

# Climate change mitigation: a case for innovative tools to regulate building heat emission in cities

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## Abstract

**Purpose** – This paper contends that, over time, urban areas contribute significantly to rising temperatures at the scales of both micro and macro climates. Building structures are identified in the literature as a primary source of urban heat generation. This paper aims to focus solely on the physical aspects of buildings, excluding operational functions and user amenities that account for heat absorption and emission by building structures. Currently, no city incorporates the propensity of buildings to emit heat as a criterion for building approval. Arguing that regulating this criterion can help mitigate urban heat, this paper addresses the pivotal question: What compelling case exists for implementing a diagnostic and regulatory framework or tool to assist cities in approving buildings that emit less heat?

**Design/methodology/approach** – This research used the desktop research and evidence-based methods to source information to rationalize the need for an innovative regulatory tool that would enable cities to approve buildings with reduced heat emissions. Such a tool would complement existing climate change mitigation green building strategies in urban areas.

**Findings** – Through a systematic literature review, this research identified four main themes influencing urban heat from buildings: green infrastructure, building envelope, materials and urban morphology. Despite extensive scholarly discussion of these factors, a critical gap remains about their integration into systematic diagnostic and regulatory frameworks or tools for the approval of low-heat-emission buildings.

**Practical implications** – The findings underscore the necessity for governments to combine both technological and policy initiatives to mitigate climate change causes and impacts. By integrating tools that promote low-heat-emission buildings into regulatory frameworks, cities can significantly enhance their sustainability efforts.

**Originality/value** – This research contributes by highlighting the urgent need for cities to adopt proactive regulatory measures in climate change mitigation, specifically focusing on reducing heat emissions from buildings.

**Keywords** Climate change, Mitigation, Urban heat island (UHI), Building permit

**Paper type** Research paper



## 1. Introduction

Urbanization is a major cause of rapid physical, economic and socio-demographic changes in cities. These changes have contributed directly and/or indirectly to urban climate change, as this

paper will show. Rapid population expansion, combined with extensive energy usage, is bound to exert an unfavorable impact on climate change as a result of human-caused greenhouse gas (GHG) emissions (IPCC, 2007). Climate change currently stands as one of the most pressing dilemmas confronting humanity. Escalated GHG emissions lead to diverse detrimental environmental consequences, encompassing alarming global temperatures, diminishing ice masses, warming oceans, heightened sea levels, occurrences of severe weather and ocean acidification (Change, 2018). Earlier in 2018, the Intergovernmental Panel on Climate Change (IPCC) released a specialized report regarding the global temperature escalation of 1.5°C above pre-industrial levels. The report underscored that mean global temperatures have risen by approximately 1°C since the pre-industrial epoch and that human-induced warming is contributing approximately 0.2°C to global mean temperatures each decade (Tollefson, 2018).

The potential risk of human activities associated with the generation of GHG that leads to climate change increases as human settlements grow and human activities intensify. In this sense, urban expansion plays a role in driving climate change across various levels (Susca *et al.*, 2022). Currently, there is a swift and intricate rise in urban population due to the migration of individuals from rural regions to urban centers (Madlener and Sunak, 2011), along with other causes, such as immigration, natural birth increase and economic pursuits. In cities, people and their activities are “housed” in structures built for designated land-use purposes. The clustering of people, activities and structures in cities impacts urban heat balance. Due to changes in this equilibrium, densely developed urban regions experience higher air temperatures compared to the adjacent rural areas. This occurrence is referred to as the urban heat island (UHI) effect (Oke, 1988). It is an extensively studied phenomenon, and when its consequences intermingle with those of climate change, they can notably influence the thermal environment of urban areas (Phelan *et al.*, 2015). Cities in warm climates tend to be more affected by UHI (Kleerekoper *et al.*, 2012; Li *et al.*, 2019; Martilli *et al.*, 2020; Santamouris, 2014b). Forecasts indicate that the UHI effects are expected to exacerbate in the forthcoming decades as a consequence of urbanization (Koomen and Diogo, 2017). The combined impacts stemming from both climate change and UHI are anticipated to exert a significant influence on local climatic conditions. UHI magnifies the risks and vulnerabilities associated with climate change in urban regions, particularly concerning the rise in temperatures and GHG emissions (Erell *et al.*, 2012; Nguyen *et al.*, 2022). This alteration in the equilibrium between the localized climate and the constructed environment underscores the heightened demand for enhancements in the energy efficiency of pre-existing buildings.

Urgent and proactive actions are imperative to tackle the UHI phenomenon cost-effectively. Studies have identified various causes of UHI, e.g. anthropogenic heat, substantial thermal mass in buildings and paved surfaces, restricted evapotranspiration, low wind patterns and air pollution. To mitigate UHI effects, a combination of approaches has been advocated, e.g. integrating urban green spaces, incorporating water bodies and using cool materials (Aleksandrowicz *et al.*, 2017; Fahed *et al.*, 2020). These tactics ideally demonstrate efficacy in curbing ambient or surface temperatures (Oke, 1988). Nonetheless, the viability of these techniques can be hindered due to challenges posed by city skyline restrictions, limited urban space availability and the existing layout of urban structures. For example, both green and cool roofs might not substantially impact street-level temperatures if buildings exceed ten floors in height (Santamouris *et al.*, 2017). The growing density of cities often results in insufficient space for vegetation and water bodies. Additionally, making significant changes to existing urban structures may be challenging to accomplish within a short timeframe (Qi *et al.*, 2019). Visibly missing from these tactics, and of interest in this paper, is a “tool” to regulate the heat emitted by building structures.

Besides the existing initiatives documented in the literature to mitigate UHI effects, this paper opines that land use, building regulation and construction management initiatives need to be explored by researchers. Buildings cover a substantial portion of urban land and stand

as a primary driver of elevated local temperatures (Zhou and Chen, 2018). In the future, as building density increases, the influence of buildings on UHI is projected to increase. Therefore, it is crucial to address the role of buildings in UHI and transform them into barriers rather than contributors to urban warming, thus offering opportunities for UHI mitigation (UHIM). It is of paramount importance to tackle the role of buildings in UHI and reshape them from being contributors to urban warming into elements that mitigate such warming, thereby creating avenues for effective UHIMS. This paper observed that, currently, the “best” tools that cities use to address the energy use and carbon emissions of buildings are the GBRs. The most popular examples of the systems are Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM), Haute Qualité Environnementale (HQE), Green Star, Estidama, etc. These systems are necessary, but they must be complemented by the kind of preventive and cost-effective framework for which a case is made in this paper.

A major contention in this paper is that cities generate heat that causes micro and macro climates to heat up over time. In cities, specific sources of heat generation can be identified. One major source that has been indicted in the literature is building structures. Various aspects and elements of buildings are known to produce heat, including urban surfaces with low reflectivity (albedo), intricate urban morphology, waste heat emissions and a scarcity of vegetation. For this paper, the interest and focus are in and on the physical structure of buildings, and not their functions and user-added operating amenities. One main question is addressed in this paper: What compelling case can be made for a diagnostic and regulatory framework or tool help cities to permit or approve buildings that would produce less heat? This paper argues that to combat the UHI, there is a need to establish a diagnostic and regulatory framework that should be tailored to the specific needs and challenges of each city. This framework would complement existing initiatives like the GBRs, designed to address GHG emissions in urban areas. Essentially, this framework positions cities to address the issue of heat generation from building structures at its source by establishing construction guidelines that reduce heat emissions into urban surroundings. Unlike many technology-driven approaches, this framework would prioritize user-friendliness, adaptability to local contexts and cost-effectiveness in its implementation. This research adopts the desktop and evidence-based techniques to answer the research question and achieve the research aim. 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.

## 2. Methodology

The review methodology used in this paper aligns with Tranfield *et al.*'s systematic review guidelines (Tranfield *et al.*, 2003). The initial stage involves the review's planning, which commences with the conduction of semi-structured interviews involving seven subject matter experts (SMEs). Interviews were conducted with seven SMEs in the fields of architecture, engineering and construction (AEC) from diverse organizations. Two of the experts are civil engineers, four are architect engineers and one is a construction manager. The interview focused on current practices, challenges and opportunities of building construction and urban microclimate. All the experts confirmed that there is currently no diagnostic and regulatory framework or tool in the extant literature and in practice that help cities to permit or approve buildings that would produce less heat. Furthermore, the SMEs highlighted that heat mitigation measures are intricately woven into an extensive array of strategies and operational undertakings by relevant agencies. They pointed out that none of the cities they mentioned have a distinct plan solely dedicated to addressing urban heat mitigation. However, in each city, there is at least one heat-mitigation strategy seamlessly integrated into other ongoing initiatives. Occasionally, such strategies are inconspicuously

integrated. As an illustration, certain building codes function to alleviate the UHI effect, irrespective of whether this is the city's explicit objective. These suggestions have served as a catalyst for the authors to pinpoint the research issue, primarily centered around creating a compelling case for a diagnostic and regulatory framework or tool help cities to permit or approve buildings that would produce less heat.

The second phase involves conducting a review, during which literature articles were searched using various databases like Google Scholar, IEEE, Scopus, Wiley Online Library and Science Direct. The search was performed using topic and title keywords, carefully developed to ensure relevant articles were covered while minimizing irrelevant search results. **Table 1** presents the combinations of keywords used for this systematic literature review on UHIM measures. No specific timeframe was established, as the objective was to comprehensively explore a wide spectrum of literature pertaining to UHIMS. The research process included terms such as "global warming," "climate change," "urbanization," "built environment" and "building construction." Initially, a total of 6,535 articles were identified. Then, a meticulous exclusion process was undertaken to eliminate unsuitable papers and further enhance the precision of the search. The author established selection criteria that justified the inclusion or elimination of each record, based on the review's stated purpose. Since some articles are indexed in multiple databases, duplicates were identified and removed through data cleaning. Keywords and abstracts were meticulously evaluated to narrow down potentially pertinent articles, and their full texts were scrupulously scrutinized. This included cross-referencing their references to ensure valuable contributions were not omitted. Following the completion of all data refinement procedures, a cumulative total of 98 articles remained in the data set. **Figure 1** describes the search and selection process.

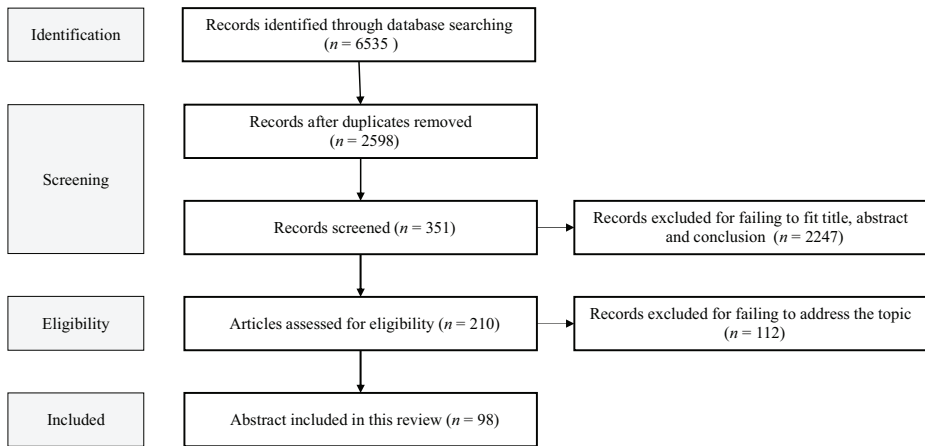
The third and final stage involves sharing the outcomes, which entails a thorough evaluation of the scrutinized studies, identification of research gaps and formulation of recommendations for forthcoming research endeavors. Subsequent sections offer a condensed overview of the discoveries, aimed at addressing the research inquiries.

### 3. Discussion of identified literature

The literature on the concepts covered in this research is vast and cuts across various fields of research and practice. As a result, definitions, discussions and applications of the concepts

**Table 1.** The standards used to choose publications for inclusion in this research review

Selection criterion	Description
Keywords	"Urban heat island," "UHI mitigation," "global warming," "climate change," "urbanization," "built environment" and "building construction," "urban morphology," "urban geometry," "cool materials"
Document type	Academic papers published in journals, conference proceedings, book chapters
Peer-review status	Priority was accorded peer-reviewed documents, then credible gray literature sources were used, e.g. monographs and empirical research publications by reputable independent research and policy institutes, organizations or consultancies
Database websites	Google Scholar, Scopus, IEEE, Wiley Online Library and Science Direct
Language	English
Publication date range	No time limit was considered



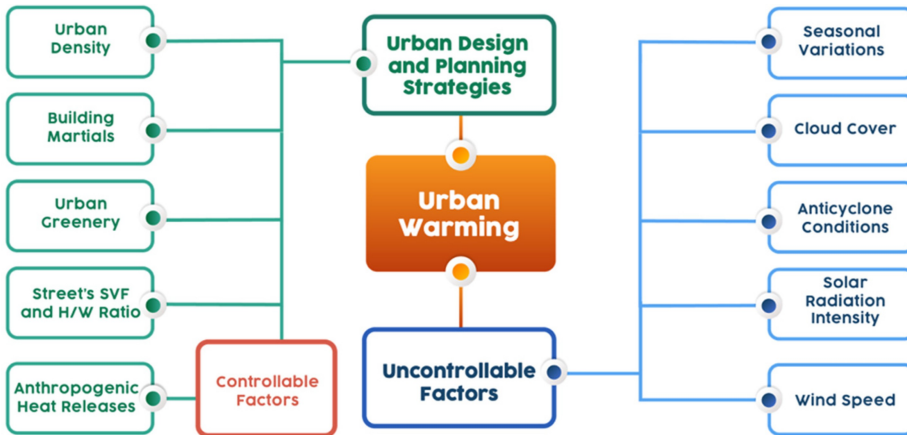
**Figure 1.** The search and selection process

tend to be discipline-specific and sometimes conflicting or contradictory. The review of the literature in this section draws from various relevant sources. The interface between the literature and the aim of this study is highlighted. The rest of the section is organized as follows. First, this section starts with an in-depth illustration of the factors and that contribute to UHI. Next, it gives a detailed overview about the UHIM strategies identified in previous studies to address the new challenges of the urban microclimate (UMC) to mitigate the adverse impacts of the built environment. Following that, this section elaborates on the key challenges that hinder the implementation of UHIMS. Finally, the section provides an overview of the identified research gaps derived from the analyzed literature.

### 3.1 Factors affecting urban heat island intensity

The main objective of this research is to review, identify and examine current UHIMS rather than the factors that cause UHI. Hence, this section offers a comprehensive outline of the factors related to the built environment that may increase urban temperatures stemmed from the findings from the literature. The escalating impact of rapid urbanization, characterized by heightened construction and alterations in land usage, has been acknowledged as a significant driver of UHI (Sun *et al.*, 2019; Cao *et al.*, 2020; Lima *et al.*, 2019). Numerous studies have underscored the escalating urban density, expanded paving of urban surfaces and the gradual sprawl of urban areas into their surroundings (Lai *et al.*, 2018; Lai *et al.*, 2018; Herath *et al.*, 2021). Forecasts by the United Nations project a global population rise to 9.7 billion by 2050 and 10.4 billion by 2100 (United Nations, 2022), inevitably intensifying the UHI phenomenon. As population figures surge, the expansion and extension of urban areas become inescapable. Consequently, this section facilitates an enhanced comprehension of UHI and its causative factors, serving as a foundation for forthcoming climate mitigation endeavors and the pursuit of urban sustainability (Shen *et al.*, 2023).

There are various variables that contribute to UHI. They can be categorized into two groups: controllable factors and uncontrollable factors, as illustrated in Figure 2. The uncontrollable factors, also known as temporary effect variables, encompass climate-related elements independent of human presence or actions. These factors encompass climatic zone, seasonal variations, diurnal timing and wind conditions (Rizwan *et al.*, 2008). The



**Figure 2.** Factors affecting UHI

Source: Author's own work

controllable factors, also known as permanent effect variables, include built and anthropogenic factors such as vegetation cover, water bodies, building material, sky view factor and anthropogenic heat sources (Rizwan *et al.*, 2008; Kim *et al.*, 2018). There are many other controllable factors, including urban population through population distribution and human activities (Yue *et al.*, 2019). Table 2 summarizes the most influential built environmental factors found in the literature into two categories: materials and urban morphology.

### 3.2 Urban heat island mitigation strategies

Over the past few decades, substantial efforts have been undertaken to formulate approaches aimed at alleviating the detrimental consequences of UHI in urban areas. Gaining a comprehensive comprehension of these mitigation techniques and strategies is imperative to effectively tackle the emerging challenges posed by UMC. Moreover, identifying the resources potentially designated for mitigating the adverse ramifications of the constructed environment is of paramount importance. Numerous research studies have delved into an array of factors and urban characteristics that contribute to the creation and augmentation of UHI. However, this research argues that the factors in the literature and some of them do not have any relevance to this research. Therefore, this research has developed an analytical framework to cluster the built environment UHIMS. This research has identified five themes that are discussed in detail below, which are green infrastructure, building envelope, materials, urban morphology and blue infrastructure.

**3.2.1 Green infrastructure.** Green infrastructure in urban environments plays a crucial role in alleviating the adverse effects mentioned above. By establishing cooling buffer zones, where green spaces provide shade, urban areas can be cooler compared to sun-exposed areas affected by direct solar radiation (Marando *et al.*, 2022). These cooler zones contribute to improved microclimatic conditions and promote human health (Georgi and Dimitriou, 2010). Green infrastructure is effective in reducing maximum urban air temperatures and minimizing temperature fluctuations (Jayasooriya *et al.*, 2017). Studies have shown that green infrastructure not only mitigates UHI but also reduces energy consumption for cooling

**Table 2.** Key UHI contributors in urban context

Contributing factors	How to contribute	(Farhadi et al., 2019)	(Yuan et al., 2017)	(Lin et al., 2020)	(Lin and Morawska, 2020)	(Gunawardena et al., 2017)	(Vujovic et al., 2021)	(Uljpiani, 2018)	(Yin et al., 2018)	(Dinda and Chatterjee, 2022)	(Zhou and Chen, 2018)
<i>Materials</i>											
Low albedo	Less reflected radiation	X	X	X	X	X	X	X	X	X	X
Low emissivity	Less emitted radiation			X	X	X	X	X	X	X	X
Low conductivity	Less transferred heat			X	X	X	X	X	X	X	X
High thermal capacity	More absorbed heat				X	X	X	X	X	X	X
Dark color	More absorbed radiation	X	X	X	X	X	X	X	X	X	X
Limited access to plants, water	Less evaporative cooling	X	X				X				X
Wind-sheltered locations	Little turbulence					X	X	X	X	X	X
Surface roughness	Less reflected solar heat			X	X	X	X	X	X	X	X
<i>Urban morphology</i>											
Limited SVF	Increased net heat storage within buildings	X	X	X	X		X	X	X	X	X
Higher AR – H/W ratio	Less air flow and more trapped solar radiation		X	X	X		X	X	X	X	X
Street orientation	Limited amount of solar access and wind speed	X	X	X	X		X	X	X	X	X
Green/water bodies coverage ratio	Less cooled area		X	X	X	X	X	X	X	X	X
Density	More GHG emissions	X	X	X	X	X	X	X	X	X	X

buildings during the summer. This approach also concurrently addresses temperature fluctuations resulting from building materials (Gago *et al.*, 2013).

**3.2.2 Green roofs.** The substantial influence of green roofs in mitigating UHI phenomenon has been extensively examined in scholarly works. This is attributed to their capacity to lower both air and surface temperatures within urban areas by offering shading, extracting heat from the atmosphere and decreasing the temperature of roof surfaces (e.g. Susca, 2019; Yang *et al.*, 2018; Jamei *et al.*, 2021; Razzaghmanesh *et al.*, 2016). Furthermore, green roofs offer more than just a direct contribution to urban cooling by decreasing air and surface temperatures within canopy and rooftop environments. They also result in a noteworthy decrease in the cooling load demanded by buildings, a pivotal aspect in addressing urban overheating challenges. The cooling impact of green roofs displays notable variations contingent upon their extent of coverage and the time at which measurements are taken. An investigation carried out in Taipei scrutinized temperature reductions across a 2.5 m roof span, revealing that the cooling effect is more pronounced during daytime than at other periods of the day.

In a comparable study, green roofs exhibited an average reduction of 0.26°C in air temperature when contrasted with conventional black roofs (Sun *et al.*, 2012). Pertinent literature has additionally demonstrated that green roofs elevate the albedo of urban areas and curtail the UHI effect (e.g. Knaus and Haase, 2020; Santamouris, 2014a; Imran *et al.*, 2018). Research has highlighted that the albedo of green roofs spans from 0.7 to 0.85, a range significantly surpassing the albedo values of conventional bitumen or gravel roofs, which typically range from 0.1 to 0.2 (Berardi *et al.*, 2014).

The influence of green roofs on cooling for pedestrians remains a topic with unresolved conclusions, and the outcomes concerning the role of green roofs in alleviating UHI at the pedestrian level present conflicting results. For instance, a study carried out in Tokyo, Japan, revealed that expansive green roofs on medium- and high-rise buildings offer limited cooling effects for pedestrians (Chen *et al.*, 2009). Conversely, a comparable study carried out in Hong Kong revealed that green roofs implemented on high-rise buildings yield a cooling effect at the pedestrian level, amounting to a maximum of 0.12°C (Ng *et al.*, 2012). Other research has indicated that the cooling effect diminishes as the vertical separation between the roof and ground expands. Although green roofs display a discernible cooling effect in low-rise regions, their contribution to cooling at the pedestrian level is considerably constrained (Berardi, 2016; Zölch *et al.*, 2016).

Research findings have also underscored the significance of the shape, species and biomass arrangement of plants in determining the cooling effect of green roofs (Berardi *et al.*, 2014; Jim and Tsang, 2011). In China, a study used simulations to ascertain the most effective plant configuration for green roofs within distinct climate zones. The study's outcomes highlighted that in regions primarily influenced by cooling requirements, plants characterized by a substantial leaf area index (LAI) wield a pivotal impact on the thermal efficacy of green roofs (Zeng *et al.*, 2017).

Additional research has documented adverse repercussions of green roofs in tropical environments. For instance, within such regions, green roofs could exhibit nearly tenfold elevated levels of sediment and nutrient concentrations in stormwater runoff when contrasted with conventional bare roofs (Chen and Kang, 2016). Furthermore, the anticipated reductions in runoff from green roofs in tropical areas do not materialize as significantly due to the influence of the substantial rainfall levels, as both retention and detention mechanisms are affected by the heightened precipitation characteristic of these regions. Green roofs, particularly within tropical climates, demand rigorous maintenance to attain optimal cooling

effects within urban settings; otherwise, they can transform into sources of pollution in hot and humid cities (Hashemi *et al.*, 2015; Vijayaraghavan, 2016).

3.2.3 *Vertical greening systems.* Another category of green infrastructure is represented by vertical greening systems (VGS). Extensive literature presents diverse definitions encompassing various VGS types, leading to occasional perplexity and misconceptions when categorizing systems and their constituent elements. Frequently used descriptors include “green wall” (Manso and Castro-Gomes, 2015; Susca *et al.*, 2022), “vertical greening system,” “vertical greenery system” or “green vertical system” (Medl *et al.*, 2017; Price *et al.*, 2015; Taher *et al.*, 2019). Moreover, green façades are alternatively referred to as “façade greening” (Pérez *et al.*, 2017; Sheweka and Mohamed, 2012), while “vertical garden” (Manso and Castro-Gomes, 2015; Weinmaster, 2009) and “living walls” (Charoenkit and Yiemwattana, 2016; Shafiee *et al.*, 2020) are prevalent terminologies for designating green walls. To ensure enhanced clarity, this research will exclusively use the term VGS to denote any manifestation of plant growth occurring on, upward or against wall surfaces.

VGS not only enhances the visual appeal of urban landscapes (Peng *et al.*, 2020), but it also mitigates the impact of UHI by leveraging evapotranspiration and shading (Shafiee *et al.*, 2020; Wong and Yu, 2005). Additionally, VGS has an impact on indoor air temperature within buildings (Hao *et al.*, 2020). Research has also demonstrated that VGS can effectively lower a building’s surface temperature during summer and provide insulation in winter (Safikhani *et al.*, 2014). In urban areas with dense development, these systems contribute to the creation of a microclimate where the space between buildings, known as the “canyon,” experiences lower temperatures due to transpiration processes facilitated by plants (Bustami *et al.*, 2018; Pan *et al.*, 2018). The presence of VGS brings about various direct and indirect advantages, such as noise reduction (Pérez *et al.*, 2016; Wong *et al.*, 2010), improved air quality (Charoenkit and Yiemwattana, 2017), increased urban biodiversity (Madre *et al.*, 2015), aesthetic enhancement (Magliocco, 2018), increased property value (Price *et al.*, 2015) and recognition in green building rating systems (Jiang *et al.*, 2020; Weinmaster, 2009). By integrating nature into contemporary architectural designs offered by VGS, also known as biophilic design, there can be potential psychological benefits for human well-being (Ghazalli *et al.*, 2019). As a result, the study of VGS has expanded to encompass a more multidisciplinary approach to research.

In summary, the wealth of studies showcasing the cooling effect of VGS (e.g. Jamei *et al.*, 2021; Wang *et al.*, 2022; Iaria and Susca, 2022) solidifies them as a promising solution for mitigating the UHI phenomenon (Perini *et al.*, 2013; Price *et al.*, 2015; Zaid *et al.*, 2018). Notably, the application of vertical greening methods on perpendicular surfaces offers the advantage of conserving valuable space resources (Hoelscher *et al.*, 2016). A notable study conducted by Shafiee *et al.* (Iaria and Susca, 2022) in Shiraz, Iran, showed a remarkable decrease of 8.7°C in ambient temperature achieved through the implementation of green walls. Moreover, by reducing temperature fluctuations and minimizing the maximum and minimum ambient temperatures, VGS contribute to creating more stable and comfortable microclimates.

3.2.4 *Building envelope.* 3.2.4.1 *Building geometry and orientation.* When formulating the design of building facades and openings, a range of factors are taken into account, encompassing building classification, materials and the solar heat gain coefficient. Nonetheless, the importance of building geometry and orientation parameters in influencing facade functionality is frequently overlooked (Susorova *et al.*, 2013). These parameters encompass elements such as the ratio of windows to walls, building orientation, openings, configurations of shading devices and internal spatial arrangements (Azmi and Ibrahim, 2020).

Given that the orientation and geometry of buildings exert a significant influence on energy consumption across the entire lifecycle of a building, it is imperative to meticulously contemplate and integrate these aspects during the initial stages of design. Efficient management of solar heat gain is heavily contingent on urban morphology, building geometry and orientation. Furthermore, factors like the incorporation of external/internal shading devices and the extent of glazing play a significant role in determining the degree of control (Castaldo *et al.*, 2018; Cui *et al.*, 2017). Below is a comprehensive list of the building geometry and orientation factors that are examined in this study.

3.2.4.2 Insulation. Improvements in thermal insulation within buildings can wield a notable influence on mitigating the effects of the UHI on cooling energy consumption (Abu-Jdayil *et al.*, 2019; Aditya *et al.*, 2017; Jelle, 2011). Guattari *et al.* (2018) found that the influence of UHI on cooling energy consumption in residential buildings exhibited fluctuations ranging from 18% to 41%, contingent upon the design and technologies implemented within the building envelope. In Rome, Italy, Zinzi and Carnielo (2017) observed a reduction in UHI-related impacts on cooling energy consumption in residential buildings as a result of enhanced thermal insulation in the building envelope. Conversely, a study conducted in Modena, Italy, centered around a university library, yielded findings that did not demonstrate noteworthy effects on modeled UHI impacts when incorporating cool coatings on the roof and opaque vertical surfaces (Magli *et al.*, 2015). These findings suggest that the role of thermal insulation in influencing the UHI's impact on cooling energy consumption may differ across various building types, but further research is necessary to gain a more comprehensive understanding.

Urban expansion in large cities typically involves the use of substantial materials for constructing building envelopes, including materials such as brick and concrete. This selection of heavy materials possesses a significant heat capacity, allowing them to store substantial amounts of solar heat. Ibrahim's research [35], which explored uninsulated and insulated building envelopes, yielded promising results. Through the implementation of thermal insulation, the temperature of the west wall surface experienced a substantial reduction of up to 26°C, declining from 49°C to 23°C. This outcome signifies that thermal insulation stands as a commendable solution for mitigating surface temperatures effectively. Furthermore, the adoption of cavities as an insulation strategy for building envelopes is extensively adopted. Scholars have emphasized the significance of employing ventilated double skin façades, citing their capacity to avert building overheating by absorbing solar radiation (de Gracia *et al.*, 2015; Lin *et al.*, 2022).

3.2.4.3 High performance glazing. Buildings possess remarkable potential to contribute to the global reduction of total energy consumption, and glazed areas hold notable importance in decreasing heat losses from the building envelope. In addition to double-glazed windows, substantial endeavors are being undertaken on a global scale to innovate novel, environmentally friendly, sustainable and multifunctional glazing technologies. These technologies encompass transparent insulation material (TIM) glazing (Paneri *et al.*, 2019), vacuum glazing (Cuce and Cuce, 2016), low-emissivity coated (low-E) glazing (Somasundaram *et al.*, 2020), phase change material (PCM) glazing (Li *et al.*, 2020) and smart glazing (Casini, 2014).

3.2.4.4 Double-skin façade. Double-skin façade (DSF) is a prominent design strategy adopted to minimize heat transfer and alleviate the influence of the UHI on a building's energy performance. In essence, DSF can be described as a configuration that consists of two layers of glass, with an intervening air cavity serving as an effective insulating barrier against extreme temperature conditions (Boake *et al.*, 2003). With the recognition of the significant impact of UHI on buildings, there is an observed inclination among architects and engineers

toward embracing and integrating the concept of DSF into their design practices. This growing trend reflects a keen understanding of the potential benefits that DSF offers in terms of reducing heat transfer and enhancing energy efficiency in buildings while simultaneously addressing the challenges posed by UHI effects. By incorporating DSF into building designs, professionals in the field aim to strike a balance between architectural aesthetics, environmental sustainability and occupant comfort, making DSF a compelling choice in the pursuit of innovative and energy-efficient building solutions.

3.2.4.5 Building openings. Openings play a crucial role in building facades, facilitating natural light, ventilation, visual integration with the surroundings and heat transfer (He, 2019). However, the operation of windows can have implications for various building parameters (Palme *et al.*, 2017). For instance, while openings in buildings offer views to the outdoors, they can simultaneously influence thermal performance, ventilation setups and acoustic conditions. Hence, there is a growing emphasis on the necessity for building facades that are adaptive and capable of self-adjustment. A practical approach to address this is the incorporation of shading devices in combination with well-designed and properly oriented openings, which effectively reduces solar heat gain and subsequently decreases the cooling loads of buildings (Bellia *et al.*, 2013). This approach is particularly advantageous in regions with hot climates, where the mitigation of excessive solar heat gain is of utmost importance.

3.2.4.6 Building heating, ventilation and air conditioning systems. Heating, ventilation and air conditioning (HVAC) systems wield a crucial role in urban energy consumption. As cities become more densely populated, the overall energy usage rises, and HVAC systems notably contribute to this escalation in energy consumption, particularly as their load intensifies in response to higher temperatures (Huang *et al.*, 2020; Jin *et al.*, 2020). Consequently, there exists a necessity to enhance the technological capabilities of HVAC standards to improve overall energy efficiency. Another study carried out in Mumbai discovered that a synergistic approach involving the utilization of HVAC systems and structural cooling, which involves a network of pipes absorbing heat from the building structure to prevent its entry into living spaces, can yield a notable alleviation of the burden on HVAC systems. This, in turn, leads to a substantial reduction in energy consumption (Dwivedi *et al.*, 2019).

Kohler *et al.* (2017) investigated the impact of distinct spatial planning policies on both the intensity of the urban UHI and the energy requirements for heating buildings in Germany and France. Their findings indicated that space heating energy needs exhibit remarkable similarity between the compact and moderately compact scenarios, particularly when accounting for the variations in the amount of developable land permitted in each scenario. Simulation outcomes imply that variations in heating energy demands are intricately tied to the volume of buildings to be heated, rather than disparities in the simulated built patterns. According to Burillo *et al.* (2019), from a technological advancement perspective, it holds promise to address UHIM in hot regions by designing AC systems that exhibit enhanced efficiency under elevated temperatures, thereby ameliorating peak loads during extreme heatwaves. This research contends, following a comprehensive review of the existing literature, that energy consumption, HVAC systems and waste heat are underrepresented subjects within the UHI literature. Given the pivotal significance of these topics in both UHI intensification and mitigation, future research should accord greater emphasis to this domain.

3.2.5 Materials. 3.2.5.1 Albedo. The urban temperature is influenced by the delayed transmission and radiation of high waves from various sources, such as roofs, building surfaces and streets, which absorb heat and release it into the environment (Farhadi *et al.*, 2019; Gago *et al.*, 2013). The intensity of this phenomenon is determined by factors such as surface exposure to the sky and material attributes, encompassing factors like albedo,

reflectivity and thermal inertia (Yang *et al.*, 2015). Albedo, which plays a significant role in UHI mitigation, refers to the overall reflection of radiation by a given system. It is quantified on a scale ranging from 0 to 1, where a surface with 0 albedo absorbs all incoming radiation, while a surface with an albedo of 1 reflects all radiation (Cotana *et al.*, 2014). The utilization of high-albedo materials has been shown to contribute to the reduction of heat absorption, thereby aiding in mitigating UHI (Krüger *et al.*, 2011; Rosso *et al.*, 2016; Pisello *et al.*, 2015). This, in turn, leads to the moderation of ambient air temperature during heat wave conditions (Falasca *et al.*, 2019) and surface temperature in open spaces (Smith *et al.*, 2023). Conversely, the use of low-albedo materials has been found to intensify the UHI effect (Mohajerani *et al.*, 2017), elevate ambient temperature within localized areas (Synnefa *et al.*, 2008), as well as increase energy consumption levels (Akbari, 2009).

#### Cool roofs

A cool roof is characterized as a roof that displays elevated solar reflectance and notable thermal emittance (Gao *et al.*, 2014). The adoption of high-albedo materials as alternatives to traditional roofs has emerged as a crucial strategy for mitigating UHI effect (Yang *et al.*, 2018; Wang *et al.*, 2022). Numerous studies have demonstrated the effectiveness of cool roof materials, which are assessed based on their albedo values, as a UHI strategy. For instance, research conducted in Singapore unveiled that the extensive implementation of cool roofs can ameliorate daytime heat stress, although the advantages tend to diminish during the peak period of the UHI's intensity at night (Li and Norford, 2016). Similarly, in a densely populated urban area in Ho Chi Minh, Vietnam, a study demonstrated that the adoption of cool roofs can lead to a modest reduction of 0.1°C in air temperature, while significantly lowering the temperature of roof surfaces (Huynh and Eckert, 2012). In Colombo, Sri Lanka, a study indicated that elevating the albedo of walls and roofs by 0.3 within densely urbanized zones resulted in a reduction of 0.3°C in maximum daytime air temperature and 0.6°C in nighttime temperature (Emmanuel and Fernando, 2007). Additionally, Salata *et al.* (2017) proposed that the integration of cool roofs holds the potential to decrease health risks by approximately 60% in areas characterized by hot and humid conditions. Furthermore, Georgescu *et al.* (2014) assessed the impact of highly reflective roofs on near-ground air temperatures in urban areas and found that nationwide implementation on all buildings could potentially lower air temperatures by 1.47°C.

#### Cool façades

A handful of studies have also examined the connection between building facade materials and UHI. The materials used in building facades within urban areas exert a substantial impact on the overall thermal equilibrium of the urban environment. Consequently, the quantity of materials with high albedo properties on the vertical facades also has a discernible impact on UHI (Morini *et al.*, 2017; Wonorahardjo *et al.*, 2022; Falasca *et al.*, 2019; Yang *et al.*, 2015). As a general rule, a lighter colored building envelope will result in lower solar heat gain compared to a darker color (Cheng *et al.*, 2005). In the case of non-conditioned buildings, a higher albedo can contribute to reduced indoor air temperature and radiant temperature. Within air-conditioned buildings, an elevation in albedo correlates with a reduction in the requisite cooling load (Synnefa *et al.*, 2007; Akbari *et al.*, 2001; Nazarian *et al.*, 2019). When the thermal resistance of the external wall material is enhanced, the relevance of the albedo of the exterior wall diminishes in relation to indoor heat gain. The albedo of the roof exerts a more substantial influence on the solar heat gain of a building compared to the walls.

Several studies argue that the effectiveness of low albedo facades varies depending on the density of the urban scenario, with higher effectiveness observed in high-density settings, whereas increasing albedo values on facades demonstrates greater effectiveness in low-

density scenarios (Alchapar *et al.*, 2015; Yang and Li, 2015). When accounting for air temperature as a variable, it has been noted that urban facades with high albedo values result in reduced temperatures for building heights up to 12 m. Conversely, using low albedo on walls at a height of 15 m is advisable. This suggests that the transition point emerges between the fourth and fifth stages of building height (Alchapar and Correa, 2016). Furthermore, Santamouris *et al.* (2018) proposed that enhancing the overall albedo of a city can result in a maximum ambient temperature reduction of up to 3°C and a 20% decrease in cooling demand for residential buildings. Another study by Ihara *et al.* (2015) highlighted those new architectural designs can contribute to increased solar exposure, thus amplifying the impact of heat islands. In this regard, Enríquez *et al.* (2017) put forth the proposition that ceramics, due to their mechanical and chemical resistance, cleanliness, durability and decorative versatility, are highly effective materials as they combine high albedo and low thermal diffusivity.

3.2.5.2 Evaporative materials. Strategies centered on evaporation for mitigating the UHI effect entail cooling through the liberation of latent heat. By contrast, approaches involving green infrastructure leverage a blend of evapotranspiration and heat reflectance to deliver cooling effects (Taleghani and Berardi, 2018). Therefore, preserving and increasing green spaces (Aboelata and Sodoudi, 2020; Xiao *et al.*, 2018), implementing green roofs (Wang *et al.*, 2022), planting street trees (Shiflett *et al.*, 2017), using green parking lots (Sultana and Satyanarayana, 2022), establishing wetlands (R. Sun *et al.*, 2012), employing sprinklers (Hendel *et al.*, 2016), incorporating permeable pavements (Ferrari *et al.*, 2020), using reflective surfaces (Kyriakodis and Santamouris, 2018) and using heat regulating materials (Saffari *et al.*, 2018) have all been studied and recommended as effective strategies for UHIM.

Evaporative pavements encompass various types, including porous, permeable and pervious pavements. While these terms are often used interchangeably in discussions on evaporative pavements, Qin (2015) provides distinct definitions for each, highlighting their unique characteristics. It is crucial to consider the complete structure of the pavement when addressing evaporative pavements. In the case of pavements subjected to high traffic loads, the permeability or porosity typically pertains solely to the top layer of the pavement. Enabling water to penetrate the entirety of the pavement structure would jeopardize both its base and sub-base components. Consequently, when citing permeable or porous pavements in research studies, it is vital to explicitly outline the complete composition and structure of the pavement, considering its intended purpose as well. This consideration ensures a comprehensive understanding of the performance and functionality of evaporative pavements.

3.2.6 Urban morphology. 3.2.6.1 Sky view factor. Sky view factor (SVF) plays a crucial role in the study of UMs, particularly in relation to urban morphology. It functions as a marker for evaluating the arrangement and concentration of structures within an urban region. SVF denotes the ratio of the open sky hemisphere visible from a particular ground location, which remains unblocked by urban features like buildings, landscape or trees (Chun and Guldmann, 2014; Oke, 1988). A smaller SVF indicates a higher density of buildings and less solar radiation reaching the ground. Numerous studies have investigated the impact of SVF on UMs (e.g. Dirksen *et al.*, 2019; Farhadi *et al.*, 2019; Han *et al.*, 2022; Huang and Wang, 2019; Yin *et al.*, 2018). The findings generally indicate that reduced SVF values are linked to decreased daytime temperatures and increased nighttime temperatures within urban canyon areas (Chen *et al.*, 2012; Kim *et al.*, 2022; Svensson, 2004). This occurs due to canyons characterized by a low SVF, which obstructs the penetration of solar radiation. As a result, there is a decrease in the overall amount of solar energy entering these urban canyons,

leading to a reduction in daytime air temperatures within them. At night, urban canyons with a low SVF hinder the release of long-wave radiation emitted by the ground surface. This obstruction interferes with the natural cooling mechanism, leading to elevated nighttime air temperatures within these canyons (Givoni, 1998).

Mills (1997) emphasized the significance of solar exposure and SVF in determining the heat balance of building structures on a daily basis. Furthermore, Girdharan *et al.* (2004) found that a 1% decrease in SVF could lead to a 1%–4% reduction in daytime UHI intensity, particularly in subtropical climates. SVF is also associated with variations in intra-urban temperatures. The average SVF over a specific area, serving as an indicator of urban building geometry, exhibits a linear correlation with temperature fluctuations in the city center (Unger, 2009). Chen *et al.* (2012) discovered an inverse relationship between the areal averaged SVF and the elevation of daytime air temperatures in urban locations. They also observed that the influence of SVF varied depending on the density of buildings. In this study, SVF is considered a crucial variable for providing a comprehensive description of urban geometry, and the range of SVF examined is expanded up to 0.8 to explore design strategies centered around urban greenery for enhancing the outdoor thermal environment (Chatzipoulka and Nikolopoulou, 2018; Wang *et al.*, 2016; Wei *et al.*, 2016).

A constrained view of the sky leads to a rise in the retention of heat within buildings and contributes to UHI. Trees also have an impact on SVF, yet they do not accumulate a significant amount of heat themselves (Klemm *et al.*, 2015). A study conducted in Beirut, Lebanon, discovered that although the presence of SVF has minimal impact on nighttime air temperature, the air temperature rises during the middle of the day due to the influence of strong solar radiation caused by high SVF levels (Fahed *et al.*, 2020). The threshold for SVF lacks a universal standard. In densely populated, tall urban areas like Hong Kong, a location with an SVF exceeding 0.3 is regarded as relatively open space. This stands in contrast to European cities' norms and practices (Girdharan *et al.*, 2007). Hence, this dissertation contends that determining the ideal SVF range should be established through research tailored to the characteristics of each individual city.

3.2.6.2 Building density. Building density refers to the proportion of the site area occupied by buildings in relation to the total area. A higher building density, characterized by a greater number of buildings within a designated planning unit, often leads to inadequate ventilation conditions (Lin *et al.*, 2017). Conversely, a lower building density fosters a more desirable residential environment. Studies have shown that increased building density is associated with higher temperatures (Perini and Magliocco, 2014; Petralli *et al.*, 2014).

The density of urban areas and the extent of open spaces between buildings play a role in shaping the intensity of the UHI (Erell *et al.*, 2012; Chun and Guldmann, 2018). Numerous comparative studies suggest that urban areas characterized by compact and high population density exhibit a higher UHI intensity compared to cities that are more spread out and less densely populated (Liu *et al.*, 2021; Erell *et al.*, 2012; Perini and Magliocco, 2014; Zhou *et al.*, 2017). For example, Connors *et al.* (2013) contend that UHI intensity is often elevated in denser urban cores, attributed to the tight configuration of buildings in relation to the available open spaces, as highlighted by the build-to-open-space ratio. Nonetheless, differing research viewpoints emerged, with some studies challenging this stance and emphasizing that the expansive structure of urban areas has led to an intense UHI (Liang *et al.*, 2020; Lin *et al.*, 2017; Wang *et al.*, 2016). Meanwhile, other research validated the intricate connection between urban structure and UHI. As an illustration, Debbage and Shepherd (2015) proposed that enhancing the contiguous layout of urban spaces could raise the average annual UHI, irrespective of whether cities are compact or spread out. On the other hand, Connors *et al.* (2013) contend that urban cores with greater population density often exhibit elevated UHI

intensity as a result of the close configuration of built and open spaces. In a similar vein, Kohler *et al.* (2017), assert that cities marked by extensive low-density residential expansion could display a diminished UHI impact compared to urban centers that are more compact and densely built. The authors provide reasoning for this based on the increased presence of available areas and surfaces that allow liquids to pass through. However, they also acknowledge that this does not automatically lead to cities being more environmentally friendly or having better energy consumption. Hence, the impact of building density on the temperature of outdoor air differs significantly depending on various climate circumstances and urban environments. It is crucial to consider the specific local conditions to properly understand the data and evidence.

3.2.6.3 Floor area ratio. The floor area ratio (FAR) indicates how the total floor area of buildings relates to the area of the site on which they are located (Lan and Zhan, 2017). Typically, a higher FAR indicates taller buildings within the same site area, while a lower FAR suggests the opposite. Studies have demonstrated that higher building density and the presence of high-rise structures can contribute to increased temperatures in urban centers (Chun and Guldman, 2014; He *et al.*, 2019; Ren *et al.*, 2022). On the other hand, lower building density and higher FAR values are generally associated with lower temperatures (Hu *et al.*, 2020; Yin *et al.*, 2018). However, some studies have presented contradictory findings. Stone and Rodgers (2001) argued that low-density residential areas contribute more heat compared to higher-density dwellings. Bourbia and Boucheriba (2010) found that high-density areas exhibit lower temperatures during the daytime when comparing building height-to-width ratios in various residential areas. Taleghani *et al.* (2015) highlighted the comfortable microclimate provided by compact urban forms in The Netherlands compared to other studied urban configurations. Similarly, several researchers concluded that temperature increases with the expansion of roof area and floor area ratio in compact urban blocks (Chun and Guldman, 2014; Wei *et al.*, 2016).

An investigation carried out in Hong Kong (Lin *et al.*, 2017) examined the correlations between FAR and building density, revealing that sites hosting more densely constructed buildings generally encounter reduced outdoor air temperatures. It clearly illustrates the significance of building shading in lowering daytime air temperatures within urban environments characterized by a sub-tropical climate. Higher FAR and greater building density lead to heightened obstruction of sunlight by structures, leading to reduced solar heat absorption throughout the daytime hours. However, the counterintuitive aspect is that the adverse connections between these two variables and early nighttime UHI appear contradictory. One could argue that higher FAR and greater building density may result in the formation of deeper urban canyons, contributing to elevated air temperatures during nighttime due to a reduced capacity for heat dissipation. One potential reason behind this outcome could be that the extremely large size of the building absorbs a significant amount of heat throughout the day, and it requires an extended period to dissipate that heat into the atmosphere.

### 3.3 Urban heat island mitigation challenges

Local governments hold substantial influence over the creation, size and growth of the UHI phenomenon through their development policies and choices. This study presents ample evidence from existing literature regarding UHI and its association with urban climate concerns. Various UHIMS and climate-related suggestions for cities have been proposed. Despite these efforts, the potential for elevated urban temperatures remains a considerable concern, posing a significant threat to human welfare.

Numerous studies have demonstrated that only a handful of cities have taken effective and feasible measures to address UHI. For instance, cities like Stuttgart, Germany (Hebbert, 2014), and London, UK (Mills, 2014), have taken steps in the right direction. In essence, most cities have not made substantial changes to fully transform into climate-adaptive urban areas, despite numerous studies highlighting the positive outcomes that various mitigation approaches could offer against UHI effects. As discussed in this section, UHIMS primarily focuses on using materials with high reflectivity and cool surfaces, incorporating urban vegetation, implementing green roofs/walls/surfaces and making adjustments to urban layout and building designs. Table 3 presents a selection of recent research on UHI studies that showcase various methods for alleviating its effects. However, it is important to highlight that the practical implementation of these strategies has frequently been overlooked in UHI research, underscoring the persistent significance of these implementation challenges (Millard-Ball, 2012; Dare, 2019).

Some studies show that the challenges in implementing UHI mitigation strategies arise from several factors. First, inadequate investments and prioritization by policymakers have hindered effective urban climate adaptation actions (Vogel and Henstra, 2015). Second, spatial planning has gained recognition as a promising method for improving the sustainability and adaptability of urban areas. However, the specific responsibilities of urban governmental entities and the action plans of management organizations in the context of UHI studies remain unclear (Castán Broto, 2017; Lee and Painter, 2015). Third, urban areas are characterized by complex and interconnected systems, including buildings, infrastructure and vegetation. Effective UHIM requires a comprehensive understanding of these systems and their interactions (Hayes *et al.*, 2022). The complexity of urban environments makes it challenging to design and implement successful mitigation measures.

Fourth, existing urban infrastructure poses a significant challenge. Many cities have well-established structures that were not designed with UHI mitigation in mind. Retrofitting these structures to incorporate UHIM features can be complex and costly (Larsen, 2015). Additionally, limited physical space in urban areas poses challenges for the implementation of green spaces, such as parks and gardens, which are effective in reducing UHI effects (Leal Filho *et al.*, 2017). The fifth challenge lies in coordinating and collaborating with various stakeholders. UHIM requires the involvement of multiple entities, including urban planners, architects, engineers, policymakers and community members. Achieving consensus and effective collaboration among these stakeholders can be challenging due to differing priorities and interests (Parsaei *et al.*, 2019). Sixth, integrating UHIM into building design and urban planning often requires additional investments. However, budgetary constraints and competing funding priorities can hinder the allocation of adequate resources for UHIM efforts (Aleksandrowicz *et al.*, 2017). Seventh, a lack of comprehensive guidelines and specific standards for UHIM in the built environment poses a challenge. While there are general sustainability guidelines, specific guidelines focused on UHIM in urban planning and building construction are limited. The absence of standardized practices and regulations makes it challenging for practitioners to implement effective UHIM measures (Akbari, 2009).

Finally, UHIM strategies may conflict with other urban development goals, such as density, transportation and economic growth. Balancing multiple objectives and addressing trade-offs can be complex, requiring integrated and interdisciplinary approaches (Kabisch *et al.*, 2016). Addressing these challenges requires a multidisciplinary approach and collaboration among researchers, practitioners, policymakers and communities. Efforts should be made to develop innovative solutions, establish clear guidelines and secure adequate funding to implement UHIMS effectively in the built environment.

**Table 3.** Summary of some recent studies on the UHI (2016–2022)

Ref	Location	Target		Scale			Methodology		Mitigation strategy			Implementation consideration	
		SUHI	UCL	UBL	Building	Neighborhood	City	Simulation	Experimental	Urban morphology	Green/blue infra.		Cool materials
(Yang <i>et al.</i> , 2018)	Singapore	X	X		X		X			X			-
(Kandya and Mohan, 2018)	India	X	X		X			X					-
(Santamouris <i>et al.</i> , 2018)	Australia	X				X	X			X			-
(Zheng <i>et al.</i> , 2022)	Japan	X			X		X			X			-
(Toucheai <i>et al.</i> , 2016)	Canada	X			X		X			X		X	-
(Hsieh and Huang, 2016)	Taiwan		X			X	X		X				-
(Kolekotsa <i>et al.</i> , 2022)	Australia	X	X			X	X		X				-
(Kyriakidis and Santamouris, 2018)	Greece	X				X	X	X					-
(Sharma <i>et al.</i> , 2016)	USA	X				X	X					X	-
(Aboelata and Sodoudi, 2020)	Egypt	X	X			X	X			X			-

#### 4. Research gaps

The literature review on UHIMS has revealed several important research gaps that need to be addressed in future research efforts. First, the findings from the SMEs are supported by the literature, which also identifies a significant gap in this area. For example, [Santamouris \(2015\)](#) highlights the lack of cohesive policies targeting UHIM in many cities worldwide, corroborating the SMEs' observations. Additionally, [Oke \(1982\)](#) emphasizes that most municipalities do not have dedicated strategies to combat UHI, and the measures that do exist are often integrated into broader environmental policies, aligning with the SMEs' remarks on the inconspicuous integration of such measures. [Zhou et al. \(2017\)](#) discuss the challenges in implementing heat mitigation strategies, emphasizing the need for comprehensive urban planning that specifically addresses UHI. Moreover, there is a dearth of studies specifically examining how building heat contributes to UHI and the frameworks that municipalities worldwide use to permit or approve buildings based on the heat they emit into the atmosphere. For instance, [Rizwan et al. \(2008\)](#) note the limited research on the direct impact of individual buildings on urban heat. They argue that most studies focus on broader urban planning strategies rather than specific building contributions. Furthermore, studies by [Erell et al. \(2012\)](#) suggest the necessity for more detailed guidelines and frameworks that municipalities can adopt to effectively regulate building heat emissions. These studies reinforce the need for targeted research and strategic policy development to address the specific contributions of building heat to UHI.

Second, there is a need for more comprehensive and integrated approaches to UHIM that consider the interconnectedness of urban planning, building design, civil engineering and policy frameworks. While current UHIMS focuses on individual aspect or elements, such as green roofs or cool pavements, there is a lack of research exploring how these strategies can be effectively combined and implemented within a holistic framework to achieve maximum impact in reducing urban heat. This paper suggests that future research should aim to develop integrated UHIMS approaches that consider the synergies and trade-offs between different strategies. Third, there is a dearth of research on the evaluation and assessment of the effectiveness of UHIMS in different urban contexts. While numerous studies have examined the impact of specific UHIMS, such as urban greening or reflective coatings, there is a need for comprehensive evaluation frameworks that assess the long-term effectiveness, scalability and adaptability of these strategies. Future research should focus on developing standardized evaluation methods and tools to accurately measure and compare the performance of UHIMS across diverse urban environments.

Fourth, potential interactions between UHIMS and other sustainability goals, such as energy efficiency and carbon reduction, require further investigation. While UHIMS aims to mitigate urban heat, it is essential to understand the potential trade-offs and synergies with other environmental objectives. For example, the use of certain UHIMS may have unintended consequences on energy consumption or carbon emissions. Future research should explore the co-benefits and conflicts between UHIMS and other sustainability targets to ensure that the pursuit of UHIM aligns with broader sustainability goals. Finally, although the challenges associated with implementing UHIMS have been acknowledged in the literature, there is limited research on the economic feasibility and cost-effectiveness of these strategies. Future research should examine the financial implications of UHIMS implementation, considering factors such as construction costs, maintenance expenses and potential energy savings. Addressing these research gaps will contribute to a more comprehensive understanding of UHIMS and facilitate the development of effective and sustainable urban planning and construction practices to mitigate the adverse effects of UHI.

## 5. Conclusion

Cities are critical to the fight against climate change. Currently, there are technological and financial tools that cities use for this fight. However, there is no coherent regulatory policy tool for the fight. This provides the justification for the tool framework in this paper. In cities, buildings, the physical structures that house human activities, are primary sources or causes of heat emission into the UM. The paper contends that regulating the factors of buildings that affect heat embodiment and emission would enable cities to reduce the heat emitted by buildings into the atmosphere. This paper used desktop and evidence-based research techniques to elucidate the factors influencing a building's propensity to absorb and emit heat, systematically categorizing these factors into five principal themes. The identified themes offer valuable insights into how buildings contribute to the UHI effect and highlight areas for intervention. However, to strengthen the validity of these findings, future research should incorporate statistical analyses to rigorously test and confirm the impact of each factor. By integrating these validated factors into building review processes, cities can develop more effective strategies for approving or rejecting buildings based on their heat emission profiles. This approach not only supports the reduction of heat-related issues in urban environments but also advances the broader goal of sustainable urban development. As cities increasingly confront the challenges of climate change and energy efficiency, the adoption of evidence-based frameworks for building approval becomes crucial in fostering more resilient and environmentally friendly urban landscapes.

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