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Performance of Green Roofs on Building Energy Efficiency in Tropical and Subtropical Climates

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Abstract. This research examines the performance of green roof architectural designs in enhancing energy efficiency in buildings within tropical and subtropical climates. Green roofs, which integrate vegetation and planting media, can improve energy efficiency by reducing the heat absorbed by buildings, thereby increasing indoor thermal comfort and lowering the need for air conditioning. The study employs a comparative method to analyse the performance of green roofs in improving energy efficiency across both climates. From 218 selected searches, 15 studies indicate that both intensive and extensive green roofs can reduce the surface temperature of concrete roofs through vegetation evapotranspiration, leading to decreased energy consumption, particularly for air conditioning.

Keywords. Green Roof, Evapotranspiration, Energy Efficiency, Tropical Climate, Subtropical Climate

1. Introduction

The World Economic Forum (WEF) report highlights climate change and extreme weather events as one of the five major threats that will impact the world by 2030 [1] [2]. One of its consequences is the urban heat island effect, which is predicted to increase global building energy demand by up to 40% and contribute to 26% of carbon dioxide (CO_2) emissions, with 18% coming from the urban sector [3] [4] [5] [6].

Climate change is closely related to rising temperatures triggered by the concentration of greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), water vapour (H_2O), and nitrous oxide (N_2O), all of which can exacerbate the greenhouse effect and global warming [7]. This phenomenon triggers longer and more intense heatwaves [8] [9], affecting almost all regions and worsening thermal comfort in buildings due to the urban heat island effect [10].

The heat absorbed is reflected back into the environment, worsening air quality and health [11]. The implementation of mitigation technologies is crucial, especially in sectors dependent on fossil fuels [12] and the use of building materials that absorb and reflect heat [13]. High temperatures can also increase humidity, lowering thermal comfort [14], physical health, and work productivity. Conversely, productivity increases at comfortable temperatures [15]. Since humans spend around 90% of their time indoors [16], thermal quality becomes crucial.

Table 1. Thermal Condition Parameters, According to the Technical Planning Standards for Energy Conservation in Building Design in Indonesia
Source: SNI 03–6572–2001

No.	Category	Effective Temperature (ET)	Humidity (RH)
1.	Cool Comfortable	20.5^{0}C – 22.8^{0}C	50%
	Upper Threshold	24	80%
2.	Comfortable	22.8^{0}C – 25.8^{0}C	70%
	Upper Threshold	28	-
3.	Warm Comfortable	25.8^{0}C – 27.1^{0}C	60%
	Upper Threshold	31^{0}C	-

Table 2. Thermal Condition Parameters According to the American National Standards Institute (ANSI)
Source: ANSI 55–56

Temperature Condition	Maximum Change Ratio
23^{0}C – 25^{0}C	1.1^{0}C – 2.2^{0}C Per hour (h^{-1})
Air Humidity Condition	**Maximum Change Ratio**
60%	10 % - 20 % Per hour (h^{-1})
Indoor Air Velocity	
0.05-0,23 Metres per second (m/s)	

In *Determining Lines of Equal Comfort* (Transactions of the American Society of Heating and Ventilating Engineers, Vol. 29, 1923) [17], thermal comfort is a measure that takes into account heat radiation, relative humidity, and air movement temperature, known as Effective Temperature (ET). According to Lippsmeier [18], the comfort limits can be calculated using (ET), which values depend on the geographical location and the ethnic characteristics of the study subjects, as described in Table 3.

Tabel 3. Comfort in Effective Temperature (ET)
Sumber: Building in the Tropics, [18]

Author	Location	Human Groups	Comfort Limits (TE)
ASHRAE	USA	Researchers	20,50C -
Rao	Selatan (30° LU)	India	24,50C TE
Webb	Calcutta	Malaysia	200C - 24,50C
	(22° LU)	Cina	TE
Mom	Singapura	Indonesia	250C - 270C
Ellis	Equato	Europe	TE
	Jakarta		
	(6°LS)		200C - 260C
	Singapura		TE
	Equator		220C - 260C
			TE

Lippsmeier [18], revealed that the range of thermal comfort in the equatorial region lies between 19°C ET (lower threshold) and 26°C ET (upper threshold). Productivity begins to decline when temperatures exceed 26°C ET, with discomfort levels at 33.5°C ET, and conditions become intolerable at 36°C ET.

Architectural designs, such as green roofs, can improve environmental quality [19] by reducing building energy consumption through vegetation evapotranspiration [13] [20], which decreases solar radiation absorption. Green roofs are an innovative solution to enhance thermal comfort [21] and energy efficiency in buildings [22].

However, the application of green roofs in tropical climates requires more in-depth research compared to subtropical climates. Several factors need to be considered, including: a) air temperature, b) solar radiation, c) humidity, d) wind speed [23], e) building characteristics [24], f) technology and types of green roofs [21], and g) depth and composition of planting media [25].

The success of green roofs depends on these factors, with varying results between tropical and subtropical climates. This study aims to address three main questions: 1) How many studies provide quantitative data on the performance of green roofs in tropical and subtropical regions? 2) Under what conditions can these parameters be obtained? 3) To what extent is the effectiveness of green roof performance aligned with the findings of existing studies?

2. Literature review

The review was conducted on peer-reviewed journal articles sourced from *GoogleScholar* and *ScienceDirect.* The search utilised relevant synonymous terms to identify publications related to the "Effectiveness *of* Green Roof Performance in Enhancing Energy Efficiency." The focus of the review is on articles documenting the performance of green roofs in energy efficiency within tropical and subtropical regions. This study also incorporates the role of green roofs in mitigating the urban heat island effect, as this service has a close correlation with improving thermal conditions in buildings [26].

In this research, inclusion criteria were applied to facilitate the analysis and comparison of research objects. This approach enables the researcher to draw more structured conclusions, provide new insights, and enhance the understanding of the context and contributions of each study.

3. Method

2.1. Research Method

This study uses a comparative review method to analyse and identify similarities and differences, following the PRISMA 2020 guidelines [27]. The purpose of this review is to present the performance of green roof services and provide information regarding the documented level of evidence. Additionally, the research compares the quantification of green roof effectiveness and considers the heterogeneity of these services.

The PRISMA 2020 guidelines, also applied by Francis and Jensen [28], provide a clear reporting framework for the methods, findings, and rationale of the research. Although typically used in critical evaluation reviews, these guidelines are also relevant for other types of reviews.

2.2. Research Location

The research locations included in this review refer to literature that has undergone the inclusion selection process and is distributed across several countries, as presented in Figure 1.

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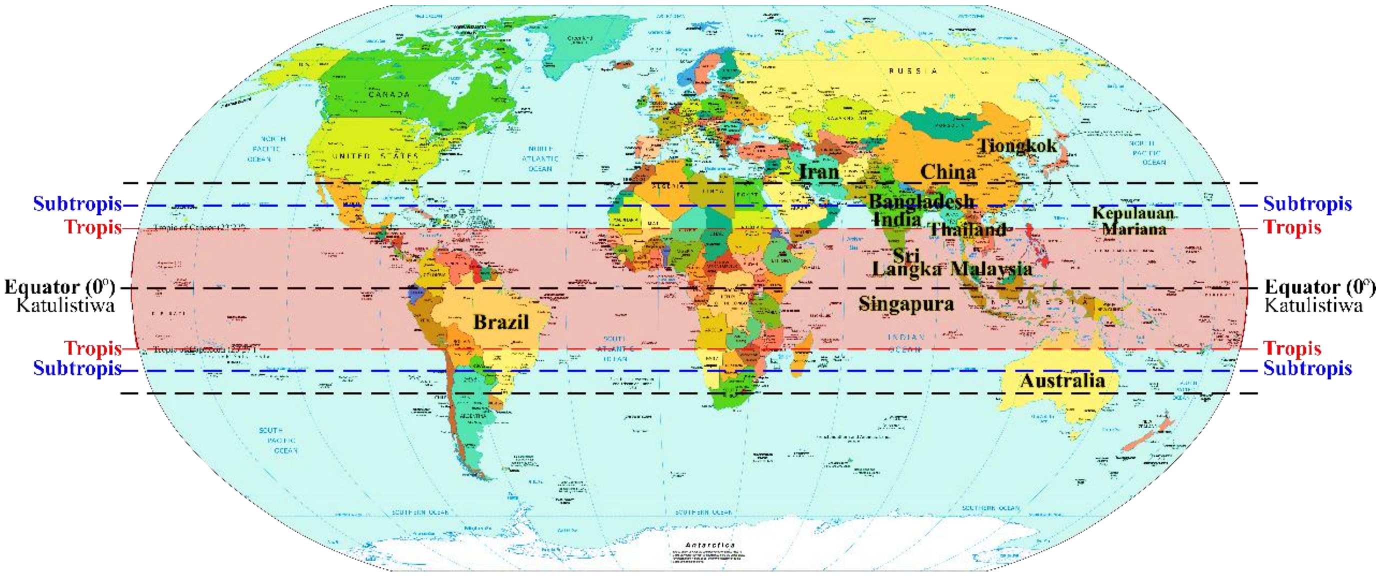

Figure 1. Research Location, in Tropical and Subtropical Climates
Source: *https://commons.wikimedia.org/wiki/Atlas* (Developed by the researcher, 2025)

2.3. Data Analysis

The data sources are from GoogleScholar and ScienceDirect, with Mendeley used for managing references and citations. VOSviewer is also employed to support the visualization of networks and the density of relevant research data. The search keywords used are presented in Table 4.

Tabel 4. Keywords, Search Results, and Data Sources
Sumber: Researcher's Analysis, 2025

Energy Consumption	Search Results	Database	Search Results		Database
1. The performance of green roofs in energy efficiency in tropical climates	29.100	*Google Scholar*	**Article I.**	**2,850**	*Science Direct*
2. The performance of green roofs in energy efficiency in subtropical climates	21.000	*Google Scholar*	**Article II.**	**1,559**	*Science Direct*

All search results from the databases will be selected based on inclusion criteria, with specific requirements that must be met for a study to be included in this review. The relevant inclusion criteria for this research include: 1) publication year between 2016 and 2024, 2) abstract, 3) topic, 4) keywords, 5) green roof service performance, and 6) tropical and subtropical climates. The search was conducted in both Indonesian and English. Literature that is irrelevant to the research objectives, does not meet the inclusion criteria, or is not available in full text (open access) will be excluded.

This research discusses the role of green roofs in mitigating the urban heat island effect, although this topic is not explicitly mentioned in the main title. Given its correlation with the increasing energy demand in urban buildings globally, mitigating the urban heat island effect is considered one of the benefits of green roofs, contributing to reducing the use of fossil energy [29] in buildings.

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The exclusion criteria for this study include green roof services that are not discussed, such as rainwater management, ecological connectivity, and air quality improvement, even though these topics may be covered together in a single journal or article.

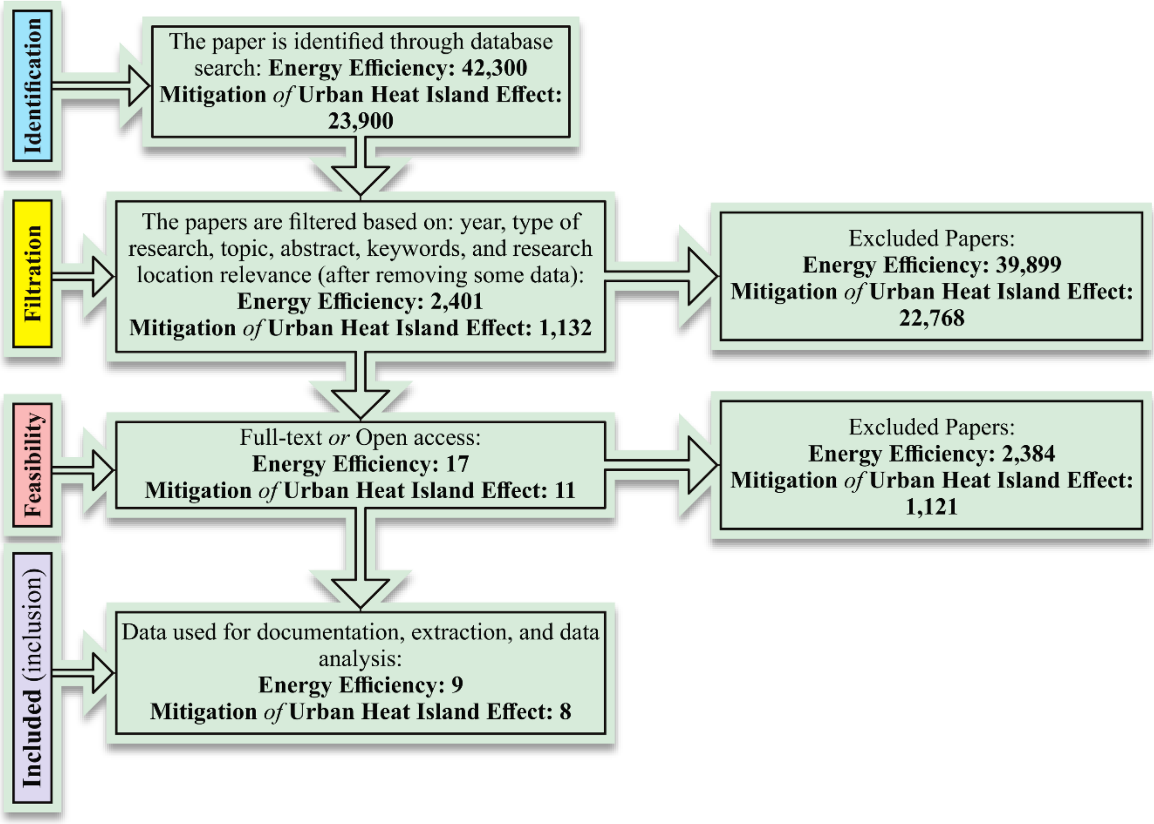

Figure 2: Summary of the journal/paper, which has undergone a systematic review process in Francis and Jensen 2017, as adapted by the author.

Source: Francis and Jensen, [28]

This research also uses VOSviewer software to visualise and analyse bibliometric networks and the relationships between abstracts or keywords, in order to facilitate understanding and identification of connections within the data.

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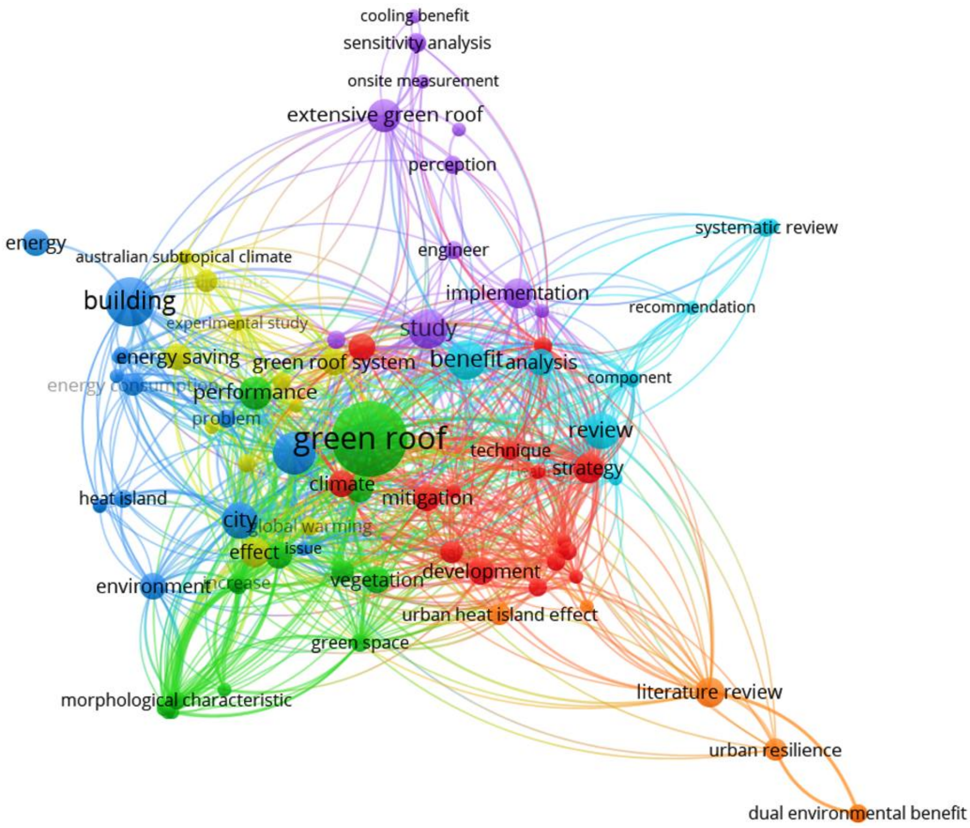

Figure 3: Network Visualization of Data Relationships
Source: *VOSviewer*, 2025

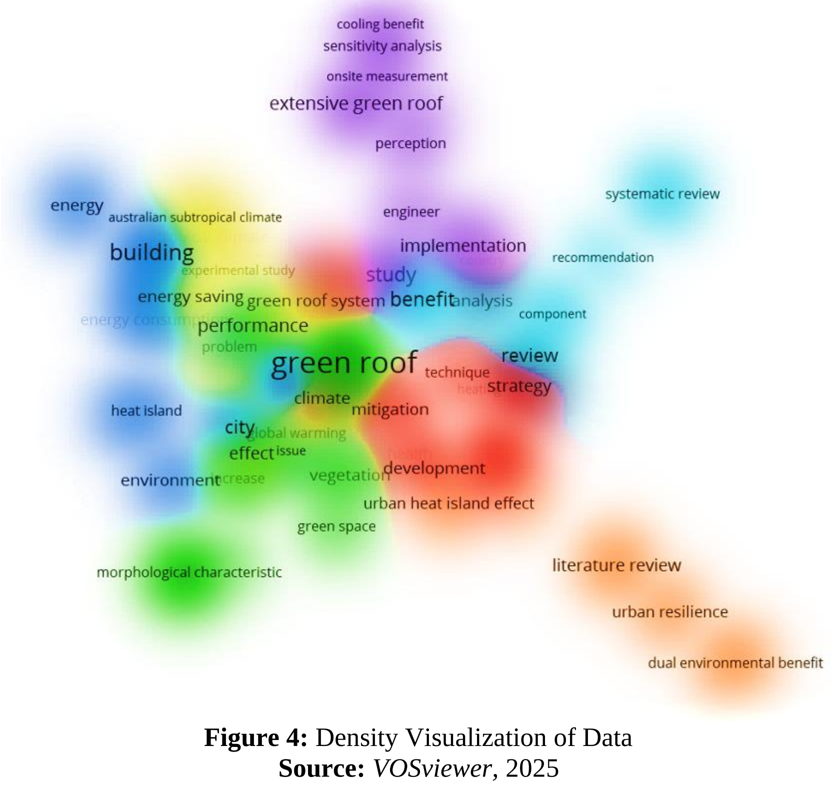

Figure 4: Density Visualization of Data
Source: *VOSviewer*, 2025

The data from the selected studies are then inventoried and presented in the form of tables or matrices to facilitate comparisons between studies. The collected data are subsequently analysed to identify patterns, trends, similarities, and differences in findings from the validated research results, following the PRISMA 2020 reporting guidelines.
These guidelines ensure that the systematic review report is clearly organised, well-documented, and includes the methods, findings, and underlying reasons for the research. Based on the analysis results, the researchers conclude specific findings and provide recommendations for future research that focuses on the suitability of green roof implementation to enhance energy efficiency as a solution in architectural design.

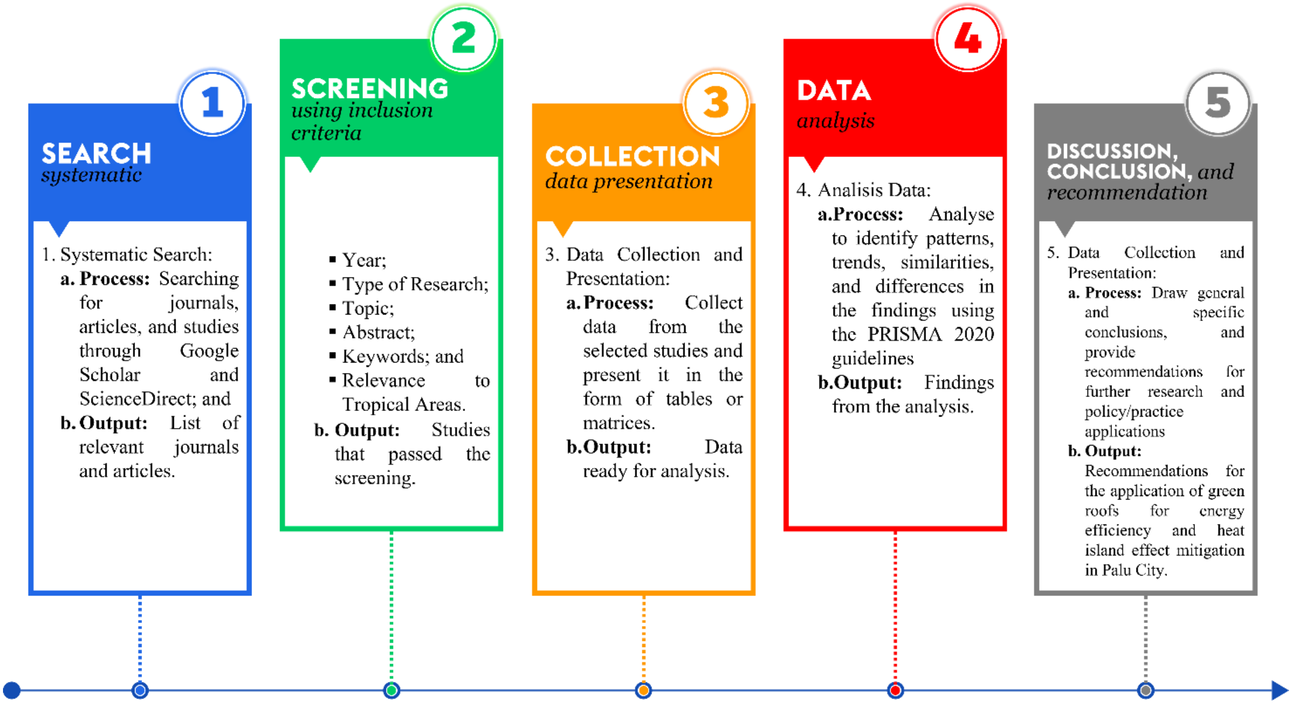

Figure 5: Flowchart, Data Analysis Framework
Source: Researcher's Analysis, 2025

3. Results

A review of 15 articles discussing green roofs in relation to energy efficiency in tropical and subtropical climates found that their contributions vary depending on the selection criteria applied. This review revealed that green roofs contributed to energy efficiency in all 15 studies, while the mitigation of the urban heat island effect was addressed in 7 out of 15 studies, with some examining both benefits simultaneously.

The researchers will discuss the documented evidence reviewed by identifying challenges in integrating green roofs into urban areas with tropical and subtropical climates.

A. What is a Green Roof?

A green roof, also known as a living roof, is a roofing system covered with vegetation and growing media [30]. Terms such as "green roof, living roof, ecological roof, vegetated roof, and roof garden" [31] [32], are used to define two types of green roofs: extensive and intensive green roofs. These roofs feature natural or self-sustaining vegetation [24] adapted to local climatic conditions [23] [32].

Intensive Green Roofs: Designed for various types of vegetation, including trees and shrubs, these roofs use growing media 15-60 cm or more in depth. They are suitable for buildings capable of supporting heavier loads [20] [33].

Extensive Green Roofs: These are simpler and require less maintenance, with shallow growing media of 5-10 cm. They are planted with drought-resistant species such as sedum and moss, imposing a lighter load on the building structure [20] [33].

Figure 6: Extensive Green Roof
Source: https://www.holcimelevate.com/dach-en/insights/intensive-vs-extensive-green-roofs

Figure 7: Intensive Green Roof
Source**:** https://www.holcimelevate.com/dachen/insights/intensive-vs-extensive-green-roofs

B. Criteria/Classification and Parameters of Green Roofs

The documented criteria for green roofs encompass two types: extensive and intensive green roofs [20], as outlined in Table 5.

Tabel 5. Summary of Green Roof Classification Criteria
Sumber: Besir and Cuce [20], 2018

Classification	Extensive Green Roof	Intensive Green Roof
Usage	Primarily functional, not accessible	Aesthetics and recreation, accessible
Maintenance	Low maintenance, minimal intervention	High maintenance, regular upkeep required
Construction	Lightweight, shallow growing medium (5-10 cm)	Heavy, deeper growing medium (15-60 cm)
Plants	Drought-tolerant and hardy plants (sedum, moss, grass)	Variety of plants, including shrubs, trees, and flowers
Weight	Lightweight, suitable for buildings with low load-bearing capacity	Heavy, requires stronger structural support
Function	Provides environmental benefits (insulation, rainwater management, biodiversity)	Provides environmental and aesthetic benefits, as well as recreational space

Green roofs can reduce energy consumption [34] and mitigate the urban heat island effect by lowering atmospheric temperatures [35], thereby providing thermal comfort for occupants [36]. While they possess excellent rainwater retention capacity, rainwater management aspects are not discussed in this paper. Beyond environmental benefits, green roofs have the potential to enhance the quality of urban life, which depends on factors such as air temperature, location, design, technology, materials, and the type of vegetation used [23].

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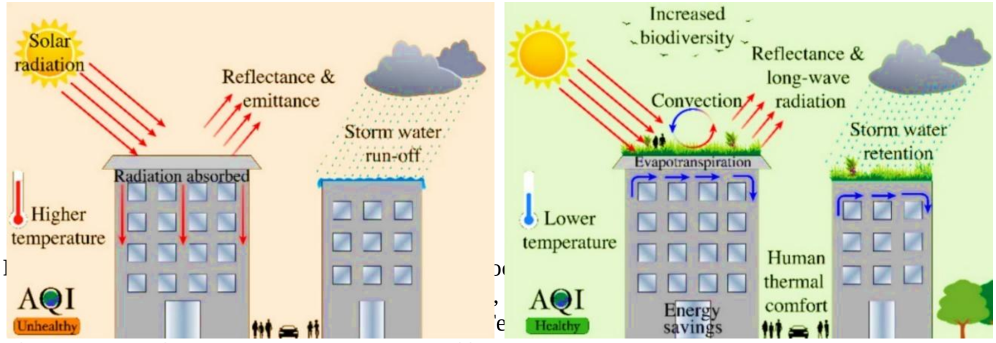

The success of green roofs in building energy efficiency and mitigating the urban heat island effect can be measured through two key parameters: the efficiency of electricity consumption, calculated using the formula: **g/m², Δ% atau Δ °C** [28].

Table 6: Parameters for Measuring the Effectiveness of Green Roof Services
Source: Francis and Jensen, [37]

g/m² (grams per square meter)	Δ% (percentage change)	Δ°C (change in degrees celsius)
is a unit commonly used to measure the amount of material or biomass within a specific area. In the context of green roofs, this can refer to the quantity of plants, substrate, or other materials present on the roof surface per unit area.	is a unit used to indicate changes in a value in percentage form. For instance, if temperature or energy consumption decreases by 20%, it can be expressed as Δ% = -20%. This helps in understanding the extent of the impact of green roof interventions on the measured variables.	is a unit used to indicate temperature changes. For example, if the temperature in a specific area decreases from 30°C to 25°C, then Δ°C = -5°C. This is important for measuring how effective green roofs are in reducing surrounding temperatures.

These three units help quantify and compare the effectiveness of green roofs in terms of energy efficiency and urban heat island mitigation, as well as in creating thermal conditions within buildings that comply with national and international standard parameters.

C. Components of Green Roof Design

Green roofs consist of multiple layers, including vegetation, growing media or substrate, sand, filter fabric, drainage layer, root barrier, insulation, and waterproof membrane. The arrangement of these layers can vary depending on the design, function, and desired services, as illustrated in Figure 9. Several types of green roofs commonly used in various countries include intensive green roofs and extensive green roofs.

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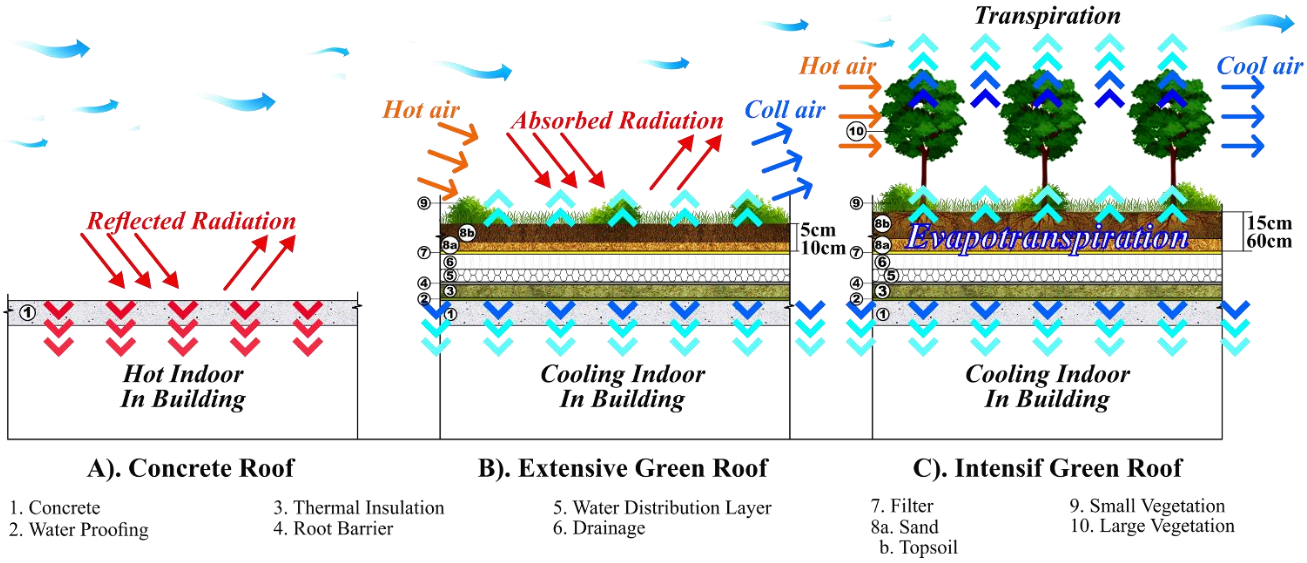

Figure 9: Komponen Atap Hijau, Serta Struktur Skematik Mekanisme Pendinginan Pada Siang Hari
Source: Gaochuan Zhang [38], 2019 (Developed by the Researcher, 2025)

D. Green Roof Services and Performance Documented in the Review

D.1. Energy Efficiency

Green roofs have five potential services for urban environmental protection [36], namely: 1) reducing energy consumption, 2) enhancing stormwater management, 3) reducing the urban heat island effect, 4) increasing biodiversity, and 5) improving air quality. However, in this study, the primary focus of the author is on the performance of green roof services in reducing energy consumption for thermal conditioning of indoor spaces.

The application of green roofs in tropical and subtropical regions can be an energy efficiency solution for building structures, which also simultaneously mitigates the urban heat island effect, supported by various researchers, as summarised in Table 7.

Table 7: Energy Efficiency Generated from Green Roof Design in Tropical and Subtropical Areas, According to Selected Literature
Source: Researcher's Analysis, 2025

No.	Researcher/Year	Study Area *and* Climate	Research Findings
1.	Wiecko. 2016, [22]	Guam, Mariana Islands/Tropical	• In sunny climates, a concrete slab covered with vegetation can be up to 12°C cooler, while in rainy climates, the temperature of the concrete slab with a vegetation layer is around 9°C.
2.	Chowdhury, Hamada. 2017), [39]	Dhaka, Bangladesh/Tropical	• With the substrate temperature indoors decreasing between 2.5 to 3.5°C, as the vegetation cover on the green roof increases.
3.	Herath, Halwatura. 2018, [40]	Colombo, Sri Lanka/Tropical	• The simulation shows the best temperature reduction of 2.03°C at R1 in T6, 1.06°C at R2 in T4, and 1.59°C at R3 in T6.
4.	Yang, Pyrgou. 2018, [21]	Singapore/Tropical	• The green roof reduces heat absorption by 15.53 KWh/m² (37%).

5.	Lee, Louis S H. 2018, [41]	Tiongkok/Subtropical	• The green roof reduces the internal surface temperature of the roof by up to 19.80°C and 6.21°C, respectively.
6.	Y. Zhang. 2019, [42]	Guangzhou, China/Subtropical	• The green roof reduces the internal surface temperature of the roof, air temperature in the space, and daily cooling electricity consumption by up to 12.5°C, 4.9°C, and 16.7 percent, respectively.
7.	Anwar M. 2020, [43]	Queensland, Australia/Subtropical	• Energy savings of 13.65% (simulated) and 11.70% (measured) compared to a non-green roof.
8.	Koranteng, Simons. 2021, [44]	Focus on areas with Tropical Climate	• 5 out of 8 scenarios showed better performance, with a temperature reduction of around 1.5°C.
9.	Rahman, Zaid. 2022, [45]	Putrajaya, Kuala Lumpur, Malaysia/Tropical	• The surface temperature of the green roof is significantly lower (22.9°C) compared to the conventional non-green flat roof (46.7°C), with a difference of 23.8°C. • These findings indicate that the green roof acts as thermal insulation, which can reduce ceiling temperature by -3.7°C.
10.	Pragati, Shanthi Priya. 2023, [23]	Chennai, Tamil Nadu, India/Tropical	• The combination of green roofs and green walls with three modeling variations successfully reduced the temperature by a) 1.87°C, b) 1.79°C, and c) 1.90°C. • Green roofs can reduce heat transfer through building roofs by up to 80%.
11.	Zheng X. 2023, [46]	Tiongkok/Subtropical	• The maximum air temperature reduction on the intensive green roof is 0.37°C. • The maximum air temperature reduction on the extensive green roof is 0.35°C.
12.	Kachenchart and Panprayun. 2024, [36]	Thailand/Tropical	• Green roofs can reduce surface temperature by up to 12°C. • The highest carbon dioxide removal of 3.01 $kgCO_2/m^2$ and greenhouse gas mitigation of 28.46 $kgCO_2eq/m^2$/year. • Reducing heat transfer from outside to inside the space by up to 84%.
13.	Zhang, Soe. 2024, [34]	a. Singapura/Tropical. b. China/Subtropical, and Moderate c. Brazil/Tropis; d. Iran/Subtropical and Subpolar; and e. India/Tropical	• In Singapore, the maximum surface temperature is reduced by around 30°C, the air temperature at a depth of 300mm can be lowered by 4.2°C, and the surface air temperature is reduced by 20°C. • In China, the temperature of the green roof with shade plants is on average 17.1°C cooler compared to the surrounding environment, and it reduces the maximum daily surface temperature by 5.2°C. The air temperature at a 10 cm substrate thickness is reduced by 0.7°C. • In Brazil, the thermal comfort index was successfully obtained with an average value of 5.88°C. • In Iran, the air temperature in the test area was reduced by 0.68°C.

			• In India, the indoor air temperature decreased by 5.1°C.
14.	Jia, Weng. 2024, [47]	Brazil/Tropical	• Cooling energy reduction, with an average reduction ranging from 39.30% to 100% for cool roofs and 38.38% to 100% for green roofs.
15.	Scolaro Ghisi. 2024, [48]	Brazil/Tropical	• Green roofs provide the highest thermal comfort percentage in all climates, ranging from 57.3% to 82.2% in living rooms and 69.8% to 96.3% in bedrooms, depending on the local climate.

D.2. Mitigation of Urban Heat Island Effect

Green roofs reduce the urban heat island effect through the evapotranspiration of vegetation [13] [20] [23] [44] [46], which includes the evaporation of water and transpiration through stomata. This process increases air humidity, lowers the surrounding temperature, and removes heat, with one gram of water able to eliminate 540 calories of heat energy [49]. Plant photosynthesis also reduces carbon dioxide, mitigates the greenhouse effect, and cools the urban air.

Vegetation on green roofs absorbs, reflects, and intercepts solar radiation, converting solar energy into chemical energy, while simultaneously reducing radiation reaching the surface and beneath the concrete roof through evapotranspiration. This helps to reduce the thermal radiation effect from construction materials such as asphalt and concrete [13] [50].

The soil and vegetation layers function as insulators, regulating the heat exchange between the interior space and the environment. The soil absorbs solar energy during the day, preventing heat from reaching the roof substrate [49], and releases thermal energy at night. This effect can reduce heat entering the building by 7%–70% [50].

4. Discussion and conclusion

4.1. Discussion

Facing climate change and the projected extreme weather events, which are identified as one of the top five threats over the next decade [1] [6], mitigation and adaptation efforts have become increasingly urgent. Green roofs, as a nature-based solution, play a role in energy savings, urban heat island mitigation [51], rainwater management [52], biodiversity enhancement [53], and air quality improvement [54]. This solution supports urban resilience to climate change and rising temperatures due to greenhouse gas concentrations [55].

However, the effectiveness of green roofs is influenced by factors such as design, cost, technology, as well as local climate, geological, and hydrological conditions. Further research with documented quantitative data is needed to understand its optimal potential in local contexts.

4.2. Conclusion

The synthesis of 15 studies in tropical and subtropical regions shows that green roofs can reduce surface temperatures to varying degrees, depending on climate, vegetation, the number of floors, design, and the type of green roof. A systematic review in countries with both climates yielded consistent findings that supported each other without significant differences. Table 8 compares the parameters and criteria of green roofs in optimising energy efficiency and mitigating the urban heat island effect.

Table 8: Summary of Green Roof Performance in Tropical and Subtropical Climates
Source: Researcher's Analysis, 2025

Criteria	**Minimum Indoor Air Temperature *in* Tropical Climate Buildings**	**Minimum Air Temperature on Concrete Slab Surface *in* Tropical Climate**	**Main Components *of* A Green Roof**
Extensive Green Roof (ER)	5,1°C India	12°C Thailand	Light vegetation with a low LAI (Leaf Area Index), using a growing medium of 5-10 cm
Intensif Green Roof (IR)	3,5°C Banglades 3,7°C Malaysia	4,2°C Singapura	Vegetation with a high LAI (Leaf Area Index) [29], using a growing medium of 15-60 cm
Criteria	**Minimum Indoor Air Temperature in Subtropical Climate Buildings**	**Minimum Air Temperature on Concrete Roof Surface in Subtropical Climate**	**Main Components *of* A Green Roof**
Extensive Green Roof (ER)	5,2°C China 4°C Australia	0,35 °C Tiongkok	Light vegetation with a low LAI (Leaf Area Index), using a growing medium of 5-10 cm
Intensif Green Roof (IR)	6,21 °C Tiongkok	0,37 °C Tiongkok 0,68°C Iran	Vegetation with a high LAI (Leaf Area Index) [29], using a growing medium of 15-60 cm

Based on 15 studies conducted in tropical and subtropical regions, both extensive and intensive green roofs have proven effective in saving energy and mitigating the urban heat island effect. The substrate and vegetation act as additional insulation, maintaining more stable indoor temperatures during both day and night. Through evapotranspiration, the vegetation helps lower the surrounding air temperature, while its surfaces are more effective in reflecting solar radiation compared to conventional concrete roofs, thereby reducing heat trapped in urban areas. To maximise ecological benefits and minimise maintenance, it is recommended to use heat- and drought-tolerant plants.

References:

[1] IPCC, *Global Warming of 1.5°C*. Cambridge University Press, 2022. doi: 10.1017/9781009157940.
[2] International Energy Agency, “International Energy Agency, 2023,” https://www.iea.org/energy%02system/buildings/space-cooling.
[3] D. Liu, “International energy agency (IEA),” in *The Palgrave Encyclopedia of Global Security Studies*, Springer, 2023, pp. 830–836.
[4] S. Opatvachirakul, “Energy Policy and Planning Office,” *EPPO, Interview, Bangkok, Thailand the*, pp. 3–18, 2009.

[5] Y. Li *et al.*, “A review on carbon emission accounting approaches for the electricity power industry,” *Appl Energy*, vol. 359, p. 122681, 2024.
[6] D. Liu, “International Energy Agency (IEA),” in *The Palgrave Encyclopedia of Global Security Studies*, Springer, 2023, pp. 830–836.
[7] Y. Pracastino Heston, “Perubahan Iklim di Perkotaan,” 2015. [Online]. Available: www.diandracreative.com
[8] M. F. Irma and E. Gusmira, “Tingginya Kenaikan Suhu Akibat Peningkatan Emisi Gas Rumah Kaca Di Indonesia,” *JSSIT: Jurnal Sains dan Sains Terapan*, vol. 2, no. 1, 2024.
[9] D. Amaripadath, R. Rahif, W. Zuo, M. Velickovic, C. Voglaire, and S. Attia, “Climate change sensitive sizing and design for nearly zero-energy office building systems in Brussels,” *Energy Build*, vol. 286, p. 112971, 2023.
[10] M. Y. Joshi and J. Teller, “Urban integration of green roofs: Current challenges and perspectives,” *Sustainability*, vol. 13, no. 22, p. 12378, 2021.
[11] P. Shahmohamadi, A. I. Che-Ani, I. Etessam, K. N. A. Maulud, and N. M. Tawil, “Healthy environment: the need to mitigate urban heat island effects on human health,” *Procedia Eng*, vol. 20, pp. 61–70, 2011.
[12] D. H. C. Toe, “Application of Passive Cooling Techniques to Improve Indoor Thermal Comfort of Modern Urban Houses in Hot-Humid Climate of Malaysia,” *(No Title)*, 2013.
[13] A. Mohajerani, J. Bakaric, and T. Jeffrey-Bailey, “The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete,” *J Environ Manage*, vol. 197, pp. 522–538, 2017.
[14] B. Talarosha, “Menciptakan kenyamanan thermal dalam bangunan,” *Jurnal Sistem Teknik Industri*, vol. 6, no. 3, p. 0, 2005.
[15] F. Idealistina, “Model termoregulasi tubuh untuk penentuan besaran kesan termal terbaik dalam kaitannya dengan kinerja manusia,” *Disertasi Magister Institut Teknologi Bandung, tidak dipublikasikan*, 1991.
[16] S. S. Cheung, J. K. W. Lee, and J. Oksa, “Thermal stress, human performance, and physical employment standards,” *Applied physiology, nutrition, and metabolism*, vol. 41, no. 6, pp. S148–S164, 2016.
[17] V. Engineers, *Journal of the American Society of Heating and Ventilating Engineers*, vol. 34. The Society, 1928.
[18] G. Lippsmeier, “Tropenbau= Building in the tropics,” *(No Title)*, 1969.
[19] F. Frota de Albuquerque Landi, C. Fabiani, C. Santini, A. L. Pisello, and F. Cotana, “Environmental Sustainability of Earth-Based Materials for the Carbon Neutrality of the Built Environment,” in *Shot-Earth for an Eco-friendly and Human-Comfortable Construction Industry*, Springer, 2023, pp. 85–100.
[20] A. B. Besir and E. Cuce, “Green roofs and facades: A comprehensive review,” *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 915–939, 2018.
[21] J. Yang, A. Pyrgou, A. Chong, M. Santamouris, D. Kolokotsa, and S. E. Lee, “Green and cool roofs’ urban heat island mitigation potential in tropical climate,” *Solar Energy*, vol. 173, pp. 597–609, 2018.
[22] G. Wiecko, “Green Roofs in the Tropics Conserve Energy,” *The Open Atmospheric Science Journal*, vol. 10, no. 1, pp. 1–5, Feb. 2016, doi: 10.2174/1874282301610010001.
[23] S. Pragati, R. Shanthi Priya, C. Pradeepa, and R. Senthil, “Simulation of the Energy Performance of a Building with Green Roofs and Green Walls in a Tropical Climate,” *Sustainability (Switzerland)*, vol. 15, no. 3, Feb. 2023, doi: 10.3390/su15032006.

[24] N. Kamarulzaman, S. Z. Hashim, H. Hashim, and A. A. Saleh, "Green roof concepts as a passive cooling approach in tropical climate-an Overview," in *E3S web of conferences*, EDP Sciences, 2014, p. 01028.
[25] S. S. G. Hashemi, H. Bin Mahmud, and M. A. Ashraf, "Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review," Aug. 22, 2015, *Elsevier Ltd*. doi: 10.1016/j.rser.2015.07.163.
[26] M. Santamouris, "Cooling the cities - A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments," *Solar Energy*, vol. 103, pp. 682–703, 2014, doi: 10.1016/j.solener.2012.07.003.
[27] M. J. Page *et al.*, "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews," Mar. 29, 2021, *BMJ Publishing Group*. doi: 10.1136/bmj.n71.
[28] L. F. M. Francis and M. B. Jensen, "Benefits of green roofs: A systematic review of the evidence for three ecosystem services," Dec. 01, 2017, *Elsevier GmbH*. doi: 10.1016/j.ufug.2017.10.015.
[29] Y. Zheng and Q. Weng, "Modeling the effect of green roof systems and photovoltaic panels for building energy savings to mitigate climate change," *Remote Sens (Basel)*, vol. 12, no. 15, p. 2402, 2020.
[30] K. Vijayaraghavan, "Green roofs: A critical review on the role of components, benefits, limitations and trends," May 01, 2016, *Elsevier Ltd*. doi: 10.1016/j.rser.2015.12.119.
[31] B. Dvorak and A. Volder, "Green roof vegetation for North American ecoregions: a literature review," *Landsc Urban Plan*, vol. 96, no. 4, pp. 197–213, 2010.
[32] E. Oberndorfer *et al.*, "Green roofs as urban ecosystems: ecological structures, functions, and services," *Bioscience*, vol. 57, no. 10, pp. 823–833, 2007.
[33] M. A. Hossain, S. Shams, M. Amin, M. S. Reza, and T. U. Chowdhury, "Perception and barriers to implementation of intensive and extensive green roofs in Dhaka, Bangladesh," *Buildings*, vol. 9, no. 4, p. 79, 2019.
[34] X. Zhang, A. N. Soe, S. Dong, M. Chen, M. Wu, and T. Htwe, "Urban Resilience through Green Roofing: A Literature Review on Dual Environmental Benefits," in *E3S Web of Conferences*, EDP Sciences, Jun. 2024. doi: 10.1051/e3sconf/202453601023.
[35] D. Li, E. Bou-Zeid, and M. Oppenheimer, "The effectiveness of cool and green roofs as urban heat island mitigation strategies," *Environmental Research Letters*, vol. 9, no. 5, p. 055002, 2014.
[36] B. Kachenchart and G. Panprayun, "Selection of tropical plants for an extensive green roof with abilities of thermal performance, energy conservation, and greenhouse gas mitigation," *Build Environ*, vol. 265, Nov. 2024, doi: 10.1016/j.buildenv.2024.112029.
[37] L. F. M. Francis and M. B. Jensen, "Benefits of green roofs: A systematic review of the evidence for three ecosystem services," *Urban For Urban Green*, vol. 28, pp. 167–176, 2017.
[38] G. Zhang, B. J. He, Z. Zhu, and B. J. Dewancker, "Impact of morphological characteristics of green roofs on pedestrian cooling in subtropical climates," *Int J Environ Res Public Health*, vol. 16, no. 2, Jan. 2019, doi: 10.3390/ijerph16020179.
[39] S. Chowdhury, Y. Hamada, and K. Shabbir Ahmed, "Indoor heat stress and cooling energy comparison between green roof (GR) and non-green roof (n-GR) by simulations for labor intensive factories in the tropics," *International Journal of Sustainable Built Environment*, vol. 6, no. 2, pp. 449–462, Dec. 2017, doi: 10.1016/j.ijsbe.2017.09.001.

[40] H. Herath, R. U. Halwatura, and G. Y. Jayasinghe, “Modeling a tropical urban context with green walls and green roofs as an urban heat island adaptation strategy,” *Procedia Eng*, vol. 212, pp. 691–698, 2018.
[41] L. S. H. Lee and C. Y. Jim, “Thermal-cooling performance of subtropical green roof with deep substrate and woodland vegetation,” *Ecol Eng*, vol. 119, pp. 8–18, 2018.
[42] Y. Zhang, L. Zhang, L. Ma, Q. Meng, and P. Ren, “Cooling benefits of an extensive green roof and sensitivity analysis of its parameters in subtropical areas,” *Energies (Basel)*, vol. 12, no. 22, Nov. 2019, doi: 10.3390/en12224278.
[43] M. Anwar, M. G. Rasul, and M. M. K. Khan, “Performance Analysis of rooftop greenery systems in Australian subtropical climate,” in *Energy Reports*, Elsevier Ltd, Feb. 2020, pp. 50–56. doi: 10.1016/j.egyr.2019.08.017.
[44] C. Koranteng, B. Simons, and D. Nyame-Tawiah, “Simulation-Based Analysis of The Effect of Green Roofs on Thermal Performance of Buildings In A Tropical Landscape,” *Journal on Innovation and Sustainability RISUS*, vol. 12, no. 1, pp. 45–56, Apr. 2021, doi: 10.23925/2179-3565.2021v12i1p45-56.
[45] A. A. Rahman, S. M. Zaid, N. Dinie, and A. M. Shuhaimi, “Effects of Green Roof in Reducing Surface Temperature and Addressing Urban Heat Island in Tropical Climate of Malaysia,” 2022.
[46] X. Zheng *et al.*, “Green roof cooling and carbon mitigation benefits in a subtropical city,” *Urban For Urban Green*, vol. 86, p. 128018, 2023.
[47] S. Jia, Q. Weng, C. Yoo, H. Xiao, and Q. Zhong, “Building energy savings by green roofs and cool roofs in current and future climates,” *npj Urban Sustainability*, vol. 4, no. 1, Dec. 2024, doi: 10.1038/s42949-024-00159-8.
[48] T. P. Scolaro, E. Ghisi, and C. M. Silva, “Effectiveness of Cool and Green Roofs Inside and Outside Buildings in the Brazilian Context,” *Sustainability (Switzerland)*, vol. 16, no. 18, Sep. 2024, doi: 10.3390/su16188104.
[49] Y. Chen and N. H. Wong, “Thermal benefits of city parks,” *Energy Build*, vol. 38, no. 2, pp. 105–120, Feb. 2006, doi: 10.1016/j.enbuild.2005.04.003.
[50] G. Zhang, B. J. He, Z. Zhu, and B. J. Dewancker, “Impact of morphological characteristics of green roofs on pedestrian cooling in subtropical climates,” *Int J Environ Res Public Health*, vol. 16, no. 2, Jan. 2019, doi: 10.3390/ijerph16020179.
[51] M. H. Jahangir, A. Zarfeshani, and M. Arast, “Investigation of green roofs effects on reducing of the urban heat islands formation (The case of a municipal district of Tehran City, Iran),” *Nature-Based Solutions*, vol. 5, p. 100100, 2024.
[52] A. M. Mendes, C. M. Monteiro, and C. Santos, “Green Roofs Hydrological Performance and Contribution to Urban Stormwater Management,” *Water Resources Management*, pp. 1–17, 2024.
[53] P. Ndayambaje, J. S. MacIvor, and M. W. Cadotte, “Plant diversity on green roofs: A review of the ecological benefits, challenges, and best management practices,” *Nature-Based Solutions*, p. 100162, 2024.
[54] S. Vitaliano, S. Cascone, and P. R. D’Urso, “Mitigating built environment air pollution by green systems: An in-depth review,” *Applied Sciences*, vol. 14, no. 15, p. 6487, 2024.
[55] K. H. D. Tang, “Urban Solutions to Climate Change: An Overview of Latest Progress,” *Academia Environmental Sciences and Sustainability*, vol. 1, no. 2, Sep. 2024, doi: 10.20935/AcadEnvSci7342.