Comparison of methodologies for determining the thermal performance of houses with a concrete wall-type structural system

Comparação de metodologias para determinação do desempenho térmico de casas com sistema estrutural do tipo paredes de concreto

Comparación de metodologías para determinar el comportamiento térmico de viviendas con sistema estructural tipo muro de hormigón

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Abstract
The thermal performance of a building is an important factor in homes when it is concerned with offering the user the thermal comfort that the user is entitled to have. A building must be designed for the climate in which it is inserted in order to have a greater potential in providing thermal comfort, and still save energy. This work aimed to evaluate the thermal performance, according to the guidelines of the Brazilian Performance Standard NBR 15575 of a single-family building located in the city of Águas Belas-PE, Brazil. The evaluation of thermal performance was performed through two procedures present in NBR 15575: the simplified procedure and the computational simulation. As a methodology, an exploratory research and a case study were carried out. The evaluation through the simplified method was given by calculations of thermal transmittance and thermal capacity of the building envelope, that is, of the facade walls and roof. The computational simulation was performed using the EnergyPlus program, which with climatic information and a three-dimensional model of the building was able to test the climatic conditions on the building and determine its thermal behavior. The results obtained through the analysis by the two procedures previously mentioned were compared and analyzed according to the requirements of NBR 15575, were small divergences between them was noted. Computer simulation proved to be more effective when compared to the simplified procedure.
Keywords: Thermal performance; Computational simulation; Thermal comfort; Simplified process.

Resumo
O desempenho térmico de uma edificação é um fator importante em habitações quando se preocupa em oferecer ao usuário o conforto térmico que o mesmo tem direito a ter. Uma edificação deve ser projetada para o clima em que ela

está inserida para possuir um maior potencial em fornecer conforto térmico, e ainda economizar energia. Este trabalho teve como objetivo avaliar o desempenho térmico, segundo as diretrizes da norma brasileira de desempenho NBR 15575 de uma edificação unifamiliar localizada na cidade de Águas Belas-PE, Brasil. A avaliação do desempenho térmico foi realizada através de dois procedimentos presentes na NBR 15575: o procedimento simplificado e a simulação computacional. Como metodologia, foi realizada uma pesquisa exploratória e um estudo de caso. A avaliação através do método simplificado foi realizada pelo cálculo da transmitância térmica e capacidade térmica da envoltória da edificação, ou seja, das paredes de fachada e da cobertura. A simulação computacional foi realizada a partir do programa *EnergyPlus*, que com informações climáticas e um modelo tridimensional da edificação foi capaz de ensaiar as condições climáticas sobre a edificação e determinar o comportamento térmico da mesma. Os resultados obtidos através da análise pelos dois procedimentos anteriormente citados foram comparados e analisados conforme exigências da NBR 15575, sendo notadas pequenas divergências entre eles. A simulação computacional se mostrou mais efetiva quando comparado ao procedimento simplificado.
Palavras-chave: Desempenho térmico; Simulação computacional; Conforto térmico; Processo simplificado.

Resumen
El rendimiento térmico de un edificio es un factor importante en las viviendas cuando se trata de ofrecer al usuario el confort térmico al que tiene derecho. Un edificio debe estar diseñado para el clima en el que se inserta con el fin de tener un mayor potencial de proporcionar confort térmico y aún así ahorrar energía. Este trabajo tuvo como objetivo evaluar el desempeño térmico, de acuerdo con los lineamientos de la norma brasileña de desempeño NBR 15575 de un edificio unifamiliar ubicado en la ciudad de Águas Belas-PE, Brasil. La evaluación del desempeño térmico se llevó a cabo a través de dos procedimientos presentes en NBR 15575: el procedimiento simplificado y la simulación por computadora. Como metodología se realizó una investigación exploratoria y un estudio de caso. La evaluación mediante el método simplificado se realizó calculando la transmitancia térmica y la capacidad térmica de la envolvente del edificio, es decir, los muros de la fachada y el techo. La simulación por ordenador se realizó mediante el programa EnergyPlus, que con información climática y un modelo tridimensional del edificio fue capaz de probar las condiciones climáticas del edificio y determinar su comportamiento térmico. Los resultados obtenidos a través del análisis por los dos procedimientos mencionados anteriormente fueron comparados y analizados de acuerdo con los requisitos de la NBR 15575, notándose pequeñas divergencias entre ellos. La simulación por computadora demostró ser más efectiva en comparación con el procedimiento simplificado.
Palabras llave: Rendimiento térmico; Simulación computacional; Comodidad térmica; Proceso simplificado.

1. Introduction

One of the housing programs that Brazil has is the Minha Casa Minha Vida Program (MCMVP), created in 2009 by the Ministry of the Cities. Among all government programs, it is considered one of the largest, whether in terms of resources made available, but also in terms of coverage throughout the national territory (Moreno, 2013).

Due to the national energy crisis that occurred in 2001, Brazil started to be more concerned with energy savings. In this way, thermal performance standards began to be developed for all cases. Among them, NBR 15220 (ABNT, 2005), which establishes a Brazilian bioclimatic zoning contemplating various recommendations and constructive strategies and NBR 15575 (ABNT, 2021), thermal performance standard for buildings containing up to five floors, among other areas that it addresses.

In the design phase of a building, whether large or medium, the use of natural ventilation has been a tool to minimize high temperatures in countries like Brazil, for example. Computational analysis is one of the most used methods for studying ventilation behavior in buildings (Morais & Labaki, 2017).

Thus, this study aimed to evaluate the thermal performance of single-family buildings of social interest, such as concrete walls, located in the city of Águas Belas-PE, bioclimatic Zone 8 of Brazil. Two procedures established in NBR 15575 (ABNT, 2021) were used, the simplified process and the computer simulation. For the second case, the *Energyplus* program was used.

The research is justified by the fact that the thermal comfort of a residence is something basic that every user of the residence must have. Thus, the intention was to analyze the thermal performance based on the norm of these houses with the natural ventilation of the region where they were built.

2. Literature review

2.1 Concrete walls

Due to the increase in real estate activities due to the "Minha Casa Minha Vida" housing program, construction companies began to seek economic and productive construction systems, without compromising the quality and performance of buildings. The construction method with reinforced concrete walls has been a viable alternative for this type of enterprise. It presents advantages in terms of deadlines, costs and quality, being a constructive system that presents speed of execution and optimization of finish and labor much better compared to other methods on the market. Therefore, companies that have entered the housing market have chosen this method instead of other construction methods (Gaywala & Raijiwala, 2011).

For the NBR 16055 (ABNT, 2012), the structural elements that have the self-supporting potential molded in loco have a length ten times greater compared to its thickness. That is the definition of concrete walls. The final result of concreting is a structure with no apparent joints that is capable of distributing efforts in all areas of application, thus characterizing a monolithic reinforced concrete structure (Góes, 2013).

Even though this construction method can be used in any type of construction, the economic factor is what determines its viability. Thus, it is necessary to evaluate the number of uses of the forms, which is the determining point in the final cost and, consequently, in the attractiveness of choosing the concrete walls molded in loco (Corsini, 2011).

According to Tutikian (2008) and Tutikian and Molin (2015), concrete walls are commonly produced with self-compacting concrete. Also, the concrete must be well dosed, so that its properties in the anhydrous, fresh and hardened states must be well known and designed (Mehta & Monteiro, 2008). The walls and slabs must be concreted at the same time. After removing the molds, walls are ready to receive the final finish. Thus, the pipes and conduits are already embedded in them, in addition to in some cases specific elements and the windows and doors (NBR 16055, 2012).

Even though it is a standardized method, thus having an order to follow, the execution of concrete walls can change from company to company, depending on the construction process that each one adopts, as an example the items that can vary are, types of concrete used, type formwork and the closing and shoring of the material (Venturini, 2011).

The standard NBR 16055 (ABNT, 2012) recommends that the shapes of concrete walls are designed in such a way that they present: resistance to stresses during the execution process, such as environmental actions, temporary structure loads and accidental effects that may be caused by logistics of launching and densification of concrete; adequate rigidity to guarantee the project specifications, in addition to the integrity of the structural elements, at most keeping within the tolerances provided for in that same standard; tightness and conformity of the geometry of the parts that will be molded with it.

The choice of the type of form will depend on how many times it will be used, the degree of repetition, the quality required, both in the finish and in the structural part, thickness of the walls and the thrust generated by the weight of the concrete. Steel forms are generally used, in view of their durability. There are also wooden and plastic forms. It is emphasized that a study must be carried out to identify the availability of the shapes in the construction region where it will be used.

2.2 Thermal performance of structures

Considering the need to improve thermal comfort in homes due to the recurrence of unsatisfactory performances with increased energy consumption, many researches have been carried out in the area of new materials and components for walls and roofs, including the coupling of materials such as thermal insulation and even waste.

Moreno (2013) notes that the building executions of social interest programs always take place in series. Thus, there is little concern about the particularities of the region where this building is being built. For example, care regarding the adequacy of the project according to the climate of each region. Thus, what can happen is that the performance of these homes is lower than the minimum values required by NBR 15575 (ABNT, 2021).

2.2.1 Features

Lamberts (2011) states that air velocity is a parameter defined by its magnitude and direction. When referring to thermal environments, what is taken into account is the effective air velocity, that is, the magnitude of the flow velocity vector at the considered measurement point. According to NBR 15220 (ABNT, 2005), the relative humidity of the air is the "quotient of the absolute humidity of the air by the absolute humidity of the saturated air for the same temperature and atmospheric pressure".

According to Roriz (2013), the main variables that interfere with the thermal behavior of a structure are the characteristics of the architectural project, that is, its position in relation to the sun, the size and positioning of the openings and also the materials used in the construction. In the case of materials, the variation will depend on the thermal properties, the thermal capacity, the thermal transmittance and also the sun.

2.2.2 Brazilian standards regarding thermal performance

NBR 15575 (ABNT, 2021) is the standard that defines the mandatory minimum performance requirements for building systems, taking into account the needs of its users and the conditions that are exposed in a building, throughout its useful life. Thus, thermal performance is one of the quality requirements, with the criteria for assessing internal temperature in the summer being taken as the maximum values and, in the winter, the minimum values.

This standard deals with the thermal performance of buildings. It is divided into five parts. In the second part, it deals with the methods of calculating the thermal properties of the closings of a building. In the third part, it deals with Brazilian bioclimatic zoning, demonstrating the minimum design requirements in order to provide thermal comfort in single-family homes of social interest in all Brazilian bioclimatic zones.

Carvalho (2014) states that in the design phase it is extremely important to have knowledge about the climate, geography and the location where the projected building will be built. This is because these are the variables that will interfere with the thermal behavior of the residence, thus generating thermal discomfort or comfort to users.

In the case of openings for ventilation, NBR 15575 (ABNT, 2021) determines that they must have adequate dimensions to provide internal ventilation over some of the rooms in the residence. This requirement applies to environments that have a long stay, such as living rooms, kitchens and bedrooms.

2.2.3 Thermal performance in homes

Givoni (1962) did an important job that even today contributes a lot to studies related to natural ventilation in the internal environment. He presented a study on the effects of external air speed on the average air speed inside the building, using experiments in a wind tunnel with a reduced model of a room with openings in opposite walls simulating cross ventilation. The author considered three directions of incident wind in the opening and varied the sizes of the openings, always obtaining as a result the use of the wind (percentage of average speed obtained internally in relation to the incident wind at the same height). This idea can characterize the best geometric points of the openings in order to have energy efficiency and thermal comfort.

The construction site of the houses under analysis in this work has specific climatic characteristics, where according to the National Institute of Meteorology - INMET, the period of drought between the months of June to November stands out, when the precipitation is reduced and high temperatures are observed and also high relative humidity.

For Lamberts *et al.* (2014) when all these factors mentioned above work together, they cause thermal discomfort to the building user. Thus, the user feels the need to seek thermal comfort in his home by means of electronic equipment, such as a fan and air conditioning, which consequently increases the consumption of electricity, generating more costs. Situation that could have been avoided if a thermal performance study had been carried out on the building during the design phase. Yudong *et al.* (2012), states that the residential sector is the one that consumes the most electricity in the world, causing social, economic and also environmental damage.

According to the World Business Council for Sustainable Development - WBCSD (2007), the knowledge and technologies that are known can eliminate this problem and still improve the comfort indexes of the home. Thus, measures aimed at reducing the use of electrical refrigeration and/or ventilation equipment are important across the country, transforming building components and building systems into ideal opportunities to assist in such a reduction. Even more because one of the basic functions of single-family homes is the environmental comfort of its users, which is an indispensable parameter in the design of the project and which must be ensured throughout its useful life.

2.2.4 Natural ventilation

According to Izard and Guyot (1980), as well as Lukiantchuki (2015), there are at least three reasons for promoting the ventilation of the environments: maintaining healthy conditions, contributing to thermal comfort and cooling the building's internal structures through thermal exchange between air and walls.

Ventilation is a natural cooling strategy through the renewal of air in the built environment. In summer, the main purpose of ventilation is to increase the dissipation of human heat by convection and evaporation to achieve a feeling of comfort. Ventilation can improve the thermal sensation if the interior temperature exceeds 29°C or the relative humidity exceeds 80% (Lamberts *et al.*, 2014).

The ventilation required for summer comfort depends on other environmental variables (average radiant temperature, indoor air temperature, among others), since thermal comfort is related to the dissipation of heat that the human body is producing and what is eventually receiving from the environment by convection and / or radiation (Pereira, 2019).

Design strategies must be used to ensure the natural ventilation of the environment, keeping it comfortable. In planning the ventilation of a building, the following project resources can be highlighted: adapting the shape and orientation of the building to the dominant breeze to produce crossed air currents; designing fluid spaces; facilitate vertical ventilation; use elements to direct the air flow inwards and check the influence of the positioning of the openings on the facades (Rodrigues, 2008). Among the architectural solutions commonly used, cross ventilation is provided by openings in opposite (or different) walls with pressure differentials caused by the action of the wind.

Montenegro (1984) points out that in order to obtain a good circulation of natural ventilation in a residence, it is necessary that both the outlets and the air inlets are well located. In the case of the entrance, it is recommended that it is located in the lower parts of the environment. And the exit on the opposite side, that is, at the top of the building. In this way, there will be good air circulation and good thermal performance.

The main reason for residences located in regions of Brazil that have a tropical climate to experience thermal discomfort is due to the poor positioning of the ventilation openings and also the great solar radiation that exists in that region. The lack of concern about thermal comfort on the part of some designers is also a sad reality.

Through the use of brise-soleils, cobogó walls and vegetation, the building surfaces can be protected from direct solar radiation. The control of the glazed areas is essential and must be different for each orientation. For the climatic conditions of a tropical country in the southern hemisphere, the north façade must be protected by horizontal sunshades, because on this façade there will be predominantly horizontal and elevated solar paths.

2.3 Heat transfer

Heat transfer procedures in an environment are necessary to keep it thermally pleasant. This exchange varies according to each component, as there is a variation from material to material. The properties of the building elements must be understood for the analysis of the thermal performance of the building in question. The known mechanisms are thermal conductivity, total thermal resistance, thermal transmittance and thermal comfort.

According to NBR 15220 (ABNT, 2005) thermal conductivity can be expressed as a physical property of a homogeneous and isotropic material, which presents a constant heat flow, with a density of 1 W/m², when exposed to a temperature gradient of 1 Kelvin per meter. In other words, it is nothing more than the ability of a material to conduct heat in regions with high temperatures. It has unit of measurement W/(m².K).

The total thermal resistance is characterized as the sum of the thermal resistances of all the layers that constitutes an element with the surface thermal resistances. They are related to the air layers close to the surfaces, whether internal or external of the same element, which are responsible for heat transfers. And its unit of measurement is W/(m².K), according to NBR 15220 (ABNT, 2005). NBR 15220 (ABNT, 2005) defines thermal transmittance as the "Inverse of total thermal resistance" and is represented by the unit W/(m².K). Thermal comfort is a very important factor that must be present in all Brazilian homes as an essential condition for its users. Therefore, it is necessary that in all constructions it is thought about in the design phase, taking into account the current rules that regulate all the procedures to be analyzed to obtain this condition.

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2013) defines thermal comfort as being the state of mind that brings satisfaction with the thermal environment that the individual occupies. Thus, the lack of this condition can result in mood swings and even prevent the individual from being able to perform some functions in that environment due to the discomfort generated by the absence of thermal comfort.

According to Lamberts (2011), studies carried out in the area of thermal comfort seek to carry out an analysis, in addition to dictating what are the basic conditions for an assessment. It also guides ideas for the design of a comfortable environment for human activities. And yet, to establish the main methods to be observed in the thermal performance analysis.

Kroemer and Grandjean (2005) affirm that it is difficult for a person to notice the climate of the interior of a room while occupying it, as long as it provides a pleasant climate. Thus, the more uncomfortable the climate provided by the environment, the more it will attract the attention of the occupants and may even cause changes in the functions of the human body. Overheating, for example, can cause tiredness and drowsiness, as well as reduced physical performance.

3. Methodology

The research in question is about the thermal performance of houses with the construction system of concrete walls located in the harsh Pernambuco. It can be classified as exploratory research, which according to Gil (2017), provides greater familiarity with the problem. It may involve bibliographic surveys, interviews with people experienced in the researched problem. It usually takes the form of bibliographic research and case study.

Initially, a bibliographic search was carried out, with the objective of gathering data and information, which will serve as a foundation for the construction of the proposal (Gil, 2017). It covered topics such as concrete, concrete walls, thermal performance of structures, natural ventilation and heat transfer.

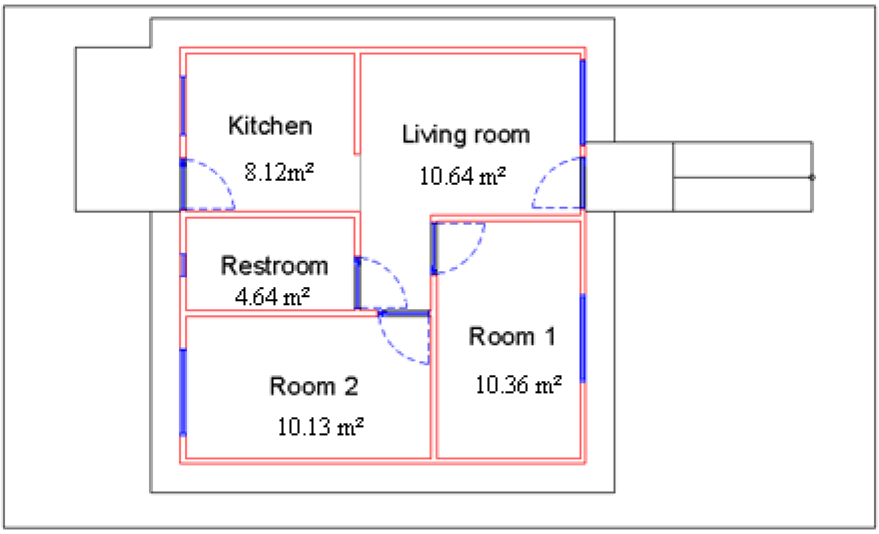
To perform the numerical analysis, NBR 15575 (ABNT, 2021) was taken as the basis. As the standard itself indicates the program, EnergyPlus was used and Sketchup 2017 was used to model the building together with open Studio 2.3.0. The studies by Silva (2015) and Moreno (2013) were also taken as a basis.

As a technique, a field study was carried out, which according to Gil (2017), is carried out through direct observation of the activities of the studied group and interviews with informants, seeking to obtain the explanations and interpretations that occur in that reality. The data for analysis were obtained from a work located in the harsh Pernambuco, northeastern Brazil, plants from the housing plot were collected that served for the study in question.

3.1 Sample characterization

The material for analysis of this work was a residence belonging to a housing complex, located in the harsh Pernambuco, northeastern Brazil. A representation of the residence's floor plan can be identified in Figure 1.

Figure 1. Floor plan of the analysis residence.



Source: Authors (2021).

As the city in which the residence is located is not in the bioclimatic zones of NBR 15220 (ABNT, 2005), it recommends that you collect data from a nearby city that has a similar climate. The chosen city was Ibimirim-PE, which is located in Zone 8. The residence has only one ground floor, built in 2020, has approximately 50.4 m² of built area.

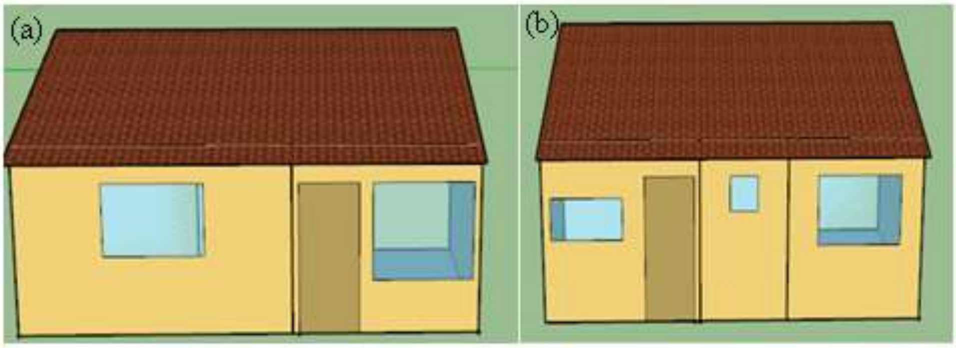
The construction was carried out through construction systems of concrete walls and roofing with ceramic tile. The characteristics of each building element of the building will be presented below.

The model was built by defining the thermal zones of each environment as an isolated zone, that is, closed, thus presenting a unique thermal behavior. Zones were defined for the environments that would be analyzed, which are those of long stay, being the living room and the two bedrooms, thus totaling 3 thermal zones.

As already mentioned, all the analysis environments were molded according to the specifications and characteristics of the residence's floor plan. Another configuration was that it did not consider the existence of heat exchanges between the thermal zones as recommended by NBR 15575 (ABNT, 2021), due to the fact that the environments present the same thermal conditions.

Then, the windows and doors of the house were inserted, they were placed as transparent openings, in the case of windows and opaque, in the case of doors. In Figure 2, the three-dimensional model of the residence, front view, can be seen.

Figure 2. Front view of the three-dimensional model



Source: Authors (2021).

Analyzing the three-dimensional model above, it is noted that the residence has large openings in both the living room and the bedroom Figure 2 (a). These openings will provide natural ventilation, thus making these environments comfortable. In Figure 2 (b), there is a view of the back of the residence, where it is possible to observe the presence of the window of the second bedroom. Looking Figure 2 (b), it can be seen that the second room also has a large window, thus allowing natural ventilation.

3.2 Evaluation of thermal performance

The thermal performance of the building was carried out in accordance with the characteristics expressed in the floor plan and with the data of the location of the residence. Just as the work is a case study, it is important not only to express the characteristics of the property, but also to detail the methods on which it was evaluated.

3.2.1 Evaluation according simplified procedure

As parameters of analysis, the thermal transmittance and thermal capacity were used to evaluate the roof and facade wall of the residence, according to NBR 15220 (ABNT, 2005). And also, the values of all the thermal properties of the materials that make up these elements were taken from this same standard.

In the calculation of the coverage, only one parameter was verified, which was that of thermal insulation, by means of the value obtained from the thermal transmittance. In the building's facade walls, the two analysis parameters mentioned above, thermal transmittance and thermal capacity, were taken into account. According to the values obtained, through them it is possible to verify the comfort that the residence provides to its occupants in the analyzed environments.

Another assessment that the standard requires in this process is regarding the vertical sealing system, both internal and external. In this case, the method of assessing the minimum ventilation area was used, calculated by the following Equation 1.

$$A = 100.\left(\frac{Aa}{Ap}\right)(\%) \quad \text{(Eq. 1)}$$

Where:

Aa = Represents the value of the area of the openings intended for ventilation, so all areas that prevent this wind circulation should be disregarded. For example, the windows and window parts that are closed.

Ap = is the floor area of the room.

For the Bioclimatic Zone 8, where the residence under study is located, the area required to obtain a minimum performance is A ≥ 8%.

3.2.2 Evaluation according to computational simulation

For the evaluation of thermal performance through computational simulation, a three-dimensional model of the residence was built using SketchUp Pro 17.0 which could be simulated later using EnergyPlus software version 8.4. The connection between the graphical interface and the simulator was made through Legacy OpenStudio SketchUp Plug-in 2.3.0.

3.2.3 Simulation boundary conditions

After finishing the modeling in the SketchUp, the necessary settings for the simulation in the EnergyPlus were made. The first configuration was the insertion of the climate file for the city of Ibimirim-PE. As previously mentioned, the city in which the residence is located does not have these data on the website, so a nearby city with similar climatic conditions was chosen in the program, made available by the Energy Efficiency in Buildings Laboratory - LabEEE. This climate file is the result of measurements made by the Meteorological Institute (INMET), linked to some climate data conversion calculations.

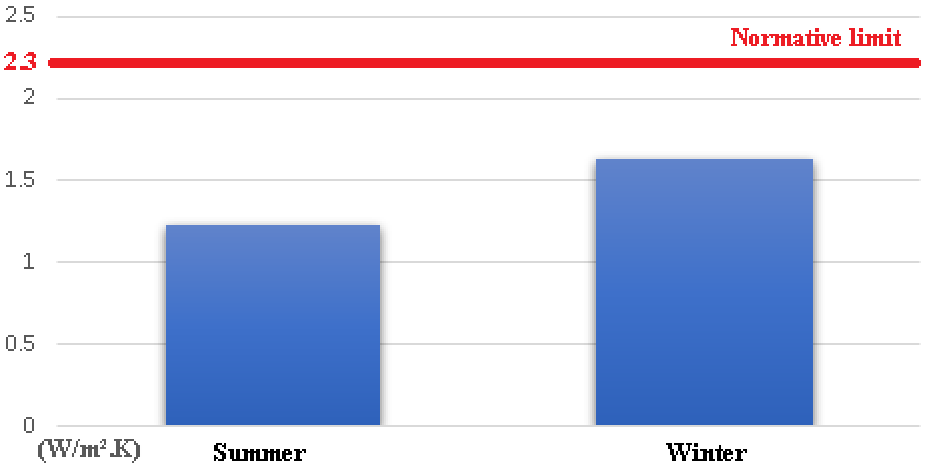
For the infiltration configuration, an air renewal rate of 1ren / h was considered. There was no need to simulate again, as the building performed satisfactorily in accordance with the requirements of the standard.

4. Results and Discussions

4.1 Results of the simplified procedure

According to item 11 and its subsequent of the NBR 15575 (ABNT, 2021) (Simplified Procedure) and with the adopted materials, it was possible to calculate the values of thermal transmittance for the covering system and facade walls, as well as the thermal capacity values for facade walls. In the case of the roofing system, the calculated thermal transmittance value was 1.63 W/(m².K), for winter (upward flow) and 1.23 W/(m².K), for summer (downward flow), thus respecting the maximum value established in NBR 15575 (ABNT, 2021) of 2.3 W/(m².K), for the Bioclimatic Zone 8, where the residence is located. Thus, it can be said that both are meeting the minimum requirement required by the standard (Figure 3).

Figure 3. Thermal transmittance values calculated for winter and summer for the roof

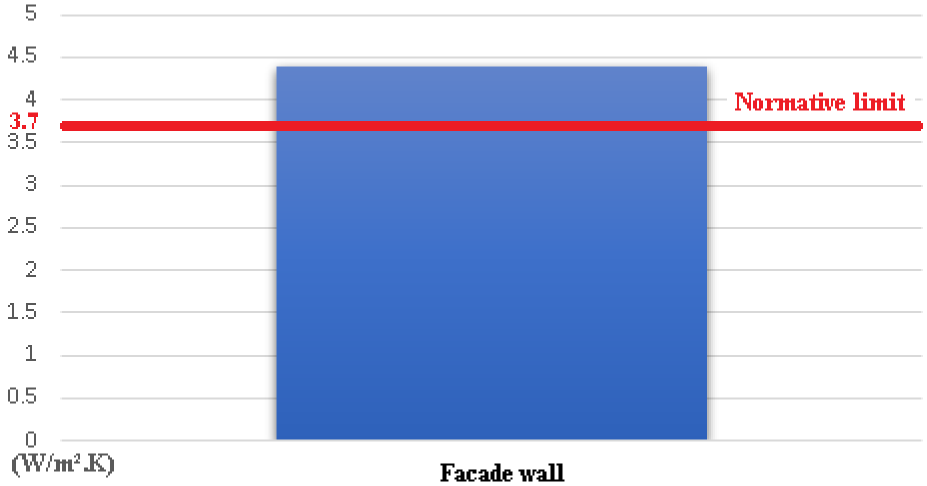


Source: Authors (2021).

When looking at the Figure 3, it is clear that in both seasons the roof of the building presented a minimum acceptable performance in accordance with the requirements. This provides adequate thermal comfort for the region in which it is located.

However, for the calculation referring to the facade walls, the calculated value of thermal transmittance was 4.40 W/(m².K), being higher than the maximum limit established in NBR 15575 (ABNT, 2021) of 3.7 W/(m².K), presenting an unsatisfactory performance to what the standard requires (Figure 4).

Figure 4. Thermal transmittance values calculated on the walls.



Source: Authors (2021).

Observing Figure 4, it can be seen that the facade walls do not meet the thermal performance criteria established by the standard through the simplified procedure. Table 1 shows the results obtained through the calculations performed previously.

Table 1. Results of the evaluation using the simplified procedure.

Construction system	Criterion evaluated	Values (W/m². K)		Performance
		Calculated	Required	
Roof (summer)	Thermal transmittance (W/(m².K))	1.23	≤ 1.5	Intermediate
Roof (winter)		1.63	≤ 2.3	Minimum
Facade Walls		4.40	≤ 3.7	Unsatisfactory

Source: Authors (2021).

It can be seen that the residence presented a minimum acceptable performance in coverage when considered the same in winter, in summer it has an intermediate performance, which is better than the minimum performance. However, the façade walls resulted in an unsatisfactory performance, thus making it necessary to perform the computer simulation that will make a more complete and accurate analysis to see if the façade really presents an unsatisfactory performance or not.

As for the assessment to the minimum ventilation area in the long-stay rooms, the results obtained are in the Table 2.

Table 2. Summary of calculated areas in the environments.

Environment	Calculated area	Required area	Performance
Living room	19.03%	≥ 8%	Minimum
Room 1	14.80%		Minimum
Room 2	14.48%		Minimum

Source: Authors (2021).

Based on the values obtained from the areas calculated in the long-stay environments, it can be said that in all three locations that were analyzed, it resulted in minimum performance in terms of the requirements of the standard. Thus, it is clear that the building was well designed for the region where it is located, as large openings for ventilation were used.

4.2 Results of computational simulation

The building was simulated for typical summer days, as recommended in NBR 15575 (ABNT, 2021). Since the residence is located in the bioclimatic Zone 8, the standard makes no requirement regarding analyzes for typical winter days. It should be simulated paying special attention to the bedrooms and living room, as they are long-stay environments. Initially, simulations were carried out with an air renewal rate equal to 1 ren/h, for both summer and winter. When analyzing the results, he did not notice the need to simulate again and increase the rate of air renewal, since the results obtained were satisfactory.

Before proceeding to the analysis of the results obtained, Table 3 shows the withdrawal of NBR 15575 (ABNT, 2021), which denotes the conditions for the residence to have a minimum performance acceptable by the standard. It is from these requirements that the analysis of the data obtained will be carried out.

Table 3. Criteria for evaluating thermal performance for summer conditions.

Level of performance	Criterion	
	Zones 1 a 7	Zone 8
M	Ti, máx ≤ Te, máx	Ti, máx ≤ Te, máx

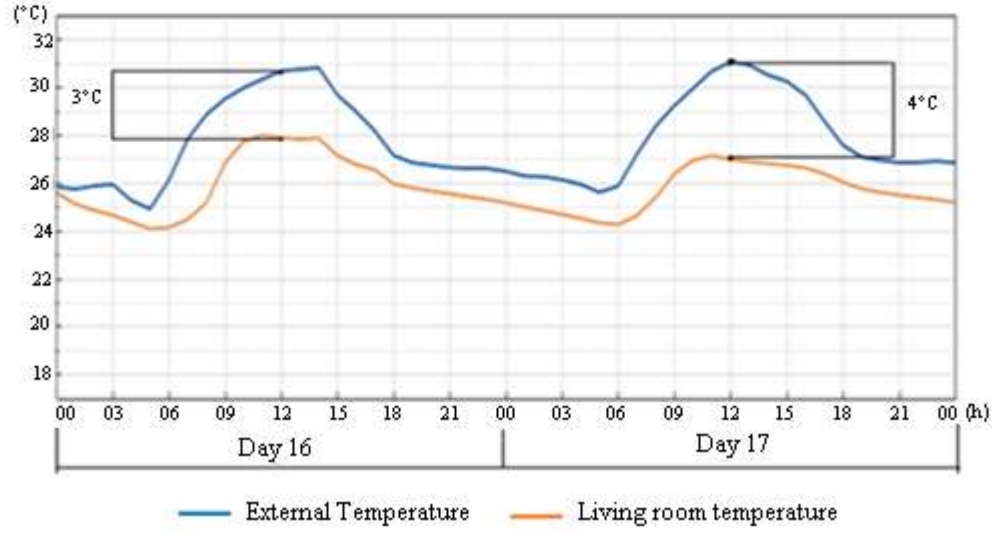
Ti, máx is the maximum daily value of the air temperature inside the building, in degrees Celsius;
Te, máx is the maximum daily value of the air temperature outside the building, in degrees Celsius;
Ti, min is the minimum daily value of the air temperature inside the building, in degrees Celsius;
Te, min is the minimum daily value of the air temperature outside the building, in degrees Celsius;
NOTE: Bioclimatic Zones according to NBR 15220 (ABNT, 2005).

Source: NBR 15575 (ABNT, 2021).

The zone in which the city of residence is located is Zone 8, so to obtain minimum performance according to the standard, it is necessary that, in the worst case, the internal temperature of the environments is equal to the external temperature.

The results will be presented room by room for a better understanding of the situation of each one on typical summer days. The 16th and 17th of December were chosen as the typical summer day to carry out the analysis. In Figure 5, it is possible to observe the behavior of the Living Room throughout the day on the chosen date.

Figure 5. Simulation for a typical summer day in the Living Room.



Source: Authors (2021).

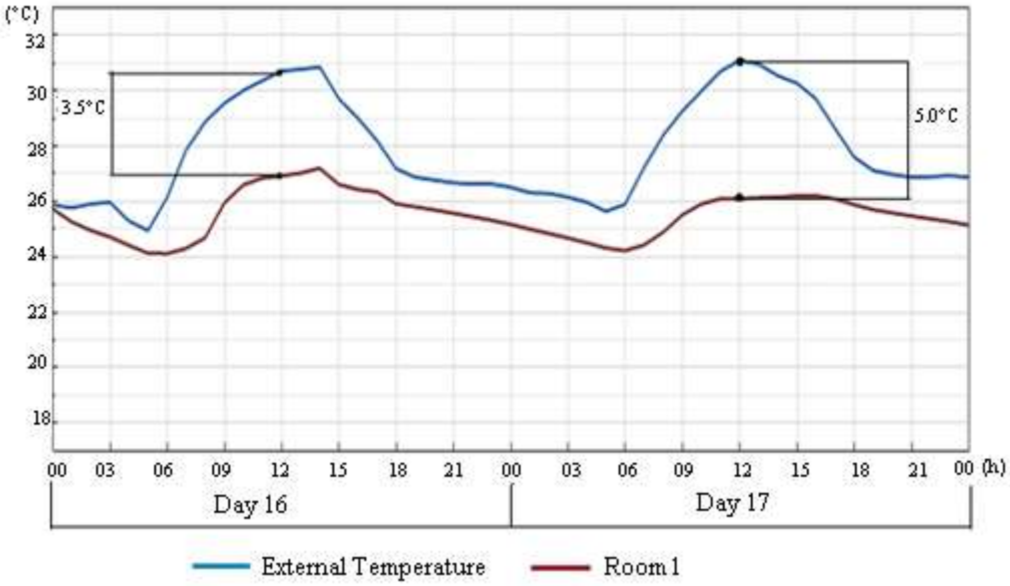
The figure above represents all temperatures for the 16th and 17th of December in the Living Room. The blue line is the temperature outside the room and the orange line refers to the internal temperature. It is noted that throughout the day and night the temperature of the room is lower than the outside temperature, thus achieving a minimum performance in accordance with the requirements of the standard, making the environment comfortable thermally speaking.

Another point to highlight is the difference in temperature at 12 o'clock, usually a time when there are high temperatures. In this case in question, there was a difference of 4 °C between the living room and the external environment. In this way, the living room has a performance that exceeds the requirement of the standard.

If the calculated performance does not meet the minimum requirements of the standard, it recommends performing the simulation again, this time increasing the rate of air renewal to 5 ren/h and maintaining the residence in the same way. However, in this case it was not necessary.

Then there is the simulation result for Room 2, which is located next to the living room. Both have openings facing north, so it is expected to show similar results because they receive the same ventilation and almost the same opening area. In Figure 6, the result of the simulation of Room 2 in relation to the external environment is observed.

Figure 6. Simulation for a typical summer day in Room 2.



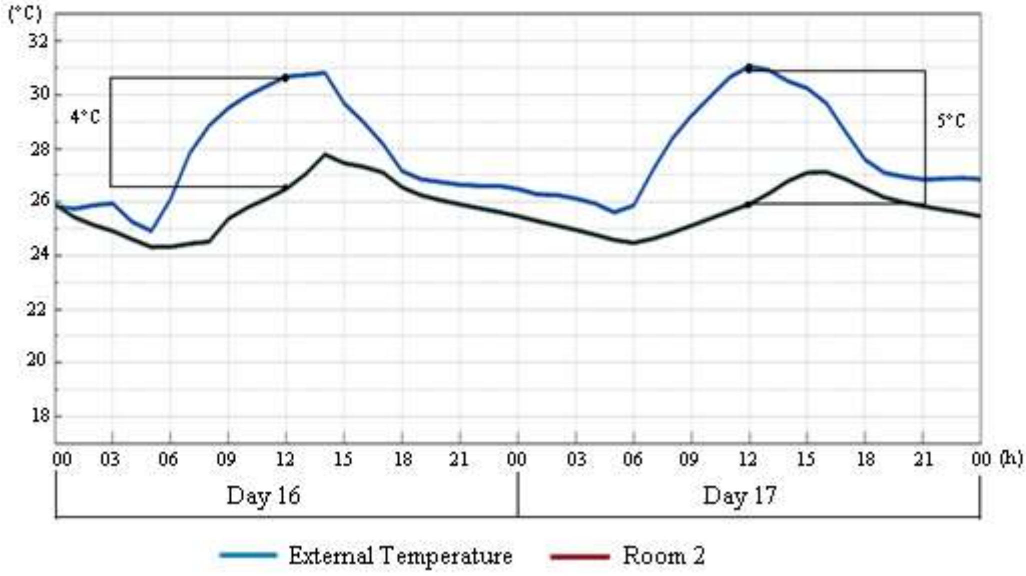
Source: Authors (2021).

The Figure 6 represents all temperatures as a function of time on the 16th and 17th of December, the blue line represents the temperature in the external environment and the brown line represents the temperature inside the social room. It is noticed that during both days the internal temperature was lower than the external temperature, thus making the environment pleasant thermally. Thus, it has the minimum performance required by the standard. It is not necessary to simulate again by increasing the rate of air renewal.

Once again, the times when there is a greater temperature difference between the environments, is in the morning, a result similar to what was obtained in the living room, as had already been predicted, the small difference between them, is due to the fact that the opening of the living room has a larger area. During the night, which is the time when this environment will have the greatest use, there is an average difference of 2 °C. Thus, it can be said that the room has adequate thermal comfort.

In the case of Room 1, it is possible that it will present results slightly different from Room 2, considering that they are positioned geographically opposite, while one is facing north, the other facing south. Thus, they will not receive the same ventilation throughout the year. In Figure 7, the temperature results for Room 1 are shown.

Figure 7. Simulation for a typical summer day in Room 1.



Source: Authors (2021).

Figure 7 represents all temperatures as a function of time on the 16th and 17th of December, the blue line represents the temperature in the external environment and the black line represents the temperature inside Room 1. During both days, the internal temperature was lower than the external temperature, thus making the environment thermally pleasant. Thus, it has the minimum performance required by the standard. It is not necessary to simulate again by increasing the rate of air renewal.

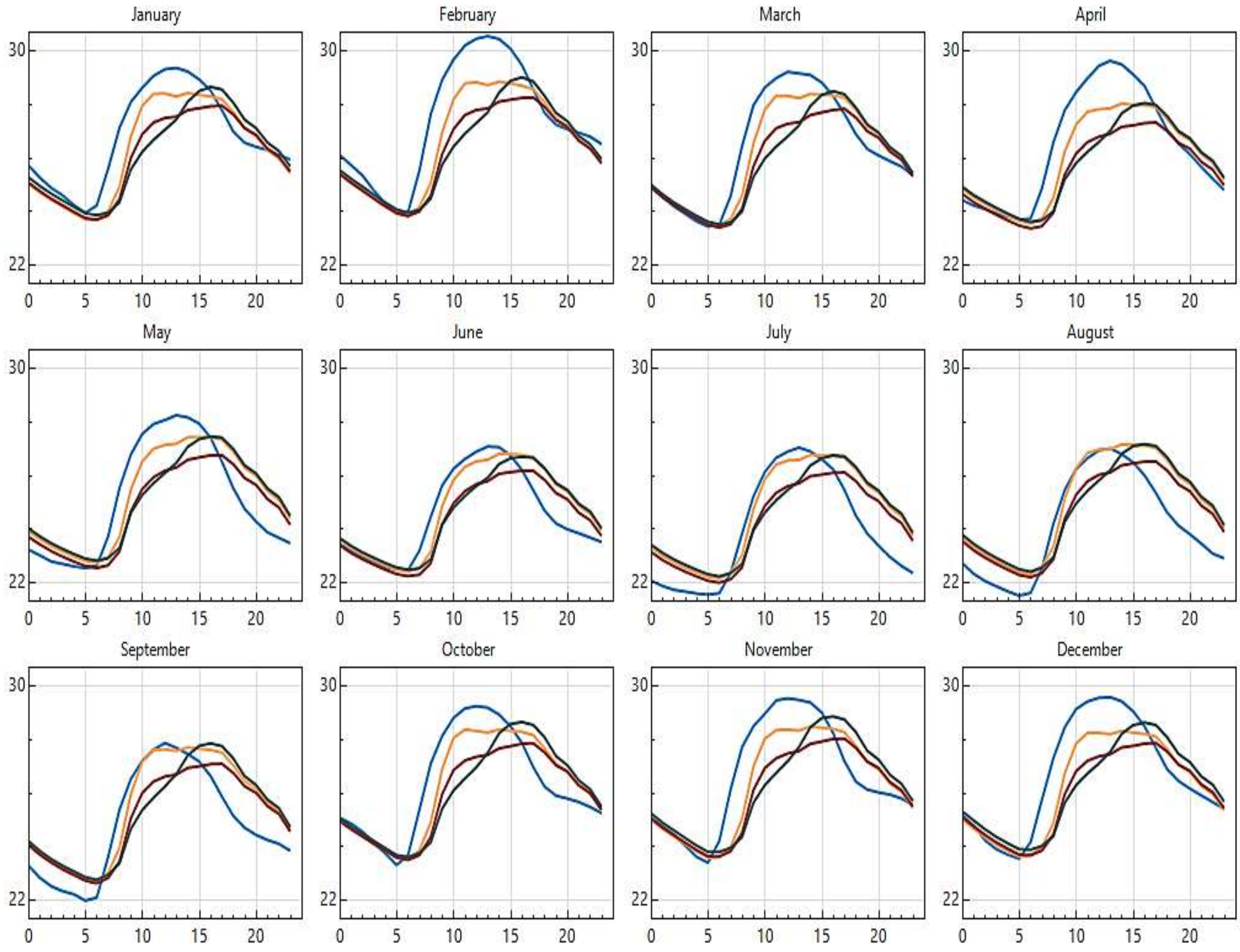
Again, the time when the greatest temperature difference occurred was in the morning and early afternoon, from 6 am to 3 pm, on both days. However, in this room it has changed a little compared to the other two mentioned above, when observing the late afternoon and all-night hours. It is noted that the difference between the temperature of the internal and external environments is smaller, when compared with the results obtained with the living room and the other bedroom.

This is due to the fact already mentioned earlier that the opening of this room faces the opposite side of the other two environments. Thus, the ventilation that arrives at this window is different, causing it to have a higher temperature when compared to other long-lasting environments. But even so, this room presented a minimum performance in accordance with the requirements of the standard, thus containing adequate thermal comfort for its users.

It is worth mentioning once again that it is not necessary to analyze the typical winter days for this bioclimatic zone, according to the norm.

In Figure 8, you can see a summary of the temperature behavior throughout the year, not just on typical days. This simulation is not required by the standard, but was performed as additional information.

Figure 8. Temperatures throughout the year, typical days of each month, depending on the hours of the day.



Source: Authors (2021).

In Figure 8, the colors of the lines representing the long-stay environments are the same as those used in the other graphs. Pay particular attention to the months of December, January, February and the beginning of March, as they are the summer season. When analyzed, it is possible to notice that on all typical days of each month the temperature presented an acceptable value according to the requirements of NBR 15575 (ABNT, 2021). It is cooler than the outside during the day and a little warmer in the evening to provide a better night's sleep, thus featuring pleasant thermal comfort.

Another situation to note is the winter months, June, July, August and September, which are the coldest months for the study region. It was realized why in this bioclimatic zone it is not necessary to carry out the simulation for the winter, since in every month the building presented a minimum performance in accordance with the requirements of the standard.

4.3 Comparison of results

During the simulation by the simplified process method, the facade wall did not obtain minimum thermal performance in accordance with the requirements of the standard, thus making it necessary to carry out an analysis by the computer simulation method as it is more accurate and demonstrates the temperature behavior in the environments.

When performing the computer simulation of the long-stay environments, he obtained a different result to that calculated in the simplified process. In the simulation, the entire residence presented minimum thermal performance according to the requirements of the standard, as can be seen in Table 4.

Table 4. Comparison of the results of the two processes.

Criterion adopted	Simplified process	Computational simulation
Requirement of the NBR 15575	Walls: U ≤ 3.7 W/(m².K)	Summer: Ti, máx. ≤ Te, máx.
Results obtained	Roof (summer): U = 1.23W/(m².K) Walls: U = 4.40 W/(m².K)	All environment presented: Ti, máx. ≤ Te, máx
Analysis of thermal performance	Roof: Minimum Walls: Unsatisfactory	- Minimum performance

Source: Authors (2021).

Thus, it is noted the importance of performing computer simulation, as it brings a more complete analysis of the situation and with more reliable data. Being safer with reality and accurate in the data, making it possible to even make changes, if this analysis was carried out in the construction design phase, to obtain adequate thermal comfort.

In addition, the results corroborate the research by Moreno (2013) and Silva (2015), where the effectiveness of using these methodological procedures in the characterization of the thermal performance of a building is verified.

5. Final Considerations

The results showed small divergences. When evaluated by the simplified procedure, it would be used for the roof, thus not requiring computational analysis of the same, since in the case of the facade wall it did not meet the specifications of the standard, thus making it necessary to perform the computer simulation of the same.

When this computer simulation was performed, the results obtained demonstrated that the entire residence has a minimum acceptable thermal performance, according to the requirements proposed by the standard. Thus, contradicting the results obtained in the calculations of the simplified process, which denotes the importance of computational simulation. Thus, it is noted the importance of performing computer simulation, which brings more accurate results, with more reliable data than the other process. For the case in question, its thermal performance was approved according to NBR 15575 (ABNT, 2021).

According to these results, it is clear that the simplified procedure can be a quick, low-cost and accessible tool. However, it can present some uncertainties in its results, considering that there was a divergence in them even when compared to the computer simulation.

Computational simulation, on the other hand, is a little more complex and time-consuming, as it requires knowledge of the EnergyPlus, SketchUp programs and appropriate computational tools. This makes it more complicated to perform, but also possible.

This research brings an important contribution in what is said to clarify the issue of thermal performance in construction with execution of concrete wall in social housing. It makes possible the appropriate use of this constructive method and also the improvement of comfort conditions in this constructive modality. It allows the reduction of expenses with electricity, extra equipment such as air conditioning, which would assist in the search for thermal comfort.

As suggestions for future works, there is the possibility of analyzing the thermal performance in other housing complexes located in the countryside of Pernambuco, as well as making this analysis for different types of construction systems, such as structural masonry and conventional masonry.

References

ABNT - Associação Brasileira de Normas Técnicas. (2012). *NBR 16055: Paredes de concreto moldadas no local para a construção de edificações – Requisitos e Procedimentos*. Rio de Janeiro, Brasil.

ABNT - Associação Brasileira de Normas Técnicas. (2021). *NBR 15575-1: Residential buildings - Performance Part 1-1: Standard database of weather files for the evaluation of thermal performance using the computer simulation procedure.* Rio de Janeiro, Brazil.

ABNT - Associação Brasileira de Normas Técnicas. (2005). *NBR 15220: desempenho térmico de edificações – parte 2: métodos de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator solar de elementos e componentes de edificações.* Rio de Janeiro, Brasil.

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2013). *Standard 55-2013: Thermal environmental conditions for human occupancy,* Atlanta, EUA.

Carvalho, R. C. (2014). *Cálculo e detalhamento de estruturas usuais de concreto armado: segundo a NBR 6118:2014*. (4a ed.), EDUFSCAR.

Corsini, R. (2011). *Paredes normatizadas*. Nº 183¸ Téchne.

Gaywala, N. R. & Raijiwala, D. B. (2011). Self-compacting concrete: a concrete of next decade. *Journal of Engineering Research and Studies*, vol. II, Issue IV, 213-218. Retrieved from https://www.technicaljournalsonline.com/jers

Gil, A. C. (2017). *Como elaborar projetos de pesquisa*. (6a ed.), Atlas.

Givoni, B. (1962). *Basic Study of Ventilation Problems in Houses in Hot Countries.* Israel: Building Research Station of the Institute of Technology. Retrieved from https://www.worldcat.org/title/basic-study-of-ventilation-problems-in-housing-in-hot-countries-final-report/oclc/4526741

Góes, B. P. (2013). *Paredes de Concreto Moldadas "in loco", Estudo do Sistema Adotado em Habitações Populares*. Monografia (Graduação em Engenharia Civil) – Universidade Federal do Rio de Janeiro, Rio de Janeiro. Retrieved from repositorio.poli.ufrj.br/monografias/monopoli10008999.pdf

Izard, J. L. & Guyot, A. (1980). *Arquitectura bioclimática*. Gustavo Gili.

Kroemer, K. H. E. & Grandjean, E. (2005). *Manual de ergonomia: adaptando o trabalho ao homem*. (5a ed.), Bookman.

Lamberts, R. (2011). *Introdução ao EnergyPlus.* Laboratório de Eficiência. Universidade de Santa Catarina, Florianópolis-SC.

Lamberts, R., Dutra, L. & Pereira, F. O. R. (2014). *Eficiência energética na arquitetura.* (3a ed.), Eletrobras/Procel.

Lukiantchuki, M. A. (2015). *Sheds Extratores e Captadores de Ar Para Indução da Ventilação Natural em Edificações.* Tese (Doutorado em Arquitetura e Urbanismo), Instituto de Arquitetura e Urbanismo, Universidade de São Paulo, São Carlos. 10.11606/T.102.2015.tde-07082015-180544

Morais J. M. S. C. & Labaki, L. C. (2017). CFD como ferramenta para simular ventilação natural interna por ação dos ventos: estudos de caso em tipologias verticais do "Programa Minha Casa, Minha Vida. *Revista do Ambiente Construído.* 17(1), https://doi.org/10.1590/s1678-86212017000100133

Mehta, P. K. & Monteiro, P.J.M. (2008). *Concreto: Microestrutura Propriedades e Materiais.* (3a ed.), Pini.

Montenegro, G. A. (1984). *Ventilação e cobertas: estudo teórico, histórico e descontraído*. Blucher.

Moreno, A. C. R. (2013). *Minha Casa Minha Vida: Análise de desempenho térmico pela NBR 15.220-3, NBR 15.575, Selo Casa Azul e RTQ-R.* Dissertação (Mestrado em Tecnologia do Ambiente Construído) – Programa de Pós-Graduação em Ambiente construído e Patrimônio Sustentável, Universidade Federal de Minas Gerais, Belo Horizonte. http://hdl.handle.net/1843/AMFE-9HXPCY

Pereira, A. R. (2019). *Análise do conforto térmico para usuários de uma moradia universitária e do desempenho térmico de sua envoltória*. Dissertação de Mestrado (Mestrado em Engenharia Civil). Centro Federal de Educação Tecnológica de Minas Gerais - CEFET-MG. https://sig.cefetmg.br/sigaa/verArquivo?idArquivo=2226496&key=1d6671574459653b81c8aceaad894fe4

Rodrigues, L. S. (2008). *Ventilação natural induzida pela ação combinada do vento e da temperatura em edificações.* Dissertação de Mestrado (Mestrado em Engenharia Civil). Universidade Federal de Ouro Preto. http://www.repositorio.ufop.br/handle/123456789/2361

Roriz, M. (2013). *Desempenho térmico e as paredes de concreto.* http://nucleoparededeconcreto.com.br/destaque-interno/desempenho-termico-e-as-paredes-de-concreto.

Silva, L. D. T. (2015). *Investigação do uso e da aplicação das técnicas CFD para estudo e análise de ventilação natural por ação dos ventos em espaços urbanos.* XII 104 f. Dissertação (Mestrado em Arquitetura o urbanismo) - Universidade Federal de Viçosa, Belo Horizonte. http://www.locus.ufv.br/handle/123456789/7650

Tutikian, B. F. (2008). *Concreto autoadensável.* Pini.

Tutikian, B. F. & Molin, D. C. D. (2015). *Concreto Autoadensável.* (2a ed.), Pini.

Venturini, J. (2011). Casas com paredes de concreto. *Revista Equipe de Obra*, v. VII, n, 37, http://www.equipedeobra.com.br/construcao-reforma/37/artigo220698-2.asp

WBCSD - World Business Council for Sustainable Development. (2007). *Energy Efficiency in Buildings: Business realities and opportunities.* Summary report, Geneva, Suíça. https://www.wbcsd.org/Programs/Cities-and-Mobility/Resources/Business-realities-and-opportunities-Summary

Yudong, M. A., Kelman, A., Daly, A. & Borrelli, F. (2012). *Predictive control for energy efficient buildings with thermal storage: Modeling, simulation and experiments.* IEEE Control Systems Magazine, Piscataway, USA. 10.1109/MCS.2011.2172532