RCTA
Revista Colombiana de Tecnologías de Avanzada
UNIPAMPLONA

Thermal analysis of façades through infrared thermography for the identification of variables associated with surface temperature differences in buildings located in warm climates

Análisis térmico de fachadas mediante termografías infrarrojas para la identificación de variables asociadas a las diferencias de temperatura superficial en edificaciones de clima cálido

PhD. Erika Tatiana Ayala García[1], MSc. Jessica Viviana Sánchez Zúñiga[2]
PhD. Jorge Sánchez Molina[3]

[1] **Universidad Francisco de Paula Santander,** Facultad de Educación Arte y Humanidades, Grupo de Investigación Taller de Arquitectura y Gestión del Territorio TAR_GET, Cúcuta, Norte de Santander, Colombia.
[2] **Universidad Francisco de Paula Santander,** Facultad de Educación Arte y Humanidades, Grupo de Investigación en Tecnología Cerámica GITEC, Cúcuta, Norte de Santander, Colombia.
[3] **Universidad Francisco de Paula Santander,** Facultad de Ciencias Básicas, Grupo de Investigación en Tecnología Cerámica GITEC, Cúcuta, Norte de Santander, Colombia.

Correspondence: jorgesm@ufps.edu.co

Received: june 10, 2026. **Revised:** august 20, 2026. **Accepted:** september 07, 2026. **Published:** september 10, 2026.

How to cite: E. T. Ayala García, J. V. Sánchez Zúñiga, and J. Sánchez Molina, "Thermal analysis of façades through infrared thermography for the identification of variables associated with surface temperature differences in buildings located in warm climates", *Revista Colombiana de Tecnologías de Avanzada (RCTA)*, vol. 2, no. 48, pp. 262–272, sep. 2026, doi: 10.24054/rcta.v2i48.4537

Abstract: The thermal behavior of architectural envelopes directly influences comfort conditions and energy consumption in buildings located in warm climates. Therefore, the objective of this paper is to analyze the thermal behavior of façades through infrared thermography for the identification of surface temperature differences and, in this way, evaluate the thermal impact of architectural design variables on thermal comfort in buildings located on the campus of the Francisco de Paula Santander University, in San José de Cúcuta, Colombia. The methodology is quantitative with an experimental approach based on in situ measurements using specialized technology for data collection. Three representative case studies were selected for the comparative analysis of variables such as orientation, materiality, and surroundings. The results indicate that southeast and southwest orientations present the highest surface temperatures, exceeding 40°C. Furthermore, materials such as grooved concrete and concrete slabs are identified as materials associated with higher surface temperatures, while elements such as openings and vegetation contribute to heat dissipation, even in orientations with greater solar incidence. In addition, the ambient temperature exceeds the local thermal comfort range (23.5 °C and 28.5 °C), which demonstrates unfavorable climatic conditions in all case studies. In conclusion, the thermal behavior of buildings depends on the interaction between orientation, materiality, and surrounding variables, as well as on the implementation of passive strategies such as ventilation, light-colored materials, and vegetation in warm climate contexts.

Keywords: confort térmico, envolvente arquitectónica, materiales, termografía infrarroja.

Resumen: El comportamiento térmico de las envolventes arquitectónicas influye directamente en las condiciones de confort y en el consumo energético de las edificaciones en climas cálidos. Por tanto, el objetivo de este manuscrito consiste en analizar el comportamiento térmico de fachadas mediante termografía infrarroja para la identificación de diferencias de temperatura superficial y de esa manera, evaluar el impacto térmico de variables de diseño arquitectónico sobre el confort térmico en edificaciones ubicadas en el campus de la Universidad Francisco de Paula Santander, en San José de Cúcuta, Colombia. La metodología es cuantitativa con enfoque experimental basado en las mediciones in situ con tecnología especializada para la toma de datos. Se seleccionaron tres casos de estudio representativos para el análisis comparativo de variables como orientación, materialidad y entorno. Los resultados indican que las orientaciones sureste y suroeste presentan las mayores temperaturas superficiales, superando los 40°C. Asimismo, materiales como el concreto estriado y las losas de concreto se identifican como materiales asociados con mayores temperaturas superficiales, mientras que elementos como aperturas y vegetación contribuyen a la disipación del calor, incluso en orientaciones con mayor incidencia solar. Además, la temperatura ambiente supera el rango de confort térmico local (23.5 °C y 28.5 °C), lo cual evidencia las condiciones climáticas desfavorables en todos los casos de estudio. En conclusión, el comportamiento térmico de las edificaciones depende de la interacción entre variables de orientación, materialidad y entorno, y de la implementación de estrategias pasivas como ventilación, materiales claros y vegetación en contextos de clima cálido.

Palabras clave: Normativa de publicación, procedimientos, publicación, formato IEEE.

1. INTRODUCTION

Global warming is a reality affecting the planet that calls for a critical examination of decision-making across different industries. In the architecture and construction sector, building operation accounted for 28% of global CO_2 emissions in 2018. In addition, the construction industry, excluding building operation, accounted for 11% of emissions, according to the International Energy Agency [1]. For this reason, architecture as a whole must continue and accelerate the transition toward energy efficiency in order to mitigate the negative environmental impacts associated with energy consumption, the urban heat island effect, dependence on fossil fuels, air, water, and soil pollution, among others, with the aim of ensuring healthy environments, improving the thermal comfort of indoor spaces, and providing affordable housing quality [1]–[3].

Based on this premise, buildings have a direct impact on climate change. Although the field of study is very broad, multiple authors agree that the main factors contributing to this issue are the rapid urbanization of cities, limited knowledge of the properties of building materials, anthropogenic heat, geographical location, and climatic characteristics, which also contribute to the intensification of the Urban Heat Island (UHI) phenomenon [3]–[6].

Although this phenomenon was initially analyzed on a large scale to examine the differences between temperature dynamics in urban and rural areas by Oke in 1987 [7], advances in technology have made it possible to obtain satellite and local data using specialized equipment, such as infrared thermal imaging cameras and sensors. These technologies enable the measurement of surface and ambient temperature and humidity and, consequently, the quantification of the benefits and savings associated with new construction practices [3]–[6].

The urban heat island phenomenon affects people's quality of life because it does not mitigate outdoor climatic conditions. According to multiple authors, the intensification of the urban heat island varies according to vegetation cover [3]–[8], the thermal properties of surface materials [2], [7], [9], [10], solar exposure of façade surfaces [11]–[13], shadow projection [3], building orientation, the geometry of urban canyons [7], among other factors.

Based on the above, the main causes of this problem are the morphology and composition of buildings. The adverse effects of buildings designed without any type of planning generate a series of challenges and demands, such as high energy consumption by air-conditioning systems, human discomfort, reduced productivity, and deterioration of health [1].

1.1. Analysis of the Building Envelope

The main purpose of buildings is to protect occupants from external environmental factors that cannot be controlled because they are variable conditions, such as temperature, solar radiation, wind speed, precipitation, humidity, soil quality, among others. These factors are considered loads that affect and condition the physical and formal characteristics of buildings [1].

In summary, buildings constitute a protective layer that regulates external variables and provides indoor air quality and thermal comfort for occupants [1]. However, the composition of the building's outer layer has traditionally been divided into façade wall and roof elements, rather than being considered as an integrated building envelope or skin that protects the building as a whole [14].

The elements comprising this envelope are the result of a set of design decisions associated with the outermost layer, including continuous cladding systems and the sealing of exterior joints around façade openings [1]. In addition, these decisions include the selection of reflective materials and the design of openings for natural lighting and ventilation, among others [14].

In this regard, the surface temperature of a building envelope is conditioned by solar radiation and material properties [9]. Likewise, color and surface absorptance influence the amount of incident energy that is absorbed, which can be transferred by conduction through the material according to its thermal inertia and thermal conductivity properties, resulting in variations in the recorded surface temperatures [9], [16], [17].

In this context, infrared thermography makes it possible to identify differences in surface temperature; however, these differences do not constitute evidence of heat flows toward the interior of the building, but rather represent a non-invasive strategy for obtaining information related to the surface thermal behavior of materials [16], [17]. Regardless of the field of study, the infrared thermography technique must consider three factors that influence the analysis: the operator, that is, the thermal imaging camera; the observed system; and the environment [18].

However, since the focus of this research is oriented toward the thermal analysis of buildings, the factors related to the observed system (buildings) and the environment (climatic conditions) are described in the case study section. The operator involved in applying this technique is an infrared thermal imaging camera with specifications such as high thermal sensitivity, or Noise Equivalent Temperature Difference (NETD), an average accuracy of ±2 °C or ±2%, and spatial resolution determined by the Instantaneous Field of View (IFOV) and image acquisition frequency [18]. These characteristics make it possible to diagnose the thermal performance of buildings and conduct the intended thermal analysis.

The analysis of the building envelope should consider improvement measures that incorporate adaptive sustainable construction strategies according to the type of intervention, in order to adapt to the infrastructure of the built environment, take advantage of existing elements, and consequently mitigate negative environmental impacts [6]. According to [6] and [19], the main strategies generally include green infrastructure, such as parks, green façades and/or green roofs; blue infrastructure and evaporative cooling; cool materials with selective properties for roofs, pavements, and façades; reduction of anthropogenic heat generated by urban and building activities; shading and ventilation through urban morphology; and geothermal measures [2], [3], [6].

In addition to promoting urban tree planting through public spaces and building envelopes, [5] also suggests territorial planning of land allocated for public use in urban development projects, the development of environmental policies, incentives for the use of construction materials with high solar reflectance and efficient irrigation systems, as well as continuous monitoring and evaluation of recorded data. However, promoting the implementation of these strategies at the city level requires interinstitutional collaboration among academia, industry, and government through the formulation and management of projects with a significant impact on mitigating urban heat islands generated by urban infrastructure [5].

Table 1 summarizes quantitative results from studies related to the thermal behavior of building envelopes and façade surfaces, considering the study object, the variables analyzed, the recorded temperature differences, and the measurement instruments implemented.

Table 1: *Thermal differences recorded in building envelopes through infrared (IR) thermography measurements and numerical modeling.*

Study object	Variables	Thermal differences	Measurement method
Residential building façade, Zaragoza [11]	Solar exposure, seasons, surface temperature, color, solar absorptance	7.4 °C between sun-exposed and shaded surfaces in summer, and up to 1.2 °C in winter	IR thermography, thermo-hygrometer, and climatic data
Church roofs in Cúcuta [12], [13]	Geometry, solar incidence, thermal conductivity, orientation, heat transfer	Reduction between 10% and 70% in domed envelopes and up to 77% in inclined planes, depending on orientation	Solar incidence simulations
Church roofs in Cúcuta [12], [13]	Geometry, solar incidence, thermal conductivity, orientation, heat transfer	Between 3.79 °C and 20.19 °C depending on the inclination of the surface planes	Heat transfer simulations in ANSYS
Agricultural building envelopes [16]	Surface thermal distribution, thermal bridges	Between −7.3 °C and 6.1 °C	IR thermography and numerical modeling
Products for ceramic façade systems [9]	Materiality, geometry, heat transfer, thermal properties	Between 1 °C and 7 °C according to the geometry and variations of the product's exterior surfaces	Heat transfer simulations in ANSYS

Source: *Authors' own elaboration.*

Therefore, the contribution of this research focuses on exploring infrared thermography as a non-invasive identification and analysis strategy to relate differences in surface temperature to architectural design variables in three buildings on the campus of the Universidad Francisco de Paula Santander, San José de Cúcuta campus. The study provides a thermal assessment of surfaces characterized by different orientations, materiality, façade configurations, and surrounding conditions, providing supporting information to guide future research on building envelopes.

1.2. Case Study: Buildings Located on the Campus of the Universidad Francisco de Paula Santander in Cúcuta, Colombia

In the context of Cúcuta, Norte de Santander, Colombia, warm climatic conditions predominate, with average temperatures ranging from 26.2 °C to 34.4 °C throughout the year. In addition, recorded solar irradiance represents an environmental challenge for the city, as the highest values range from 664.2 W/m² to 796.8 W/m² [20]. This has direct implications for high temperatures and solar exposure of building façades (environment). Consequently, high-energy-consumption building practices arise, such as the implementation of cooling systems and mechanical ventilation for indoor climate conditioning.

Although the urban heat island phenomenon encompasses multiple research areas and variables, this study is limited to understanding the impact of buildings at a small scale. Therefore, the selected case study consists of the buildings located on the campus of the Universidad Francisco de Paula Santander, Cúcuta campus (observed system). The campus includes a wide variety of building typologies, the use of diverse local materials, landscaped and non-landscaped recreational areas such as plazas, among other characteristics. The selection of this case study supports the development of the research through the exploration, comparison, and evaluation of variables for the thermal analysis of façades and the consideration of sustainable improvement measures.

2. METHODOLOGY

The methodology consists of a quantitative research study with an experimental approach that enables the exploration of results through in situ measurements using specialized data acquisition technology. The research is structured into four stages: (1) identification and selection of case studies, (2) thermal measurement of façades, (3) analysis of thermal bridges, and (4) evaluation of the impact of architectural design variables on thermal comfort.

In the first stage, the buildings located on the campus of the Universidad Francisco de Paula Santander, Cúcuta campus, were identified and surveyed. Variables such as orientation, exposure to solar radiation, materiality, façade configuration, use, occupancy, and age were considered. Three representative case studies were selected from the buildings located on the UFPS campus to compare variables associated with design and architecture with the subsequent thermographic measurements. The selection corresponds to an applied and localized case study, aimed at the comparative analysis of variables associated with architectural design and the surface thermal differences of the selected buildings.

The second stage consisted of measuring the temperatures of the exterior surfaces of the selected buildings using infrared thermography, along with measurements of ambient temperature. In addition, conventional photographic records of the selected façades were obtained in order to establish a comparative basis for the thermal analysis of the façades and their surroundings.

In the third stage, differences in surface temperatures were analyzed based on the correlation between architectural design variables and thermal results. This approach makes it possible to identify thermal behavior patterns and their relationship with the configuration of the building envelopes.

The experiment comprised three case studies, with four façades analyzed per building and five measurement sessions, for a total of 60 façade-session observations. During each measurement session, surface temperature was recorded for each façade, together with ambient temperature and relative humidity. Thus, each façade had five observations (n = 5), corresponding to the five measurement sessions. The recorded surfaces were subsequently characterized according to the materials and elements present on each façade. Therefore, not all materials were represented across all orientations or in all three case studies.

Surface temperature values were obtained through point measurements on the surfaces identified in the thermographic images captured using a FLIR E4 camera. The infrared resolution is 80 × 60 pixels, with thermal sensitivity (NETD) < 150 mK, an IFOV of 10.3 mrad, accuracy of ±2 °C or ±2% of the reading, a spectral range of 7.5–13 μm, and a measurement range of −20 °C to 250 °C. The equipment also features a fixed-focus lens and a 45° × 34° field of view. During the experiment, the operating configuration of the equipment was kept unchanged, without applying differentiated emissivity settings according to the material.

For each identified material or element, a measurement point was selected on the corresponding surface, and the temperature indicated by the camera was recorded. The images were reviewed using the FLIR Tools application, without applying regions of interest (ROI). Therefore, the recorded values correspond to point temperatures rather than mean, maximum, or minimum temperatures of regions of interest.

Based on this information, quantitative data processing was performed using descriptive statistics. For each façade surface, average values were calculated from the five measurement sessions and subsequently compared according to orientation, material, and case study. All records obtained during the five measurement sessions were included in the analysis, without applying subsequent exclusion criteria.

Finally, in the fourth stage, the thermal impact of architectural variables on building thermal comfort was evaluated using the Givoni psychrometric chart as a reference. This made it possible to establish relationships between the observed conditions, bioclimatic strategies, and potential improvement measures aimed at optimizing thermal performance.

3. RESULTS AND DISCUSSION

3.1. Identification and Selection of Case Studies

For the identification and selection of the case studies, an initial survey of the buildings on the Universidad Francisco de Paula Santander campus, Cúcuta campus, was conducted based on planimetric information provided by the institutional planning office, complemented by in situ observations. Figure 1 illustrates the urban plan of the UFPS university campus. This stage made it possible to establish a database of 55 buildings and spaces located on the campus, including variables such as typology, use, volumetric configuration, and general characteristics of the buildings.

Fig. 1. *Urban plan of public spaces with UFPS projections.*
Source: *UFPS Planning Office (2019).*

Based on this information, an initial classification was established according to the number of floors: buildings with 1 or 2 floors (E1), buildings with more than 3 floors (E2), open-plan structures with roofs (P), and open spaces (A). According to this classification, 50% of the properties correspond to

E2-type buildings, which have larger façade areas and, therefore, more suitable conditions for thermal analysis. Consequently, this typology was defined as the main preselection criterion. The second most prevalent type of property on the UFPS campus is E1 (31%), followed by open spaces dedicated to outdoor recreational areas (A – 15%), and, to a lesser extent, open-plan structures with roofs (P – 4%).

As a second filter, variables associated with the construction stage and the main façade materials (MPF) were incorporated. These included exposed-face brick (MPF_01); reinforced concrete frame system with exposed-face brick infill (MPF_02); gres tile cladding (MPF_03); smooth and fluted concrete (MPF_04); exposed-face brick with a smooth stucco and painted finish (MPF_05); smooth stucco and painted finish with a metal envelope (MPF_06); reinforced concrete frame system with exposed-face brick infill and overhangs (MPF_07); exposed concrete block (MPF_08); and smooth stucco and painted finish (MPF_09). Figure 2 illustrates the classification of the buildings according to construction stage and MPF.

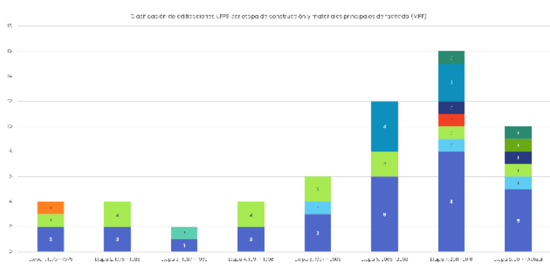

Fig. 2. Classification of UFPS buildings by construction stage and main façade materials (MPF).
***Source:** Authors' own elaboration.*

Construction time was considered as part of the characterization of the buildings during the case study classification and selection process. Although this information made it possible to identify differences among the buildings existing on the campus, it does not represent a direct variable in the analysis of surface temperature differences.

In addition, the type of surrounding environment (natural, artificial, or mixed) was considered as a complementary criterion, with buildings presenting mixed conditions being prioritized because of their comparative potential.

The application of these criteria reduced the analysis universe from 55 to 12 buildings, from which the final selection of three case studies was made. This selection considered buildings that were more representative in terms of material diversity, construction stages, and surrounding environment, in order to analyze different thermal behaviors within a controlled sample. The selected case studies correspond to the Torre Administrativa (ETA), Fundadores (EFU), and Bienestar Universitario (EBU) buildings, which represent different construction stages and façade material configurations.

Once the case studies had been selected, they were characterized according to the architectural design variables of the façades. For this stage, the building envelope criteria proposed in [14], [21] were considered.

Under this observation framework, the Torre Administrativa building was identified as being characterized by the predominant use of exposed gres brick as an envelope system. The Fundadores building is characterized by the presence of traditional materials, such as concrete with smooth and fluted textured finishes. The Bienestar Universitario building stands out for its combination of reinforced concrete frame systems, smooth finishes, and metal envelopes, allowing variations in façade configuration and their relationship with the surrounding environment to be analyzed.

The façades were coded according to their orientation with respect to the cardinal directions: north (FN), northeast (FNE), northwest (FNO), east (FE), west (FO), south (FS), southeast (FSE), and southwest (FSO). This made it possible to standardize the identification of the analyzed surfaces. Figure 3 identifies the façades according to the site layout of the Torre Administrativa (ETA), Fundadores (EFU), and Bienestar Universitario (EBU) buildings on the UFPS campus.

Fig. 3. Representative façades of the selected case studies after classifying the buildings according to the number of floors, main façade materials, and construction stage.
***Source:** Authors' own elaboration.*

3.2. Thermal Measurement of Façades

Surface temperatures of the exterior surfaces of the buildings were measured over five days in December 2025, between 11:30 and 14:00, in order to capture conditions with higher solar radiation incidence.

The selection of December corresponded to the period available for conducting the experimental phase of the research. Therefore, the results correspond to the environmental conditions recorded during the five measurement sessions and do not represent the annual thermal behavior of the buildings.

During each measurement session, façade surface temperatures were recorded, along with complementary environmental variables, including ambient temperature and relative humidity, for correlation with the surrounding conditions.

Figure 4 presents the thermographic records of the façades of ETA, EFU, and EBU. During the measurement period, façade surface temperatures ranged from 28.1 °C to 46.2 °C, evidencing a wide thermal range. Meanwhile, ambient temperature values ranged from 27.7 °C to 39.6 °C, and relative humidity ranged from 45% to 75.5%. These ranges provide context for the thermal behavior observed on the façades in relation to the environmental conditions during the measurement period.

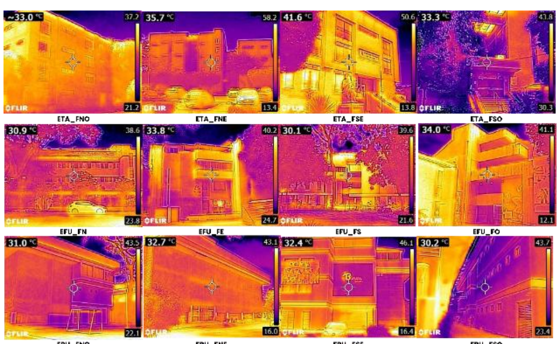

Fig. 4. *Termografías infrarrojas de las fachadas de ETA, EFU y EBU.* ***Source:*** *Authors' own elaboration.*

3.3. Analysis of Thermal Differences in Façade Surfaces and Surroundings

The analysis of surface temperatures reveals a thermal pattern associated with façade orientation and material type. In general, façades with south (S) and southeast (SE) orientations recorded the highest values, with surface temperatures ranging from 32.5 °C to 46.3 °C, followed by west (W) and southwest (SW) façades, with temperature variations ranging from 30.3 °C to 38.3 °C. Meanwhile, façades oriented toward the north (N), northeast (NE), and northwest (NW) exhibited surface temperatures ranging from 29 °C to 35.3 °C. However, the thermal behavior of floor surfaces varies mainly as a function of the material rather than façade orientation.

Table 2 summarizes the average ambient and façade surface temperatures according to material, building, and its application within the case study. The façade surface category comprises the materials that make up the building façade systems and are used in a vertical orientation. In contrast, surrounding materials are those implemented on exterior floor surfaces, used in a horizontal orientation, as well as vegetation located in the immediate surroundings of each façade. Since the materials and elements identified vary among the case studies, those that are not present in a given building are indicated as Not Applicable (N/A) in Table 2.

Table 2: *Average temperatures (°C) of the ambient environment and façade surfaces according to material, building, and its application in the case study.*

Category	Materials	ETA	EFU	EBU
Climatic data	Ambient temperature	32,4	34,5	34,0
Façade surfaces	Exposed-face brick	35,2	N/A	N/A
	White ceramic tile cladding	N/A	31,1	N/A
	Fluted concrete	40,3	36,4	N/A
	Smooth concrete	N/A	32,6	N/A
	White stucco and paint finish	N/A	N/A	31,8
	Reinforced concrete frame structure with red and white stucco and paint finish	N/A	N/A	35,8
	Aluminum metal grille	N/A	N/A	31,9
	Aluminum framing	34,4	31,9	34,7
	Glass windows	32,7	30,2	32,0
	Openings or apertures	26,6	29,5	27,6
Surroundings	Exterior floor with gres tile	40,7	35,2	N/A
	Exterior floor with concrete slab	44,9	38,5	40,8
	Grass surface	28,9	N/A	N/A
	Vegetation	26,5	26,4	N/A

Source: *Authors' own elaboration.*

Note: *The values correspond to average temperatures obtained from the surfaces identified according to material and case study.*

Temperature variability according to orientation is presented in the descriptive analysis of the results.

The materials recorded on the façade surfaces exhibit a thermal range between 30.2 °C and 40.3 °C. The material with the highest recorded temperatures is fluted concrete, located in ETA (average: 40.3 °C) and EFU (average: 36.4 °C), as shown in Figure 5. The variation in temperatures according to façade orientation ranges from 5.1 °C (EFU) to 12 °C (ETA). However, the presence of vegetation in the immediate surroundings of the façades contributes to mitigating heat transfer, while material diversity helps balance thermal loads, as demonstrated by the EFU case study, with improvements of 3.8 °C with smooth concrete and 5.3 °C with white ceramic tile cladding compared with fluted concrete.

Likewise, the reinforced concrete frame structure with red and white stucco and paint finish located in EBU records an average temperature of 35.8 °C and a temperature variation of 5 °C according to façade orientation, as shown in Figure 5. Although the structure exhibits a high thermal value, the presence of materials such as walls with white stucco and paint finish and the aluminum metal grille envelope also represents thermal improvements of approximately 3.9 °C. The EBU case study demonstrates the importance of exploring alternative materials to mitigate the heating of façade surfaces, as it incorporates two types of materials with similar thermal behavior but different functions: protection and ventilation.

Fig. 5. *Thermographic images of façade and surrounding surfaces: reinforced concrete frame structure (left), fluted concrete (center), concrete slab floors (right).*
Source: *Authors' own elaboration.*

The exposed-face brick records an average temperature of 35.2 °C, similar to that of the reinforced concrete frame structure. Thermal performance improves on the NE façade (32.9 °C), but increases on the SE façade (39.5 °C). Meanwhile, elements such as glass windows and aluminum framing record average temperatures of 31.6 °C and 33.7 °C, respectively, and are also present in all three case studies. In contrast, openings or apertures exhibit the lowest thermal values among the façade surface category, with an average temperature of 27.9 °C, as shown in Figure 6.

Fig. 6. *Thermographic images of openings and naturally ventilated corridors in buildings.*
Source: *Authors' own elaboration.*

In the following category, the materials identified in the surroundings consist of exterior floor surfaces made of gres tile, concrete slabs, grass, and vegetated areas with dense trees of heights similar to those of the buildings. According to Table 1, exterior concrete slab flooring is present in all three case studies, mainly for vehicular circulation within the UFPS campus. The average temperature is 41.1 °C, with EFU being the case with the lowest temperature due to the type of pedestrian traffic, whereas the EBU (40.8 °C) and ETA (44.9 °C) cases correspond to vehicular traffic.

Likewise, exterior gres tile flooring records high temperatures of approximately 37.9 °C, with a variation of 5.5 °C between EFU and ETA. In contrast, the exterior grass surface present in ETA reduces the temperature to 28.9 °C. However, the temperatures recorded in the vegetation closest to the façades of the case study buildings show an average of 26.5 °C.

This perspective provides guidelines for proposing improvement measures that, rather than restricting or eliminating the use of a material, complement it with other design alternatives that provide a more balanced temperature distribution. Therefore, the following objective will consider this analysis to relate the thermographic records to the climatic data of the surroundings.

3.4. Evaluation of the Impact of Architectural Design Variables on Thermal Comfort

The climatic conditions of the city of San José de Cúcuta present an average temperature of 27.1 °C, with a thermal comfort range between 23.5 °C and 28.5 °C [20]. During the measurement period, the ambient temperatures recorded at the façades (27.7 °C and 39.6 °C) exceeded this range during the hours of highest solar incidence. This comparison is used as a reference for outdoor environmental conditions and not as a direct assessment of indoor thermal comfort in the buildings.

The relationship between surface temperatures and environmental conditions was analyzed based on the difference between the surface temperature and the ambient temperature recorded in each measurement. The observed differences ranged from −9.4 °C to 13.5 °C, evidencing surfaces with temperatures both below and above the recorded ambient conditions, consistent with the surface temperature ranges presented in Table 2.

The consideration of the thermal comfort range aims to evaluate improvement measures according to comfort requirements based on the findings of the research, the literature, and the support of digital tools (Climate Consultant 6.0), as suggested by [6]. The generation of the psychrometric chart guides the selection of design strategies toward achieving thermal comfort. Figure 7 illustrates the psychrometric chart for San José de Cúcuta generated using Climate Consultant 6.0.

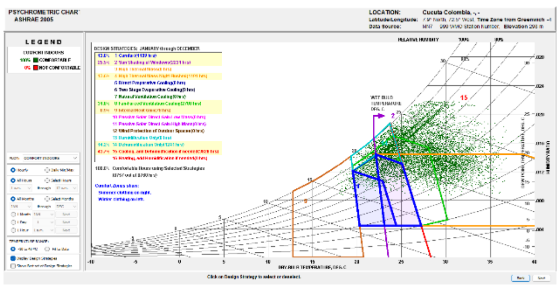

Fig. 7. *Psychrometric chart for San José de Cúcuta.*
Source: *Authors' own elaboration using Climate Consultant 6.0.*

In this regard, the northeast (NE) and northwest (NW) orientations present values closer to the thermal comfort range, whereas the southeast (SE) and southwest (SW) orientations record the highest temperatures, confirming the influence of solar radiation on the thermal behavior of building envelopes.

Based on the comparative thermal analysis of surface temperature differences, it is possible to identify that the variations do not depend exclusively on orientation, but rather on the interaction between material type, façade configuration, and surrounding conditions. The highest temperatures were recorded in the S and SE orientations, while comparisons of the same material across different orientations showed variations of up to 12 °C for fluted concrete and 6.6 °C for exposed-face brick. Likewise, differences between surface temperature and ambient temperature ranged from −9.14 °C to 13.5 °C during the measurement sessions analyzed. Materials such as fluted concrete on façades and floor slabs exposed to solar incidence recorded higher surface temperatures, whereas elements such as vegetation and openings exhibited lower surface temperatures.

In this context, passive strategies such as cross-ventilation, the use of light-colored materials, and the incorporation of vegetation are proposed as potential improvement measures based on the recorded temperatures and the principles of bioclimatic design for warm climates according to Climate Consultant, aimed at reducing thermal gains and promoting natural ventilation.

Overall, the results show that the thermal behavior of buildings is directly associated with architectural design decisions, highlighting the importance of integrating climatic criteria into the design of building envelopes in warm-climate contexts.

4. CONCLUSIONS

The analysis of façades using infrared thermography establishes that the thermal behavior of façade systems responds to a set of interacting variables, including orientation, materiality, and immediate surrounding conditions. In this regard, the orientations with greater solar incidence, southeast (SE) and southwest (SW), recorded the highest surface temperatures, whereas north-facing orientations exhibited lower surface temperatures compared with orientations with greater solar incidence.

Infrared thermography made it possible to identify that the highest surface temperatures were recorded on surfaces with dark-colored materials, such as fluted concrete on walls and concrete slabs on floors, which exceeded 40 °C. In contrast, elements such as openings and vegetation exhibited lower surface temperatures under the conditions analyzed.

Likewise, the recorded ambient temperatures exceeded the thermal comfort range established for the city of San José de Cúcuta, indicating outdoor environmental conditions with greater solar radiation. This highlights the need to incorporate bioclimatic design criteria from the initial stages of architectural project design and planning.

Based on the results obtained and the literature reviewed, cross-ventilation, the use of light-colored materials, and the incorporation of vegetation in the immediate surroundings are proposed as potential strategies to mitigate the increase in surface temperatures in façade systems of buildings in warm climates.

In this regard, thermographic analysis is consolidated as a useful tool for decision-making in the design and evaluation of building envelopes in warm climates.

The results of the thermal analysis of façade surfaces correspond to the particular conditions of the three case studies and to the measurements conducted over five days in December 2025, between 11:30 and 14:00. Therefore, the analysis is descriptive in nature and is limited to the environmental conditions recorded during the measurement sessions, without intending to establish statistical generalizations or represent the annual thermal behavior of buildings in warm climates.

Finally, the application of infrared thermography in the three case studies made it possible to relate differences in surface temperature to variables such as orientation, materiality, façade configuration, and surrounding conditions. In this regard, its implementation as a non-invasive strategy provides information on the surface thermal behavior of building envelopes and makes it possible to identify specific conditions in the buildings analyzed that can be considered in future improvement processes.

REFERENCES

[1] Ching, F. D. y Shapiro, I. M., 2024. "*Arquitectura ecológica: Un manual ilustrado*". Editorial GG.

[2] Piracha, A. y Chaudhary, M. T., "Urban air pollution, urban heat island and human health: a review of the literature", *Sustainability*, vol. 14, *no.* 15, July, 2022, doi: https://doi.org/10.3390/su14159234

[3] Mohamed-Irfeey, A. M., Chau, H. W., Sumaiya, M. M. F., Wai, C. Y., Muttil, N. y Jamei, E., "Sustainable mitigation strategies for urban heat island effects in urban areas", *Sustainability*, vol. 15, no. 14, July, 2023, doi: https://doi.org/10.3390/su151410767

[4] Moreno-García, M. C. y Serra-Pardo, J. A., "El estudio de la isla de calor urbana en el ámbito mediterráneo: una revisión bibliográfica", *Biblio3W Revista Bibliográfica de Geografía y Ciencias Sociales*, vol. 21, no.1.179, noviembre 2016, doi: http://www.ub.es/geocrit/b3w-1179.pdf

[5] Niebles, M., "Cubiertas ecológicas: estrategia de manejo del efecto isla calor urbano en Barranquilla", Tesis de maestría. Universidad de la Costa, Barranquilla. Departamento de Civil y Ambiental, 2024.

[6] Palme, M. y Carrasco, C., "Isla de calor en ciudades de Chile: una revisión. Intensidad, variabilidad, impactos y medidas de mitigación", *Avances en el estudio de islas de calor urbano en América Latina.* México, Editor: CIGA-UNAM, 2024, págs. 306-328.

[7] Cabras, E, "Efectos de la morfología de las calles en el fenómeno de la isla de calor urbana en la ciudad de Barcelona: Estudio del comportamiento térmico de calles urbanas con diferente relación de aspecto (H/W) y orientación en dos barrios de Barcelona", tesis de maestría. Universitat Politècnica de Catalunya., Barcelona, 2014.

[8] Borbolla-Gaxiola, C., Osuna-Gallardo, M. G. y Zazueta-Medina, L. R., "Caracterización de las islas de calor urbanas superficiales en una agrociudad. El fenómeno de isla de frío urbano en Culiacán, México", *Quivera: Revista de Estudios Territoriales*, vol. 26, no. 2, julio, 2024, doi: https://doi.org/10.36677/qret.v26i2.22970.

[9] Colmenares-Uribe, A. P., Sánchez-Molina, J., Diaz-Fuentes, C. X. y Sánchez-Zuñiga, J. V., "El diseño de producto cerámico como estrategia de mitigación de transferencia de calor en envolventes arquitectónicas". Ecoe Ediciones S.A.S., 2023.

[10] Montalbán Pozas, B., Lucas Bonilla, M. y Lorenzo Gallardo, J. M., 2024, *Determinación de islas de calor urbanas mediante monitorización de una muestra de viviendas*. Ibiza: Convención Internacional de arquitectura Técnica.

[11] Barbero-Barrera, M. D. M., Tendero-Caballero, R. y García de Viedma-Santoro, M, "Impact of Solar Shading on Façades' Surface Temperatures under Summer and Winter Conditions by IR Thermography", *Architecture*, vol. 4, no. 2, April, 2024, doi: https://doi.org/10.3390/architecture4020014.

[12] Colmenares-Uribe, A. P., Diaz-Fuentes, C. X. y Diaz-Umaña, Y., "Rendimiento térmico y geometría de cubiertas en iglesias de San José de Cúcuta, Colombia", *VLC arquitectura. Research Journal*, vol. 11, no. 1, April, 2024, doi: 10.4995/vlc.2024.20612

[13] Diaz-Umaña, Y., Colmenares-Uribe, A. P. y Diaz-Fuentes, C. X., "Study of Solar Incidence on Roof Surface Geometry of Churches in San José de Cúcuta, Colombia: Analysis of Architectural Enclosure in Hot Weather". *The International Journal of Architectonic, Spatial, and Environmental Design*, vol. *19*, no. 1, December, 2024, doi:

https://doi.org/10.18848/2325-1662/CGP/v19i01/71-92.

[14] González-Vásquez, M. R. y Molina-Prieto, L. F., “Envolvente arquitectónica: un espacio para la sostenibilidad”. *Arkitekturax Visión FUA*, vol. 1, no. 1, noviembre, 2018, doi: https://doi.org/10.29097/26191709.201

[15] Garrido, I., Solla, M., Lagüela, S. y Rasol, M., “Review of InfraRed Thermography and Ground-Penetrating Radar Applications for Building Assessment”, Advances in Civil Engineering, vol. 2022, no.1, September 2022, doi: https://doi.org/10.1155/2022/5229911

[16] Junga, P., Koutný, T., Tichá, Z., Kudělka, J. y Mareček, J., “Possibilities of Detecting and Evaluating Thermal Defects in Agricultural Building Envelopes Using Simultaneous Infrared Thermography and Computer Modelling”, Acta Technologica Agriculturae, vol. 27, no. 3, pp. 179–186, September, 2024, doi: 10.2478/ata-2024-0024.

[17] Balageas, D. L, “Termografía infrarroja: una técnica multifacética para la Evaluación No Destructiva (END). Asociacion Argentina de Ensayos No Destructivos y Estructurales.”, en *IV Conferencia Panamericana de END* Buenos Aires, october, 2007.

[18] Pérez Rondón, F. A., “Conceptos generales en la gestión del mantenimiento industrial”, Bucaramanga: Ediciones USTA, Universidad Santo Tomas, 2021, pags. 107, E-ISBN: 978-958-8477-92-3.

[19] Santamouris, M. y Kolokotsa, D. (2016). Urban Climate Mitigation Techniques. Routledge.

[20] Sánchez Molina, J, Narváez Ortega, M y Sánchez Zúñiga, J., “Cerámica constructiva envolventes verticales en la ciudad de Cúcuta”, Bogotá: Ecoe Ediciones, 2023, págs. 157, e-ISBN: 978-958-503-576-8.

[21] R. Velasco y D. Robles, «el diseño y la evaluación de envolventes arquitectónicas para climas tropicales»., Rev. arquit., vol. 13, n.º 1, pp. 92–105, jul. 2011.