

The Efficacy of Green Roofs in Mitigating the Urban Heat Island Effect

Jacob J.

Mountain View High School, 1614 Oak Ave, Los Altos, CA 94024, United States

ABSTRACT

The Urban Heat Island (UHI) effect is a phenomenon where urban cities experience significantly warmer temperatures than their surrounding rural areas due to human activities and darker-colored surfaces. The UHI effect poses significant environmental, economic, and public health risks. This literature review synthesizes existing research to investigate green roofs as a nature-based solution, their impact, and evaluates the effectiveness of extensive and intensive green roof types. An analysis of the three mechanisms that green roofs use to impact temperature: evapotranspiration, shading, and thermal insulation was conducted. A key finding is that their performance is not uniform; intensive systems generally provide superior cooling but require deeper substrates and greater plant biomass, while extensive systems are less impactful but offer a more cost-effective, accessible alternative. However, the cooling potential of both types is also dependent on climate and soil moisture, with a certain “tipping point” below which evapotranspirative cooling is far less effective. The review concludes that green roofs are an effective strategy for reducing Urban Heat Island Intensity (UHII), but their optimal implementation depends on designs based on the context, supportive policies such as mandates and financial incentives, and the local climate. Future research should focus on the long-term performance of green roofs, as they are a recent solution to the anthropogenic climate-induced UHI effect, and determine which plants are optimized for efficiency across different climatic zones and water usage.

Keywords: Green roofs; extensive green roofs; intensive green roofs; evapotranspiration; Urban Heat Island; urban cooling; nature-based solutions; climate mitigation

INTRODUCTION

In the modern world of cities, the dark surfaces of asphalt pavements and conventional rooftops have catalyzed the phenomenon known as the Urban Heat Island (UHI) effect. This effect is characterized by a disparity between a city's temperature and its

rural neighbors, a problem that exacerbates energy consumption, elevates air pollution levels, and poses severe public health risks during heatwaves to citizens in those cities (1). The primary causes of the UHI effect are the lack of vegetation, which provides shade and evapotranspirative cooling in a neighborhood. Instead, cities are constructed with heat-absorbing and re-radiating common building materials (2). As cities worldwide seek sustainable solutions to this growing challenge, green roofs have emerged as a promising strategy to mitigate the UHI intensity (UHII) (1). The Urban Heat Island intensity is the quantifiable temperature difference between an urban area and its

Corresponding author: Jacob J, E-mail: jiangt72@gmail.com.

Copyright: © 2026 Jacob J. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Accepted August 12, 2026

<https://doi.org/10.70251/HYJR2348.4410611068>

surrounding, less-developed rural areas.

Urban planners have developed several strategies to combat the UHI effect. One example is using high albedo materials to reflect solar radiation, building reflective or “cool roofs” (3). Another potential solution is having urban forestry and street trees provide increased shade and evapotranspirative cooling, and installing permeable pavement, which allows water to infiltrate the ground more easily (1). However, each of these approaches has limitations. Reflective roofs do not provide an ecological benefit that vegetation does, and urban tree planting is not always feasible in dense cities without available ground space. On the other hand, Green roofs have emerged as a promising alternative because they utilize unused rooftop space to reintroduce vegetation, with about 15-25% of a city’s total surface area as available roof space instead of valuable ground-level land (1).

Green roofs (vegetated roofs or eco-roofs) are systems where a roof is covered with vegetative shading over the roof. Unlike other mitigation strategies, green roofs provide a variety of benefits. For example, they not only cool the urban environment but also manage stormwater, enhance biodiversity, and improve building energy simultaneously (4). Green roofs are categorized into extensive or intensive types; extensive green roofs are characterized by a shallow growing medium (typically 2–6 inches deep). The vegetation is low-weight, drought-tolerant plants like sedums with minimal maintenance requirements. In contrast, intensive green roofs require deeper soil (6 inches to several feet). Intensive green roofs support a wider variety of plants, such as shrubs and small trees. However, they have a greater strain on the roof structure and require more maintenance. Intensive roofs resemble more traditional rooftop gardens (1).

Green roofs have great potential for combating UHI. This potential lies in their ability to reintroduce natural processes that happen in vegetation that have been lost in urban areas. These mechanisms are shading, evapotranspiration, and thermal insulation. Through these mechanisms, green roofs can significantly reduce not only surface temperatures, but also ambient air temperatures. Wong *et al.* (2021) found that green roof surfaces can be up to 54 degrees Fahrenheit, or 30 degrees Celsius, cooler than conventional roofs, which shows their impact on reducing heat transfer into buildings and surrounding urban air (5). Similarly, the U.S. EPA reports that roofs with vegetation can be up to 56°F cooler than conventional rooftops on summer days (1). Beyond just cooling, green roofs can also provide benefits such as stormwater management, carbon

sequestration, as well as habitat creation. Research has also shown significant energy savings, with a city-wide implementation by Seoul designers of extensive green roof systems. Lee *et al.* (2024) found that extensive green roofs could reduce monthly energy consumption by up to 0.64 kWh·m⁻², 7.7% of the city’s energy usage at the time (6). Additionally, Santamouris further reviews green roofs’ contribution to reducing energy demand for cooling cities, demonstrating their multifunctional system beyond just controlling heat (3).

However, green roofs’ effectiveness varies significantly based on their shape and system design, with the largest distinction between extensive and intensive systems. They can also be influenced by regional climatic conditions, such as temperature, surrounding humidity, and precipitation patterns (4,5). This variability means that a one-size-fits-all approach is ineffective, and a clear synthesis of their performance differences is currently lacking in the literature. To address this, this review seeks to synthesize existing research to answer the following research question: How do green roofs affect UHI, and what is the effectiveness of different types of green roofs? This review focuses on analyzing the mechanisms of cooling and the efficiency of extensive vs intensive systems.

To answer this question, this paper has been separated into several key sections. First, Section 2 discusses the intricacies and harm that the Urban Heat Island can cause. Then, Section 3 analyzes the primary biological mechanisms of how green roofs provide cooling, such as evapotranspiration and shading. Following this, Section 4 directly compares the effectiveness, costs, and benefits of extensive versus intensive green roof systems. Section 5 evaluates the performance of these systems under different climatic and regional conditions. Finally, Section 6 concludes with a synthesis of these findings, potential policies that can be implemented to reduce the UHI effect, and possible recommendations for future research. Overall, this review aims to synthesize current research on the cooling mechanisms of varying green roofs, compare performance between system types, and evaluate the resulting impact on the urban heat island effect.

THE MULTIFACETED HARMS OF THE URBAN HEAT ISLAND EFFECT

While the UHI effect is commonly viewed as merely a disparity in temperature, its true impact can be far greater. It has a drastic effect on the environmental,

economic, and social parts of urban society. The UHI effect is not just a matter of discomfort to an urban citizen; it is a significant environmental issue that has high costs for a city and its inhabitants.

Public Health Crises And Elevated Mortality

The greatest harm that UHI can have on humans is its impact on our health. Increased ambient temperatures are significantly augmenting the number of heat-related illnesses, such as heat exhaustion, heat stroke, and even cardiovascular and respiratory complications (1). These extremely dangerous conditions threaten the lives of many citizens, and these changes in temperature are not limited to the hottest period of the day; the elevated nighttime temperatures prevent us from recovering from the greater heat exposure. During periods of extreme heat like summer highs, populations such as the elderly, children, outdoor workers (e.g., construction), and those with pre-existing health conditions are vulnerable to heat-related illnesses. UHI can also have an effect on air quality. The increased heat accelerates chemical reactions that produce ground-level ozone (also known as smog). Smog is very dangerous, as it's an extremely potent respiratory irritant, which contributes to cases of asthma and other chronic lung diseases across the world (4). This dual effect of heat and poor air quality greatly threatens compounding health risks.

Increased Energy Consumption and Strain on Infrastructure

The UHI effect has created a positive feedback loop of energy demand. As temperatures rise, demand for air conditioning increases to compensate for it. This inevitably leads to a dramatic increase in electricity consumption, raising costs for residents and businesses, and a heavier strain on the energy grid, which increases the risk of blackouts during extreme heat events in urban areas (1). The energy required for this compensation is often generated by fossil fuel-powered plants, which in turn release more greenhouse gases and air pollutants, further contributing to regional warming and air quality problems, a positive feedback loop of environmental degradation.

Economic Impacts and Reduced Labor Productivity

The consequences of UHI translate into substantial economic losses. These can include direct costs, such as higher energy bills citywide (1). There are also indirect costs, such as lost labor productivity (7). Extreme heat can make outdoor work, like construction, extremely

dangerous, delaying construction and other industries, while also reducing cognitive function and productivity in non-climate-controlled indoor environments. The potential of heat exhaustion or heat stroke raises potential healthcare costs; extreme temperatures wear down infrastructure like roads and electrical systems, and reduced water quality is due to heated stormwater runoff.

Environmental Degradation and Water Quality

Finally, heated stormwater runoff can be extremely detrimental. Impervious surfaces like concrete roads transfer the heat into the stormwater runoff, which then flows into rivers, streams, and lakes. The sudden increase in the water temperature can be lethal to aquatic life, such as fish and other organisms that are sensitive to water temperature (1). The heated runoff also contributes to thermal pollution, which disrupts local aquatic systems and increases thermal pollution (8). This intricate link between land-based heat and water health is a critical, though often overlooked, environmental harm.

In summary, the UHI effect is more than just an increase in temperature. It is a threat to public health (9), a driver of increased energy consumption and economic costs (1), and a cause of urban environmental degradation. Fully understanding the possible harm that the UHI effect can have is essential for justifying and prioritizing urban mitigation strategies, such as green roofs (4).

MECHANISMS OF GREEN ROOF COOLING

Green roofs mitigate the UHI effect through a combination of biological and physical processes that alter the surrounding temperature. The primary mechanisms that are identified in the literature are evapotranspiration, shading, and thermal insulation.

Evapotranspiration

Evapotranspiration, the process of evaporation from the soil and transpiration from plants, is one of the principal cooling mechanisms. This natural process consumes solar energy to power itself, thereby reducing the energy available to heat the surrounding area (10). The effectiveness of evapotranspiration is extremely dependent on the available moisture in the soil. Mihalakakou *et al.* found that well-watered green roofs were much cooler at night compared to a conventional roof (2). However, the study also identified a “tipping point” around a soil moisture content of $0.12 \text{ m}^3 \cdot \text{m}^{-3}$. Below this tipping point, the cooling effectiveness

diminishes, and if it falls into extremely dry conditions, the cooling effectiveness could disappear entirely (11). This study highlights that the cooling potential of evapotranspiration is not constant; it rather depends on the water availability and irrigation practices.

Shading And Albedo

The second principal cooling mechanism is the shading of the roof. The vegetation layer of a green roof provides direct shading, which intercepts solar radiation before it can hit and heat the underlying roof, preventing a drastic increase in temperature (5). Furthermore, the plant canopy typically has a higher albedo than conventional dark roofing materials, such as asphalt. Albedo is the reflectivity of a substance, and albedo itself is a cooling mechanism, like the glaciers at the North Pole. A plant that has a high albedo results in a greater proportion of incoming solar radiation being reflected into the atmosphere, rather than being absorbed, which directly reduces the surface heat gain (3). The combination of shading and higher albedo can lead to substantial surface temperature reductions. Studies show that green roof surfaces can be up to 30°C (54°F) cooler than conventional roofs, lowering the heat transferred through the building and the surrounding urban air (5).

Thermal Insulation

The final cooling mechanism is thermal insulation, specifically of the plants and the building. The substrate and vegetation layers act as a thermal buffer, reducing heat transferred into the concrete and building, which allows this insulation effect to moderate indoor temperatures. For example, green roofs can reduce the heat entering the building during summer and the heat escaping during winter (12).

The combined impact of the three mechanisms evapotranspiration, shading, and insulation, also translates into significant energy savings for buildings. The U.S. EPA states that green roofs can reduce cooling requirements by 70% and lower indoor air temperatures by 27°F compared to conventional roofs (1). These reductions have side effects, as reducing the cooling demand will lower the associated greenhouse gas emissions from power plants, which will create a positive feedback loop for urban climate mitigation.

COMPARING EXTENSIVE AND INTENSIVE GREEN ROOF SYSTEMS

Now that we have discussed the processes green roofs use to cool the roof, we can differentiate the 2 types of green roof systems. The structural and design differences between extensive and intensive green roofs often lead to distinct performance characteristics, cooling efficiencies, and economic considerations. These important distinctions make the choice between them a very critical strategic decision. A comparison of these systems is presented in Table 1.

Structural and Vegetation Differences

The fundamental distinction between green roof systems lies in the depth of the growing soil. Extensive systems utilize a shallow substrate (less than 6 inches), which limits the available plants to hardy, drought-tolerant vegetation. They often consist of sedums, mosses, and grasses to resist extreme weight (1). Extensive roofs are extremely lightweight and often more suitable for retrofitting existing buildings, not requiring any major structural reinforcement, making it more price-efficient. In contrast, intensive systems, with their deeper soil

Table 1. *Structural and Functional Comparison of Extensive versus Intensive Green Roof Systems.*

Characteristic	Extensive Green Roofs	Intensive Green Roofs
Growing Medium Depth	2-6 inches (1)	6+ inches to several feet (1)
Vegetation Types	Sedums, grasses, mosses, drought-tolerant herbs	Shrubs, perennials, grasses, small trees
Structural Support	Minimal, often suitable for retrofits	Significant, requires planned reinforcement
Maintenance Needs	Low, occasional weeding and inspections	High, regular watering, weeding, and pruning

Note: "Extensive" refers to shallow green roof systems roughly 2-6 inches of growing medium, often consisting of drought-tolerant and low growing vegetation. "Intensive" refers to deeper systems around 6+ inches to several feet, that support diverse plant communities, including shrubs and small trees. Data compiled from U.S. EPA (2025), Green Roofs for Healthy Cities (2025), and Getter & Rowe (2006) (1, 13, 14).

substrates (6 inches to several feet), can support a much more diverse array of plants, such as perennials, shrubs, and even small trees (13). This greater diversity and biomass come at the cost of significantly higher weight, which will require robust structural support from the building and more intensive maintenance akin to a ground-level garden (14).

Comparative Cooling Effectiveness

Research consistently indicates that intensive green roofs generally offer superior cooling potential, especially considering the city's ambient air temperature reduction. A modeling study in Berlin found that irrigated intensive green roofs can reduce said ambient air temperature by 0.71 K during the day (4). In the metropolitan area of Adelaide, a study concluded that intensive, or deeper, green roofs have far greater temperature reduction compared to extensive counterparts (15). The reason for this is that a deeper substrate allows for greater root growth, more water retention, and more constant evapotranspirative cooling, especially during dry seasons.

This is not to say that extensive systems are completely ineffective. Under well-watered conditions, they contribute significantly to cooling effectiveness. However, their performance is far more susceptible to variables in the climate. A study in Utrecht showed that extensive sedum roofs have an average 24-hour effect of a slight (0.2°C) increase in air temperature 15 cm above the roof, but their performance diminished to that of a conventional roof during dry conditions (16). Therefore, while the intensive systems offer far higher peak performance, extensive systems remain a faster, valuable, and lower-cost option, particularly when project constraints like costs are low.

THE ROLE OF CLIMATE AND REGIONAL VARIABILITY

As previously established, cooling performance depends on the type of green roofs, but they could also be affected by local and regional climatic conditions. While not focusing on the effect of climate on green roofs, green roofs still depend on factors such as the background climate, various seasonal variations, as well as precipitation patterns.

The Influence of Climatic Zones

The benefits of green roofs can fluctuate greatly depending on the local Climate. Research consistently

shows that their performance greatly benefits from a humid subtropical climate (6). A large-scale study in Seoul, which has a humid climate, found that a city-wide implementation of extensive green roofs could reduce monthly energy consumption by up to 0.64 kWh·m⁻² (7.7%) (6). This reveals the great potential of urban green roofs in these climates. However, the cooling effectiveness in these regions is also different from other meteorological conditions, especially the availability of water for evapotranspiration (17). In contrast, the performance of green roofs can vary in other climate types. For instance, a study in Hong Kong's humid subtropical climate found that an extensive green roof exhibited cooling effectiveness in spring, summer, and fall, but warming effects in winter (17). This also indicates green roofs have different impacts in different seasons, which is a critical consideration for the annual energy simulations.

All in all, the climate zone still has an effect on the effectiveness of green roofs. While we have not focused on this subject, it is still important to note its significance.

Green Roofs as A Nature-Based Solution

Green roofs are an example of a nature-based solution (NbS), which is defined as “actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits” (18). Unlike conventional devices, such as mechanical cooling systems, green roofs use natural processes to survive the UHI effect, a biotic solution to an abiotic effect.

Nature-based solutions are fundamentally beneficial for many reasons. Firstly, they provide multifunctionality. Green roofs don't just cool the air; they can manage stormwater by absorbing rainfall, save energy by reducing the energy consumption of cooling systems, enhance urban biodiversity, improve air quality, and increase the well-being of those who dwell in the cities (1). A gray solution is a traditional human-engineered approach to an environmental problem, typically involving built infrastructure like concrete pipes, seawalls, or water treatment plants. A gray solution, like an air conditioner, only provides cooling and consumes significant energy to do so.

Secondly, nature-based solutions like green roofs are inherently more adaptive and more resilient than the average. As climate patterns shift, the living system of a green roof can respond, while ordinary roofs can be worn down by the sudden change. Furthermore, by

replicating natural processes, green roofs create more sustainable cities that work with ecological cycles rather than against them, which offers a natural path against the UHI crisis (4).

DISCUSSION AND SYNTHESIS

This literature review has examined the efficiency of green roofs in mitigating the UHI. Green roofs are a powerful nature-based solution that directly counters UHI through the mechanisms of evapotranspiration, shading, and thermal insulation (1). The synthesis of these findings reveals that the cooling potential is not uniform but is significantly influenced by system design.

Firstly, a clear difference in cooling effectiveness exists between green roof types. Intensive systems, with their deeper substrates and more diverse vegetation options, generally have a better cooling effectiveness and higher ambient air temperature reduction (4). In contrast, extensive systems, while less effective during dry periods and with a smaller variety in vegetation due to their shallow soil, provide a more accessible and cost-effective solution, particularly for retrofitting existing buildings (1).

Secondly, the performance of both systems is impacted by regional climate and water availability. There is a “tipping point,” below which the evapotranspirative cooling effectiveness diminishes significantly (8). In climates or during heatwaves, the cooling functionality can be severely compromised without required irrigation (4), as summarized in Table 2.

Research Limitations and Counterarguments

This field of research does face several important limitations. A significant gap in knowledge can make it difficult to predict the green roof’s durability and cooling efficacy over time (4). Many studies rely on short-term data or modeling, which may not fully capture the impacts of changing climate patterns from climate change and other consequences.

A prominent counterargument against widespread adoption of green roofs is their higher initial cost compared to conventional alternatives (1). This economic barrier can deter building developers and property owners, despite the evidence of long-term savings from energy reductions and increased roof longevity (19). Furthermore, some critics have pointed to a potential design conflict: plant species must balance high evapotranspiration for cooling with low water consumption for sustainability (8). This balance can be difficult, especially with cheaper extensive roofs being able to support a small range of plants. Certain tree species in intensive roofs, while effective for shading, can emit biogenic volatile organic compounds (BVOCs) that can contribute to creating an ozone layer at ground level (9).

Policy Implications and Recommendations

The evidence synthesized in this review leaves a strong foundation for political action. To overcome economic barriers and incentivize the widespread adoption of green roofs, urban areas have a list of arguments.

Table 2. Key Factors Affecting Green Roof Cooling Performance.

Factor	Impact on Cooling Performance	Key Takeaway
Roof Type	Intensive roofs generally provide greater cooling than extensive roofs, due to deeper soil and more vegetation (4).	A performance-cost difference does exist; intensive roofs offer higher performance but at a greater initial investment (1).
Climate & Water	Evapotranspiration, a primary cooling mechanism, is dependent on soil moisture and local humidity.	Performance will drop during droughts (8). Irrigation and careful plant selection is crucial for reliable performance in dry/arid climates (4).
Weather Extremes	The cooling effectiveness significantly decreases under extreme heat conditions compared to typical average weather, for example, like a fierce summer (4).	Green roofs are part of, but not the complete solution for heatwave mitigation.

Note: “Roof Type” compares extensive and intensive systems. “Climate & Water” focuses on regional humidity, precipitation patterns, and soil moisture availability. “Weather Extremes” refers to the impact of severe temperature events on cooling performance. Impact on cooling refers to the temperature reduction potential. “Key Takeaway” highlights the main practical implication for implementation. Based on analysis of studies cited in this review.

Financial Incentives

Direct subsidies and grants have proven highly effective in increasing green roof construction. For example, in Basel, Switzerland, subsidies of 20-40 CHF per m² were offered, which successfully stimulated the industry before transitioning to a mandate (20). Similarly, payment for stormwater collection directly rewards property owners for the runoff retention that is provided by green roofs, which can create permanent economic benefits (1). Additionally, density bonuses, which allow developers to build larger structures in exchange for including green roofs, are also a powerful piece of regulation. In Portland and Chicago, this tool has been successfully implemented, with one developer receiving permission for an extra 12,000 square feet of condos in return for a 4,000-square-foot green roof (21). This non-monetary incentive can allow for greater urban construction with less of a risk of the UHI effect.

Mandates/Building Codes

For maximum enforcement, cities can require green roofs on all new and retrofitted flat roofs, as seen in Basel. This policy has resulted in approximately 40% of Basel's flat roof area being greened, which has made it a global leader in green roof area per capita (20).

Public Leadership/Education

Installing green roofs on public buildings, such as the renowned example of Chicago's City Hall, allows the public to view green roofs, a great design testing space for green roofs, and normalizes the technology (21). Supporting research and disseminating case studies can tailor designs to different local climates and build confidence among private developers to attempt green roofs of their own.

As such, while limitations in long-term data and valid economic concerns do exist, the evidence supports that green roofs are an effective strategy for mitigating the UHI effect. The path forward requires smart, context-sensitive policies that leverage the beneficial effects of green roofs to make a sustainable, resilient, and cooler urban environment.

CONCLUSION

This literature review investigated how green roofs affect UHI and evaluated the effectiveness of different kinds of green roofs. Green roofs are a powerful and multifaceted strategy for mitigating the UHI, directly addressing the core problem of urban overheating by

reintroducing nature-based processes into the structure of roofs. The thesis of this paper is that the efficiency of different green roofs stems from the processes of evapotranspiration, shading, and thermal insulation, and that their performance is contingent upon the design choice and also the climate. The findings confirm this, revealing that while intensive green roofs generally offer superior cooling, extensive systems are a more cost-effective and accessible alternative, particularly for retrofitting preexisting buildings. Crucially, the performance of both is dependent on soil humidity.

The value of green roofs extends beyond just simple temperature reduction. As a nature-based solution, they provide an extensive list of benefits, including managing stormwater, saving energy, increasing biodiversity, and improving human well-being. Ordinary gray infrastructure cannot replicate these effects. The multifunctionality of green roofs makes them an indispensable component towards the goal of sustainable urban development. To ensure their use, policymakers must adopt a strategic mix of financial incentives, regulatory measures (like density bonuses), and mandates to overcome the obstacles of initial cost barriers and accelerate widespread green roof adoption.

For future research, three key directions are necessary. First, there is a critical need for long-term studies across various climatic zones to better understand the performance, durability, and the impacts of a changing climate on green roofs. Second, research should focus on optimizing plant species uses in green roofs and the compositions of substrates to maximize cooling and water efficiency. This is particularly true in arid and semi-arid regions, where there is less moisture naturally in the soil. Finally, more investigation is needed into the synergistic effects of combining green roofs with other mitigation strategies, such as cool pavement roads and greater urban forestry. Together, the ultimate goal is to develop integrated blueprints for city-wide cooling to defeat the UHI effect.

In conclusion, green roofs represent a more proven, adaptive, and natural approach to combating the UHI effect. Their implementation is not merely a technical upgrade but a fundamental step toward creating more resilient, livable, and sustainable cities for the future.

FUNDING SOURCES

This research did not receive grants from any other institution in public, private, or non-profit sectors.

CONFLICT OF INTEREST

The author declare that there are no conflicts of interest related to this work.

REFERENCES

1. US EPA O Using Green Roofs to Reduce Heat Islands. Available from: <https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands> (accessed on 2026-7-31).
2. Mihalakakou G, *et al.* Green roofs as a nature-based solution for improving urban sustainability: Progress and perspectives. *Renewable and Sustainable Energy Reviews*. 2023; 180: 113306. <https://doi.org/10.1016/j.rser.2023.113306>
3. Santamouris M Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*. 2014; 103: 682-703. <https://doi.org/10.1016/j.solener.2012.07.003>
4. Wang X, *et al.* The effectiveness of cool and green roofs in mitigating urban heat island and improving human thermal comfort. *Building and Environment*. 2022; 217: 109082. <https://doi.org/10.1016/j.buildenv.2022.109082>
5. Wong NH, *et al.* Greenery as a mitigation and adaptation strategy to urban heat. *Nature Reviews Earth & Environment*. 2021; 2 (3): 166-181. <https://doi.org/10.1038/s43017-020-00129-5>
6. Adilkhanova I, *et al.* Green roofs save energy in cities and fight regional climate change. *Nature Cities*. 2024; 1 (3): 238-249. <https://doi.org/10.1038/s44284-024-00035-7>
7. Yuan Y, *et al.* Unraveling the global economic and mortality effects of rising urban heat island intensity. *Sustainable Cities and Society*. 2024; 116: 105902. <https://doi.org/10.1016/j.scs.2024.105902>
8. Liu H, *et al.* Impacts of green roofs on water, temperature, and air quality: A bibliometric review. *Building and Environment*. 2021; 196: 107794. <https://doi.org/10.1016/j.buildenv.2021.107794>
9. Tong S, *et al.* Urban heat: an increasing threat to global health. *BMJ*. 2021; 375: n2467. <https://doi.org/10.1136/bmj.n2467>
10. Liu Z, *et al.* On-site assessments on variations of PM_{2.5}, PM₁₀, CO₂ and TVOC concentrations in naturally ventilated underground parking garages with traffic volume. *Environmental Pollution*. 2019; 247: 626-637. <https://doi.org/10.1016/j.envpol.2019.01.095>
11. Heusinger J, *et al.* Extensive green roof CO₂ exchange and its seasonal variation quantified by eddy covariance measurements. *Science of The Total Environment*. 2017; 607-608: 623-632. <https://doi.org/10.1016/j.scitotenv.2017.07.052>
12. Ouldboukhitine SE, *et al.* Assessment of green roof thermal behavior: A coupled heat and mass transfer model. *Building and Environment*. 2011; 46 (12): 2624-2631. <https://doi.org/10.1016/j.buildenv.2011.06.021>
13. About Green Roofs. Available from: <https://www.greenroofs.org/about-green-roofs> (accessed on 2026-7-31).
14. Getter KL, *et al.* The Role of Extensive Green Roofs in Sustainable Development. *HortScience*. 2006; 41 (5): 1276-1285. <https://doi.org/10.21273/HORTSCI.41.5.1276>
15. Heusinger J, *et al.* Surface energy balance of an extensive green roof as quantified by full year eddy-covariance measurements. *Science of The Total Environment*. 2017; 577: 220-230. <https://doi.org/10.1016/j.scitotenv.2016.10.168>
16. Peng LLH, *et al.* Seasonal and Diurnal Thermal Performance of a Subtropical Extensive Green Roof: The Impacts of Background Weather Parameters. *Sustainability*. 2015; 7 (8): 11098-11113. <https://doi.org/10.3390/su70811098>
17. Climate Explainer: Nature-Based Solutions. Available from: <https://www.worldbank.org/en/news/feature/2022/05/19/what-you-need-to-know-about-nature-based-solutions-to-climate-change> (accessed on 2026-7-31).
18. Manso M, *et al.* Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews*. 2021; 135: 110111. <https://doi.org/10.1016/j.rser.2020.110111>
19. Green roofs in Basel, Switzerland: combining mitigation and adaptation measures. Available from: <https://climate-adapt.eea.europa.eu/en/metadata/case-studies/green-roofs-in-basel-switzerland-combining-mitigation-and-adaptation-measures-1> (accessed on 2026-7-31).
20. Planted roof case studies. Available from: <https://www.gsa.gov/governmentwide-initiatives/federal-highperformance-buildings/highperformance-building-clearinghouse/water/planted-roof/case-studies> (accessed on 2026-7-31).
21. Solcerova A, *et al.* Do green roofs cool the air? *Building and Environment*. 2017; 111: 249-255. <https://doi.org/10.1016/j.buildenv.2016.10.021>