



## COMPARATIVE THERMAL ANALYSIS BETWEEN A CONVENTIONAL HOUSE AND A HOUSE WITH NATURAL VENTILATION

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### Resume

**Objective:** Currently, human beings are feeling the effects of global warming and high temperatures, and it is necessary to seek new forms of ventilation. This work aims to develop a prototype in order to propose a sustainable solution to improve the residential indoor temperature.

**Methodology:** To compare the internal temperature of a standard house, with an unconventional ventilation house that was proposed in the prototype, in order to verify its efficiency. For this, statistical analyzes were carried out through the data of the measurements carried out in the two prototypes, which occurred at different times (14:00 and 18:00) during the period of 51 days.

**Relevance:** Natural ventilation implies a sustainable method constituted by the natural flow of air providing the environment with a more pleasant sensation, being very relevant to the quality of life of the human being.

**Results:** By comparing the average internal temperature between them, it was possible to verify that the average internal temperature of the standard house was significantly higher than the house with unconventional ventilation, considering the heat period. It analyzed that factors such as climate, humidity, period (time) and the window inserted in the prototype, influenced the temperature of the environment.

**Conclusion:** The main conclusion of the work is given by the fact that the proposed prototype provided a reduction in temperature using natural methods, and consequently a possible reduction in electricity consumption contributing to a more sustainable world.

**Keywords:** ventilation, health, window, sustainable, climate.

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Special Edition Guest Editors - Mudanças climáticas e planejamento urbano: cenários e desafios

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## ANÁLISE TÉRMICA COMPARATIVA ENTRE UMA CASA CONVENCIONAL E UMA CASA COM VENTILAÇÃO NATURAL

### Resumo

**Objetivo:** Atualmente o ser humano vem sentindo com os efeitos do aquecimento global e as altas temperaturas, sendo necessário buscar novas formas de ventilação. Este trabalho tem como objetivo desenvolver um protótipo a fim de propor uma solução sustentável para melhorar a temperatura interna residencial.

**Metodologia:** Comparar a temperatura interna de uma casa padrão, com uma casa de ventilação não convencional que foi proposta no protótipo, a fim de verificar sua eficiência. Para isso foi realizado análises estatísticas através dos dados das medições realizadas nos dois protótipos, que ocorreram em horários distintos (14h e 18h) durante o período de 51 dias.

**Relevância:** A ventilação natural implica em um método sustentável constituído pelo fluxo natural do ar proporcionando ao ambiente uma sensação mais agradável, sendo bastante relevante para a qualidade de vida do ser humano.

**Resultados:** Através da comparação da média de temperatura interna entre eles foi possível constatar, que a média de temperatura interna da casa padrão foi significativamente maior do que a casa com ventilação não convencional, considerando o período de calor. Analisou que fatores como o clima, a umidade, o período (horário) e a janela inserida no protótipo, influenciaram na temperatura do ambiente.

**Conclusão:** A principal conclusão do trabalho se dá pelo fato de que o protótipo proposto proporcionou uma redução na temperatura utilizando de métodos naturais, e conseqüentemente uma possível redução no consumo de energia elétrica contribuindo para um mundo mais sustentável.

**Palavras-chaves:** ventilação, saúde, janela, sustentável, clima.

## ANÁLISIS TÉRMICO COMPARATIVO ENTRE UNA VIVIENDA CONVENCIONAL Y UNA VIVIENDA CON VENTILACIÓN NATURAL

### Resumen

**Objetivo:** Actualmente, el ser humano está sintiendo los efectos del calentamiento global y las altas temperaturas, y es necesario buscar nuevas formas de ventilación. Este trabajo tiene como objetivo desarrollar un prototipo con el fin de proponer una solución sostenible para mejorar la temperatura interior residencial.

**Metodología:** Comparar la temperatura interna de una casa estándar, con una casa de ventilación no convencional propuesta en el prototipo, con el fin de verificar su eficiencia. Para ello se realizaron análisis estadísticos a través de los datos de las mediciones realizadas en los dos prototipos, las cuales ocurrieron en diferentes horarios (14:00 y 18:00) durante el lapso de 51 días.

**Relevancia:** La ventilación natural implica un método sustentable constituido por el flujo natural de aire proporcionando al ambiente una sensación más agradable, siendo muy relevante para la calidad de vida del ser humano.

**Resultados:** Al comparar la temperatura interna promedio entre ellas, fue posible verificar que la temperatura interna promedio de la casa estándar fue significativamente mayor que la casa con ventilación no convencional, considerando el período de calor. Se analizó que factores como el clima, la humedad, el período (tiempo) y la ventana insertada en el prototipo, influían en la temperatura del ambiente.

**Conclusión:** La principal conclusión del trabajo está dada por el hecho de que el prototipo propuesto proporcionó una reducción de la temperatura por métodos naturales, y conseqüentemente una posible reducción del consumo de energía eléctrica contribuyendo a un mundo más sustentable.

**Palabras clave:** ventilación, salud, ventana, sostenible, clima.



## Introduction

Nowadays the world has been suffering big climate changes both by natural and man influence (Cortese & Natalini, 2014). Activities like wildfires lead to higher temperatures, In addition to having a higher increase of atmospheric gasses causing global warming due to the GreenHouse Effect (Cortese & Natalini, 2014). As a way of dealing with the heat we use Fans and ACs providing a better environment, Although the use of these tools can lead us to a higher energy consumption.

Due to the higher demand of energy, providing it to the world has become way harder (Altoé et al., 2017) Thus the so expensive energy bills, Besides increasing even more, The greenhouse effect has exposed a great challenge on the power generation industry. The 2001 brazilian power crisis has affected not only the politics but also the social aspect of the country, stimulating the power department privatization.

Some factors that led to the crisis involved a shortage of rainfall, which would come from low water levels in the hydroelectric power plants, and there was a delay in the construction of energy transmission and generation work.

According to Altoé et al. (2017), due to the electricity shortage, the federal government had to take drastic measures to ensure essential services such as hospitals, police stations, among others, had electricity to operate. For this purpose, scheduled blackouts were implemented over a period of nine months to prevent overloading of the system. Additionally, households and businesses were required to replace light bulbs and some equipment to minimize electricity consumption. Nighttime events such as concerts, parks, and circuses were prohibited, and there was no public light.

Analyzing the events resulting from this situation, the lack of planning and investment in the Brazilian energy sector became evident. Another event that highlighted the strain on the system was the blackout that occurred in the interior of São Paulo in 1999, where there was a deterioration in the transmission network (Leme, 2018). Investments in the electric sector declined by approximately 3 to 4 billion reais per year from 1980 to 1998, according to Rosa (2002 as cited in Leme, 2018). These facts demonstrated that the money invested was insufficient to meet the high consumption demands (Leme, 2018).

The search for more appropriate methods that utilize natural air circulation to reduce heat and electricity usage becomes a solution to this situation. The path to be developed involves architectural strategies to enhance air circulation and better utilize natural ventilation, resulting in a more pleasant environment (Rodrigues, 2021). One way to implement these constructive techniques involves the placement of doors and windows in buildings to make the construction process more efficient regarding natural ventilation.

With the use of natural ventilation, sustainability is employed in the field of civil



construction since it relies on natural resources, making it environmentally friendly (Roque & Pierri, 2018). This phenomenon occurs when the wind enters the interior space naturally, "flowing through it," and exiting through openings and gaps present in the walls. As a result, the thermal sensation is more pleasant, leading to a decrease in electricity bills, reduced internal temperature and heat, and improved health benefits (Morais, 2013). When designing a building, the number of openings in the structure should be taken into account to allow for good natural ventilation.

This study aims to compare the internal temperature of a conventional house with a house utilizing unconventional ventilation, demonstrating its efficiency. The hypothesis is that houses with better air circulation will generate a milder temperature, and in the case of the prototype with superior ventilation and windows with an inclination that ease air outflow, there will be less accumulation of hot air near the ceiling, as the window's inclination promotes the convection process, enabling the exchange of internal hot air with external cold air.

Thereby, two prototypes were employed: one representing a conventional house with only a common window, and the other with an additional window at the top, having a smaller opening than usual and an opposite inclination to a typical awning-type window. This design allows the escape of hot air and the entry of cold air.

The collection of primary and quantitative data takes place by reading a digital thermometer, performed twice a day at 2 PM and 6 PM. In the end, the average temperature was compared using the "Student's t-test," considering its standard deviation, variance, coefficient of variation, and making a comparison between both prototypes. Thus, it is expected that by conducting this experiment, there will be an improvement in internal air circulation, along with constant and more effective air renewal, providing a healthier environment and reducing the use of air conditioning and fans. The conducted experiment intensifies research with a quantitative approach, applied in nature, with descriptive and exploratory statistics, representing an experimental and cross-sectional study.

## **Theoretical reference**

### **Sustainability**

Sustainability implies the conscious use of natural resources to preserve nature in a way that satisfies the conditions of both current and future generations (Manhães & Araújo, 2014).

Currently, sustainability in the construction industry is a milestone, as this sector is one of the largest consumers of raw materials (Marafão, 2021). In order to reduce the need for these resources and minimize environmental impacts, some constructive aspects are currently implemented, such as the use of ecological bricks, natural ventilation, natural lighting,



rainwater harvesting, and material recycling, among others, according to Corrêa (2009 as cited in Manhães & Araújo, 2014).

Ecological bricks are made from a type of soil, cement, and water, and their production does not involve firing in kilns, as in the case of ceramic blocks. This significantly reduces the emission of polluting gases into the atmosphere and minimizes material disposal and waste. Moreover, this type of material is considered more durable for construction, serving as a good acoustic and thermal insulator. The brick's design includes interlocking and holes, allowing for the passage of hydraulic and electrical systems without the need to break the brick, thus generating fewer waste materials compared to ceramic blocks, where breaking is required for these systems' passage (Fiais & Souza, 2017).

Regarding natural ventilation and lighting, these aspects provide thermal comfort and lighting through openings such as doors and windows. This reduces the need for electric equipment like air conditioning, fans, or lights to create a comfortable environment (Vanderlei, Gonçalves & Silva, 2019).

Rainwater harvesting, on the other hand, can be reused for purposes like flushing toilets, house cleaning, and garden irrigation, but it is not recommended for human consumption. This system reduces the high consumption of water and helps to avoid wastage (Nogueira, 2017).

## Types of Ventilation

An indispensable natural resource to human beings is the air circulation promoted by the wind, which is formed due to differences in atmospheric pressures between two regions and involves the movement of air masses influenced by local effects, such as soil roughness (Silva, Gonzalez & Filho, 2011). This fact is extremely important for human health, as proper ventilation allows for satisfactory circulation of air contaminants and provides a more pleasant temperature (Marques, 2019).

There are several principles associated with air movement, such as friction, where the air moves slowly near the Earth's surface compared to the atmosphere; inertia, where the air moves in the same direction without encountering any obstacles; and the result of high and low-pressure zones. When there is a change in terrain roughness, it significantly impacts local ventilation, as new obstacles hinder the passage of predominant winds, resulting in a warmer thermal sensation in the area (Brown & Dekay, 2000 as cited in Silva, Gonzalez & Filho, 2011).

Natural ventilation is a sustainable method that does not cause environmental impacts since it does not rely on mechanical systems. Its principle is based on the natural flow of air, providing comfortable temperature conditions in the environment and maintaining good air quality. Its implementation leads to energy savings, reduced greenhouse gas emissions, and,



most importantly, improved air quality for human respiration. It is important to consider design aspects, local winds, and the surrounding environment when employing this type of ventilation in a project (Cunha, 2010 as cited in Scherer & Masutti, 2019).

In the process of cross ventilation, the use of windows on opposite or adjacent facades of the property is essential, as the pressure difference will force the entry and exit of air from the environment. The position of the windows is crucial because changing the direction of the wind makes the air circulation more efficient in the area (Marques, 2019). Therefore, windows that allow air intake should be placed in high-pressure areas, while windows for air outflow should be located in low-pressure areas (Scherer & Masutti, 2019). When designing an open floor plan with cross ventilation, attention should be given to dividers and barriers, ensuring low resistance to air circulation (Marques, 2019). It is worth noting that cross ventilation is not recommended for hospital projects as bacteria transmission through the air could occur (Pereira, 2020).

The principle of the chimney effect is related to the physical process of heat transfer, convection, where denser fluid tends to descend and less dense fluid tends to rise, creating air flows. Utilizing upper openings in the center of the design, such as chimneys, allows this process to occur more rapidly, as hot air will exit through roof lanterns, zenithal openings, or wind-driven exhaust vents (Pereira, 2020). In some situations, glazed chimneys are employed to heat their interior through solar radiation, accelerating this phenomenon (Marques, 2019).

Induced ventilation utilizes thermal induction mechanisms for cooling the air. The principles are based on convection, where warm air rises and cool air descends. To make this process efficient, openings are located near the ground, allowing fresh air to enter and push the hot air upwards, with the exits placed at the ceiling, such as sheds and lanterns (Pereira, 2020).

In arid climates, where evaporation exceeds precipitation, achieving a better thermal sensation involves evaporative cooling, as used in Oscar Niemeyer's work in Brasília. In these constructions, extensive water mirrors or lakes are strategically placed in the direction of air currents, allowing the wind passing over the water to carry a certain percentage of humidity, bringing cooler air to these areas (Pereira, 2020).

### **Construction systems focused on thermal aspects**

Construction systems involve technology and the method in which the building is constructed, directly affecting its thermal comfort, cost, time, and appearance (Tiedt & Cordeiro, 2021).

The most well-known system in this area is masonry or conventional brickwork, which utilizes ceramic bricks and structural elements combined with reinforced concrete. Its applicability involves separating spaces using reinforced concrete beams, pillars, and slabs



(Tiedt & Cordeiro, 2021). Since it does not require skilled and specialized labor, this method often leads to the emergence of +construction pathologies, resulting in a high generation of waste and significant environmental impact (Pereira, 2018). Additionally, this type of masonry allows for medium to large openings and is more straightforward to make future renovations or changes to the project (Tiedt & Cordeiro, 2021).

Structural masonry allows for the enclosure of the property to be done together with the structure using ceramic or concrete blocks. Skilled labor is required for this method, reducing material waste and making it more cost-effective and efficient, with a good compatibility with electrical and plumbing plans (Pereira, 2018). The size and openings are defined through the modulation of the blocks used, so walls cannot be easily modified or removed in future changes, and there may be some aesthetic limitations (Tiedt & Cordeiro, 2021).

Steel Frame utilizes structural elements based on galvanized steel profiles, closed with cementitious boards, wood, or drywall. It is extremely beneficial for the environment due to low waste generation and the absence of water usage in the construction process. Furthermore, its use implies better thermal and acoustic insulation for the building, as well as reduced weight, low cost, and larger openings (Pereira, 2018).

In the Wood Frame construction method, the structure is made of solid wood, often from reforested sources like pine. This system provides greater resistance to certain phenomena like termites and humidity due to the use of OSB panels and autoclaving processes on the wood (Tiedt & Cordeiro, 2021). Its benefits include excellent acoustic and thermal insulation, low waste generation, low cost, and quick execution time, making it highly favorable to the environment due to its use of reforested wood. Specialized labor and limitations on the number of floors are crucial aspects of this method (Tiedt & Cordeiro, 2021). Ensuring proper waterproofing is also indispensable for this method (Pereira, 2018).

Concrete walls have a solid reinforced concrete structure, with plumbing and electrical installations embedded within them, reducing material waste. The construction involves the use of metal or wooden molds filled with concrete, which varies in size according to the project (Pereira, 2018). For large-scale constructions, this construction method is recommended since the forms can be reused, reducing overall costs. Its advantages include high resistance to high temperatures, low material waste, and good productivity. However, it is not suitable for environments that require good thermal and acoustic insulation, and once constructed, it is challenging to make alterations or changes to the walls (Tiedt & Cordeiro, 2021).

The PVC concrete system involves PVC panels with measurements according to the project, which are assembled to construct the walls. Electrical and plumbing systems are passed through these panels, and then concrete is used to fill them. This method results in low waste generation, a cleaner and more organized work site, and good thermal and acoustic insulation. However, in areas with strong winds, this method is not recommended as it may



cause some vibrations in the structure (E.A., 2020).

For buildings constructed using shipping containers, several processes need to be carried out, such as welding, sheet metal work, and painting. Additionally, such constructions should have a habitability certificate, certifying that the structure is safe and free from chemical, biological, and radioactive agents. Care must be taken to ensure good thermal and acoustic insulation and to prevent rust through specific treatments (E.A., 2020).

Hyperadobe construction uses raschel bags with open mesh, eliminating the need for barbed wire between the layers. The bags are filled with soil and compacted manually to stabilize them. This technique provides a pleasant and healthy local climate inside the residence. The walls safely absorb and retain vapor when the humidity level is relatively high, and release it when the humidity level drops, resulting in an indoor humidity level between 40% and 60%, which is healthier for people (Biletska, 2019).

With a wall thickness and plaster of approximately 40 cm, the internal temperature is maintained constant, avoiding heat loss from the house to the outside or vice versa, thus achieving energy efficiency. Moreover, this method allows for cost savings since the only element used is earth, while traditional methods require concrete making, the use of ceramic blocks or similar materials, and reinforcement for wall construction. It is essential to highlight that proper waterproofing is crucial to prevent constant moisture contact, and walls need protection from rain during construction. This method is considered a low-impact housing solution (Biletska, 2019).

## Heat Transfer

Heat transfer can be defined as the rates of heat transfer from one system to another due to the temperature difference between them (Çengel & Ghajar, 2012). There are three ways in which this process occurs: conduction, convection, and radiation.

The process of conduction involves the transfer of energy from a more energetic element to adjacent neighboring particles with less energy. This phenomenon occurs in all three physical states of matter (solid, liquid, and gas). For this to happen, a condition must be met: there should be no movement of its mass. In liquids and gasses, conduction occurs through collisions and diffusion of molecules in their random movement, while in solids, it occurs due to the vibrations of the molecules in the lattice. Important factors influencing this type of heat transfer are geometry, thickness, material type, and temperature difference (Çengel & Ghajar, 2012).

The process of convection is present in various everyday situations, such as cooking food, cooling, and heating a room, among others. These situations involve the rising of warm air and the descending of cold air, forming a cyclical system. Forced convection involves inducing the flow of fluid over a surface using fans, pumps, etc., while natural convection





corresponds to the fluid movement driven by buoyancy forces (Çengel & Ghajar, 2012).

Thermal radiation results from heat transfer through radiation, and its process occurs through electromagnetic waves, not requiring a material medium to propagate. The presence of a medium actually hinders its radiation. Furthermore, thermal radiation encompasses part of the electromagnetic spectrum, including the visible range. It is worth noting that the emitted properties of an element depend on the orientation of the surface and the temperature (Coelho, 2012).

## Methodology

The project consists of research with a quantitative approach of applied nature, as it conducts an experiment to analyze its effects (Gerhardt & Silveira, 2009). Additionally, the study involves descriptive statistics using tables and graphs, as well as exploratory analysis through statistical comparisons of temperature means, using the independent and one-tailed Student's t-test with a significance level of 0.05.

According to Santade (2014), the quantitative approach employs quantification in data collection and analysis, and this process should be objective, rational, and punctual. Furthermore, the descriptive study aims to describe the specificities of a particular situation or establish relationships between variables, while the exploratory study delves into ideas by conducting a literature review to better understand the problem (Koche, 1997 as cited in Heerd & Leonel, 2007)..

For Jacobsen (2016), primary data are those collected by the individual to complement their project. Therefore, this study encompasses this concept, as quantitative and qualitative data from the prototypes were collected for statistical analysis. Due to the data being collected during the research process, it qualifies as a cross-sectional study.

According to Heerd & Leonel (2007), research is considered experimental when it analyzes the variables that influence the study element and its effects. It is also necessary to determine ways to control this phenomenon. Thereby, this concept is evident in this project, as the influence of construction methods, global warming, and other factors affects the temperature of an environment, and the use of electrical and natural systems is employed to mitigate the place thermal sensation.

To collect data from the prototypes, measurements were taken using a digital LCD thermometer of the brand OHPRO, with an accuracy of about 1°C and a measurement range of -50°C to 70°C, recording the indoor and outdoor temperatures of the environments twice a day (2:00 PM and 6:00 PM) in the city of Brasópolis-MG, with an average municipal temperature of 19.4°C according to Climate-Data (C.D., 2021).

The data were obtained during the period from 27/08/2021 to 16/10/2021 for each prototype, totaling 51 days, as stipulated by the program GPower© 3.9.1.2, considering a

significance level of 5%, 95% reliability, test power of 80%, and a medium effect size, resulting in a sample size of 102 temperature data points.

An intentional sampling was used to obtain the data. Additionally, research was conducted in scientific articles, libraries, and climate and weather sources (through a mobile app with reference to the website *Weather.com*), and the data were entered into Microsoft Excel© 365 for tabulation and development of tables and graphs.

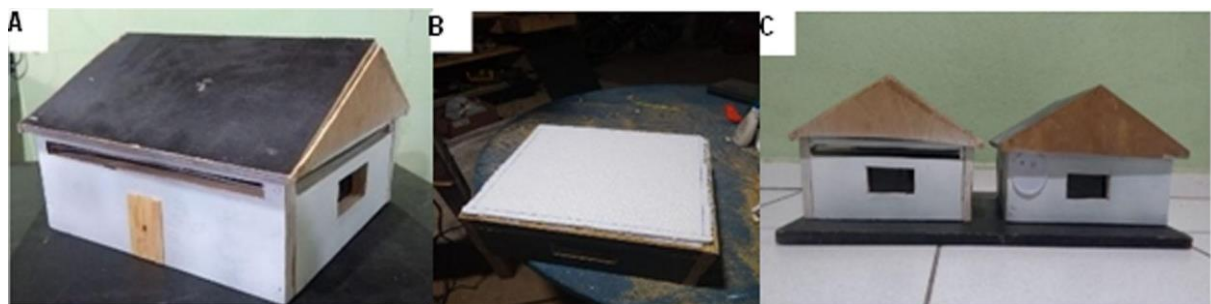
The MINITAB© 16 software was used to apply the general linear model test, using paired data considering all the analyzed variables. It is a multivariable test to verify the influence of each variable analyzed (climate, prototype type, collection time, and relative humidity) on the temperature value obtained, using multiple regression, Analysis of Variance test for 3 groups or more, and Tukey test on two means, considering a significance level of 0.05.

For data analysis, the difference between internal temperature and external temperature was considered, analyzing the gain of internal temperature compared to external temperature when the result obtained is positive, or the reduction of internal temperature compared to external temperature when the result obtained is negative.

The prototypes consist of two types of houses (figure 1a), with dimensions of 30 cm x 12 cm, made of 1.7 cm thick plywood representing the walls and roof, and the door was represented by popsicle sticks. A 1 cm thick polystyrene sheet was used as the ceiling (figure 1b), and acrylic was used for the windows (figure 1c).

## Figure 1

*Views of the prototypes*



**Source:** Own authorship

The first prototype has a door with dimensions of 4 cm x 8 cm and a window of 8 cm x 4 cm, with a hole in the upper left corner of the wall to allow the thermometer to be inserted for internal measurement. In the second prototype, these two items are present, with the addition of two windows (one on the wall containing the door, 4 cm x 8 cm, and the other on the wall containing the window, 8 cm x 4 cm), both with dimensions of 27 cm x 1.5 cm and inclined in the opposite direction to the Maxim ar type. It is worth noting that the scale used was 1:25.



## Data Analysis

The data collected during the 51-day period stipulated by the GPower© 3.9.1.2 program were all entered and tabulated in Excel for analysis through graphs, mathematical calculations, and the general linear model, which includes ANOVA/Tukey tests and independent and one-tailed Student's t-test, considering all study variables in a multiple manner with a significance level of 0.05. This analysis aimed to determine if the non-conventional ventilation house was effective or not.

By creating a box plot of the temperatures measured in the two prototypes and at both times, it was possible to identify any outliers, that is, any values outside the standard range, as this could interfere with the means and subsequently with the other analyses to be performed. At 18:00, an outlier was observed in the prototype without the upper window (conventional ventilation), so this data point was discarded to avoid interference in the analyses. After excluding this data, the box plot was redone, and no values outside the standard range were found. It is important to note that the analyzed data refers to the thermal difference between the internal and external temperatures.

Regarding the distribution of data, the Ryan Joiner normality test was performed, determining a p-value greater than 0.05, indicating that the samples come from a population with a normal distribution. The sphericity test also showed that the samples have equal variances and covariances. Once the prerequisites were verified, it was possible to apply the general linear model test, considering the variables of climate, humidity, period (time), and window, and it was found that these elements account for 52.09% of the temperature variation.

**Table 1**

*Table of temperature values and Analysis of Variance/Tukey for groups considering the general linear model*

Weather	N	Average	DP	p Value	Gr
Sun	24	5,8	3,08	<0,0001	A
Clean sky with a few clouds	18	2,7	2,29		B
Partly cloudy	86	2,5	2,36		B
Cloudy	74	2,2	1,40		B
Open Sky	8	1,6	0,41		B

**Source:** Own authorship

From the data in Table 1, the number of days analyzed, the mean, and the standard deviation (SD) of the temperature variation (obtained by subtracting the internal temperature from the external temperature) are shown. The p-value of the ANOVA test considered in the

general linear model and the Group (Gr) of the analyzed difference are also displayed, allowing us to visualize that the "Sun" climate period had the highest average difference in internal temperature, differing from the other climates.

The internal temperature of the house during the sunny weather has a mean of 5.8°C higher than the external temperature, while the other climates showed an increase in temperature ranging from 1.6°C to 2.7°C compared to the external temperature. Therefore, the average temperature difference for the sunny weather compared to the others presents a significant difference in the data, as verified by the ANOVA test, with a p-value of < 0.0001, and the Tukey test, which shows which group differs from the rest, as seen in the column of groups. Only the "Sun" is in Group A, while "Clear sky with few clouds," "Partly cloudy," "Cloudy," and "Open sky" are all in Group B, differentiating the groups with different letters, according to the MINITAB©16 program.

**Table 2**

*Time and Temperature analysis (Tukey test)*

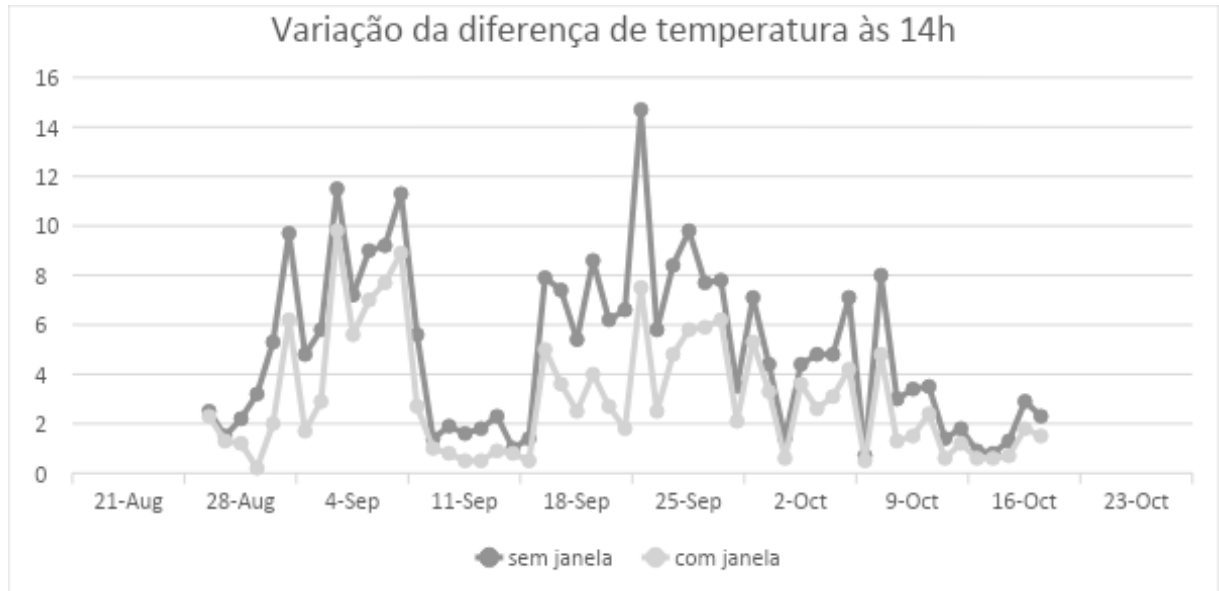
Timetable	N	AVG	DP	p Value	Gr
2:00 PM	106	3,6	3,07	< 0,00001	A
6:00 PM	104	2,3	1,19		B

**Source:** Own authorship

According to the averages of the temperature difference between internal and external temperatures at the two time periods presented in Table 2, it was observed that at 2 PM, there was a higher average temperature difference (°C). Therefore, it can be concluded that the internal temperature at this time is higher than at 6 PM. Due to the significant difference in data at 2 PM, both time periods are in different groups in the column of groups, with 2 PM belonging to Group A and 6 PM to Group B. Comparing the temperature at 6 PM with that at 2 PM, it was noticed that the maximum difference between the two is approximately 0.67°C, and the minimum difference is about 1.87°C, based on the values of the 95% confidence interval.

**Table 3**

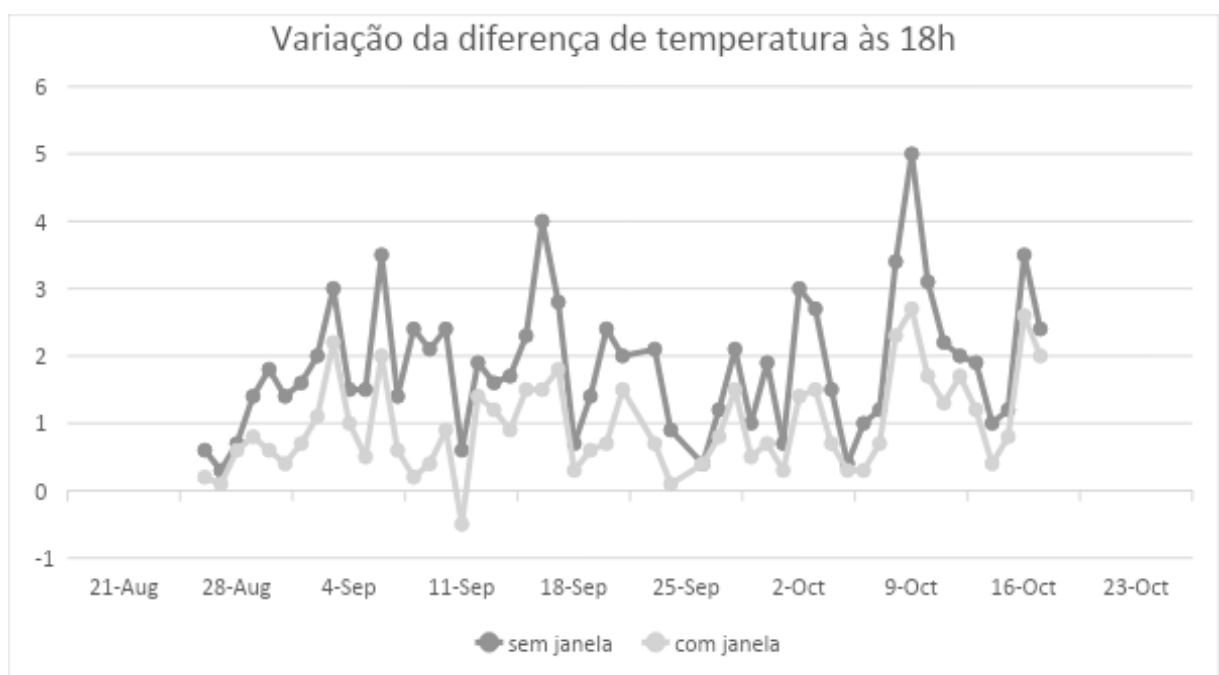
Graph of temperature difference at 2 PM in the two prototypes between August 27th and October 18th, 2021



Source: Own authorship

**Table 4**

Graph of temperature difference at 6 PM in the two prototypes between August 27th and October 18th, 2021



Source: Own authorship



Analyzing the graphs of the temperature differences between the internal and external of each prototype at both times, it is clear that the internal temperature of the house with a window is always lower than the house without a window. The day with the highest variation between the two houses at 2:00 PM (Table 3) was on September 23rd, with the house without a window showing a temperature difference of 14.7°C between the internal and external temperatures, while the one with a window had a temperature difference of 7.5°C, resulting in a noticeable difference of 7.2°C. At 6:00 PM (Table 4), the day with the highest variation between the two houses was on September 5:00 PM, with the house without a window showing a temperature difference of 4°C, while the one with a window had a temperature difference of 1.5°C, resulting in a difference of 2.5°C.

According to Gratia et al. (2004 as cited in Silva, Gonzalez & Filho, 2011) and Andreasi (2007 as cited in Silva, Gonzalez & Filho, 2011), ventilation during the day provides a cooling sensation that helps control body temperature, with an air velocity of approximately 0.2 m/s for temperatures above 18°C. From the graphs shown in Tables 3 and 4, it can be observed that both temperatures of the prototypes with and without a window are above 18°C. Therefore, the house with a window will have greater air circulation, as the wind will enter through the Maxi air window and, being denser, will descend while the warm air rises, following the convection process, resulting in cooling of the environment and control of body temperature as mentioned.

On the other hand, the house with conventional ventilation will not undergo this process, and thus the thermal sensation in the location will be hotter and quite unpleasant, as the individual will perceive the environment as more stuffy. As pointed out by Gratia (2004 as cited in Silva, Gonzalez & Filho, 2011) and Andreasi (2007 as cited in Silva, Gonzalez & Filho, 2011) regarding diurnal ventilation, it can be analyzed that the 2:00 PM and 6:00 PM measurements correspond to daytime, but their averages are different, as at 6:00 PM there is a perception of a breeze, leading to the perception that the environment is better ventilated compared to 2:00 PM.

**Table 5**

*Analysis of temperature difference between the prototypes*

Prototypes	N	AVG	DP	p Value	Gr
Windowless	105	3,7	2,93	< 0,0001	A
With Windows	105	2,2	2,08		B

**Source:** The authors themselves (2021)

Analyzing the data from Table 5, it was possible to evaluate through the average temperature difference between the internal and external temperatures that the house without



a window had a higher average temperature difference. Thus, its internal temperature is significantly higher than the house with a window. Therefore, both houses belong to distinct groups, as can be observed in the group column where each one has a different letter, indicating a significant difference.

Silva, Gonzalez & Filho (2011) affirm that the use of windows provides better thermal comfort to the environment, as air enters and circulates inside, creating a cooling sensation in the residence due to its velocity, as stated by Gratia et al. (2004 as cited in Silva, Gonzalez & Filho, 2011) and Andreasi (2007 as cited in Silva, Gonzalez & Filho, 2011). Based on the authors' ideas, it is evident from the data analyzed in Table 3 that the house with a window had a lower internal temperature due to air circulation. Thus, it is clear that the use of the window was of utmost importance for maintaining a more pleasant and cooler temperature in the location.

Therefore, the use of windows in residential constructions is essential. However, it is important to pay attention to the master plan and building codes of each city when designing them, as they contain the required dimensions for lighting and ventilation openings for each room. For example, Article 70 of the master plan of Itajubá-Minas Gerais, in the complementary law number 100 (2019), provides the necessary requirements for openings in each room, described based on the sum of the areas of the openings of each room, as shown in proportion to the area of the location

## Conclusion

The conducted study demonstrated the efficiency of houses with windows in providing a better thermal sensation during hot periods, as evidenced by the statistical tests analyzed, where the mean and standard deviation between houses with and without windows allowed for the comparison of their values in these aspects. Additionally, the use of windows enables good air circulation, heat exchange, and dispersion of pollutants, which is extremely beneficial for human health and well-being, as it relies on natural resources.

Residences employing this method experience greater energy savings as they do not require the use of appliances such as fans or air conditioners to reduce indoor temperature. Consequently, reduced electricity consumption leads to lower energy bills, resulting in financial savings. Another favorable aspect is the reduced waste of natural resources, leading to less environmental impact. This way, the chances of overloading the electrical system are minimized, preventing occurrences like the 1999 blackout in the interior of São Paulo and the 2001 Brazilian energy crisis..

For houses lacking windows, the thermal sensation is warmer, around 1.5°C higher than those with an additional window, as proposed in the project, considering the prototype



size. In such settings, individuals perceive the environment as stuffy, which is extremely detrimental to health, as such places are more prone to respiratory and skin allergies, such as asthma, rhinitis, contact dermatitis, and other respiratory diseases due to air pollution, mold, and odors from confined spaces. Therefore, the living conditions become challenging.

It is worth noting, based on the conducted analyses, that factors such as climate and time of day also significantly influence the internal-external temperature difference. For instance, it was observed that a sunny day can increase the indoor temperature of the residence by an average of 5.8°C compared to the external temperature, which is, on average, 3.1°C higher than the second highest value found in the sample—clear sky with few clouds. Consequently, the variation of climate should also be considered in building designs.

Another significant factor that influenced the temperature gain was the data collection time. It was found that a house at 2 PM had an internal temperature 3.6°C higher than the external temperature, which is 1.3°C higher than the 6 PM time in the same situation. This aspect is relevant in residential projects to create models with minimal heat loss throughout the day, should one wish to retain this heat during the nighttime, or models with greater heat dispersion, if required for very hot regions, to maintain a more comfortable indoor temperature.

Therefore, it is important to highlight the benefits of conducting studies on buildings related to natural ventilation, allowing for the development of structural projects that maximize wind speed for environment cooling using windows and openings. Moreover, builders and designers should always be attentive to sustainable construction methods, aiming to better utilize the resources present in the environment, such as wind, to achieve a more comfortable thermal sensation and other benefits.

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