PRECURSOR OF URBAN HEAT ISLAND EFFECT AND ITS MITIGATIONS -A REVIEW

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Abstract : Due to rapid growth of urbanization, Urban Heat Island (UHI) effect is increasing in urban areas, ultimately affects human health, energy consumption, environment and ecology. This article reviews the literature on UHI effect, its precursors and mitigations. Microclimate studies done in past years reveals the factors responsible for UHI effect and also provides information for better urban planning. Indian scenario differs from the other countries due to its geographical conditions. Furthermore it critically reveals the role of meteorological parameters and pollution in UHI effect.

***Index Terms* – Urban Heat Island, Thermal Comfort, Health.**

I. INTRODUCTION

The Urban Heat Island (UHI) is a phenomenon that affects several scores of individuals worldwide. the upper temperatures experienced in urban areas compared to the surrounding rural area has huge consequences for the health and wellbeing of individuals living in cities (Mohajerani,2017). The increased use of manmade materials and increased anthropogenic heat production are the most causes of the UHI. This has led to the understanding that increased urbanisation is the primary explanation for the urban heat island (Mohajerani,2017). The UHI impact additionally ends up in increased energy needs that any contribute to the heating of our urban landscape, and therefore the associated environmental and public health consequences. Pavements and roofs dominate the urban surface exposed to star irradiation.

This report demonstrates that UHI mitigation techniques are best employed in combination with each other. As a results of the study, it had been concluded that this mitigation measures need development to form them relevant to various climates and throughout the year. There also are several possible sources of future study, and different measures for mitigation are represented, thereby providing scope for future research and development following this report.

Various anthropogenic and industrial activities in urban habitations make a visible climate impact within the variety of increase of temperature of the air close to the ground as compared to its surrounding rural areas. This development is termed the urban heat island (UHI) impact. the main explanation for UHI is replacement of natural land with artificial engineered surfaces that are created of brick, concrete, asphalt, stone, and different similar surfaces typical to urban areas having a considerably high heat capacity and thermal admittance which will capture and store higher quantities of heat. This afterward will increase near surface temperatures of surrounding urban environment (Yadava,2017). This increased energy is then slowly discharged to the atmosphere throughout the night as long-wave radiation, creating cooling a slow process and therefore elevated night time (typically minimum daily) temperatures becomes a key characteristic of the UHI impact. anthropogenic heat discharged from vehicles, power plants, air conditioners and different heat sources considerably contribute to intensify the UHI impact. With the increasing trend of urbanization, urban population gets affected in terms of energy consumption and health particularly within the summer (Yadava,2017).Following are the causes for the urban heat island effect.

- Reduced vegetation in urban regions: Reduces the natural cooling impact from shade and evapotranspiration.
- Properties of urban materials: Contribute to absorption of solar power, inflicting surfaces, and therefore the air above them, to be hotter in urban areas than those in rural surroundings.
- Urban geometry: the height and spacing of buildings affects the quantity of radiation received and emitted by urban infrastructure.
- Anthropogenic heat emissions: Contribute extra heat to the air.
- Weather: certain conditions, like clear skies and calm winds, will foster urban heat island formation.
- Geographic location: Proximity to large water bodies and mountainous parcel will influence local wind patterns and concrete heat island formation.

Following are four broader variables that influenced the behaviour and performance of the cool and green roofs. (Yang,2018)

Climatological variables

- Intensity of solar radiation which determines heat storage, surface temperature and thermal balance of roofs.
- Ambient temperature which determines the sensible heat released by roofs.
- Ambient Humidity and precipitation which determines the moisture balance in green roofs.
- Wind speed and atmospheric turbulence which determines heat transfer coefficient between the surface and atmosphere.

Optical variables

- Roof albedo and emissivity defines the performance in reflective roofs.
- Absorptivity of vegetation defines the shielding effects in green roofs.

Thermal variables: Thermal capacity of roofs.
Hydrological variables: Irrigation rate and moisture content of soil

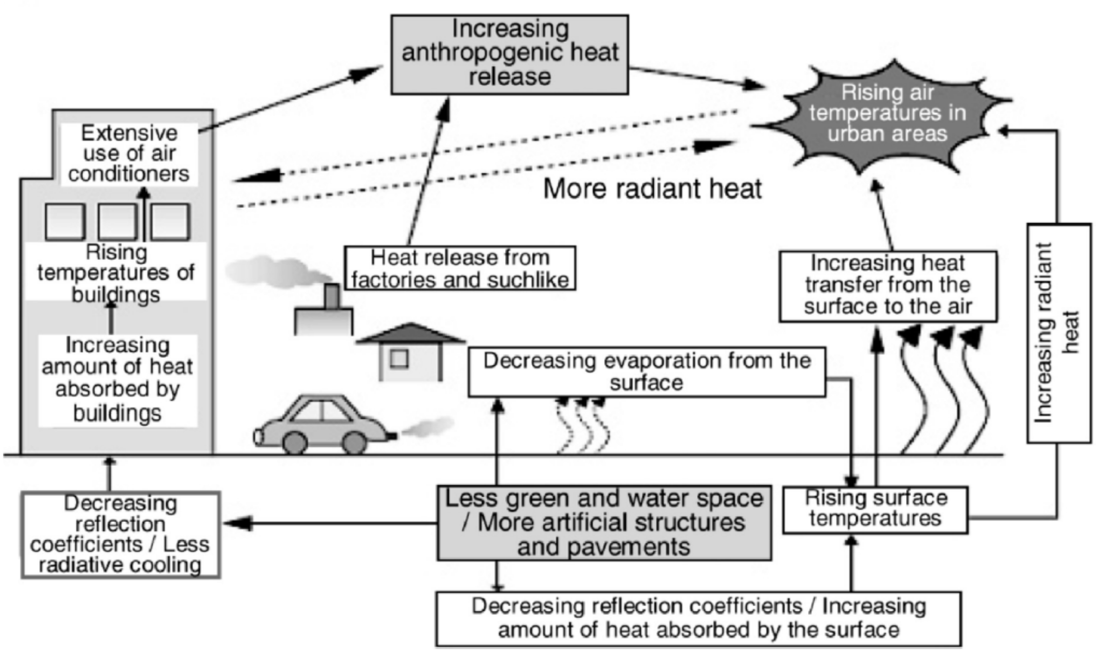

Figure 1: Causes of Urban Heat Island effect (Mohajerani,2017).

II. REVIEW METHODOLOGY

On the whole, 10 research papers and 2 review paper have been selected for executing this literature review. Among them, 6 paper have discussed on the urban heat island precursors while 5 research papers have considered factors responsible as well as mitigations of urban heat island effect. 1 of the research papers gives meteorological parameter influence in Urban Heat Island effect. Iterative searches focused on various keywords such as "Urban Heat Island", "UHI Causes", "UHI Mitigations", "Urban microclimate".

Fallmann et. al. (2016) Although mitigation measures can be taken in to account there are some negative impact on air quality is ascertained. Natural vegetation tends to dissipate sensible heat in favour of heat of transformation, that successively decreases the surface temperature and also the average height of the physical phenomenon. In average, the temperature is reduced by 1.2 °C and 1.3 °C for the high reflectivity and vegetation scenario, an augmented surface reflectivity (Albedo) leads to a stronger temperature decrease during the day than for the night time. The study may prove that a rise of albedo and urban vegetation is in a position to improve air quality, resulting in reduction of daily mean ozone concentration. A decrease of turbulent kinetic energy (TKE) because of a lower temperature results in a lower rate of turbulent mixture and a decrease of the mixing layer height, so leading to higher near surface concentrations of primary pollutants. A rise of primary air pollutants NO and CO by 5–25% is observed. Additionally, extremely reflective surfaces will increase peak ozone concentration by up to 12% because of a high intensity of reflected shortwave radiation accelerating chemical science reactions.

Mohan et. al. (2012) The ascertained Temperature difference in urban and rural areas for Delhi was 8.3°C, which is considerably lower than the results based on North American and European cities. Artificial energy flux densities, heat capacity of the urban fabric, and evapotranspiration in cities could have wide variations for various climates and demography. The impact of meteorological parameters like wind speed and direction moreover as atmospheric stability was observed on the intensity and location of the urban heat island hotspots. A relationship of most UHI and population showed that UHI in Delhi are under expected from the empirical relationships obtained for North- American and European cities with lower population than Delhi. Lower anthropogenic heat fluxes of Delhi because of a developing economy coupled with the environmental condition and demographic variations will be attributed for lower UHI in Delhi. However, rising population and alter in LULC and associated anthropogenic activities concern strategic mitigation measures within the city to stop additional strengthening of heat island effect. Thus, with rising population and consequently increasing built up areas and associated anthropogenic activities, it's imperative to implement heat island mitigation methods within the city in nowadays in order that additional intensification of heat island effect within the city will be prevented.

Sharma et. al. (2015) The study was conducted in Bhatinda city of Punjab state in India. Urban areas was observed to exhibit highest temperatures which could be attributed to roads, paved pathways, vicinity to over-bridge and high traffic load. Some of the rural sites exhibited high temperatures which were comparable to urban temperatures. It was also stated that city temperatures were 2-5˚C higher than its surroundings due to cemented pavements and increased vehicular exhaust. Further, elevated temperatures at some of rural sites could be due to the fact that these sites have been undergoing urbanization in the last few years. Urban heat island effect was not evident during night time. This could be due to location of Bathinda in the vicinity of desert that allows for rapid cooling at night.

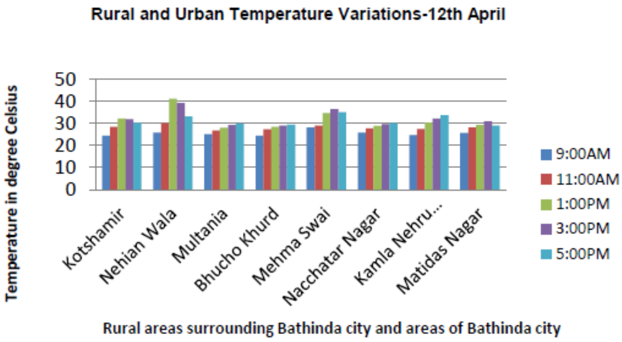

Figure 2(a): Rural and Urban temperature variations 12 April (Sharma,2015).

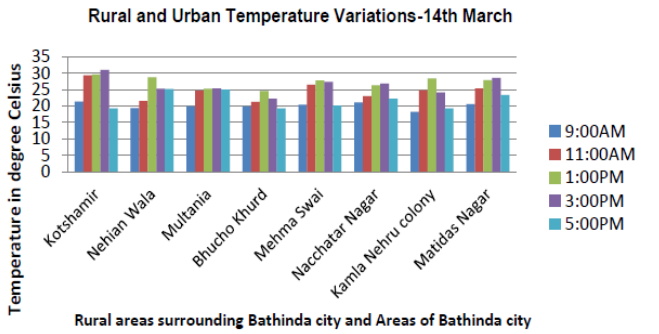

Figure 2(b): Rural and Urban temperature variations 14 March (Sharma,2015).

Kotharkar et. al. (2018) Heat sinks were stated in land-cover having dense vegetation, which includes VNIT NEERI and Seminary hills areas of Nagpur. From the urban planning perspective, the comparative analysis of local climate zones plays a significant role in understanding the thermal behaviour of urban areas. Such careful evaluation of UHI could benefit the local authorities to identify the areas of priority and level of urban interventions required for UHI mitigation. Given methodology includes Local Climatic Zones mapping, data collection technique using fixed station points and mobile traverse survey conducted during the month of December 2015 and February 2016 of winter season. It also examines the thermal phenomena in different Local Climatic Zones with respect to city's average for identifying critical areas. The maximum temperature difference was observed 4.09 °C between two Local climatic zones on 2nd February 2016. Clear cloud cover and low wind speed climatic conditions was observed during the day which supports strong UHI, as well as during night with clear cloud and absent windy conditions. The result shows that UHI intensity within built up area , in winter season for Nagpur city, ranges from 1.76 to 4.09 °C. The compact low-rise present at the urban core were found to be warmer than other major Local Climatic Zones present in the inner areas of the city. It was also stated that thermal variation, between traditional Local Climatic Zones and the Local Climatic Zones with subclasses.

Cardoso et. al. (2017) It was stated that magnitude of impact is strongly affected by synoptic conditions, especially precipitation, cloudiness, and wind. In the study, researchers shown the relationship between atmospheric stability and heat islands in tropical cities, where the temperature differences are pronounced under calm conditions. Urban morphology and land cover are important factors for the formation of UHIs in Paranavaí, Rancharia, and Presidente Prudente. Verification of the role of built density in increasing the UHI magnitudes, whereas vegetation is directly related to lower temperatures. Although high magnitudes are identified in densely built areas, the effects of surface relief on lowering the city temperatures are significant, especially when traversing vegetated areas. The UHI magnitudes depend on the reporting method. For example, the average UHI magnitude was up to 2.7°C in Rancharia, 3.5 °C in Paranavaí, and 3.7°C in Presidente Prudente for five summer nights (December 2013–January 2014). In contrast, using daily data from the traverses, magnitudes were 4.7 °C, 5.5°C, and 6 °C, respectively. Tropical cities remain constantly warm and sunny, and the heat islands can magnify the thermal discomfort in urban areas. Therefore, the urban climate of small and medium sized cities in the tropics has its own significance. As urban areas are growing, knowing where UHIs are going to happen and what affects their magnitude will allow for better urban design and planning methods. UHI magnitudes were higher in areas with closely spaced buildings with few or no trees and building materials that are not appropriate for the region's climate and thermal comfort.

Farhadi et. al. (2019) It is stated that the better orientation of buildings and canyons, suitable materials for pavements in various urban areas, the number and type of vegetation and trees, etc. are items which can be accurately studied in outdoor environments to provide optimized conditions regarding UHI and thermal comfort. The availability of simulation tools in recent time has made it possible to carry out the studies related to UHI and provide more practical results for urban policymakers. It is also stated that changes in urban geometry may not practical for existing urban sites, but relevant results can be useful in new planning and constructions. The results indicate that changes in the urban form cause remarkable differences in related parameters compared to the materials and green spaces. Thus, priority should be given to parameters in the urban plans associated with UHI effect. Vegetation and construction and covering materials are effective urban characteristics which can be modified even in existing urban areas. Although high quality studies provide scientific results for each factor, different geometric properties can produce contradictory effects on various parameters. Deep urban canyons produce remarkably lower maximum air and ground surface temperatures, while these streets can reduce wind ventilation. In the case of UHI and thermal comfort, an integrative assessment, is required for geometry and form. Although the rotation of buildings reduces the air temperature and UHI effect but it leads to increase in amount of radiations and reduced wind speed has been caused more intense thermal discomfort. An evaluation was carried out using various parameters including air (Ta) and surface temperatures (Ts), sky view factor (SVF), wind speed (WS), mean radiant temperature (MRT) and physiological equivalent temperature (PET). The results indicate that proper design of urban infrastructure would greatly mitigate UHI especially for new sustainable developments while thermal comfort improvements can be effectively achieved by increasing the urban vegetation coverage. Although current research and previous studies have compared the strategies affecting UHI, optimization of the given strategies can be investigated in future researches.

He et. al. (2018) The paper reviews the previous studies that have indicated that meteorological parameters such as wind, precipitation, cloud coverage, fog and air quality have significant impacts on UHI phenomenon. The researcher has developed UHI mitigation techniques and strategies based on meteorological characteristics and synoptic conditions. Urban developers can obtain better understandings of using them to mitigate UHI effects. Some suggestions are presented for urban planning and development for the mitigation of UHI effects. Mitigation of UHI by natural means are as follows as stated in the paper. It is matter of concern to store rainwater in urban surfaces to maintain the evaporative cooling of precipitation. For newly developing cities, it is essential to consider local wind source and optimally arrange buildings, structures and vegetation for building urban ventilation corridor and future UHI mitigation. For well-built cities, constructing compensation space for the formation of local cold wind sources can mitigate UHI effects. Cloud coverage also plays vital role in mitigating UHI by natural means. The absorption and reflection of long-wave and short-wave radiation determine the effects of cloud coverage on UHI effects as well as cloud thickness also of greater consideration. Fog also blocks solar radiation, which can reduce the heat acceptance at the ground surface. Aerosols can reduce the short-wave solar radiation that reaches urban space. However, in some specific situations, aerosols can on the contrary enhance the absorption of long-wave solar radiation, increasing urban heat in a large magnitude and leading to aggravated UHI effects. Ultimately, unreasonable construction of cities will lead to rainwater loss and wind hard to penetrate urban space, and then consequently strengthen UHI effects. Some suggestions are presented for urban planning and development for the mitigation of UHI effects. Urban rainwater can be stored by allowing rainwater to go to original water bodies and low-lying areas. Urban pervious layers should be well-constructed to improve the ground permeability by increasing urban green space and using permeable blocks (pavements), so as to transform soil as a natural water-absorbing medium for the improvement of ground moisture conservation. Ventilation can be improved through connections of urban open areas, like major roads, open spaces, green lands and low-rise buildings. Highrise and tall buildings that blocks prevailing wind can be shaped appropriately to improve the ventilation efficiency of cities. Urban surface can be paved with cool materials, grass lands and water bodies to further provide cold sources for introduced wind, so as to extend the working distance of ventilation corridors. For cities that have heated wind, green barriers (i.e. trees and forests) should be set at the windward of the city, to block hot wind.

Kotharkar et. al. (2017) Satellite-based land surface temperature studies have been considerable on the strong negative correlation between the presence of vegetation and the formation of UHIs. Local Climate Zone mapping (LCZ) has been used to classify urban fabric and rationally analyze the effects of particular physical attributes on UHI formation in Delhi, Colombo, Nagpur and Kochi. LCZ maps could be utilized to generate optimum land use and building design scenarios that would be economically viable and effectively reducing the UHI intensities. Multidisciplinary approach must be taken for the study of UHI effect. Architects and urban planners gain valuable knowledge from the results of UHI studies that correlate aspects of city design to the fluctuations in human thermal comfort. The ratio of energy consumed per land area showed that the western region was the highest consumer of electricity with nearly three times as much energy use per hectare as each of the remaining regions of South Asia. The thermal discomfort was observed to be high due to the combination of intense solar radiation, high temperatures, and low wind speeds, especially on clear days. The worst conditions were evident in wide streets with low-rise buildings and no shade trees. The most comfortable conditions were observed in narrow streets with tall buildings, especially if shade trees were present, as well as in areas near the coast where the sea breeze had a positive effect. High pollution level in and around cities are prone to increase UHI by modifying the radiative properties of the atmosphere.

Taha et. al. (2015) The purpose of this study was to research the impacts of urban heat-island mitigations, via increased surface albedo, on regional and urban meteorology, emissions, and ozone air quality over a range of summer conditions in California. The ozone air-quality impacts of heat-island mitigations are then converted into precursor emission equivalents. Coupled atmospheric models employed in this effort show that important cooling of the urban canopy and boundary layers are often achieved, significantly throughout the daytime, however that warming also can occur. The air-quality enhancements are important wherever surface albedo is increased. Downwind of changed areas, the air-quality impacts are often positive or negative looking on meteorological conditions affecting the formation, transport, removal, and mixing of ozone and its precursors. Overall, and accounting for each positive and negative impacts of increased urban albedo, the models show useful net effects for California.

Wang et. al. (2018) here is a significant positive relationship between UHI Impact and O_3 concentration and a significant negative relationship between UHI Impact and NO_2 concentration. The relationships have a north-south difference in the study area (Yangtze River Delta) due to land cover, topography and meteorological conditions. There always been a difference between coastal and inland cities, because the sea breeze effects are evident in coastal areas. The UHI, horizontal transport and vertical mixing of air pollution are affected by the prevailing wind direction and topography. The author also reveals that the effect of the UHI is related to the increase of surface temperature and the decrease of vegetation cover. The UHI effect is closely related to the ozone precursors emission and meteorological conditions in urban areas. Satellite observations and surface observations show that the urban climate is a result of a combination of the natural environment and human activities. The UHI is also related to the urban size, topography and vegetation. Urbanization tend to increase heterogeneity of the urban underlying surface, altering the meteorological conditions, and the land-atmosphere system, which can closely affect the spatial and temporal distribution of air pollutants. The mitigation of urban air pollution should be reflected in the planning of urban expansion, such as the urban area should be controlled within a remarkable range, there should be an increase in the urban vegetation cover, and the city location should be selected to avoid unfavorable weather.

Yadav et. al. (2017) Investigation has been done for the intra-city urban heat island effect in the two regions of Delhi, namely National Physical Laboratory (NPL) area and Safdarjung (SAFD) area. UHI Impact has been calculated as the average temperature difference between NPL and SAFD areas, derived from meteorological stations data located in the areas for the 2010–2013 periods. The impact of wind speed, wind direction, relative humidity and LULC factors on UHI was stated. It was also stated that UHI effect exists in the SAFD area due to presence of more built up surface and relative lack of vegetation areas compared to NPL area. Diurnal variations revealed that daytime UHI Impact was stronger than night-time UHI Impact and its values have been found to be highest (3 °C) in the morning hours (0700–0900 h), noon time to the lowest values (0.2 °C) in the evening hours (1500–1800 h) before again starting moderately building up to 0500 h. UHI of magnitude 0.2–3 °C could be able to rise electricity demand in range of 37.87 GWh to 1856 GWh over the base electricity supply of city and related rise in CO_2 emissions would be 0.031–1.52 million ton for Delhi city. Meteorological parameters such as wind speed and relative humidity has significant negatively effects on UHI. The ground level O_3 and UHI are not evident to be directly correlated to each other. Increased UHI in an urban area has effects on energy consumption resulting in remarkable emissions of greenhouse gases and other pollutants responsible for global warming and harmful effects on human health which cause discomfort to the inhabitants of the area.

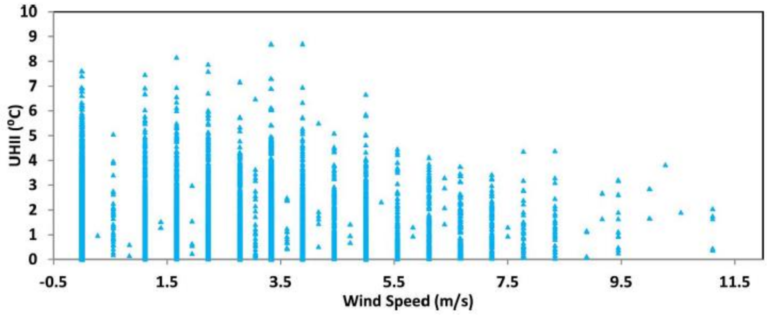

Figure 3(a): Relation of UHI Impact with wind speed in SAFD area during 2010–13 (Yadav,2017).

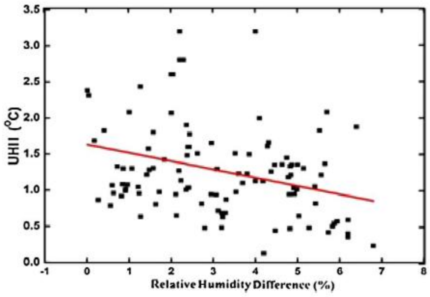

Figure 3(b): Relation of UHI Impact with Relative Humidity in SAFD area during 2010–13 (Yadav,2017).

Yang et. al. (2018) The study was done in Singapore which shows that during peak periods (9 am to 5 pm) cool roofs reduce heat gain by about 0.14 KWh/m^2 (8%) and green roofs mitigate considerably less to about 0.008 KWh/m^2 (0.4%). And for the whole of a summer day, cool and green roof reduces heat gain by 15.53 (37%) and 13.14 (31%) KWh/m^2 respectively. Which shows remarkable difference in heat gain. The numerical simulation results provide evidence which are an appropriate selection of roof materials contribute to the reduction of the negative effects of UHI. However it was stated that cool roofs have increased mitigation potential compared to green roofs for the climatic conditions of Singapore as vegetation can add to latent heat flux due to evapo-transpiration and requires higher maintenance as compared to cool roof. Irrigated green roofs present a increased mitigation potential than nonirrigated green roofs since water will retain heat and delay the heat transmission to the inside.

III. CONCLUDING REMARKS

Based on this review study, the following concluding remarks are drawn:

1) Local climate zones study is required for each city to accurately measure UHI effects, because every city has its own local climate even intracity sub climates also exist. Meteorological parameter also affect the urban areas positively or negatively.
2) Anthropogenic heat is one of the precursor to UHI effect. As increase in population also increases anthropogenic heat which will ultimately contribute to higher intensified UHI.
3) Urban geometries and urban construction materials also plays vital role in contributing UHI effect in city areas. During new planning and construction on urban site, It is promising to consider these factors to partly mitigate UHI effect.
4) Human health and thermal comfort are heavily affect by UHI effect in city areas. India is the tropical country and in many areas humidity is quite high therefore thermal comfort is adversely decreased. Electricity consumption increases with increase in UHI due to required cooling increases.
5) Increase in vegetation, cool roof and cool pavements can mitigate UHI effect. High reflectivity of construction materials reflects short wave and long wave solar radiation ultimately reduces heat accumulation in urban materials.
6) Wind speed and rainfall remarkably reduces UHI effects. In coastal region sea breeze also reduces UHI effect. Mitigation are possible but requires to explore optimal solution to mitigate UHI.

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