

Bioclimatic Design Technical Parameters for Green Roofs in the Urban Context of Guayaquil

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Abstract— *Urban overheating has become a critical environmental challenge in cities located in warm-humid climates, driven by rapid urbanization, increased surface impermeability, and the reduction of green areas. Among passive bioclimatic strategies, green roofs have gained attention for their potential to improve building thermal performance and mitigate the urban heat island effect. However, their effective implementation requires the integration of technical design criteria with local regulatory frameworks. This article analyzes bioclimatic design criteria and the regulatory context applicable to green roofs in the urban environment of Guayaquil. The study adopts a qualitative and descriptive approach based on a comprehensive review of scientific literature and an analysis of current building and urban regulations. Key bioclimatic parameters—such as substrate thickness, vegetation selection, water management, and structural considerations—are identified and contrasted with existing normative provisions to assess their compatibility and level of integration. The results reveal that, while green roofs demonstrate significant potential to reduce surface temperatures and enhance thermal comfort in warm-humid conditions, local regulations lack specific technical guidelines to support their standardized application. This regulatory gap limits the widespread adoption of green roofs as a climate-responsive urban strategy. The findings highlight the need to incorporate explicit bioclimatic and technical criteria for green roof design into local regulatory instruments. Establishing such guidelines could facilitate their implementation, improve thermal performance in buildings, and contribute to broader urban sustainability and climate adaptation goals.*

Keywords— *Green roofs; Bioclimatic design; Urban heat island; Warm-humid climate; Building regulations*

I. INTRODUCTION

Accelerated urban growth and increasing city densification have produced significant transformations in the built environment, particularly in regions characterized by warm-humid climates. The replacement of natural surfaces with impervious materials, combined with the progressive reduction of urban green areas, has contributed to rising surface and air temperatures in cities, resulting in the phenomenon known as the urban heat island [1]. This condition negatively affects thermal comfort, increases building energy demand, exacerbates climate vulnerability, and degrades overall urban environmental quality [2].

Within this context, bioclimatic design has emerged as a fundamental approach for adapting the built environment to local climatic conditions. Through the application of passive strategies, bioclimatic design aims to optimize the thermal performance of buildings, reduce energy consumption, and enhance indoor and outdoor comfort without relying on mechanical systems. Among these strategies, green roofs stand

out for their ability to integrate vegetation into the building envelope, contributing to thermal regulation and improved urban environmental balance [3].

Green roofs, defined as construction systems that incorporate vegetation layers, growing substrate, and drainage systems over building roofs, have been widely studied for their capacity to reduce surface temperatures, enhance thermal inertia, and promote evapotranspiration processes. Numerous studies have demonstrated that green roofs can significantly reduce heat gains in buildings and contribute to the mitigation of the urban heat island effect, particularly in climates with high solar radiation and elevated relative humidity [4].

In addition to their thermal benefits, green roofs provide complementary environmental advantages that reinforce their relevance as a sustainable urban strategy, including stormwater retention, improved air quality, noise reduction, and increased urban biodiversity. However, the performance of these systems is strongly dependent on technical design parameters, such as appropriate plant species selection, substrate thickness and composition, structural load capacity, and maintenance requirements [5]. These factors must be addressed comprehensively from a bioclimatic perspective to ensure effective performance.

In the city of Guayaquil, which is characterized by consistently high temperatures, high relative humidity, and ongoing urban expansion, the implementation of green roofs represents a viable strategy for improving building thermal performance and reducing the impacts of urban overheating. Despite the growing body of scientific evidence supporting their benefits, local implementation remains limited and lacks specific technical regulations to guide their design and construction [6].

The absence of clear regulatory guidelines hinders the systematic adoption of green roofs and creates uncertainty during the design, approval, and construction processes. Consequently, it is necessary to examine the existing regulatory framework and contrast it with bioclimatic design criteria identified in scientific literature, to identify regulatory gaps, opportunities, and potential technical guidelines that support their application within the local urban context [7].

Therefore, the objective of this article is to analyze bioclimatic design criteria and the applicable regulatory framework for green roofs in the urban context of Guayaquil [8], establishing a theoretical and contextual foundation that supports the integration of this strategy as an effective tool for thermal mitigation and urban sustainability. This research aims to provide technical insights that may serve as a reference for

professionals, researchers, and decision-makers involved in architectural design and urban planning.

II. MATERIALS AND METHODS

This research adopts a qualitative, descriptive, and analytical approach aimed at examining the bioclimatic design criteria and regulatory framework applicable to green roofs in warm-humid urban contexts. The methodological strategy is based on documentary analysis and comparative evaluation, structured to ensure a systematic and replicable research process.

Research Design

The study follows a non-experimental research design, as it does not involve field measurements or experimental manipulation of variables. Instead, it focuses on the synthesis and critical analysis of existing scientific knowledge and regulatory instruments [9]. This approach is appropriate for establishing a theoretical and contextual foundation for green roof implementation, particularly in regions where empirical data remain limited. The study area to be analyzed is categorized by the central area of Guayaquil, comprising the historic center where high masses of recurring heat islands are concentrated both during the day and in the afternoon. These samples were defined by sampling the points of population concentration within the study area.



Fig. 1 Heat islands in the historic center of Guayaquil

Scientific Literature Review

A comprehensive review of scientific literature was conducted to identify key findings related to the thermal performance of green roofs and their role in mitigating the urban heat island effect. Academic databases and scholarly search engines were consulted, prioritizing peer-reviewed journal articles, reviewing papers, and technical studies addressing green roofs, bioclimatic architecture, urban climate, and building environmental performance in the last 10 years [10].

The selection criteria included relevance to warm-humid climates, availability of quantitative or qualitative thermal performance indicators, and the inclusion of design or construction parameters applicable to urban buildings. Studies focusing on substrate characteristics, vegetation selection, evapotranspiration processes, water retention capacity, and insulation performance were systematically analyzed. The extracted information was organized into thematic categories to facilitate comparison and synthesis.

Identification of Bioclimatic Design Criteria

Based on the literature review, a set of bioclimatic design criteria relevant to green roofs was identified. These criteria included but were not limited to roof typology (extensive or intensive), substrate depth and composition, plant species adapted to local climatic conditions, irrigation and drainage systems, structural load capacity, and maintenance requirements [11]. Attention was given to criteria that influence thermal regulation under high temperature and humidity conditions.

Each criterion was evaluated in terms of its contribution to thermal mitigation, energy efficiency, and environmental performance, allowing the identification of parameters most suitable for application in warm-humid urban environments [12].

Regulatory Framework Review

In parallel, a detailed review of the regulatory framework governing building construction, urban development, and environmental sustainability was carried out for the city of Guayaquil. Municipal ordinances, construction codes, urban planning instruments, and environmental regulations were examined to identify existing provisions related to green infrastructure, sustainable building practices, and climate-responsive design [13].

The regulatory analysis focused on determining whether green roofs are explicitly addressed or implicitly referenced through broader sustainability or environmental performance requirements. The level of technical detail provided by each regulatory document was assessed, along with its potential to support or constrain the implementation of green roofs in practice.

Comparative and Analytical Procedure

To evaluate the alignment between scientific recommendations and regulatory provisions, a comparative analysis was conducted using analytical matrices. These matrices enabled the systematic comparison of bioclimatic design criteria derived from the literature with the requirements and guidelines identified in the regulatory framework.

Through this process, areas of convergence, regulatory gaps, and inconsistencies were identified. This analytical procedure facilitated the assessment of the current regulatory capacity to support green roof implementation and highlighted opportunities for integrating bioclimatic design principles into local building regulations.

Data Synthesis and Interpretation

The final phase of the methodology involved the synthesis and interpretation of the data analyzed. Findings from the literature review and regulatory analysis were integrated to develop a coherent framework of bioclimatic design criteria applicable to green roofs in the local context. This synthesis provided the basis for discussing the implications of regulatory limitations and proposing considerations for future policy development and technical guidelines [14].

III. RESULTS AND DISCUSSION

The comprehensive review of scientific literature and regulatory documents provides a detailed understanding of the role of green roofs as a bioclimatic strategy in warm-humid urban environments. The results are discussed in relation to thermal performance, design variables, regulatory constraints, and their broader implications for urban sustainability and climate adaptation.

Thermal Behavior of Green Roof Systems

The analyzed studies consistently demonstrate that green roofs outperform conventional roofing systems in terms of thermal behavior. Significant reductions in surface temperatures were observed, particularly during peak solar radiation hours, which can be attributed to the combined effects of shading, increased thermal inertia, and evapotranspiration. These processes reduce the amount of heat absorbed by the building envelope and limit heat transfer into interior spaces [15].

In warm-humid climates, where high air temperatures are accompanied by elevated moisture levels, green roofs contribute to moderating both surface and ambient temperatures [16]. The literature indicates that these systems help stabilize indoor thermal conditions by reducing diurnal temperature fluctuations, which in turn lowers cooling energy demand. While the degree of thermal improvement varies according to system configuration and climatic conditions, the overall trend supports the effectiveness of green roofs as a passive cooling strategy [17].

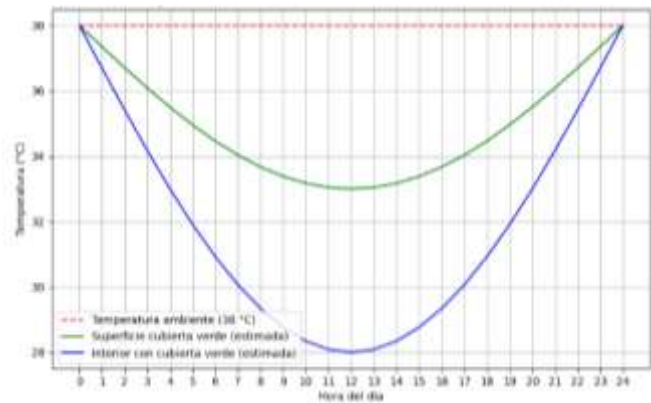


Fig. 2 Thermal behavior of the roof at 38°C (Sample constant taken from buildings in downtown Guayaquil)

Impact of Design Variables on Performance

The results highlight that the thermal performance of green roofs is highly sensitive to bioclimatic design parameters. Substrate thickness emerged as one of the most influential variables, as deeper substrates enhance thermal mass and moisture retention capacity, thereby increasing cooling potential through evapotranspiration. However, increased substrate depth also introduces structural constraints that must be carefully evaluated during the design phase [18].

Vegetation characteristics, including plant type, coverage density, and adaptability to local climate, were also found to significantly influence performance [19]. Plant species that are well adapted to warm-humid conditions tend to maintain higher evapotranspiration rates and require less maintenance, resulting in more consistent thermal benefits over time [20]. Conversely, inappropriate vegetation selection can reduce system efficiency and increase maintenance demands.

Water management systems play a critical role in sustaining green roof performance. Adequate drainage prevents waterlogging and structural damage, while controlled irrigation ensures sufficient moisture availability during dry periods. In warm-humid climates, where rainfall patterns may be irregular, water management strategies directly affect the longevity and effectiveness of green roof systems [21].

TABLE 1
DESIGN VARIABLES FOR THE PERFORMANCE OF GREEN ROOFS IN
GUAYAQUIL (TAKEN FROM THE HEAT ISLAND SAMPLE OF DOWNTOWN
GUAYAQUIL)

Design Variable	Description	Evaluation Indicator or Parameter	Relevance for Guayaquil (tropical hot-humid climate)
Type of green roof	Classification of the system: extensive, semi-intensive, or intensive	System depth and structural load	Extensive roofs are lighter and more common in housing; intensive roofs provide greater thermal capacity
Substrate depth	Depth of the vegetation growing layer	cm of substrate	Greater depth increases thermal inertia and water retention
Substrate composition	Mixture of organic and mineral materials	Percentage of organic matter, porosity, density	Should be lightweight with good moisture retention and drainage for heavy rainfall
Vegetation type	Plant species used in the roof system	Climate adaptation, evapotranspiration	Species should be tropical and resistant to heat and humidity
Vegetation cover	Percentage of area covered by plants	% cover	Greater coverage reduces direct solar radiation and surface temperature
Water retention capacity	Capacity of the system to store rainwater	Liters/m ² retained	Reduces urban runoff and helps regulate flooding
Drainage system	Layers that allow excess water to drain	Drainage capacity (mm/h)	Essential due to intense rainfall in tropical climates
Irrigation system	Mechanism used to supply water	Irrigation type (manual, drip, automatic)	During dry periods it maintains evapotranspiration and cooling
Thermal insulation of the system	Ability to reduce heat transfer into the building	Indoor/outdoor temperature difference	Green roofs can lower indoor temperatures through thermal inertia and evapotranspiration

Roof slope	Inclination of the roof	Degrees or slope percentage	Influences water drainage and substrate stability
Orientation and solar exposure	Relationship of the roof to solar radiation	Daily hours of solar radiation	In tropical regions solar radiation is high and constant throughout the year
Structural capacity	Load supported by the building structure	kg/m ²	Determines the feasibility of installing the system
Construction layers	Waterproofing, root barrier, drainage, and filter layers	Number and type of layers	Ensure durability and prevent leaks
Green roof area	Total installed surface area	m ²	Larger areas have greater impact on temperature reduction and runoff control
Maintenance	Activities required to maintain the system	Frequency of irrigation, pruning, fertilization	Maintains the thermal and hydraulic performance of the system

In warm tropical climates like that of the Ecuadorian coast, specifically in Guayaquil, green roofs can reduce interior temperatures, increase thermal inertia, and decrease energy consumption, as well as retain rainwater and reduce urban runoff.

Contribution to Urban Heat Island Mitigation

Beyond individual building performance, the reviewed literature suggests that green roofs can contribute to urban heat island mitigation when implemented at a broader scale. By reducing surface temperatures and limiting heat storage in urban materials, green roofs can influence microclimatic conditions and improve outdoor thermal comfort [22]. However, the extent of this impact depends on factors such as spatial distribution, roof coverage ratio, and integration with other green infrastructure elements.

These findings indicate that green roofs should be considered not only as isolated building-level interventions but also as components of comprehensive urban climate strategies [23]. Their cumulative effect can enhance urban resilience to increasing temperatures and climate-related stressors.

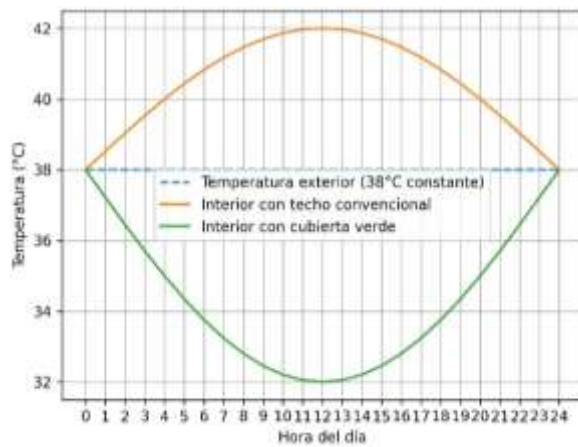


Fig. 3 Thermal comparison between conventional roof and green roof (continuous exposure to 38°C)

Regulatory Context and Technical Limitations

The regulatory analysis revealed a notable lack of specific technical provisions addressing green roof design and implementation. Existing regulations generally promote sustainability and environmental performance but do not provide detailed guidance on green roof systems. This absence of specificity limits the ability of regulatory frameworks to support consistent and effective application.

In the case of Guayaquil, this regulatory shortcoming is particularly relevant due to the city’s climatic vulnerability and rapid urban development. Without clear technical guidelines, green roofs remain largely discretionary, dependent on individual initiative rather than institutionalized practice. This situation constrains their potential contribution to urban climate mitigation.

Discussion: Bridging Science and Regulation

The comparison between scientific evidence and regulatory frameworks reveals a clear disconnect between research findings and policy implementation. While the literature provides robust evidence supporting the thermal and environmental benefits of green roofs, regulatory instruments have not yet fully incorporated this knowledge into enforceable or incentive-based mechanisms [6].

From a bioclimatic standpoint, the integration of scientifically validated design criteria into building regulations could enhance the effectiveness and reliability of green roof applications. Establishing minimum standards for substrate depth, vegetation selection, and water management would help ensure consistent performance and reduce uncertainty for designers and developers.

Moreover, the inclusion of green roofs within urban planning and sustainability policies could support broader objectives related to energy efficiency, climate adaptation, and public well-being [24], [25]. This discussion underscores the importance of aligning technical knowledge with regulatory action, enabling evidence-based strategies to be systematically adopted within the built environment.

IV. CONCLUSIONS

This study examined the bioclimatic design criteria and regulatory framework applicable to green roofs in warm–humid urban environments, with particular attention to the context of Guayaquil. The findings confirm that green roofs represent a technically viable and environmentally effective strategy for improving building thermal performance and mitigating urban heat accumulation in climates characterized by high temperatures and humidity [26].

The analysis of scientific literature demonstrated that green roofs can significantly reduce roof surface temperatures, moderate heat transfer into buildings, and contribute to improved indoor thermal conditions through mechanisms such as shading, thermal mass, and evapotranspiration [27]. These benefits highlight the relevance of green roofs as a passive bioclimatic solution capable of reducing cooling energy demand and enhancing urban environmental quality [25].

The results also revealed that the effectiveness of green roof systems is highly dependent on specific design parameters, including substrate thickness and composition, vegetation selection adapted to local climatic conditions, and appropriate water management strategies. Without the integration of these bioclimatic criteria, the thermal and environmental performance of green roofs may be limited, particularly in warm–humid contexts.

From a regulatory perspective, the study identified a lack of detailed technical guidelines within existing building and urban planning regulations. Although sustainability and environmental performance are increasingly recognized in regulatory instruments, the absence of explicit provisions for green roof design and implementation constrains their widespread adoption. This regulatory gap represents a missed opportunity to leverage scientifically validated strategies for urban climate adaptation [28].

In conclusion, the incorporation of bioclimatic design criteria for green roofs into local regulatory frameworks could facilitate their systematic application and maximize their benefits at both building and urban scales. Future research should focus on applied studies that evaluate the long-term thermal performance of green roofs under local climatic conditions, as well as on the

development of policy instruments that promote their integration into sustainable urban development strategies.

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