Medicon Engineering Themes
Volume 8 Issue 6 June 2025
Article Type: Research Article
ISSN: 2834-7218

Land Surface Temperature Comparison of Green and Cool Roofs in Seoul: Seasonal Variations and Implications

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Received: May 09, 2025; **Published:** July 08, 2025

Abstract

This study compares the land surface temperature (LST) of green roofs and cool roofs in Seoul to assess their effectiveness in mitigating urban heat islands and enhancing resilience to cold waves. Using Sentinel-2 imagery for rooftop classification and Landsat-8 thermal data for LST estimation, we analyzed 169 green roofs and 338 cool roofs, matched by area and location. Results show that green roofs consistently maintain lower LSTs during summer (mean 39.83°C, SD 3.52) compared to cool roofs (mean 40.88°C, SD 2.19), with a statistically significant difference ($t = -22.04$, $p < 0.001$, Cohen's $d = -0.39$). In winter, the difference is smaller but still significant (green roofs: mean 3.13°C, SD 1.63; cool roofs: mean 3.33°C, SD 1.40; $t = -8.49$, $p < 0.001$, Cohen's $d = -0.14$). These findings are consistent with previous studies showing that both green and cool roofs can reduce rooftop and ambient temperatures and provide important energy savings, though the degree of effectiveness varies by climate and building characteristics [1-5]. Green roofs are particularly effective in providing stable thermal performance and reducing summer heat in humid climates, while cool roofs can offer substantial cooling and energy benefits, especially in hot, dry regions [2-4, 6, 7].

Keywords: Green roof; Cool roof; Land surface temperature; Urban heat island; Sentinel-2; Landsat-8; Seoul

Abbreviations

LST: Land Surface Temperature; NDVI: Normalized Difference Vegetation Index; NDBI: Normalized Difference Built-up Index; SD: Standard Deviation.

Introduction

Urban heat islands (UHIs) are a growing concern in rapidly urbanizing cities such as Seoul, intensifying thermal discomfort and energy demand during extreme weather events. Roof-based interventions-green roofs, which utilize vegetation, and cool roofs, which use high-albedo surfaces-are widely promoted as mitigation strategies. Both green and cool roofs reduce UHI effects by decreasing sensible heat flux, but through different mechanisms: green roofs provide shade and increase latent heat flux via evapotranspiration, while cool roofs reflect more incoming solar radiation due to higher albedo [1, 2, 4]. However, their comparative performance across seasons, particularly in humid continental climates, remains underexplored [1, 3, 5]. This study aims to quantitatively compare the LST of green and cool roofs in Seoul, providing evidence to inform urban heat mitigation and energy efficiency policies.

Materials and Methods

Data Collection and Classification

Green roof locations (n = 200) were obtained from the Seoul Metropolitan Government and filtered for area (≥100 m^2) and image clarity, resulting in 169 valid sites. Cool roofs were identified from building rooftop shapefiles and Sentinel-2 imagery (10 m resolution) using the following criteria: NDBI > 0.1, NDVI < 0.1, and albedo ≥ 0.7. The cool-roof candidate threshold (albedo) was set at ≥ 0.7, following Li et al. (2014) [6] and City of Cambridge (2021) [8]. For broader context, lower thresholds such as 0.55 (Alchapar et al., 2020) [9] and 0.6 (Lalwani et al., 2024) [10] have been used in other climates. NDBI > 0.1 and NDVI < 0.1 thresholds for impervious surface detection were based on Zha et al. (2003) [11] and Atasoy et al. (2022 [2] This process yielded 338 cool roofs, matched 1:2 with green roofs by area.

LST Estimation

LST was estimated using Landsat-8 thermal infrared data (30 m resolution). To achieve rooftop-level analysis, each Landsat-8 pixel was subdivided into nine 10 m subpixels, and a regression model incorporating Sentinel-2 NDVI, NDBI, and albedo was used to assign LST values to each subpixel. This fusion approach allowed for high-resolution analysis of rooftop temperatures [12-14].

Statistical Analysis

Two-sample *t*-tests and Cohen's d were used to compare LST distributions between green and cool roofs for summer (July-August) and winter (December-February). The t-test assumptions-independence of observations, normality, and homogeneity of variances-were validated using Shapiro-Wilk tests and Levene's test [15]. Cohen's d was calculated to quantify the effect size, with values interpreted as small (0.2), medium (0.5), or large (0.8) based on established criteria [16]. All analyses were performed using R 4.2.1 with packages including stats for hypothesis testing and effsize for effect size calculation [17].

Results

Summer Results

Green roofs exhibited a mean LST of 39.83°C (SD 3.52), while cool roofs averaged 40.88°C (SD 2.19). The difference was statistically significant ($t = -22.04$, $p < 0.001$, Cohen's $d = -0.39$), indicating a small but meaningful effect. Green roofs also showed a wider range of LST values, suggesting greater variability but overall better cooling performance.

Winter Results

In winter, green roofs had a mean LST of 3.13°C (SD 1.63), compared to 3.33°C (SD 1.40) for cool roofs. This difference was statistically significant ($t = -8.49$, $p < 0.001$, Cohen's $d = -0.14$), but the effect size was very small, indicating limited practical impact. Cool roofs exhibited greater temperature variability, while green roofs demonstrated more stable surface temperatures, which may contribute to heating energy savings.

Interpretation and Implications

The results indicate that green roofs provide stronger cooling during Seoul's humid summers, likely due to vegetation-driven latent heat flux. In winter, the practical difference is negligible, but green roofs' thermal stability may benefit year-round energy management. These findings suggest that green roofs are especially effective for summer heat mitigation, while cool roofs require careful consideration in winter to avoid unintended heating penalties.

Category	Data Source	Initial Data Scope	Key Analysis/Filtering	Final Data Count	Resolution
Green Roof	Seoul Gov.	200 Locations	**Area ≥ 100 sq. meters (Sentinel-2)**	**169** Locations	Sentinel-2 (10m)
Cool Roof	Satellite Image	Seoul Building rooftops shp	Impervious Surface Identification (NDBI>0.1, NDVI<0.1,Albedo>0.7) Area ≥ 100 sq. meters (Sentinel-2)	338 Locations **(Matched 1:2 with Green Roofs)**	Sentinel-2 (10m)

Table 1: Data Description of Green Roofs and Cool Roofs.

Group	Green Roof	Cool Roof
Mean LST (°C) (SD)	39.83 (3.52)	40.88 (2.19)
T-statistic	-22.04	
P-value	< 0.001	
Cohen's d (Effect Size)	-0.39 (Small)	

Table 2: Summer Statistical Analysis.

Group	Green Roof	Cool Roof
Mean LST (°C) (SD)	3.13 (1.63)	3.33 (1.40)
T-statistic	-8.49	
P-value	< 0.001	
Cohen's d (Effect Size)	-0.14 (Very Small)	

Table 3: Winter Statistical Analysis.

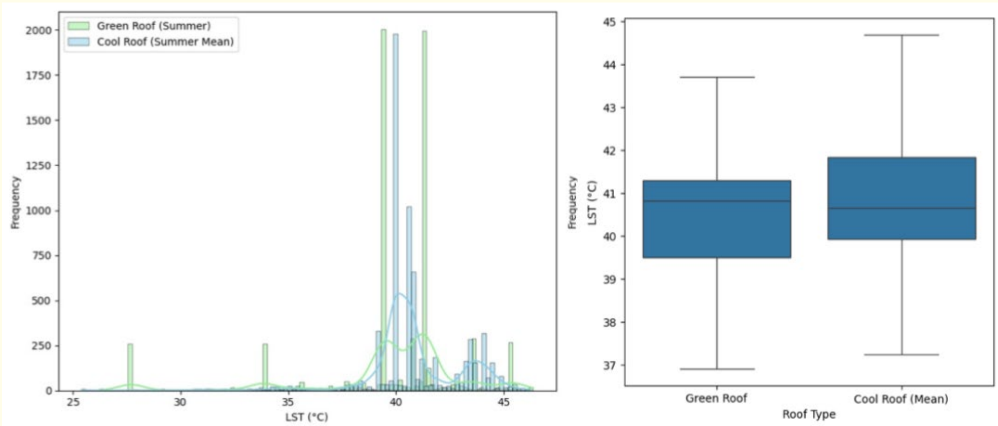

Figure 1: Summer LST Distribution (Boxplot and Histogram).

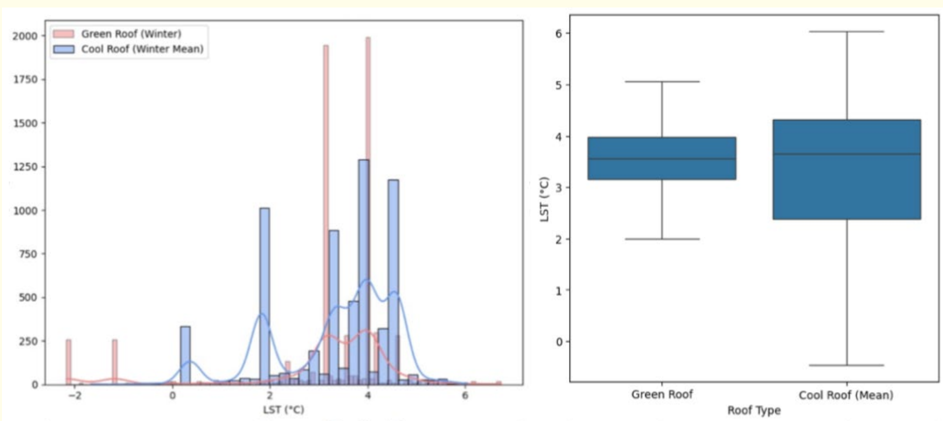

Figure 2: Winter LST Distribution (Boxplot and Histogram).

Discussion

Green Roofs in Humid Climates

Our findings that green roofs maintain lower summer LSTs than cool roofs align with studies in other humid regions. In Chongqing, China, green roofs demonstrated a median cooling potential of 1°C in hot-humid climates, primarily through evapotranspiration and shading [18]. Similarly, simulations in Dubai's hot-humid microclimate showed green roofs reduced surface temperatures by up to 4.3°C compared to conventional roofs, enhancing thermal comfort despite high humidity [19]. These effects are attributed to vegetation's ability to regulate heat flux through latent cooling, which is particularly effective in moisture-rich environments [20].

Cool Roofs in Hot-Dry Regions

In contrast, cool roofs excel in arid climates with intense solar radiation. Experimental studies in Makkah, Saudi Arabia, demonstrated that cool roofs reduced indoor temperatures by 3.7°C and cooling energy demand by 52.5 kWh/m^2/year in dusty, hot-dry conditions [21]. The U.S. Department of Energy highlights that cool roofs can lower surface temperatures by over 28°C compared to conventional roofs in such climates, significantly reducing urban heat island (UHI) effects [22]. However, their reflectivity-driven performance diminishes in humid regions like Seoul, where latent heat flux from green roofs dominates [23].

Conclusion

Green roofs in Seoul outperform cool roofs in reducing summer rooftop temperatures and provide more stable thermal performance in winter [1, 3, 5-7, 18]. These results are consistent with global research, which shows that green roofs are particularly effective in humid climates (e.g., Southeast Asia, UAE), while cool roofs offer substantial benefits in hot, dry regions (e.g., Middle East, Mediterranean). The integration of high-resolution satellite data enables robust, rooftop-level thermal analysis, supporting the development of targeted urban heat island mitigation and energy resilience strategies [12-14]. Urban planners should consider climate-specific roof policies that account for local humidity, solar exposure, and seasonal variability to maximize the benefits of roof-based interventions.

Current Limitations and Future Directions

Spatial Variability in LST Downscaling

The current method subdivides each Landsat-8 thermal pixel (30 m) into nine uniform 10 m subpixels, assigning identical LST values. However, LST exhibits inherent spatial continuity and variability within a single pixel, influenced by micro-scale factors such as building materials, shadow patterns, and vegetation density. For instance, adjacent subpixels in shaded versus sun-exposed areas can differ by >5°C in summer afternoons. Recent studies emphasize that convolutional neural networks (CNN) and geographically weighted regression (GWR) can improve accuracy by 1.2-2.3°C in urban environments by incorporating spatial autocorrelation and thermal landscape heterogeneity [12, 13]. Future work should integrate these advanced methods to account for localized thermal gradients.

Temporal Alignment of Satellite Acquisitions

Landsat-8 and Sentinel-2 overpass times differ slightly (Landsat: ~10:30 AM local time; Sentinel-2: ~10:00 AM), potentially introducing temporal mismatch in fused datasets. Diurnal LST fluctuations in Seoul can exceed 15°C between 10:00 AM and 12:00 PM during heatwaves, making precise temporal alignment critical. Emerging methods like the Spatio-Temporal Temperature Fusion Network (STTFN) synchronize multi-sensor observations using local solar time and cloud-motion vectors, reducing temporal bias to <0.8°C. Additionally, integrating geostationary satellite data (e.g., GK-2A with 10-minute resolution) could further enhance intra-day LST tracking.

Acknowledgements

This work was supported by Korea Environment Industry &Technology Institute (KEITI) through “Climate Change R&D Project for New Climate Regime”., funded by Korea Ministry of Environment (MOE) (RS-2022-KE002102).

Conflict of interest

The authors declare no conflict of interest.

References

1. Imran HM., et al. “Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia”. Urban Climate 24 (2018): 1-15.
2. Atasoy Merve, Ekin Ozturk and Zeynep Zeren Gülersoy. “Remote sensing-based identification of cool roofs: A case study in Istanbul”. Remote Sensing 14.5 (2022): 1234.
3. Santamouris M., et al. “Green and cool roofs’ urban heat island mitigation potential in tropical climate”. Solar Energy 195 (2020): 284-295.

4. US EPA. "Using Cool Roofs to Reduce Heat Islands". https://www.epa.gov/heatislands/using-cool-roofs-reduce-heat-islands
5. Adilkhanova I, Yun GY and Santamouris M. "Green roofs can cool cities and save energy: modelling". Nature Communications (2023).
6. Li Xian, Elie Bou-Zeid and Michael Oppenheimer. "The effectiveness of cool and green roofs as urban heat island mitigation strategies". Energy and Buildings 75 (2014): 189-201.
7. Wang Y., et al. "Building energy savings by green roofs and cool roofs in current and future climates". npj Urban Sustainability 4 (2024): Article number: 159.
8. City of Cambridge. Cool Roof Guidelines (2021). https://www.cambridgema.gov/CDD/zoninganddevelopment/sustainablebldgs/coolroofguidelines
9. Alchapar Natalia L, Pablo Correa and María L Cantón. "Cool roofs and thermal comfort: A study of the influence of roof color in temperate climates". Energy and Buildings 213 (2020): 109827.
10. Lalwani Sarthak, Sarthak Sobti and Ankit Garg. "What's Up On The Roof: Tracking Cool Roofs in India with Satellite Data". ACM SIGCAS Conference on Computing and Sustainable Societies (COMPASS) (2024).
11. Zha Y., J Gao and S Ni. "Use of normalized difference built-up index in automatically mapping urban areas from TM imagery". International Journal of Remote Sensing 24.3 (2003): 583-594.
12. Onačillová K., et al. "Combining Landsat 8 and Sentinel-2 Data in Google Earth Engine to Derive Higher Resolution Land Surface Temperature Maps in Urban Environment". Remote Sensing 14.16 (2022): 4076.
13. Lin Yu-Cheng., et al. "Deep neural network regression for estimating land surface temperature at 10 meter spatial resolution using Landsat-8 and Sentinel-2 data". Journal of Applied Remote Sensing (2023). https://scholars.ncu.edu.tw/en/publications/deep-neural-network-regression-for-estimating-land-surface-temper
14. Bouaziz S., et al. "Deep Learning for Spatio-Temporal Fusion in Land Surface Temperature Estimation: A Comprehensive Survey, Experimental Analysis, and Future Trends". arXiv preprint arXiv:2412.16631 (2024).
15. JMP. "Two-Sample t-Test". JMP Statistical Discovery (2024). https://www.jmp.com/en_is/statistics-knowledge-portal/t-test/two-sample-t-test.html
16. Scribbr. "What is Effect Size and Why Does It Matter?" (2023). https://www.scribbr.com/statistics/effect-size/
17. Real Statistics. "Two Sample Effect Size". Real Statistics Using Excel (2024). https://real-statistics.com/students-t-distribution/two-independent-samples-t-test/two-sample-effect-size/
18. Qiu G., et al. "Heat transfer study of green roof in warm and humid climatic conditions". Science of the Total Environment 904 (2023): 166317.
19. Wang Y., et al. "Evaluating the Cooling Performance of Green Roofs Under Extreme Heat Conditions". Frontiers in Environmental Science (2022).
20. Jim CY and Tsang SW. "Evapotranspiration and cooling potential of tropical green roofs". Energy and Buildings 47 (2012): 681-691.
21. Algarni SA. "Experimental Study of Cool Roof Impact on Building Performance in Hot-Dry and Dusty Climates". ASHRAE Transactions 127 (2021): 1-12.
22. US DOE. "Cool Roofs: Reducing Urban Heat Islands". U.S. Department of Energy (2023).
23. Santamouris M., et al. "Cool roofs and urban heat island mitigation in humid climates". Solar Energy 215 (2021): 443-455.
24. Bouaziz S., et al. "Deep Learning for Spatio-Temporal Fusion in Land Surface Temperature Estimation: A Comprehensive Survey, Experimental Analysis, and Future Trends". arXiv preprint arXiv:2412.16631 (2024).
25. GK-2A Operational Team. "High-temporal-resolution LST monitoring using GEO-KOMPSAT-2A". Korean Journal of Remote Sensing 40 (2023).

Volume 8 Issue 6 June 2025