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Review

Urban heat island: a primary guide for urban designers

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ABSTRACT

Today, the most severe issue in metropolitan areas is rising surface temperature due to poor urban design. Given the significance of the urban thermal island, numerous studies have been done to discover the mechanisms influencing its growth and decline. Thermal comfort is relatively simpler to accomplish inside a building, whereas it is considerably more challenging to achieve in open spaces, and hence far less work has been done on it. The construction of urban thermal islands has emerged as one of the most serious concerns of our day, and it has captured the scientific community's attention. Attention to this subject has expanded dramatically in scholarly articles and research, particularly in the recent decade. Because of the subject's relevance, this study aims to undertake a systematic evaluation and thematic analysis of papers and scientific research in this field. According to studies, the urban heat island is influenced by climatic elements and city-building factors. All climate influences are sunlight, wind speed and direction, cloud cover, soil and air humidity, precipitation, latitude, seasonal change, topography, and proximity to rivers and the sea. Although these elements are almost uncontrolled in existing cities, they are essential in finding new cities or deciding the direction of city development. The second element category is controllable and primarily connected to city planning and building. Recognizing the significance of these factors can demonstrate the relevance and value of urban planning and design in lowering urban heat islands. We review the nature and aspects of this phenomenon in this article by exploring the theoretical foundations of this topic.

1. Introduction

For many, the supply of basics like fresh water, food security, and electricity is anticipated to be impacted by a climate warming system. Concurrently, efforts to mitigate and adapt to climate change will equally inform and influence the global development agenda. It is crucial to understand how climate change and sustainable development are related. The least equipped to withstand the projected shocks to their social, economic, and environmental systems will be the most negatively impacted by these shocks. These poor and emerging countries-primarily the least developed- will be the majority [1]. In comparison, this increase is outweighed by an increase in the number of families, implying that the overall number of people per family drops. As a result, our cities will continue to grow, putting further strain on the existing urban area. Current urbanization patterns significantly impact how we plan, build, and live in our cities. The transition from rural to urban settings includes a variety of human-caused consequences, such as a loss of biodiversity or a lack of water supplies [2]. It also affects the shape and energy budgets of the urban environment, leading to higher temperatures than in the undeveloped environment [3-5]. The Urban Heat Island (UHI) phenomenon is centered on this. Luke Howard, a British meteorologist, was the first to study the phenomenon; in 1818, he found a sizable rise in the center of London [6]. For a long time, neither science nor politics supported the UHI. This changed in 1971 when the Club of Rome issued its Limits to Development report. The study was the first to explore the consequences of population development on UHI, making it one of the most visible repercussions of human-caused environmental change. In general, the study sparked a fundamental debate regarding the reality of climate change and a search for factual data to demonstrate human proficiency in it. In the case of UHI, the formation and consequences were examined and analyzed until it became clear that an increasing proportion of our population was subjected to urban atmospheric conditions. The dilemma of climate change and UHI has seen substantial adjustments in the recent two decades as politicians and cultures have begun to pay greater attention to the issue. The worldwide debate was dominated by effect evaluation and how to deal with them, leading to significant new knowledge on preventative and adaptation activities. However, because politicians and society have called for a comprehensive solution to the effects of climate change and UHI, the efforts taken thus far have not been practicable. The emphasis shifted from natural science to a multidisciplinary approach, emphasizing information development and collaboration among scientists, planners, and decision-makers. To develop sustainable locations, urban planners and designers must handle the repercussions of this argument, such as higher knowledge volumes, demand for diverse, sustainable settings, and improved political and social wealth [6]. However, in the recent debate, other consequences, such as increasing sea levels or global warming, have overshadowed the UHI hypothesis. This is not surprising given the calamities in Bangladesh and New Orleans, but the UHI should not be neglected. For example, recent heat waves in Europe have sparked a significant national discussion, with thousands of direct causes of death and sickness. Furthermore, there are significant effects on municipal water and energy supplies. Rising energy demand strains city climates and water supplies [7]. Thus, the UHI is one of several climate change-related outcomes that put space planners under pressure; planners must use vast amounts of new knowledge to create well-planned and secure areas. Environmental experiments have created several theories regarding limiting adverse impacts in the case of the science-based UHI. The main thing today is to understand how to apply all of the current knowledge and how to deal with the influence of politics and culture in creating well-planned and thriving areas, and therefore how to implement the steps successfully. More research must be conducted to clarify how to build a clear UHI strategy for a region and apply all broad initiatives in local planning practice. In this approach, the adverse effects of UHI will be reduced, assuring long-term growth in our cities.

2. Urban heat island: concept

There are several points of view when it comes to challenging UHIs. Few people will immediately begin dreaming about global warming, while others will speculate about the Pacific Ocean's tiny islands, but the primary number has never been heard. The position of UHI is always relatively limited or nonexistent in today's discourse on climate change, environmental development, and eco-engineering. This lack of exposure can be interpreted in various ways, all of which must be addressed in this study. Still, one of them is the phenomenon's vague and dubious existence. This section will explain the exact phenomenon, beginning with the fundamentals of UHI [8]. There are substantial differences in the notion of UHI and its outcomes. The influence of urban surfaces, wind patterns, and global warming is widely debated. However, there is a consistent interpretation of the underlying concept of UHI, which can be defined as the variation in temperature between urban and rural areas (Figure 1) [2]. In literature, UHI is an improvement in urban temperature. The question here is, what is the exact growth and how it is made. Measurements and forecasts vary worldwide due to current variations in geographic climate conditions [9]. An examination of a wide range of environmental and planning literature indicates the issue of the UHI's thermal effect notion. As a result, it is critical to research on a local scale to explain the case of the urban environment, considering the particular climatological and morphological circumstances. To better understand the specific causes of UHI and its relevance to urban planning, we shall first review the theoretical foundation of this section.

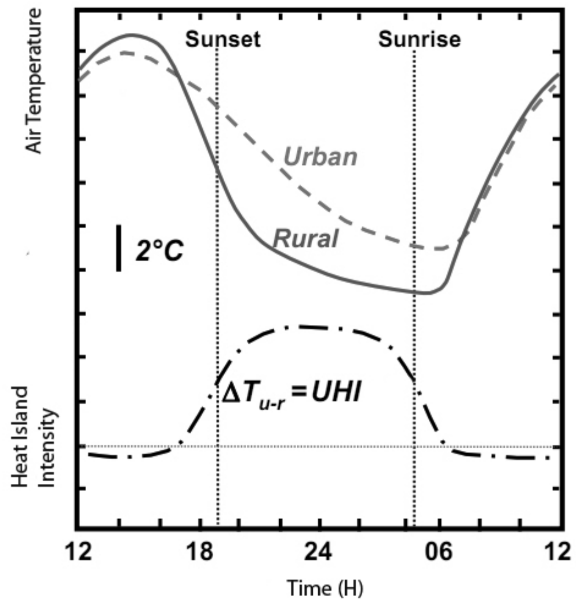

Figure 1. The definition of an urban heat island [5]

2.1 Theoretical basis

For urban heat islands, the lowest atmospheric level affects state and local climates. At the same time, other experts believe that UHI's effects on global temperatures have yet to be fully realized. The UHI-world climate change relationship will be discussed further in this section.

2.1.1 Urban climatology

While people have historically adapted to their surroundings, climate change poses new and unprecedented hazards to lives and livelihoods. Given increasing uncertainties and ambiguity about climate adaptation, interest has grown in the previous two decades. Even though it was initially used in the 1990s, the IPCC definition gained traction. The fourth of these evaluations is "the most recent change in natural or human systems in response to current or expected climatic stimuli or their repercussions, which mitigates harm or capitalizes on positive opportunities" [10]. Additionally, the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) meetings have added to this growing knowledge. COP 21 highlighted the importance of setting a global goal for adaptation "develop adaptation capability, enhance resistance, and reduce climate change vulnerability" [11]. In addition to natural disasters, metropolitan areas are at risk from unexpected climatic hazards (e.g., urban heat islands, impervious surfaces exacerbating flooding, coastal development threatened by sea-level rise, etc.) [12]. Additionally, most people on Earth live in metropolitan regions [13]. Many assets are at risk from climate change because they are hubs of the global economy [14].

Additionally, urban locations provide distinct options for adaptability. First, judgments for adaptation frequently call for locally specialized activities, which are best suited by local-level decision-making [15]. Secondly, urban settings foster inventiveness and efficient energy usage. Numerous charity foundations, in particular, encourage local adaptation by funding initiatives like the Kresge Foundation's examination of urban populations' climatic resiliency and susceptibility to urban adaptation. The initiative will assist in meeting urgent demands for climate action and guide decisions regarding housing, land use, water supply management, transportation, and other issues relating to policies and finances, including motivating local communities to act and advising them on what to do to improve their health and resilience to climate change. Fourth, given the significance of cities in addressing climate change, cities have lately become more competitive, as seen by growing interest in C40, 100 Resilient Cities, etc. [16]. This results from numerous cities' adaptation efforts and expanding research on urban adaptation [17]. Additionally, the Adaptation Clearinghouse of the Georgetown Climate Center [18] tracks some state-level adaptation proposals, and researchers have examined the data. The demands and progress of urban adaptation are examined in recent study literature [19]. Additionally, a sizable examination of national adaptability has been conducted, which includes monitoring national risk, addressing climate change threats, and enhancing overall national adaptability [20].

2.1.2 Urban climate

The urban climate closely interacts with energy demand, outdoor comfort, and energy systems. The geometric complexity, heterogeneity, and link of cities to meteorological events confound urban microclimate modeling [21]. The city and climates are two artificial and natural systems that are inextricably linked in constructing various city places such as buildings, green rooms, urban networks, etc. Aside from practical, visual, and aesthetic aspects, it is also vital to consider the city's climate and climatic design standards. The four primary climatic factors in the architectural structure of urban areas are "Solar Radiation," "Wind Flow," "Relative Humidity," and "Temperature." Controlling the two indicators of sun radiation and wind flow allows for precise relative temperature and humidity control. As a result, the first stage in climatic design is to understand the influence of changes in these climatic factors on environmental comfort.

2.1.2.1 Solar radiation

The sun is the source of the energy that determines our climate. Radiation from the sun reaches Earth as electromagnetic energy. All things emit electromagnetic radiation, which may be thought of as waves with peak-to-peak lengths that vary with the surface temperature of the item. The electromagnetic radiation from the sun that penetrates Earth's atmosphere has a peak within the visible human range of wavelengths, around 400-700 nanometers, and the temperature at the sun's surface is approximately 6000°K, four (nm). We refer to the whole range of the solar spectrum, which extends from 280 nanometers (nm) to around 3000 nm (or 0.28 micrometers, abbreviated m, to 3 m), as short waves or solar radiation [22]. Understanding solar efficiency is crucial for urban planners and architects when designing urban structures. As the most logical approach to gathering solar energy, it is crucial to incorporate solar electricity into buildings with rooftops and façades. It has a significant impact on architecture. Mature solar technologies are more likely to produce preferable solutions during the early design phase. Early integration can be eased when architects know where the most significant energy may be produced. Real estate developers may also find solar power a crucial asset because they can see the energy produced in the envelope [23]. Furthermore, energy conservation and emission reduction have been elevated to a crucial strategic position in the People's Republic of China's 13th Five-Year Plan on Energy Strategy. Solar energy is excellent for sustainable energy with no restrictions and can be utilized everywhere. Solar energy usage offers enormous development potential and is reliable and effective. Solar energy generation and use in urban areas will limit the excessive use of traditional fossil fuels, prevent the deterioration of urban ecosystems, and ensure that urban areas have a healthy natural ecosystem [24]. The first area is where emergencies with energy usage may be addressed and finally resolved in the city. The lack of solar potential included in the conventional urban planning process, which is a deciding element to attain smart energy cities made up of zero energy structures, gave rise to the discussion of solar urban planning. The modern city that Le Corbusier envisioned was not realized. However, considering urban planning as the first sector to apply solar design logic was a creative idea. Energy experts and urban planners have long considered solar radiation and associated difficulties as active elements in urban development. The Urban Heat Islands (UHI) and Outdoor Thermal Comfort have been recognized as prosperous urban design areas among the numerous solar energy instances researched. UHI will quickly discuss these two areas of urban design below [25].

2.1.2.2 Urban heat island

In the 1810s, Luke Howards made the first reference to urban heat. In contrast to the city's rural surroundings, he saw "an artificial excess of heat" in London. Mitchell (1953) began his studies in the United States in the 1950s. Recently, there has been much global study on the urban heat island effect [26]. In metropolitan settings, a microclimatic phenomenon is referred to as a "Heat Island." It entails an appropriate air temperature rise in metropolitan regions, which is often warmer than the nearby rural neighborhoods (Figure 2). When breezes are light, the temperature differential is often more suitable at night than during the day. In terms of the seasons, the urban heat island effect primarily affects those who live in cities in the summer and winter. Addressing the UHI hazard to human health in urban areas is essential. The intensely scorching summer temperatures substantially impact the quality of life in cities. They may be summed up as a severe decline in public health, a warmer biosphere, and increased energy use [27]. The UHI phenomenon has an impact on urban areas for several reasons. The primary factor is the physical properties of the materials that make up urban surfaces, which absorb solar energy rather than reflect it. Longwave Radiation is emitted depending on the surface's excess warmth, especially at night. A constant energy balance is also maintained by the tiny amounts of natural surfaces often present in metropolitan settings. The waste heat produced by energy usage is another aspect of the temperature rise [27].

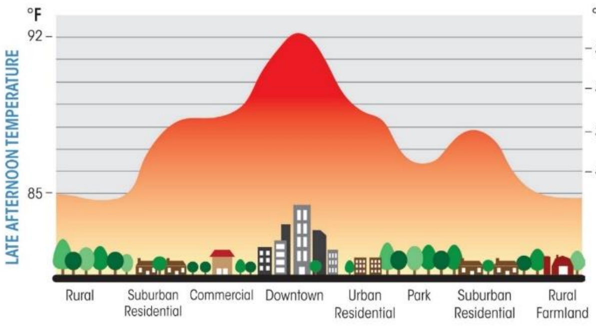

Figure 2. Diagram of an urban heat island phenomenon [27]

The negative consequences of climate change are made worse by the rising urban development rate. Specifically, energy demand has increased by 14% over the past ten years because of its fast urbanization. By 2030, at least 61% of the world's population will live in cities. Nearly four billion people, or 80% of the world's urban population, will live in the cities of industrialized nations, accounting for 95% of the population growth. However, this development may present a chance for ecologically responsible urban renewal or rebuilding [28]. The following are some significant factors that have fueled the expansion of UHI in metropolitan areas:

Surface: The critical element impacting UHI is the soil surface content. Solar power is collected in the city and emitted during the day and night. Therefore the disparity between the thermal entry of urban areas and their rural counterparts would also increase the heat island's size. Urban heat islands would be constrained by the increased emissivity from the sky and wind [29], demonstrating the most significant differences between urban and rural temperatures [30]. Urban surfaces use materials that absorb short-wave radiation to boost their thermal capacity, which increases their ability to absorb solar energy [31].

Lack of plants: There is a wealth of data on how plants and greenery affect air temperature. According to reports, large parks are typically 1-2°C colder than populated areas, although this temperature difference can reach up to 5°C [29]. Lack of vegetation in urban areas reduces the evapotranspiration, shade, and cooling benefits of plants that promote UHI and warm the city [30].

High buildings: High-rise building situations need special consideration. Because continuous slab buildings have varied surfaces that reflect and absorb sunlight, keeping urban areas warmer, they can obstruct fresh air and wind flow [28].

Human Activity: Environment-harming human actions include using air conditioning, driving, and building factories [32]. Both directly and indirectly, heat is affecting the climate. These processes pollute the environment, affect the input and exhaust radiation, and release heat and humidity [33]. This increased temperature could lead to detrimental health and environmental and economic consequences on the local environment [34]. Experts claim that excess heat exposure in the United States kills more people every year than deaths from other combined cases [28]. These high-heat occurrences disproportionately harm the city's young, old, and sick residents, and it appears that there is insufficient economic assistance to mitigate the adverse health effects of excessive heat [35]. The cost of living would go up if UHI were improved since it would require more energy for cooling and refrigeration in urban areas. Additionally, it is predicted that energy consumption will rise by 2 to 4% for every one-degree Celsius increase in the intensity of the UHI [30]. Compared to this, due to fast urbanization, energy demand has increased by 14% over the past ten years [36]. Because energy is essential to human life, this will soon become a worldwide concern due to the risk that energy may become scarce [37]. In a hot and dry climate, UHI is more likely to result in high temperatures and decreased air moisture, decreasing comfort and heat stress in metropolitan areas (Figure 3) [29].

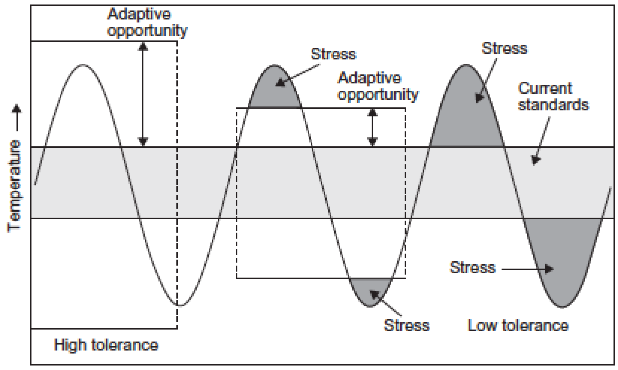

Figure 3. The consequence of adaptation possibility: Thermal stress is much less likely to occur as there are more chances for environmental management [40].

All of these conditions are made worse by the UHI, including heat and cold stress, excessive sun exposure, bug infestations, water, and air pollution, waste, noise, adverse effects on energy consumption, and fires. Heat exhaustion, heat syncope, heart attacks, and heat cramps are symptoms of UHI, which also refer to heat and heart failure [38]. The possible effects of UHI include the unfavorable social and economic effects of hot weather. Only necessary confinements will be made to the unpleasant environment, i.e., by limiting outside social activities and going shopping and working [39]. An essential aspect of this is the expanding usage of air conditioning, which drives up energy costs and consumption, leading to frequent power outages and air pollution [30]. Local heat waves may impact the welfare and health of residents in addition to temperature factors. Over 800 people perished in Chicago's 1995 heat wave [41]. In 2003, heat-related diseases in Paris led to 15,000 fatalities across Europe [42]. Air pollution will rise as a result of urban heat islands. According to studies by Sarrat et al. [43], urban heat islands in Paris affect the levels of ozone and nitrogen oxide (NO_x) . The energy needed for cooling also rises due to the urban heat islands. In turn, additional heat is released into the city, aggravating the urban heat island effect [44]. The unexpected effects of human activity on the climate, or accidental climate change, are most evident in urban settings. Cities influence climate and atmospheric composition changes at local, regional, and even planetary dimensions. As cities struggle to deal with catastrophic occurrences like storms, floods, and droughts, the atmosphere also influences their infrastructure, citizens' health, and public safety. In order to intelligently limit undesirable effects and increase advantageous ones, proper knowledge, description, and modeling of these interactions are required. In the end, this offers the scientific information required to plan, oversee, and run communities that are healthier, more sustainable, and more resilient [45]. By examining the historical and environmental effects of global urbanization, this part establishes the framework for the urban climate.

Outdoor thermal comfort: There are several reasons to improve the outside environment in urban areas. Making cities more appealing and accessible is now more crucial because of the positive social, cultural, and economic effects. If the outside environment is thermally comfortable, utilization of the metropolitan region is more likely to rise. Additionally crucial to human well-being is thermal comfort. This is particularly crucial in warm nations since rising temperatures raise the risk of heat-related illnesses. Furthermore, in friendly nations where suitable outdoor areas enhance outdoor liveability, outdoor activities are available for most of the year. The interior climate will also benefit from a thermally suitable external environment, resulting in less energy used for space cooling [46]. Recent ecosystem changes have impacted the viability of outdoor constructed settings [47]. Effective urban planning, which attempts to produce successful and useable outdoor spaces, is tested by the cumulative consequences of these changes in urban outdoor spaces. The thermal environment is given great significance as one factor affecting the outdoor environment's quality. Therefore, urban planners and designers investigate how people perceive and engage with outside weather situations. While accommodating their daily needs, the thermally comfortable urban environment may let individuals interact with their surroundings. On the other hand, unfavorable temperatures may make people less likely to engage in outside activities and use more energy for inside cooling [48]. One thermal comfort index is computed and used to indicate the combined impact of the study's environmental variables (such as air temperature, relative humidity, wind speed, and radiant temperature) and two individual components (such as garment insulation and metabolic activity level). To evaluate and forecast comfort in thermal settings, more than one hundred thermal comfort indices have been employed; the majority of these were created to identify interior conditions [49]. Among others, the top three thermal comfort indices- Physiological Equivalent Temperature (PET) [50], Universal Thermal Climate Index (UTCI) [49], and Outdoor Standard Effective Temperature (OUT SET) [51] were created especially for outdoor conditions and are frequently used in thermal comfort studies conducted outside. Other standard outdoor thermal comfort indices include PET UTCI, OUT SET, Thermal Discomfort Index (TDI), Effective Temperature (ET), Operative Temperature (TOP), and Perceived Temperature. These indices are in addition to PET UTCI and OUT SET (PT). The projected mean vote (PMV) or adaptive predicted mean vote was employed in several research (aPMV). However, the steady-state assumption of PMV may render it unreliable in the face of changing external circumstances. In early research, de Freitas [52] employed the Caloundra beachgoers as case studies to determine thermal sensation threshold values using the Skin Temperature Energy Balance Index (STEBIDEX) and Heat Budget Index (HEBIDEX). The Effective Standard Temperature (SET) thermal comfort index was expanded by Pickup and de Dearso that it could be used in outdoor situations. This thermal index has been employed in several comfort studies and continues to serve as the foundation for two-node models [46]. The most common outdoor thermal comfort indices utilized in recent investigations were PET or UTCI. Please also de Freitas and Grigorieva [53] and Coccolo et al. [54] for a thorough analysis of thermal comfort indices. Let us think about thermal comfort in the outdoors, with the complexity of the high spatial and temporal variability of environmental variables. The interplay between the physical environment, physiological, and psychological factors is even more difficult. Outdoor thermal comfort has been a hot topic due to discussions about sustainable urban settings, often unwelcoming developments in city centers, and the growing significance of open spaces under climate change [48]. A consistent deep core temperature of about 37^{o}C must be maintained for the human body to operate appropriately, balancing heat gains and losses from the environment and basal metabolic rate. According to the physiological reactions of the human body, this fundamental heat balance equation reflecting the heat exchange between the body and the atmosphere has served as the foundation for current thermal regulations [55]. The main environmental factors influencing the thermal environment and comfort include air and mean radiant temperature, air movement, and humidity. Additional characteristics that define system changes that affect the body's heat generation and dissipate to the environment include behavioral acts like clothing and metabolic activity, along with the corresponding energy production. Solar radiation is an extra climatic factor in interior settings that have been used to describe the physiology of thermal comfort in the outside context. In order to assess the thermal load that individuals are subjected to, over 100 thermal comfort and stress indices have been created experimentally or based on advanced energy budget models. These indices have been used as indications for alert systems, urban planning, ergonomic guidance, and public weather services [48]. The original wind chill index was one of the earliest and most popular indexes to consider wind's influence on refrigeration [56]. This indicator has been frequently applied and modified in public weather forecasts [57], especially in nations with extremely cold climates. A workshop conducted online in 2000 due to decades of systematic Windchilla use served as the foundation for creating the Windchill program. On the opposite end of the spectrum, Thom's discomfort index (DI), also known as a temperature-humidity index (THI), is a well-liked empirical assessment for warm, humid conditions [58]. In the interim, urban designers developed an interest in thermal comfort to enhance space design. In what was known as the "Bioclimatic Chart," Olgyay [59] incorporated the impacts of many climatic components, including solar radiation data, which were to be employed for outdoor circumstances (Figure 4). The heat balance model of the human body used inside to determine thermal comfort levels was also updated by Penwarden [60] to include a term for solar radiation. Different garment insulation values were incorporated in the Olgyay chart [59], an improvement over earlier models. Two different comfort charts are provided for wandering in the sun and the shade. There are categories for merely sweating, comfortable, and slightly shivering, and the combined effects of sun and shade with air temperature, wind, and different garment levels may be investigated. Later, Arens and Bosselmann [61] offered further recommendations for comfort criterion. They put forth much effort to improve downtown San Francisco and Toronto.

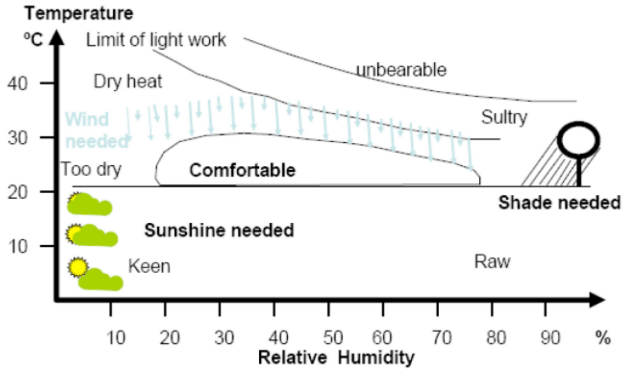

Figure 4. The Olgyay bioclimatic chart [59]

The Physiological Equivalent Temperature (PET), based on an energy balance model of human physiology, was one of the most widely used indices created for the outdoor setting [50]. Since PET utilizes °C as its unit, it is easier for experts other than biometeorologists to understand and is thus more commonly utilized. Since its creation, it has been widely used as a universal thermal index to evaluate thermal settings [62]. It has been utilized in modeling studies to assess how geometry and other design-related factors affect the comfort of outdoor spaces [46]. In contrast, Rayman and other software models for assessing outdoor thermal comfort conditions have included it as an index [63] and the three-dimensional ENVI-MET [64]. The fact that all thermal indices, including PET, are based on steady-state energy balance models of the human body is an essential limitation of most thermal indices. Thermal equilibrium is an uncommon occurrence for humans outside, nevertheless. Because of this, the steady-state method is inadequate [65]. In response, COST Action 730 created and released the UTCI, or Universal Thermal Comfort Index, in the summer of 2009 [49]. The dynamic 340-node model developed by Fiala [66] is the foundation of the UTCI, which enables estimations of the thermal status of various body sections. With numerous technologies that simulate the human body's anatomical, thermal, and physiological characteristics, we can now evaluate outdoor thermal comfort to differing degrees of sophistication. Nevertheless, we have removed people from their natural environment [48]. We are facing a similar, if not wider, divergence in the outdoor context, much like how studies in climate chambers alienated people from entire buildings, leading to the debate between conventional and adaptive thermal comfort conditions [67] and ultimately to adaptive comfort standards [55]. Such a discussion might be crucial when creating public places for sustainable urban settings with wider consequences for climate change [48]. In order to better comprehend the gap between actual and simulated data, we need to go beyond thermal physiology without minimizing the thermoregulatory system's role in obtaining thermal comfort in an outdoor setting. The living person is not a "closed system," as Cabanac [68] emphasizes, and behavioral, and other cognitive variables may improve our comprehension of the subject.

2.1.3 Surface UHI

Surface temperatures influence air temperatures indirectly but significantly in the long run. A part of the urban canopy layer influences temperatures at the micro-level. At temperatures ranging from 27 to 50°C (50 to 90°F), surfaces exposed to sunlight, such as concrete or asphalt, can become hotter than the surrounding air, whilst shaded areas maintain similar air temperatures. These warmer floors mainly contribute to night-time urban heating, creating heat and preventing the town from cooling. This type of UHI is present in the weather, particularly solar radiation, and it varies around the planet [69]. Additionally, because they cause sun exposure, the micro-scale location and street geometry elements have a significant impact. Using a remote sensing approach, the surface UHI data are frequently shown as thermal pictures [70].

2.1.4 Atmospheric UHI

Another phenomenon is a UHI in the atmosphere, which elevates air temperatures. Even slight variation exists between the atmospheric island's intensity and surface temperatures. The average difference in temperature between urban and rural areas is between 1.2 and 4.4 degrees (2 and 8 degrees Fahrenheit) [71]. It is the main reason urban regions produce warmer air than rural areas due to the spatial effect of UHI, which is a theoretical notion of UHIs. As a result, the UHI phenomenon is primarily determined by its atmospheric presence and is only influenced by surface temperatures [69]. The canopy and borders, components of the planetary limits, make up the two levels of any atmospheric UHI. Islands in the canopy layer, where humans reside, may be found in the lowest layer of the atmosphere from the Earth to its boundaries [69]. Locally, they boost the air's temperature in the streets or small areas. The street canyón, a deep, narrow city street that commonly experiences UHI, is a typical canopy layer occurrence [72]. The leading causes of this form of UHI include evapotranspiration, albedo change, construction materials, and urban planning [2]. Islands of constrained strata emerge at the mesoscale and impact whole cities or nearby metropolitan regions. The layer that stretches from the end of the canopy layer to where urban landscapes impact the atmosphere is known as the boundary layer [72]. The actual location is 2 kilometers above the horizon of the majority of nations. Essential aspects of UHIs include city layout, spatial geometry, wind and weather patterns, and urban energy budgets [2].

2.2 Urban heat island formation

To explain processes and ramifications at the national and local levels, we must first understand the urban climate. According to Landsberg [4], the urban climate is connected to global climatic changes rather than being a distinct phase. Geological circumstances, the troposphere, and the lower layers of the atmosphere all impact it. The synoptic or large-scale atmosphere regularly interacts with the urban setting and produces a variety of complicated and sluggish weather phenomena. An essential and significant process that regulates emission concentrations is the effect of temperature on wind cycles [73]. Climates in rural and urban areas change due to geography and terrain structure. Urban terrain is a heavily built, packed, and impermeable surface, whereas rural or agricultural lands are typically differentiated by vegetation, loose soil, and open space. Based on this distinction, Surface Heat Islands (SHIs), the first type of UHIs, are created. Atmospheric Heat Islands, the second group of UHIs, may be distinguished from SHIs (AHIs) [4].

2.2.1 Urban heat island; urbanization

In 1973, Oke [74] established the first connection between urbanisation, city size, and UHIs. He found a significant association between the population density (P) of 10 North American cities and the difference in urban-rural temperatures (T) using data and models from earlier studies. Urbanization and city size to UHI's is found using equation (1) [74].

$$\Delta T_{u-r(\max)} = 2.96 logP - 6.41 \quad (1)$$

Although this model is solely centered on the ideal situation of UHI, the topic of urbanization and UHIs was exceptionally helpful. It started a series of studies on the connection between temperature and the metropolis. Nearly fifty years later, the causes of UHI training in cities were examined and reported. Three critical aspects result from urbanization processes, albeit there is no consensus on their exact causes and actions:

2.2.1.1 The built environment

The move from rural to urban has various implications. With this in mind, there are two immediate effects. Second, when settlements expand their borders, the natural terrain is transformed into new built-up regions. One of the crucial regulators in surface ecosystems, evapotranspiration processes, is reduced by vegetation and natural soil deterioration [73]. The warmth of the surface of the trees and the plants fell, as did the shade [75]. The contemporary urban surface or materials, which collect heat rather than reflect it, serve as enhanced heat reservoirs. The material's thermal emittance, heat capacity, and Albedo cause this. The most important is "Albedo, a diminutive of the Latin word albus (white). After reflecting off a surface, the amount of radiation or light is transmitted into the atmosphere. The oil's thermal absorption, heat, and Albedo bring this on. It is the quantity of radiation or light that the Earth emits into space. The Latin word albus is where the word "albedos" comes from "(White) and are harsher [9].

2.2.1.2 The human activity

More residents are now affecting the urban landscape as cities become more considerable. An example is excess heat generated on a warm day by average air conditioning. Besides, people have waste heat in themselves, which results in higher air temperatures. These causes are called anthropogenic heating [5].

2.2.1.3 Urban geometry

Urban geometry is another aspect affecting the UHI. The density of the area, measured by the houses' scale and distance, influences the overall temperature, particularly during the night [76]. Urban geometry has three influences on the city's climate, according to Voogt [77]. First, concentrating solar radiation in areas of the building leads to more excellent absorption of solar radiation. Secondly, the Sky View Factor and radiation depletion are influenced by closely spaced houses. Third, population density impacts air-to-surface traffic, which decreases convective heat loss. Three aspects are part of urban energy, including the built environment and human interaction. There are specific criteria by which urban geometry interacts with UHI in particular:

Albedo changes [a]: Albedo refers to the overall percentage of solar energy a particular surface reflects [78]. The average reflectiveness time, angle, and spectrum on a specific surface or surface combined is what the word means, which can be interpreted in various ways. In other words, Albedo is the capacity of a surface to reflect solar radiation, which makes it an essential component in urban climates. To better comprehend different Albedos, Table 1 provides some common Albedos for various surfaces. We may assume that human surfaces that are dark have lower albedos than surfaces that are bright because dark surfaces receive less sunlight and generate more heat [73]. Connor is researching exactly how Albedo and urban surface temperatures are related. On the dark-colored surface, he saw that outlying neighborhoods had a higher average temperature. In conclusion, significantly darker materials and surfaces impacted by people result in decreased Albedo and heat gain [79].

Table 1. Examples of Albedo's for different surface types [79]

Asphalt	**0.05-0.10**
Concrete	0.10-0.30
Forest	0.15
Bare Soil	0.20-0.30
Brick	0.20-0.40
Green Gra	0.25
White Cement	0.78
Snow	0.85

Solar radiation/ sky view factor: Urban geometry frequently influences urban temperatures through solar Radiation and the Albedo. Based on Albedo and urban geometry, the sun's energy typically reflects, dissipates, and is absorbed in urban areas [70]. The difference between the two factors is how solar radiation contributes to the impact. Brief or visible light, which humans perceive as light, alters albedos. On the other hand, the consequences of urban geometry are susceptible to longwave or infrared radiation. Urban topography is essential, but the total solar radiation balance of absorbed heat through albedo adjustment prevails [80]. Longwave Radiation, usually rereleased at night into the atmosphere, may be contained in urban environments and materials during the day. Improving urban texture and the urban response contributes to stronger solar radiation absorption. Also, the radiative heat emission at night is disrupted because of the small open space. The urban canyon, a little street flanking significant buildings, is a well-known phenomenon of this dilemma. Although the high facilities produce shadows throughout the day, the radiation touching the soil is mirrored and retained in the materials several times. The heat is trapped, and these streets do not cool off at night because of the restricted entry into the open air [81]. The Sky View Factor frequently reflects the link between urban layout and thermal impacts (SVF). The SVF is an index representing the sky's visible surface [70]. A low SVF, for example, results in street heat capture and the formation of a street canyon. Giridharan explored the link between urban temperatures and the SVF after demonstrating significant relationships between night-time UHI and viewing variables in Hong Kong. Thus, the SVF Index is important in UHI because it measures the influence of urban geometry and solar radiation on urban temperatures [82].

Anthropogenic heat [Q_F]: The preceding section defined the heat created by human energy use, primarily by cars and energy use in buildings. This extra heat is thus the outcome of greater human mobility or production behavior. Oke [5] expresses the exact idea of anthropic heat as the following formula:

$$Q_F = Q_{FV} + Q_{FH} + Q_{FM} \quad (2)$$

The heat produced by automobiles, stationary sources (air conditioning), and metabolism are referred to as Q_{FV}, Q_{FH}, and Q_{FM}. Metabolism is the utilization of resources and the cost of the humans in formulation 3. Thus, elevated human behaviors lead to higher urban air temperatures in three distinct ways [80].

Sensible heat [H]: Sensible heat is the heat we experience due to surface-air differences [70]. Convection circles form when metropolitan areas heat the air above, removing the further temperature increase. However, population density also reduces convective heat loss. Mills [83] and Bottema [84] investigated the relationship between a surface-air exchange (or ventilation) and urban density. Figure 5 depicts how urban spatial patterns influence surface-air exchanges as a function of urban and raw material density (the standardized area percentage) and Z_0/h longitude. It teaches us that as a city's built-in density grows, so does its roughness, resulting in less airflow and lower convective heat loss (Figure 5). This is accomplished in the urban canopy layer, and the proportion of built-up regions is modified.

Evapotranspiration [λE]: The movement of moisture from the soil, plants, or trees to the atmosphere is known as evapotranspiration. It includes perspiration from plants and trees and water and solar evaporation. Areas are impacted by cooling [70] and assess power to deeper soil layers [85]. Moving from rural to urban settings has lessened this opportunity to cool down places. According to Bastiaanssen, who has researched evapotranspiration, it is a component of the surface's energy balance and is determined by other factors like soil or responsive heat [H]. This suggests that the system is overly intricate [86].

Thermal storage [G]: The usage of ground heat has not received as much research as other factors. In general, decreased solar reflectance in metropolitan locations improves soil heat storage. Recent research, however, has indicated that urban layout and certain building materials impact heat storage. In summary, thermal stocking and higher urban temperatures are the only effects attributed to the decreased reflection of urban materials [70].

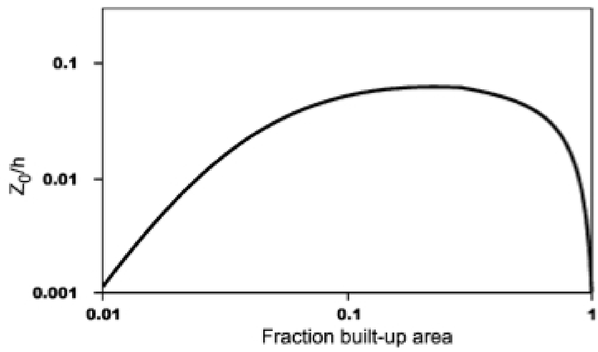

Figure 5. Convective heat loss mills [84]

3. Urban heat islands impact

The most well-acknowledged advantages of UHI mostly pertain to well-being. To maintain and safeguard the environment. National discussions on UHIs and their impact have resulted from recent heat waves that killed thousands of people. However, the effects on the water and energy market have recently received increasing attention. Although many US communities have dealt with these issues for years, the UHI has introduced new, challenging issues that require sufficient attention. This section will first go through the impacts of UHI on cities and the areas around them, starting with an increase in energy usage.

3.1 Energy

To keep you comfortable when temperatures rise, more cooling is needed. As a result, suburban neighborhoods and large office buildings use more power and switch to air conditioning and other sources of cold air. A significant factor affecting UHIs is the increase in energy use, which also affects a range of other occurrences. Energy shortages are generally caused by rising energy usage in the following sectors:

1. Energy production and potential shortages. This puts pressure on the electricity generated and provided during the heat wave. In order to maintain good energy sources for the coming decades, power output could thus be improved during warmer periods. Emerging technologies will also be introduced, and delivery and distribution will also increase. Nevertheless, the energy economy is another approach to this problem. That is one of the most significant issues with air pollution in cities nowadays due to global warming [87].

2. Increased power production, consumption, and carbon emissions from new fossil fuel combustion. The impact on public health and air quality will be discussed in the next section.

3. The increased use of water. Metropolitan primary energy sources continue to compress the thermodynamic cycle using much water [2].

4. Humans cause more heat pollution. Increase in human activity results in increased heat, known as anthropogenic heat. More anthropogenic heat is produced as a result of primary air cooling. This is a continuous circle since it is one of the causes of UHI. Without interference, this influence would merely enhance the overall impact of UHIs [8].

3.2 Heat stress

The European towns and people's uneasiness during the 2003 heat wave was made evident. The effects were considered in France, with minimal adaptation and public awareness. In the summer, 15,000 hospital admissions and fatalities were recorded [89]. The heatwave claimed the lives of over 35,000 people in Europe, which sparked several discussions regarding heatwaves, UHIs, and their effects at the national and international levels. Klinenberg offers a different illustration of how heat waves and UHIs might have an impact [90]. Heat waves and UHIs in cities have severe and significant health effects. Urban officials and politicians usually lack awareness of their predicament, which results in inadequate education and an underestimation of the thermal danger. Medically speaking, a person is in danger if they have heat stress, a condition in which their core body temperature rises significantly. Some symptoms are heat cramps, redness, and health hazards such as heat stroke [91]. As a result, heat waves and exhaustion threaten urban public health. Additionally, social and other variables raise the risk of heat stress. For instance, old and socially isolated persons are more vulnerable to heat waves than others. The United States Centre for Control and Prevention of Diseases (CDC) has published preventive guidance for personal health and safety on its website on these additional factors. According to the US Centers for Disease Control and Prevention (2009), the following are some of the hazards and susceptible groups:

1. Elderly people and kids who are not watched by or under control.
2. Individuals who are unobserved or uncontrolled and are socially or physically isolated.
3. A lack of preparedness and knowledge.
4. Insufficient hydration consumption, irrespective of the amount of activity.
5. Increasing heat quickly in cars or other vehicles.
6. Outdoor activities that are not regulated or watched

As a result, some groups of people and circumstances also exacerbate the hazards associated with metropolitan heat. Residents must be informed of the dangers of heat waves to shield themselves from the repercussions. Based on the knowledge a person may have access to, this is essentially a responsibility of the individual concerning heat stress [91].

3.3 Air quality

UHI has negative impacts on urban air quality, even though they are caused mainly by intense stress on public health. Higher temperatures increase energy requirements in urban settings, as this section addresses. Increased demand immediately correlates to increased oil output, which has the impact of raising fossil fuel carbon [70]. Smog is moreover frequently brought on by high temperatures. According to Heat Island Research Group studies, every degree of Fahrenheit beyond 70°F. Accidents involving smog have increased by 3%. Smog and previous pollutants harm the human body, causing low discomfort, severe breathing conditions, and even lung cancer [92].

3.4 Water resources

UHI's role in this situation is significant for four reasons: First, a general temperature increase impacts water resources in the area, increasing drought and reducing availability for the metropolis [2]. This deficiency impacts many areas, including public health, industry, climate efficiency, marine habitats, etc. Second, heat emission happens when precipitation strikes urban surfaces like buildings and floors. After that, the water temperature is automatically increased. The gross rise may reach 7 degrees Fahrenheit when it reaches the sewer. Following transit and deposition in the lakes, rivers, and streams, the elevated temperature will impact the existence and habitats of aquatic ecosystems [93]. Thirdly, a lack of clean water significantly impacts agricultural productivity, typically consuming 75% of a region's total water supply. With less water available, crops and yield suffer, and agricultural commodities' quality and output decrease. The Waterplan should end this and provide plenty of water for both urban and rural areas [94]. Fourth, in addition to the biological impacts of water quality, elevated temperatures directly impact the biosphere. Especially when natural settings undergo fast changes, natural species and ecosystems cannot adapt, which results in decreased exosomes and a loss of biological diversity. UHIs are hazardous to whole ecosystems and animals because they cause a considerable temperature spike over a certain period [89].

3.5 Economics

Anything used to be expensive. Calculating the dynamic evolution and composition of the UHI and its outcomes is more expensive. However, higher carbon dioxide and ozone levels are linked to more illnesses and higher hospital and healthcare costs. Furthermore, during periods of harsh weather, production and human activity decrease. For instance, outdoor work is affected by high temperatures and slows down during heat waves, especially building and maintenance. Taking corrective and mitigating action is also advantageous for the city [8].

4. Discussion: Urban Heat Islands Design Strategies

Adding such theoretical backgrounds gives the basis for UHI adaptation/mitigation. This section aims to conceptualize all potential urban planning and architecture policy initiatives in line with the study design. An outline of proposed potential approaches focused on scientific articles has been made here to accomplish this conceptualization.

4.1 Urban Forestry

The loss of vegetation restricts the process of evapotranspiration and the release of latent heat. As large-scale urban expansion patterns develop, this is one of the primary causes of the UHI effect. Therefore, conserving present biomass while planting new trees and plants is a clear action. Urban forestry increases the amount of evapotranspiration, the number of shadows it casts, and the amount of sunlight that may enter the canopy. Kurn et al. [95] and the US Environmental Protection Agency [70] estimated that woods could be up to 5°C [9°F]. Suburban neighborhoods containing plants and trees are 2-3°C [4-6°F] cooler than comparable non-green neighborhoods. Colder than open regions. Other research has also shown how vegetation lowers the urban temperature, including Yoshida [96] and Nabeshima [97].

4.2 Cool roofs

The roof is one of the two main factors influencing the urban Albedo. As was covered in the Albedo section, it affects the balance between solar energy absorption and reflection. By absorbing sunlight, darker surfaces may heat up to 82 °C (182 °F), which impacts air temperatures. On any given day, conventional roofs can be between 55 and 85°F [31-47°C] cooler than the air, according to considerable research on the efficiency of cool roofs by Konopacki et al., whereas cold roofs appear to settle at a temperature between 10 and 20°F (6-11°C) [98]. There are three main categories of cooling-down roofs: single-ply membranes, cool roof coatings, and biomass. The first and second types of cool roofs thus employ unique materials that change the solar radiation budget. The third type of roofing, called "green roofing," combines cool roofing with more unusual urban flora. Especially in large building projects and residential neighborhoods, cool and green roofs are extensively employed in the US.

4.3 Cool Pavement

Like cool roofs, heated flooring raises temperatures throughout the urban energy budget. Figure 6 illustrates a roadway with typical pavement and heating effects. The temperature of the surface is in the range of 140 to 150 °F. the temperature of the road (is 60-65°C). Traditional flooring keeps the heating fuel in place, raising the air and surface. Permeable floors are only one example of cutting-edge, cooler flooring developed through various research methods. When moisture is present, this flooring enables air, water, and water to move through the floor to avoid cooling [70]. Further research on cooling pavements is done by Haselbach [99] and Mallick [100], concentrating on the various options to reflect solar light as effectively as feasible.

Figure 6. The temperature of pavements [100]

4.4 Green Buildings

The term "green building" is somewhat ambiguous since it refers to various laws, regulations, standards, and building materials emphasizing long-lasting constructions. As a result, not all of these treatments were specifically designed to adjust to UHIs; other events impacted some. However, all green building activities were supervised by the US Green Building Council (USGBC), a nonprofit organization that promotes green buildings globally. The primary endeavor of this organization is The Leed, a world certification system. Green building solutions may be used in the design, construction, operations, and maintenance with the help of this accreditation [101].

5. Conclusion

Although there are several recommendations and standards for reducing the urban heat island, each city's circumstance is unique. In order to lessen the severity of the UHI, political decision-makers, legislators, or urban planners must implement several methods addressed in this research. However, the city's well-planned tree-planting initiative is its main tactic for reducing the severity of the UHI. The four rest tactics are impacted by increasing the awareness strategy. Without sufficient knowledge of the effects of the outdoor living environment on the enclosed environment and the extent to which it might jeopardise human comfort and health, appropriate levels of comprehension of land management and plant cover, roof cover and new materials, buildings and traffic activity strategies will not be attained. Political decision-makers, planners, and architects must put more effort and support into decreasing the UHI and lessening its impacts on the city. The general people must exert fresh and increased pressure on political decision-makers so that they are forced to accept the necessity of important new national and regional initiatives on urban sustainability without reservation. Planning and designing for the UHI of the city requires developing several techniques and rules that guarantee the cities stay vibrant and aesthetically built as planned. The city's sustainable, liveable, beautiful, and prosperous vision may be achieved using climate-responsive design principles.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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