International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 04 | April - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

To Assess the Effectiveness of Planning Techniques Mitigation Measures in Reducing the Urban Heat Island Effects

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ABSTRACT

High temperature in the city centers than its surroundings known as the Urban Heat island (UHD) effect, which causing discomfort to the urban dwellers in the summer time is gaining much attention around the world because the wc getting urbanized as it advances in technology. Alterations of area, improper urban planning, air pollution, etc. causing this increasingly growing phenomenon and it is accountable for human discomfort, human casualties and decline climate. in this paper, an attempt has been taken to review various measures to encounter UHI effect and the process these strategies work is described with diagrams. Using high albedo materials and pavements, green vegetation green roofs, urban planning, pervious pavements, shade trees and existence of water bodies in city areas are the potential mitigation strategies on which discussion is done in this paper with the limitations. Green vegetation seems to be the effective measure and other strategies can play a major role under proper condition. Rapid growth of population and resulting urbanization is gaining momentum where urban areas are developed in significant proportion in India leading to changes in existing landscape, buildings, roads, and other supporting infrastructure. Such a change replaces open land and vegetation in the form of permeable surfaces with concrete surfaces which are impermeable and dry in nature which leads the formation of urban heat islands whereby urban region experience warmer temperatures than their adjacent rural surroundings. Such heat island effect increases energy consumption in urban areas along with other negative impacts. The authors of the present paper focus on reduction of heat island effect in urban areas along with compatible strategies in Indian conditions partly to address higher energy consumptions and partly to reduce other negative impacts being caused on account of such heat island effect. the authors have carried out a case study of a Jaipur a pink city of India.

KEYWORDS: Urban heat island, Mitigation, Planning techniques, Green Infrastructure, Reduction strategies, Energy savings.

1. INTRODUCTION:

One such climatic impact of urbanisation is the Urban Heat Island (UHI) effect. It has been observed that cities in India are gradually becoming warmer than their rural surroundings and also the global average. The UHI effect refers to the phenomenon where urban areas are significantly warmer than their rural surroundings due to human activity. The annual mean UHI intensity of urban India has been estimated to be 0.1°C per decade, which is higher than the global average of 0.09°C per decade. UHI has serious implications on society as it leads to increased energy consumption for cooling, heat-related illnesses, and even mortality. In India, increased temperature in cities can also lead to more discomfort and inconvenience to the general public and urban poor who have little or no access to amenities to combat thermal stress.

The rapidly increasing urbanisation in India has led to tremendous land use/land cover (LULC) change in the cities during the last few decades. LULC transitions in urban areas are mainly characterised by large-scale transformation of vegetative land to built-up land, which gives rise to a myriad of environmental problems like loss of green cover, air and water pollution, and changes in microclimate.

Urban heat island (UHI) has drawn considerable attention in recent years and is becoming a critical issue worldwide as cities rapidly develop. UHI itself is defined as a phenomenon where temperature in urban areas is higher than that in rural areas. The main cause of UHI is the modification of energy balance in urban areas. This is caused by several factors such as the substantial conversion of natural green areas to impervious surfaces as a consequence of rapid urban development as well as consequences of global climate change. The negative effect of UHI has been widely documented around the world. The UHI effect contributes to increasing energy consumption through cooling requirements reducing air quality morbidity and mortality effects due to heat stress and increasing water demands Considering the potential harmful impacts of UHI on human lives, mitigation approaches are currently a major priority for researchers. Several studies have proposed, developed and implemented mitigation strategies such as: the modification of a building and surface material the alteration of urban morphology the installation of irrigation systems and the inclusion of green infrastructure (GI) in the planning of cities. In a broad term GI is defined as an "interconnected network of green spaces that conserve natural systems and provides assorted benefits to human population". It includes both natural and designed greening—from parks and street trees to green roofs, gardens and green laneways. GI is recognized as a critical urban infrastructure which is equally important to transport networks. It is considered to include effective strategies in mitigating the adverse effects of UHI. GI regulates the microclimate (a local set of atmospheric conditions that differ from those in the surrounding areas) through shading and evapotranspiration. Shading reduces ambient air temperature by blocking solar radiation, thus restricting the increase in air temperature as well as ground surface temperature. Evapotranspiration refers to transpiration from plants and evaporation from water bodies and soils. The absorbed solar energy is converted into the latent heat of evaporation thus the temperature of the surrounding area is cooled. Several studies have highlighted the role of vegetation in cooling air temperature in semiarid cities and urban areas, such as inside and around buildings urban parks urban streets and private landscapes. The temperature reduction heavily depends on canopy covers and the health status of vegetation. The ability to reduce temperature is also emphasized by Muller who found that vegetation reduces temperature rather than water surfaces.

1.1 BACKGROUND OF THE URBAN HEAT ISLAND EFFECT

In most of the large cities, the temperature at the heart or the center of the city is noted to be higher than its surroundings or the suburban area. The phenomenon is called Urban Heat Island (UHI) effect (Adinna et al. 2009; Synnefa et al. 2008). In other words, cities demonstrate greater temperature in its center than the surrounding rural areas, which is known as Urban Heat Island effect (Yamamoto 2006). There forms a temperature difference between the cities and the surrounding suburbs because of the effect (Yamamoto 2006) which causes discomfort to the city dwellers. When a huge amount of natural land is replaced by artificial built surface that absorbs incoming solar radiation or heat and re-radiate it at night, it develops (Oke 1982 and Quattrochi et al. 2000). The fact is the case that the phenomenon exists in almost every big city (Yamamoto 2006). Numerous factors are held accountable for this effect, including anthropogenic heat release, surface cover, climatic conditions, air pollutants, etc. (Yamamoto 2006). According to Oke, T.R. (1982) under proper conditions, UHI may be up to 10-15°C. As a consequence of the microclimate created by the UHI, the demand for energy to cool buildings increases (Adina et al. 2009). Furthermore, to meet the demand, more generation of power is needed, which results increased amount of greenhouse gases emission and decline of climate. One of the vital reasons for the formation of UHI is the large amount of built up surfaces like concrete, asphalt which has a high heat capacity (Akbari et al. 2001). Low albedo materials are further contributing to worsening the phenomenon. According to Taha (1997), when non reflective and water- resistant, impervious materials at the surface takes the place of natural vegetation, Urban Heat Island is created. It is a process which varies with the built regions and geographical conditions of a metropolitan area (Grimmond & Oke 1999). Another reason to exacerbate the Urban Heat Island effect is improper planning of cities (Li, K. et al.) Taha, H. (1997) says air pollutants from industrial processes, power plants, exhaust gases from the vehicles and anthropogenic heat may add to the intensity of UHI effect. According to Akbari et al. (2001) the demand for electricity rises up from 2-4% for every 1°C rise in temperature. In a typical urban area, surfaces are darker and vegetation is less than its surroundings. The temperature difference of a typical city with its surrounding rural areas may be as much as 2.5°C in a warm summer daytime, which may cause for additional 5-10% municipal peak electricity demand (Akbari et al. (2001). However, in the winter season, as it is cold in the environment, the UHI effect plays a positive role for the city dwellers by providing them with warm air (Shahmohamadi 2010, Voogt 2004, Mobaraki 2012). However, it has a negative effect in the summertime on the comfort of human health and energy consumption both day and night.

2. CAUSES OF URBAN HEAT ISLAND AND ITS EFFECT:

The Urban Heat Island (UHI) effect is a phenomenon where urban areas experience significantly higher temperatures compared to their rural counterparts. This temperature differential is most noticeable during the night, when urban areas retain heat absorbed during the day, leading to warmer night time temperatures.

2.1 CAUSES:

According to Santamouris et al. (2007); Akbari et al (2001) and Oke (1987) the following are the causes of UHI :

- Low amount of evapotranspiration because of less vegetation
- Absorption of solar radiation due to low albedo
- Hindrance to the flow of air because of higher rugosity
- High amount of anthropogenic heat release

However, there are a number of factors which contribute to the formation of Urban Heat Island. The factors which play a significant role in the creation of UHI are described below.

2.1.1 LOW ALBEDO MATERIALS:

According to Bouyer (2009), albedo is evaluated by the ratio of the reflected solar energy to the incident solar energy. It depends on the arrangement of surfaces, materials, pavements, coatings, etc Albedo has a direct impact on the formation of the microclimate. The albedo of a city varies according to various factors like surface arrangement 1.e. orientation, heterogeneity; materials for roofs, pavements etc. (Bouyer et al 2009). If the albedo of the urban surface is low, it will store more solar energy and the effect will be increasing of urban temperature Le creation of the urban microclimate

2.1.2 HUMAN GATHERING

As the human gathering is prominent at the city centers owing to the availability of various facilities, emission of CO2 is also huge in these areas. CO_2 stores heat, causing enhanced atmospheric temperature. The ultimate effect is that it assists in the formation of heat island to a great extent

2.1.3 INCREASED USE OF AIR CONDITIONER

To provide comfort to the human beings at summertime, air conditioner is massively used with a rising trend Air conditioners keep a building cool inside, but release the heat absorbing from inside to the atmosphere (Okwen 2011). As a consequence, the outside environment is warmed leading to the increasing of atmospheric temperature.

2.1.4 DESTRUCTION OF TREES

To meet the demand of various urban facilities, forests are wiped out in a massive scale. Lesser trees means less cooling efficiency. Trees intercept the solar heat and also absorb CO_2 for their own photosynthesis, making the environment cool (Akbarı et al 2001). With the destruction of plant life, the efficiency of cooling system goes radically down, causing creation of the process.

2.1.5 URBAN CANOPY

In urban areas, there are multilayer buildings. The heat reflected by a building is trapped by the nearby taller buildings which is known as the urban canopy (Masson 2006). UHI is exacerbated with the formation of urban

2.1.6 WIND BLOCKING

Due to the presence of densely situated buildings, wind velocity is reduced. As a result, the cooling effect by convection lessens. So, the heat trapped, cannot be blown out, resulting intensification of the effect (Priyadarsini 2008).

2.1.7 AIR POLLUTANTS

In the urban areas, especially in the city centers, air pollution is eminent. Exhaust gases from vehicles and industrial pollutants released in the environment, trap solar radiation (Bose 2009). Thus, the temperature rises and the microclimate effect becomes stronger.

The causes are summarized in the following figure:1

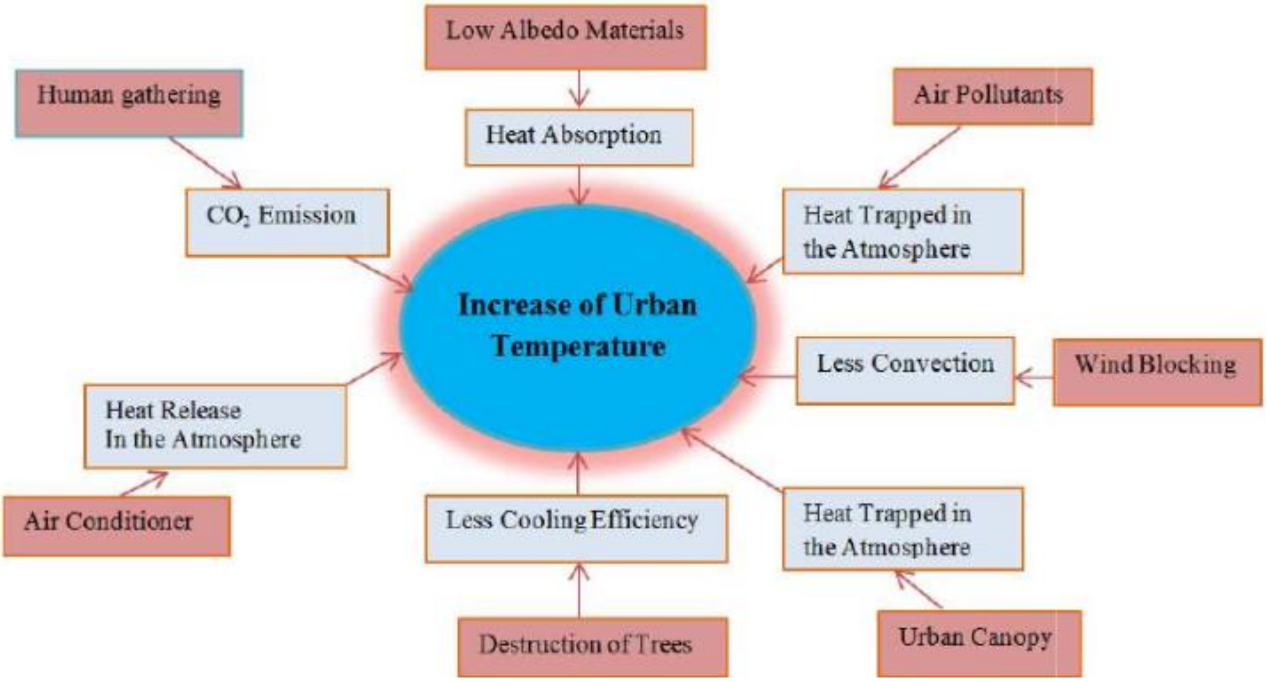

Figure:1 Process of urban heat island formation

https://www.researchgate.net/publication/283507719_Urban_Heat_Island_Causes_Effects_and_Mitigation_Measures_-A_Review

2.2 EFFECTS:

The effects are devastating in the summertime especially in the tropical and arid regions. It causes discomfort to the people living in the middle of the city. Owing to the excessive heat people with little enduring capability undergo heat stress and it causes illness as well as death (Voogt 2004). Furthermore, the increased temperature will cause more energy required to cool the buildings to provide comfort to the people. This will augment the expenditure of the people and government as well. For every 1°C temperature increase, the energy demand may go up by 2-4% in the summertime (Akbarı, 2001). Nonetheless, those people working outside of buildings or on the roads or in open places are the worst sufferers of the microclimate effect. As the demand for electricity soars, more fossil fuel is also burned causing high emission of green house gases to meet the demand tending to worsen the condition and decine of climate (Adinna 2009). At the same time, increased use of air conditioners leads to worsening of the effect even more. However, in the winter season, the UHI effect tends to give people comfort owing to the increased temperature (Shahmohamadi 2010; Voogt 2004; Mobaraki). The following figure illustrates how UHI affects human lives.

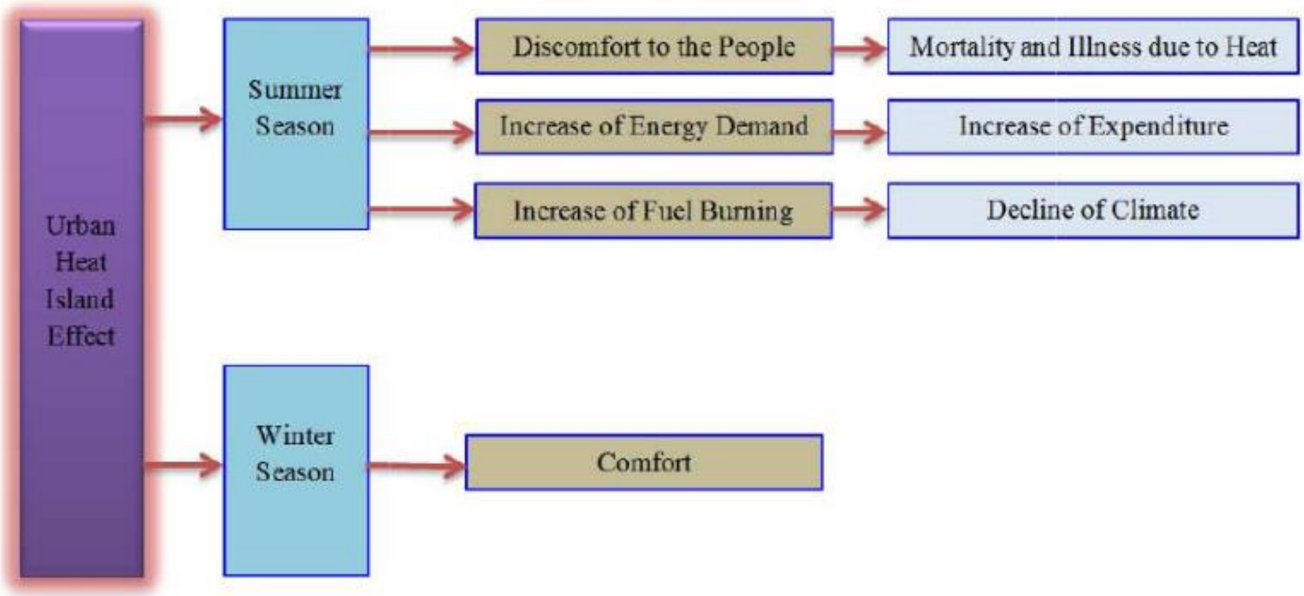

Figure:2 Effects of urban heat island formation

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3. STRATEGIES TO REDUCE URBAN HEAT ISLAND:

According to Sailor (2006) the urban heat island effect mitigation can be done in two ways. One is by increasing the albedo of the urban surface and the other is by increasing evapotranspiration. However, the major strategies to mitigate the UHI effect are described below:

3.1 HIGH ALBEDO ROOFING MATERIALS:

Dark roofs absorb heat from the sunlight and make houses warm. In contrast, light colored roofs with similar insulation properties do not get warmed significantly by reflecting solar radiation (Akbari et al. 2001). So, the choice of roofing color can contribute to temperature reduction. Roofing materials with low albedo absorb solar heat and make the house warm which results in high consumption of energy for air conditioning. So, one of the mitigation strategies is to use high albedo roofing materials. If cool surfaces are achieved through changing color, it adds no extra cost to the roof (Bretz et al. 1998 and Rosenfeld et al 1992). The EPDM materials which have a rubber like nature, have no impact on cost for change of color (Sailor 2006). Sailor (2006) suggests white materials which have albedo greater than 0.60 instead of black materials having albedo of 0.05 to 0.10 can be used as roofing materials. Bretz et al (1998), Akbari et al (1998) and Konopacki et al. (1997) observed the effectiveness of albedo by using roofing materials of different albedo ranging from 0.20 to 0.60 and they found that the roof temperature dropped by 25°C for 0.60 albedo compared to that of 0.20 albedo. According Sailor, D. J (2006) the action of convection of the roofing materials has a role to play to the effectiveness of UHI effect mitigation strategies. One of the problems which are incorporated with the reflective roofs is that the reflection capability lessens with age because of the soot (Berdahl et al. 2002). However, it can be easily compensated by cleaning it periodically Again, for cool roofs, there is an issue of aesthetics. For commercial buildings, it is not a matter of headache, but in case of residential buildings, house owners tend to use deep colored roofs to make it look less dirty over the period of time (Bretz and Akbari 1994, 1997). On the other hand, cooling roofs glares at daytime. For a roof parallel to the street level, it is not to be considered. Nevertheless, a sloping roof may create enough glares to hamper the vision of drivers which may cause accidents (Bretz and Akbari 1994, 1997). So, the color of sloping cool roof should be selected by taking this into account.

3.2 HIGH ALBEDO PAVEMENTS:

More solar radiation could be reflected if the road and highway pavements were of high albedo materials (Akbari et al. 2001). So, proper selection of pavement materials can also contribute to the reduction of UHI effect. Levinson, & Akbari, H. (2002) suggested some reflective concrete surfaces after curing various concrete mixes of albedo ranging from 0.41 to 0.77. Sailor (2006) suggests that white cement mixtures can be made for which the albedo should be higher than the most reflective gray cement mixtures. However, use of high albedo materials for roads and highway pavement may not be so much effective because of the sky view factor. Even if, it is used, some of the reflection will be intercepted by the buildings surrounding it. In addition to it, a large proportion of it is covered by vehicles in most of the daytime. The problem of glaring which is associated with cooling roofs is also accompanied with the high albedo pavements. Sailor (2006) states that high albedo pavements may increase visibility at night, thus reduces the requirement of light. He continues that at day time glaring will have negative effect regarding visibility Again, the wearing action will lessen the reflectivity of pavements within a very short time due to vehicle movement So, Durability and visibility should also be taken into account before going to take the initiative.

3.3 GREEN VEGETATION:

Increasing the amount of vegetation is one of the most effective strategies to mitigate the effects of the urban microclimate. (Wilmers, 1988, Dimoudi and Nikolopoulou, 2003. Synnefa et al., 2008, Takebayashi and Morryama, 2009, Xua et al., 2010). This can be achieved by tree plantation both in residential and municipal tree plantation programs (Sailor 2006). Trees contribute to reducing the heat island effect by their evapotranspiration (Akbari et al 2001, Dimoudi and Nikolopoulou 2003). Again, trees have a direct effect on reducing the UHI effect as it absorbs CO_2 (Akbari et al. 2001). According to Robitu et al. 2006 and Pearlmutter et al. 2009 empirical derivations also demonstrated reduced temperature if green vegetation is applied. The statement is also backed by Steenveld et al. 2011 and Heusinkveld et al. 2012. In the heart of cities, as the human gathering is huge, the emission of huge amount CO_2 leads to the increase of temperature Increased number of trees will help to mitigate the condition by absorbing CO2. Theuwes et al carried out an experiment in Rotterdem by using two tricycle equipped with instruments to measure 3D radiation components, temperature, humidity and wind speed. Their bike traverse supported the finding of the previous research According to Theuwes et al. temperature usually decreases by 0.6K for each 10% addition of vegetation. For this mitigation strategy, it should also be taken into account that trees hinder the natural flow of air within the urban areas (Heisler 1989). So, cooling breezes may not work effectively

3.4 SHADE TREES:

Shade trees are those with a huge canopy and can provide protection to houses and pedestrians from direct sunlight keeping them comparatively cool Shade trees also help to cut down the temperature by evapotranspiration process (Sailor 2006) In the United States, near about 200,000 shade trees were planted every year between 1992 and 1996 as a strategy to mitigate heat islands, protect climate, and improve air quality in urban areas (Scott et al. 1999). The principal role of shade trees is that sunlight is intercepted by it keeping the buildings comparatively cool (Akbari et al 2001). It reduces the building air conditioning, lowers the air temperature and improves the air quality Planting shade trees involve some sort of maintenances and cost pertaining to it Estimation given by Akbari et al. (2001) states that the savings associated with the benefits of shade trees may be up to $200 in its entire life And the maintenance cost may range between $10 to $500 per tree At the same time, shade trees need several years to grow up and start protecting a building from severe heat. Shade trees are also vulnerable to extreme storms posing threat to human life (Sailor 2006). The routes of these trees may also affect the foundation of the adjacent buildings and streets. Again, there may not be enough space in a land property to plant a shade tree. This is a problem in densely populated countries like Bangladesh, India, China, etc. So, before going for this option, careful judgment should be made to handle all the situations properly.

3.4 PERVIOUS PAVEMENTS:

Impervious pavements do not allow water to infiltrate and cooling effect by evapotranspiration is not significant in this case (Sailor 2006) If the impermeable pavements are replaced with pervious pavements which will allow water to infiltrate, it can be expected that it will be able to reduce the temperature to a reasonable extent Infiltrated water will help keep the pavement cool and directly affecting the temperature

3.5 WATER BODIES:

Increased amount of water bodies may reduce temperature due to their evaporative action and enhanced wind speed is the opinion of Robitu et al (2006) Again, as the heat absorption capacity of water is high, it will help to reduce the urban temperature In contrast to this proposition, the bike traverse experiment by Theuwes et al. does not support this statement and opposes that it exacerbates the condition. The reason behind this was described as the high thermal inertia limits of water prevent nocturnal cooling once it is warmed. The stable nocturnal condition which limits the wind speed may also be another reason. So it is needed to investigate more whether extended water bodies in urban areas help to lower the temperature or not.

3.6 URBAN PLANNING:

Proper urban planning can also play a vital role in the mitigation of the UHI effect Yamamoto (2006) has described an urban planning approach situated on the bank of river His suggestion is to build the buildings in such a way that wind path is created for cool airflow from the river into the city If buildings are built parallel to the direction of river, no airflow will occur in to the city If the buildings are positioned at a 45° angle, wind will get channel if it flows only in one direction. But if flows from the opposite direction, it cannot get away inside the city However, airflow will occur in case the buildings are perpendicular to the river He also mentioned that this option is expected to play a major role in the fore coming days and it deserves further attention. In other types of cities, it is expected that if there is sufficient amount of free space and channel to circulate the wind, it will help to minimize the effect of the urban microclimate.

3.7 GREEN ROOFS:

According to Wong (2005) roofs in the cities represent about 21% to 26% of the city area. So, if the roofs are made green by vegetating, it will act a major role in mitigating the UHI effect. Green roofs absorb heat and filter the air, keeping the temperature low (Getter 2006). Plants utilize heat energy to continue their evapotranspiration process, making the environment cool. In addition to it, green roofs help to delay the runoff duration which will keep the cities cooler for a longer period (Getter 2006). As it also absorbs water, it keeps itself cooler, helping to reduce the temperature Again, green roofing will bring energy balance to the corresponding

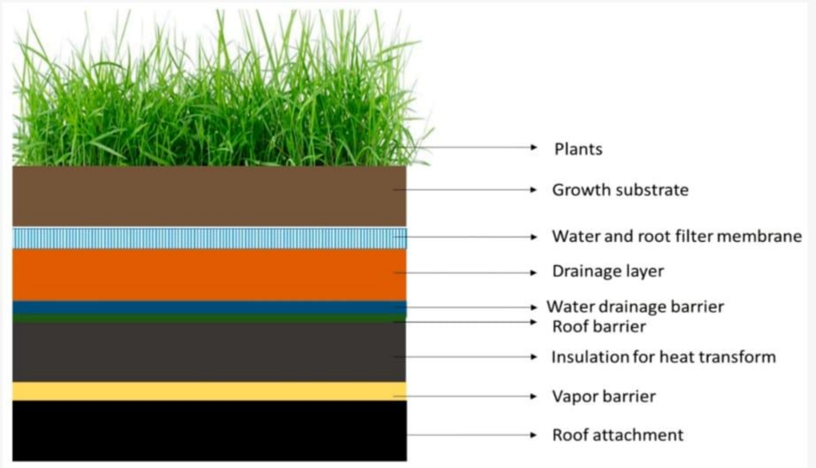

Figure: 3 The typical layer of a green roof system

No	Strategies and techniques	Definition	Benefits
1	Green roof	A green roof is an addition to the existing roofing system of an existing building for the purpose of growing flora (URL1, 2018).	✓ Green roof reduces the necessity for the accumulation of Storm Water ✓ In an urban environment it reduces the UHI effect by covering many of the concrete surfaces or other surfaces that might have the possibility to generate heat. ✓ The plants in the green roof catches many pollutants that helps to reduce pollution. Also, it reduces the amount of noise being generated.
2	Cool roof	A roofing system that provides higher reflectance and higher thermal emittance as compared to other type of roofs is known as a cool roof. Thus, a cool roof has the capacity to reflect visible, infrared and ultraviolet wavelengths of the sun which in turn reduces the amount of heat being transferred into the building. Roof can also be able to radiate the absorbed or non-reflected solar energy (URL2, 2021).	✓ Reduces use of Energy resources – Less energy is transferred to the building through a cool roof which results into less consumption of energy and reduces the need for artificial cooling of the building through methods like air conditioning. ✓ As the energy consumption reduces the emission of gases such as greenhouse gases and others which results into air pollution reduces simultaneously. ✓ Because of the reduction of the air temperatures within the building due to cool roof, it also reduces the risk for illness and deaths related to heat.
3	Cool pavements	Cool pavements remain cooler as compared to other traditional pavements in the sun. Cool pavements can be permeable or reflective in nature. The reflectance of a pavement can be enhanced by using reflective aggregate such as a clear binder or a reflective surface coating (URL3, 2021).	✓ Cool Pavements help to reduce the outside atmospheric temperature due to which the air conditioners consume less energy for cooling buildings. As cool pavements also act as an alternative to street lights in some places, thus it helps in reducing the energy consumption through electricity of street lights. ✓ Cool temperature reduces the amount of heat absorbed by the earth's surface reducing the surface temperature and also reducing the warming effect caused by greenhouse gases. ✓ Light coloured pavements or cool pavements provides better reflectance of Street lights and vehicle headlights at night thus providing a better visibility to the drivers at night.
4	Increasing trees and vegetation cover	It is the process of increasing the green areas by increase in the amount of tree plantations and vegetative covers in a specified site or area.	✓ It reduces Albedo effect reducing the reflectance of solar energy from the earth's surface, results into the reduction of the atmospheric temperature and also decreases UHI effect. ✓ Vegetative Covers are also responsible for the reduction of soil erosion, energy intakes and biogeochemical fluxes which in turn determines the ecological conditions (Schowalter, 2017).

https://www.academia.edu/69554791/Urban_Heat_Island_Effect_Causes_Impacts_Methods_of_Measurement_and_Mitigation_Options

4. LITERATURE REVIEW:

In order to know the generation of UHI, we need to know the source of the heat that is generated and contained in the urban areas, is mainly from the solar radiations and from anthropogenic heat which is generated from industrial power plants, automobiles, air conditioners and others. Most of the anthropogenic heat immediately enters into the environment in the direct form. Whereas, only a part of the solar radiations entering the environment directly is responsible for the heating effects, the remaining solar radiations are being absorbed by the urban built structures and becomes responsible for heating up the environment indirectly. The basic heat transfers and the energy conservation processes play their significant roles in the heat exchange processes (Rizwan et al., 2008).

Table 2. Shows the temperature recorded during the three summer months of the 7 prominent points within the core city area of Jaipur also known as Walled City of Jaipur and also the average temperature calculated during summer of these points.

A	Location Walled city (core area)	Temperature (°C) May	Temperature (°C) June	Temperature (°C) July	Temperature (°C) Average
1	Chand Pole	43	45	44	44.00
2	Choti Chopad	45	48	44	45.67
3	Badi Chopad	45	48	44	45.67
4	Subhash Chowk	42	45	43	43.33
5	Ghat Gate	43	45	43	43.67
6	Sanganeri Gate	44	45	43	44.00
7	Ajmeri Gate	45	47	44	45.33

Table 3. Shows the temperature recorded during the three summer months of the 15 prominent points within the Surrounding city area of Jaipur and also the average temperature calculated during Summer of these points

B	Location Outer city (surrounding)	Temperature (°C) May	Temperature (°C) June	Temperature (°C) July	Temperature (°C) Average
8	C-Scheme	37	42	37	38.67
9	Ramniwas Garden	36	37	35	36.00
10	Sethi Colony	39	41	38	39.33
11	Adarsh Nagar	39	40	38	39.00
12	Golf Club	33	35	33	33.67
13	Tilak Nagar	40	41	39	40.00
14	Bapu Nagar	38	40	38	38.67
15	Gandhi Nagar	37	40	38	38.33
16	Malviya Nagar	37	39	36	37. 33
17	Jagatpura	38	40	37	38.33
18	Pratap Nagar	38	44	37	39.67
19	Sanganer	40	42	39	40.33
20	Mansarowar	41	43	40	41.33
21	Nirman Nagar	40	44	40	41.33
22	Vaishali Nagar	39	43	39	40.33

The amount of solar radiation captured by structures of urban spaces on ground level such as walls and roof facets, non irrigated green areas, irrigated garden spaces, lawns and paved areas and others are at a different level. Such high amount of radiation is continuously absorbed and accumulated in the form of heat energy from the natural and manmade urban structures from morning till late afternoon. Later, as the sun sets, gradually the environment starts to cool down. Thus, the heat which is stored in the urban structures is now released in the environment. The process and the amount of heat released by the urban structures depends on certain factors which can be controlled, these factors include building materials and the sky view factor. In an urban area, huge amount of construction materials is kept in small spaces which absorbs high intensity of solar radiations (Giridharan et al., 2004). The ability to release heat through long wave radiations in urban areas is quite low because of decreased sky view which results into large amount of heat accumulation within buildings. It is also being observed that the albedo, which is the comparison between reflected light and the incident light, is quite low in urban areas, because of the typical street canyon configurations and becomes one of the main reasons of air temperatures being significantly high (Kondoh and Nishiyama, 2000). The design parameters of albedo and sky view factors are hence considered to be two very important factors in the making of UHIs.

Table 4. Shows the average temperature of the core city area of Jaipur and the average temperature of the surrounding area of the city of Jaipur for the summer months of May, June and July and then the UHI intensity is calculated for the summer months as per the formula given earlier

Month	Tu (City Core) (˚C)	Ts (Surrounding area) (˚C)	UHI intensity (Tu – Ts) (˚C)
May	43.86	38.13	5.73
June	46.14	40.73	5.41
July	43.57	37.6	5.97

The UHI effect is formed mainly due to increase in the built up urban fabrics which occurs due to various factors including increase in the population density of built-up areas and presence of vegetation in fractions, which leads to increase in the absorption and trapping of solar radiation (Grimmond, 2007). Hence, the increased built-up areas of urban spaces can have effects such as changes in albedo, thermal capacity change, increase in roughness and there is a significant modification in the surface-energy budget (Arnfield, 2003).

Also, the urban space is also responsible for the increase in the anthropogenic carbon dioxide emissions, generated due to the burning of fossil fuels for heating and cooling effects, due to certain industrial processes and also because of vehicular transportations (Grimmond, 2007). Researches concludes that continuous urbanization leads to progressive increase in the UHI intensity and the other studies depict that urban impact have a significant effect on the recent warming trends (Zhou et al., 2004; Hamdi, 2010; Diensta et al., 2019).

The temporary variables have a significant effect on the UHI that is being formed, including anticyclone conditions, which in turn result into the increase of UHI intensity (Pongracz et al., 2006). Many researches and studies depict the influence that the wind speed and cloud cover have on UHI, and certain results show that there is a negative correlation between UHI and wind speed and cloud cover (Kim and Baik, 2005). Reduction strategies and technologies of UHI effect is given in the **Table 1.**

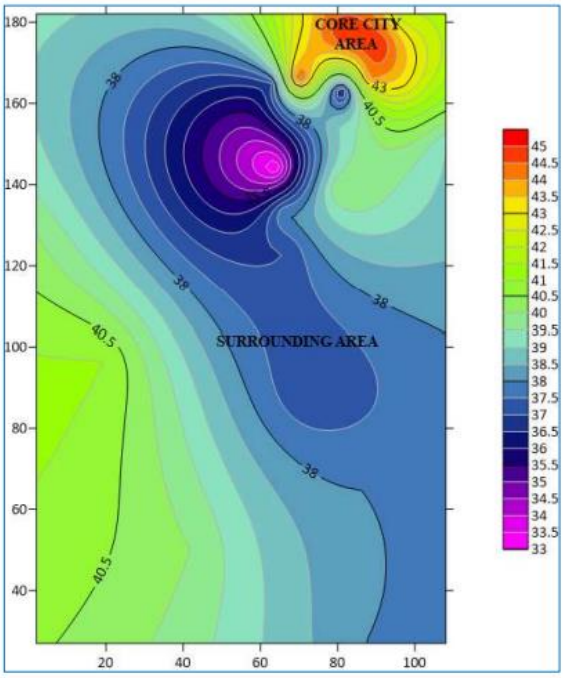

Fig. 4. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of May.

https://www.mdpi.com/2073-4441/12/12/3577

5. CASE STUDY:

A Case Study of Jaipur is a city which has a hot semi-arid climate which is influenced by monsoons. It has long and extreme hot summers, also short and mild winters. Jaipur is one of the prominent UHI zone similar to many other major cities of the world (Mukhopadhyay, 2016). The UHI effect depends positively on the anthropogenic inclusion of the natural landscapes within a designated urban area (Oke, 1987).

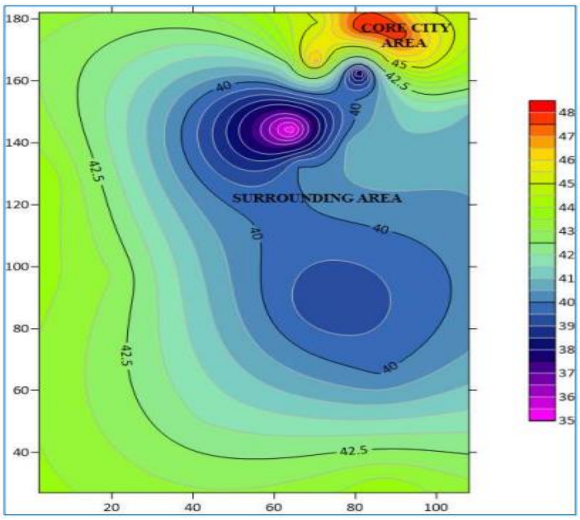

Fig. 5. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of June.

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Henceforth, with the expansion of the urban area, the UHI intensity also increases at a rapid pace. In order to explain this process, we calculated the UHI intensity of Jaipur City as the difference between the average temperatures of the core urban area and those of its surrounding areas within the designated boundary of the city (Zhou et al., 2013) for particularly of summer season. The equation to derive UHI intensity is as follows:

UHI intensity (°C) = Tu – Ts

where; Tu is the mean temperature of the urban core area and Ts is the mean temperature of the surrounding area. Water bodies have been excluded as it effects the temperature of an area immensely (Miles and Esau, 2017).

For calculating the average temperature for summer season of Jaipur City, the formula to be considered is:

T average (°C) = (T1 + T2 + T3)/3

where; T1, T2 and T3 is the average temperature for the month of May, June and July, respectively.

The temperature recorded during the three summer months of the 7 prominent points within the core city area of Jaipur was given in the **Table 2.**

At the same time, the temperature recorded during the three summer months of the 15 prominent points within the Surrounding city area of Jaipur was given in the **Table 3.**

UHI intensity for the months May, June and July has been calculated based on actual observations recorded during these months at different identified locations as per **Table 4.** It would be evident from the table that the UHI intensity during these months are in the range of 5 to 6 °C which is quite significant.

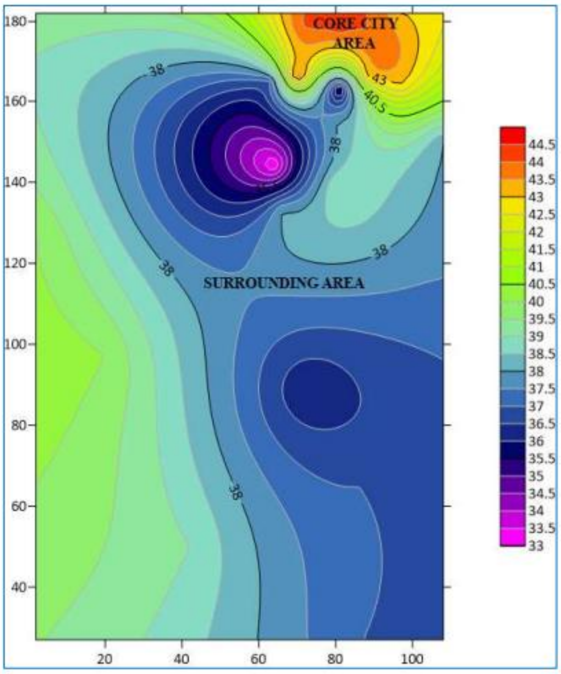

Fig. 6. Showing temperature contours of Jaipur within the city core and the surrounding city used for the calculation of the UHI intensity for the month of July.

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It would be quite evident from these figures that there is a clear heat island reflection within the walled city of Jaipur mainly due to extensive concreting of walled city, minimum green surface area and generation of air pollutants from automobiles and other sources with least atmospheric dispersion of such pollutants.

6. CONCLUSION:

Among all the mitigation strategies, green vegetation seems to be the most effective measure to encounter UHI effect. Also, its effectiveness is well proven and widely accepted by the experts as a very much efficient mitigation measure. At the same time, it has a few drawbacks. However, cities where tree plantation in a large scale is not feasible, use of high albedo materials and pervious pavements may be adopted. Green roofs may play an important role in this case also. On the other hand, as a small scale mitigation measure, shade trees can be used where there is enough space in the house yard considering its limitations. In growing cities, proper planning must have to be done to minimize the effect economically Presence of water bodies in the city areas is a controversial issue to some researches and more researches should be carried out for this mitigation strategy. Use of high albedo pavement has numerous limitations and its effectiveness is not so much great. Thus, it should be taken as the last option for the UHI mitigation measure

UHI phenomenon is quite usual in urban areas because of extensive concreting, less open spaces with green cover, significant generation of air pollutants from automobiles and other sources, least air pollutant dispersion ability, unbalancing of albedo effect etc. Such UHIs lead to extensive power and water consumption in cities, activation of air pollutants by extensive heat, and causes diseases to urban population. Therefore, the UHI needs to be addressed on a scientific scale linking forward and backward issues in an integrated manner. The authors of the present paper have highlighted the indicators responsible for creating heat island, its consequences and estimation. A case study of Jaipur was undertaken by the authors' where they revealed the fact that walled city of Jaipur has significantly been prone to heat island. A comprehensive integrated planning needs to be taken up to address this emerging issue.

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