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ORIGINAL

Passive Strategies in Rural Housing: Optimization of thermal comfort in cold humid climate, Vereda San Antonio - Ospina

Estrategias Pasivas en Viviendas Rurales: Optimización del confort térmico en clima frío húmedo, Vereda San Antonio- Ospina

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ABSTRACT

The research focused on the application of bioclimatic strategies in rural housing in the village of San Antonio, in Ospina, Nariño. Bioclimatic architecture was defined as a design approach that integrated the climatic environment and natural resources to create comfortable and sustainable spaces. In this context, the study sought to respond to the challenges of the cold humid climate characteristic of the region, where low temperatures and high humidity had a negative impact on the habitability of the houses. To address this problem, a detailed analysis of variables such as temperature, relative humidity, wind direction, topography and vegetation was carried out. Data collection was carried out through IDEAM records and in situ measurements with specialized instruments, which allowed us to understand the climatic patterns and their impact on thermal comfort conditions. The results showed that the relative humidity reached high values, generating risks of condensation and deterioration of materials, while the minimum temperatures represented a challenge for the natural heating of the houses. Based on the Givoni diagram, passive strategies such as the Trombe wall, bioclimatic greenhouses, bioclimatic windows and wood fiber insulation were selected to optimize the capture and conservation of solar energy. These strategies were evaluated through simulations and construction analysis, which demonstrated their effectiveness in improving thermal comfort and energy efficiency. In conclusion, the research validated that the implementation of these passive solutions made it possible to adapt rural dwellings to their climatic context, guaranteeing wellbeing for the inhabitants and reducing dependence on active air conditioning systems.

Keywords: Bioclimatic Architecture; Thermal Comfort; Passive Strategies; Cold-Humid Climate; Sustainability.

RESUMEN

La investigación se centró en la aplicación de estrategias bioclimáticas en viviendas rurales de la vereda San Antonio, en Ospina, Nariño. Se definió la arquitectura bioclimática como un enfoque de diseño que integró el entorno climático y los recursos naturales para crear espacios confortables y sostenibles. En este contexto, el estudio buscó responder a los desafíos del clima frío húmedo característico de la región, donde las bajas temperaturas y la alta humedad incidieron negativamente en la habitabilidad de las viviendas. Para abordar esta problemática, se realizó un análisis detallado de variables como temperatura, humedad relativa, dirección de vientos, topografía y vegetación. La recolección de datos se llevó a cabo mediante registros del IDEAM y mediciones in situ con instrumentos especializados, lo que permitió comprender los patrones climáticos y su impacto en las condiciones de confort térmico. Los resultados evidenciaron que la humedad relativa alcanzó valores elevados, generando riesgos de condensación y deterioro de materiales, mientras que las temperaturas mínimas representaron un desafío para la calefacción natural de las viviendas. A partir del diagrama de Givoni, se seleccionaron estrategias pasivas como el muro Trombe, invernaderos bioclimáticos, ventanas bioclimáticas y aislantes de fibra de madera, orientadas a optimizar la captación y conservación de la energía solar. Dichas estrategias se evaluaron mediante simulaciones y análisis constructivos, lo que demostró su eficacia en la mejora del confort térmico y la eficiencia energética. En conclusión, la investigación validó que la implementación de estas soluciones pasivas permitió adaptar las viviendas rurales a su contexto climático, garantizando bienestar para los habitantes y reduciendo la dependencia de sistemas activos de climatización.

Palabras clave: Arquitectura Bioclimática; Confort Térmico; Estrategias Pasivas; Clima Frío-Húmedo; Sostenibilidad.

INTRODUCTION

Bioclimatic architecture is defined as an approach to architectural design that harmoniously integrates climatic conditions and natural resources from the environment with the aim of creating livable, comfortable, and sustainable spaces. This approach prioritizes efficient energy use and reduced environmental impact through active or passive strategies that take advantage of elements such as solar orientation, natural ventilation, and the thermal properties of materials.[1,2]

From this perspective, this research focused on the application of bioclimatic strategies for rural dwellings in the village of San Antonio, Ospina Nariño, considered an area of great environmental and anthropic importance given that this region has developed a traditional empirical architecture, characterized by the use of local materials and ancient construction techniques.[3,4,5] This study is particularly relevant today, when geographical and climatic conditions present specific challenges for the adaptation of adequate and resistant housing.[6,7]

The village of San Antonio in the municipality of Ospina, in the south of the department of Nariño, has a total area of approximately 5 km^2 and is located 11 kilometers from the town center of Ospina. It has an important road within which the studied dwelling is located.

In San Antonio, where a cold, humid climate prevails, climatic conditions have specific characteristics that significantly influence the thermal behavior of homes. In this context, temperatures tend to be lower, especially during the winter months, with moderately high humidity levels. These climatic conditions imply a greater risk of condensation and moisture accumulation in structures, which can lead to deterioration problems.[8,9]

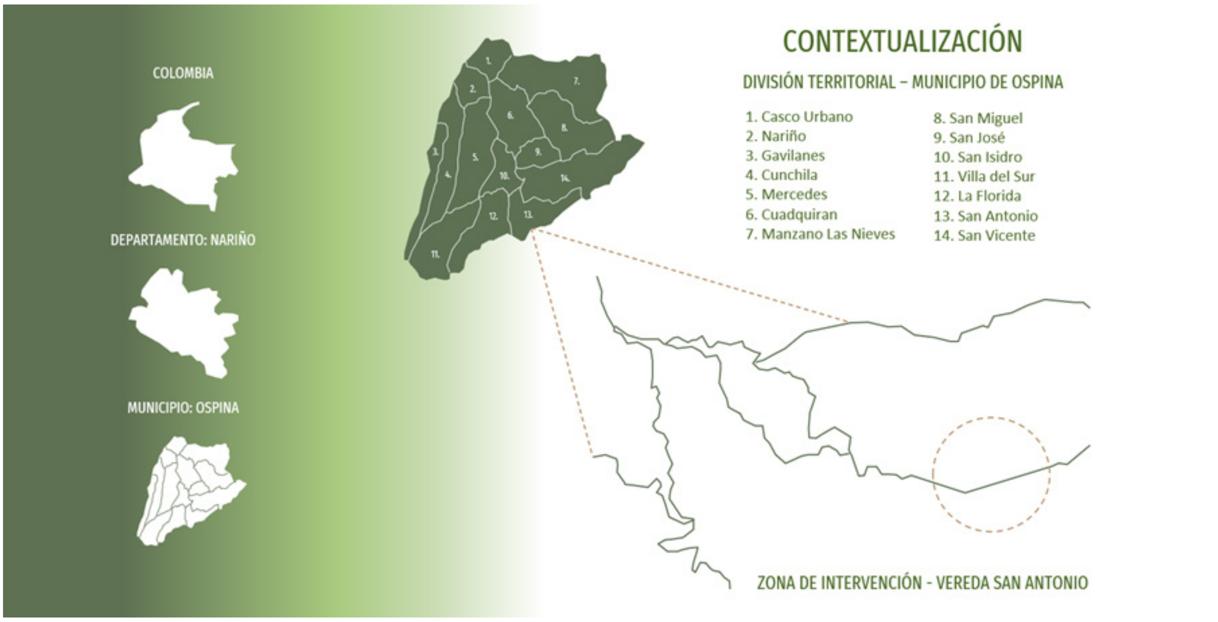

Figure 1. Contextualization (Territorial division of the municipality of Ospina Nariño)

The analysis of climatic conditions is of great relevance, as they allow for the definition of meteorological patterns and trends and facilitate the understanding of climatic behavior. In a cold, humid climate such as that of the village of San Antonio, it is essential to take these climatic conditions into account when designing homes and structures.[10] Proper thermal insulation management, moisture prevention, and designs that take advantage of natural conditions (such as sunlight and ventilation) are essential for creating homes that are comfortable for their inhabitants and respectful of the environment.[11,12] In addition, thermal comfort is fundamental to the well-being of inhabitants, and in rural contexts such as the one studied, the application of bioclimatic strategies can be an effective approach.[13]

The research addresses the problem of thermal comfort in rural homes and offers a theoretical and practical framework that can be replicated in other rural contexts with similar characteristics. This allows the benefits of bioclimatic architecture to be extended to a wide range of communities and significantly improves their quality of life.[14,15,16]

METHOD

The methodology used involves a detailed analysis of local climatic conditions, including temperature, wind currents and direction, relative humidity, topography, and vegetation, among other relevant factors. In addition, the specific needs and requirements of users are identified. The selected bioclimatic strategies are aimed at improving the thermal comfort of homes, which take full advantage of the beneficial aspects of the environment.

Information was obtained by consulting the platform of the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) to access meteorological data from the station closest to the area. This tool provided data on maximum, minimum, and average monthly and annual temperature and humidity in order to analyze climatic variations in the study area over a ten-year period.

In addition, data on temperature and relative humidity were collected in situ. The protocol used was based on data collection using a digital thermohygrometer (Ut333 from Unit-t) capable of measuring in a range of 1,7 to 9 meters. Several reference points were selected outside each of the homes included in the study sample to effectively capture and represent climatic variations in the study area. At each sampling point, consecutive measurements were taken for a total of 10 minutes per space. This allowed an average to be calculated and momentary fluctuations to be smoothed out. The measurements were carried out in a time interval ranging from 9:00 a.m. to 4:00 p.m. to accurately capture the period of maximum and minimum solar exposure during the day.

Measurements were taken at a standardized height of 1 meter above ground level, which optimized the capture of thermal radiation from the environment. In addition, measurements were taken in both exposed areas and those under the influence of shade provided by vegetation, which enabled a meaningful comparison of the different microclimates.

Measurement of environmental variables outside and inside the study home. Relative humidity is a climatic factor that allows the durability of structures and materials to be analyzed. This means that high levels of relative humidity can affect the durability of building materials and encourage the appearance of mold and problems related to the deterioration of the house. In rural contexts such as San Antonio, relative humidity can influence the thermal sensation of the inhabitants. This climatic parameter not only plays a fundamental role in the perception of climate, but also plays a role in regulating thermal comfort.

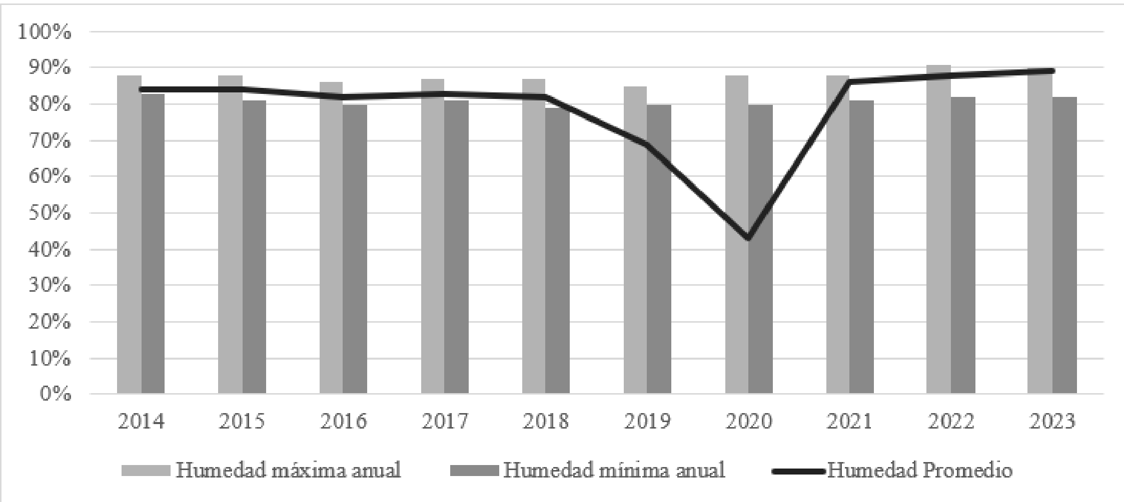

Figure 2. Maximum, average, and minimum relative humidity in the village of San Antonio in the period 2014-2023

Detailed relative humidity records obtained by IDEAM over the last decade reveal climate trends, showing that, in recent years, humidity has fluctuated between 85 % and 92 %. In 2019, there was a lower percentage of relative humidity, while in 2022 there was a peak of 92 % relative humidity. High relative humidity can cause condensation on cold surfaces inside the home, such as windows, walls, and ceilings. This can negatively affect thermal comfort and damage building materials. High humidity can make it difficult to heat the home, as humid air requires more energy to increase in temperature compared to dry air.

On the other hand, when analyzing the data for the year 2023, several important considerations can be drawn, for example, between 50 % and 100 % there is a possibility that condensation may occur under certain conditions. Condensation can lead to mold problems, material deterioration, and loss of energy efficiency. It is important to examine design strategies that prevent condensation, especially on exterior surfaces in this case.

Temperature directly influences the perception of thermal comfort, where extremely high or low values can lead to feelings of excessive heat or cold, respectively. Seasonal and daily temperature patterns are determined based on temperature variation. Temperature records obtained by IDEAM over the last decade reveal climate trends with temperature fluctuations between 7,6 °C and 21,2 °C. The climate variability observed in San Antonio has a direct impact on the thermal comfort of rural dwellings. During the cold months, minimum temperatures can make it challenging to maintain a warm and comfortable indoor environment. The need for passive thermal conditioning strategies is evident, prompting consideration of elements such as thermal insulation and passive heating systems.

However, the information obtained on minimum and maximum temperatures based on our own measurements in the San Antonio region is necessary to understand local climatic conditions and their implications. The temperature variation in 2023 shows maximum temperatures above 15°C and suggests that the region may experience periods of mild heat, which may be especially relevant during the warmest months of the year. On the other hand, the minimum temperature of 6°C indicates that nights may be too cold at certain times of the year. Seasonal variation in temperatures should be considered when proposing thermal comfort strategies in homes.

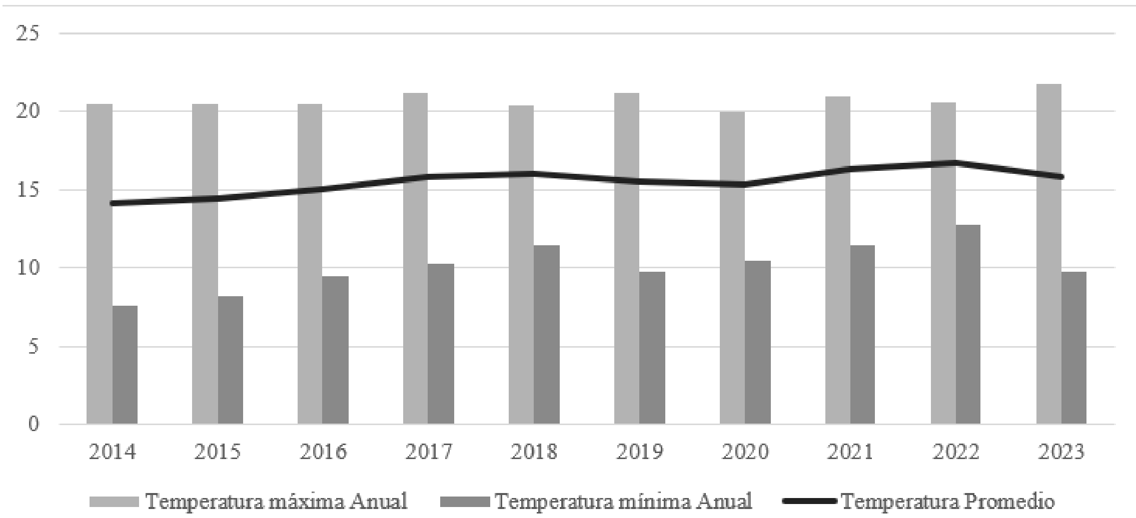

Figure 3. Maximum, average, and minimum temperatures in the village of San Antonio for the period 2014-2023

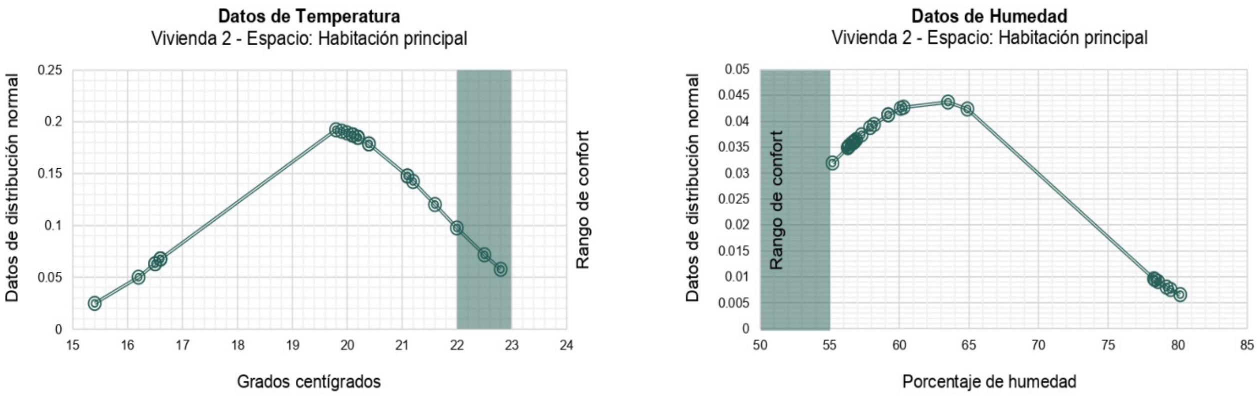

Figure 4. Statistical distribution to determine the percentage of comfort

The analysis of the statistical distribution of climate data—specifically temperature and relative humidity—made it possible to identify patterns of environmental behavior in different areas of the study area. This tool was used to identify the areas that could be most affected in terms of comfort, in line with the Givoni model and standards, which consider these parameters when assessing habitability conditions. Taking into account this overview of potentially compromised areas, it is possible to establish more precise guidelines for the design of bioclimatic strategies adapted to local conditions.

Table 1. Statistical distribution to determine the percentage of comfort

Average relative humidity	**Standard deviation**	**Maximum comfort**	**Minimum comfort**	**% within thermal comfort**	**% outside comfort**
62	2,065113984	55	50	0	100 %
Average temperature	Standard deviation	Maximum comfort	Minimum comfort	% within thermal comfort	% outside comfort
19,58 °C	9,077462061	23°C	23°C	12,5	87,5 %

The graph shows the probability (represented as a percentage) of achieving thermal comfort through passive solutions, taking into account the limits established for a comfort range. The study area has predominantly cold and humid climatic conditions, characterized by average temperatures below the thermal comfort threshold and consistently high relative humidity levels. These conditions directly affect users' perception of comfort and impact both thermal well-being and the energy efficiency of buildings. The measures, articulated from a climate-sensitive design perspective, not only improve the habitability and comfort of spaces, but also contribute to resilient measures against climate variations.

The thermal comfort ranges according to the Givoni diagram correspond to the humidity and temperature conditions in which the human body requires the minimum amount of energy to adjust to the environment. In the Givoni diagram, the comfort zone temperature is usually between 20°C and 25°C, while humidity is in the range of 50 % to 55 %. The comfort zone is defined as the area where climatic parameters do not require any structural adjustments to achieve well-being and where any average building meets the conditions for providing a pleasant thermal sensation.(1)

Table 2. Data corresponding to average humidity and temperature ranges

Variable	**Range**	**Sensation**	**Description**
Relative humidity	Less than 30 %	Dry	May feel uncomfortable and cause dryness.
	Between 50 % and 55 %	Comfortable	Optimal range
	Over 60 %	Humid	May feel sticky and uncomfortable, especially if the temperature is high.
Temperature	Less than 67°F	Cold	Thermal discomfort
	Between 20 °C and 23 °C	Comfortable	Optimal range
	Over 30 °C	Hot	Intense heat, generally uncomfortable for most people.

The thermal comfort range in terms of relative humidity taken as a reference in this research is between 50 % and 55 %, considered optimal to avoid feelings of dryness or excess humidity in the indoor environment. At the same time, temperature ranges may vary according to individual preferences and particular climatic conditions; however, for this study, the objective is to maintain an average indoor temperature of 23-° C. This temperature guarantees the thermal comfort of the occupants in a cold, humid climate, reducing dependence on active air conditioning systems and prioritizing passive solutions adapted to rural housing.

The detailed solar analysis identified the optimal surfaces for the implementation of passive construction solutions aimed at taking advantage of thermal gains from solar radiation during the day. This analysis was based on the study of the solar trajectory throughout the year and integrated key variables such as latitude, longitude, altitude, and seasonality in order to evaluate the solar behavior incident on the architectural envelope.

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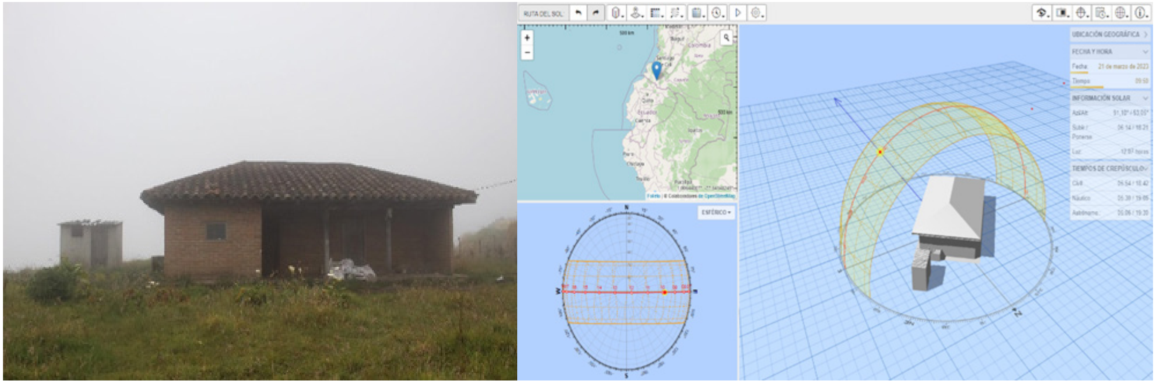

Figure 5. Housing selected for the study and solar trajectory

In cold climates, although solar gain is essential for improving indoor thermal comfort, it is necessary to consider control mechanisms that prevent overheating during the warmer months. Solar analysis makes it possible to predict this behavior and guide the design of passive solar protection elements such as eaves, lattices, movable blinds, or plant barriers, which contribute to strategically shading exposed openings and facades.

In the case study, the solar trajectory analysis shows that the front facade is directly exposed to sunlight between 2:40 p.m. and 6:15 p.m., while the rear facade receives direct solar radiation between 6:45 a.m. and 10:30 a.m. This information is key to the location of passive thermal collection devices and solar protection elements, in order to optimize the energy performance of the home.

Once the bioclimatic diagnosis had been carried out using the Givoni diagram, a representative housing unit was selected for the application of passive thermal conditioning strategies. The selected dwelling is a contemporary building that incorporates elements of vernacular architecture in the layout of its interior spaces. Structurally, it features a framework based on wooden pillars and materials such as clay tiles, exposed fired brick, and concrete cladding. Its selection was based on factors such as its topographical location, the absence of vegetation cover to mitigate the impact of direct winds, and the diversity of materials used, which provide a suitable context for evaluating thermal performance and the relevance of the proposed passive strategies.

Internal measurements of the house represent the first step toward creating customized solutions that are perfectly adapted to the complexities of the built and natural environment, allowing for a focus on the layout of spaces where thermal comfort is difficult to achieve. The variation in internal temperature fluctuates between 16,2 °C and 22,8 °C, indicating an interior space with stable temperature levels, although without reaching the thermal comfort range.

The relative humidity recorded in the main room is relatively constant, although it peaks at 80,2 % at certain times of the day, with minimum and maximum fluctuations close to each other. In this case, additional passive strategies could be considered, such as optimizing natural ventilation, using curtains or blinds to manage solar radiation, and selecting materials that provide better insulation, which could help to further optimize the thermal comfort and energy efficiency of the room. The measurements in the main room of the house studied indicate a stable and comfortable indoor environment in terms of humidity and temperature.

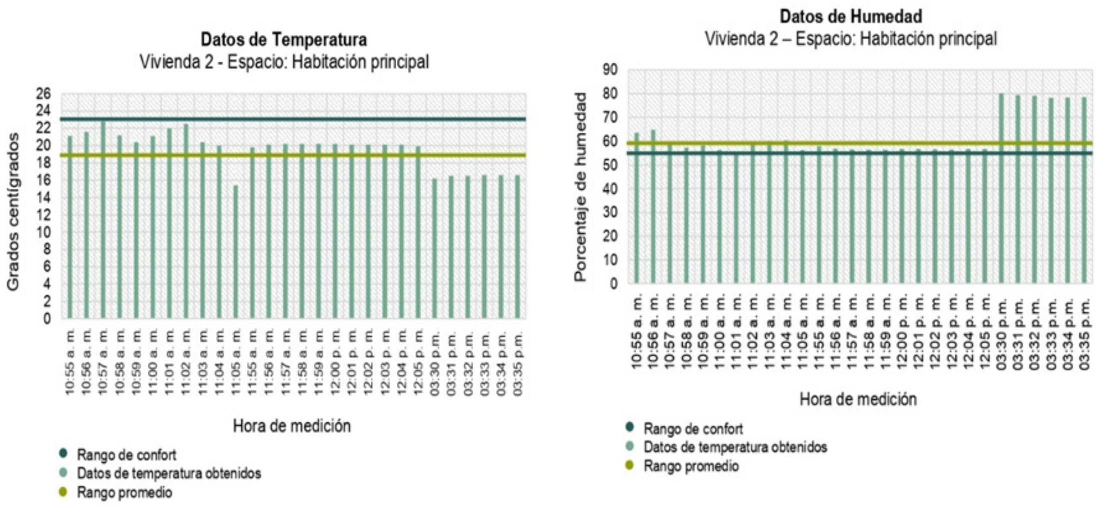

Figure 6. Measurements taken inside the home

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Determination of existing passive bioclimatic strategies for cold-humid climates

To select the most appropriate passive strategies, Givoni's psychrometric chart is used, a tool that allows the specific temperature and humidity conditions in each of the homes evaluated to be analyzed. °In this diagram, the temperature range between 15°C and 21,5°C (° °C) is identified as the zone of applicability of internal gains, in which thermal comfort can be achieved through the passive use of solar energy. Under these conditions, an architectural intervention is proposed to optimize the capture of solar radiation on strategic surfaces of the building. This energy is stored in thermal mass elements designed to accumulate heat and release it progressively into the interior spaces, ensuring efficient and sustained thermal distribution that responds to heating needs throughout the daily cycle.

The strategies involve the capture and redistribution of internally generated heat, taking advantage of daily activities and elements of the home to modulate temperature and humidity. The choice of internal gains as a key strategy is based on the understanding that daily life in this region generates a significant amount of heat at specific times of the day.

The effectiveness of these systems depends largely on the concept of thermal conservation. The entire process would be counterproductive if the heat generated were lost by escaping from the interior space or if it could not be used when solar radiation ceases. In this sense, three types of solar utilization systems can be distinguished according to the relationship between solar incidence and the environment to be heated: direct, indirect, and independent.

Direct systems involve heating the room through the direct action of the sun's rays. Indirect systems, on the other hand, cause solar radiation to first strike a thermal mass located between the sun and the environment to be heated. Independent systems are characterized by having solar collection and thermal storage separated from the living space.

In this regard, the implementation of Trombe walls, thermally insulated roofs, bioclimatic greenhouses, bioclimatic windows, and wood fiber insulation seeks to make the most of solar energy and natural resources. These strategies, based on the principles of bioclimatic architecture, are adapted to local climatic conditions. Through the analysis of each of the strategies, the operating principles, advantages, practical applications, and environmental benefits obtained by implementing these solutions in housing interventions are explored.

Trombe wall: The standard design of a Trombe wall consists of placing a glass panel at a distance of approximately 2 to 5 centimeters from a dark masonry wall, which is usually 10 to 41 centimeters thick and commonly constructed of brick, stone, or concrete. This system harnesses solar energy by allowing heat to pass through the glass, be absorbed by the thermal mass wall, and then gradually released into the interior of the home.

The key to its operation lies in the difference in wavelengths between direct solar radiation and the heat re-emitted by the thermal mass. While direct solar radiation, with shorter wavelengths, easily passes through the glass, the heat re-emitted by the wall has longer wavelengths, which makes it difficult for it to pass through the glass. This phenomenon, described by Wien's displacement law, allows the Trombe wall to efficiently retain heat between the glass panel and the masonry wall, maximizing its absorption and limiting its loss to the outside. In addition, because the glass panel is placed on the outside of the wall, heat can be transferred unimpeded into the interior of the home. This process, known as convective heat transfer, typically takes about 8 to 10 hours in a standard 20-centimeter-thick Trombe wall.

Bioclimatic greenhouse: A bioclimatic greenhouse is a type of construction that combines elements of architecture and technology to create a warm and stable indoor environment by using natural solar energy and minimizing external energy consumption. These solar greenhouses operate as passive systems that harness the principles of the greenhouse effect to reduce the energy demands of the home while preserving the environment.

The greenhouse has a transparent or translucent structure that allows solar radiation to enter during the day. The structure is thermally insulated to retain the heat generated by solar radiation and reduce heat loss. A thermal mass, such as concrete, brick, or stone, is used to absorb and store heat during the day and release it at night. During the day, solar radiation penetrates the greenhouse through the transparent structure and heats the thermal mass. The air heats up and rises to the ceiling, while at night, the thermal mass releases the heat stored during the day, maintaining a stable temperature inside the greenhouse.

Wood fiber insulation panel: Wood fiber is a thermal and acoustic insulation material made from crushed natural wood. To improve its properties, specific additives can be added to make it fire-resistant or protect it against insects and rodents. This insulation is widely valued both for its ability to maintain a stable interior temperature and for its effectiveness in reducing outside noise, especially in wooden roofs. Its use is growing rapidly in architecture and engineering thanks to its combination of energy efficiency, sustainability, and low environmental impact.

Among its benefits, it stands out for its moisture regulation, as it is ideal for humid climates because it absorbs excess water and expels it in a controlled manner. It also minimizes sudden temperature changes by

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retaining heat during the day and releasing it gradually at night, effectively adapting to hot and cold climates and providing efficient insulation. It is made from wood waste, is an environmentally friendly material, and can be reused after reaching the end of its useful life.

Bioclimatic window: this is a type of window designed to take advantage of natural resources such as the sun, natural ventilation, and thermal inertia to regulate the temperature and humidity inside a home or building. The window is strategically oriented to maximize solar energy capture during the winter and minimize direct sun exposure in the summer. The window design may also include elements such as eaves, blinds, or awnings to control sunlight entry. High-quality insulating materials are used in the window frame and glazing to reduce heat loss in winter and excessive heat gain in summer.

The above passive strategies help to optimize solar gain in winter and minimize it in summer through the use of walls and facades. Simulations and numerical calculations are used to evaluate solar incidence on homes and identify areas with the greatest potential for passive solar energy utilization.

Understanding the U-value and its application in different bioclimatic strategies allows us to design buildings that naturally adapt to the climate and respond to users' needs in an efficient and responsible manner. The proposed construction solution takes into account the U-value of the different building components to determine their thermal insulation capacity. The U-value is a crucial factor in the design and construction of efficient and sustainable bioclimatic solutions. By selecting materials and construction systems with a low U-value, we can reduce energy consumption, improve thermal comfort, and contribute to protecting the environment.

In the context of architecture and energy efficiency, authors such as Francis D.K. Ching in his book Building Construction Illustrated and Donald Watson in Time-Saver Standards for Architectural Design Data have addressed the issue of the U-factor and its associated ranges in relation to sustainable building design. These authors provide detailed information on typical U-factor values for a variety of building materials and components, which supports the reference to the range between 0,1 and 1,2 W/m^2K.

According to García[2] in his publication on calculating cooling loads, solar gain is the amount of thermal energy that a building gains through its envelope (walls, roof, windows) due to solar radiation. This energy can be both beneficial, providing free heating in winter, and harmful, causing overheating in summer if not managed properly.

The equation $Q = U \cdot A \cdot \Delta T$ is a simplification of heat transfer calculations and is commonly used in the thermal analysis of buildings. Each term represents a key factor:

- Q: represents the amount of heat transferred (solar gain in this case) through a surface in a given period of time. It is measured in Watts (W).
- U: is the overall thermal transmission coefficient. It indicates how easily heat is transmitted through a material or building component. It is expressed in Watts per square meter Kelvin (W/m^2K). The value of U depends on the type of material, its thickness, and the boundary conditions.
- A: is the surface area through which heat transfer occurs. It is measured in square meters (m^2).
- ΔT: is the temperature difference between the interior and exterior of the building. It is measured in degrees Celsius.

The equation works as follows: the amount of heat gained by a building (Q) is directly proportional to the surface area, since the greater the area exposed to the sun, the greater the solar gain. The temperature difference because the greater the temperature difference between the interior and exterior, the greater the heat flow to the interior, and the thermal transmission coefficient because a lower U-value indicates better thermal insulation, as it reflects less heat loss transferred in a construction solution.

As mentioned above, it should be noted that the equation $Q = U \cdot A \cdot \Delta T$ is a simplification. In reality, heat transfer is a more complex phenomenon, influenced by factors such as direct and indirect solar radiation, convection, infrared radiation, etc. In addition, the thermal transmission coefficient U varies depending on boundary conditions, humidity, temperature, and other factors. Solar gain is not uniform. It varies throughout the day, the seasons, and depends on the orientation of the surface.

The results of the thermal analysis applied to the dwelling show that under controlled conditions, the spaces evaluated (bedroom and kitchen) show a thermal increase due to internal gains calculated using an equation. The kitchen shows a higher thermal contribution (0,7747 Wh, equivalent to 1,467° C), compared to the bedroom (0,6623 Wh, equivalent to 1,255° C), which is associated with a greater temperature difference in that space. The data provide information related to the thermal envelope with a low U-value of 0,083, which helps to conserve the heat generated internally. This is effective in cold climates for improving thermal comfort without resorting to active systems and validates the functionality of the strategies applied to the dwelling.

Finally, to verify the efficiency of the airtightness application through the use of air currents, the FlowIllustrator program was used to help visualize the air currents entering and exiting the home through leaks and openings, providing an understanding of the critical points of airtightness. The software allows the air infiltration rate to be quantified in cubic meters per hour per square meter ($m^3/h/m^2$). This information is

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essential for evaluating the airtightness level of the home and comparing it with established standards to verify compliance.

ESPACIO	GRADOS CENTÍGRADOS DE DIFERENCIA	FÓRMULA APLICADA (Q = U·A·ΔT)				
		U	AREA	ΔT	Resultado en W*h	Resultado en °c
VIVIENDA 2 (Habitación)	1.05	0.083	1.05	7.6	0.66234	1.255
VIVIENDA 2 (Cocina)	1.05	0.083	1.05	8.89	0.7747635	1.467

Figure 7. Construction simulation and results of degree Celsius contribution

By analyzing air currents, it is possible to identify specific points in the home where the greatest air leakage occurs, allowing for more effective airtightness measures. In this case, the modeling of the home with the established interventions was evaluated in order to verify whether the airtightness standard is met.

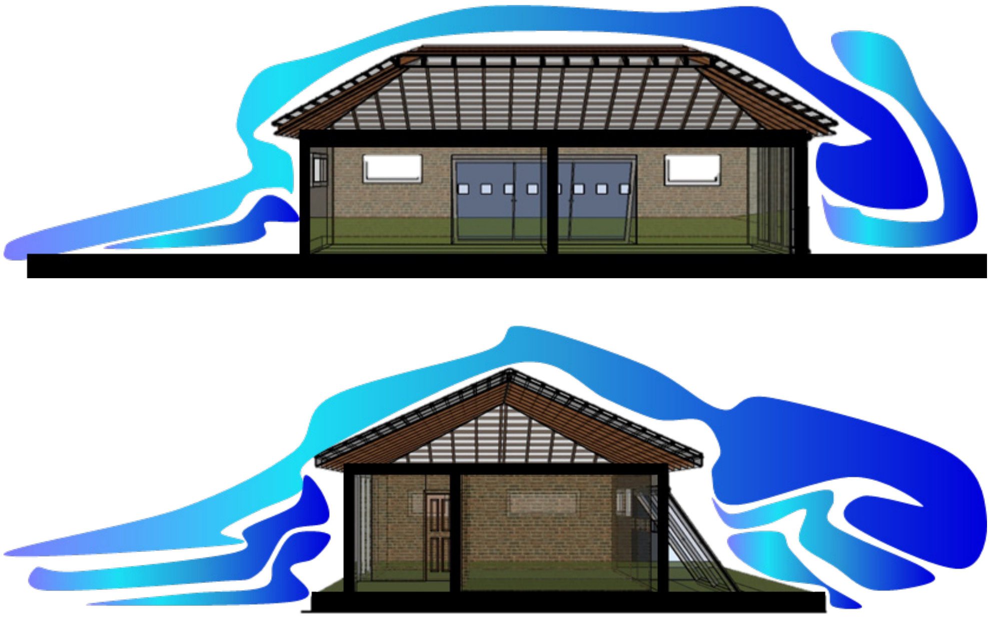

Figure 8. Simulation of local wind behavior with implementation of passive strategies in the home

CONCLUSIONS

Incorporating a bioclimatic approach is relevant in rural contexts, where local climatic conditions are often underestimated, despite their decisive influence on the quality of life of the inhabitants. The research shows that by integrating passive design strategies adapted to the specific conditions of the environment and vernacular architecture, it is possible to substantially improve indoor thermal comfort and, with it, the overall well-being of communities.

From a methodological point of view, the study is distinguished by its combination of historical meteorological data with empirical in situ measurements, which established precise correlations between environmental variables and the performance of the passive strategies implemented. This approach, based on quantitative evidence, overcomes the limitations of traditional methods by offering results that are more representative and adjusted to the reality of rural buildings.

One of the most relevant contributions of the research is the development of a quantitative correlation model, which allows the effectiveness of various passive strategies to be associated with the construction and spatial characteristics of rural dwellings. This model, validated through digital simulations and field measurements with devices such as thermo-hygrometers, is a decision-making support tool for architectural design, resulting in the selection and optimal location of passive solutions.

The evaluation of the thermal performance of passive strategies, supported by digital tools and empirical data, has provided a deeper understanding of how these strategies respond to variables such as structural thermal deficiency, orientation, and the materiality of rural buildings.

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FINANCING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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