BUILDINGS AND URBAN HEAT ISLAND: A REVIEW OF PLANNING MITIGATION METHODS AND LESSONS

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There is a nexus between urban heat, global warming, and climate change. One viewpoint, indeed consensus, in the literature by leading climate change experts is that, for several practical reasons, cities will be the battleground for combating climate change. Using the Urban Heat Island (UHI) phenomenon as one of various measures of how cities contribute to global warming and, ultimately, climate change, it is important to analyze the various methods by which cities combat this phenomenon, and to identify lessons that cities around the world can share with, or learn from, each other. The main question addressed in this research is, what specific planning methods are documented in the empirical and conceptual literature by which cities currently monitor and manage the UHI phenomenon, thereby making cities more sustainable and livable, and mitigating their negative impacts on climate change? This exploratory and theoretical research used the desktop method to answer the research question. The outcomes of this research would highlight extant UHI mitigation methods around the world, and lessons that cities can learn and share in combating climate change.

Keywords: UHI, Heat mitigation strategies; Climate change, Green roof, Green wall.

1 INTRODUCTION

Cities have been described as the hotbeds and battlegrounds for the fight against climate change for various reasons. The rapid increase in urban populations and the constrained availability of urban spaces have resulted in densely packed and high-density urban layouts in many cities (Ngarambe et al. 2021). The concentration of the global population and human activities within urban settings has diverse effects on the urban microclimate (Lowry 1977). Urban regions experience urban overheating, marked by elevated temperatures in comparison to the surrounding rural areas (Oke 1981). This phenomenon results from cities as paved islands that trap and emit heat. Labeled as urban heat islands (UHI), cities emit heat that warms the air and produces urban microclimates that, in turn, affect the macro or global climate. Existing studies show that urban regions are experiencing higher temperatures compared to rural areas due to various factors, including human-generated heat, extensive thermal mass from buildings and paved surfaces, and the low presence of vegetation in densely populated urban areas. The UHI effect is a significant concern because of its adverse impacts on society, the environment, and the economy. Over time, cities have adopted various initiatives to mitigate and adapt to the impacts of UHI. Various studies have presented different UHI mitigation strategies (UHIMS) and their levels of effectiveness.
Nevertheless, this research contends that despite the growing attention to this issue, there is evidence that the problems of UHI remain formidable, thus raising questions about the efficacy of extant mitigation methods, and/or the need for new and more innovative methods. The paper reviews the academic and empirical literature and summarizes specific urban approaches, systems, or procedures to mitigate cities’ negative impacts on UHI and by extension on climate change. The main research question addressed in this study is, what specific methods are documented in the literature by which cities currently monitor and manage the UHI phenomenon, thereby making cities more sustainable and livable, and mitigating their negative impacts on climate change? Some of the existing UHIMS are briefly reviewed below.

Across the world, various UHIMS are being implemented by governments at all levels. Among the mitigation methods in use by cities today are the utilization of thermally massive building materials, complex urban morphology, urban surfaces with low reflectivity (albedo), complex urban structures, the harnessing of waste heat, and limited vegetation density. (Kim et al. 2018, Li and Zhou 2019, Liu and Morawska 2020). Other strategies of UHIM are also in use including water bodies, vegetation, and cool materials. Ideally, these strategies are implemented to effectively reduce ambient or surface temperatures (Oke 1988, Santamouris and Kolokotsa 2016). Yet, the strategies are not necessarily effective due to the constraints posed by the expansion of city skylines and limited urban spaces. For instance, the impact of green and cool roofs may be negligible at street level if the buildings exceed ten floors in height (Santamouris and Kolokotsa 2016). In addition, as cities become increasingly densified, there is limited room for vegetation and water bodies to be incorporated (Qi et al. 2019). Redesigning and modifying existing urban areas to mitigate UHI may also be challenging in the short term (Qi et al. 2019). As urban populations continue to grow, the implementation of these UHIMS will face even greater challenges, especially considering the ongoing urban consolidation. Therefore, in addition to focusing on water bodies, vegetation, and agricultural lands in the context of land use and land cover (LULC), buildings should be given priority as the main sector for UHIM. They occupy the largest proportion of urban land and are a significant contributor to higher local temperatures (He et al. 2019, Stewart and Oke 2012). Therefore, buildings should be modified to deter rather than facilitate heat emission.

2 METHODOLOGY

This research used the desktop and evidence-based research methods to collect the information needed to review the effects of various planning strategies to counteract or mitigate UHI effects in cities. The main objective of the strategies is to reduce both energy consumption and greenhouse gas (GHG) emissions in cities. The research theme is multidisciplinary; therefore, data was obtained from databases of different disciplines. Over 150 scholarly articles were reviewed from the multidisciplinary literature that spans 4 particular fields, namely, architecture, civil engineering, urban planning and design, and construction. This is to demonstrate the robust and the diverse perspectives and insights on the research subject. The ‘planning’ nature or common denominator of the strategies reviewed from diverse disciplines resulted from the key search terms used by the researcher.

3 UHI MITIGATION STRATEGIES

Many studies have investigated numerous factors that play a role in the creation and intensification of the UHI (Khamchiangta and Dhakal 2019, Palme et al. 2016, Xiao et al. 2018). To bring focus to the staccato of the factors, this research developed an analytical framework to identify, classify,
and organize the various factors. For the purpose of this review, the clusters of categories were developed. The resultant clusters are discussed below.

3.1 Building Envelope

Building envelope consists of three main elements, namely, cool building envelopes, green roofs, and green walls. Building envelope is the most exterior part of a building. The exterior, particularly modifications to it, plays a pivotal role in mitigating the singular effect they have on the urban microclimate. These modifications have the potential to decrease the amount of heat absorbed by structures and subsequently reduce the heat released into their surrounding environment.

**Cool Building Envelopes:** Cool buildings materials, also known as highly reflective envelopes, have been extensively researched and recognized as effective means of reducing both building thermal loads and ambient air temperatures (Di Giuseppe et al. 2017). The use of cool paints with high solar reflectance and thermal emittance for roofs has been explored in various studies (Akbari et al. 2016, Yuan et al. 2016). These paints offer the potential for energy and cost savings in cooling spaces by utilizing materials with medium to high solar reflectance and excellent thermal emittance. Implementing cool materials on building envelopes presents a relatively straightforward and cost-effective solution to combat the challenges of UHI and global warming, particularly when compared to costly retrofits focused on improving the thermal insulation of the building envelope.

**Green Roofs:** Green roofs, also known as "living roofs" or "roof gardens," offer several benefits such as improved roof insulation, reduced cooling load for buildings during hot summers, and maintaining lower outdoor air temperatures in their vicinity (Wang et al. 2022). While green roofs have a higher albedo compared to conventional dark roofs, their cooling effects are primarily attributed to the role of vegetation in capturing sunlight and facilitating evapotranspiration, which releases stored water into the atmosphere and helps in lowering urban temperatures (Rosenzweig et al. 2006). These types of roofs are especially effective in cooling areas affected by extensive impervious pavements, including rooftops, which contribute to a city's overall impervious surface area (Coseo and Larsen 2014). The diverse physical and physiological characteristics of vegetation on green roofs enable cities to benefit from various ecosystem services beyond mitigating urban heat island effects, such as stormwater management, roof preservation, biodiversity support, and aesthetic enhancement (Getter and Rowe 2006).

**Green Walls:** Green walls, also known as vertical greener systems (VGS), encompass various systems that enable greening vertical surfaces of buildings, including façades, walls, blind walls, partition walls, etc., by utilizing a selection of plant species (Coma et al. 2017). Green walls can be broadly categorized into two main types: green façades and living walls (Manso and Castro-Gomes 2015). Green façades typically exhibit slower surface coverage and involve a limited range of plant species. Conversely, living walls, whether modular or continuous, allow for more uniform vegetation growth across the surface and the use of diverse plant varieties (Perini et al. 2013). The implementation of green walls serves two primary purposes: firstly, they enhance the building's aesthetic appeal and provide shading, and secondly, they contribute to creating a microclimate in the vicinity of the building. These thermal regulations are primarily facilitated by the shading effect on the building's façade, water transpiration through the leaves of the plants, and water loss from the substrate through evaporation. Both green roofs and green walls exemplify what Eric Fromm (Fromm 1964) coined the term ‘biophilia’ for. In essence, biophilic initiatives are those that bring nature directly to and into buildings.
3.2 Urban Geometry Optimization

The open spaces within urban environments are influenced by various geometrical factors related to the layout and morphology of buildings. These factors play a crucial role in determining the shape, size, and orientation of these open spaces and create the boundary between urban structures and the surrounding open areas. Consequently, these urban geometrical factors have a significant impact on the urban microclimate, as they influence the absorption of solar radiation, the wind conditions, and the heat transfer between buildings and the outdoor environment (Andreou 2014). From the existing literature, three key urban geometry optimization factors have been identified for further investigation.

Sky View Factor (SVF): SVF serves as an important indicator for evaluating the building layout and density within urban areas (Wei et al. 2016). A smaller SVF value indicates denser building coverage, resulting in reduced solar radiation reaching the ground (Oke 1988). Numerous studies have been conducted to investigate the impact of SVF on local thermal conditions. The findings consistently indicate that lower SVF values are associated with lower daytime temperatures and higher nighttime temperatures in urban canyon regions (Svensson 2004). This can be attributed to low SVF canyons blocking solar radiation, leading to reduced net solar income during the day and subsequently lower air temperatures in urban canyons. Conversely, during nighttime, low SVF hinders the escape of long-wave radiation from the ground surface, slowing down the cooling process of the urban canyons and resulting in higher nighttime air temperatures (Givoni 1998).

Height-to-Width (H/W) Ratio: H/W ratio, representing the height of a building divided by the width of a canyon, plays a significant role in indicating the openness of a street (Bakarman & Chang, 2015). Street canyon refers to the urban street structure where buildings are continuously aligned on both sides of the street, forming basic units of the urban layout (Karimimoshaver et al. 2021). Street canyons can be broadly categorized into two groups: shallow canyons with an aspect ratio lower than 0.5, and deep canyons with an aspect ratio larger than 2. Numerous studies have demonstrated that a higher H/W ratio is associated with lower air temperature and ground surface temperature within street canyons (Bakarman and Chang 2015, Chen et al. 2012, Li et al. 2020).

Orientation of Street Canyons: In addition to SVF and H/W ratio, street orientation significantly influences local solar radiation and wind conditions. Numerous studies have highlighted the combined impact of street orientation and H/W ratio on the thermal environment within streets. For N/S oriented streets, a higher H/W ratio exceeding 0.8 resulted in a more comfortable outdoor thermal environment, while for E/W oriented streets, increasing the H/W ratio had limited effects on thermal environment improvement. In the context of temperate climates, finding an optimal canyon orientation for UHI mitigation proves challenging due to the conflicting requirements of hot and cold seasons (De and Mukherjee 2018). Therefore, it is advisable to consider indoor and outdoor conditions, urban characteristics, and climate while designing street orientations (Aleksandrowicz et al. 2017).

4 IMPLICATIONS OF FINDINGS

A foremost implication of the findings of this review is the affirmation that there are practical, creative, and effective climate change mitigation and adaption initiatives that cities are currently undertaking or implementing. Secondly, cities across the world should build on effective initiatives, share, and cross-pollinate ideas about effective initiatives. Thirdly, the review highlights the need and urgency to continuously engage urban and climate experts, scientists and practitioners in research, experiments and discourse that help to formulate creative and feasible climate change mitigation and adaptation strategies. The climate mitigation and adaptation measures presented in this review are all nature-based or nature-related. The paper acknowledges
that there is various other initiative in the literature that are technological, educational, and economic in nature. The review posits that the relationship among all initiatives must be complementary and mutually reinforcing. The latest IPCC report of 2022 clearly specified urban planning as one of the focus areas for climate change mitigation and adaptation. This review presented impeccable evidence from the robust multidisciplinary literature to support the IPCC’s position and prescription. For the reasons advanced in this review, cities are UHI that increasingly pose an existential threat to humans, the environment, the economy and to life on planet earth. Anthropogenic activities, way above and beyond stochastic events, are concentrated in cities, thus causing cities to be the climate change risk and danger they are. For this reason, this review agrees with the consensus in the literature, and justified that cities should be at the forefront of combatting climate change.

5 CONCLUSION

A widely held view in the literature was reiterated in this review, that cities are a major cause of climate change, and they must be relentless in formulating and implementing UHI mitigation initiatives. The review briefly discussed key methods that cities across the world implement to mitigate UHI effects. Extant discourse of these initiatives debates the effectiveness of the methods, and how adoptable or adaptable the methods are by cities seeking mitigation models and benchmarks. The literature reveals a notable absence of a universally accepted classification system for UHIM measures, along with a lack of explicit selection criteria guiding the components of various classification systems discussed in this review. The successful implementation of mitigation measures relies on consistent and determined actions supported by governments. As an applied science, UHIM research is particularly attuned to the significant requirements of municipal authorities, striving to offer practical solutions to the challenges of UHIM as perceived by stakeholders. By addressing these challenges with concrete answers, researchers aim to effectively combat the urban heat island phenomenon and create more sustainable and livable urban environments. While this review only outlined current methods documented in the empirical and conceptual literature by which cities currently monitor and manage the UHI, this review acknowledges that there are various critical aspects of the UHI challenge that policy makers and researchers must formulate mitigation initiatives for. Research into UHI and mitigation measures must keep up with the ferocity of climate change in order to avert the calamities that climate change portends for human civilization.

References


