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TAPANCO IN VERNACULAR HOUSES IN QUERÉTARO, MEXICO. USE AND HYGROTHERMAL EFFICIENCY

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EL TAPANCO EN VIVIENDAS VERNÁCULAS DE QUERÉTARO, MÉXICO. USO Y EFICIENCIA HIGROTÉRMICA

O “TAPANCO” NAS MORADIAS VERNACULARES DE QUERÉTARO, MÉXICO. USO E EFICIÊNCIA HIGROTÉRMICA.

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RESUMEN

Hoy día son evidentes las consecuencias climáticas provocadas por las emisiones de gases de efecto invernadero (GEI) que encaminan a alcanzar 2.7 °C de calentamiento global hacia 2100. La dependencia energética de las edificaciones es una de las causas principales, pues demandaron solo para calefacción el 50% del consumo de energía global en 2021, siendo necesario implementar sistemas bioclimáticos pasivos de climatización. Este trabajo documenta la utilización en viviendas vernáculas de Querétaro, México, de un eficiente sistema pasivo tipo ático, denominado “tapanco”, consistente en una cámara de aire inerte que funciona como amortiguador térmico. Se evaluó un caso aplicando metodologías de medición con termo-higrómetros, complementando con termografía y simulación termo-eólica. Los hallazgos de índices higrométricos adecuados, propiciados por el sistema, lo convierten en alternativa relevante de solución pasiva en el diseño arquitectónico bioclimático futuro, para abatir los índices energéticos y climáticos adversos.

Palabras clave
arquitectura vernácula, arquitectura bioclimática, calentamiento global, eficiencia energética.

ABSTRACT

Today, the climatic consequences caused by greenhouse gas (GHG) emissions are evident and are on track to see global warming of 2.7 °C by the end of the century. The energy dependence of buildings is one of the main causes, since they required 50% of global energy consumption in 2021 just for heating, making it necessary to implement passive bioclimatic air conditioning systems. This work documents the use in vernacular dwellings in Queretaro, Mexico, of an efficient attic-type passive system, called “tapanco”, consisting of an inert air chamber that functions as a thermal buffer. A case was evaluated by applying measurement methodologies with thermo-hygrometers, complemented with thermography and thermo-wind simulation. The findings of adequate hygrometric indices, fostered by the system, make it a relevant alternative for a passive solution in future bioclimatic architectural design, to reduce adverse energy and climatic indices.

Keywords
vernacular architecture, bioclimatic architecture, global warming, energy efficiency.

RESUMO

Hoje, as consequências climáticas das emissões de gases de efeito estufa (GEE) são evidentes e estamos a caminho de atingir 2,7°C de aquecimento global até 2100. A dependência energética das edificações é uma das principais causas, pois elas representaram 50% do consumo global de energia apenas para aquecimento em 2021, tornando-se necessário implementar sistemas passivos bioclimáticos de climatização. Este trabalho documenta a utilização de um eficiente sistema passivo tipo sótão, chamado “tapanco”, em moradias tradicionais de Querétaro, México. O sistema consiste em uma câmara de ar inerte que atua como amortecedor térmico. Foi avaliado um caso utilizando metodologias de medição com termo-higrômetros, complementadas por termografia e simulação termo-eólica. Os resultados dos índices higrométricos adequados proporcionados pelo sistema fazem dele uma solução passiva alternativa relevante como solução passiva no futuro projeto arquitetônico bioclimático, visando reduzir os índices energéticos e climáticos adversos.

Palavras-chave
arquitetura tradicional, arquitetura bioclimática, aquecimento global, eficiência energética.

INTRODUCTION

The current serious climatic effects can be significantly reduced by reducing Greenhouse Gas emissions (hereinafter, GHG), which, due to human energy dependence, are the cause of global warming. These should be kept at 1.5 °C or below to avoid the climate debacle by 2100 (United Nations Environment Programme, 2021).

Many buildings have high energy demands in their lifecycle and are not thermally functional. This is mainly due to their materials' terrible thermal properties and inadequate architectural design and insulation. The reason for this is that construction is globally standardized, and disregards local climates or energy implications (Intergovernmental Panel on Climate Change, 2022). This leads to electro-mechanical air conditioning being the most sought-after solution in the residential sector (Aguilera et al., 2018). A noteworthy fact is that, in 2021, heating alone accounted for 50% of global energy consumption (Global Crisis Response Group, 2022). At present, the energy efficiency of buildings is the main problem to be solved in this sector, because indoor air conditioning is the world's highest energy consumer. Hence, proposing a passive bioclimatic system solution is the central theme of this study.

If we want to reach a goal where energy efficiency is the key principle governing the construction of residential buildings, this should be done through ways of building that avoid mechanical air conditioning. This can be achieved through improved designs that consider the local climate. It is also necessary to propose the use of low-embodied energy materials, as well as to include passive bioclimatic strategies and nature-based solutions that allow buildings to adapt to the future climate. The implementation of these proposals looks to decrease energy requirements (Intergovernmental Panel on Climate Change, 2022), while allowing comfort and ensuring human well-being.

On the other hand, it is evident that current architectural paradigms are obsolete and, for the same reason, must be questioned to make a turn toward other types of already proven solutions, such as vernacular architecture. These, based on the ancestral knowledge product of centuries of observation and experimentation, have historically demonstrated efficiency in their physical adaptability, through natural materials and bioclimatic strategies, and they represent a powerful alternative for energy efficiency (hereinafter, EE).

Vernacular houses use passive strategies to guarantee hygrothermal comfort with almost zero energy demand because they do not use electro-mechanical systems, even when they lack electricity. They are built through shortage and meticulous resource management, representing a sustainable environmental heritage at the service of the current building. Developing countries preserve samples of these habitats that may represent model systems of adaptability (Rapoport, 2003).

In Querétaro, vernacular constructions have been documented in several climatic regions (Figure 1), such as those that use the passive bioclimatic system called "tapanco", which consists of an inert air chamber that functions as a thermo-acoustic buffer, fostering suitable indoor hygrothermal conditions, in diverse climates.

Hence, the objective of this work consists of documenting the use of the tapanco passive bioclimatic system in the vernacular dwellings of Querétaro and evaluating their hygrothermal efficiency by analyzing a case located in an extreme temperate climate zone, using internal-external parameter measurement methodologies for this. First, measurements were made with hygrometers; second, an analysis was made with thermographic photographs, and finally, thermo-wind modeling and simulation were made. This starts from the hypothesis of associating internal comfort with thermal regulation and relative humidity, extrapolating thermal performance to extreme conditions through simulation considering the design and materials.

Figure 1. Rural and urban vernacular housing of Querétaro. Source: Preparation by the authors.

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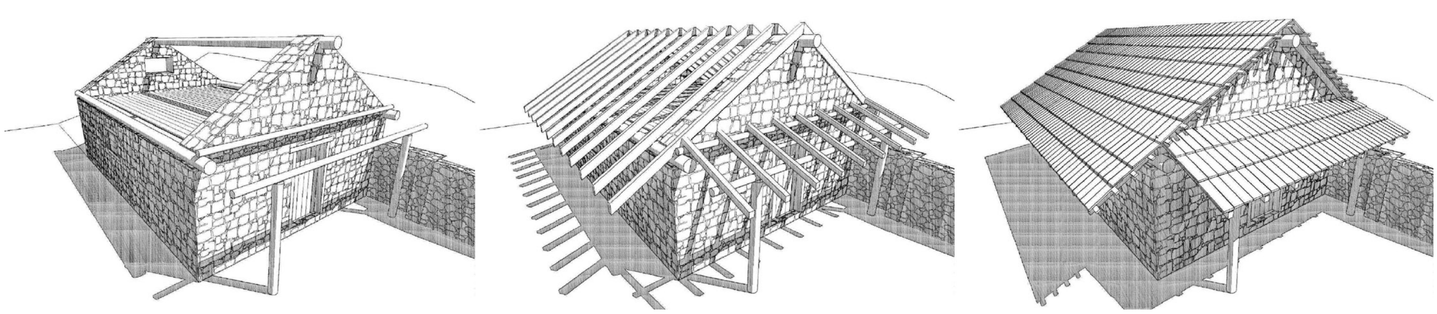

Figure 2. Wood and tejamanil tapanco structure. Source: Preparation by the authors.

The results allow verifying the suitability of tapanco to produce indoor hygrometric comfort, considering it as a design alternative for architectural models that are thermally and energy efficient. Once this knowledge has been scientifically translated to current architectural requirements, it will be very useful to face future climates.

The purpose of this study is not to specify the rates of decrease in energy expenditure with the use of the system. However, it can be confirmed that according to the works of Martín-Consuegra et al. (2014) and Suárez et al. (2018), both the implementation of passive bioclimatic strategies, as well as uninhabitable attics or "cool ventilated roofs", mainly on sloping roofs, have a significant impact on the improvement of EE.

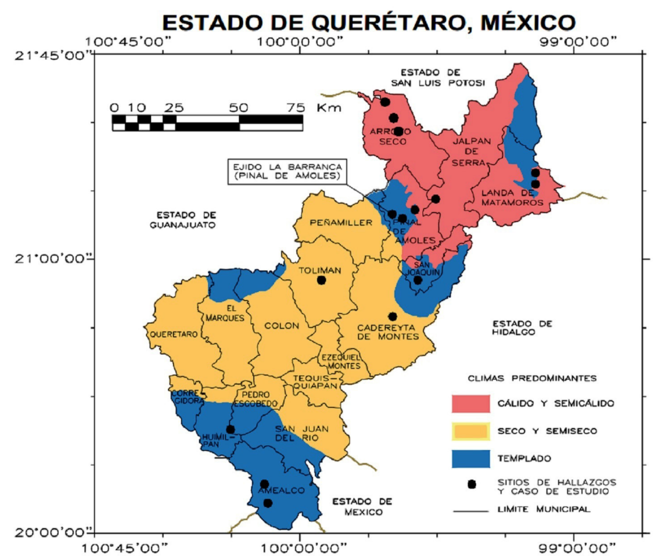

Figure 3. Political and climatic division of Querétaro. Location of sites with findings and case study. Source: Prepared by the authors with data from INEGI, 2017.

BACKGROUND

Vernacular tapanco in querétaro

The attic has been a passive bioclimatic strategy used for centuries, which consists of a thermal insulation chamber. A similar element has been used in the vernacular architecture of Queretaro, namely the "tapanco", whose name comes from the Nahuatl "tapantli" (roof) and the suffix "co" (in). This is a type of attic used to store objects and dry seeds or plants. It consists of a height division in a room using a horizontal board, forming a mezzanine that has no habitable function, unlike the attic (Figure 2).

This mezzanine works as a thermo-acoustic buffer by optimizing the thermal transmittance values of the roof "delaying" the passage of the outdoor temperature, for long enough to keep the interior stable until restarting the thermal cycle, also reducing the noises due to rain or hail. It is useful in temperate or warm weather, using a vent in the tympanum to remove inert air. Fifteen sites with evidence of this element have been documented in Querétaro, in diverse climatic regions, highlighting the locality of extreme temperate climate, "La Barranca" in the municipality of Pinal de Amoles, where the measurements were made (Figure 3).

The architectural conformation of the rural vernacular tapanco, completely covers the bay, based on a truss and strut type structure, made with small beams, bars, and rafters, and is covered with small wooden tiles called "tejamanil", which are manually made locally (Figure 4).

In the traditional houses of more urban areas, there are large tapancos (Figure 5) that also use a larger-scale truss-type structure, covered with a clay roof, which rests on one-rod thick masonry walls (80 cm).

These vernacular constructions have other passive strategies that contribute to their thermal efficiency, which are not the subject of analysis in this study, but are interesting to mention, such as a wise combination of local materials with good thermal inertia; the use of semi-buried "thermal walls"; the frank east-west orientation of the bays; and the use of endemic vegetation to reduce sunlight and humidify, etc.

Figure 4. Tapancos in rural areas of Querétaro. Source: Preparation by the authors.

Figure 5. Tapancos in urban areas of Querétaro. Source: Preparation by the authors.

With the decay of vernacular housing to make way for new ways of living with current notions of "evolution" (Juárez, 2022), in Querétaro, the tapanco has almost completely fallen into disuse, even the existing one collapsing, due to ignorance about its hygrothermal benefits and by allowing entry to industrial materials, with documentation on this strategy being a pressing matter.

STATE-OF-THE-ART

The current serious environmental problems have forced the establishment of EE policies in many countries, related to energy measurements and certifications as tools to minimize energy consumption and GHG emissions (Fernandez et al., 2020). This policy has established minimum requirements for envelopes and mechanical systems for thermal comfort. There are many energy standards, however, these are not applied in all countries, so many constructions consider them as a "voluntary" guideline. More than 80% of the initiatives proposed globally consist of methods focused only on the demand-consumption relationship and not on EE (Reus-Netto et al., 2019).

Reducing energy consumption without affecting comfort requires the implementation of bioclimatic architectural systems, mainly in residential buildings (Manzano et al., 2015, cited in Fernandez et al., 2020), which should be hygrothermally evaluated and monitored. The 2030 Agenda of the United Nations disseminates principles of bioclimatic architecture, energy efficiency, and the use of low-impact materials to achieve these goals.

There are works related to energy assessment, insulation requirements, implementation of passive strategies, and their relevance in EE, such as those developed by Aguilera et al. (2018), Mercado et al. (2018), Reus-Netto et al. (2019), and Fernández et al. (2020). Reference is specially made to studies by Martín-Consuegra et al. (2014), Suárez et al. (2018), and Calderon (2019), about the analysis of the thermal and energy efficiency of roof air chambers.

For sustainability, thermal functionality, and the use of passive strategies in vernacular housing, there are studies such as those by Herrera and Medina (2018), Mandrini (2022), and Juárez (2022). Also, the works of Mercado et al. (2018), Ganem-Karlen (2018), and Alamino and Kuchen (2021) refer to the importance of thermo-energetic simulation tools, infrared thermography, and others, as instruments for hygrothermal assessment. In Querétaro, practically no vernacular housing technical-architectural studies have been made under scientific methodologies, but serious research with an anthropological approach has been done, which helps to understand the phenomenon of vernacular environments.

THEORETICAL FRAMEWORK

VERNACULAR HOUSING, SUSTAINABILITY, AND ENERGY EFFICIENCY

Vernacular architecture, whose thermal behavior is achieved without resorting to electro-mechanical systems and almost zero energy demand, contributes to the environmental, economic, and quality of life aspects, in line with integral sustainability (Mandrini, 2022). This way of building is born from ancestral knowledge and the accumulation of climate adaptability experiences, with sustainable empirical references such as the conservation of knowledge; use of local materials; community participation; and diversity of solutions (Larraga et al., 2014). This appears among indigenous peoples as a response to their living needs, taking advantage of their local environment and climate, and achieving self-sufficiency and comfort. Limited resources and technologies allowed them to attain efficient solutions, harmonizing the work-family life link in interaction with the environment (Juárez, 2022).

These vernacular environments are rationally ecological and agricultural small habitats, almost self-sufficient in the production, management, and consumption of resources, which contribute to community identity and socio-cultural values, thus playing an important role in the economy, society, and environmental management (Herrera & Medina, 2018). The buildings these comprise are energy efficient throughout their entire life cycle, with almost zero demand for the extraction, production, and transfer of local, natural materials with excellent thermal properties. When they are demolished, these buildings are completely reintegrated into the natural environment or recycled. In addition, they use bioclimatic strategies that do not require electricity for air conditioning or lighting and have little electrical equipment.

COMFORT, PASSIVE BIOCLIMATIC STRATEGIES, AND HYGROTHERMAL ASSESSMENT

Comfort is a fundamental condition of habitat and architectural sustainability since it responds to the need for shelter. Incorporating sustainable constructive solutions fosters indoor thermal comfort with few energy implications, and is pertinent for analyzing traditional lifestyles that seek bioclimatic solutions (Calderon, 2019).

Thermal comfort not only depends on environmental parameters but also on other elements of the environment and the perception of the subject, in addition to sociocultural aspects (Mandrini, 2022). When interacting with electro-mechanical systems, user behavior affects the performance of buildings, and the use of energy (Mercado et al., 2018). The physical sensation of the subjects influences their well-being, efficiency, and comfort. With continuous variations of the environment, they take conscious or unconscious actions to recover the thermal balance and be comfortable (Rincón-Martínez et al., 2022), using mechanical systems that involve high energy consumption, and variables depending on the climate and the envelope (Reus-Netto et al., 2019).

The passive strategies incorporated into the architectural design (hereinafter, EPDA) contribute to energy efficiency and adapt the building to environmental conditions, improving hygrothermal comfort and reducing energy demand. The weighting of these strategies depends on the local climate, being able to resort to diverse solutions, such as the thermal insulation of roofs, walls, and floors; external colors; shading and window proportion; passive solar systems; heights and level of airtightness among others. These are implemented to reduce energy demand, and some studies demonstrate this (Aguilera et al., 2018; Instituto Nacional de Estadística y Geografía, 2017, p. 2; Martín-Consuegra et al., 2014; Mercado et al., 2018; cited in Fernández et al., 2020).

EE measures in buildings include regulations, monitoring, and evaluation, considering new buildings, energy-efficient buildings, and existing buildings (Schneider, 2015, cited in Ganem-Karlen, 2018). They also require reliable and fast diagnostic techniques. Before building, it is advisable to make a thermal simulation that emulates the comfort conditions, considering materials and climate, taking into account, for relative humidity (RH), the following relationship for non-extreme climates: at high temperatures, low relative humidities, and vice versa, (Ceja, 2012).

In vernacular architecture, forms are given in response to the combined effect between temperature, humidity, and air (Atmaca & Gedik, 2019; Bassoud et al., 2021; Chang et al., 2021; Manavvi & Rajasekar, 2020; 2021; Yan et al., 2020; Zhang et al., 2018; cited in Rincón-Martínez, 2022). The geometry is also conditioned by the materials and the need to implement passive bioclimatic strategies to achieve comfort, as will be observed in the case analyzed.

METHODOLOGY

Due to the little existing evidence, the case was chosen because it is located in an area of extreme temperate climate and because of the almost complete conservation of materials, design, and tapanco. Three types of analytical measurements are

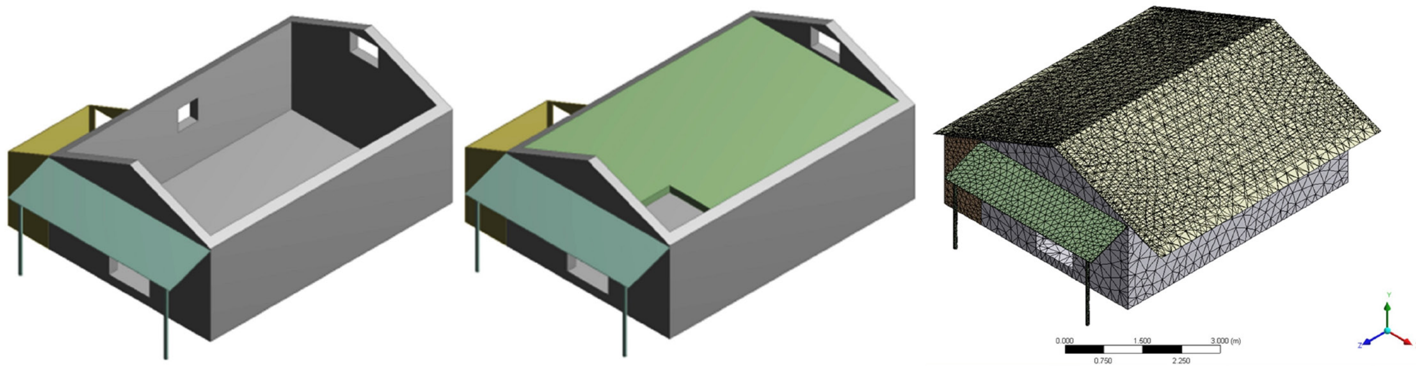

Figure 6. Model and mesh for ANSYS. Source: Preparation by the authors.

included: thermographic inspection; measurement of internal-external parameters using thermo-hygrometers; thermal and wind simulation, with which complementarity is sought and a comparison is made to obtain more reliable results.

THERMOGRAPHIC INSPECTION

The exterior mapping was done using thermographic inspection, to differentiate the qualitative behavior of the materials and contrast them with the simulation, to observe surface thermal variations and identify defects, such as structural failures, moisture, lack of insulation, and thermal bridges. Images were taken at a distance of 4 to 5 m, on November 5, 2011, around 12:00 pm, using a *Flir Systems ThermaCAM E45* camera, and *QuickReport* software from the same firm. To make quantitative thermography that would yield more reliable data, an emissivity value of 0.85 was introduced, which is around the average presented by the materials typically used in construction.

MEASUREMENTS WITH THERMO-HYGROMETERS

Internal-external measurements of temperature and relative humidity (RH) were made, using *Thermotracker* thermo-hygrometers, with continuous monitoring *in situ* for three months, from July to September, reporting data every fifteen minutes to obtain daily behavior averages. The internal sensors were installed in the following locations: one in the middle of the living space, between the tapanco and floor, away from the window; and the other, in the spatial middle of the tapanco, between the flooring and the ceiling. An external reference sensor was placed halfway between the wing (protruding part of the roof) and the floor, to protect the device from the weather and direct solar radiation. Data from the quarterly cycle were recorded and interpreted with the *Thermotracker Pro* software.

THERMO-WIND SIMULATIONS

The simulation was done using the finite element technique with the *ANSYS* program, to validate the thermographic information obtained. The model was made in *Solid Works*, considering the constituent elements: materials, tapanco, porch, and window. This model was exported to *Design Geometry* making the meshing of the control volume for the *ANSYS* analysis (Figure 6).

The materials' thermal conductivity data input into the *ANSYS* program, were: 0.28 W/m °C for wood, 0.72 W/m °C for stone, and 60.5 W/m °C for steel sheet. The finite element values were transposed to extreme situations, with a winter temperature of 5 °C, summer of 50 °C, and solar radiation of 1,050 W/m^2, registered by the weather station for the study area, on the chosen date and time.

One of the factors for heat transfer is convection, which depends on airspeed, hence a wind simulation was made in *ANSYS*. Starting from the thermal model, with a CFD meshing, a speed of 5.8 m/s was introduced, which was the average found.

On the other hand, it is relevant to note that users emphatically stated that the house is cool in summer and, mainly warm in extreme winters, not requiring tools for indoor comfort.

RESULTS AND DISCUSSION

HYGROTHERMAL ANALYSIS OF THE CASE STUDY: LA BARRANCA, MUNICIPALITY OF PINAL DE AMOLES

The geographical coordinates of La Barranca are 21° 07'36.2" N, 99° 41'08.3" W. It has a temperate sub-humid climate with summer rains, high humidity, and very low temperatures (average 14°C), even below zero at around

Figure 7. Evaluated bay. Habitable exterior and interior and tapanco. Source: Preparation by the authors.

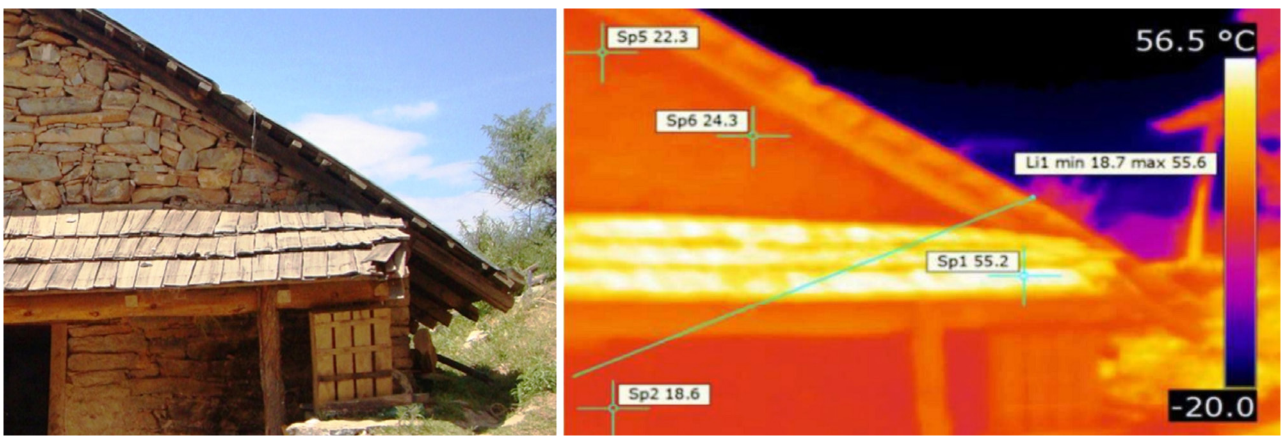

Figure 8. Thermal map - front of the house. Source: Preparation by the authors.

3,000 meters above sea level, and is one of the highest localities in the country.

Its constructions wisely combine design and endemic materials, wood and stone, with clay 55 cm thick walls that support the "gabled" truss roof and the low height boarding (1.85 m). The tapanco is formed in a triangular shape with an approximate slope of 60%, necessary to clear rain and sleet. The roof originally covered with "tejamanil", due to forest restrictions and with more than 75 years of useful life, has been coated with a galvanized sheet, without affecting its thermicity. The bay is multifunctional with dimensions of 5x7 m (Figure 7).

THERMOGRAPHIC INSPECTION

Figure 8 shows that the frontal thermal map; Sp1, which is the roof of the porch, registers the highest value with 55.2 °C. The stone tympanum, corresponding to Sp5, registers 22.3 °C. On the other hand, Sp2, located under the porch, has the lowest value, with 18.6 °C. This reflects that the thermal conditions are suitable for that space, which acts as a thermal buffer.

In Figure 9, the roof of the porch, that is, point Sp2, presents 53.6°C, which is the highest value. On the other hand, the lowest value is the floor, Sp8, with 14.3°C. Finally, Sp5, which is the wooden bench exposed to the sun, has 41.5°C.

The top of the roof is seen in Figure 10a and Figure 10b. In this, the ridge or Sp1 has 51.6°C, which is the highest value. At Sp4, which is the wooden structure, 27.5 °C is recorded. In the case of the shaded stone wall, which is Sp5, a temperature of 12.7 °C is recorded, which is the lowest value, which confirms the thermal efficiency of the wings. This becomes more noticeable in Figure 10c which shows the thermal difference between the sunny part of the tympanum and the one shaded by the wing.

Figure 11 shows the interior ceiling as seen from the tapanco. The highest temperature of 40.8°C is from a gap (thermal bridge). The running boards, Sp2, register 27.4°C; one beam, Sp5, has 22.9°C; the stone wall registers a minimum of 14.7°C.

MEASUREMENT OF INTERNAL PARAMETERS WITH HYGROMETERS

In Figure 12, the bay's internal behavior can be seen in black, which maintained a temperature between 13 and 16°C. Meanwhile, in gray, its external behavior is

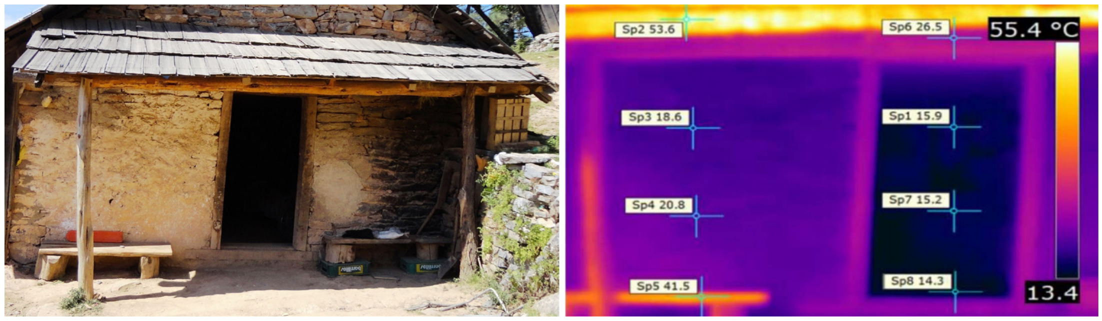

Figure 9. Thermal map - access porch of the house. Source: Preparation by the authors.

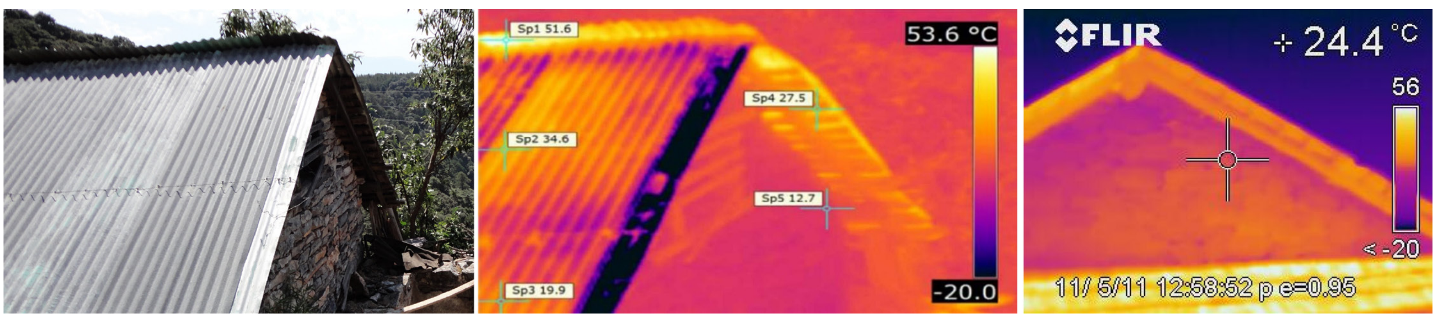

Figure 10. Thermal map – the exterior roof of the house and gable. Source: Preparation by the authors.

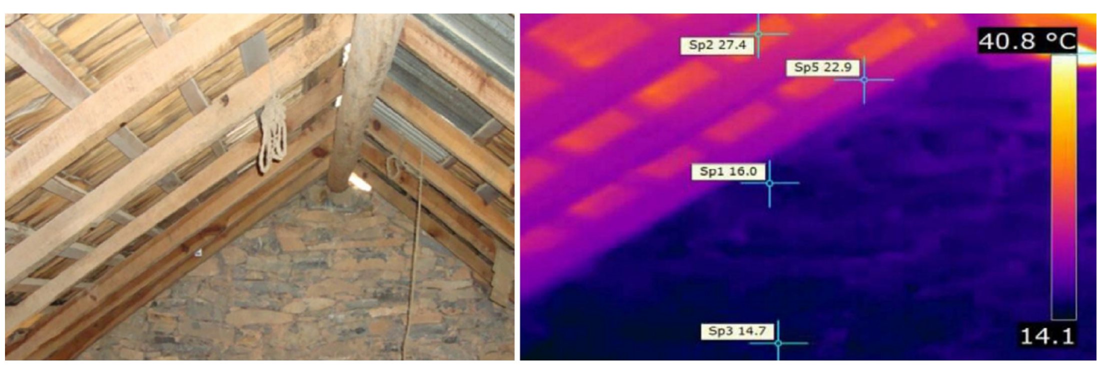

Figure 11. Interior thermal map of the tapanco. Source: Preparation by the authors.

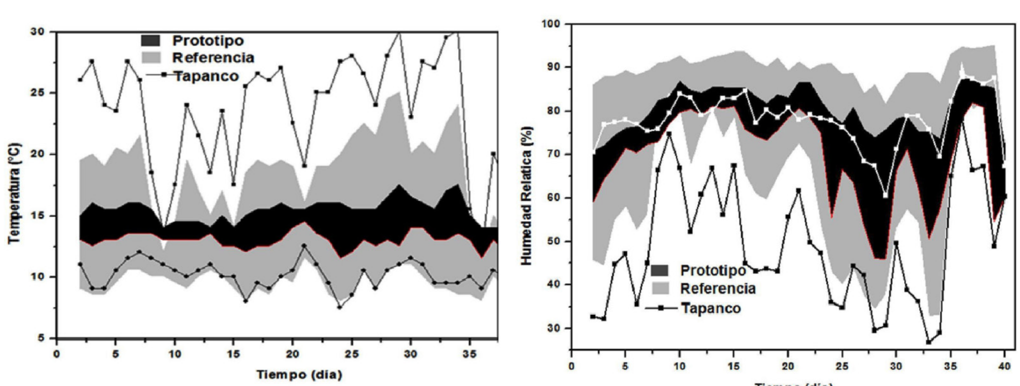

Figure 12. Indoor hygrothermal behavior. Source: Preparation by the authors.

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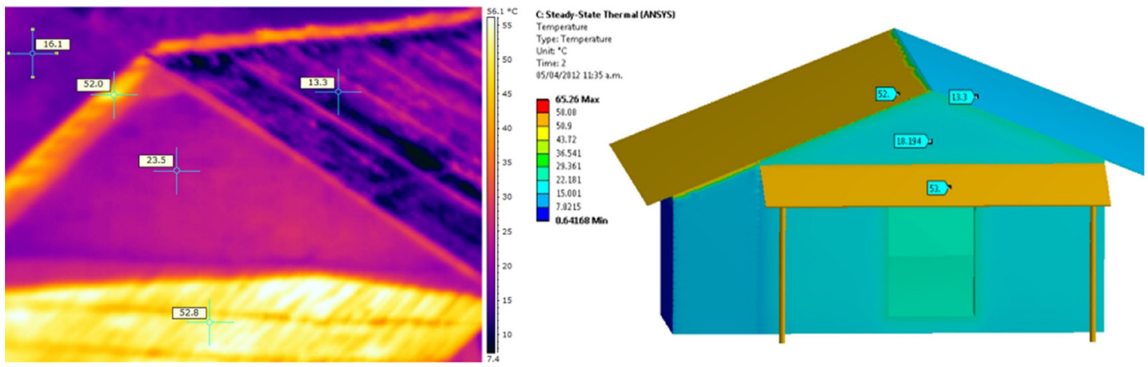

Figure 13. Exterior comparative thermography and ANSYS simulation. Source: Preparation by the authors.

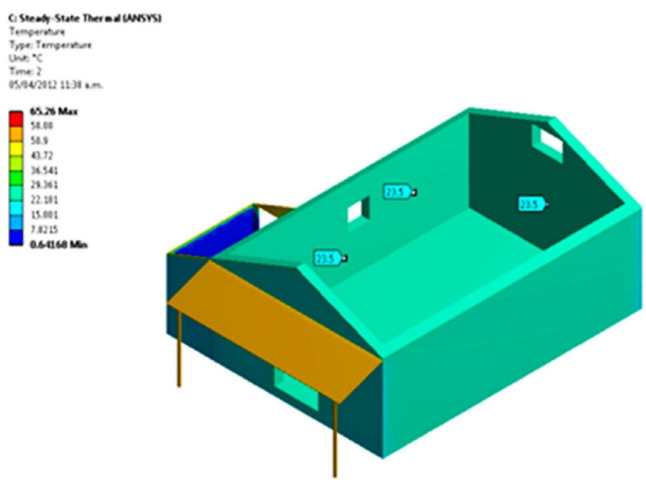

Figure 14. Simulation of indoor thermal behavior. Source: Preparation by the authors.

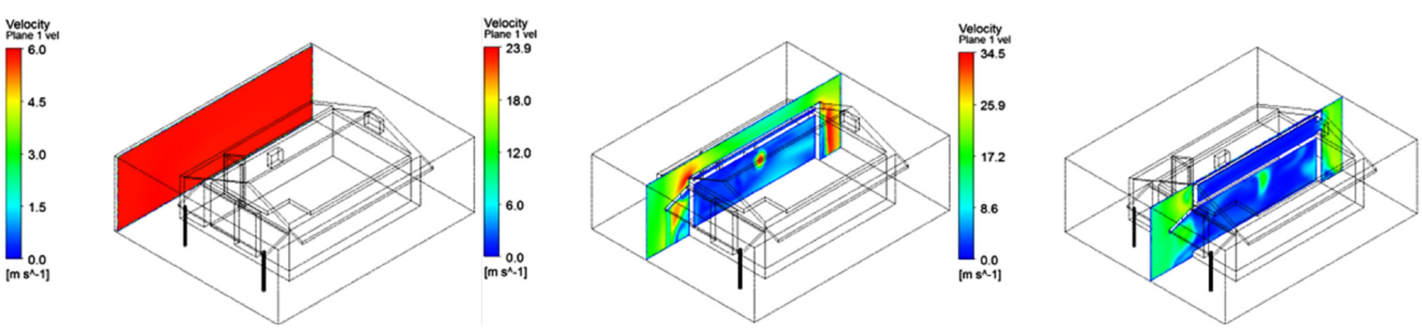

Figure 15. Simulation of airspeed behavior. Source: Preparation by the authors.

observed, with a temperature between 8 and 24 °C. The dotted line indicates the behavior of the tapanco with maximum temperatures of 30°C and minimums of 7.5°C, demonstrating that it works as a heat island by maintaining stable temperatures under this element, i.e., as a thermal buffer. The interior had between 45 and 85% RH, while, at the same time, the external device registered between 30 and 95% RH. According to these data, it is observed that the tapanco shows expected data: HR decreases when concentrating heat, because, except for tropical climates, these variables play an inversely proportional role.

FINITE ELEMENT THERMAL AND WIND SIMULATION

Once the transpolation to extreme situations is done, the results in *ANSYS* show agreement with those of the thermography (Figure 13), since both techniques have similar outdoor temperatures: about 52°C on the sunny roofs, 13°C on the shaded ones, and 18-23°C on the shaded tympanum.

The indoor measurements, which result from the finite element technique, yielded a temperature of 22.5°C ±

7.3°C, considered comfort (Figure 14), and similar to that of the analysis with thermo-hygrometers.

The wind simulation, shown in Figure 15, demonstrates that when the maximum outdoor speed is reached, the indoor one is low. This result is considered a preliminary result relative to the airtightness of the construction and should be verified later by a more detailed analysis.

The air is directed by the sides and by the top of the house as shown in the "*streamline*" from Figure 16.

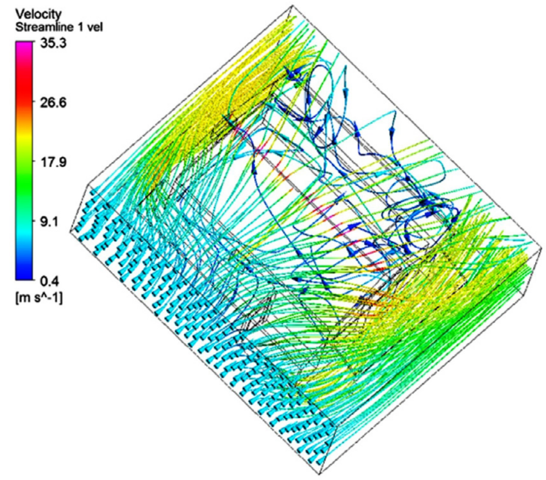

Figure 16. Streamline of the wind. Source: Preparation by the authors.

CONCLUSION

The thermography allowed observing the thermal behavior of the materials and elements with which the house is made. Wood and stone conserve low temperatures, between 12 and 16°C, while roofing has indices above 50°C. The behavior of other elements not proposed as objects of the study were also identified, such as the wings, which, although they are used for rain removal, also play a thermal role, since they cover a large part of the walls from radiation, keeping them at a low temperature that will be projected inside (Figure 8 and Figure 10).

Another thermal element is the porch, which keeps temperatures below 20°C when its roof is over 50°C. This forms a comfortable space since it buffers the direct radiation on the door, which, in turn, acts as a thermal bridge (Figure 9). The open O-P orientation of the bay combined with the inclined roof keeps half of it without solarization, with temperatures that are around 30°C, while the exposed one has values above 50°C (Figure 10), confirming the suitability of using this geometry.

The application of the three measurement techniques (thermographic inspection, thermo-hygrometric measurements, and thermo-wind simulation) allowed having a broader vision of the behavior of the prototype, concluding that the design-materials-tapanco group contributes significantly to indoor comfort. The comparison of the results reflects a good match between the hygrometric indices of the techniques, by showing averages in the habitable area of 20°C for the temperature and 65% RH.

The authors consider then the hypothesis raised is proven, as the tapanco indisputably represents the main passive bioclimatic design element in the analyzed case. It significantly regulates the hygrothermal factors and, given the indices obtained in this study, it fosters ideal conditions for human comfort, matching the parameters indicated by Olgyay (1998). In fact, there are comfort conditions even in extreme situations such as those the model has been subjected to in the simulation and which are presented on the site. Comparatively, industrialized buildings rarely present these comfortable and healthy conditions due to the inadequate thermal index of the materials, along with a design that does not consider the local climate or insulate the envelope, for which the use of mechanical air conditioning is necessary, which implies high energy demand and GHG emissions (Intergovernmental Panel on Climate Change, 2022).

On the other hand, the wind simulation allowed obtaining preliminary findings of the airtightness of the bay, which is due to an aerodynamic design that deflects the direct impact of the wind (Figure 16), as well as by the materials and the joint of the stone with clay. However, it is felt that this phenomenon should be studied in greater depth in subsequent research.

In conclusion, the authors feel that it is essential to consider the properties and behavior of materials, solarization, and the implementation of passive bioclimatic strategies in architectural design since they are fundamental elements that influence the conditions of hygrothermal comfort. It is also necessary to carry out, as far as possible, previous hygrothermal simulations that take into account the particular conditions of each project. All the aforementioned variables, when analyzed scientifically, will allow achieving indoor environmental quality that exerts influence on human health, attitudes, and performance, and understanding the problems of spatial design (Alamino & Kuchen, 2021).

The analysis of the tapanco and other vernacular architecture bioclimatic strategies, as well as their sustainability, are inescapable topics in the research. Under scientific approaches, it represents a very practical theoretical basis for rethinking paradigms and conceptual models of present and future architecture, which should be eminently passive and contribute to EE.

In light of the results obtained in this work, in-depth scientific analysis of these vernacular manifestations that are a source of millenary architectural knowledge and that today entail a solution that if not unique, is very efficient and relevant, is imperative. The authors consider that this topic should urgently be promoted as a systematic and constant line of research in Academia, due to the rapid extinction of many of these living samples of ancestral knowledge.

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