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# Sustainable Mitigation Strategies for Urban Heat Island Effects in Urban Areas

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**Abstract:** The globe is at a crossroads in terms of the urban heat island effect, with rising surface temperatures due to urbanization and an expanding built environment. This cause-and-effect connection may be linked to weather-related dangers, natural disasters, and disease outbreaks. Urbanization and industrialization will not lead to a secure and sustainable future. Finding solutions to problems such as the heat island effect is at the forefront of scientific research and policy development. Sustainable ways to decrease urban heat island impacts are a core principle for urban planners. This literature study examines the benefits of adding green infrastructure and sustainable materials in built-up areas to reduce the urban heat island effect. Materials such as reflective street pavements, coating materials including light-colored paint, phase-change materials, color-changing paint, fluorescence paint, and energy-efficient appliances are considered sustainable materials, whereas green infrastructure like green roofs, green walls, green parking and pavements, and shaded streets are considered to mitigate the urban heat island effect. The hurdles to the widespread adoption of such practices include a lack of governmental legislation, insufficient technological development, an erroneous estimation of economic gains, and unwillingness on the part of impacted parties.

**Keywords:** built environment; green urban infrastructure; sustainable building materials; urban development; climate change



**Citation:** Irfeey, A.M.M.; Chau, H.-W.; Sumaiya, M.M.F.; Wai, C.Y.; Muttil, N.; Jamei, E. Sustainable Mitigation Strategies for Urban Heat Island Effects in Urban Areas. *Sustainability* **2023**, *15*, 10767. https://doi.org/10.3390/su151410767

Academic Editor: Baojie He

Received: 10 June 2023
Revised: 4 July 2023
Accepted: 6 July 2023
Published: 9 July 2023



## 1. Introduction

Rapid advancement in the built environment and increasing urbanization are altering ecosystems and climates, with surface temperature being one of the most influential factors [1], and increased energy consumption in the urban environment contributes directly to the rise in surface temperature [2]. Due to urbanization and human activities, the urban heat island (UHI) effect, which is caused by an increase in surface temperature, is one of the most severe problems in urban areas [3]. The impact of UHI can be measured by using the heat and humidity index (THI), the related stress index (RSI), and the number of Beer Garden days [4]. The UHI effect has a negative influence not only on the environment but also on the health of the inhabitants. Multiple studies indicate that indigestion is a common problem, as well as nervous system disorders such as memory loss, depression, irritability, and sleeplessness [5].

In addition to that, the UHI's thermal impact may cause a significant circulation of pollution, resulting in local winds that migrate from suburban to urban areas, bringing city-contaminated air that is now present in rural areas back to urban areas, worsening urban air pollution and also increasing the financial burden on city dwellers. The solar radiation captured by urban surfaces is influenced by factors such as the number of buildings, their orientation, and the distance between them [6]. The arrangement of buildings has a significant impact on the distribution of shadows and temperature differences throughout a city. The canyon-like shape of streetscapes surrounded by high-rise buildings has an effect on wind patterns in urban canyons due to the intricate heat exchange between the mass of the buildings and the surrounding atmosphere [7]. Urban heat exchange is affected by a number of factors, including the thermal characteristics of urban surface materials, color, texture, and coverage [8].

The lack of vegetation in urban areas increases the amount of heat absorbed by different components such as buildings, pavement, and roads. Human activities such as driving and HVAC (heat, ventilation, and air conditioning) systems are also major contributors to heat accumulation in the atmosphere. Basically, the UHI effect is measured on three different levels: the ground level, the canopy level, and the urban level [9]. Specifically, the thermal behavior of surface materials and their exposure to solar radiation impact the UHI effect. The atmosphere over urban areas can be affected by the emission of heat and subsequent convectional mixing of the heat [10]. The amount of heat accumulated in the canopy layer is affected by a number of factors, including the geometry and orientation of open spaces, the aspect ratio, the sky view factor, the land cover materials, and the direction and velocity of the wind [11,12].

The urban surface layer's emitted heat is blended together by turbulence in the air above the canopy layer of the urban areas [13]. Above the canopy layer, local air is mixed, leading to the formation of a warm air dome over inhabited areas [14]. Due to the convective nature of the atmosphere, the urban boundary layer tends to be at its thickest at midnight. Due to its high heat resistance, the air has a relatively thin surface layer that only goes down a few centimeters [15]. By late afternoon, when the urban canopy has been heating in the sun for several hours, the air temperature in the canopy layer has reached its maximum [16]. Although the urban boundary layer is at its thickest in the evening, when warm air is pulled into the lower atmosphere, it forms a dome of warm air above the urban zone. The rural boundary layer fluctuates throughout the day, reaching its highest point at the same time as the day's highest surface temperature [17].

Responses to the effect of UHIs can be categorized as either adaptation or mitigation. Adaptations are made to decrease the harm, whereas mitigation is an activity performed to lessen the intensity or amount of the effect. The UHI effect can be adapted to and mitigated at the building, neighborhood, municipal, and regional levels. This study is an attempt to fill a need in the existing literature by offering a synoptic perspective of sustainable green infrastructure and materials that may be used in urban areas to reduce the UHI impact. Table 1 presents the background of the strategies reviewed in this study for the mitigation of UHIs. According to prior research by Shishegar 2014, increasing urban green spaces like parks, street trees, and green roofs may help reduce the UHI impact [18]. Petzold and Mose 2023 also undertook a study that investigated the economic and social factors around urban greening infrastructure [19]. Hence, the results from this study and ensuing suggestions aim to benefit the built environment in its pursuit of UHI mitigation strategies. Consequently, presented herein is the specific scope of the study:

- Identifying suitable green infrastructure that can be incorporated within the built-up areas in the urban setting.
- The identification of sustainable materials that can be integrated with building components to reduce the UHI effect.
- Examining the principle behind those identified techniques and their effectiveness in implementation.
- Identifying the most prevalent obstacles to the widespread implementation of the identified UHI mitigation strategies in urban areas and proposing solutions to these problems.

The next section describes the methodology implemented in this review. Section 3 describes the green infrastructure and sustainable materials that could be incorporated into the urban environment. Section 4 examines the obstacles to applying these sustainable strategies in urban settings. Finally, a summary of the study is presented and conclusions are drawn in the last section.

**Table 1.** Background of the strategies incorporated in this study on UHI mitigation.

| No | UHI Mitigation Strategies | | Description |
|---|---|---|---|
| 1 | Green infrastructure | Green roofs | Rooftop of a building that is partially or fully covered with vegetation and a substrate for plant growth. |
| | | Green walls | Vertical walls that are either completely or partially covered in plants. Consists of panels attached to an internal or external vertical structure. |
| | | Green façades | Natural climber plants are grown on the exterior of a building with the help of an auxiliary framework. |
| | | Green parking, Pavements, and shaded streets | The amount of solar energy absorbed decreases as the percentage of vegetative cover increases, allowing for the use of evaporative cooling on roads, parking areas, and sidewalks using water-retentive pavements and permeable porous pavers. |
| 2 | Sustainable materials | Reflective street pavements | In order to reduce the surface temperature and sensible heat emissions, reflective pavements that have a higher albedo (than regular pavements) are used. |
| | | Coating materials | Various materials can be integrated into the interior or exterior of building structures, as well as other urban components, with the aim of mitigating the impacts of UHIs. |
| | | | The ability of retro-reflective materials to redirect light to their original source is a useful and unique attribute. |
| | | | Materials that store and release latent heat to boost the apparent thermal capacity of buildings and urban structures and lower their peak surface temperatures. |
| | | | Materials that undergo a thermochromic color change in response to temperature. |
| | | | Capture the photovoltaic energy of solar radiation, release the light emission, and aid in increasing the surface's ability to reflect light. |
| | | | Reducing energy consumption and running costs and lowering greenhouse gas emissions. |

## 2. Materials and Methods

The issue of UHIs and sustainable mitigation practices is gaining relevance among individuals residing in densely populated urban areas. Global industrial and development activities have led to an increased emphasis on environmental sustainability, which marks a departure from past practices. Given the escalating expenses associated with the UHI phenomenon, it is imperative to prioritize the identification of sustainable measures aimed at mitigating its adverse impacts. Despite the fact that a number of studies have already been conducted to identify sustainable green strategies, this study will concentrate on a variety of urban-specific strategies that incorporate the built environment. This study reviewed over 315 documents to gather the recent literature; however, 163 were irrelevant to the study's objectives and out-of-date. Consequently, they were excluded. Table 2 presents detailed descriptions of the reviewed articles and the details from various academic sources (ScienceDirect, PubMed, Scopus, Google Scholar, etc.). UHI, UHI mitigation methods, the built environment and green infrastructure, and climate change were all used as search keywords for relevant papers.

Figure 1 describes the methodology undertaken to conduct this study. First, a literature study was conducted in order to bring to light many problems that have been associated with the UHI. Extensive explanations are given of global sustainable programs that have adopted innovative methods in lieu of more conventional ones. Methods for protecting against solar heating are explored, such as using green roofs, living walls, green façades, innovative road and pavement designs, coatings made from paint, phase-change materials, color-change materials, fluorescence materials, and sun shade. The adoption of more energy-efficient appliances in favor of older, less efficient models is another method of reducing the UHI's impact on the environment. Finally, the limitations and constraints of commonly used solutions for mitigating the effects of UHIs have been highlighted.

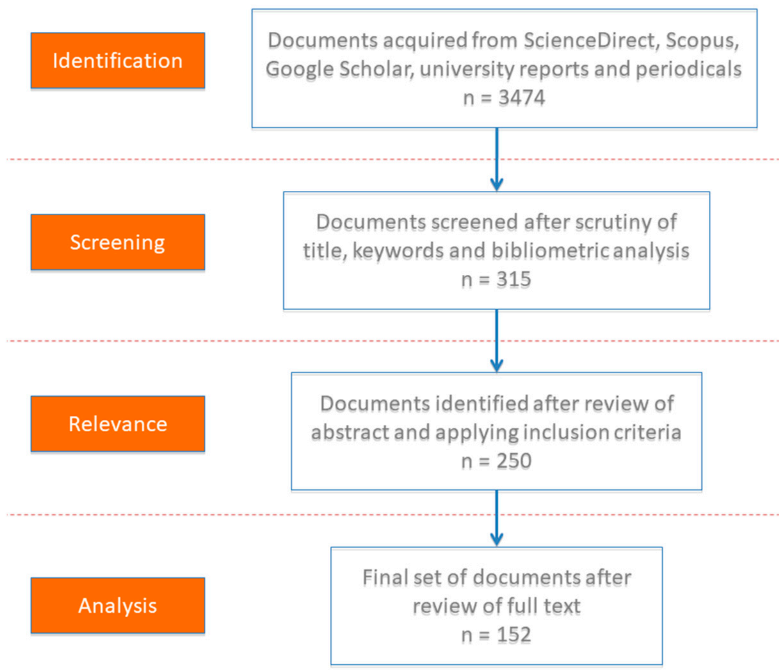


**Figure 1.** Methodology undertaken for conducting this study.

**Table 2.** Description of articles referred to for the study.

| | | Green Infrastructure | | | | Sustainable Materials | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Journal Name (Short Form)** | **No. of Reviewed Papers** | **Green Roofs** | **Green Walls** | **Green Parking, Pavements, and Shaded Streets** | **Innovative Streets and Pavements** | **Light-Colored Paint** | **PCM** | **Color-Changing Materials** | **Fluorescence Materials** | **Energy-Efficient Appliances** | **No. of Times Cited in Other Sections of This Paper** | **Total no. of Times Cited in This Paper** |
| *J. Alloys Compd* | 2 | | | | 1 | 1 | | | | | | 2 |
| *J. Build. Eng.* | 1 | | | | | | 1 | | | 1 | | 2 |
| *J. Nanomater* | 1 | | | | | | | 1 | | | | 1 |
| *J. Vis. Exp* | 1 | | | | | | | | 1 | | | 1 |
| *Sustain. Cities Soc* | 1 | | | | | | | | | | 1 | 1 |
| *Woodhead Publishing* | 1 | | | | | | | | 1 | | | 1 |
| *ACS Appl. Mater. Interfaces* | 2 | | | | | | | 2 | | | | 2 |
| *ACS Sustain. Chem. Eng* | 1 | | | | | 1 | | | | | | 1 |
| *Adv. Exp. Med. Biol.* | 1 | | | | | | | 1 | 1 | | | 2 |
| *Adv. Intell. Syst.* | 1 | | | | | | | | 1 | | | 1 |
| *Adv. Mater* | 1 | | | | | | | 1 | | | | 1 |
| *Adv. Mater. Sci. Eng.* | 1 | | | | 1 | | | | | | | 1 |
| *Adv. Opt. Mater* | 1 | | | | | | | 1 | | | | 1 |
| *Adv. Photonics Res* | 1 | | | | | | | 1 | | | | 1 |
| *Adv. Sci* | 1 | | | | | | | 2 | 1 | | | 3 |
| *Agric. For. Meteorol* | 1 | | | 1 | | | | | | | | 1 |
| *Ain Shams Eng. J* | 2 | 1 | | | 1 | | | | | | | 2 |
| *Appl. Acoust* | 1 | | 1 | | | | | | | | | 1 |
| *Appl. Sci* | 1 | | | | | | | | | 1 | | 1 |
| *Appl. Therm. Eng* | 2 | | | | | 1 | 1 | | | | | 2 |
| *Archit. South Africa* | 1 | | 1 | | | | | | | | | 1 |
| *Architecture* | 1 | | | | | | | | | | | 1 |
| *Atmos. Chem. Phys* | 3 | 2 | | | | | | | | | | 2 |
| *Atmos. Meas. Tech* | 1 | | | | | | | | | | | 1 |
| *Atmosphere* | 2 | | 1 | 1 | | | | | | | | 2 |

**Table 2.** *Cont.*

| Journal Name (Short Form) | No. of Reviewed Papers | Green Infrastructure | | | | Sustainable Materials | | | | | No. of Times Cited in Other Sections of This Paper | Total no. of Times Cited in This Paper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Green Roofs | Green Walls | Green Parking, Pavements, and Shaded Streets | Innovative Streets and Pavements | Light-Colored Paint | PCM | Color-Changing Materials | Fluorescence Materials | Energy-Efficient Appliances | | |
| *Biomater. Sci.* | 1 | | | | | 1 | | | | | | 1 |
| *Build. Environ.* | 7 | 1 | 1 | 1 | 1 | | | | | | | 4 |
| *Buildings* | 4 | | | 2 | 2 | | | | | | | 4 |
| *Chem. Eng. J* | 1 | | | | | 1 | | | | | | 1 |
| *City Environ. Interact* | 1 | | | | | | | | | | | 1 |
| *CivilEng* | 1 | | | | 1 | | | | | | | 1 |
| *Color Res. Appl.* | 1 | | | | | 1 | | | | | | 1 |
| *Concr. Int.* | 1 | | | | 1 | | | | | | | 1 |
| *Conference Proceedings* | 3 | 1 | | 1 | 3 | 1 | | | | | | 5 |
| *Constr. Build. Mater* | 9 | | | 2 | 4 | 1 | 3 | | | | | 10 |
| *Elsevier book chapters* | 3 | | | 1 | 1 | 1 | | | | | | 3 |
| *Energy* | 1 | | | | | | | 1 | | | | 1 |
| *Energy Build* | 3 | | | | 1 | 3 | | | | | | 4 |
| *Energy Procedia* | 1 | 1 | | | | | | | | | | 1 |
| *Energy Res. Soc. Sci.* | 1 | | | | | | | | | | | 1 |
| *Energy Rev.* | 1 | | | | | | | | | | | 1 |
| *Eng. Technol. Appl. Sci. Res* | 1 | 1 | | | | | | | | | | 1 |
| *Environ. Fluid Mech* | 1 | | | | | | | | | | | 1 |
| *Environ. Plan. B Plan. Des.* | 1 | | | | | | | | | | | 1 |
| *Environ. Res. Lett.* | 1 | | | | | | | | | | | 1 |
| *Environ. Sci. Pollut. Res* | 1 | | | 1 | | | | | | | | 1 |
| *Epoch book chapter* | 1 | | | | | | | | | | | 1 |
| *Fresenius Environ. Bull* | 1 | | | 1 | | | | | | | | 1 |
| *Ind. Eng. Chem. Res* | 1 | | | | | 1 | | | | | | 1 |
| *Indoor Environment, Berkely Lab* | 1 | | | | | | | | 1 | | | 1 |
| *Int. J. Eng. Res. Technol* | 1 | | 1 | | | | | | | | | 1 |
| *Int. J. Environ. Res. Public Health* | 1 | | 1 | | | | | | | | | 1 |
| *Int. J. Environ. Sustain* | 1 | | | | | | | | | | | 1 |
| *Int. J. Pavement Eng* | 1 | | | | 1 | | | | | | | 1 |
| *InTech* | 1 | | | 1 | | | | | | | | 1 |
| *IOP Conf. Ser. Mater. Sci. Eng* | 1 | | | 1 | 1 | | | | | | | 2 |
| *J. Am. Soc. Farm Manag. Rural Apprais* | 1 | | | | | | | | | | | 1 |
| *J. Build. Eng* | 1 | | | | | | | | | 1 | | 1 |
| *J. Clean. Prod* | 3 | | | | 2 | | | | | | | 2 |
| *J. Energy Storage* | 1 | | | | | 1 | 1 | | | | | 2 |
| *J. Environ. Eng.* | 1 | | | | 1 | | | | | | | 1 |
| *J. Environ. Manage* | 2 | | 1 | | 1 | | | | | | | 2 |
| *J. Road Eng* | 1 | | | 1 | | | | | | | | 1 |
| *J. Text. Inst.* | 1 | | | | | | | 1 | | | | 1 |
| *Mater. Horizons* | 1 | | | | | | | 1 | | | | 1 |
| *Mater. Today Proc* | 1 | 1 | | | | | | | | | | 1 |
| *Materials* | 3 | | | 1 | 2 | | 1 | | | | | 4 |
| *Polymers* | 1 | | | | | | | 1 | | | | 1 |
| *Proc. Natl. Acad. Sci. USA* | 1 | | | 1 | | | | | | | | 1 |
| *Procedia Eng.* | 1 | | | | | | | | | | | 1 |
| *Prog. Plann* | 1 | 1 | | | | | | | | | | 1 |
| *Transportation Res. Rec.* | 1 | | | | 2 | | | | | | | 2 |
| *Remote Sens* | 1 | | | 1 | | | | | | | | 1 |
| *Remote Sens. Environ* | 1 | | | 1 | | | | | | | | 1 |
| *Renew. Energy* | 1 | | | | | 1 | 1 | 1 | 1 | | | 4 |

**Table 2.** *Cont.*

| Journal Name (Short Form) | No. of Reviewed Papers | Green Infrastructure | | | Sustainable Materials | | | | | | No. of Times Cited in Other Sections of This Paper | Total no. of Times Cited in This Paper |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Green Roofs | Green Walls | Green Parking, Pavements, and Shaded Streets | Innovative Streets and Pavements | Light-Colored Paint | PCM | Color-Changing Materials | Fluorescence Materials | Energy-Efficient Appliances | | |
| *Renew. Sustain. Energy Rev* | 7 | 2 | | 3 | 2 | 1 | 1 | | | 1 | | 10 |
| *Resources* | 1 | | 1 | | | | | | | | 1 | 2 |
| *Sci. Rep* | 1 | | | | | | 1 | | | | | 1 |
| *Sci. Total Environ* | 2 | | | 1 | | | | | | | | 1 |
| *Sol. Energy* | 3 | | | | | 3 | | | | | | 3 |
| *Sol. Energy Mater. Sol. Cells* | 2 | | | | | 1 | | 1 | 1 | | | 3 |
| *Surf. Coatings Technol.* | 2 | | | | | 1 | | | 1 | | | 2 |
| *Sustain. Cities Soc* | 2 | | | | 1 | | | | | | | 1 |
| *Sustain. Energy Rev* | 1 | | | | | | | | | | 1 | 1 |
| *Sustainability* | 15 | 2 | 1 | 2 | 3 | | | | | | 1 | 9 |
| *Sustainable Cities and Innovation* | 1 | | | | | | | | | | | 1 |
| *Urban Clim* | 2 | | | | | | | | | 1 | | 1 |
| *Urban Ecosyst* | 1 | | | 1 | | | | | | | | 1 |
| *Urban Stud. Res* | 1 | | | | | 1 | | | | | | 1 |
| **Total references** | | | | | | | **152** | | | | | |

## 3. Incorporation of Green Infrastructure into Buildings

Green infrastructure is the addition of blue (water) and green (vegetation) components in contrast to the constructed environment to improve and manage environmental systems to enhance the quality of life in the ecosystem [20]. These green assets, if well-planned and designed, could mitigate the negative impacts of urban heat islands (UHIs) and climate change while also improving residents' quality of life. Green infrastructure is the strategic approach to developing and optimizing sustainable management systems of urban natural ecosystems in the face of climate change challenges. Innovative and well-developed potential practices can be considered by urban planners inside the built environment, including the implementation of green strategies into the main components, such as rooftops, façades, parking areas for buildings, pavements, walls, and landscaping areas to reduce the UHI effect with sustainable green and blue concepts.

Given the limited land resources, significantly increasing the density of green space is a challenging task. As a result, enhancing the spatial arrangement of green space could be a viable option. The significance of green space in mitigating urban heat islands (UHIs) is attributed to its spatial characteristics, including size, composition, and configuration [21]. As such, it is important that the unique qualities and characteristics be taken into account throughout planning, construction, and maintenance [22]. The environmental sector is put to the test by green infrastructure, which calls for a holistic and environmentally friendly strategy that integrates more concerns. Pressures may also be felt regarding the growing concerns of energy demand, consumption, and production, all of which have direct and indirect effects on the environmental facet of developing building infrastructure. Heat gain and loss are major factors on roofs since they represent the greatest exposed space. Traditional roofing practices using a variety of materials have contributed to the excessive heat buildup within structures and in the immediate vicinity [23]. As a result, many regions of the globe are becoming familiar with the practice of initiating green roofing approaches by using greenery techniques and regulating the excessive heat and heat variations surrounding the plants.

Façades are huge potential vertical spaces on structures, and these areas will expand as the buildings rise in height. Despite the vertical openness to the surroundings, the UHI effect is significantly impacted by façades due to the solar heat absorption potential and heat release from nearby buildings [24]. The streets and paving systems around a structure are essential in making it accessible to the public. The UHI impact is influenced by the layout of streets and pavement, including whether they are exposed to or sheltered from the sun, as well as by nearby buildings and other factors. The right planning of roadways and pavements, as well as the inclusion of sustainable flora, is crucial. As a result, the introduction of novel green infrastructure techniques into high-rise buildings and a full investigation of the seriousness of all these components via past literature studies are required for the present situation. Each facet of green infrastructure is examined in depth in this section.

### *3.1. Green Roofing Techniques*

A green roofing system is one of the useful tools for reducing the UHI effect by cooling the surrounding atmosphere. The built environment is being built at the expense of parks and other green spaces as a result of rapid urbanization [25]. This leads to a scarcity of vegetation, which reduces canopy interception and transpiration within the city, raising temperatures and lowering humidity [26]. Changing the characteristics of rooftops can help alleviate some of these issues. The addition of vegetation and soil to unused rooftop spaces is typically seen as a good method for making buildings more environmentally friendly [27]. Hence, green roofs are just rooftops that have had vegetation transplanted onto a growing medium. Benefits to the buildings' aesthetics, the environment, and the economy can be gained by encouraging the development of green roofs. Vegetation, substrate, filter fabric, drainage material, a root barrier, and insulation are the components that comprise a green roof [28]. Figure 2 shows the typical layers of a green roof system.

Substituting man-made, impermeable surfaces in built environment areas is the primary driver of UHIs [29]. Vegetation holds water in order for it to be evaporated back into the air through evapotranspiration, which not only cools the vegetated surface and low-level atmosphere but also lowers the amount of energy held in urban materials and released as heat [30]. Latent heat results from the transformation of evapotranspiration energy into the cooling of water vapor molecules in the higher atmosphere [31]. Rainwater evaporation converts some of the solar energy into latent heat, but hard, non-porous surfaces still collect most of the solar radiation and radiate them as heat. Roofs that are too warm boost the UHI but also allow more heat into a building, leading to higher indoor temperatures [10].

Rising temperatures also raise the peak loads required to meet the requirements for air conditioning and refrigeration, which can result in increased emissions of greenhouse gases (GHGs), and other pollutants [32]. Green roofs may provide additional benefits to building occupants and city dwellers, including reduced heating and cooling costs and increased durability of roof membranes due to temperature fluctuations [33]. Reduced stormwater runoff and combined sewage overflow, which occurs when the sewer system is flushed during extreme rainfall events, are also added benefits of green roofing. Green roofs can be either intensive or extensive. Intensive green roofs have a thick substrate layer, a large diversity of plants, high upkeep, high capital cost, and a higher weight; therefore, they usually require a lot of maintenance in the form of fertilizing, weeding, and watering [34]. However, extensive green roofs have a thin substrate layer, low capital cost, low weight, and minimal upkeep. Extensive green roof systems are often employed when no further structural support is required [34].

Part of the water that falls on a green roof is absorbed by the developing substrate or is held in pore spaces. Vegetation can take water in and either store it in their tissues or release it back into the air through a process called transpiration. The remaining water is sent into the drainage system after passing through the filter cloth. Water will be held back since it can be stored in the granules' pores or the drainage modules' compartments. One of the most critical factors is the growth medium, which must be able to retain water for the plant to thrive. Substrate for green roofs often consists of lightweight volcanic rocks, making it excellent at retaining moisture [35]. Energy savings from green roofs are an enticing prospect in the construction industry. By increasing the efficiency of a building's insulation, they help cut down on the amount of energy needed to heat and cool them [36]. A green roof can lower indoor temperatures which depend on the roof's green area. Increases in shading, improved insulation, and a larger thermal mass of the roof system are mostly responsible for the noticeable rise in thermal performance.

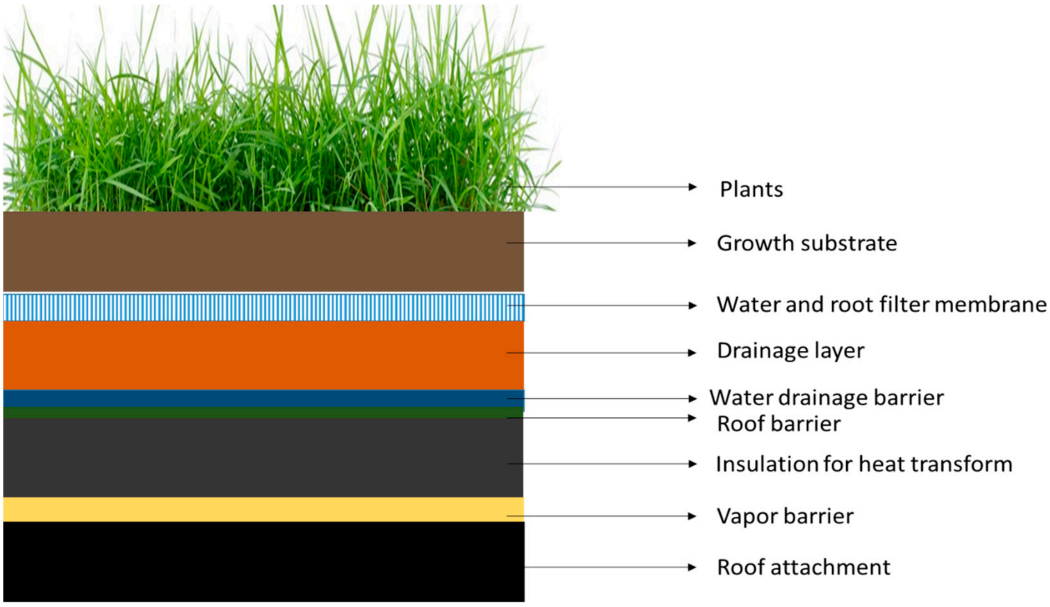


**Figure 2.** The typical layers of a green roof system [37].

### *3.2. Green Wall Techniques*

One alternative to using traditional wall construction to reduce the UHI effect is to use green walls, which are covered in plants. When compared to low-rise buildings, high-rises have a greater expanse of wall surface area and thus a greater potential for greenery implementations, increasing the effectiveness of such practices. The execution makes use of vertical walls that are either completely or partially covered in plants, resulting in an extravagantly verdant aesthetic [38]. Despite centering on UHI mitigation techniques, it provides a pleasant perspective and contributes to a livelier environment. Green walls improve air quality and aesthetics by removing carbon dioxide ($CO_2$), which is a GHG, from the air, therefore reducing temperatures inside and out [39].

Living walls and green façades are the two main types of green walls. A living wall consists of panels attached to an internal or external vertical structure (Figure 3), whereas a green façade is a system in which a natural climber plant is grown on the exterior of a building with the help of an auxiliary framework (Figure 4) [40]. The panels are ideal for growing upholstery plants. A green façade is a wall that has been grown over by plants that either climb or cascade over the wall. Initially, the constructors had climbing plants attach themselves directly to the walls [41]. However, green façade practices nowadays have shifted toward constructing structural frames and enabling plants to climb them rather than planting them directly on the walls because of the concern that the root systems of the climbers could potentially cause damage. Plants can be established anywhere from the foundations to intermediate planters to the roofs of buildings. Within a short period of time, these plants completely colonize the walls, changing them into lush, verdant green walls [42].

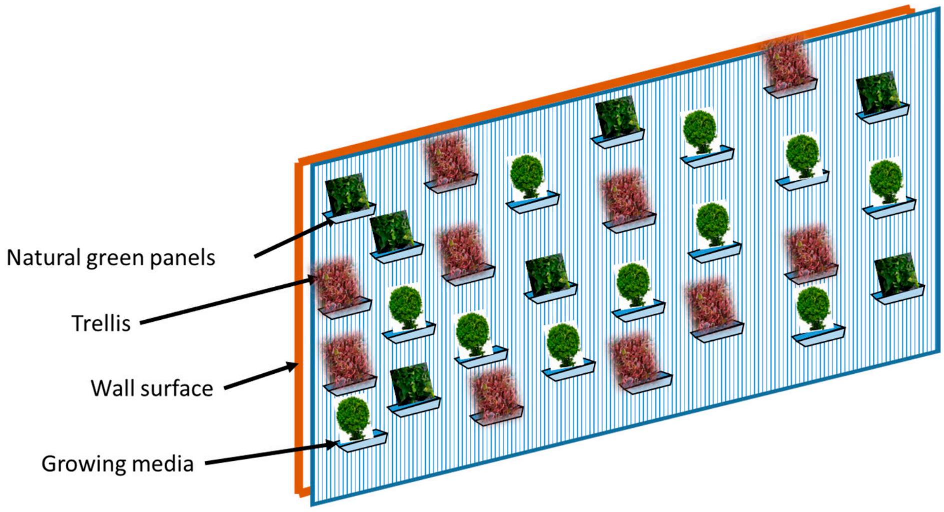


**Figure 3.** Sample structure of a living wall.

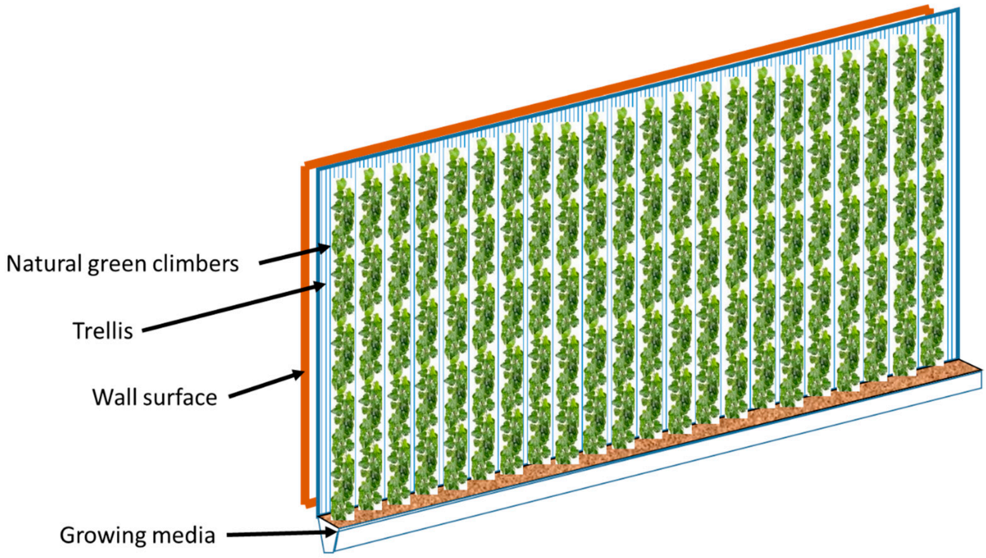


**Figure 4.** Sample structure of a green façade.

A green façade can either be added to an existing wall or stand alone. Living walls are composed of a metal framework, a PVC layer, and an air layer [43]. Due to its relatively low weight, it may be constructed virtually anywhere and in any size. This system supports numerous plant species, including a combination of vegetation, perennial flowers, low shrubs, and ferns, among others [44]. It performs effectively in a variety of climatic conditions. However, by selecting species that are more suited to the current environmental conditions, system maintenance is an important aspect. The variety and density of plant life on living walls, as well as the self-automated watering and fertilizing system that helps keep them healthy, need more attention and maintenance than green façades.

The success of a green wall relies on several aspects, including the growth rate of the plants used in the design, the temperature they can tolerate, and the amount of light they get, all of which must be taken into account when selecting a plant species [45]. Due to a confluence of factors, a poorly thought-out planting scheme might result in an overgrown wall, inadequate sunlight exposure, insufficient water absorption, or even inappropriate plant species selection [46]. Therefore, vertical greening systems, if implemented properly, have the potential to have long-lasting, positive effects on the immediate functional area of the inside building and the greater surrounding area as well as on the health and quality of life of humans in the vicinity. The following Table 3 provides a comparison of the description, benefits, and limitations of different types of green wall.

**Table 3.** Different types of green wall.

| No | Type of Green Wall | Description | Benefits | Limitations |
|---|---|---|---|---|
| **1** | Modular Panel Façade | Made of steel, box arrangement, panel depth between 6 and 25 cm based on plants and planting shrubs | Planting in containers Long irrigation interval Ease of moving boxes Quick growth Drip irrigation No need for ground support | Less possibility of plasticity stress to the plant with height from earth Certain plants only |
| **2** | Modular Trellis Panel Façade | Strong, 3D galvanized steel wire; plants not attached directly to the green façade. limited growth with multiple tendril supports | Large area Can make curved shapes Less stress on the plant Normal irrigation | Concrete wall is needed Speed of growth depends on wall size Ground base needed |
| **3** | Cable–Tensile Façade System | Cable system, planting is possible in ground or between floors or on roof | Suitable for public spaces Stress depends on planting location Normal irrigation Air corridor on the wall | Short distance to the hub Long duration of growth |
| **4** | Cable Façade System | Cable Suitable for rapid-growing plants Ground/cable base | Can construct in many directions Wire net system Wall support Less stress on the plant Normal irrigation Air corridor on the wall | Short distance to the hub Long duration of growth Ground base needed |
| **5** | Wire Net Façade System | Cable Suitable for slow-growing plants Needs support | Integrate with cable systems Easy installation Ability to create different sizes and patterns More flexible Less stress on plants Normal irrigation | Less distance to grids Long duration of growth |
| **6** | Stainless Steel Frame Façade | Less weight-bearing wall Independent structures Gap between façade and frame | Firmly on the ground Airflow to wall Normal irrigation | Long duration for growth |
| **7** | Living Felt Wall | Felt made of non-decaying materials, placing plants in felt pumps and picker irrigation plant in the ground, then transferred to the location | Weight-bearing Allowing airflow Quick growth | Pump for irrigation of plants |
| **8** | Active Living Wall System | Biological filter mechanical ventilation Pull fresh air through a vent Places plant roots between two layers Fertilize through water | Similar to green roof system Increase in air purification capacity Hydroponic system | Ventilation system needed Frequent maintenance |
| **9** | Passive Living Wall System | Light systems Modular panels Drip irrigation system No air circulation needed | Using of hydroponic system | Air purification capacity low |

### *3.3. Green Parking, Pavements and Shaded Streets*

One such method of reducing UHIs is through increasing tree cover and creating shade. Trees' leaf density, leaf area, and evapotranspiration all have a role, as do their geometric qualities. Urban temperatures and land surface elevations may be stabilized to some degree by the careful planning and design of urban landscaping and green areas [47]. During the summer, the amount of solar energy absorbed is decreased as the percentage of vegetative cover increases, especially if the canopy index is high [48]. Trees in urban regions face a number of challenges due to impervious cover, poor soil moisture, nutritional scarcity, a lack of rooting volume, water/air pollution, and transport-related toxicity [49]. The longevity of tree populations in cities is further affected by factors such as low-temperature pressures, anthropogenic heat sources, air turbulence, and high wind speed owing to urban canyons [50]. Tree species vary in their evapotranspiration rates, heat, and drought tolerance based on a number of factors including morphology, physiology, local water supply, and wind velocity. Although pavement surface temperatures are raised by direct solar radiation, they are lowered by tree canopies. As the amount of asphalt, concrete, and other impermeable surfaces grows, the overnight temperatures rise [51]. Improvements in nighttime urban warming mitigation may be achieved by the elimination of non-permeable surfaces.

Increasing the ratio of impervious surfaces to canopy cover is an important mitigating technique. Solar radiation through the canopy helps keep the ground below at a constant temperature. Pavement undergoes a freezing and thawing cycle as a result of nighttime heat loss and temperature drops. Cracks in the pavement form as a result of the pavement's exposure to repeated cycles of freezing and thawing [52]. As the rate of pavement degradation rises, the pavement's useful life decreases. Trees may reduce daytime temperatures, which in turn reduces the temperature gradients between the road and the surrounding landscape. The pavement's durability is increased as a result of this [53]. The UHI may be mitigated by urban shade because it lowers local temperatures and slows down the rate at which heat is conducted away from surfaces. The geometry, structure, leaf size, and canopy cover density of trees are all quantifiable factors in urban shade.

Creating tree-shaded areas improves occupants' thermal comfort inside the built environment in hot climates [5]. Trees with a wide canopy may block solar radiation and the rays reflected off concrete, asphalt, glass, and other man-made surfaces. The quality of shade may be enhanced by increasing canopy leaf area, size, density, projection, and transmissivity [54]. Shade may cut down on heat intake from buildings and other structures, as well as on heat exchange and surface temperatures. Leaf structure, epidermal features, and angle all have a role in reflectance. A foliar canopy affects absorption, and it is most often assessed by calculating the leaf-area index, chlorophyll content, and water content of the plant [55]. The quantity of solar radiation that penetrates a canopy may be measured using a dimensionless ratio such as transmissivity, which is affected by the structure of the canopy [56].

A variety of mechanisms, including reflection, absorption, and transmission, allow trees and other plants to diffuse solar radiation. Part of the solar energy that is taken in is used for photosynthesis, while the rest is transformed into heat [57]. This is because the leaves warm up as they absorb more heat. Water from the leaf is turned into water vapor and exhaled into the atmosphere via the stomata. Water vapor is converted during the conversion process, which results in the leaf cooling as a result of the loss of latent heat [58]. Plants are able to chill the air around them by taking in carbon dioxide during photosynthesis and exhaling it during transpiration. When combined with shade, this technique causes an overall cooling of the environment throughout the summer [59].

The peak air temperature is higher in open terrain than in vegetative areas. Suburbs devoid of mature trees tend to be warmer than their tree-lined counterparts [59]. It is warmer on barren ground than in irrigated areas and it is warmer on artificial turf pitches than on grass grounds. The Leaf Area Index (LAI) is a metric for measuring the impact of trees on urban surface temperatures. This establishes a connection between the amount of greenery present and the amount of water lost to evaporation in urban settings [60]. Several factors, including tree species, age, hydraulic state, vapor pressure deficit, soil nutrient availability, seasonal changes, groundwater conditions, and wind speed, all play a part in determining the LAI [61].

There are techniques to include water storage in paving systems, allowing for the use of evaporative cooling on roads, parking areas, and sidewalks [62]. Cooler temperatures are maintained on water-retentive pavements because less solar energy is converted to heat through conduction. There are several types of water-repellent pavements, including porous pavers, permeable pavers, and pervious pavers [63]. Water permeates porous pavers through tiny holes in their surface. These pavers typically include a cellular grid design, and the holes within the grid are filled with moisture-retaining materials [64]. Grass is a great choice for infill because it promotes transpiration from the root to the shoot of the plant and brings moisture from the ground up to the surface, where it can evaporate and cool the pavements below [65]. In contrast to previous and porous choices, permeable pavers allow water to flow over their surface rather than through them and are made from concrete or kiln-fired clay bricks [66]. In order to facilitate the evaporation of surface water, a path is made between pavers by the use of spacer lugs or small holes. It was about as warm as concrete during the day and about as cool as asphalt at night, making this paver an ideal alternative. It follows that the evaporative cooling effect of permeable pavers is marginal.

## 4. Sustainable Materials for UHI Effect Mitigation

The incorporation of sustainable building materials into the built environment is another key contributor to the UHI impact. The building's preconstruction, construction, and finishing materials all contribute considerably. Streets and pavements composed of impermeable and highly heat-absorbent materials, painting materials with high thermal effects, and utility efficiency appliances that release high heat and GHGs contribute significantly to UHI effects. Sustainable construction materials are not only economically feasible but also minimize harmful emissions and UHI effects, hence minimizing the total environmental impact. Buildings should make use of environmentally friendly building materials and technologies in a manner that is suitable and contextual. Locally made or obtained construction materials qualify as sustainable. These items comprise recycled and industrial byproducts and waste materials. Sustainable materials are thermally efficient and have a lesser environmental effect. The manufacturing of these building materials takes much less energy than the production of contemporary or conventional building materials.

### *4.1. Innovative Streets and Pavement Systems*

The idea of adopting novel pavements to reduce the UHI effect has gained popularity in recent years in highly populated regions. In order to produce cool pavements, conventional pavements may make use of already available pavement technologies by modifying the materials, implementing sustainable strategies, or introducing brand-new materials [67,68]. If a pavement increases solar reflectance ability, increases the evaporation process, or decreases the release of sensible heat into the urban atmosphere, then it will remain cooler than traditional pavement [53]. Cool pavements are categorized into reflective, evaporative, and heat-harvesting pavements [62]. In order to reduce the surface temperature and sensible heat emission, reflective pavements have a higher albedo than regular pavements. Evaporative pavements are those that retain water at the surface or in the subsurface for the purpose of evaporative cooling. Subduing the surface temperature, heat-harvesting pavements collect energy from the sun and use it for other purposes. The topic of cool pavements has expanded beyond pavement cooling technology to include the impact of such pavements on the weather in cities [69].

Paving materials that are designed to keep temperatures down, such as those that are reflective of light, increase the rate at which water evaporates or have some other cooling effect [70]. It will always be colder than standard asphalt, and it will radiate less heat into the atmosphere. Since the hottest time of the day typically occurs in the summer, when the release of sensible heat is crucial to the formation of the UHI, a cool pavement must be able to reduce its daily maximum temperature [29]. Pavements that have been sealed with a material that is reflective of light will have less of an impact on the environment [71]. A sealed surface is created by pressing finely graded aggregates into a thin layer of hot bitumen that has been spread over an existing pavement [61]. Due to the aggregates being partly exposed, the surface albedo should be somewhere between that of the asphalt binder and that of the aggregates themselves [72]. Solar reflection is shown to be highly dependent on the aggregate's color and the pavement's age [73]. Chip seal pavement's albedo is observed to decline with age yet remains higher than that of regular asphalt concrete [74]. Although generating white slurry seal requires re-formulating the emulsifier and increasing the price, it has limited applications because of the increased albedo the pavement receives from it [75]. It is also possible to greatly improve asphalt pavement's reflectivity by the use of other methods, such as painting with light colors or micro surfacing with light-colored materials [76].

Incorporating white cementitious materials and light-colored pebbles into concrete mixes can create highly reflective pavements [77]. The albedo of hydrated concrete is principally determined by the cement's solar reflectance, with other ingredients playing a supporting role. Although the addition of fly ash, which reacts with calcium hydroxide to produce stronger concrete, can decrease albedo slightly, it can also increase longevity [78]. The solar reflecting ability can be altered by a wetting, soiling, and abrasion process after being exposed [79]. The reflectivity of the fine aggregates and paste is what primarily determines the albedo in the aged state. High reflectivity can also be seen in white topping and roller-compacted pavements. Streets with minimal traffic in urban areas may have a white overlay of only two to four inches thick [80].

Although reflective pavements keep the heat off in the summer, they can have the opposite effect in the winter by making the road surface colder [81]. During the summer, a pavement surface with high reflection is preferable, while a surface with low reflectance during the winter is preferable. Due to a reversible molecular structure transition that occurs at elevated temperatures, the albedo of thermochromic materials shifts when their surfaces warm and cool [82]. Thermochromic substances and their doses can affect the transition temperature. Adding $TiO_2$ to this thermochromic coating could increase its reflectivity [83]. When thermochromic pigments were added to asphalt binder, it was discovered that the binder retained its temperature more effectively in both hot and cold climates [84]. Similarly, it was discovered that cement paste with thermochromic pigments could maintain a colder temperature in hot conditions and a warmer temperature in cold environments than plain concrete paste [65]. Thermochromic materials can be impregnated into concrete; however, this process may reduce the concrete's strength.

Therefore, the ability of permeable pavement to maintain a low temperature depends on whether or not the evaporative flux is greater than the extra heat uptake brought about by the pavement's low thermal inertia [85]. A pervious paver is a porous concrete that allows water to flow through it instead of collecting and pooling on the surface. Large, uniform-sized aggregates are coated with a concrete paste or asphalt binder to create pervious concrete [86]. Since the pavement systems drain easily, the permeable pavers in this concrete do not collect or hold too much percolating water. Pervious pavements have been found to be as hot as black asphalt pavements on sunny summer days because of their higher solar radiation absorption and lower heat inertia than conventional pavements [87]. Pervious pavements may be considered cool pavements due to their lower temperature at night and their ability to cool faster than regular concrete. This is because the roughness of the pervious surface reduces its albedo, allowing it to soak up more solar energy than regular concrete would. When compared to conventional concrete pavement, pervious concrete pavement has a lower solar reflectance index [88]. When compared to regular concrete, pervious concrete is reported to have a lower thermal inertia. The texture of pervious concrete is coarser than that of regular concrete. With a higher heat convective coefficient, this concrete could be more effective in dissipating heat in breezy conditions [89].

Unless the pervious concrete is re-wetted at a suitable time, the evaporation of the preceding concrete adds relatively little to the decrease in surface temperature [90]. Too much water seeps through pervious concrete too quickly for it to be effective at preventing evaporation. Adequate water is required for evaporative cooling and water-holding pavements, which retain most of their moisture in the surface layer [76]. Water-retentive pavements differ from permeable pavements in their pore structure and evaporative capacity. Water-retentive fillers are often incorporated into concrete to increase its capacity to store water. A water-retentive pavement is one that, when saturated, can hold onto rainwater for a period of time by using specific filler materials [91]. In addition, when the evaporated water close to the surface is gone, the water-retentive filler's pore structure can draw water from the base via capillary force. After being watered, the dry surface of a water-retentive block can absorb water at a rate greater than its absorptivity [65]. Refilling water-retentive pavements with wastewater is one strategy for increasing their resistance to evaporation [92]. Wastewater is sprinkled on water-retentive pavements in some places to extend the cooling effect of evaporation. The use of high absorptive infill and recycled water for irrigation both assist keep pavements at a more comfortable temperature than the vegetation around them [93].

### *4.2. Various Coating Materials*

#### 4.2.1. Painting with Light-Colored Materials

One potential solution to the UHI effect is the use of solar-reflective coatings for the building envelope [94]. Extensive global modeling and field studies have confirmed that highly reflective materials, when combined with thermal energy storage and conservation measures, are an effective strategy to combat the UHI effect [95]. Traditional cool materials with diffuse reflectance do not appear to resolve concerns connected to rising urban density, such as the proximity of buildings and canyon phenomena [96]. As a matter of fact, with a diffusive nature, some of the reflection will be absorbed by nearby structures. The favorable effect they have on UHIs is also mitigated since reflected radiation from diffuse vertical surfaces is absorbed more strongly by pavements and roads [97]. The ability of retro-reflective (RR) materials to redirect light to their original source is a useful and unique attribute. RR materials are now used for traffic safety applications such as road signs and work clothing but are not commercially available for use as building coatings [98]. Coating urban patterns with RR materials may mitigate UHIs by reducing the amount of sunlight that is reflected to nearby structures and roads [99].

Currently, high reflectance coatings made from acrylic materials, elastomeric, silicone, fluoropolymer, or mixtures thereof, are widely utilized globally to mitigate the UHI impact [8]. Several highly reflective artificial coatings may be far cooler than naturally occurring white materials but still a few degrees warmer than the ambient temperature [100]. The solar reflectance, emissivity value, and thermal capacity of white reflective materials all contribute to the surface temperature range that these materials exhibit. Hence, most white reflective coatings deteriorate and lose their luster, which is a major issue for the industry [101]. A further problem with white coatings is that they allow bacteria to multiply rapidly on the surface [102]. Roof washing can restore some of the roofing material's optical qualities but may reduce its reflectivity. White reflective coatings lose their reflectivity months to years after they are applied.

Many factors, including the coatings' composition and treatment, as well as the surrounding environment, affect optical performance and the likelihood of an increase in optical durability [103]. Compared to white paints made with organic binders, those made with inorganic components are more optically stable and have higher solar reflectance and emissivity. It has been discovered that doping titanium dioxide with Al, Li, or K significantly improves the photostability of the coatings without affecting their reflectance [8]. The coatings' self-cleaning characteristics and optical performance are both improved by the incorporation of photocatalytic technology. When titanium dioxide ($TiO_2$) nanoparticles are incorporated into a coating, the deposited organic substances are broken down into sulfate, water, nitrate, and carbon dioxide, which are then washed off by water cleaning or rain [104].

This drastically reduces the adhesion of bacteria to the coating's surface. The surface temperatures of white, man-made materials with high reflectivity and emissivity are only slightly higher than the surrounding air temperature. Since they dramatically lower the emission of sensible heat into the atmosphere, they are very helpful in preventing cities from becoming uncomfortably hot. An important downside of highly reflecting white materials is that their optical and thermal performance may degrade significantly with age [105]. There are a variety of mitigation solutions that make use of commercially available colored, spectrally selective materials with high spectral reflectivity in the near-infrared wavelength range and a high emissivity value. Materials that reflect infrared rays have a much higher solar reflectance compared to materials of the same color and type [106].

To boost reflectivity, scientists have turned to polymeric inorganic hybrid materials and organic or inorganic pigments with near-infrared spectrum reflectivity [107]. Pigments that reflect infrared light and are made from inorganic materials have superior optical stability, great durability, and high temperature stability. Heavy metals in pigments could be bad for the environment. For the most part, the melt blending procedures of polymeric inorganic hybrid materials are less harmful to the environment [108]. Infrared-reflecting pigments can be used with any solvent, including those used to dissolve polyesters, fluoropolymers, and acrylics, as well as those used in water-based coating chemistry [109]. When pigments are combined with binders and other compounds, a coating can be created. It is reflective because the coating's pigment has a different refractive index in the infrared spectrum than the binder.

On the other hand, if the coating's transparency to infrared (IR) radiation is not affected by the difference between the IR refractive indexes of the pigment and binder, then the coating will be transparent to IR radiation [110]. When trying to generate a reflective surface, infrared reflective coatings can be put directly over any material, while infrared-transmitting coatings require a near-infrared reflecting background. A near-infrared transmission coating can be applied when the substrate has a high IR reflectance; however, a white basecoat and an IR-transmitting coating can be applied instead when the substrate is absorbing [111]. The reflectance of the substrate, the thickness of the coating, the roughness of the surface, and the possible backscattering of the pigments all play major roles in determining the composite material's spectral reflectance [112].

The optical properties of the pigments, binder refractive index, pigment volume concentration, and particle size all have a role in regulating this. However, the near-infrared (NIR) and solar reflectance of cool coatings are observed to increase with the thickness of the white base coat and can reach a maximum constant value above a specific thickness, suggesting that smoothing the rough surface of the materials boosts reflectivity across all wavelengths. Roofing and paving materials can receive IR reflective coatings [113]. IR--reflecting materials have a far lower surface temperature than traditional materials of the same color, allowing for less sensible heat to be released and significantly less urban hyperthermia as a result [114]. The emittance and solar reflectance of IR-reflecting materials exposed to the external environment are diminished due to weathering, aging, and soiling [115].

#### 4.2.2. Phase-Change Materials (PCMs)

Another tactic for minimizing the UHI effect is the use of PCMs that store and release latent heat to boost the apparent thermal capacity of buildings and urban structures and lower their peak surface temperatures. Most PCMs are noncorrosive, nontoxic, and compatible with a wide range of other materials used in asphalt and concrete pavement and roofing goods, and they can be categorized as either organic, inorganic, or eutectic mixes [116]. With the help of PCMs, asphaltic pavements are less likely to experience thermally-induced rutting and cracking, and the viscoelastic qualities of asphalt binders are less likely to degrade [8]. Concrete pavements' resistance to cracking, curling strains, hydration processes, and thermal shrinkage can all be enhanced by using PCMs [117]. It is feasible to reduce the surface temperature of pavements and release the stored energy at a later time by including PCMs within the pavement's mass [118].

The amount of PCMs in the entire mixture, the phase-change materials employed, the method used to incorporate PCMs into the pavement, the thermal and optical characteristics of the pavement materials, and the local climatic circumstances all influence how much the surface temperature can be lowered [119]. The thermal capacity and the heat transmission quality of the pavements are both affected by the volume percentage of the PCMs [120]. Because of the low conductivity in the liquid phase, PCMs impede heat transfer in the mass of the pavement, leading to higher surface temperatures even as their presence in the mix increases the possibility for latent heat storage and hence reduces surface temperatures [94]. Choosing the PCM melting point is important because it determines how long it takes to heat up the pavement to its maximum temperature and how fast it cools down again [121]. The melting temperature selection should be based on the local climate and the thermal balance of the pavement [122]. It is possible to use many PCMs, some of which have quite varied melting points. When used in construction or urban planning materials, PCMs pose a serious leakage danger when in their molten condition [123]. Micro-encapsulation, macro-encapsulation, and porous inclusion are among the preferred ways of putting them into construction materials [119].

#### 4.2.3. Color-Changing Materials

Materials that undergo a thermochromic color change in response to temperature can, for example, be bright and reflective in the summer and dark and absorbing in the winter. A wide variety of thermochromic materials, including thermochromic combinations, with a wide range of color-changing mechanisms, are known. Sol-gel films' luminescence shifts [124], surface plasmon absorption [125], liquid–crystal phase transitions [126], dye–dye and dye–polymer aggregation and disaggregation mechanisms [127], photonic crystals' refractive index modulation [128], and pH changes [129] are the most common examples of the many known mechanisms. Thermochromic pigments and leuco dyes require the use of three distinct components: a solvent that regulates the color-change temperature; a color former such as spirolactone, spiropyran, triphenylmethane, or fluorane; and a color developer [130]. At the melting point of the thermochromic substance, the solvent turns from a solid to a liquid, allowing the developer and the color former to dissolve into it [131].

Thermochromic systems lose their color when the hydrogen bonds between the solvent and the color former are severed [132]. In thermochromic materials, the solvent reverts to the solid phase and the color former regains its original color when the temperature drops below the freezing point [133]. Leuco dyes' color transition temperature is easily modifiable by experimenting with various dyes and solvents. By combining different thermochromic ingredients, it is possible to create thermochromic mixes with more than one color change. Without damaging their color-changing characteristics, the composites can change from gray to pink, green to blue, and white at temperatures close to 24 °C [8]. It is the molar ratios of the three components in the thermochromic mixture, as well as their chemical properties, that determine the color quality and thermochromic qualities of leuco dye-based materials [134]. Important issues with aging arise with thermochromic materials based on the use of leuco dyes because of fading and the loss of reversibility. Molecular oxygen is reduced and reactive oxygen species are produced in an irreversible photochemical process triggered by ultraviolet (UV) radiation [135]. There is a great possibility for mitigation in the built environment from thermochromic materials.

#### 4.2.4. Fluorescence Materials

One of the creative strategies that may be used in UHI impact mitigation procedures is to capture the photovoltaic energy of solar radiation, release the light emission, and aid in increasing the surface's ability to reflect light [8]. There are two different kinds of fluorescent substances: bulk fluorescent substances like ruby and nano-fluorescent substances like quantum dots [134]. Combining a polymer with a colloidal quantum dot solution is an alternate method for depositing quantum dots on a substrate. By using this method, the danger of luminous deterioration brought on by the aggregation of quantum dots is reduced [136]. Quantum dots and fluorescent materials offer a great opportunity to reduce the UHI effect.

Some pigments have shown promise for effective fluorescence and look to be economically and enduringly viable. Ruby, an aluminum oxide pigment with chromium added, was the first of its kind. It is useful for making things in shades of red and pink [137]. Another option is calcium copper tetra-silicate with either barium (Ba) or strontium (Sr) in place of the calcium, the finest results to yet have been obtained with calcium and strontium compounds [138]. The near-infrared fluorescence is preserved throughout the mixing process. A coating of synthetic rubies, with its rich dark red hue and fluorescence advantage, is a positive sight [139]. These pigments are alkaline earth copper silicates, which are often manufactured using solid-state chemical methods. In a nutshell, the oxides or carbonates of the component metals are well mixed and then heated in air to a temperature approaching 900 °C for a few hours [140]. It is common for the dark compound copper oxide to remain as an impurity after the synthesis. The pigment will be gray instead of blue if there is an excess of copper oxide [141].

### *4.3. Use of Energy-Efficient Appliances*

The energy used by buildings and the one-third of all GHG emissions they account for are both significant contributors to UHIs. Reducing energy consumption and running costs and lowering greenhouse gas emissions across the life cycle of buildings requires proper building design and construction, the sufficient use of energy sources, and the discovery of innovative materials [142]. Climate parameters and climate zones are crucial in adjusting to and minimizing the impacts of UHIs since they influence so many elements of building design and operation [143]. New energy budgets must be established, and the energy efficiency of buildings and whole cities must be improved. Taking climate dynamism into consideration throughout the building design process is crucial because it allows for more accurate sizing of residential hot water, heating, and cooling systems, as well as more thoughtful material selection [144]. To achieve a building design that reduces the negative impacts of UHI while still adapting to the urban environment, codes and standards must be flexible enough to accommodate changing circumstances.

Thus, it is important to establish new climatic zones and formulate suggestions to provide appropriate thermal conditions for future epochs. The construction industry has a unique potential to cut down on waste disposal and resource consumption via the development of economically and ecologically sustainable materials based on the integration of secondary materials as alternatives. Appliances that reduce energy use have an enormous impact on these two important environmental goals. Materials that quickly disperse energy are highly valued in the quest for efficiency and the mitigation of carbon emissions. However, domestic energy savings are reliant on users' technical and habitual behavior; in fact, energy-efficient home appliances provide better energy efficiency and sustainability than the habitual adjustment of turning off appliances when not in use [145].

## 5. Challenges in Implementing UHI Mitigation Strategies

Despite the fact that a great deal of work is being done to find solutions to the problem of the UHI in highly urbanized regions where environmental concerns are paramount, there are still certain practical limitations that are encountered by the initiators. The lack of government legislation, inadequate technology, an inaccurate estimate of the economic advantages, and reluctance on the part of individuals are all examples of these limitations. The largest problem is the government's lack of policies aimed at reducing UHIs and providing direction to those who would want to implement such efforts. As previously indicated, government policies are the single most effective tool for advancing urban sustainability programs [146]. Yet, ineffective government initiatives may dampen public excitement.

However, while being aware of the environmental, economic, and social advantages of implementing sustainable initiatives in a voluntary manner, developers and private sectors sometimes find it difficult to use newly offered technology. The failure to regularly update the local experience and feedback report is also cited as a serious challenge. Despite the obvious advantages to business, local governments in certain nations continue to enact policies that are harmful to the environment [147]. Companies in the private sector are often hesitant to take on such initiatives because they fear failure in the absence of adequate government oversight and funding [148]. Although there has been a lot of attention on innovation and technical progress in the research studies, there are still several technological roadblocks that prevent widespread implementation. While each city has its own unique characteristics from its climate to its high concentration of urban features, different applications must be adapted to work in each one.

Building characteristics, roof pitches, plant types, and other accessibility variables all put constraints on the available options. To provide one example, the roofs of older buildings are not designed to support considerable weight; therefore, only a large system with low structural loading may be employed. However, the lightweight and expansive mechanism is unable to withstand much wind. Furthermore, urban floods, the UHI phenomena, and the diminishment of urban landscapes are all primarily driven by the growth in buildings and pavement. Numerous cities are dominated by skyscrapers; however, these structures almost never have any roof space left over for greenery because of the presence of expensive and necessary construction services. In addition, green roof plants may attract mosquitoes and other pests, which can cause problems for nearby households. Metals like aluminum, copper, zinc, and iron, used in roofing, may contribute to environmental degradation if they are not used appropriately [149].

Many advantages, including those related to protecting the environment, enhancing biodiversity, and enhancing occupants' quality of life, cannot be evaluated in terms of economic returns and hence act as a barrier to adoption by developers and the private sector. However, there are challenges in calculating the economic advantages of UHI reduction owing to a lack of appropriate resources and improper auditing methods. Meanwhile, prices increase. The upfront costs of designing, building, maintaining, and watering such a roof might be more than conventional roofs [34]. Dislike might emerge from a lack of understanding and knowledge about the repayment time frame. Economic gains are complicated by the widely varying lengths of time it takes to get a return on investment [150]. The time it takes to recoup the investment made in a large project is a drawback despite the fact that it may ultimately save money [151]. A major roadblock is the reluctance of designers and developers to implement new tactics, mostly due to concerns that locals will not like them and the resulting excess of unnecessary space. This issue emphasizes the need for a more informed and supportive public.

## 6. Discussion

The UHI effect and its harmful effects from built environments inside urban areas were detailed in this study. It is obvious that the conventional methods of construction and the rapidly rising number of buildings in urban areas have exacerbated environmental challenges. Multiple initiatives are now conducting research and development to identify the optimal solution for low-impact architecture and design of buildings and built environments that will also minimize the UHI effect. This research focused on two primary strategies: the incorporation of green infrastructure into the built environment and its components and the use of sustainable materials in buildings. Green infrastructure, such as green roofs, green façades, green parking, green roadways, and green pavements, were considered and examined. Incorporating plants and the evapotranspiration of plants, reducing the heat impact and increasing the cooling nature of the environment, and also adding value to the green space and protecting the ecosystem, green roofing has been identified as a potential solution to conventional roofing systems by attaching plants and regulating the thermal effect within the building interior and the near surroundings of the building.

However, this has also brought about some unfavorable outcomes, such as providing a safe haven for insects and certain dangerous reptiles and necessitating the implementation of remedies to problems like water leaks and root penetration in the structure. In contrast, green façades use the vertical surface area of the structure and may be used without affecting the building's performance. Similar to green roofs, green walls and living walls are a kind of vertical garden seen on high-rise buildings. Others are framed and connected to the buildings rather than the façades themselves. Green roofing and other forms of direct façade attachment have been linked to structural damage and water leakage, although these problems may be mitigated if the right preventative measures and repair methods are used [152]. However, such damage caused by plants may be avoided in the case of frame-supported façades, although doing so may lead to increased expenses.

It is true that the designers of sustainable green buildings are being urged to cut down on parking spaces in an effort to limit the number of individual vehicles used. However, in certain circumstances, parking spaces are essential and the number of vehicles is unavoidable due to insufficient public transit options. With the use of tree canopies and highly reflecting indexing paint, parking lots may be made more environmentally friendly and less detrimental to the environment. This will cause plants to produce a cooling action known as evapotranspiration. Pavement and road designs that include vegetation to minimize heat gain, promote water infiltration and percolation, and decrease the UHI impact are preferable from an environmental and economic perspective. The heat absorption of a building and the UHI effect are both largely attributable to the materials used in construction [143]. The thermal impact of the materials, including their absorption and reflection of heat, must be carefully examined throughout the construction process. Using sustainable construction practices and sustainable building materials in high-rise structures is the most effective way to mitigate the UHI impact. By using highly reflective paint, you may limit the amount of heat absorbed by a building's exterior.

Incorporating phase-change materials into construction allows for the absorption and storage of thermal energy through a phase transition. Because of this, the ambient temperature drops. Color-changing materials can be white during times of high solar radiation, increasing reflectivity and decreasing heat gain, and black during times of low solar radiation and low temperatures inside the building, absorbing heat and lowering the need for heating, both of which help to lower GHG emissions and the UHI. By doing so, the fluorescence effect is achieved and the heat gain of the building is decreased thanks to the incorporation of fluorescence materials into the building components. GHG emissions may be lowered and energy use can be lowered by using appliances that are more energy-efficient. In this way, it is not only worthwhile but also economically useful, and it helps to mitigate the UHI impact. While all of these green infrastructures and materials have helped with UHI reduction and mitigation measures, there are several obstacles to their widespread use in tall buildings that must be overcome. A lack of government regulation, poor technology, an overestimation of economic benefits, and individual hesitation are all factors holding progress back. Sustainable built environments in dense urban settings will pave the way for environmental friendliness, a lesser UHI effect, and comfort for occupants and other living beings and integrated ecosystems in the future by fixing the problems and making it accessible to anyone, anywhere in the globe.

## 7. Conclusions

This article compares and analyzes many cutting-edge strategies for decreasing the negative impacts of UHIs. The use of green roofing systems, green façades, and green parking, pavement, and streets in place of traditional nature enhances the amount of green space, aids in the implementation of heat reduction measures, and lessens the impact on the environment through the cooling effect of metabolic processes. Green walls provide a viable alternative and a large canvas on which to grow vegetation vertically. Sustainable greenery mitigation measures will be bolstered by the replacement of roads and pavements for walkers in highly urbanized areas with green installations. To further minimize solar radiation absorption and boost surface heat, shading arrangements and coating materials with specialized functions like white coloring, PCMs, color changes, and fluorescence need to be implemented.

The adoption of energy-efficient appliances is an important step in mitigating the effects of global warming caused by the production of GHGs and limiting the rise in global surface temperature. The buildings, parks, water features, roadways, and recreational spaces that make up urban areas will vary from one location to the other. Depending on the type of building (such as residential, hotel, industrial, office, and retail complex buildings), many greening initiatives and methods may be viable to execute. This study's main limitation is that it only took into account typical buildings and their accompanying subcomponents like parking lots, pavements, and roadways. Hence, there are numerous challenges that must be overcome before this idea can be used on a global scale, but doing so will help to move closer to an environment where UHIs have less of an impact and, hopefully, eventually have no effect at all. This is true on a local as well as global scale, and it may be achieved via the implementation of efficient laws and regulations, the discovery of new methods for handling existing problems, and the sharing of the findings of relevant research and development initiatives.

The key findings from this review are listed below:

- The rapidly urbanizing cities around the world necessitate ecologically mindful and sustainable ways to build.
- The UHI effect is a critical urban phenomenon; however, adequate mitigation efforts will lessen the effects on the environment as well as on the safety and health of inhabitants.
- Infrastructure and building materials as well as greening the built environment are crucial in managing UHIs.
- New and existing buildings should include infrastructure with green roofs, walls, façades, green parking, water retaining pavements, and shaded roadways, which have proven benefits toward mitigating UHIs.
- The incorporation of sustainable and environmentally friendly materials into the built environment, such as innovative street and pavement systems, a variety of coating materials, and the use of energy-efficient appliances, has provided a number of benefits and been proven to be highly effective in lowering the UHI effect.

**Author Contributions:** Conceptualization, A.M.M.I., H.-W.C., M.M.F.S. and E.J.; methodology, A.M.M.I., H.-W.C., N.M. and E.J.; validation, H.-W.C., C.Y.W., N.M. and E.J., formal analysis, A.M.M.I.; investigation, A.M.M.I.; resources, A.M.M.I., H.-W.C. and E.J.; data curation, A.M.M.I.; writing—original draft preparation, A.M.M.I.; writing—review and editing, H.-W.C., N.M. and E.J.; visualization, A.M.M.I. supervision, H.-W.C., N.M. and E.J.; project administration, A.M.M.I.; funding acquisition, H.-W.C., N.M. and E.J. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available.

**Acknowledgments:** The authors are grateful to the peer reviewers for reviewing the manuscript and providing valuable feedback.

**Conflicts of Interest:** The authors declare no conflict of interest.

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