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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

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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: thermal comfort, architectural envelope, infrared thermography, materials.

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

INTRODUCTION

Global warming is a reality of the planet that demands a critical look at decisions in the different industries. In the case of the architecture and construction sector, the use of buildings accounted for 28% of global CO2 emissions in 2018; in addition, the construction industry, regardless of buildings, accounts for 11% of emissions, according to the International Energy Agency[1]. For this reason, architecture in general must continue and accelerate the transition towards energy efficiency, so that the negative environmental impacts associated with energy consumption, the urban heat island, dependence on fossil fuels, and air, water and soil pollution, among others, can be mitigated, in order to guarantee healthy surroundings, improve the thermal comfort of interior spaces and provide 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 of this problem are the rapid urbanization of cities, ignorance of the properties of building materials, anthropogenic heat, geographic location and its climatic conditions, which also contributes to the intensification of the urban heat island (UHI) phenomenon [3]–[6].

Although this phenomenon was initially analyzed on a large scale to analyze the difference between temperature dynamics in the city and rural areas by Oke in 1987[7], thanks to technological advances it is possible to access satellite and local data collection with specialized equipment such as infrared thermographic cameras and sensors, which allow data collection of surface and ambient temperatures and humidity and, consequently, to quantify the benefits and savings of new construction practices [3]–[6].

The urban heat island phenomenon impacts people's quality of life because it does not mitigate exterior 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], the solar incidence of façade surfaces [11]–[13], shading[3], the orientation of buildings, the geometry of urban canyons[7], among others.

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

The analysis of the architectural envelope

The main purpose of buildings is to protect individuals from the exterior factors of their surroundings, some of which cannot be controlled because they are environmental variables such as temperature, solar radiation, wind speed, precipitation, humidity, and soil quality, among others. These factors are considered loads that impact and condition the physical and formal characteristics of the building[1].

In short, buildings are the protective layer that regulates exterior variables and provides air quality and thermal comfort for users[1]. However, the composition of the building's outer layer has been divided into façade wall and roof elements independently, and not as a set of envelope or skin that protects the building[14].

The elements that make up this envelope are a set of design decisions intrinsic to the first layer, such as continuous cladding systems and sealing of exterior joints at façade openings[1]. They also include the selection of reflective materials and the design of openings for lighting and natural ventilation, among others[14].

In this sense, the surface temperature of an envelope is conditioned by solar radiation and the properties of the materials [9]. Likewise, color and surface absorption influence the amount of incident energy absorbed, which can be transferred by conduction through the material according to its inertia and thermal conductivity properties, giving rise to variations in the recorded surface temperatures[9],[16],[17].

In this context, infrared thermography allows identifying surface temperature differences, although these differences do not constitute evidence of heat flows into the interior of the building, but only a non-invasive strategy for recognizing information related to the surface thermal behavior of materials [16], [17]. Regardless of the field of study, the Infrared Thermography technique must consider 3 actors that interfere in the analysis: the operator, that is, the thermal camera, the observed system and the surroundings [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 surroundings (climatic conditions) are described in the case study section. Nevertheless, the operator for performing this technique is the camera specialized in infrared thermography, with specifications such as high thermal sensitivity or "Noise Equivalent Temperature Difference", average accuracy of +/- 2°C or +/- 2%, and spatial resolution through the instantaneous field of view or Instantaneous Field of View and image frequency [18]. In this way, the thermal performance of buildings can be diagnosed to carry out the desired thermal analysis.

The analysis of the envelope must consider improvement measures that incorporate sustainable adaptive construction

strategies according to the type of intervention, so as to adjust to the infrastructure of the built surroundings, take advantage of existing elements and consequently mitigate the negative environmental impact[6]. According to [6] and[19], the main strategies are usually green infrastructure such as parks, green façades and/or roofs, blue infrastructure and evaporative cooling, cool selective materials 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 tree planting in cities through public space and architectural envelopes, [5] also suggests territorial planning of transfer zones in urban development projects, the development of environmental policies, incentives for the use of construction materials with high solar reflectance and efficient irrigation systems, and continuous monitoring and evaluation of records. However, to promote the implementation of these strategies at the city level, interinstitutional collaboration among academia, business and the state is essential, through the formulation and management of projects with high impact on mitigating the urban heat islands generated by city infrastructure[5].

Table 1 summarizes quantitative results from research on the thermal behavior of architectural envelopes and façade surfaces, considering the object of study, the variables analyzed, the temperature differences recorded and the measurement instruments implemented.

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

Object of study	Variables	Thermal differences	Measurement method
Façade of a residential building, Zaragoza [11]	Solar exposure, seasons, surface temperature, color, solar absorptance.	7.4 °C between sunny and shaded surfaces in summer and up to 1.2 °C in winter.	IR thermography, thermohygrometer and climatic data
Roofs of churches 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
		Between 3.79 °C and 20.19 °C according to the inclination of the surface planes.	Heat transfer simulations in ANSYS
Envelopes of agricultural buildings [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: own elaboration

The contribution of this research therefore lies in exploring infrared thermography as a non-invasive strategy for identifying and analysing how surface temperature differences relate to architectural design variables in three buildings on the campus of the Universidad Francisco de Paula Santander, San José de Cúcuta. The study that follows is a thermal reading of surfaces in terms of orientation, materiality, façade configuration and surroundings, offered as supporting information to guide future research on architectural envelopes.

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 between 26.2°C and 34.4°C throughout the year. In addition, the record of solar incidence also represents an environmental challenge for the city, since the highest values reach between 664.2 W/m2 and 796.8 W/m2 [20], and this implies direct consequences for the high temperatures and solar incidence of the building façades (surroundings). These, in turn, give rise to high energy consumption building practices, such as the implementation of refrigeration and mechanical ventilation systems for the climatic conditioning of spaces.

Although the urban heat island phenomenon has multiple research scopes and variables, this proposal is limited to understanding the impact of buildings at a small scale. For this reason, the case study selected consists of the buildings located on the campus of the Universidad Francisco de Paula Santander, Cúcuta branch (observed system), since it has a wide variety of building typologies, use of diverse materials and premises, tree-lined and non-tree-lined plaza-type recreation areas, among others. The selection of this case study nurtures 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..

METHODOLOGY

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

In the first phase, the buildings located on the campus of the Universidad Francisco de Paula Santander, Cúcuta branch, were surveyed. Variables such as orientation, exposure to solar radiation, materiality, façade configuration, use, occupancy and longevity were considered, and 3 representative case studies of the buildings located on the UFPS campus were selected in

order to compare variables associated with design and architecture with future thermographic measurements. The selection corresponds to an applied and localized case study, oriented toward the comparative analysis of variables associated with architectural design and the surface thermal differences of the selected buildings.

The second phase consisted of measuring the exterior surface temperatures of the selected buildings by means of infrared thermography and measuring the ambient temperature. Likewise, traditional photographic recording of the selected façades was carried out in order to build a comparative base for the thermal analysis of the façades and their surroundings.

In the third phase, surface temperature differences were analyzed based on the correlation between architectural design variables and thermal results. This 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 days, for a total of 60 façade-day observations. On each measurement day, a surface temperature record was made per façade, together with the record of ambient temperature and relative humidity. Each façade therefore had five observations (n=5), corresponding to the five measurement days. The recorded surfaces were subsequently characterized according to the materials and elements present on each façade. Not all materials are therefore represented in all orientations or in the three case studies.

Surface temperature values were obtained through point measurements on the surfaces identified in the thermographic images captured with a FLIR E4 camera. The infrared resolution is 80 x 60 pixels, with thermal sensitivity (NETD) < 150mK, IFOV of 10.3 mrad, accuracy of ±2 °C or ±2 % of the reading, spectral range of 7.5-13 μm and measurement range of -20 °C to 250 °C. The device also has a fixed-focus lens and a field of view of 45° x 34°. During the experiment, the operating configuration of the device was kept unchanged, with no differentiated emissivity adjustments according to the material.

For each material or element identified, 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); the recorded values therefore correspond to point temperatures and not to average, maximum or minimum temperatures of regions of interest.

On this basis, the quantitative treatment of the data was carried out using descriptive statistics. For each façade surface, average values were calculated from the five measurement days and subsequently compared according to orientation, material and case study. All the records obtained during the five days were included in the analysis, without applying subsequent exclusion criteria.

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

RESULTS AND DISCUSSIONS

Identification and selection of case studies

For the identification and selection of the case studies, the buildings of the campus of the Universidad Francisco de Paula Santander, Cúcuta campus, were initially surveyed based on planimetric information provided by the institutional planning office, complemented with in situ observation. Figure 1 illustrates the urban plan of the UFPS university campus. This stage made it possible to build a database of 55 buildings and spaces located on the campus that includes variables such as typology, use, volumetric configuration and general characteristics of the buildings.

On the basis of this information, an initial classification was established according to the number of storeys: buildings with 1 or 2 floors (E1), buildings with more than 3 storeys (E2), open-plan floors with roofs (P) and open spaces (A). This classification showed that 50% of the properties are E2-type buildings, which have a larger façade area and therefore better conditions for thermal analysis. This typology was consequently defined as the main preselection criterion. The second most common type of property on the UFPS campus is E1 (31%), followed by open spaces dedicated to outdoor recreation areas (A - 15%) and, to a lesser extent, open-plan floors with roofs (P – 4%).

As a second filter, variables associated with the construction stage and the main façade materials (MPF) were incorporated. These included face brick (MPF_01), a framed system with face brick (MPF_02), cladding with stoneware facing brick (MPF_03), smooth and ribbed concrete (MPF_04), face brick and cladding with a smooth stucco and paint finish (MPF_05), cladding with a smooth stucco and paint finish and a metal envelope (MPF_06), a framed system with face brick and cantilevers (MPF_07), face concrete block (MPF_08) and cladding with a smooth stucco and paint finish (MPF_09). Figure 2 illustrates the classification of the buildings by construction stage and the MPFs.



Fig. 1. *Urban plan of public space with UFPS projections.*
Source: Planeación UFPS (2019).

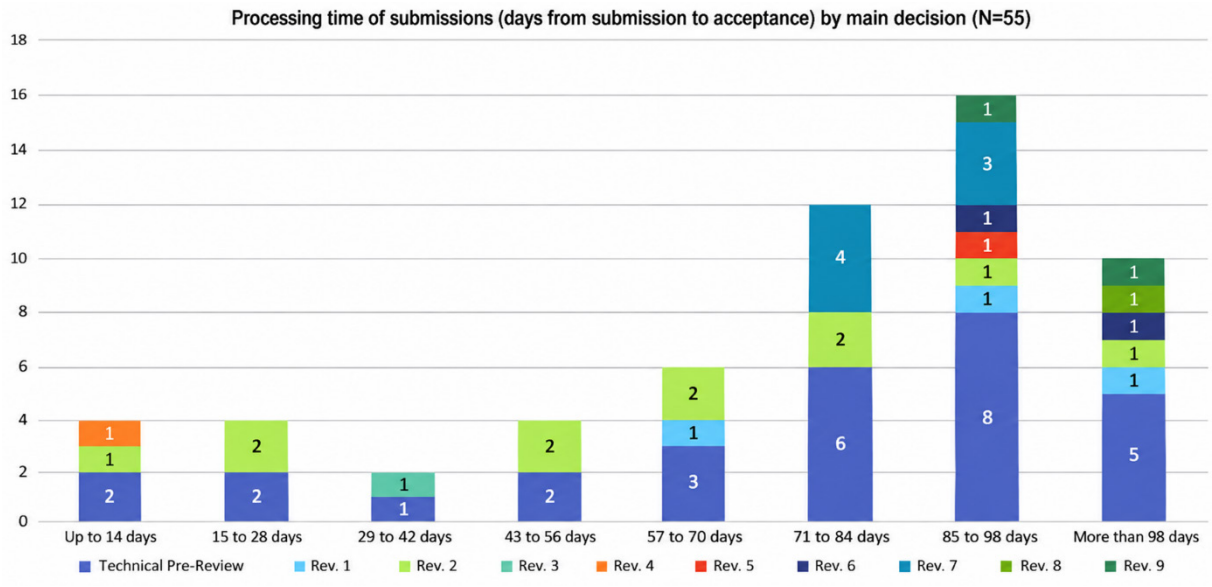

Fig. 2. *Classification of UFPS buildings by construction stage and main façade materials (MPF).*
Source: Own elaboration

Construction time was considered part of the characterization of the buildings during the classification and selection of the case studies. Although this information revealed differences among the buildings on the campus, it is not a direct variable in the analysis of surface temperature differences.

In addition, the type of surroundings (natural, artificial or mixed) was considered as a complementary criterion, prioritizing buildings with mixed conditions due to their comparative potential.

Applying 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 with greater representativeness in terms of diversity of materials, construction stages and surroundings, in order to analyze different thermal behaviors in 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 were selected, they were characterized according to the architectural design variables of façades. For

this stage, the architectural envelope criteria proposed by[14],[21]were taken into account.

Under this observation structure, the Torre Administrativa was found to stand out for the predominant use of face brick in stoneware as an envelope system, the Fundadores building for the presence of traditional materials such as concrete with smooth and striated texture finishes, and the Bienestar Universitario building for the combination of framed systems, smooth finishes and metal envelopes, which makes it possible to analyze variations in the façade configuration and their relationship with the surroundings.

The façades were coded according to their orientation with respect to the cardinal points: 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 implantation of the Torre Administrativa (ETA), Fundadores (EFU) and Bienestar Universitario (EBU) buildings on the UFPS campus.



Fig. 3. *Representative façades of the case studies selected after the classification of buildings by levels, main façade materials and construction stage. Source: Own elaboration*

Thermal measurement of façades

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

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

During each day, the surface temperatures of the façades were recorded, along with complementary environmental variables of ambient temperature and relative humidity for correlation with the surroundings.

Figure 4 presents the thermographic record of the façades of ETA, EFU and EBU. During the measurement period, the surface temperatures of the façades varied between 28.1 °C and 46.2 °C, evidencing a high thermal amplitude. Ambient temperature, in turn, recorded values between 27.7 °C and 39.6 °C, and relative humidity between 45 % and 75.5 %. These ranges make it possible to contextualize the thermal behavior observed in the façades in relation to the environmental conditions of the measurement period.

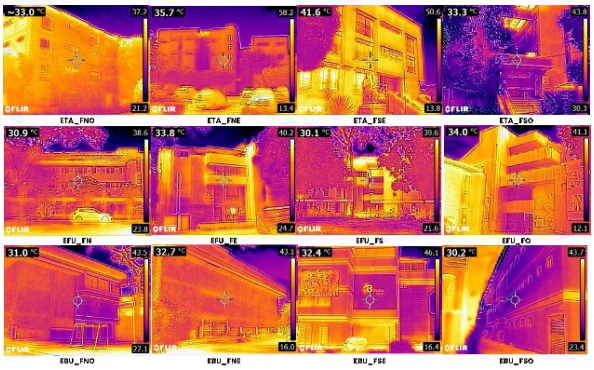

Fig. 4. *Infrared thermographies of the façades of ETA, EFU and EBU. Source: Own elaboration*

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 terms, façades with south (S) and southeast (SE) orientations record the most critical values, with surface temperatures between 32.5 °C and 46.3 °C, followed by the west (W) and southwest (SW) façades, with temperatures ranging between 30.3 °C and 38.3 °C. Façades with north (N), northeast (NE) and northwest (NW) orientations, in turn, show surface temperatures between 29 °C and 35.3 °C. However, the thermal behavior of floor surfaces varies mainly according to the material and not the façade orientation.

Table 2 summarizes the average ambient and façade surface temperatures according to the material, the building and its implementation in the case study. The façade surfaces category comprises those materials that make up the building's façade systems, used in the vertical direction. Surroundings materials, by contrast, are those implemented on exterior floor surfaces, used in the horizontal direction, together with the vegetation located in the immediate surroundings of each façade. Because the materials and elements identified vary between case studies, those not present in a building are indicated as Not Applicable (N/A) in Table 2.

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

Category	Materials	ETA	EFU	EBU
Climatic data	Ambient temperature	32,4	34,5	34,0
Façade surfaces	Face brick	35,2	N/A	N/A
	White ceramic tile cladding	N/A	31,1	N/A
	Grooved concrete	40,3	36,4	N/A
	Smooth concrete	N/A	32,6	N/A
	Stucco cladding and white paint	N/A	N/A	31,8
	Framed structure with stucco cladding and red and white paint	N/A	N/A	35,8
	Aluminum metal grille	N/A	N/A	31,9
	Aluminum frames	34,4	31,9	34,7
	Glass windows	32,7	30,2	32,0
	Voids or openings	26,6	29,5	27,6
Surroundings	Outdoor floor in ceramic tile	40,7	35,2	N/A
	Outdoor floor in concrete slab	44,9	38,5	40,8
	Outdoor floor in grass	28,9	N/A	N/A
	Vegetation	26,5	26,4	N/A

Source: own elaboration. Note: The values correspond to average temperatures obtained from the surfaces identified according to the material and case study. The variability of temperatures according to orientation is presented in the descriptive analysis of the results.

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

Likewise, the framed structure with stucco cladding and red and white paint located in EBU records an average temperature of 35.8 °C and a temperature variation of 5 °C according to the façade orientation, as shown in Figure 5. Although the structure represents a high thermal value, the presence of materials such as walls with stucco cladding and white paint and the aluminum metal mesh envelope also represent thermal improvements of around 3.9 °C. The EBU case study demonstrates the importance of exploring material alternatives to mitigate the heating of façade surfaces, because it implements two types of materials with similar thermal behavior but which offer different functions: protection and ventilation.



Fig. 5. *Thermographies of façade surfaces and surroundings: framed structure (left), grooved concrete (center), floors with concrete slabs (right). Source: own elaboration.*

Face brick records an average temperature of 35.2 °C, similar to the framed structure. The thermal behavior improves on the NE façade (32.9 °C) but increases on the SE façade (39.5 °C). For their part, elements such as glass windows and aluminum carpentry record average temperatures between 31.6 °C and 33.7 °C, respectively, and are also resources present in the three case studies. In contrast, the voids or openings record the lowest behavior in the façade surfaces category, with an average temperature of 27.9 °C, as observed in Figure 6.



Fig. 6. *Thermographies of openings and ventilated corridors in buildings.*
Source: own elaboration

In the following category, the materials identified in the surroundings are outdoor floor surfaces in porcelain stoneware, concrete slab, grass and vegetation areas such as dense trees of heights similar to the building. According to Table 1, the outdoor concrete slab floor is located in the 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, while in the EBU (40.8 °C) and ETA (44.9 °C) cases they correspond to vehicular traffic.

Likewise, the exterior gres tile floor records high temperatures of around 37.9°C, with a variation of 5.5°C between EFU and ETA. Next, the exterior grass floor present in ETA decreases to 28.9°C. However, the temperatures recorded in the vegetation closest to the façades of the case studies average 26.5°C.

This perspective defines the guidelines for proposing improvement measures that, instead of limiting or eliminating the use of a material, complement it with other design alternatives that provide a better temperature distribution. Therefore, the following objective will take this analysis into account to relate the thermographic record and the climatic data of the surroundings.

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 on the façades (27.7°C and 39.6 °C) exceeded this range during the hours of greatest solar incidence. This comparison is used as a reference for exterior environmental conditions and not as a direct evaluation of the interior thermal comfort of the buildings.

The relationship between surface temperatures and environmental conditions was analyzed from the difference between the surface temperature and the ambient temperature recorded in each measurement. The observed differences ranged between –9.4 °C and 13.5 °C, showing surfaces with temperatures both lower and higher than the recorded environmental conditions, in correspondence with the surface temperature ranges presented in Table 2.

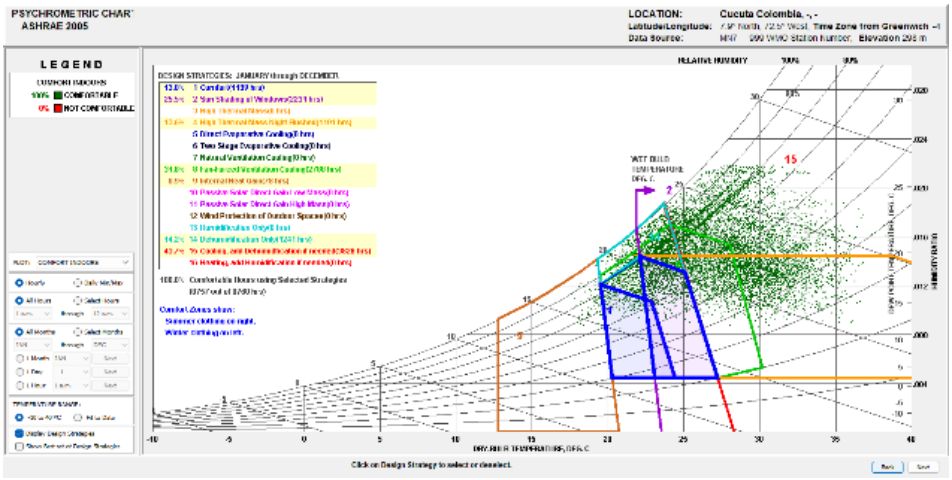

Fig. 7. *Psychrometric chart of San José de Cúcuta.*
Source: Own elaboration based on the Climate Consultant 6.0 program.

The thermal comfort range is considered in order to evaluate the improvement measures according to comfort needs, based on the research findings, 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 of San José de Cúcuta generated with the Climate Consultant 6.0 program.

In this sense, the northeast (NE) and northwest (NW) orientations present values closer to the 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 the envelopes.

The comparative thermal analysis of surface temperature differences shows that these variations do not depend exclusively on orientation; they also depend on the interaction between the type of material, the façade configuration and the conditions of the surroundings. The highest temperatures were recorded on the S and SE orientations, while comparisons of the same material across orientations showed variations of up to 12 °C in grooved concrete and 6.6 °C in face brick. The differences between surface temperature and ambient temperature ranged between -9.14 °C and 13.5 °C during the analyzed days. Materials such as grooved concrete on the façade and floor concrete slabs exposed to solar incidence recorded higher surface temperatures, while elements such as vegetation and openings presented 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 bioclimatic design principles for warm climate according to Climate Consultant, aimed at reducing heat gain and favoring natural ventilation.

Overall, the results show that the thermal behavior of buildings is directly associated with architectural design decisions, which highlights the importance of integrating climatic criteria in the conception of envelopes in warm climate contexts.

CONCLUSIONS

The analysis of façades by means of infrared thermography allows establishing that the thermal behavior of façade systems responds to a set of variables that interact with each other, such as orientation, materiality and the conditions of the immediate surroundings. In this sense, it is evident that the orientations with the greatest solar incidence, southeast (SE) and southwest (SW), recorded the highest surface temperatures, while the north orientations presented lower surface temperatures compared with the orientations with greater solar incidence.

Infrared thermography made it possible to identify that the highest surface temperatures were recorded on those surfaces with dark materials such as grooved concrete on walls and concrete slabs on floors, which exceed 40 °C. In contrast, elements such as openings and vegetation presented lower surface temperatures within the analyzed conditions.

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

Based on the results obtained and the literature consulted, 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 climate.

In this sense, thermographic analysis is consolidated as a useful tool for decision-making in the design and evaluation of architectural 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 carried out over five days in December 2025, between 11:30 and 14:00. The analysis is therefore descriptive in nature and is limited to the environmental conditions recorded during the measurement days; it does not seek to establish a statistical generalization or to represent the annual thermal behavior of buildings in a warm climate.

Finally, the application of infrared thermography in the three case studies made it possible to relate the surface temperature difference to variables of orientation, materiality, façade configuration and surroundings. Its implementation as a non-invasive strategy thus provides information on the surface thermal behavior of architectural envelopes and makes it possible to identify particular conditions of the buildings analyzed that should 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.

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