Classification, Mitigations and Methods to Detect UHI: A Review

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Abstract:

Because of urbanisation, surfaces of buildings and pavements have increasingly displaced green areas in urban areas. Because of this, solar energy is absorbed by roads, buildings, & rooftops, increasing the surface temperature over that of the surrounding air. This is known as an "Urban Heat Island" (UHI). Urban heat islands can worsen the quality of the environment where people live, increase energy demand, elevate ground-level ozone, and potentially raise death rates. Because of the seriousness of the situation, considerable study has been conducted, and a lot of literature on the subject is now available. This review presents the types, causes, effects, mitigation measures and methods to detect the UHI with their limitations. One of the major findings is that increasing landscaping areas and using high-albedo materials have a great effect on reducing UHI. The majority of researchers are working towards the detection of UHI and suggesting mitigation strategies, then reviewing the implemented mitigation measures and policy making.

Keywords:

Urban heat island (UHI); Types of UHI; UHI Causes, effects & mitigation strategies; methods to detect the UHI with their limitations;

Introduction:

Urban heat islands can worsen the quality of the environment where people live, increase energy demand, elevate ground-level ozone, and potentially raise death rates. Urbanisation is one the reasons for the rise of temperatures in urban areas, which ultimately leads to Urban Heat island (UHI)(Yang, Shi, and Cao 2020)(Arellano, Roca, and Biere 2018)(Kikon et al. 2016b)(Yin et al. 2018). Urbanization in India's metro areas has accelerated due to the diversity of the cities' economic and population growth. India is the nation with the highest rate of rural-to-urban migration. An increase in the area of buildings and roads, a reduction in green cover, a reduction in air flow due to increased built obstructions, heat input from anthropogenic sources such as air conditioners and motor vehicles, heat retention by the building mass all contribute to the microclimate in cities becoming warmer than regional temperatures. (Anshu Gupta,Vivek Dey 2009).

Microclimatic temperature increases in cities have been observed to be in the range of 1-3°C during the day and up to 12°C at night. (ARCHITECTS 2014). Such changes can have far-reaching consequences beyond the microclimate, affecting energy use, health, and economics, and can become a source of national concern. In a research by (Konopacki and Akbari 2002), In Houston, it was shown that reducing the impacts of UHI may save 82 million dollars and result in a 730 MW peak power reduction, which would result in an annual reduction of 170000 tonnes of carbon emissions.

The aim of the paper is to review the types, causes, effects, mitigation strategies with techniques to detect the UHI based on the available literature.

1.1 Definition and classification of Urban Heat Island:

Because of urbanisation, surfaces of buildings and pavements have increasingly displaced green areas in urban areas. Because of this, solar energy is absorbed by roads, buildings, & rooftops, increasing the surface temperature over that of the surrounding air. This is known as an "Urban Heat Island" (UHI) which can raise the temperature of a city by 2°c - 8°C(HaiderTaha 1997). Urban heat island (UHI) is the difference in ambient air surface temperature between the urban city centre and a nearby rural region (T.R.Oke 1987)(Kikon et al. 2016b)(Thomas et al. 2014) (Arellano, Roca, and Biere 2018).

As per (EPA 2016) infrastructure like as buildings, roads absorb and re-emit solar radiation more than landscapes such as forests and water bodies. Urban regions, where these constructions are heavily concentrated and there is little foliage, experience "islands" of hotter weather than rural areas. "Heat islands" are the name for these hotspots. Under a any circumstances, heat islands can develop.

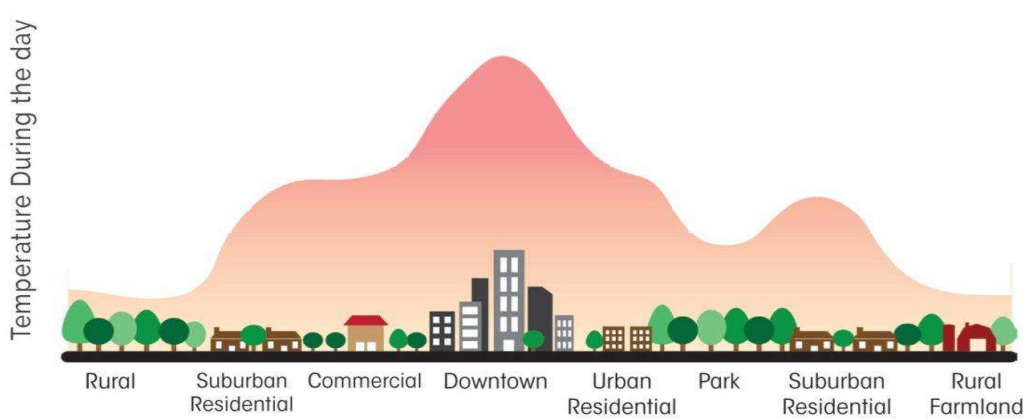

Figure 1: urban Heat island; Source: https://eco-intelligent.com/2017/04/13/the-urban-heat-island-effect/

Within a city, the temperature can also change. Some areas are hotter than others due to unequal distribution of heat-absorbing pavements and buildings, while others remain cooler due to trees and other vegetation, as illustrated in figure 1. These variances in temperature are referred to as heat islands within cities.

1.2 Types of UHI

According to how they are created, the methods used to identify and assess them, their effects, and to some extent, the treatments available to mitigate them, the UHI is divided into two different categories. (ARCHITECTS 2014)(EPA 2016).

- Surface Urban Heat Islands
- Atmospheric Urban Heat Islands

1.2.1 Surface Urban Heat Islands (SUHI):

The heat island known as SUHI is created when urban surfaces such as buildings, roads, pavements, open areas, water bodies, and vegetation heat up. On warm days, the temperature of traditional roofing materials may rise to above-air levels. (Simmons et al. 2008). The heat island known as SUHI is created when urban surfaces such as buildings, roads, pavements, open areas, water bodies, and vegetation heat up. On warm days, the temperature of traditional roofing materials may rise to above-air levels. (EPA 2016). The majority of the research that have been gathered are based on SHI, which uses thermal satellite photos, remote sensing, GIS tools, etc. (EPA 2021b).

1.2.2 Atmospheric Urban Heat Islands (AUHI):

- *Canopy Layer Urban Heat Island (CLUHI):*

  Canopy layer urban heat islands are air masses that extend from the ground to below the peaks of trees and rooftops in the area where people reside. The Near Surface Urban Heat Island, or NSUHI, is a heat island layer that is described for 1-2 metres of the layer of air near to urban surfaces. It is primarily significant to the inhabited zone of the urban environment. (ARCHITECTS 2014).

- *Boundary Layer Urban Heat Island (BLUHI):*

  BLUHI is the heat island that develops in the Boundary Layer, or the layer above the Canopy Layer, and it may reach heights of up to one kilometre or slightly more during the day and a few hundred metres or less at night (T.R.Oke 1982). The wind frequently transforms the heat island dome, which is located downwind of the city, into a plume shape (Yang, Shi, and Cao 2020) (Arellano, Roca, and Biere 2018).

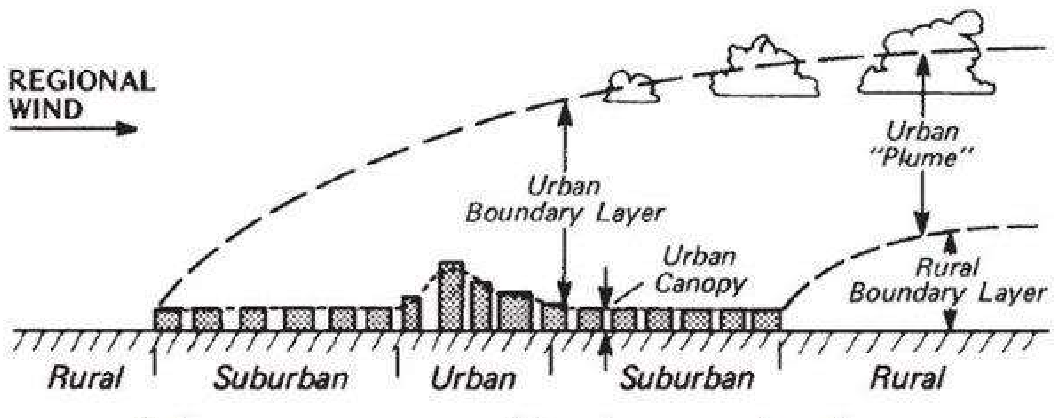

Figure 2: Urban Canopy & Urban Boundary Layers. Source: (T.R.Oke 1987)

1.3 Causes of UHI:

Urban heat islands are primarily caused by a decrease in urban vegetation, an increase in built-up hard surfaces, pollutants, and emissions. However, a number of variables influence the development of UHI. The following list of variables is an overview of those that significantly contribute to UHI:

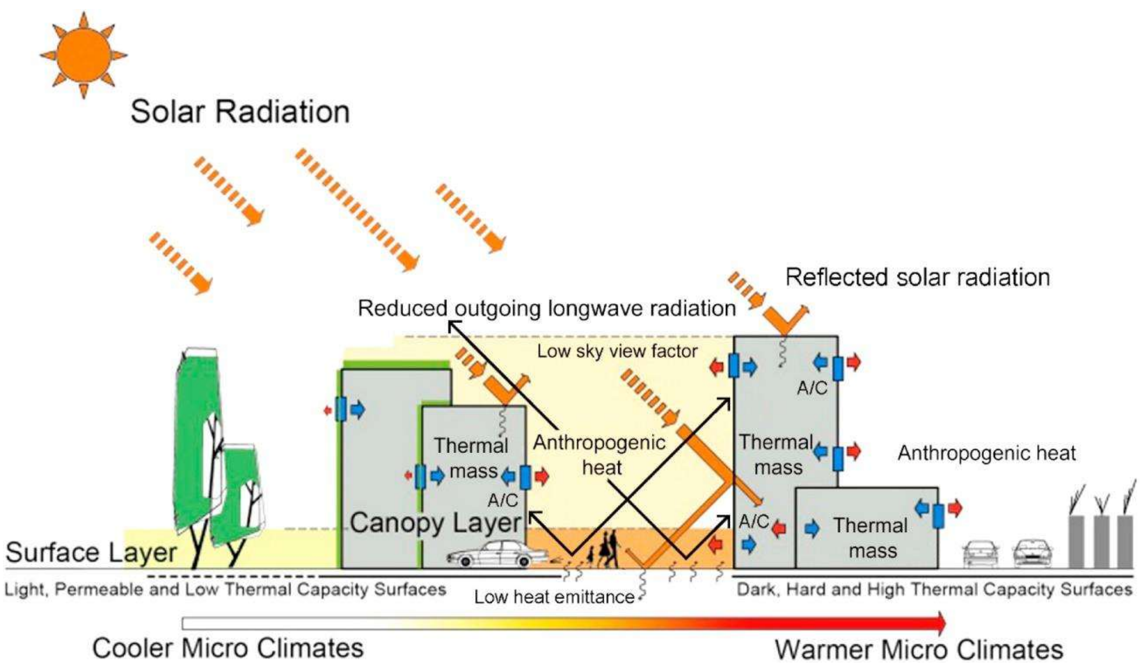

Figure 3: cause of UHI Source ; Source : (Soltani and Sharifi 2017)

1.3.1 Loss of Natural Landscapes & Permeability:

Trees, vegetation, and waters bodies in turn, chill the air by providing shade, transpiring water from plant leaves, and evaporating surface water (Hashem Akbaci, Sarah E. Bretz, Dan M. Kurn 1997) (Akbari, Pomerantz, and Taha 2001). Buildings, sidewalks, roads, and parking lots in urban areas have hard, dry surfaces that provide less moisture and shade than the surrounding green environment, which causes the temperature to rise. In rural places, vegetated surfaces have a higher rate of water penetration and evapotranspiration, whereas stormwater runoff is higher in urban areas due to impermeable surfaces (Figure4). As a result of the decreased evapotranspiration process, sensible heat flow rises in urban regions(Kleerekoper, Van Esch, and Salcedo 2012). Due to the lack of urban vegetation, the cooling mechanism is therefore largely shut down. In addition, solar heat is captured by urban surfaces during the day and released at night, which causes a significant rise in temperature in urban areas.

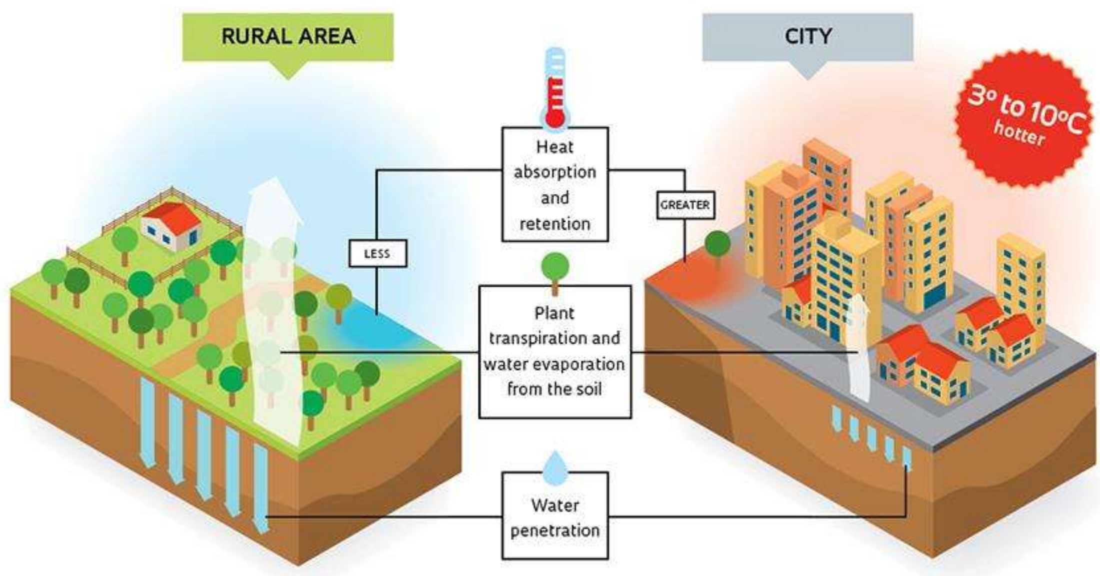

Figure 4: Loss of Natural Landscapes & Permeability; source: https://land8.com/how-landscape-architecture-mitigates-the-urban-heat-island-effect/

1.3.2 Low Albedo Materials:

The ratio of solar energy that is reflected to solar energy that is incident is used to measure albedo. It relies on how surfaces, materials, pavements, coatings, and other elements are arranged. Albedo directly affects how the microclimate develops. The surface layout of a city, such as its direction and heterogeneity, as well as the materials used for its pavement and rooftops, among other things, affect a city's albedo in different ways (Bousse 2009). Low albedo urban surfaces will store more solar energy, which will increase urban temperature and lead to the development of an urban microclimate.

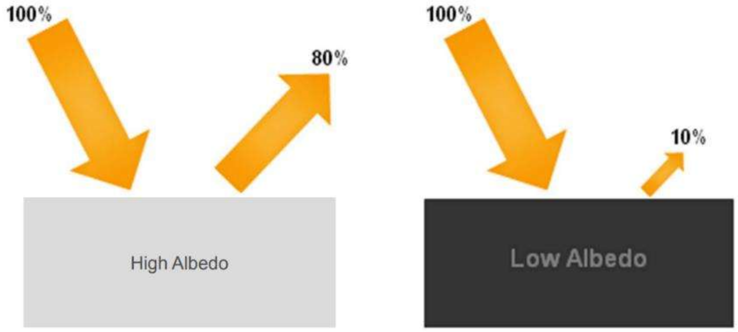

Figure 5: High & low albedo material reflection; Source: cshub.mit.edu

1.3.3 Urban Infrastructure:

The size and configuration of structures inside an urban area affect wind flow and the ability of absorb and release solar heat energy by urban surface materials is more and less respectively. In densely populated locations, taller neighbouring buildings and surfaces retain heat reflected by nearby structures, causing those structures to accumulate huge thermal masses that are difficult to dissipate heat from (Yang, Shi, and Cao 2020). According (Masson 2006), cities with lots of tall structures and narrow streets develop into urban canyons that might obstruct cooling benefits from natural wind flow. The development of canopy worsens UHI.

1.3.4 Anthropogenic Heat:

Anthropogenic heat is the heat generated by human activity that contributes to atmospheric heat islands. It is determined by summing the energy necessary for heating and cooling, running appliances, vehicles and industrial operations. Traffic volume and urban form are connected, and automobiles significantly contribute to urban heat islands and air pollution (Anshu Gupta,Vivek Dey 2009). Anthropogenic heat varies with urban activity and infrastructure, with more heat being produced by energy-intensive structures and vehicles. Particularly in denser metropolitan locations, the heat radiated from anthropogenic sources has a greater impact on UHI production (EPA 2016).

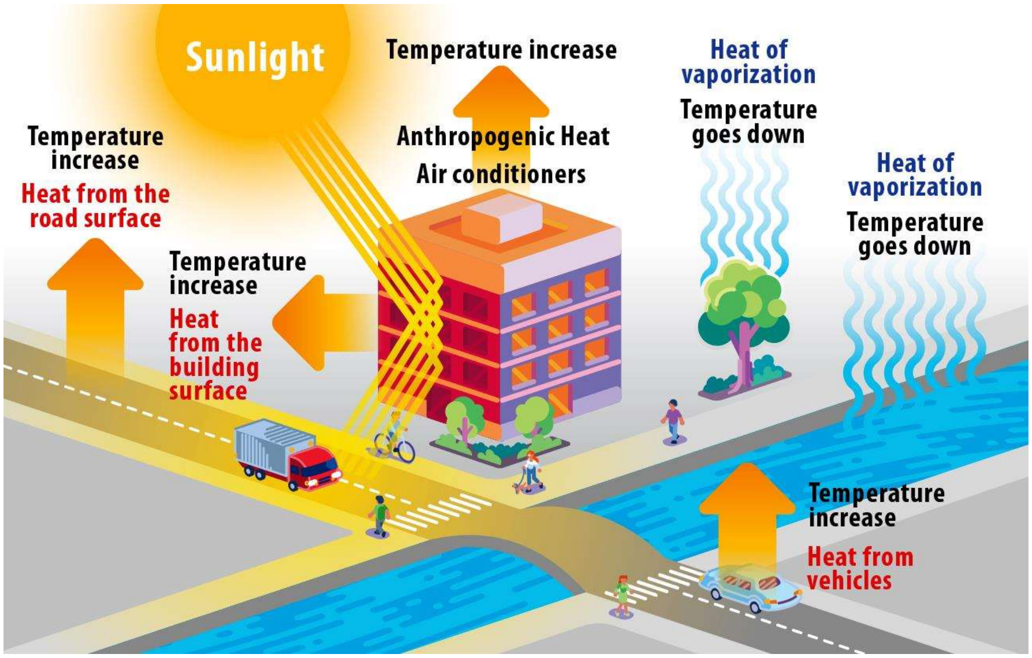

Figure 6: Factors Contributing to Urban Heat Island Effect; source: Pavement Technology, Inc

1.3.5 Weather:

Wind and cloud cover are the two main meteorological aspects that impact the occurrence of UHI. When the winds are calm and the sky is clear, urban heat islands form because these conditions enhance the amount of solar energy that reaches urban surfaces and decreasing the amount of heat that can be moved away. On the other hand, brisk breezes and cloud coverage reduce urban heat islands (EPA 2016).

1.3.6 Geographic location:

Urban heat island creation is influenced by climate and terrain, which are in part determined by a city's geographic position. For instance, big bodies of water may produce breezes that channel heat away from towns and reduce temperatures. A city may be shielded from wind or experience wind patterns that travel through it depending on the proximity of nearby mountain ranges. When larger-scale factors, including prevailing wind patterns, are comparatively weak, the relevance of local topography for heat island creation increases (EPA 2016) (RIZWAN, DENNIS, and LIU 2008).

1.4 Effects of UHI

1.4.1 Elevated temperatures in heat islands can have a range of effects on a community's environment and condition of living.

1.4.2 Increased Energy Consumption:

Heat islands boost the need for air conditioning to keep buildings cool. For every 10 C increase in temperature during the summer, energy use may increase by 2–4%.(Akbari, Pomerantz, and Taha 2001). The biggest rise in power use was observed in nations where the majority of buildings have air conditioning. This rise in demand is a factor in increased power costs (Gul and Patidar 2015).

Both the total demand for power and the peak energy demand rise as a result of heat islands. There is often a surge in demand on hot summer weekday afternoons when business and homes use air conditioning, lights, and appliances. The increased demand for air conditioning during high heat events, which are made worse by heat islands, can overwhelm systems, necessitating the use of controlled, rolling brownouts or blackouts by utilities to prevent power disruptions. (Santamouris 2020)

1.4.3 Elevated Emissions of Air Pollutants and Greenhouse Gases:

Heat islands, as previously mentioned, increase summertime power demand. Electricity providers often depend on fossil fuel power plants to provide a large portion of this demand, which raises air pollution and greenhouse gas emissions (Adinna, Christian, and Okolie 2009).

These pollutants are detrimental to human health and also have a role in the development of smog, acid rain and fine particulate matter, which are all complicated issues with air quality. Utilizing fossil fuels more frequently results in higher emissions of greenhouse gases like carbon dioxide, which are a factor in climate change (Adinna, Christian, and Okolie 2009).

In addition to their impact on emissions connected to the generation of energy, higher temperatures can also directly speed up the creation of smog. More smog will form when the climate becomes sunnier and hot, providing that all other elements stay constant, such as the quantity of precursor emissions in the air and the speed and direction of the wind. (EPA 2016).

1.4.4 Compromised Human Health and Comfort:

Increased daytime temperatures, less effective night-time cooling, and greater levels of air pollution are all caused by heat islands. These, in turn, lead to ailments including general discomfort, breathing issues, and heat stroke that are caused by the heat. (EPA 2016).

- Older people are among those who are most susceptible to heat waves. This risk is influenced by several physiologic, psychological, and social variables. (Gamble et al. 2008).
- Due to their tiny stature and other factors, young children are typically more vulnerable to high heat. Children are especially susceptible to lung disorders brought on by air pollution, which often rises during heat waves (Gamble et al. 2008).
- Low-income communities are more vulnerable to heat-related diseases due to poor housing conditions, such as a lack of air conditioning and confined living quarters, and a lack of money to find alternate refuge during a heat wave.(Gamble et al. 2008).
- Conditions like heat exhaustion and heat stroke are more likely to affect people who work outside. They are more susceptible to heat stress and ozone air pollution, especially if their jobs require a lot of physical effort. (Gamble et al. 2008).
- People with poor health, such as those with long-term illnesses, impairments, mobility issues, and those who take specific drugs, are more susceptible to severe temperatures. During heat waves, those who have diabetes, physical disabilities, and cognitive abnormalities are particularly at danger. (Gamble et al. 2008).

1.4.5 Impaired Water Quality:

When rainwater drains into storm sewers and is discharged into streams, rivers, ponds, and lakes, it heats up due to the high temperatures of the pavement and rooftop surfaces. All elements of aquatic life are impacted by water temperature, but many aquatic species' metabolism and reproduction are particularly affected. Warm storm water runoff can cause rapid temperature fluctuations in aquatic habitats, which can be extremely stressful for aquatic species and even deadly(Somers et al. 2016) (Simmons et al. 2008). Urban streams are typically hotter than streams in wooded areas due to heated water runoff from urban materials, and temperatures in urban streams rose by nearly 7°F following mild storms.(Somers et al. 2016).

1.5 Mitigation of UHI

By using a variety of mitigation methods, the intensity of the urban heat island can be lowered. Especially in cities with warm climates, UHI mitigation will help to lower local temperatures, energy consumption, and CO_2 emissions. It will also improve air quality, human health, and general human comfort. There are several solutions that have been identified and put into practise all over the world that are linked to causal variables such mutual shade, enhancing surface permeability, cool roofs, green roofs, cool pavements, increasing urban green spaces, and using high albedo materials and finishes.

1.5.1 Using Landscaping & permeability materials

- *Trees and Vegetation:*

  By providing shade and reducing air and surface temperatures through evapotranspiration, trees and other vegetation. For instance, the peak temperatures of materials that are not shaded may be more than 11°C –25°C than the shaded surfaces. Evapotranspiration can assist lower summer temperatures by 1°C –5°C, either on its own or in conjunction with shading. The most efficient way to cool a structure is often to plant deciduous trees or vines to the west, especially if they shade the building's windows and a portion of its roof. Directly shady trees and other greenery reduce the need for air conditioning in buildings. Trees and vegetation will reduce the air pollution and GHG emissions by reducing energy usage. Additionally, they clean the air and adsorb and store carbon dioxide. By absorbing and filtering rainwater, vegetation lowers runoff and enhances water quality. Trees and Vegetation may minimise noise, provide habitat for a variety of creatures, and provide aesthetic benefits. (Hashem Akbaci, Sarah E. Bretz, Dan M. Kurn 1997)(Mirzaei and Haghighat 2010)(Thomas, Sherin, and Zachariah 2014)(Yang, Shi, and Cao 2020)(Anshu Gupta,Vivek Dey 2009)(Konopacki and Akbari 2002)(Akbari, Pomerantz, and Taha 2001)(Kleerekoper, Van Esch, and Salcedo 2012)(Pallavi Tiwari 2019)(ARCHITECTS 2014)(EPA 2008)

- *Green Roofs:*

  Vegetative layer cultivated on a rooftop is known as a "green roof" or "rooftop garden." Numerous other advantages of green roofs include the reduction and filtration of stormwater runoff, the absorption of CO2 and pollutants, and, green roof can use for recreation. By way of carbon sequestration and storage and dry deposition, vegetation filters out GHG emissions and pollutants from the atmosphere. It has been demonstrated that having a connection to nature improves one's physical, mental, and productivity, lowers blood pressure, and shortens hospital stays. Nearly all storm-related precipitation can be captured by green roofs during the summer, but only around 20% can be captured during the winter. The season and rainfall patterns affect how effectively green roofs can control stormwater.

  According to the study, Kansas City's more than 700,000 square feet of green roofs added between 1999 and 2020 will prevent the emissions of 384 pounds of nitrogen oxide, 734 pounds of sulphur dioxide, and 269 tonnes of carbon dioxide in that year. Researchers at Lawrence Berkeley National Laboratory, discovered that, although costing more than cool or traditional roofs, green roofs offer much more relative advantages per sft over a 50-year of lifespan.(Sailor, Elley, and Gibson 2012)(Simmons et al. 2008)(Bousse 2009)(USA Environmental Protection Agency 2008)

- *Permeable Pavements:*

  Parking lots are one of the promising uses for permeable pavement. Low-albedo materials, which are used for roads and pavements will absorb sun's heat and raise Land surface temperatures, are typically used to pave parking lots. The perimeter and full surfaces of parking lots can be covered and shaded with vegetation, or other construction materials that support vegetation growth can be used. (ARCHITECTS 2014)(EPA 2021a)(EPA 2018)(Sailor 2006).

1.5.2 Using High albedo materials

- *Cool Roof:*

  During the hottest parts of the summer, cool roof features assist roofs retain cooler than traditional materials. The most significant attribute of a cool roof is a high albedo property, which serves to reflect sun's radiation and heat away from a building and lowers the roof temperatures. The building below keeps cooler and consumes less energy for air conditioning as a result of the reduced heat transfer. Cool roofs reduce greenhouse gas emissions and associated air pollution by reducing energy demand. With or without air conditioning, cool roofs can lower indoor temperatures, reducing the risk of heat-related diseases and fatalities. (Miller et al. 2004)(Kolokotsa et al. 2018)(Akbari, Pomerantz, and Taha 2001)(USA Environmental Protection Agency 2008).

- *Cool Pavements:*

  Regular paving materials can reach peak summer temperatures of 48°C - 67°C, delivering extra heat to the atmosphere above them and heating storm water which drains onto nearby waterways and waterbodies. Pavements are an important factor to take into account in heat island mitigation due to the size of the area they cover in urban settings. Techniques like the use of coatings or grass paving, can both be used to make cool pavements. Few benefits of cool pavements include less storm water heat up and runoff, decreased tyre noise, and enhanced night-time vision. (Kolokotsa et al. 2018) (Akbari, Pomerantz, and Taha 2001)(Karlessi et al. 2013) (Noise and Noise, n.d.)

1.5.3 Urban Design strategies

- *Urban Geometry:*

  The reduction of a building's individual impact on the urban microclimate rests mostly on changes to its exterior envelope, as opposed to the built environment as a whole. By making changes to the exterior envelop structures' heat consumption and heat emissions to the atmosphere can be reduced. (Yang, Shi, and Cao 2020) (Yin et al. 2018).

- *Building Orientation:*

  The geometrical link between built-up areas and open spaces and how roadways are orientated can both significantly affect the city's thermal climate. Due to the slow nature of changes in street network and construction volumes, modifying street geometry in existing urban settings for the purpose of UHI mitigation may not become a common mitigation strategy in most cities; however, modifying street geometry may become a viable mitigation strategy for producing short-term Urban Heat Island mitigation effects in urban areas. (Arellano, Roca, and Biere 2018)(Yang, Shi, and Cao 2020).

- *Building Facades:*

  In comparison to green roofs, vegetated façades may offer a larger cooling potential depending on the urban architecture. Vertical Greenery Systems (VGS) can offer cooling solutions to numerous floors in buildings with vast exposed façade areas, in contrast to vegetated roofing systems which may only cool the rooms directly below the roof. For vertical surfaces, there are numerous alternative greenery systems that each have their own benefits and drawbacks. Based on the benefits of its structure and cooling, VGS can be divided into three groups. (Arenghi, Perra, and Caffi 2021).

1.5.4 Reduction of Anthropogenic heat

- *Air Conditioner Heat Reduction:*

  Air conditioners can often be effectively replaced by solar cooling systems. Solar collectors are prospective substitutes for the classic compression machines typically employed in traditional air conditioning systems. In addition, air conditioners' heat emission will also be minimised. (Testi, Schito, and Conti 2016).

- *Urban Vehicles & Building appliances Heat Reduction:*

  Vehicles and building equipment both contribute to the creation of UHI effects. In a city's central business district, anthropogenic heat is one of the causes to increase the UHI to 2°C –3°C both during the day and at night. (HaiderTaha 1997). Significant heat from halogen and incandescent lamps is absorbed and stored by building materials and walls. (ARCHITECTS 2014). Buildings should be designed with natural ventilation (such as windows and walls with air vents) in order to use less energy for lighting and cooling systems. (Hayes et al. 2022). More use of public transportation and less use of personal vehicles can lower city temperatures. (R. A. Pielke, R..W. Arritt, M. Segall, M. D. Moranl and

R. T. McNider 1987). Automobiles emit heat in the lower atmosphere. In addition to lowering air temperature and pollution, CNG (Converted Natural Gas), electricity, and hydrogen fuel can be superior automotive fuel options than diesel and gasoline. Additionally, the creation of an active transportation system makes it simple for people to get around on foot and by bicycle. (EPA 2016).

1.6 Methods of urban heat island study

The air/surface temperature difference between urban and rural locations determines the UHI intensity. Globally, there is excellent acknowledgment of and reporting of UHI intensity. Luke Howard's climatic study of London in 1818 revealed "an artificial surplus of heat" compared to the countryside, which was the first evidence of UHI intensity (ARCHITECTS 2014). There are two different methods for calculating heat island intensity: observational methods and simulation methods (Mirzaei and Haghighat 2010)

1.6.1 Observational approaches:

- *Field measurement*

1.6.1.1.1 The following techniques are used to measure temperature in this situation:

1.6.1.1.2 a. Fixed Station

The data or temperature are gathered by meteorological stations or the Indian Meteorological Department, making it the simplest and most popular way for determining the severity of a heat island for any given area. (IMD)(Amirtham 2016) (Mohan, Kikegawa, and Gurjar 2012) (Kikon et al. 2016a)

The fundamental data that weather stations provide are as follows(Sharma 2021):
Precipitation totals, 2 m air temperatures, 2 m air temperatures at their highest and lowest points, Sunlight duration, cloud cover, relative humidity (RH) etc.

1.6.1.1.3 b. Field survey

In each metropolis, it is challenging to locate numerous fixed stations in the ideal positions to produce a good two-dimensional picture of the heat island; here is where field survey will assist in gathering the data. There are two categories of field measurements: Stationary survey (Mohan, Kikegawa, and Gurjar 2012) and mobile survey (Thomas, Sherin, and Zachariah 2014).

In a stationary survey, a fixed place is selected, and instruments like thermometers are used to measure the temperature variation there. For mobile surveys, a vehicle with temperature measuring equipment already mounted often travels pre-selected routes through various land use categories. Infrared thermometers, psychrometers, digital thermometers, RTD probes, automatic temperature recorders, Max tech digital thermometers, and other tools are frequently used to detect heat intensity.

1.6.1.1.4 c. Vertical sensing

Particularly in the identification of BLUHIs, vertical sensing is helpful. Sending instrumented balloons into the air, placing monitoring equipment on radio towers, or flying at various altitudes in an instrumented helicopter or aircraft are all techniques used to measure the heat island intensity. (ARCHITECTS 2014).

1.6.1.1.5 Limitations

The near surface temperature trend in urban and rural areas is typically compared when using the field measurement approach. Despite this, it should be noted that field measurement has a number of limitations when used independently. The creation and placement of measurement equipment around a city is typically an extremely costly and time-consuming task. Additionally, only a few number of parameters are typically measured at once. This strategy's weakest aspect is data analysis. Due to the large number of variables that could affect the creation of UHI, consistent generalisations cannot be established even after amassing enough data using straightforward correlations between measurements and UHI characteristics. (Mirzaei and Haghighat 2010)

- *Satellite data / Thermal remote sensing*

While remote sensing is used to find temperatures and other parameters mostly of the surface, fixed station and mobile transverses are used to monitor temperatures of both the atmospheric and surface layers (EPA 2021c). Most Urban Heat Island studies, it has been discovered (Yin et al. 2018)(Kikon et al. 2016a) use satellite imaging or remote sensing data to gather data on land surface temperature (LST), land cover and use (LULC), normalised difference vegetation index (NDVI), and other variables. These LANDSAT satellite variants have a variety of sensors, including MODIS, TIRS, ASTER, TM, OLI, GOES, NOAA, AVHRR, Each term's expansion is listed in the table below.

Abbreviation	Expansion
MODIS	Moderate Resolution Imaging Spectroradiometer
TIRS	Thermal Infrared Sensor
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
TM	Thematic Mapper
OLI	Optical Land Imager
GOES	Geostationary Operational Environmental Satellite
NOAA	National Oceanic and Atmospheric Administration
AVHRR	Advanced Very High Resolution Radiometer
ETM	Enhanced Thematic Mapper
MSS	Multispectral Scanner

Table 1: List of satellite sensors

Different spatial resolutions of temperature data are provided by the current satellite thermal sensors. From kilometres to metres, the spatial resolution ranges. The table below lists the most popular satellites and sensors for the heat island investigation along with their resolutions.

Satellite/Sensor	Resolution
LANDSAT TM	30m
LANDSAT ETM+	30m
LANDSAT MSS	60m
LANDSAT 7/ETM+	60m

EOS-1 (Terra)/ASTER	90m
LANDSAT 8/TIR	100m
LANDSAT 4/TM	120m
LANDSAT 5/TM	120m
NOAA-AVHRR	1km
EOS-1 (Terra)/MODIS	1km
GOES	4km

Table 2: Most popular satellites and sensors for the heat island investigation along with their resolutions.

In addition to the turbulent transfer from the surface, the final land surface temperature takes into account the effects of surface emissivity, albedo, moisture, and the effects of the near surface atmosphere.(Mirzaei and Haghighat 2010).

1.6.1.1.6 Limitations

Remote sensing is an extremely costly method and that photographs taken from the surface of cities cannot be stable. This is caused in part by atmospheric interactions and in part by the capabilities of the tools used. For instance, satellites that orbit the world spend a finite amount of time over one particular area, and there is always a chance that the sky will be foggy when the UHI is captured over a location. This plan is unable to capture the study domain's vertical field.

- *Small-scale modelling*

To explore the impact of UHI, a miniature metropolitan area is created. Although it is often difficult and impractical to guarantee similarity between real cases and prototypes, the prototypes are tested either in wind tunnels or outdoors. A small scale model can be used to explore the effects of a building's or a small area's environment on a few key parameters. (ARCHITECTS 2014)

1.6.1.1.7 Limitations

Small-scale models primary disadvantage is its price. A comprehensive modification is additionally necessary to achieve resemblance between the boundary circumstances of a small-scale experiment and a real-world issue. Finally, because this approach takes a long time, only certain areas of a metropolitan region may be reproduced. As a result, this technique cannot be used to investigate the UHI in both time and space while changing various factors. (Mirzaei and Haghighat 2010) .

1.6.2 Simulation approach (Numerical modelling):

1.6.2.1 To detect urban meteorological and climatological issues, including the UHI phenomenon, numerical models have been constructed. The complicated properties of the UHI, typically necessitate significant model simplifications. However, computer capabilities have greatly improved in recent years, enabling researchers to solve mathematical models on a vast scale.

- *Energy balance model (simplified model)*

The 1st law of thermodynamics, which specify that energy entering and leaving any surface must be conserved, forms the basis for the energy balance equation. The conservation of energy law is used to determine the energy budget for a given volume, and heat fluxes caused by atmospheric phenomena, velocity field changes, and turbulence are taken into account. It was First proposed for an energy balancing budget for a building canyon by (T.R.Oke 1982) at a city scale as follows:

$$Q = QH + QE - QF + \Delta QA + \Delta QS$$

1.6.2.1.1 In this equation, Q is the net radiation, QF is the anthropogenic energy release within the control volume, QH is the sensible heat flux while QE is the latent heat flux, QA is the net advection through the lateral sides of the control volume, and QS is the storage heat flux, which represents a mechanism for all energy storage within the components of the control volume.

1.6.2.1.2 Limitations

One major flaw in the energy balance model is the lack of a wind flow field. Because there is not enough data on flow patterns, this model cannot accurately reflect atmospheric events and calculate latent and perceptible fluxes. (Mirzaei and Haghighat 2010).

- *Computational fluid dynamics (CFD)*

As the effects of urbanisation are confined to extremely small regions and climate modelling at the city size is a very complex problem, there is a significant increase in the production of micro-climate models. For these aims, researchers started simulating the region at the city size using CFD (Computational Fluid Dynamics) models. CFD is a software-based platform that links computing, physics, and mathematics. It is widely utilised in both technical and scientific disciplines. LES, WRF, and ENVI MET are further models that researchers employ to verify their findings. But there is little study done on numerical models in India (Sharma 2021). The CFD models solve temperature, momentum, and mass conservation concurrently. Therefore, CFD models can represent more realistic information regarding the distribution of the UHI as compared to the UCM model (Mirzaei and Haghighat 2010) (Huo et al. 2021).

1.6.2.1.3 Limitations

One drawback of CFD models is that turbulence at the atmospheric and canopy scales cannot be modelled at the same time and length scale. Its expensive (Mirzaei and Haghighat 2010).

1.6.2.2 Types of Computational fluid dynamics (CFD)

According to several studies, the CFD simulations are typically separated into two scales.

a) Meso-scale Model
b) Micro-scale Model

a) Meso-scale Model:

Meso-scale modelling's typical impacts cover a larger area or entire city neighbourhoods. Although the greatest range of this scale is 2 - 2000 km, the typical range is around 1 - 2 km(Mirzaei and Haghighat 2010). Three subscales of the meso-scale are known as meso-α (200-2000 km), meso-β(20-200 km), and meso-γ(2-20 km)(R. A. Pielke, R..W. Arritt, M. Segall, M. D. Moranl and R. T. McNider 1987). In comparison to global-scale models, meso-scale models are both smaller and bigger than micro-scale models.

b) Micro-scale Model:

The investigations at this size provide detailed resolution over a short distance, often in the range of 1 to 100 metres. The conservation equations inside the surface layer are resolved using CFD models at the microscale, whilst bulk values of various surface attributes are assumed for the mesoscale models. The micro-scale models accurately represent certain features while taking into account intricate surface layer interactions. In this type of models, simulations are run on a narrow horizontal region for a few building pieces (e. g., a few hundred meters). Micro-scale models do not take into account the vertical atmospheric interactions, making this method suitable for studying high-Rossby number problems (Mirzaei and Haghighat 2010). Due to the enormous computational cost, it is not practical to use the micro-scale models for a full metropolis, with all the intricacies and geometries. As a result, the simulations are horizontally constrained to a narrow region in terms of some building elements (few hundreds of meter).

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Literature studies of UHI:

Topics	studies
Detection & Analyse of UHI	(Mausam 1986)(Konopacki and Akbari 2002)(Masson 2006)(Gamble et al. 2008)(Adinna, Christian, and Okolie 2009)(Anshu Gupta,Vivek Dey 2009)(Mohan, Kikegawa, and Gurjar 2012)(Thomas et al. 2014)(Amirtham 2016)(Kikon et al. 2016b)(Soltani and Sharifi 2017)(Kolokotsa et al. 2018)(Yin et al. 2018)(Arellano, Roca, and Biere 2018)(Pallavi Tiwari 2019)
Policy's and laws to decrease UHI	(Bousse 2009)(ARCHITECTS 2014)
Suggest Mitigation strategies	(Hashem Akbaci, Sarah E. Bretz, Dan M. Kurn 1997)(HaiderTaha 1997)(Akbari, Pomerantz, and Taha 2001)(Konopacki and Akbari 2002)(Miller et al. 2004)(Simmons et al. 2008)(USA Environmental Protection Agency 2008)(EPA 2008a)(EPA 2008b)(Bousse 2009)(Sailor, Elley, and Gibson 2012)(Testi, Schito, and Conti 2016)(TERI 2017)(Kolokotsa et al. 2018)(EPA 2018)(Arenghi, Perra, and Caffi 2021)(Sailor 2006)
Field measurement technique	(Mausam 1986)(Hashem Akbaci, Sarah E. Bretz, Dan M. Kurn 1997)(HaiderTaha 1997)(Miller et al. 2004)(Bousse 2009)(Mohan, Kikegawa, and Gurjar 2012)(Thomas et al. 2014)(Somers et al. 2016)(Amirtham 2016)(Soltani and Sharifi 2017)(Kolokotsa et al. 2018)
Satellite data techique	(Adinna, Christian, and Okolie 2009)(Anshu Gupta,Vivek Dey 2009)(Mohan, Kikegawa, and Gurjar 2012)(Kikon et al. 2016b)(Soltani and Sharifi 2017)(Yin et al. 2018)(Pallavi Tiwari 2019)

Simulation approach (Numerical modelling)	(Hashem Akbaci, Sarah E. Bretz, Dan M. Kurn 1997)(HaiderTaha 1997)(Akbari, Pomerantz, and Taha 2001)(Konopacki and Akbari 2002)(Sailor, Elley, and Gibson 2012)(Soltani and Sharifi 2017)(Kolokotsa et al. 2018)(Yang, Shi, and Cao 2020)(Arenghi, Perra, and Caffi 2021)
Literature Study	(T.R.Oke 1982)(HaiderTaha 1997)(Masson 2006)(Gamble et al. 2008)(Bousse 2009)(Mirzaei and Haghighat 2010)(Kleerekoper, Van Esch, and Salcedo 2012)(ARCHITECTS 2014)(Santamouris 2020)(EPA 2021b)(EPA 2021a)(EPA 2021c)

Table 3: Literature studies of UHI and there outcomes

Table 6 shows that the majority of researchers are working towards the detection of UHI and suggesting mitigation strategies, then reviewing the implemented mitigation measures and policy making. Indian researchers have made relatively little contribution to the simulation approach (numerical modelling) method compared with international studies.

Conclusion:

Due to rapid urbanisation, increase in development activities green areas area turning into urban surfaces which have nature of very low albedo and impermeability, Anthropogenic Heat Emissions through Air conditioning systems, Vehicular traffic, People density and factories are the reason for the formation of UHI. UHI can worsen the quality of the environment where people live, increase energy demand, elevate ground-level ozone, and potentially raise death rates. To reduce UHI indoors, most city dwellers use air conditioners. However, it has two major drawbacks. Firstly, greater energy use necessitates the use of more fuel, resulting in higher greenhouse gas emissions (GHG). Second, it increases the UHI outside even more. It is clear that reducing UHI has several advantages. Increasing landscaping areas have a great effect on reduction of UHI. But in some cases increasing the green spaces are not possible in cities, in that case high albedo pavements, cool roofs and green roof can be the best alternative mitigation strategy. To reduce anthropogenic heat it better to design buildings with passive design strategies, which can reduce the energy load of the building. Solar cooling & heating system and 5 star energy rating appliances are recommended for less energy consumption. More use of public transportation and less use of personal vehicles can lower city temperatures and pollution. To detect Land surface temperature and Atmospheric temperature, satellite data and field measurement are mostly used respectively. With Simulation approach, not only detecting the UHI, future climate of city can also be predictable. Maximum researchers are working towards detection of UHI and suggesting mitigation strategies then reviewing the implemented mitigation measures and policy making. So there is a need for UHI studies on policy making and reviewing the implemented mitigation measures. Indian researchers should concentrate on the Simulation technique (Numerical modelling) for UHI detection and modelling, as there has been relatively little contribution from Indian researchers in this method.

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