Revista Hábitat Sustentable Vol. 14, N°. 2. ISSN 0719 - 0700 / Págs. 08 -19
https://doi.org/10.22320/07190700.2024.14.02.01

THERMAL STUDY OF TRADITIONAL VENTILATED WALLS IN THE TROPICAL CLIMATIC CONDITIONS OF CATATUMBO, NORTE DE SANTANDER, COLOMBIA

Recibido 25/06/2024
Aceptado 16/10/2024

ESTUDIO TÉRMICO DE MUROS VENTILADOS TRADICIONALES EN CONDICIONES CLIMÁTICAS TROPICALES DEL CATATUMBO, NORTE DE SANTANDER, COLOMBIA

ESTUDO TÉRMICO DE PAREDES VENTILADAS TRADICIONAIS NAS CONDIÇÕES CLIMÁTICAS TROPICAIS DE CATATUMBO, NORTE DE SANTANDER, COLÔMBIA

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Revista Hábitat Sustentable Vol. 14, N°. 2. ISSN 0719 - 0700 / Págs. 08 -19
https://doi.org/10.22320/07190700.2024.14.02.01

RESUMEN

La propuesta de investigación está orientada a identificar una serie de tipologías de muros de cerramiento ventilados tradiciones del mercado de la construcción, como calados, celosías y paneles metálicos con el fin de desarrollar un estudio térmico bajo condiciones climáticas del Catatumbo en Norte de Santander, Colombia. La metodología es teórica a través de simulaciones de transferencia de calor bajo el método de elementos finitos en ANSYS para identificar la relación entre la permeabilidad de superficies y la incidencia en el comportamiento de temperaturas y flujos de calor. Los resultados exponen que las tipologías más permeables, como calados y celosías, registran menos transferencia de energía y temperatura a las tipologías menos permeables, como los paneles metálicos. Además, demostró que existen otros factores como forma y propiedades térmicas de los materiales que conforman las unidades constructivas. Finalmente, el estudio térmico de muros ventilados consolida información técnica de alternativas de cerramiento tradicionales como guía de diseño y planificación de viviendas y edificaciones en zonas de posconflicto, con el fin de promover el confort y la calidad del hábitat en la población mencionada.

Palabras clave
ventilación, transferencia de calor, simulación, materiales de construcción

ABSTRACT

This research proposal aims to identify a series of typologies of traditional ventilated cladding walls of the construction market, such as fretwork, lattice, and metal panels, to conduct a thermal study under the climatic conditions of Catatumbo in Norte de Santander, Colombia. The methodology is theoretical. It uses heat transfer simulations under the finite element method in ANSYS to identify the relationship between the permeability of surfaces and the impact on the behavior of temperatures and heat fluxes. The results show that the more permeable typologies, such as fretwork and lattice, register less energy and temperature transfer than the less permeable typologies, such as metallic panels. It also showed other factors, such as the shape and thermal properties of the construction units' materials. Finally, the thermal study of ventilated walls consolidates technical information on traditional enclosure alternatives as a guide for designing and planning housing and buildings in post-conflict zones to promote comfort and habitat quality in the aforementioned population.

Keywords
ventilation, heat transfer, simulation, building materials.

RESUMO

A proposta de pesquisa está orientada a identificar uma série de tipologias de paredes de revestimento ventiladas tradicionais do mercado da construção, tais como tramas, treliças e painéis metálicos, a fim de desenvolver um estudo térmico sob as condições climáticas do Catatumbo no Norte de Santander, Colômbia. A metodologia é teórica por meio de simulações de transferência de calor com o método de elementos finitos no ANSYS para identificar a relação entre a permeabilidade das superfícies e a incidência no comportamento das temperaturas e dos fluxos de calor. Os resultados mostram que as tipologias mais permeáveis, como tramas e treliças, registram menor transferência de energia e temperatura em relação às tipologias menos permeáveis, como painéis metálicos. Mostraram também que existem outros fatores, como a forma e as propriedades térmicas dos materiais que compõem as unidades construtivas. Por fim, o estudo térmico de paredes ventiladas consolida informações técnicas sobre alternativas tradicionais de fechamento como guia para o projeto e o planejamento de moradias e edifícios em áreas pós-conflito, com o objetivo de promover o conforto e a qualidade do habitat da população mencionada.

Palavras-chave:
ventilação, transferência de calor, simulação, materiais de construção

INTRODUCTION

The incorporation of natural ventilation strategies in architectural projects not only benefits occupant comfort and well-being (Ji, Lomas & Cook, 2009; Pacheco Ochoa, Jiménez Pérez & Ramírez Pérez, 2021), it also has a significant impact on the building's energy efficiency and sustainability (Mercado et al., 2018; Balter, Ganem & Barea, 2020). Natural ventilation refers to the air circulation and flow process in a given space with strategic openings, conditioned by factors such as weather, wind direction, and facade orientation, among others (Giraldo & Herrera, 2017; Mercado et al., 2018; Pacheco Ochoa, Jiménez Pérez & Ramírez Pérez, 2021).

Natural ventilation, by optimizing air quality and comfort through indoor air renewals and temperature regulation, can improve aspects such as users' physical and mental health, achieving high levels of productivity for each space's activities (Pacheco Ochoa, Jiménez Pérez, & Ramírez Pérez, 2021). However, sick building syndrome appears when the design lacks natural ventilation systems. This is a state where a building has comfort issues, ergonomic risks for users, and the prevalence of diseases, among other aspects (Jansz, 2017). In other words, employing optimal ventilation systems in a building is a strategy that can prevent the spread of viral diseases such as coronavirus (Gómez-Porter, 2021; Álvarez Rodríguez, 2022).

However, ventilation is not just limited to openings such as windows or doors. There are geographical contexts with critical climatic conditions that, despite the presence of air inlets and outlets, this solution is insufficient and, therefore, the space is uninhabitable (Atkinson et al., 2009; Batterman et al., 2017; Vartires et al., 2018; Calama-González et al., 2019; Cedeño-Quijada et al., 2022). Faced with these situations, multiple cooling strategies, such as night ventilation, solar chimneys, and ventilated enclosures emerge, providing comfort and energy consumption savings (Giraldo & Herrera, 2017; Mercado et al., 2018; Balter, Ganem & Barea, 2020).

Authors have shown that the advantages vary according to the ventilation strategy implemented in the building. For example, night ventilation with the user intervening by opening windows achieves reductions between 4°C and 5°C depending on the space's height and volume. This translates into 50% energy savings compared to daytime consumption (Mercado et al., 2018). Similarly, building retrofits with ventilated envelopes on the facades reduces energy consumption by up to 32% (Balter, Ganem & Barea, 2020). Another less conventional solution, such as solar chimneys in roof systems, renews the air and reduces thermal loads without affecting the structure of a traditional dwelling (Giraldo & Herrera, 2017).

Although ventilation is a basic need for living, there are areas in the country marginalized by armed conflict and violence where security and life take precedence. Nevertheless, to ensure human rights throughout the country, the State University System—SUE of the Ministry of Education in Colombia—called upon institutions to build peace in post-conflict areas (UFPS, 2017; La Opinión, 2021).

Under this call, Francisco de Paula Santander University participated in sustainable social housing and territorial planning projects. As ventilation is a fundamental component in the architectural composition and considers factors related to the space's function, comfort, sustainability, and efficiency, this research embraces the call by evaluating the thermal behavior of a series of ventilated walls. These consider different construction units, such as fretwork, lattices, and panels. Using the finite element method, low heat transfer simulations were run in the ANSYS software, incorporating the climatic conditions of Ocaña, located in the Catatumbo region in Norte de Santander, Colombia. The aim was to estimate the thermal characteristics of ventilated and traditional construction solutions to provide information for designers, architects, and other professionals in the construction sector. In this way, the research results are theoretical contributions to choosing materials for social housing design and planning processes.

METHODOLOGY

The research methodology for the thermal study of the ventilated walls under the climatic conditions of the theoretical Catatumbo region is divided into three phases. The first phase consists of identifying the types of constructive solutions. The second phase considers the heat transfer simulations in ANSYS, and finally, the third phase analyzes the relationship between the permeability and the thermal performance of ventilated construction solutions.

PHASE I: IDENTIFICATION OF THE TYPES OF VENTILATED CONSTRUCTION SOLUTION

The construction units chosen for the set of traditional ventilated walls in this research are the star fretwork, square fretwork in clay, square fretwork in concrete, brick lattice, metal and cane (gradua) panel, and

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metal grid panel, as shown in Figure 1. Their choice is linked to the Norte de Santander region's industrial ceramic and clay production. Therefore, most of the products use these materials to promote the use of local resources and the region's identity (Sánchez-Molina, González-Mendoza, & Avendaño-Castro, 2019).

The types of ventilated walls subjected to analysis consist of 1 wall with fired clay fretwork called *Estrella* or Star in the ceramic industry of Norte de Santander (VENT-1) (INDUARCILLA[1], 2020), 2 walls built with square fretwork, one in fired clay and the other in concrete (VENT-2, VENT-3), 3 lattice configurations with solid brick (VENT-4, VENT-5, VENT-6), 1 ventilated panel using *guadua*, a native Colombian plant similar to bamboo, and a metal frame (VENT-7) and 1 ventilated panel with a metal grill and frame (VENT-8), as shown in Figure 2. VENT-1, VENT-2, VENT-3, VENT-4, VENT-5, and VENT-6 are fixed walls, while VENT-7 and VENT-8 are types of enclosure with an access purpose, i.e., they are panel-type doors.

The ventilated walls are 2.40m high and 1.24m wide. The thickness and permeable area of the ventilated walls, recorded in Table 1 and Table 3, respectively, vary depending on the unit's measurements. This standardizes the measurements of the modules evaluated in the research.

PHASE II: HEAT TRANSFER SIMULATIONS IN ANSYS

The heat transfer simulations determine the ventilated walls' temperature distribution and heat flows. In this second phase, the ANSYS software, through the finite element method, requires 3D models in Initial Graphics Exchange Specification (IGES) format, as shown in Figure 2, the thermal conductivity of the materials used, and the climatic conditions of the municipality of Ocaña, Norte de Santander. Although Phase I initially describes the ventilated wall types, Table 1 records the coding and each study element's thickness and thermal conductivity.

As mentioned above, the municipality chosen for the simulation's climatic conditions is Ocaña, Norte de Santander, Colombia. Its geographical location in the Catatumbo region is ideal for setting up the environment, and although other municipalities have climatic conditions with higher temperatures,

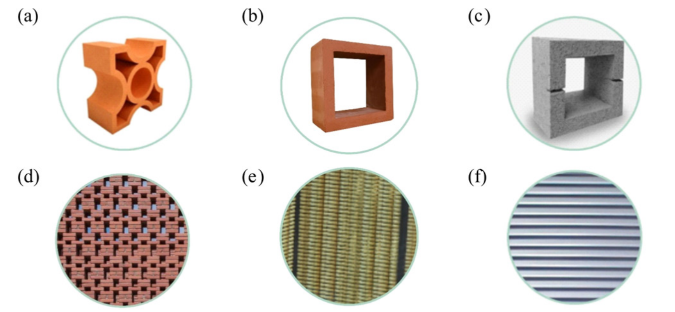

Figure 1. Types of the construction units chosen for the ventilated wall design: (a) star fretwork, (b) square fretwork in clay, (c) square fretwork in concrete, (d) brick lattice, (e) metal and cane (gradua) panel, and (f) metal grill panel. Source: Preparation by the author.

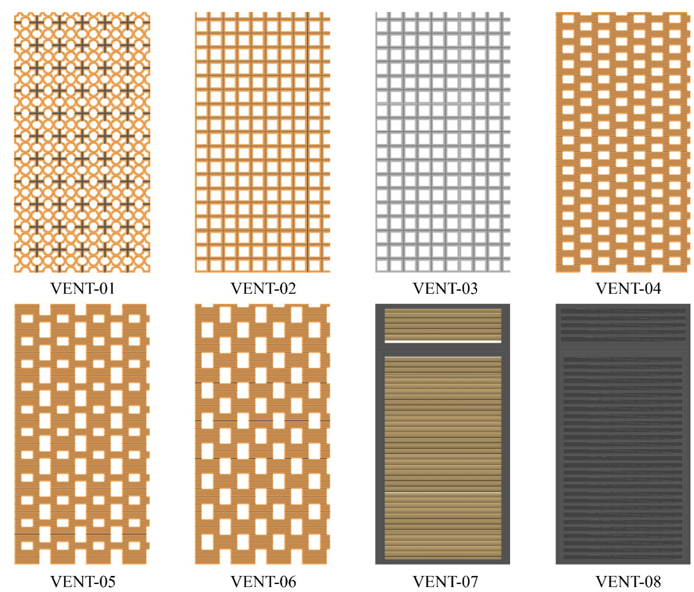

Figure 2. Ventilated wall types. Source: Preparation by the author.

only the data of the aforementioned municipality were obtained. However, thanks to tools such as GoogleEarth and MeteoRED, the climatic and geographical conditions of the municipality of Ocaña and the Catatumbo region can be visualized, as seen in Figure 3.

Below, Table 2 compiles the climatic data of the municipality of Ocaña in the Catatumbo zone of Norte de Santander. The program requires the environmental temperature, wind speed, and solar radiation to calculate the loads applied on the surfaces of the 3D model considering the conditions being simulated.

1 Association of Clay Industrialists of Norte de Santander (INDUARCILLA)

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Table 1. Coding and thermal properties of traditional ventilated wall types. Source: Preparation by the author.

Code	Wall type	Thickness (m)	Conductivity (W/mK)
VENT-1	Traditional fretwork (star)	0.085	0.407 (Vélez-Pareja, 2015)
VENT-2	Square fretwork in clay	0.12	0.407 (Vélez-Pareja, 2015)
VENT-3	Square fretwork in concrete	0.12	0.54 (Vélez-Pareja, 2015)
VENT-4	Brick lattice - Configuration 1	0.1	0.437 (Vélez-Pareja, 2015)
VENT-5	Brick lattice - Configuration 2	0.1	0.437 (Vélez-Pareja, 2015)
VENT-6	Brick lattice - Configuration 3	0.1	0.437 (Vélez-Pareja, 2015)
VENT-7	Ventilated panel with cane	0.076	Structure – 60.50 (Atsonios, Mandilaras & Founti, 2019) Guadua - 0.1417 (Ramírez-Sánchez, 2020)
VENT-8	Door with metal grill	0.076	60.50 (Atsonios, Mandilaras & Founti, 2019)

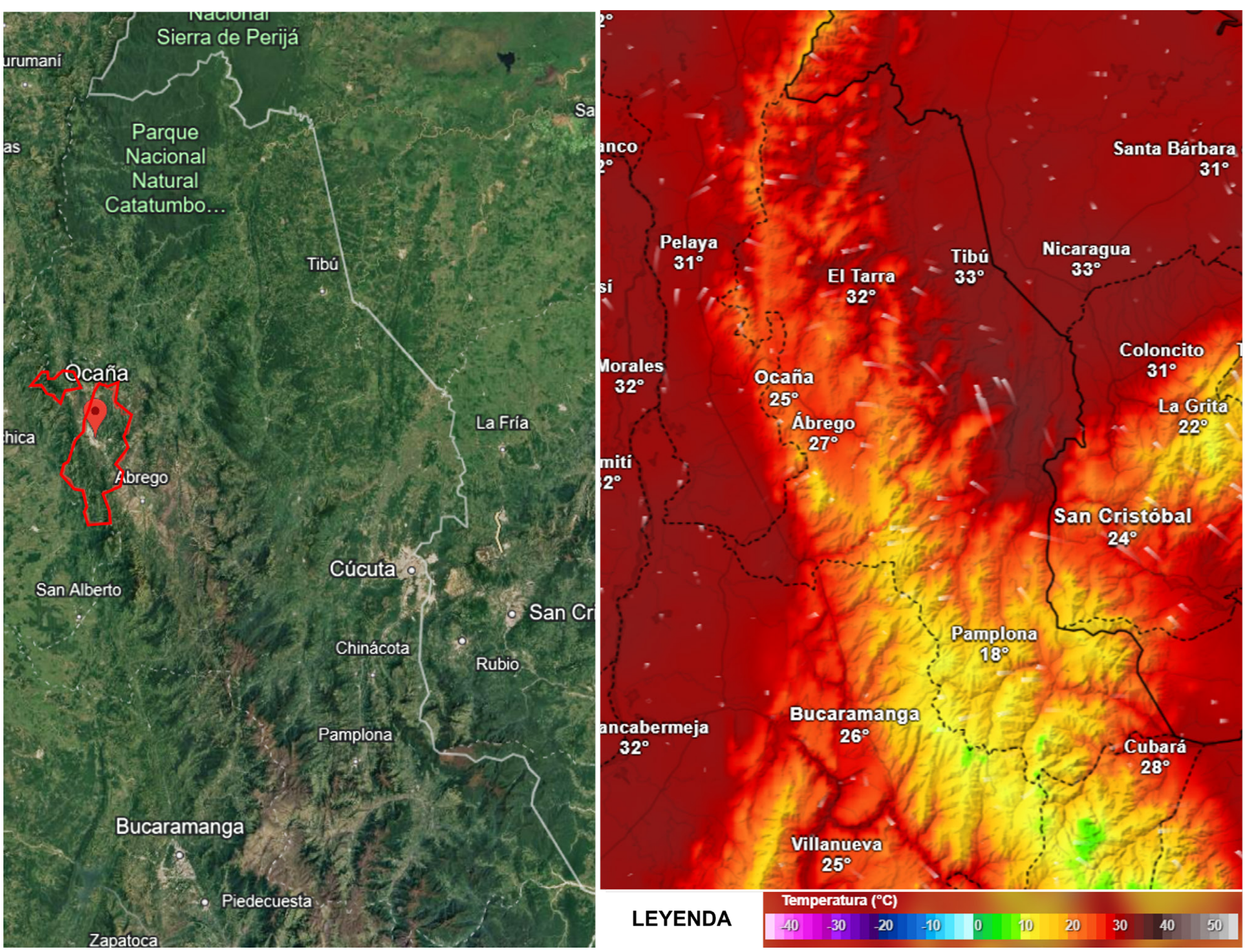

Figure 3. Geographical location of the municipality of Ocaña in the department of Norte de Santander, Colombia (Left) and thermographic map of the municipality of Ocaña and surroundings at noon (Right). Source: Google Earth and MeteoRed (2023)

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Table 2. Climate data for the municipality of Ocaña, Norte de Santander. Source: Preparation by the author.

Data	Value
Coordinates	73°19'20.0"W; 8°14'16.0"N
Average temperature	21.8°C (IDEAM², 2010)
Wind speed	3 – 3.5 m/s (SUE, 2018)
Wind conductivity	0.26 W/mK (Çengel, 2007)
Incident solar radiation	539.3 W/m2 (Sources-Freixanet, 2013)

Table 3. Permeability of the selected traditional ventilated wall types. Source: Preparation by the author.

Code	Wall type	Non-permeable surface (m2)	Permeable surface (m2)
VENT-1	Traditional fretwork (star)	0.3245	0.6755
VENT-2	Square fretwork in clay	0.3916	0.6084
VENT-3	Square fretwork in concrete	0.3916	0.6084
VENT-4	Brick lattice - Configuration 1	0.6175	0.3825
VENT-5	Brick lattice - Configuration 2	0.6365	0.3635
VENT-6	Brick lattice - Configuration 3	0.6667	0.3333
VENT-7	Ventilated panel with cane	0.84	0.16
VENT-8	Door with metal grid	0.76	0.24

Once the formal parameters (3D models), the thermal characteristics of the materials, and the climatic conditions of the environment have been defined, they are configured in ANSYS through the finite element method. This follows the methodology of Colmenares-Uribe et al. (2023), which starts with the type of analysis system, followed by engineering data, geometry, model, configuration, and solution, and ends with the results of the simulations.

PHASE III: ANALYSIS OF THE RELATIONSHIP BETWEEN AIR PERMEABILITY AND THE THERMAL PERFORMANCE OF THE VENTILATED CONSTRUCTION SOLUTIONS.

The analysis of the relationship between the permeability and the thermal performance of the ventilated construction solutions discusses the impact of natural ventilation on the heat transfer of wall types designed to allow airflow. It compares permeability, heat flows, and temperature distribution.

RESULTS AND DISCUSSION

The results record formal and technical characteristics related to the permeability of the surfaces, thermal behavior, and heat flows of the traditional ventilated wall types selected for the research.

PERMEABILITY OF VENTILATED CONSTRUCTION SOLUTION TYPES

Table 3 compiles the areas of the permeable and non-permeable surfaces of the traditional ventilated wall types from one square meter set up with each construction unit. According to the formal characteristics and the data in Table 3, the surface with the highest airflow is VENT-1, which reaches up to 67.55% permeability. It is followed by VENT-2 and VENT-3, with percentages of 60.84%. To a lesser extent, the configurations of brick lattices (VENT-3, VENT-4, and VENT-5) have permeabilities between 36.35% and 38.25%. Finally, the ventilated panels with metal grills (VENT-8) allow an airflow

2 Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM)

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Table 4. Record of maximum, minimum, and average temperatures of traditional ventilated wall types' outdoor and indoor surfaces. Source: Preparation by the author.

Code	Outdoor Temperature (°C)			Indoor Temperature (°C)		
		Minimum	Average	Maximum	Minimum	Average
VENT-1	43.54	38.80	43.58	26.95	22.21	26.71
VENT-2	44.16	41.75	44.16	24.85	22.44	24.42
VENT-3	43.16	40.90	43.16	25.08	22.82	24.72
VENT-4	50.89	45.25	50.89	31.15	25.51	32.40
VENT-5	54.38	44.60	54.38	34.83	25.05	35.53
VENT-6	54.40	44.60	54.40	31.53	24.99	35.56
VENT-7	59.59	42.57	59.59	42.56	28.94	50.75
VENT-8	51.75	49.18	50.41	50.03	44.05	51.73

of 25%, while the worst case is the ventilated panel with cane (VENT-7), which only leaves a margin of 16% ventilation.

TEMPERATURE DISTRIBUTION OF VENTILATED CONSTRUCTION SOLUTION TYPES

The temperature distribution results show maximum, minimum, and average outdoor and indoor temperatures, as shown in Table 4 and Figures 4 and 5. For the outdoor surfaces' temperatures, the maximum values match the averages. In contrast, the average indoor temperatures exceed the maximum values in most cases, except for VENT-1, VENT-2, and VENT-3.

The individual analysis of the thermal behavior examines the maximum, minimum, and average outdoor and indoor temperature differences. The individual analysis shows that VENT-6 has the most significant temperature difference between outside and inside, ranging between 19.60°C and 22.86°C. In second place, VENT-4 registers a difference of 19.74°C, followed by VENT-5 and VENT-2 with 19.55°C and 19.31°C, respectively. In fifth place, VENT-3 and VENT-1 differ by 18.08°C and 16.59°C each. Meanwhile, VENT-7 records temperature differences between 13.62°C and 17.03°C. In last place, VENT-8 registers the lowest values of all wall types between the outside and inside, where the difference only varies between 1.73°C and 5.12°C.

On the other hand, the comparative analysis is focused on identifying the best indoor thermal performances. The ventilated wall types with the lowest indoor surface values are VENT-1 and VENT-2. The thermal benefits offered by VENT-1 range from 0.23°C to 21.84°C. The wall types closest to VENT-1 are the square fretwork in clay and concrete (VENT-2, VENT-3) because the difference in minimum indoor temperatures does not reach 1°C. On the other hand, the solid brick lattices register between 2.79°C (VENT-6), 2.84°C (VENT-5), and 3.80°C (VENT-4) more than VENT-1. However, those with the worst performance compared to VENT-1 are VENT-7 and VENT-8, because indoor temperatures increase by 6.73°C and 21.84°C, respectively.

The second-best thermal performance is from VENT-2, as the comparative analysis of the maximum and average temperatures with the other wall types shows that they exceed it by between 0.23°C and 27.31°C. As in the previous case, VENT-3 registers a minimum difference between 0.23°C and 0.29°C. The similarity of the behavior is related to the shape of the walls' constructive units. The star fretwork comes second, recording an increase of between 2.10°C and 2.29°C in indoor temperatures. The solid brick lattice alternatives vary in temperature increases between 6.30°C and 7.98°C (VENT-4), 9.97°C and 11.10°C (VENT-5), and 6.68°C and 11.13°C (VENT-6). Finally, the metal frame panels are the least advantageous compared to the fretwork and lattice walls. However, VENT-7 has a lower temperature difference (17.71°C and 26.33°C) than VENT-8 (25.18°C and 27.31°C).

HEAT FLOWS OF THE VENTILATED CONSTRUCTION SOLUTION TYPES

The heat flow simulations of ventilated masonry walls show the energy concentration in the walls formed with fretwork, lattices, and grids that allow airflow. Figure 4 illustrates the heat flows obtained. In addition, Table 5 records the maximum and minimum values of the outdoor and indoor surfaces.

The analysis of the heat flows in Figure 6 and Table 5 shows that the flows with the highest concentration are the areas corresponding to the mortar joints and outdoor surfaces; on the contrary, the heat flows are concentrated mainly on the indoor surfaces of the construction units.

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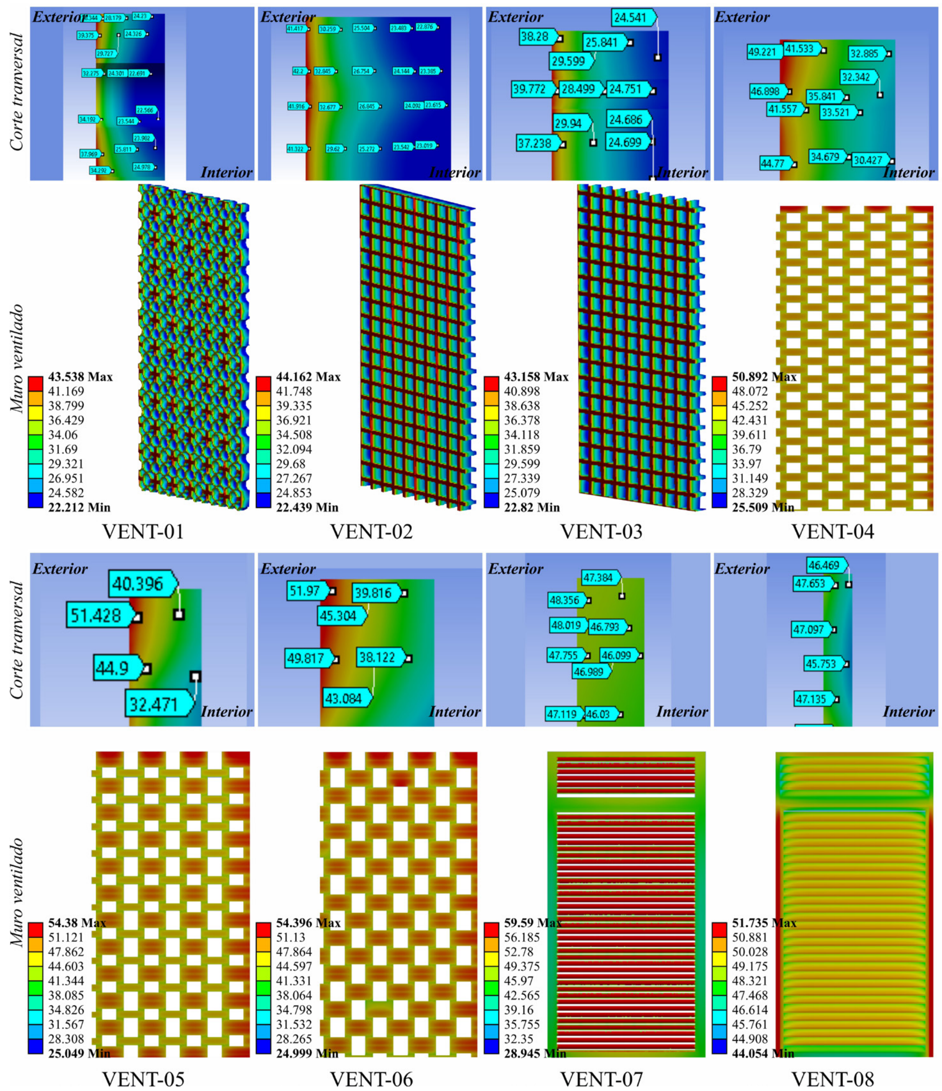

Figure 4. Temperature distribution (°C) of the selected traditional ventilated wall types. Source: Preparation by the author.

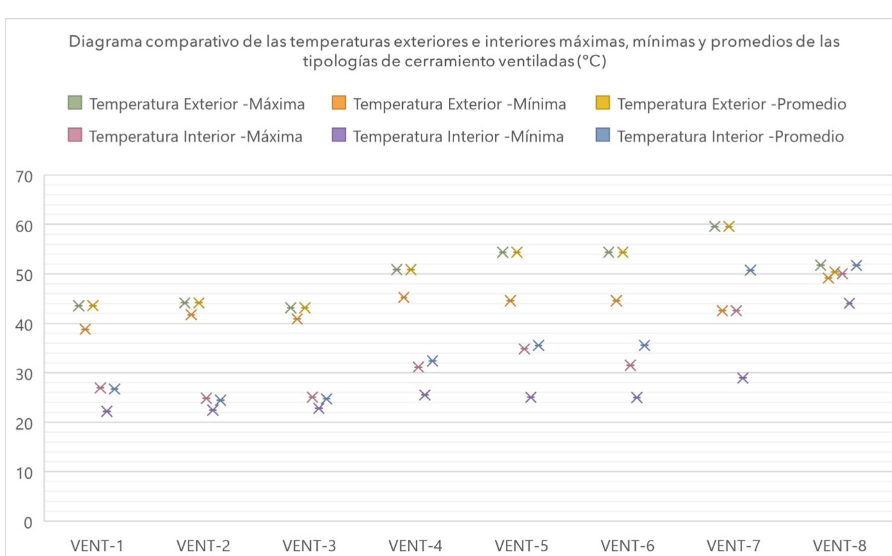

Figure 5. Comparative diagram of the ventilated enclosure types' maximum, minimum, and average outdoor and indoor temperatures (°C). Source: Preparation by the author.

Table 5. Record of maximum and minimum heat flows (W/m2) of the selected ventilated wall types. Source: Preparation by the author.

Code	Maximum heat flow (W/m2)	Minimum heat flux (W/m2)
VENT-1	325.78 – 365.78	1.91 – 42.34
VENT-2	267.55 – 343.03	3.38 – 22.25
VENT-3	290.35 – 325.98	5.32 – 23.1346
VENT-4	218.46 – 379.48	17.18 – 37.31
VENT-5	165.41 – 352.17	25.05 – 31.57
VENT-6	204.06 – 297.18	17.81 – 64.37
VENT-7	1231.20 – 3689.20	2.24 – 22.00
VENT-8	2105.50 – 3508.50	354.12 – 1405.60

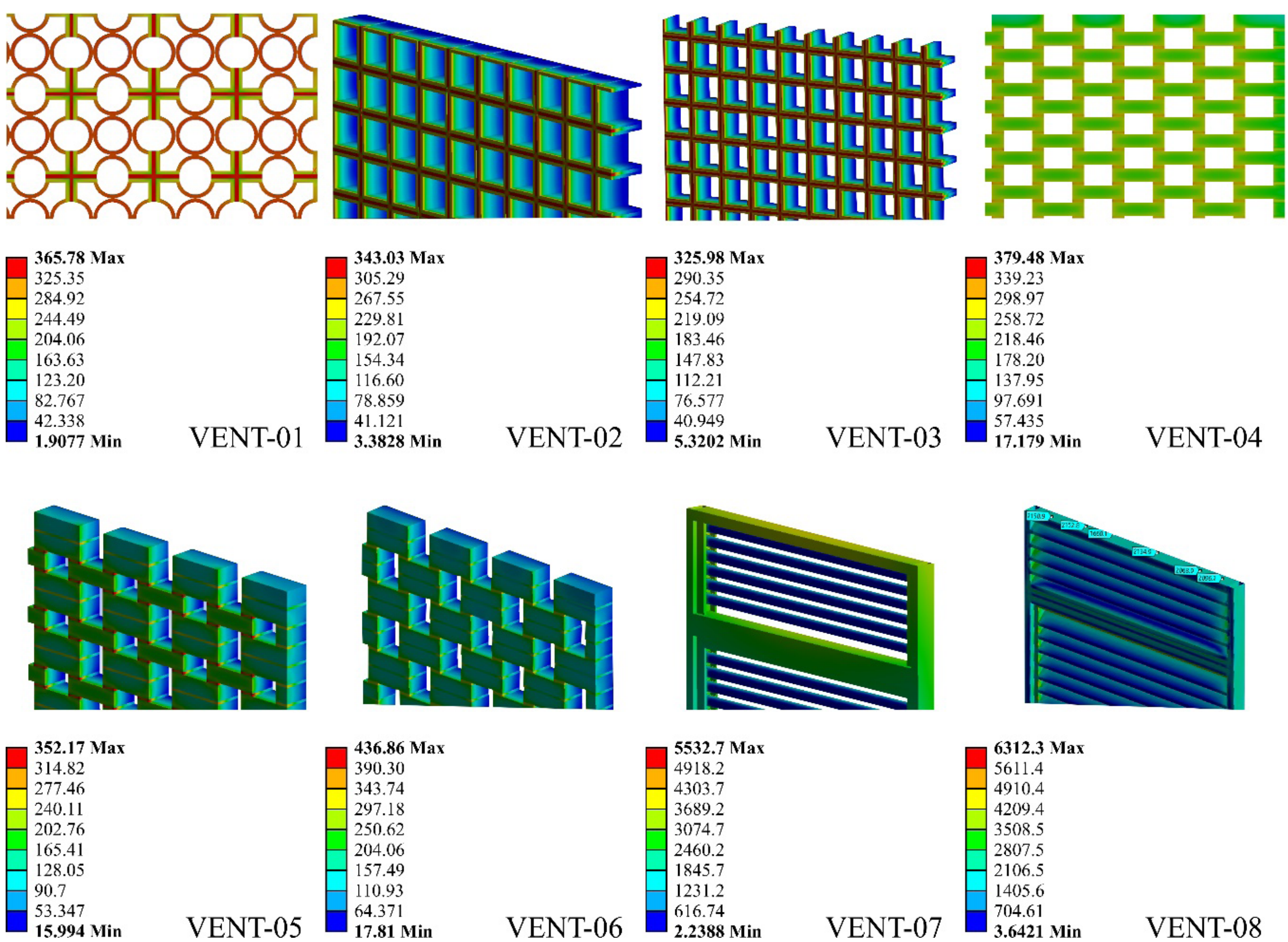

Figure 6. Heat flows (W/m2) of traditional ventilated wall types. Source: Preparation by the author.

The analysis of the maximum heat flows agrees that the areas with materials such as mortar in the joints and steel in the metal frames concentrate between 297.18 W/m^2 and 379.48 W/m^2 and between 1231 W/m^2 and 3689 W/m^2, respectively. Meanwhile, the outdoor surfaces with clay material concentrate between 10.93% and 53% less than those with higher energy.

Although the ventilated walls have common permeable areas for air circulation, this study observes three types of heat flow behaviors that vary according to the shape of the construction units. As mentioned above, the minimum heat flows are located on the indoor surfaces; however, the formal and material composition of the wall types varies as follows: In the case of the fretwork walls VENT-1, VENT-2, and VENT-3, the wall surfaces that connect the outside and inside dissipate between 88.43% and 93.51% of the heat, while the indoor surfaces dissipate almost all of the energy, namely 98.37% and 99.48%.

The second case recorded in the minimum heat flows is the solid brick lattice walls, VENT-4, VENT-5, and VENT-6. These register two zones with minimum values in the construction units' mortar joints and indoor surfaces. Although the mortar joints concentrate the heat flows with the highest concentration on the outside, the dissipated behavior of between 78.34% and 91.04% is reflected on the inside. Meanwhile, indoor surfaces increase heat absorption by between 92.89% and 95.47%.

Finally, the VENT-7 and VENT-8 panels show that the metal structure concentrates the most significant heat flows. However, the indoor surfaces of the frames dissipate between 59.94% and 89.91% of the energy. On the contrary, the horizontal elements of the *guadua* completely dissipate the heat concentration (99.41% and 99.34%).

RELATIONSHIP BETWEEN AIR PERMEABILITY AND THERMAL PERFORMANCE OF THE VENTILATED CONSTRUCTION SOLUTIONS

The thermal study of the selected ventilated wall types shows an inversely proportional relationship between the types' permeability and thermal behavior. Considering the data in Tables 3 and 4, the percentage of permeable surfaces affects the temperature decrease of the indoor surfaces.

The first example to demonstrate this statement is VENT-1, which has the highest percentage of permeability (67.55%) and, in turn, records the lowest indoor surface temperatures (between 22.21°C and 26.95°C). On the contrary, one of the ventilated panels with the lowest permeated surface, such as VENT-8 (24%), doubles the minimum temperatures of VENT-1.

Similarly, the square fretworks in clay and concrete (VENT-2 and VENT-3) also demonstrate that permeability influences the thermal benefits that a ventilated surface can obtain. In fact, with a lower permeability range, it reaches minimum temperatures similar to VENT-1 and even maximum and average indoor temperatures lower than VENT-1.

Although the least permeable typology is VENT-7, with just 16%, it shows that there are other factors in thermal performance, such as the material composition and its conductive properties. Considering the material properties (Table 1) and the heat flow analysis (Figure 4), the conductivity of the materials in the construction units also affects the thermal behavior because the capacity of the *guadua* to dissipate up to 99% of the energy concentrated on the indoor surfaces, allows it to achieve minimum temperatures similar to the minimum and average temperatures of the wall types with double (VENT-4, VENT-5, VENT-6) and up to quadruple (VENT-1) the permeability.

Similarly, the lattice configurations (VENT-4, VENT-5, VENT-6) reflect another factor to be considered in the wall design and thermal performance. Unlike VENT-1, VENT-2, and VENT-3, the lattices comprise a set of solid baked clay bricks joined by mortar joints, which implies that the brick, being a compact volume, concentrates more energy flow. On the contrary, the fretworks are constructive units designed exclusively to allow the flow of air and the entrance of light. Their volume comprises walls that generate the shape of the holes or perforations; therefore, the volume through which the energy is conducted is significantly reduced. For this reason, the lattice configurations only decrease the heat transfer on indoor surfaces by between 92.89% and 95.47%. At the same time, the fretwork types dissipate heat flows by between 98.37% and 99.48% compared to surfaces exposed to solar radiation.

CONCLUSIONS

In conclusion, incorporating natural ventilation strategies into architectural projects has multiple benefits. Apart from promoting occupant comfort and well-being, natural ventilation significantly impacts building energy efficiency and sustainability. The optimization of air quality and comfort through natural ventilation also improves users' physical and mental health.

The initiative of the State University System – SUE of the Ministry of Education in Colombia to build peace in post-conflict areas is an accelerator for the approach of research aimed at solving social problems. The relevance of the research is the commitment to set a precedent to explore new types of ventilated enclosures and evaluate the thermal behavior of different construction units from a specific context, to provide technical information that serves as a basis for choosing systems according to users' needs.

Thanks to the simulations, it is possible to understand the behavior of the heat transfer through the shape of constructive units. Considering the relationship of the comparative diagram between outdoor and indoor temperatures of Figure 5, the wall types with the best thermal performance are the VENT-1, VENT-2, and VENT-3 fretworks, followed by the solid brick lattices that increase their indoor temperatures by between 2.79°C and 3.80°C, compared to the VENT-1 fretwork. However, the metal frame types increase the indoor surface temperatures by between 6.73°C and 21.84°C compared to VENT-1 due to the high conductivity of their structures.

The types of ventilated walls selected with the highest percentage of permeability, i.e., fretwork walls and configurations with lattices, tend to show better thermal behavior and more efficient heat dissipation between the outside and inside. However, it is important to consider other factors, such as the shape and the materials used, to fully understand the impact of the permeability percentage on the ventilated walls' thermal behavior.

CONTRIBUTION OF AUTHORS CrediT

Conceptualization, C.X.D.F.; Data curation, C.X.D.F.; Formal analysis, C.X.D.F.; Acquisition of financing C.X.D.F.; Research, C.X.D.F.; Methodology, C.X.D.F.; Project management, C.X.D.F.; Resources, C.X.D.F.; Software. C.X.D.F.; Supervision, C.X.D.F.; Validation, C.X.D.F.; Visualization, C.X.D.F.; Writing - original draft, C.X.D.F.; Writing - revision and editing, C.X.D.F.

ACKNOWLEDGEMENTS

The author would like to thank Francisco de Paula Santander University's Research Group in Architecture and Alternative Materials (GRAMA) for supporting the proposal of constructive solutions for Rural Housing in Catatumbo.

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