoring UHI standards developed through research.

2. Ministry of Urban Development (MoUD)

The Ministry of Urban Development is the apex authority of Government of India at the national level that formulates policies, sponsors and supports programmes, and monitors programmes on all issues of urban development in the country, as well as coordinates the activities of various Central Ministries, State Governments, and other nodal authorities in this regard. (Ministry of Urban Development, Govt. of India.)

2.1 National Mission on Sustainable Habitat (NMSH)

The National Mission on Sustainable Habitat was introduced under the National Action Plan on Climate Change to address vulnerabilities and threats to cities from increasing urbanization. The NMSH is meant to target urban areas to make them resilient to climate change and protect them from environmental degradation. It covers the extension of the Energy Conversation Building Code 2007, better Urban Planning with modal shift to Public Transport, and Waste Management initiatives combined with Recycling of Materials with Alternatives for Energy Generation. A reduction of the UHI effect is mentioned as one of the strategies for fulfilling the overall objective of the mission.

The mission document acknowledges that the UHI effect adds on to and intensifies climate change and takes note of the cycle created by rising temperatures due to heat island effect resulting in increased demand for cooling and use of air-conditioning equipment, thereby generating more heat and adding to the rising temperatures and green house gas emissions. The mission condemns these lifestyle trends of increasing air-conditioner use and suggests the formulation of various well designed policies in support of energy efficiency measures.

The mission also points to the loss of vegetative cover as a causal factor of the UHI effect and suggests mitigation measures through good urban planning: such as increasing green cover, using cool roofs, and adopting other appropriate urban design measures. Under the head of Urban Planning, the mission relates increasing vehicular count with rising CO_2 and Green House Gas levels and stresses on promoting public transportation to reduce emissions and save on road space. The mission also discusses here the concept of low rise high density development proposed by the National Commission on Urbanization in 1988, without arriving at a conclusion in favour of or against the concept. Further, towards its vision of better urban planning, it seeks formation of a National Urban Policy that supports and encourages sustainable development at regional and city levels. The Mission proposes the making of sustainable habitat standards for the implementation of its goals, which it proposes to integrate in the National Building Code, Building Bye-Laws, Development Control Regulations and into mainstream planning through the appropriate legal framework. It also proposes to modify Town & Country Planning 2010-11 Act / DCR for promoting environmental management s. The mission proposes to use the City Development Plans (CDP's) formulated under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) as a specific tool for implementation of its envisioned standards.

The suggested strategies for implementation provide a channel to integrate UHI measures into the mainstream policies and ensure their implementation. The ground status of the mission is, however, yet to be reviewed.

2.2 National Urban Transport Policy (NUTP)

National Urban Transport Policy was formulated in the backdrop of the issues of urbanization, to address the needs of economic sustainability through the flow of goods and services, limited road space as compared to vehicular count, increasing emissions and air pollution from the increasing vehicular count, increased costs of travel, expanding cities and sprawl making non-motorized modes less usable etc. The policy was formulated to ensure quick, safe, affordable and sustainable access to public transport for all; with a vision to make transportation people centric and city specific.

To meet its agenda, the policy focuses on integrated land use- transport planning, integrated-connected multi modal transport, efficient public transport, non-motorized transport, equitable road space and cleaner transport-fuel technologies. It envisions liveable, people centric cities, whose form responds to their geographic location and is supportive of their economic base. The policy vision and focus is demonstrated through various implementation tools like city mobility plans, DDA-UTTIPEC's Street Design Guidelines etc. (Ministry of Urban Development , 2006)

The recommendations for use of alternative fuel ,cleaner technologies and promoting use of non motorized transport and integrated land-use transport planning to cut down travel distances, can be read as an indirect UHI mitigation strategy.

2.3 Urban and Regional Development Plan Formulation and Implementation (URDPFI)

Urban and Regional Development Plan Formulation and Implementation guidelines 2013 (currently draft report), a revision of 1996 guidelines, are envisioned to incorporate efficient implementation and innovative techniques for planning. These are guidelines covering both the regional and the urban planning approach, on various components of planning which can be detailed further as per specific conditions and requirements

Under the head Regional Plan, these guidelines deal with control and regulation of activities that impact the environment. The regional plan focuses on integrated development, recommending

conservation of environmental resources, protection of sensitive areas, and maintenance of green and forest cover. Under the Urban Plan the guidelines urge alternative solutions in the wake of challenges of environmental (un)sustainability and changing atmospheric conditions. It suggests that low rise high density development as mentioned in the NMSH (and derived from National Commission on Urbanization, 1988) and redevelopment, to reduce travel distances, can be considered as an urban planning measure for sustainable development.

It attributes UHI effect to the basic form of our urban centres and suggests green cities, smart cities, and compact cities as alternative approaches towards city planning. As part of these suggestions it stresses the need for open spaces and for promoting non-motorized transportation etc., which although not mentioned in direct context of mitigating the UHI effect, can be considered as suggestions for the same. Under the head of 'Micro-climate' in Green City concepts, the document lists concepts like green roof and open spaces directly to cater to the UHI effect, and also strategies such as planning as per solar and wind orientation, green buildings, water bodies and open spaces; which can also be considered to contribute towards mitigation of the heat island effect.. (Mott MacDonald, 2014)

URDPFI guidelines acknowledge the phenomena of UHI effect and identify the cause to be related to urban structure. For mitigation it proposes strategies relating to surface characteristics, land use planning and urban design. The strategies related to surface characteristics are more specific while the ones relating to urban design and planning are very general in nature.

2.4 Jawaharlal Nehru National Urban Renewal Mission (JNNURM)

The Jawaharlal Nehru National Urban Renewal Mission targets efficient and fast track development of cities particularly with respect to aspects of urban infrastructure and services for the urban poor. One of the objectives of the mission is also the planned development of identified cities, that includes the peri-urban areas, outgrowths and urban corridors, which have lead to dispersed urbanization of the cities. The National Sustainable Habitat Mission proposes to implement the vision of the Sustainable habitat Standards through the channel of city development plans which currently focus primarily on infrastructure. (Jawaharlal Nehru National Urban Renewal Mission- Overview, 2005)

The tool of CDP under the mission can act as a tool for implementing UHI mitigation strategies at the city level, particularly in existing cities.

2.5 Model Building Bye Law

Model Building Bye Law is a guiding document in MoUD's framework, based on which State Governments develop their own building bye-laws. The model building bye law states that municipalities have the power to undertake or perform various functions under certain spheres, one such sphere being environmental protection. In Part 6 Chapter 29 under the duties of municipalities, mentions management of urban environment, where it states that municipalities can engage public or private organizations for research . In relation to urban environmental management the Municipality can, either by itself or through any other agency, undertake functions relating to matters like control of air pollution, area improvement and resettlement, promotion of urban agriculture and urban forestry, development of parks, gardens and open spaces, and such other matters as the Municipality may consider necessary.

Although UHI is not mentioned specifically as a subject, the general statement provides us with a channel to introduce UHI related strategies. It states that the Chief Municipal Officer shall prepare and submit a report on the environmental status of the municipal area at the time of submission of

budget estimates, which provides an additional stage at which UHI can be made a component in reporting environmental status.

3. Ministry of New and Renewable Energy (MNRE)

The Ministry of New and Renewable Energy (MNRE) is the nodal Ministry of the Government of India for all matters relating to new and renewable energy. The broad aim of the Ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country. (Ministry of New and Renewable Energy). MNRE has investgated the potential of building integrated solar photo voltaics to supplement energy supply in cities. This has a symbiotic relationship with UHI mitigating strategies of cool roofs.

3.1National Solar Mission

The National Solar Mission was introduced under the National Action Plan on Climate Change (NAPCC) as an effort towards promoting ecological sustainable growth and addressing energy related challenges. Solar City Master Plans were introduced under this mission as a concrete action with a specific target of 10% reduction in the projected demand of conventional energy in the next 5 years, by enhancing supply through renewable energy and energy efficient measures. The guidelines for Solar City Master Plans suggest that building bye laws should be modified to achieve energy efficiency. (Ministry of New and Renewable Energy)

As the literature review has brought out a relationship between UHI and increasing energy demand, the tool of solar city master plan and proposed amendment of building bye-laws under it presents a possibility of introducing UHI mitigation strategies related with achieving energy efficiency.

4. Ministry of Power (MoP)

The Ministry of Power is responsible for the development of electrical energy in the country. The Ministry is concerned with perspective planning, policy formulation, processing of projects for investment decision, monitoring of the implementation of power projects, training and manpower development and the administration and enactment of legislation in regard to thermal, hydro power generation, transmission and distribution. The Ministry of Power is responsible for the administration of the Electricity Act, 2003, the Energy Conservation Act, 2001 and for undertaking such amendments to these Acts, as may be necessary from time to time, in conformity with the Government's policy objectives. (Ministry of Power). The Burueau of Energy Efficiency, which has also brought out the Energy Conservation Building Code for large commercial buildings is instituted under the MoP

4.1 National Mission for Enhanced Energy Efficiency (NMEEE)

The National Mission for Enhanced Energy Efficiency focuses on enhancing cost effectiveness of improvements in energy efficiency in large industries and facilities, through certification of energy savings that could be traded. It also works towards accelerating the shift to energy efficient appliances in designated sectors through innovative measures to make the products more affordable. By creation of mechanisms the mission also seeks to help finance demand side management programmes in all sectors by capturing future energy savings. And further by developing fiscal instruments to promote energy efficiency.

4.2 Bureau of Energy Efficiency (BEE)

The BEE operates under the legal mandate of the Energy Conservation Act, 2001 and has the role to develop policies and strategies, with a thrust on self-regulation and market principles, for the primary

objective of promoting energy saving measures and reducing energy intensity of Indian economy. BEE has initiated projects and programmes to achieve its goal, such as Demand side Management, Energy Efficiency in Building and Establishments and the Energy Conservation Building Code.

Energy Conservation Building Code (ECBC).

The Energy Conservation Building Code recommends building envelope, HVAC, lighting criteria for commercial buildings having connected load of more than 100kW or contract demand of more than 120kVA. Estimates based on computer simulation model indicate that ECBC compliant buildings can use 40% to 60% less energy than conventional buildings. As the building sector represents about 33% of electricity consumption in India the energy use reductions from ECBC compliance can contribute significantly to UHI risk from increased energy consumption. In addition the ECBC also directly stresses the use of cool roof to mitigate UHI. The ECBC also acknowledges the phenomenon of UHI in its user guidelines.

5. National Building Code (NBC)

The National Building Code guidelines highlight various parameters to be considered for planning, design, construction, operation and maintenance of buildings and relating to land development from sustainability point of view. NBC acknowledges the phenomenon of UHI but no mitigation measures are proposed.

Non-Governmental Initiatives

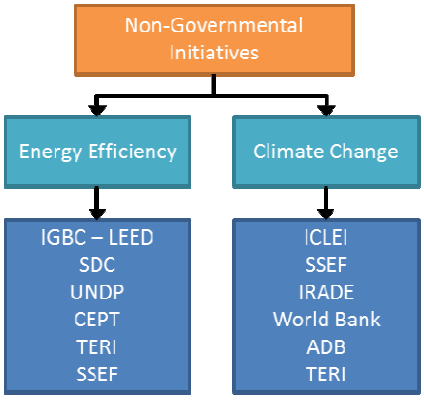


Figure 11: Non-Governmental Initiatives

There are numerous non- governmental organizations like The Energy Research Institute (TERI), ICLEI, ATKINS etc which are working in collaboration with central, state and city level authorities on various aspects which can be put under the two dominant heads Energy efficiency and Climate Change under the domain of Sustainability. ICLEI, for example, is working at the city level on different concepts like resilient cities, sustainable cities and low carbon cities. TERI is working on developing rating systems for buildings, providing research & development on various policy concerns. ATKINS as an institution is involved in various sectors, one relevant project being the development of a carbon master planning tool and development of the low carbon master plan for the cities of Madurai and Mysore in collaboration with city municipalities. WWF has worked on city level action plans for Kanpur and Meerut. Many of these organizations are providing support for preparing solar city master plans under the NSM.

TARU (an NGO), in collaboration with ACCRN, did an Urban Heat Profile for the city of Surat. The study was carried out at 6 different areas within Surat city. The selection of sites was based on parameters like areas built-up density traffic density, green areas, building type (roof, age material),

road conditions and distribution of different socio-economic groups. The study recorded maximum UHI intensity of 6 deg.C.. The study highlights that with the changing climatic zones in case of Surat and Indore different UHI mitigation strategies need to be adopted. This shows that UHI effect varies according to the particular characteristics if each region or city area.

The fact that many NGOs are in the process of collecting data, indicates that there is need for more structured research across the country in different climatic zones to build a substantive database to enable policies for UHI mitigation to be made.

Green Building Rating Systems

1. Green Rating for Integrated Habitat Assessment (GRIHA) developed by TERI

Green Rating for Integrated Habitat Assessment (GRIHA) is a national rating tool for green buildings developed by Association for Development and Research of Sustainable Habitats (AdaRSH) and endorsed by MNRE. The rating classifies the building as a green building if the its building design and construction aspects fulfil various GRIHA criteria. GRIHA aims to reduce the building energy demand, thus indirectly GRIHA rated green buildings will supply less detrimental form of energy into the environment. The rating system broadly comprises of nine different environmental categories—site planning, health & well-being, building planning & construction stage, water, energy - end use, energy - renewable, recycle recharge and reuse of water and waste management..The rating system directly addresses the heat island phenomenon; Criteria 5 of GRIHA focuses on the reduction of heat island effect by reducing total paved areas, increasing green cover and also by application of high SRI coatings on exposed materials. The rating system also advises application of cool roof/green roofs to reduce building heat gain through roofs. Though the reduction of uhi effect in not among the mandatory criteria of the rating system, yet an attempt has been made to identify and reduce the heat island effect. GRIHA rating has now become mandatory for government buildings.

2. Leadership in Energy and Environmental Design (LEED) developed by Indian Green Building Council (IGBC)

IGBC's LEED rating system is a voluntary scheme to promote sustainable design for buildings. IGBC – LEED offers rating system for residences, multi-family high-rise buildings, factories, offices, retail malls, institutions, hotels, hospitals, landscape, health-care facilities and SEZ's . The LEED rating system comprises of five different environmental categories—sustainable sites, water efficiency, energy and atmosphere, materials and resources and Indoor Environmental Quality (IEQ). Rating systems for Green Homes, New Construction and Township include criteria for Urban heat island effect (roof and non roof) under Site Selection and Planning/ Sustainable Sites, thereby directly addressing the issue. The intent is to cut down on heat island effect through use of high reflective, high albedo materials, vegetative cover and shaded spaces. The IGBC rating for townships under its SSP 6 provides maximum of 8 points for having 95% or more exposed/impervious surfaces under either tree cover/shade or with reflective materials. Whereas the rating system for green homes provides maximum of 6 points under SSP 3 (UHI non roof) and SSP 4 (UHI roof) for having minimum 50% roof area and 50% non roof area (roads, footpaths, pathways, parking etc) under either shade, vegetation and or high reflective materials. Criteria like Chloro Floro Carbon (CFC) free equipment, minimum energy requirements, energy saving measures in appliances under the head of Energy Efficiency and criteria's like preserving existing trees & water bodies and minimum 25% area under landscape are indirect measures towards the cause of UHI effect. On the whole the rating system attempts to address UHI fairly comprehensively.

SUMMARY

Policy Instruments	Urban Heat Island					
	Acknowledgement of UHI effect	Identification of Causal Factors / Suggested Mitigation Measures				Implementation Suggestions
		Land-use Planning	Building Morphology	Surface Characteristics	Urban Lifestyle	
MoEF						
National Environmental Policy						
National Mission on Green India						
National Conservation Strategy &Policy Statement on Environment & Development						
Environment Clearance (EC/EIA)						
MoUD						
National Mission on Sustainable Habitat						
National Urban Transport Policy						
Urban and Regional Development Plan Formulation and Implementation						
JNNURM						
Model Building Bye Law						
MNRE-						
National Solar Mission						
MoP-						
National Mission for Enhanced Energy Efficiency						
Bureau of Energy Efficiency						
Energy Conservation Building Code (ECBC)						
Local Govt						
DDA- UTTIPEC						
Street Design Guidelines 'for equitable distribution of road space'						
Surat and Indore Municipalities (Supported by TARU)						
Rating Systems						
ICBC (LEED) Rating						
GRIHA						

Direct mention/ addressal UHI indirectly Implied

Table 11 Summary of Indian policy review

Through the hierarchy of centre, state and city; it is quite evident that there are efforts to address or incorporate rising environmental issues in the framework of spatial planning.

In the governmental framework of the four ministries reviewed, certain instruments acknowledge and address the phenomena of UHI, its impacts, causal factors and mitigation strategies directly. While in some we can indirectly imply a link towards UHI effect. .

Under the framework of MoUD, due recognition has been given to UHI effect. UHI's link with climate change and increasing energy demand and causing environmental impact is being talked about. In particular NMSH covers the causes, impacts and mitigation measures of UHI and acknowledges the viscous cycle of energy demand. URDPFI guidelines also cover the causes and

mitigation measures under its guidelines for environmental and sustainable planning. The proposed mitigation strategies are inclined towards surface characteristics are more specific in nature, while the ones under the heads of building morphology or urban planning are very genera..

Under MoEF's framework NEP gives a broad vision for prevention of environmental degradation, which we can assume to include UHI. While NMGI, through promoting green cover indirectly, provides mitigation for UHI. The mandatory requirement of of environmental clearance, identifies building morphology and surface characteristics as causal factors. Specific mitigation measure are given for surface characteristics, while the ones for building morphology are unclear, hinting at a possible bias in the current research in India

The framework under ministries covering the energy sector gives due acknowledgment to the UHI effect . Through promoting use of energy efficient appliances and energy efficient building, the ministries are targeting the viscous cycle of energy use thereby impacting the causal factors of urban structure at the building level and also the factor of urban lifestyle.

Although an integrated approach for response to UHI is absent, however the example of collaboration of Surat and Indore's municipalities with TARU to work out a plan for their city with respect to UHI effect is showing a way forward.

Voluntary rating systems like LEED, GRIHA, and mandatory Environmental Clearance(for large projects) encourage the use of materials with lower heat gain factor and high albedo along with shading of exposed surfaces such as parking, pathways etc.

The aspect of open green spaces and shaded surfaces (urban design) is determined by default l through the provisions of the master/development plans combined with building bye-laws. This is an area where research could introduce the considerations for minimising UHI effect in master plans and building bye laws.

It can be inferred that the policies share a relationship with the status of research. In the backdrop of rapid urbanization in the country with the concerns for energy consumption and with the aim of low carbon urban development futures, it becomes imperative to push for more research on the subject to be able to address UHI effect in the existing policy framework.

Visionary documents like NSHM combined with NEP provide us with a channel through which UHI effect can be introduced into implementable actions like CDP, Master Plans, Building Bye-laws, EIA backed up by the responsibility and power of environmental protection and urban planning entrusted to urban local bodies..

PART II
DESCRIPTIVE FRAMEWORK
1. Structure of the Framework

This part of the study takes on from the inferences of the literature and policy review of the Urban Heat Island effect nationally and internationally. It proposes a theoretic framework that describes the interrelationships between the causal factors of the UHI effect and its impacts on the same with a view to be able to identify possible measures for intervention and incorporation in policy. The relationships are described as dynamic ones, whereby changes in one factor can impact and interact with one or more other factors, resulting in cumulative influences on the overall effect. This overall urban heating effect itself has rebound interactions and impacts on the factors considered to start with, as well as, others, setting up a cyclical process of influences. The magnitude of the impact of individual factors is not expressed in numerical terms but rather discussed qualitatively and considered significant more in terms of the breadth of the influence.

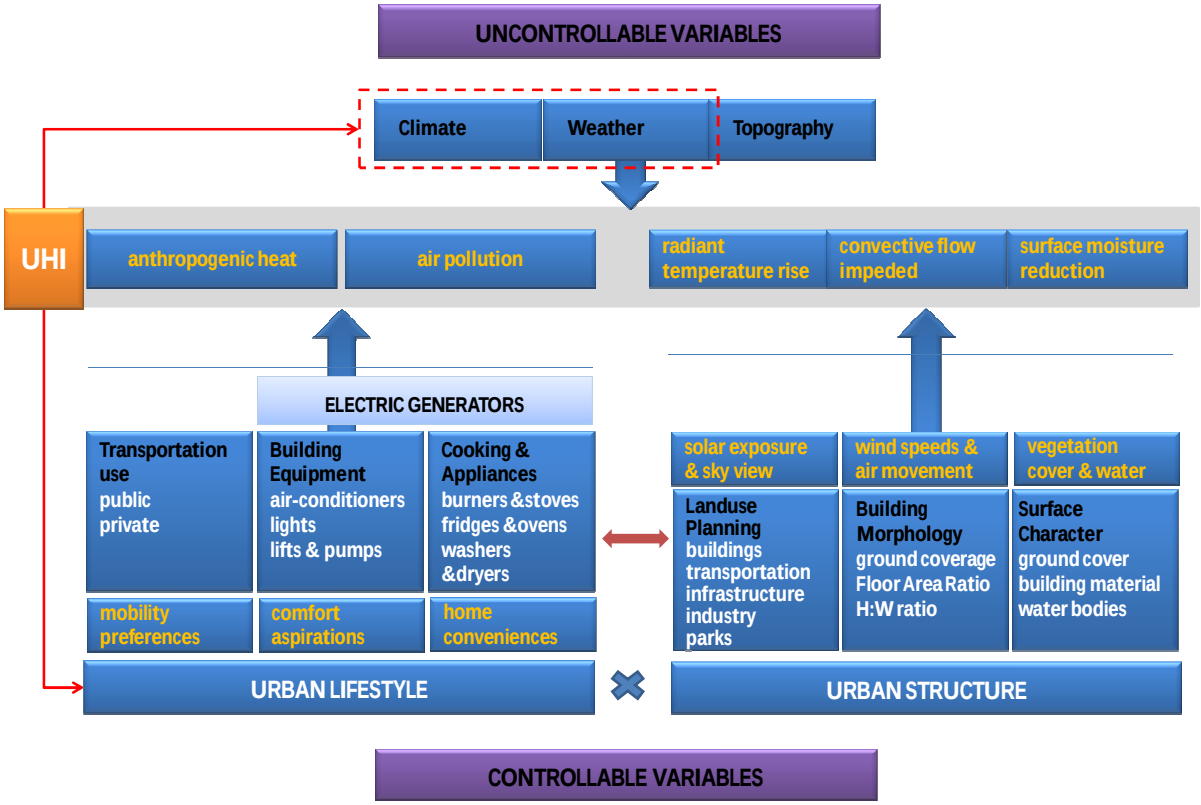


Table 12 Descriptive Framework for Urban Heat Island (UHI) Effect

The descriptive framework derives from the structure of the methodology for the literature review, dividing the causal factors into uncontrollable and controllable parameters, after Memon's chart (Memon, Leung, & LIU, 2007):

1.1 UNCONTROLLABLE FACTORS

Climate

The regional patterns of variations in environmental factors such as temperature, humidity, precipitation, wind, atmospheric pressure, and other meteorological variables over long periods of time.

Weather

The temporal patterns of variation, in environmental factors such as temperature, humidity, precipitation, wind, atmospheric pressure, and other meteorological variables over short periods of time, including seasonal and diurnal variations.

Topography

The nature of the ground surface, including form, texture, and features in a given locality. This may be considered to directly or indirectly influence the variations in environmental factors over the area in the long or short term or both.

1.2 CONTROLLABLE FACTORS

Urban Lifestyle

- **Transportation Mode** (public, private)arising from preferences for mobility
- **Building Equipment**(air-conditioners, lights, lifts & pumps)arising from aspirations of comfort
- **Cooking & Appliances**(burners & stoves, fridge &ovens, washers & dryers)arising from conveniences for the home

Urban Structure

- **Landuse Planning (buildings, infrastructure, industry, park, roads)**
- **Building Morphology (ground coverage/open space, FSI/building heights, H:W ratio/skyview)**
- **Surface Character(ground cover, building material, water bodies)**

The descriptive framework illustrates how the uncontrollable and controllable factors combine to produce microclimatic impacts that together produce what is referred to as the Urban Heat Island effect. Further, the two aspects of controllable factors, namely the, urban lifestyle factors and urban structure elements may interact in a significant way to give rise to the microclimatic influences on the environment. It may also be considered that the urban structure and urban lifestyle also multiply with each other, in that, as the structure's population concentration increases, so do the extent of lifestyle factors increase as many fold.

The framework further lists the impacts of the causal factors as:

Those arising from the urban lifestyle:

- Anthropogenic heat:
  Generated by transportation, cooking, and air-conditioning use and emitted into the local atmosphere. Standby generators used for electricity production and use for home appliances or building equipment may also contribute.
- Air pollution:
  Emitted by transportation use, cooking, and generators used for home appliances, and other electrical equipment. Includes noxious gases and pollutants that retain heat in the atmosphere and prevent it from being released.

Those arising from the urban structure:

- Solar exposure: affecting radiant temperature
  Most directly influenced by building density but also by landuse zoning allocation of the built mass as well as the character of vegetation cover on open ground. The building density is manifest in the extent of ground coverage, the allowable floor area ratio, and the ratio of the height of buildings to the width between them This influences the shading of the solar heat during the day affecting gain and radiative heat loss at night due to the related parameter of sky view factor.
- Wind speeds: affecting convective transfer
  Again, the built areas, their density, and texture, affect the larger wind patterns in a region, modulating it to produce the localized wind patterns which influence the flushing of stored heat.
- Vegetation cover : affecting surface moisture
  Based on the allocation of green areas, coverage of open areas, and character of the green cover, the comprising vegetation affects the ambient moisture content due to evapo-transpiration affecting heat retention by the local atmosphere.

These microclimatic impacts have a cumulative effect and are responsible for generating the Urban Heat Island effect or a heating up of the atmosphere above open surface and rural areas. The extent of heating up may differ based on the differential impact of the various uncontrollable and controllable factors as well as the interactive impacts between them.

In addition, the controllable factors themselves may be not only cumulative but also interactive. This means that certain urban lifestyles impacts may happen in certain urban structures and vice a versa. For.e.g lifestyle choices of transportation may be a result of provisions for public or private transport through landuse planning decisions or a result of building densities that increase transportation use intensity. Similarly, impacts of lifestyle factors such as use of air-conditioners may be influenced by building densities that impede air flows or surface character that reduces atmospheric moisture and thereby evapotransiration impacts.

Finally, the heating up of the atmosphere through the Urban Heat Island can also have rebound effects in terms of changing the so called uncontrollable factors such as weather patterns and even contributing to climatic change through global warming besides affecting the controllable lifestyle factors. The latter may entail an increase in preference for private transportation use, and in aspirations for building air-conditioning, to avoid the atmospheric heat. Such changes in lifestyle patterns hold the risk of further heating up the microclimate and setting up a viscous cycle of negative influences. Moreover, the increased energy consumption associated with these uses, increases not only the heat inputs into the atmosphere locally but also globally.

These possibilities are illustrated in the figures on next page:

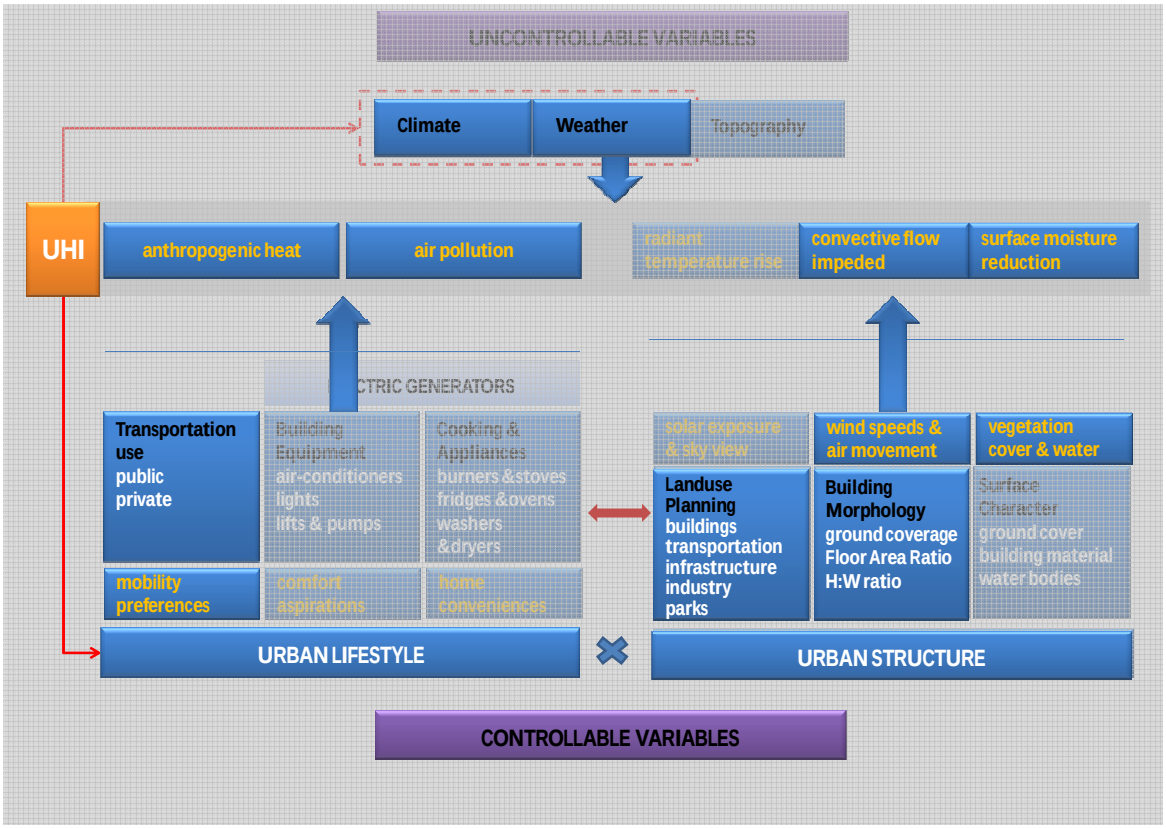


Table 13 Descriptive Framework highlighting interaction between Transport Use and elements of Urban Structure

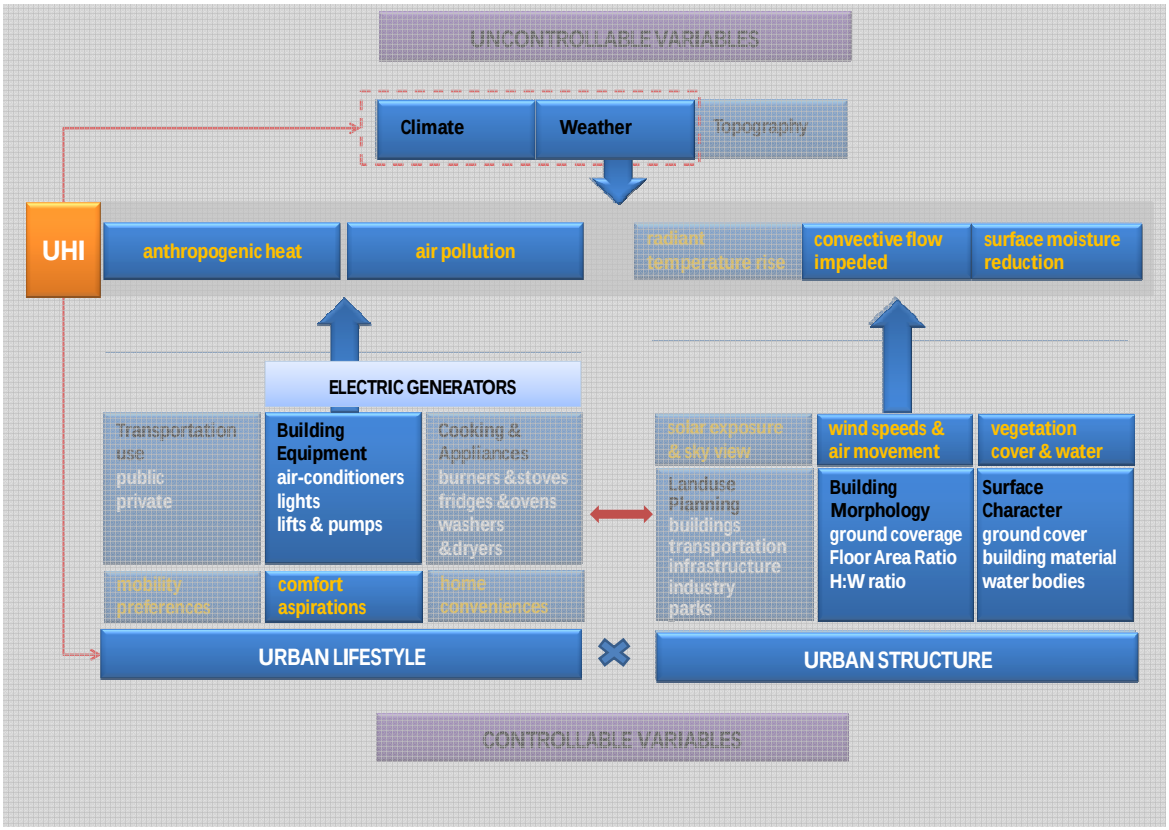


Table 14 Descriptive Framework highlighting interaction between Air-conditioner Use and elements of Urban Structure

The above described trend is significant and is becoming commonplace in many metros and large cities and also for rapidly developing tier 2 &3 cities, and is especially significant from the point of view of new cities to be built in the country.

Identification of key intervention areas based on this descriptive framework for informing policy instruments therefore becomes especially pertinent. As city planning is guided by many of the parameters listed as causative factors of UHI, such as land use zoning, building density including ground coverage, floor space index, set back provisions, as well as infrastructure requirements such as parking, utilities, and greens, that affect surface character, this framework can be used to suggest recommendations for these aspects in developmental policies. The framework also suggests that such interventions may be able to also influence lifestyle changes (e.g. lower transport use if zoning is appropriate, or lower air-condition use if densities and ground cover permit less heat retention etc.) thereby having the potential to alter the cumulative effect, as well, in more meaningful ways. What this emphasizes is the urban structure works in tandem with lifestyle factors to generate the heating effect in Urban Heat Islands by producing anthropogenic heat and air pollution which is trapped by the impacts of the urban structure. Therefore interventions in elements of the urban structure may not stand alone as developmental policies that will mitigate the environmental effects but these strategies need also to target lifestyle factors such as discouraging vehicle usage and air-conditioning use.
The descriptive framework illustrated in this section therefore presents a tool that helps identify the key levers for informing policy on mitigating the negative trends of development.

Discussion of Implications

The descriptive framework provides the basis for identifying the implication, and extent of implications of various causal factors, which can be projected for various contextual situations. A range of implications for the Indian context are described below.

UNCONTROLLABLE FACTORS

Climate

India is divided into five climate zones:
1. Hot and Dry
2. Warm and Humid
3. Temperate
4. Composite
5. Cold

It is apparent from the descriptive framework that the heating effect of the Urban Heat Island may be exacerbated in a situation where the regional conditions are already warm. This may include climatic types especially of 1. Hot Dry 2. Warm Humid 4. Composite. Incidentally these zones also correspond with the locations where the highest urban growth is projected over the coming years.

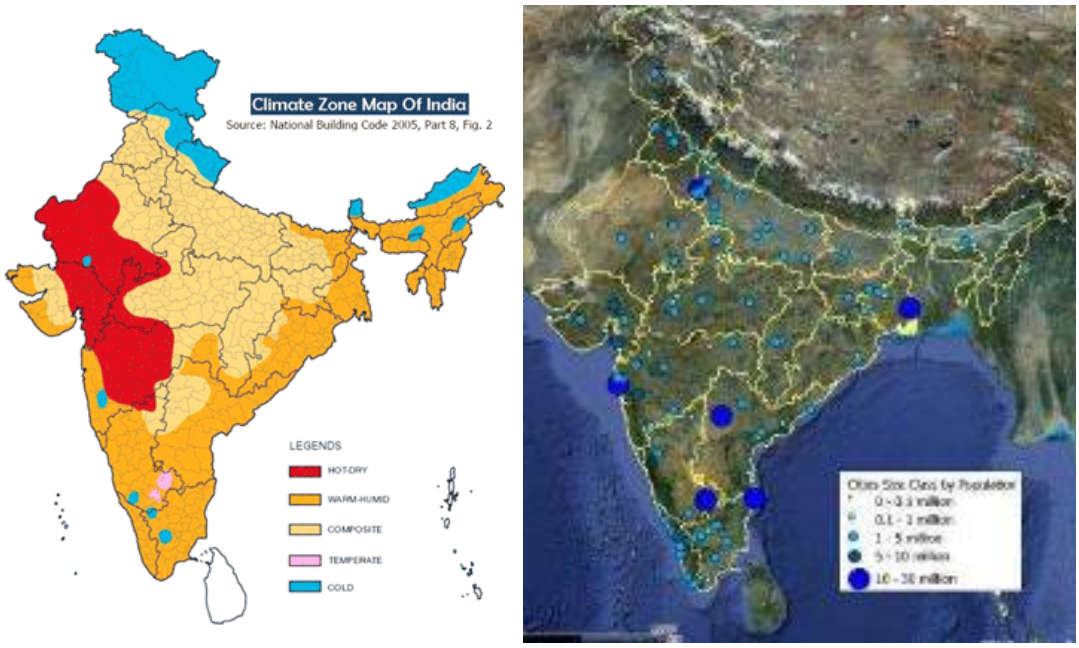


Figure 12 Climate Zones of India (Source ECBC, 2007) compared with projected urban growth for 2031 (source: IIHS)

The variations between these climatic types may influence the UHI character and behaviour due to other environmental parameters such as in humidity and precipitation etc. Therefore, , hotter climates may exacerbate the UHI intensity more than cooler ones, and there may be a different level and time of criticality in different climatic locations, for e.g. say in Chennai the highest UHI intensity may occur at 4pm in April while in Delhi it may be at 8pm in June.

Weather

The primary seasons in most of the country are:

- Summer
- Winter

There may also be intermediate seasons such as:

- Spring
- Monsoon
- Autumn

Weather patterns may also change diurnally between:

- Day
- Night

Or also between:

- Afternoon
- Evening

For example, warmer seasons with still air conditions may see a greater increase in temperatures compared to colder ones where thermal inversion may sometimes be possible, especially in polluted environments. Also it is apparent from global UHI observations that the UHI Intensity is highest in the night time, i.e. the increase in air temperatures in urban areas over the open land is the largest at that time. This may also correspond with the time of highest energy use for air-conditioning. This is characteristic especially of the cultural transition that we are going through in India with respect to comfort expectations. A significant feature of this the popular demand for comfort that occurs during the evenings and first half of the night - as sleep and rest and night being most valuable. On the other

hand hotter climates and seasons could also sometimes see greater heat during the daytime versus the night time due to the larger impact of radiant surface temperatures during the day because of the solar heat.

Topography

Physiologically, the country can be divided into the following areas:

- The northern mountains of the Himalayas
- The Indo-Gangetic Plain
- The Peninsular or Deccan Plateau
- Central Highlands
- West Coast
- East Coast
- Thar Desert and Rann of Kutch
- The Northeastern mountains
- The Brahmaputra River Valley
- The Islands of the Bay of Bengal and Arabian Sea.

Most of India where the greatest urban growth is to be seen lies in the plains. However, urban grain and texture derived from building massing and form may give rise to an urban topography which would interact with existing wind and radiation patters to influence heat storage and flushing. Locations with low wind-speeds such as those deep in land and landforms that are more closed than open may accumulate more heat may suffer and than those near the coast such as on the western boundary that may benefit from cool winds including the monsoons, especially during the day.

CONTROLLABLE FACTORS

Urban Lifestyle

- **Transportation Mode, Cooking & Appliances, Building Equipment**

  Transportation modes are changing in the current Indian scenario, there are a growing number of private vehicles and greater traffic on the roads often leading to congestion and increased air particulates and noxious gases from fumes and from friction with the ground. Although cooking fuels are cleaner in cities, the use of home appliances is increasing and so is the use of other building equipment, such as lifts as buildings go higher due to increasing densities, and air-conditioner use as urban temperatures increase. Often these sustained temperatures may be above 30 deg. when cooling loads shoot up reaching a critical situation where both peak and total loads become difficult to handle. This underpins the need to reduce UHI intensities and thereby combat air-pollution, cooling-loads, and other energy uses.

Urban Structure

- **Landuse Zoning, Building Density, Surface Character**

  As India becomes more urbanized, the conglomeration of built up areas in cities is on the rise. This means greater allocation of open area to built form, greater densities, and a harder surface character. Compared with the WHO standard for minimum 9 sqm per person open green space requirement, most of the Indian cities are found to be lacking behind the international standards, inspite of being also adopted by the UDPFI guidelines. There are policies and programmes like National Green mission and social forestry/urban forestry under which cities are proposing to increase the per person open green space.

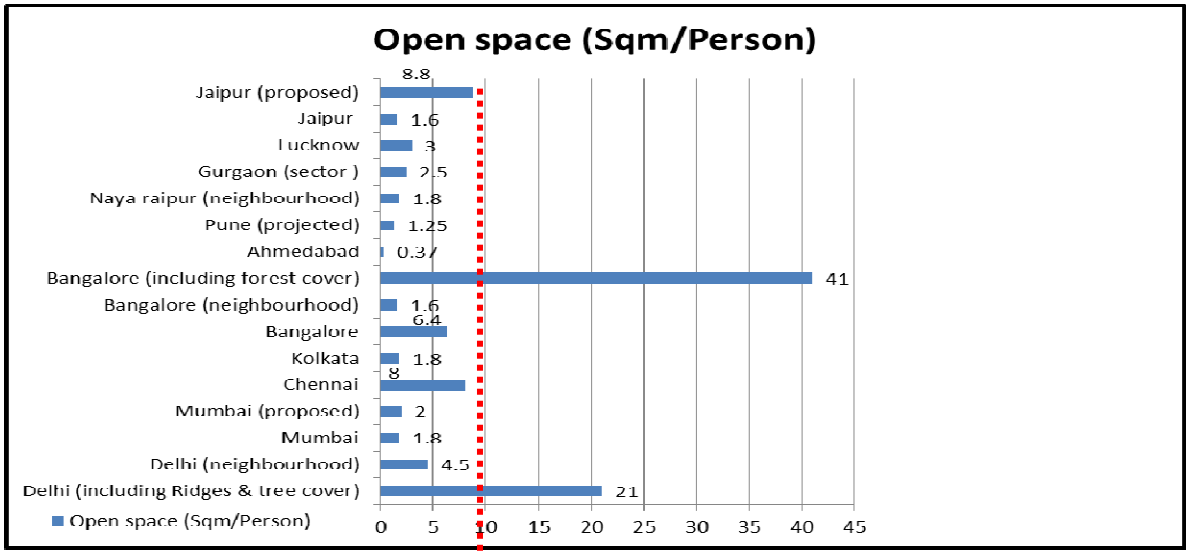


Figure 13 Open Space norms in Indian Cities

However, alongside there are proposals backing an increase in existing FSI/FAR in most of the cities and especially along metro and BRTS corridors. Therefore, on one hand there are efforts to increase open green spaces to counter the loss of natural ground cover and promote high albedo materials to reduce heat gain, and on the other there are proposals to increase FSI/FAR which will result in increased density (population & building)

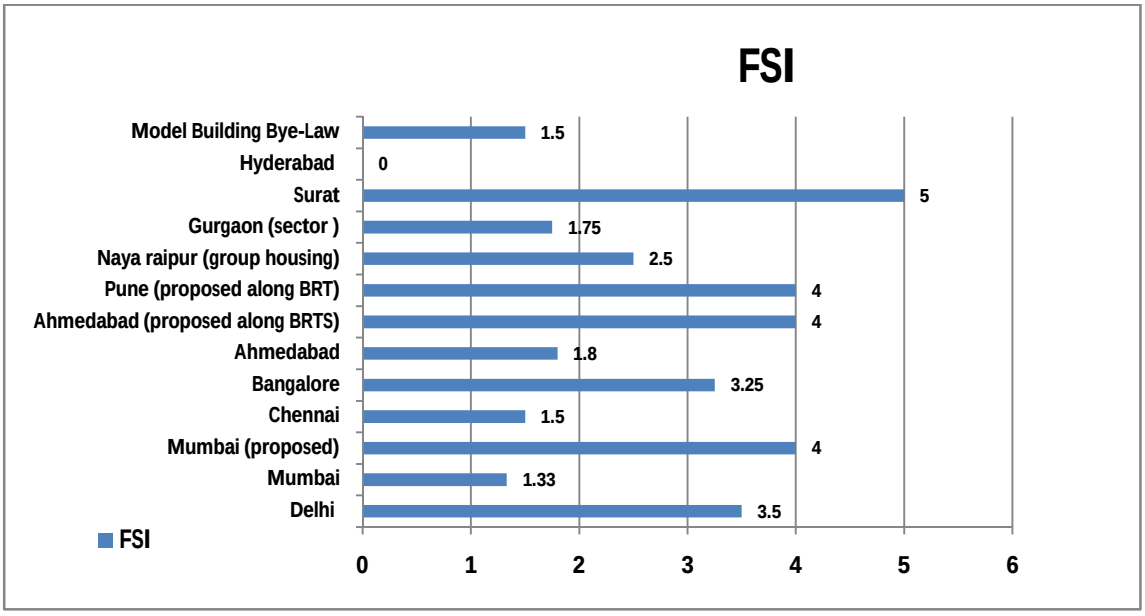


Figure 14 FSI trends in Indian Cities

At present Indian cities are moving from lower densities (FSI) towards medium densities which may be most vulnerable. This raises a question of appropriate densities in terms of accommodating both population and open space. It presses especially on the need to look at the roadmap for shaping the developing cities of Tier 1 and 2 with respect to the UHI effect as an important environmental concern.

2. Identification of Policy Instruments

The descriptive model puts controllable causal factors under two heads i.e. 'Urban Lifestyle' and 'Urban Structure' that are interconnected.. The components of Urban Structure contribute to UHI effect directly as well as indirectly through affecting Urban Lifestyle choices. Urban Structure thus becomes a critical target for mitigation measures and one that is affected through city planning measures.

Linking Policy instruments with causal factors

Having said that the causal factors under Urban Structure are parameters for city planning and having reviewed the status of UHI incorporation in existing urban planning and urban environmental policies in India, we try to link the two in the chart below:

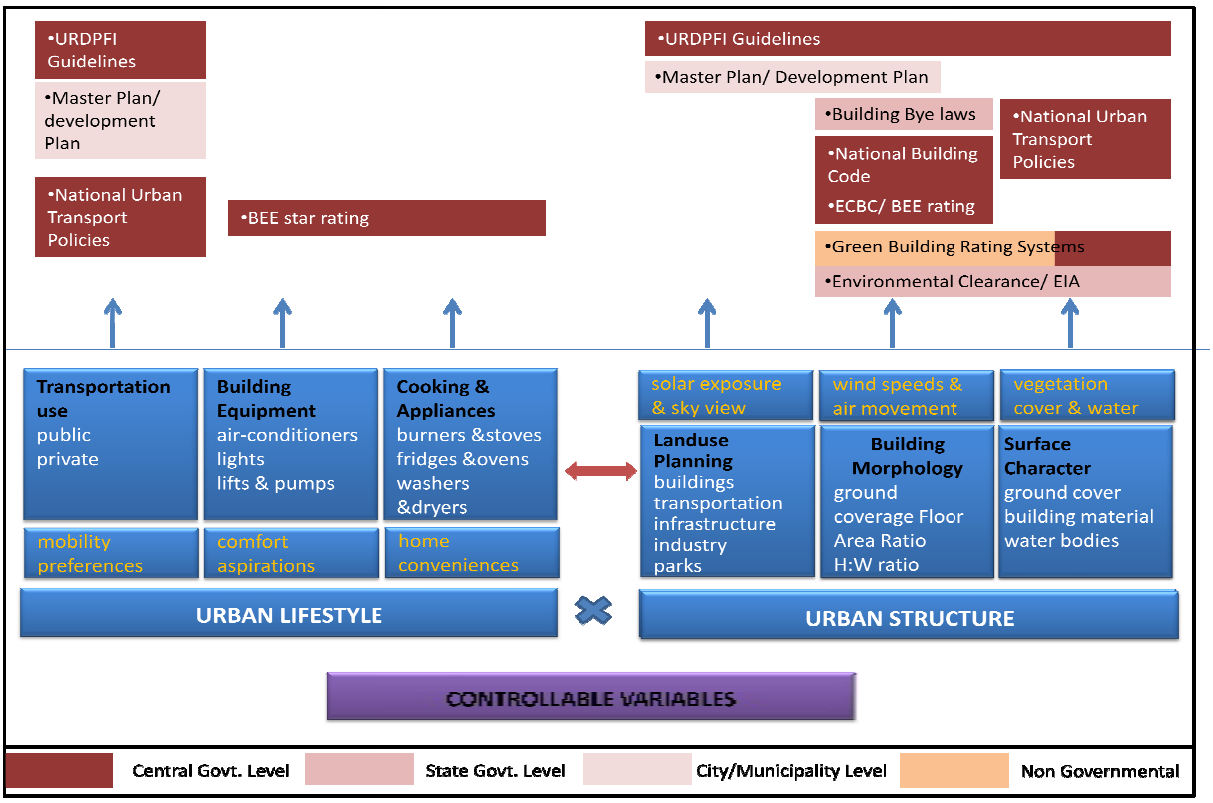


Table 15 Linkages between policy components and causal factors

As shown in the chart above, the causal factors under the head of Urban Structure are dealt under different hierarchies of the governmental system where the ministries of the central government act as nodal agencies for various policy instruments, whose implementation powers are distributed amongst the lower levels of hierarchy, as follows:

- **Land Use Planning** is guided through URDPFI guidelines at the central level under the ambit of MoUD, while master plans/city development plans act as tools for framing and implementing land use policies at city/municipality level. Land being a state subject, land policies are mostly dealt with by State governments and city master plans are prepared by development authorities and implemented by municipalities.
- **Building Morphology** is affected by development controls such as Building Bye-Laws which are formulated at state level, guided by Model Building Bye-Laws of MoUD and National Building Code at central level, and are implemented as a part of Master plan and development regulations at the city/municipality level. Green building rating systems and environmental clearance process also

have certain criteria relating to building morphology aspects such as building spacing, open space etc.

- **Surface Character** although does not feature in a dedicated policy, but is indirectly governed through components of policies, like the distribution & percentage of open space in Master Plan or provisions for parking requirements etc. in Building Bye-Laws/Model Building Bye-Laws of MoUD. Surface characteristic are also a considered criteria for points in the green building rating systems and environmental clearance provisions.

The causal factor of 'Urban Lifestyle' is influenced by Urban Structure and its policies on one hand and on the other there are certain policies that directly impact lifestyle choices. Described below are policies that directly impact causal factors under 'Urban Lifestyle'.

- **Cooking and Appliances** (choices/use) are influenced by policies or programs relating to fuel, energy conservation etc. For example BEE star ratings.

- **Building Equipment** (choices) can also be influenced through policies relating to energy conservation or energy efficiency or alternative energy source.

- **Transportation Use**- is mostly influenced combination of landuse and transport planning framework like URDPFI guidelines, NUTP and their tools along with framework relating to vehicles, public and private transportation

The table below lists the relevant policy instruments of various ministries reviewed previously and identifies the policy instruments where possible interventions can be made.:

		MoEF	MoUD	MNRE	MoP
Central Govt	VISIONARY Documents	•NEP	•National Urban Transport Policy		
		•National Conservation Strategy &Policy Statement on Environment & Development			
		•National Mission on Green India	•National Mission on Sustainable Habitat	•National Solar Mission	•National Mission for Enhanced Energy Efficiency
	Guiding Documents		•Model Building Bye Law •Urban and Regional Development Plan Formulation and Implementation		
State Govt/ City/ Municipality	Tools for Implementation	•Environment Clearance (EC/EIA)	•JNNURM-CDP •Master Plans •Building Bye-laws •DDA-UTTIPEC Street Design Guidelines •Municipalities with NGO		•Energy Conservation Building Code (ECBC) •Programmes of Bureau of Energy Efficiency
Non Govt.	Tools for Implementation	•Green Building Rating Systems			

Identified Policy instruments for possible policy intervention

Table 16 Identification of Policy instruments for possible interventions

Under the section of Indian Policies, four relevant ministries (MoUD, MoEF, MoP, MNRE) were reviewed from perspective of UHI incorporation and their existing framework was linked to causal factors of UHI in the chart above, which gives a fair idea on the policy instruments where UHI related interventions are possible. Further, in order to identify possibilities of UHI inclusion in the governmental framework with a vision for low carbon urban development we need to map, possible linkages and roles of the identified policy instruments.

Identification of Policy instruments for possible interventions

Controllable factor of 'Urban Structure' is crucial from the mitigation perspective.. MoUD becomes a crucial agency for incorporation of UHI related measures in its framework. From instruments like NUTP, URDPFI guidelines, model building bye law at central level to instruments like building bye laws, master plans, city development plans, street guidelines under its state and city level counterparts, all present a scope for inclusion of UHI related measures.

UHI is understood to be causal factor for impacting urban environment. Thus MoEF and its instrument of environment clearance seem to have a potential to include awareness and mitigation measures for UHI at scales ranging from building to city levels. At present the measures are focused more on material characteristics and open space provisions, but can be expanded to include urban structure, transportation systems and land-use planning..

As described in the previous sections and acknowledged in the National Sustainable Habitat Mission there is a vicious cycle of energy use created by Urban Structures. The Ministry of Power and the Ministry of New and Renewable Energy also become crucial agencies for policy interventions.. The two ministries are working at a scale where their frameworks influence both the heads of controllable causal factors. Thus, they will be important ministries to target for UHI inclusions.

Green building rating systems like GRIHA/LEED also provides an opportunity to extend UHI related aspects in their systems, which at present look at UHI primarily from the perspective of surface /material characteristics.

Identification of possible linkages

There are existing linkages between the visionary documents and the implementation tools, for example under MoEF the vision of the National Environment Policy is implemented through Environmental Clearance and of EIA. We believe few more linkages should be established especially between the MoP and MoUD. For example the ECBC codes and programmes of BEE can be linked or integrated in the city planning documents like master plans, building bye-laws and transport policies as well. The ministries of Urban Development and Power have inter-connected and critical roles, working in tandem towards achieving the common aim of 'low carbon urban development'.

Identification of possible role of existing policy instruments

The Environment Protection Act 1986 and 74th amendment to the Constitution, provide a statutory channel for laying emphasis on the UHI effect as an environmental degrader. The means could be incorporating strategies in existing implementation tools of city planning or giving emphasis for research on the subject.

At the central government level provisions of the guiding documents like NEP, Missions under NAPCC, NSHM, URDPFI guidelines, model building bye laws can be used as tools for introducing

UHI effect mitigation as a relevant issue and for suggesting strategies based on research for guiding implementation instruments.

Policy instruments of environmental clearance, building bye laws at state level and master plans, city development plans at city/municipality level can act as tools for implementing UHI mitigation strategies. Collaboration of city municipalities/development authorities with nongovernmental organizations can play the role of demonstrating pilot projects at different scales.

The existing policy framework, therefore, has adequate opportunities to incorporate UHI related interventions, from provisions for focused research to ground implementation in the form of short and long term strategies. A dedicated effort as in countries like Japan and USA is needed, backed by empirical research establishing key casual factors and the extent of their impacts with contextual variability for the UHI effect and intensity.

PART III
THE STAKEHOLDER'S MEETING

Figure 15 Stakeholder's Meeting in Delhi

This section documents the discussion that took place at a consultation meeting, between the invited members from various stakeholder organizations. These included invitees from governmental, non-governmental organization, and academic institutes related to urban development, energy efficiency, transportation and environment. The meeting also included a discussion of the opinion of international advisers to the study: Dr Ronnen Levinson of Lawrence Berkeley National Laboratory, California and Dr Koen Steemers of the University of Cambridge, United Kingdom.

The consultation meeting included a presentation of the status of research and policy on UHI in the world and India, also a discussion of the understandings gained from the theoretical framework developed in the study and indications for further work gained from this. In discussing the Urban Heat Island issue, the intention was also to get the opinion from the experts in the field and relevant government plan makers on the extent of possible impacts or UHI, the critical factors that may need to be addressed, the nature of policies required for mitigation measures, and the levels of city planning and development where intervention could be made. Overall the meeting which brought forward the positives of the research conducted and helped to add missing links and references to the study.

1. Discussion points

The discussion at the consultation meeting revolved around key points that emerged from the research and policy review and thereafter the development of the descriptive framework and possible operational framework for policy intervention. These were points were presented as questions in two sets and conducted in two discussion rounds each as follows:

Questions of Round 1

1. In the review of the literature on the causal factors and impacts of Urban Heat Islands, were the significant relationships between the key factors and UHI adequately highlighted?
2. While most urban development policy internationally has focussed on surface characteristics of the urban structure, why has there not been as much emphasis on the other aspects of planning regulation such as building density and distribution of urban landuse.
3. Is UHI mitigation a significant factor for the low carbon urban development of new and existing cities, in a country like India where rapid urbanisation is taking place and most of the urbanizable zone is in the hot climatic belt?

Questions of Round 2

4. Of the two broad heads within which the causal factors of UHI have been categorized in our report, i.e. 'urban structure' and 'urban lifestyle factors', the latter primarily resulting in the anthropogenic heat contributions of UHI, which of these should be targeted with greater emphasis in urban policy initiatives for the most effective impact on mitigating UHI.
5. It is clear from the relationships in the descriptive framework that there are synergistic impacts of both groups of causal factors. Does this imply a different strategy in framing regulations where such synergistic effects may be expected?
6. In developing new policy directives for mitigating UHI in the Indian developmental framework, what further research work may be required, specific to the Indian situation and how should this be formulated?

2. Summary points

The main outcomes from the discussion meeting as well as the opinions of international experts are summarized below:

Discussion Round 1

- Through the discussion on the Urban Heat Island and its various causal factors and impacts on the environment, it was concluded that the effect of UHI was adequately documented and its impact o the environment confirmed even though the exact nature and cause of the phenomenon had not been very precisely quantified yet especially in the Indian context.
- It was brought out that there were many ongoing research projects and studies aimed at calculating and mitigating the UHI effect, especially internationally and some in India as well. Some of the recent research brought to light was the work of Ronnen Levinson, on measuring the surface and canopy level temperatures in the Indian cities of Pantnagar and Hyderabad with a view to evaluating the impacts of cool roofs on UHIs; study on reading the effects of walls with low emissivity as well as reflectance of colored walls, on the UHI effected being conducted by Hashem Akbari and Rosan Field respectively; work of TARU in documenting forty buildings in Surat for surface and air temperature difference at micro and macro levels in different built up areas of the city; recent publication by IIT, Delhi on Theoretical and Applied Climatology documenting the measurements of UHI over Delhi.
- The UHI effect was realized as a potential threat for an urbanizing country like ours, however, it was considered that for the significance for low carbon growth to be driven home, a more comprehensive documentation of the effect and its broader impacts be undertaken for different contextual regions of the country. Also for mitigation impacts to be formulated and instated in policy the relative importance of the causal factors be researched to a much more quantitative level possibly through mathematical models.

Discussion Round 2

- Keeping the interrelationships between the various causative factors of the Urban Heat Island effect in mind, it was considered that further research would be necessary specifically for the Indian context before appropriate policies could be formulated. A study of the relationship between the microclimate of a region, its urban form, and the energy demands would comprehend the importance of UHI for a hot climate area like India. Another significant field of understanding would be the effect of ground and building surfaces on the temperature variations in the context of India.

- With regards to policies on UHI mitigation the most important government agencies that could play a pivotal role in incorporating the UHI effect were identified to be the Ministry of Urban Development and Ministry of Power, as these were directly concerned with low carbon urbanization.
- It was, further, considered that as there may not be a standalone policy on UHI, there was a need to look at synergies of its causal factors, such as looking at urban structure and urban lifestyle factors together as a combined idea in new and existing policies. An example quoted by international expert, Dr. Koen Steemers was the idea of 'Transport Oriented Development (TOD)' where high density development is encouraged or prioritised around public transport nodes, which then in turn could enable integration of 'green fingers' to create local reductions in UHI, increased outdoor comfort, and lower energy demand for cooling, especially in new developments. Additionally, Dr Ronnen Levison was of the opinion that mitigation measures focussed on increased roof shading, plantation, and increased pavement albedo levels could offer economical and effective ways of reducing UHI effect that could be easily retrofitted into existing developments with immediacy.
- Keeping such synergies in mind, it was considered that community and neighbourhood level initiatives at the city planning and development stage could offer probable places for UHI mitigation intervention. Further ensuring implementation of the mitigation policy at various levels through municipalities and local governments would be equally imperative.
- Further studying the causal factors of UHI through numerical models and simulations, may give convincing results towards the importance of this effect. This could be achieved by cross disciplinary and design based research, through collaborations of various agencies that measure and document those factors. Thus it may be concluded that there is need to conduct specific quantitative studies to decipher the role of Urban Heat Island, its causal factors and impacts it has on the urban microclimate taking into account the climate and geographic factors of specific to typical cities of India.

INFERENCES FROM STUDY

The inferences from the different parts of this study are summarized below:

PART I

The first part of the report has covered the breadth of existing knowledge and initiatives on the Urban Heat Island effect both internationally as well as nationally. The figure below provides an overview of the learnings from the literature review section:

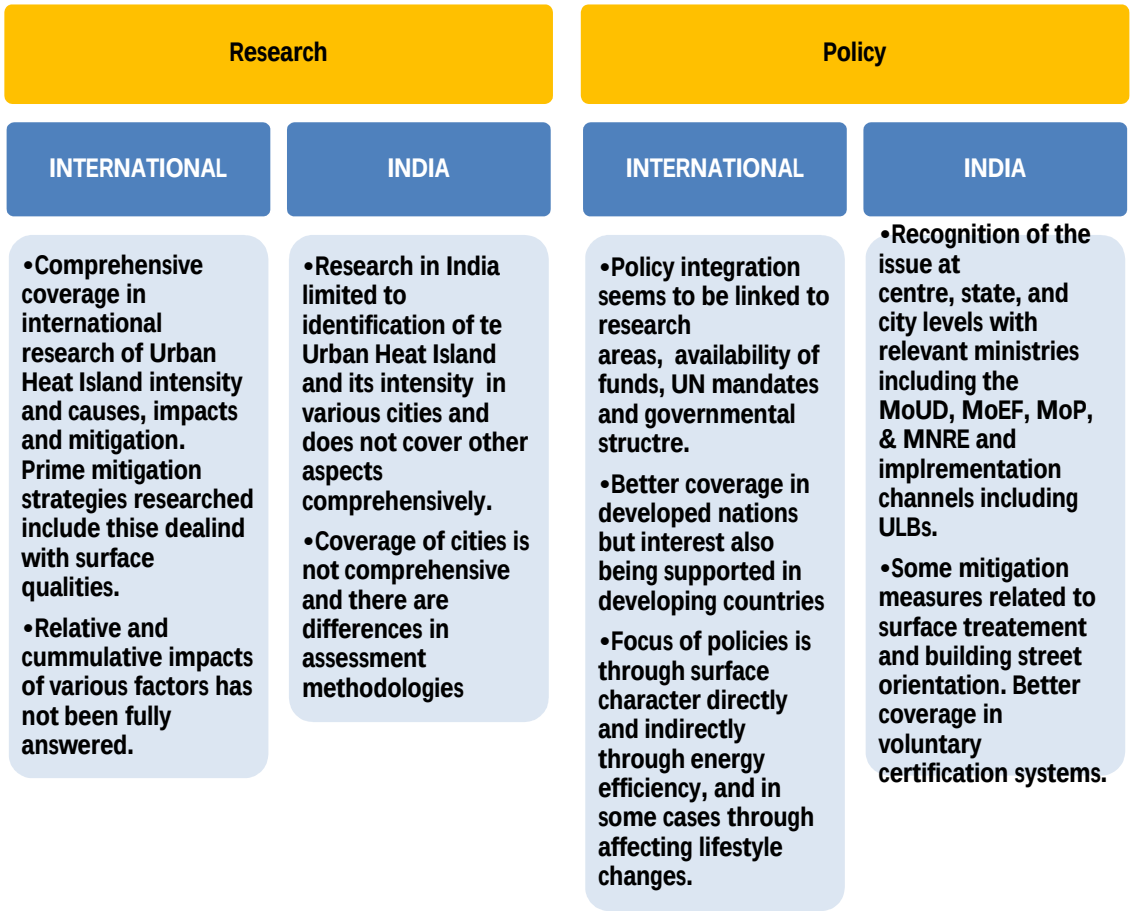


Figure 16: Literature review inferences on coverage of UHI in Research and Policy

Detailed inferences from each objective of Part 1 are listed below.

Research on UHI – International & National

- The research internationally is found to be thorough in identifying the causal factors, impacts, and mitigation effects of the Urban Heat Island effect, however, research on relative and cumulative impacts of factors is lacking. In India the research has verified the presence of UHI and established it as an environmental issue by recording its temperature intensity in many cases, but other aspects of causative factors and effectiveness of mitigation measures have not been comprehensively studied.
- International studies have largely focussed on aspects of urban structure as being instrumental in contributing to the UHI effect, including, city size & population density, building density and massing, surface character and vegetation, while urban lifestyle factors of transportation use have been also considered. In India the UHI effect has primarily been looked at in relation to city size and in some cases building density and lifestyle factors have been mostly ignored.

- While international research has looked at increased energy consumption, increased air pollution, health, and economic influences, besides increased temperatures, as impacts of UHI. Indian research has primarily highlighted only the temperature increase as an effect of UHI. Other factors, however, also need to be empirically evaluated to establish the extent of the impact of the UHI effect and thereby imperativeness of further research on and implementation of mitigation measures.
- Internationally, mitigation strategies to reduce the UHI effect have focussed on surface characteristics and many are incorporated into the urban planning guidelines and building construction codes. In India, on the other hand research on effectiveness of mitigation strategies for combating the UHI effect has barely begun.
- It has been noted that internationally the maximum UHI intensity was recorded as 12°C whereas in India the maximum recorded increase was 8°C. It may be considered that UHI intensity would vary with climate type, city density, and city development etc. and therefore research in India would need to be more comprehensive to cover this variation.

Initiatives and Policies- International

- On the international policy level, policy recommendations are closely tied to national and international research that was followed up by the governments of these nations. The policy making and research seems to be generally supported and pushed by the mandates of the United Nations. The presence of policy recommendations is also tied to the availability of funds for the purpose.
- While researching the policies on mitigation of Urban Heat Islands it has been observed that the phenomenon is more thoroughly researched and addressed over a longer period of time by nations that are Developed Nations than those which are still Developing. This may be a direct result of the fact that these nations were urbanized early and hence recognised the UHI effect earlier, and that they had a longer period of time to observe and collect data related to the phenomenon and try out strategies of mitigation. Also possibly, these nations were targeted for capping their emissions earlier and therefore were forced to examine some of the aspects which may also affect Urban Heat Islands, although Developing Nations are also now being helped in their environmental agendas through various financial mechanisms.
- Moreover, it is observed that countries working toward UHI mitigation tend to concentrate their funding and implementation on short term programs such as building energy efficiency, cool roofs, and street surface improvements. Issues of land use, urban planning, built form and density do not consistently form part of most UHI mitigation programs. This may possibly have to do with ease of implementation and inadequate availability of research on the importance of such interventions and their interactions with other aspects of city growth and well-being. Lifestyle changes have received some recognition in countries such as Japan and countries of the EU, but could get more attention.
- In many countries UHI is placed under the larger umbrella of climate change or global warming at the central level- its implementation being specifically structured at state, regional and city level. This is true of Japan and the EU countries with centrally motivated projects and schemes compared to the US which has mostly city and state level programs and interventions. This reflects on the importance of the governmental structure for implementation and success of policies.

Initiatives and Policies- National

- The existing structure of policies, guidelines etc. with the ones focused on urban development directly acknowledge the phenomena of UHI. They state certain causal factors related to city form, materials, and air pollution, and provide for mitigation measures which are mostly related to building-street orientation and surface treatment/increase of green cover.

- Visionary documents like NSHM combined with NEP provides us with a channel at the central level, through which UHI effect can be introduced into implementable actions like CDP, Master Plans, Building BYE-laws, EIA backed up by the responsibility and power of environmental protection and urban planning entrusted upon urban local bodies. Apart from governmental organisations there are some non-governmental organisations as well that take into account the UHI and have given implementation to mitigation strategies.
- The visionary documents/guidelines at the central level that already directly consider and suggest measures that will help mitigate the UHI include, the NSHM and URDPFI guidelines under MoUD, the Environmental Clearance for large development projects under MoEF with coverage till city level development, and ECBC, 2007 under MoP and MNRE. Indirect impacts may be from the National Transport Policy under MoUD, National Mission on Green India under MoEF, BEE star ratings under MoP, and National Solar Mission under MNRE.
- The implementation instruments at the local level that directly refer to the UHI include only the DDA Street Design Guidelines and efforts of the municipalities of Surat and Indore. Besides governmental instruments, voluntary rating systems like LEED and GRIHA also directly have recommendations which include aspects of mutual shading, parking norms, and surface character, to counter the UHI effect.
- Generally, there is primarily only a recognition of the UHI effect in the existing governmental framework and a mention of mitigation measures, but possibly the lack of sufficient research on the subject in the local context has resulted also in a deficiency in a comprehensive coverage of relevant strategies.

Overall, while there has been better coverage of the UHI aspect both in International Research and Policy, national initiatives have been restricted although efforts at addressing the phenomenon in a structured way have now begun to be initiated. Moreover, while most research and policy, even globally, has been concerned largely with surface characteristics of the urban environment, there needs to be a better recognition and resolving of urban planning, building morphology and lifestyle factors as well. Incorporation of informed policy to address the Urban Heat Island effect in urban development instruments therefore, requires significant efforts in the form of comprehensive and sustained endeavours and appropriate incorporation at the right levels.

PART II

Descriptive Framework

Further to the literature review, Part II of the report has developed a descriptive framework describing the theoretical relationships between the various causative factors of the UHI effect and based on this evaluated the potential for policy intervention in the country. This section has had the following key outcomes:

- Presentation of a reference theoretical guiding framework of UHI influencing parameters, bringing out interactions between uncontrollable and controllable influences as well as between urban lifestyle and urban structure parameters, as well as their synergistic effects. In doing so the discussion of the framework has also thrown up possible scenarios of criticality that may occur in various contextual conditions of the country and how they may possibly be dealt with. This offers insight into the key levers that need to be affected in different situations.
- Identification of the policy sections, sectors, and scales where UHI mitigation may be addressed, highlighting the nature of mitigation measures that may be feasible and successful.

At the central level visionary documents and guideline recommendations through the ministries of MoUD & MoEF, have been identified for addressing aspects of urban structure & MoP & MNRE for influencing aspects of urban lifestyle. At the local level implementation tools like Development plans, Building Bye Laws, & focussed codes may be useful while implementation bodies like the ULBs and municipalities could form the requisite channels,

PART III

Stakeholder Consultation

A consultation meeting of key stakeholders was held to discuss the key points that emerged from the literature review and the theoretical framework. These, as discussed in Part III of the report broadly fell under two heads that were then discussed in two rounds:

Discussion round 1: significance of study and confirmation of research and policy review results.
Discussion round 2: avenues for policy integration and areas for further research for achieving this.

The salient points that emerged from the Stakeholder Consultation are enumerated below.

- Urban Heat Island was agreed to be a real phenomenon that needed to be addressed in both extended research and efficient policy initiatives in the Indian context. The need for further research on the impact of UHI on energy, economy, health, etc. was highlighted.
- The research covered in the review was found to be fairly comprehensive in the coverage of the issue and role of causal factors. Additional references and contact persons were suggested to take the work further.
- It was pointed out that there was a need to disaggregate the relative impacts of the causal factors in a context specific way to be able to work out the most effective mitigation strategies. Research capabilities and strengths of various Indian institutes were brought out towards this end.
- Concepts such as those of ‘anthropogenic heat intensity’ were put forth as a way of understanding the combined effects of lifestyle and design factors. Such concepts could be considered as possible handles for the development of policy to deal with UHI.
- Examples of such policy could include:
    a. stricter energy efficiency requirements for buildings in high density areas
    b. relaxed requirements and possible higher densities could be considered in climate zones with mild weather
    c. encouragement of waste heat release from air- conditioning systems at the top of buildings
    d. reduce vehicle movement where higher densities are required, by providing for public transport, or encourage higher densities only at public transportation nodes.
    e. use of high parking charges in high density areas to discourage private vehicle use.
    f. attempt for quick exits from housing and commercial developments directly to the motorway
    g. Consider mixed use model for higher density development with day use commercial at the lower levels and night use residential at the higher levels.
- The Ministry of Urban Development and the Ministry of Power were identified as the operational ministries for the implementation of UHI mitigation policy. It was also considered that while further research is conducted on the subject some broad recommendations could be made based on the literature review and the concepts discussed at the consultation meeting.

FUTURE DIRECTIONS

The outcomes from this 'Scoping Study for Policy Initiatives to Minimize Urban Heat Island Effect for Low Carbon Urban Growth', has established the necessity for further research.

It is inferred that policies share a relationship with the status of research prevalent and available. In the backdrop of rapid urbanization in the country with the concerns of energy consumption and with the aim of low carbon urban development future, it then becomes imperative to push for more research on the subject to be able to address the issue of UHI effect in a detailed and specific manner at city level. This study has highlighted the nature of the research that may be required to inform necessary action on UHI mitigation, the expertise available nationally for carrying out the research, as well as the potential value of specialist support and collaboration internationally.

The research directions that have emerged fall under the following broad themes:

1. **Empirical research to prepare a comprehensive and comparable database on UHI intensity in Indian cities in various climatic contexts:** Although several research projects have been conducted, and some are in the process of being conducted in various cities in different parts of the country, they have followed differing methodologies and have had varying objectives. While the incidence of heat island effect is clearly established the metrics and modes of measurement differ. The empirical data from different city contexts in each of the climatic zones of the country, obtained through a uniform methodology, would enable an establishment of the UHI formation and its intensity. It would be on this basis that a view on mitigation measures could be taken.
   The hypothesis, implicit in this Scoping Study, has been that the UHI effect, if not attended to, would have negative implications vis-a-vis the objective of low-carbon urban development, and that urban development norms and building bye-laws need to incorporate measures that minimise the UHI effect. Empirical data would verify this hypothesis.
2. **Research to assess the extent of the impact of UHI on the environment, energy use, economics, and health in the Indian context:** The research should cover the key climate zones and large, medium, and small cities. The perspectives of the impact of UHI on comfort, health and energy consumption for thermal comfort, would each require data in a particular form. It would be necessary to establish the linkages and use appropriate metrics for a quantitative understanding of each of the impacts. Again, the empirical data from different city contexts in each of the climatic zones of the country obtained through a uniform methodology would enable an appreciation of the scale and quantum of the impacts of the UHI effect. This may be act as a driver for policy change.
3. **Simulation research to help disaggregate the relative impact of various causal factors on UHI individually and in combination with other parameters, with the help of numerical models:** The urban heat island phenomenon has been explained as a combined effect of climate weather, local geography, surface characteristics, urban morphology, and anthropogenic heat. Of these, surface characteristics, urban morphology and anthropogenic heat are, to a large extent, a result of city development controls and building byelaws. This is of considerable relevance in India where large scale urban regeneration, urban expansion and many new cities are on the anvil. It would be useful to quantify the relative contribution of these causal factors to the UHI effect. This probably requires numerical modelling and simulation. This would be critical for informing mitigation efforts in using measures with maximum efficiency.

4. **Estimation of the feasibilities and impact of various mitigating strategies in the local contexts of the country:** The intensity and periodicity of the UHI effect would vary from place to place and climate to climate. The database generated by the first research action stated above would indicate when and where the UHI effect is more pronounced or critical. This would enable a prioritisation if various mitigation strategies, according to local contexts and whether they are measures for alleviating existing conditions or intended to address prospective development in cities.

In addition to research work to provide a sound basis for instituting UHI mitigation, this project also puts forth the following agendas for policy level actions to address UHI effectively:

- **Comprehensive incorporation of UHI strategies developmental instruments**
- **Attempts to synergize the take of various ministries on the UHI issue.**

It is seen that UHI would be a relevant subject at many levels of policy and would figure in several implementation instruments that are already in operation. A concise document may be prepared for UHI related inclusions at the policy level and for harmonising of UHI related measures in the existing implementation instruments.

It is clear that without a focussed approach the Urban Heat Island phenomenon may get neglected, with significant rebound consequences on energy use, climate change, and the economy. As we move into a phase of rapid urban growth this is the opportune moment to confront the issue of UHI in India.

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