Comparison of thermal performance of walls using the computational simulation method from NBR 15.575/2021

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Abstract: The demand for new housing has led companies in the construction industry to seek construction methods that allow the construction of new housing complexes in a quick and practical way. This article aims to present a comparative analysis, in terms of thermal performance, between the wall system made of reinforced concrete cast in situ and the conventional one made of ceramic brick, within the climatic context of the municipality of Paulo Afonso-BA. The analysis of thermal performance is supported by the computational simulation method of NBR 15.575/2021. For this purpose, the EnergyPlus software was used as a tool. The results indicated that the building model made of reinforced concrete walls cast in place can achieve intermediate thermal performance, obtaining a saving of approximately 46.8% in the artificial conditioning thermal load when compared to a reference model. Furthermore, the thermal performance obtained by the conventional system does not surpass that of reinforced concrete walls cast on site.

Key words: semi-arid; envelope; reinforced concrete; ceramic brick

1 Introduction

Reinforced concrete wall sealing is one of the systems used to assist in the process of producing new housing complexes in Brazil (Mendes; Fabrício; Imai, 2017). According to the Brazilian Concrete Institute, this is a quick-to-execute system, especially when compared to the conventional masonry wall system (IBRACON, 2018).

This construction method was one of the first to be evaluated by SINAT, with its standard - NBR 16.055 - only being published in 2012 by the Brazilian Association of Technical Standards (ABNT, 2012). Even with the approval of this innovation by SINAT, the increased use of reinforced concrete walls in housing across different parts of Brazil has led researchers to study their performance from various aspects.

However, the need to produce new housing on a large scale often leads to the construction/replication of designs and building systems that do not take into account essential issues such as the local climate and, consequently, the thermal performance and comfort of residents (Costa, 2017). Thus, studies conducted over the last decade have highlighted issues related to the suitability of reinforced concrete walls in different climatic conditions in Brazil, pointing out negative aspects of their thermal behavior.

Standard 15.575, from 2013, presented three different methods for evaluating the thermal performance of buildings. Based on these methodological procedures, research also concluded that reinforced concrete wall systems did not perform well thermally when subjected to certain climatic conditions, as observed by Sorgato et al. (2014), Sorgato, Melo, and

Lamberts (2014), Oliveira et al. (2015), and Moraga (2017).

In 2021, amendment No. 1 to NBR 15.575 was published, describing new procedures for evaluating the thermal performance of dwellings (ABNT, 2021), given the gaps and inconsistencies in the original version of the standard. With the publication of this new proposal, new studies should be conducted to verify the behavior of the construction systems used in buildings in Brazil, admitting the new ones. Thus, the various criticisms made about the thermal behavior of dwellings with reinforced concrete walls cast on site can be discussed in order to verify whether the observations made previously remain valid based on the new methods of analysis.

In view of the above, this study seeks to evaluate the thermal performance of a single-family housing model by comparing the system of vertical reinforced concrete walls cast in situ with the conventional ceramic brick system, within the climatic context of the municipality of Paulo Afonso-BA, observing the influence of orientation on the aforementioned performance.

2 Theoretical reference

2.1 Criticisms of the thermal performance assessment simulation method of the Brazilian standard: NBR 15.575/2013

Thermal performance can be defined as the minimum thermal behavior expected from a building, taking into account the responses to the external climate and the conditions of use of the spaces, aiming for better indoor thermal comfort conditions in its usage condition (Mattos, 2015). The standard that provides the methods for assessing thermal performance in Brazil, NBR 15.575 (ABNT, 2013), underwent several modifications during its development to better address the aforementioned issues. After its publication in 2013, it continued to be the subject of various studies and critiques aimed at improving the methodologies used in assessing thermal performance.

Some of the criticisms and proposed changes that have been made in recent years regarding the computer simulation method for thermal performance evaluation proposed by the standard will be presented below, up to the most recent version, published in 2021.

NBR 15.575/2013 established two normative procedures (simplified and computational simulation) for evaluating the thermal performance of residences and a third (field measurement) of an informative/non-normative nature. Before the publication of the version that came into effect in 2013, Grigoletti and Sattle (2010) had already realized that, by focusing only on the properties of walls and roofs and not on the building as a whole, the simplified method would not express the thermal behavior of the building in a realistic way.

According to NBR 15.575-1/2013, if unsatisfactory performance of the requirements and criteria (transmittance and thermal capacity) was verified, as suggested by the simplified procedure, on the part of the sealing and roofing systems in a building, a global evaluation of the building was recommended using the computational simulation method (ABNT, 2013). Thus, the normative text led to the interpretation that there was a connection between the suggested evaluation methodologies.

Regarding the relationship between the two aforementioned procedures, Sorgato et al. (2014) state that these (simplified and simulation methods) did not present equivalence after conducting a critical analysis of both. That is, in their research, it was observed that a building that met the minimum performance through evaluation by the simplified method would not necessarily meet that same level of performance in the evaluation by the simulation method, thus noting a contradiction in the standard.

Regarding the simulation method, the 2013 version established for the analysis of the thermal performance of projects that, both in summer and winter, the thermal conditions inside the residential building should be better than, or, depending on the situation, equal to, those of the external environment. In light of this, it was defined as a criterion for a typical

summer day that the maximum daily value of the indoor air temperature of rooms where people spend extended periods (living rooms and bedrooms), excluding the presence of internal heat sources (occupants, lamps, other equipment in general), should always be less than or equal to the maximum daily value of the outdoor air temperature in order to meet the minimum performance level. To achieve intermediate and superior levels of thermal performance, the limit of the difference between the temperatures of the spaces was increased (ABNT, 2013).

Similarly, for winter, at the minimum performance level, environments where people would spend extended periods of time should have temperatures equal to or higher than the outside temperature plus 3 °C. To meet the other two performance levels, the difference was 5 and 7 °C, respectively.

The standard stipulated that the comparison between temperatures should be carried out, depending on the location, only for one or two days of the year, defined as a typical summer day and a typical winter day (ABNT, 2013). These days represented, respectively, the hottest and coldest day of the year according to the average calculated for the period of the last 10 years.

According to observations made by Sorgato et al. (2012) and Dell-Santo, Alvarez, Nico-Rodrigues (2013), in studies to assess the recommendations in the standard regarding computer simulation, it was necessary for this method to consider not only two days, but all 8,760 hours of the year in the performance evaluation. Furthermore, it should consider hourly variations in space occupancy, lighting and equipment power, natural ventilation, among other aspects, to make the evaluation by the aforementioned method more realistic.

Upon resuming their studies on the simulation process of the standard, published in 2013, Sorgato et al. (2014) once again perceived the presence of gaps in the computational simulation procedure, this time pointing to the lack of establishment of conditions for the building's floor within the standard, since, according to them, the way in which the contact between the ground and the floor is modeled can cause significant changes in the evaluation of the building's thermal performance.

Regarding the evaluation of thermal performance in dwellings, NBR 15.575/2013 represents progress for the country. However, as can be observed, since its drafting and even after its publication in 2013, several criticisms have continued to be made due to the established evaluation procedures for the thermal performance of dwellings. In view of this, changes to the normative text began to be discussed with the aim of improving its methodology for analyzing thermal performance.

Thus, the aforementioned standard underwent a review process, with an amendment published in March 2021. The changes made aimed to adjust the evaluation methods to the criticisms described above.

3 Methodology

The applied research in this work is divided into 2 stages. In the first phase, the typology of the building to be evaluated in this work was defined. Therefore, the study used the project of a single-family building, which was approved for construction in 2021 by the Municipality of Paulo Afonso-BA and made available by the respective municipal entity.

Next, an evaluation was carried out using the computer simulation method in order to verify what levels of thermal performance can be achieved by the single-family housing unit when different vertical sealing systems are adopted: cast-in-place reinforced concrete walls (MReal) and conventional ceramic brick walls (MMod).

For the simulation, the EnergyPlus software, version 9.3, was used, a tool responsible for calculating internal temperatures and heat exchange in the building modeling, meeting the requirements of amendment no. 1 of NBR 15.575 (ABNT, 2021).

In the building modeling, a TMY (Typical Meteorological Year) climate file was used, as suggested by the standard (ABNT, 2021), with hourly data referring to the city of Paulo Afonso (ZB-7), between the years 2004 and 2018, obtained from Crawley and Lawrie (2022). Figure 2 shows the simulation steps and variables obtained for analysis.
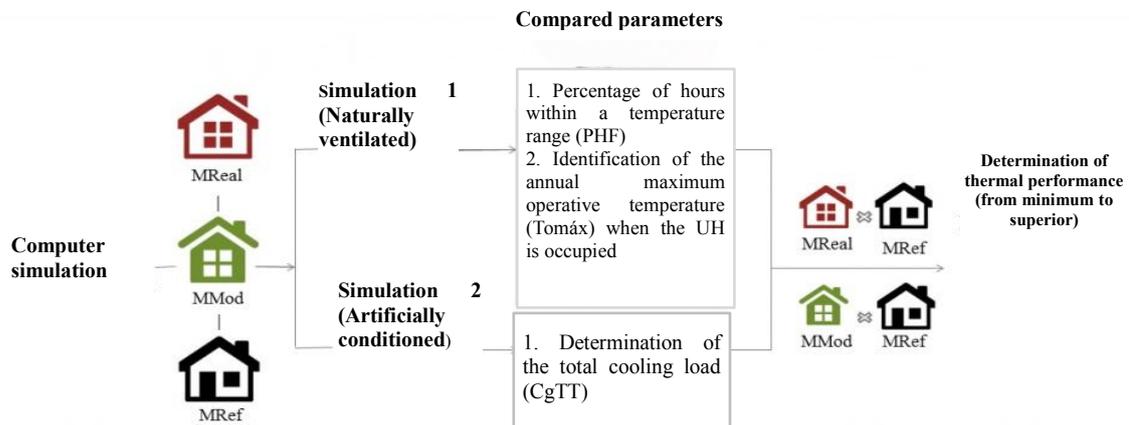

Figure 2. Building evaluation using the simulation method (Source: Prepared by the authors)

3.1 Characterization of the object of study

The analysis was conducted considering the building with its main facade oriented towards the cardinal directions, allowing for the study of the influence of the building's geographical orientation on its thermal performance.

The building's roof will be made of fiber cement tiles, with a plaster ceiling, thus representing the real model (MReal). According to Morishita et al. (2011), the aforementioned roof configuration has a thermal transmittance (U) equal to 1.95 W/(m²K), a thermal capacity (CT) equal to 32 kJ/m², an absorptance (α) of 0.4, a solar heat factor (SHF) of 3.1, and a longwave emissivity (ε) equal to 0.9.

Regarding the vertical walls, the walls adopted by the designers have a thickness of 10 cm. The wall system of the real model will be made of cast-in-place reinforced concrete. This type of wall has a thermal transmittance (U) of 4.40 W/(m²K), a thermal capacity (CT) of 240 kJ/m²K, a solar absorptance (α) of 0.2, a solar heat factor (FS) of 3.5, and a long-wave emissivity of 0.9. In order to verify whether the type of construction system adopted in the original project will have significant differences in terms of thermal performance compared to a dwelling built with a conventional masonry vertical wall system, a second project was also evaluated.

The modified model (MMod) has the same thermo-physical and architectural properties as the actual design, except for the walls. For this, the external and internal walls were made of six-hole ceramic brick (9.0 cm x 14.0 cm x 24.0 cm) and internal and external mortar with a thickness of 2.5 cm. According to Morishita et al. (2011) and Weber et al. (2017), this has a thermal transmittance of 2.39 W/(m²K), a thermal capacity of 159 kJ/m²K, a thermal lag of 3.3 hours, a solar absorptance of 0.8, a solar heat factor of 1.9, and an emissivity of 0.9. The air chamber of the element is represented by a thermal resistance of 0.175 m².°C/W.

The walls have internal and external (2.5 cm) mortar coating, as can be seen. The following thermal properties were assumed for the coating: longwave emissivity equal to 0.9 and solar absorptance of 0.2 (ABNT, 2005; Morishita et al., 2011; Weber et al., 2017).

The windows used in the bedrooms measure 1.20 m x 1.20 m and are sliding double-leaf windows with a sill 1.00 m from the floor, thus providing 50% ventilation (Lamberts; Dutra; Pereira, 2014). This model is installed in both bedrooms. The windows used in the bathrooms are awning windows, measuring 0.60 m x 0.60 m, with a 1.60 m sill and a 50% ventilation opening (Lamberts; Dutra; Pereira, 2014). The main entrance door to the living room is made entirely of glass.

The transparent elements are made of ordinary glass with a thermal transmittance of 5.7 W/m².K, a solar factor (SF) of 0.87, and a thickness of 6 mm. The doors of the interior rooms and kitchen were considered to be made of wood with thermal property values equal to those of the reference model, as were the window frames and the floor configuration.
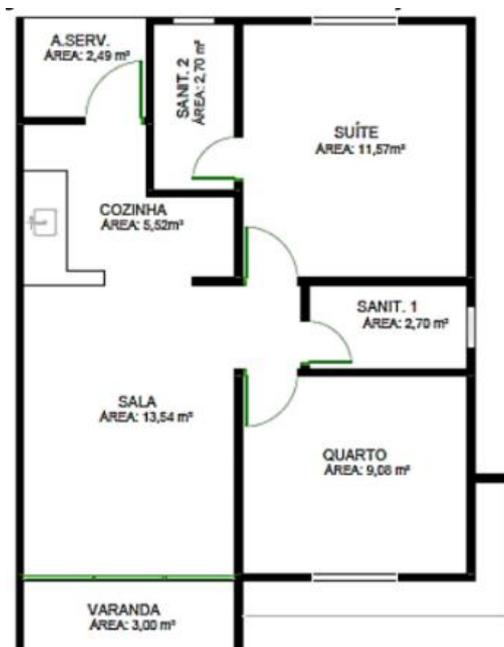
3.2 Housing unit modeling

Figure 3. Floor plan of the evaluated dwelling (Source: Paulo Afonso, 2021.)

Figure 3 shows the building's floor plan with the areas. Figure 4 shows the virtual models (real, modified, and reference) used in the simulations. For the geometry of the models, the dwelling was considered as a whole, with each room being a thermal zone, except for the living room and kitchen, which are combined spaces and were simulated as a single thermal zone.

(a) real and modified model   (b) reference model
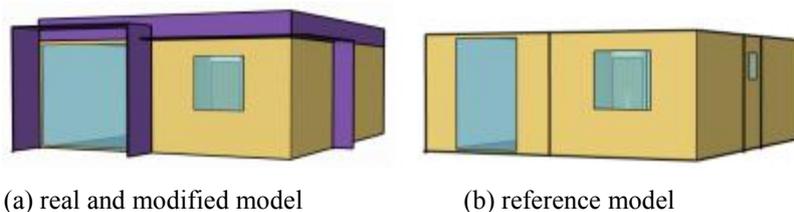
Figure 4. Perspectives of the house simulation model

(Source: Prepared by the authors themselves.)

In both the real and modified models, the volumetric characteristics, the percentages of transparent elements and ventilation openings, the thermal properties of the construction systems, and the presence of fixed external shading elements were maintained. In both the real and modified models, as well as in the reference model, the window frame properties followed the recommendations of the reference model, given that the specifications were not present in the original project. The same ground contact condition was also assumed for all models.

In the reference model (MRef), the volume corresponds to that of the real model. However, the percentages of transparent elements and openings for ventilation, as well as the thermal properties, were altered to the values established by the new procedure for configuring the reference model (ABNT, 2021). Furthermore, all modeling of occupancy, internal loads, space usage periods, use of natural ventilation, and artificial conditioning was carried out according to the recommendations of the aforementioned standard.

4 Results and discussion

To evaluate the thermal performance of the building envelope, according to the criteria established by NBR 15.575-1/2021, it is necessary to determine the range of external temperatures that serves as a reference for the temperature analysis in the APPs (environments of prolonged occupancy). This range is identified by means of the annual average of the dry-bulb external temperature (TBSm) from the climate file used in the simulation. For the present case, the calculated TBSm was 26.7 °C.

Based on the TBSm, the operating temperature range of the APP (ToAPP) is defined as 28.0 °C, which should be considered as a reference for calculating the percentage of hours that each APP is occupied within this limit. In other words, this value is considered an operating temperature limit at which the environment is deemed suitable for occupancy and meets the minimum level.

Based on the identification of the reference interval, the first criterion for evaluating thermal performance at the minimum level is determined, that is, the percentage of hours in which the unit will be within the operating temperature range (PHFT$_{UH}$) during its respective occupancy period.

4.1 Meeting the minimum level

To meet the minimum thermal performance level, PHFT$_{UH, real}$ must be greater than 90% of that obtained for the reference model (PHFT$_{UH,ref}$). Additionally, the evaluated UH must meet the maximum operative temperature criterion of the residential unit (Tomax,$_{UH}$). To achieve the minimum thermal performance, the maximum operative temperature of the evaluated model must be less than or equal to the maximum operative temperature observed in the reference model, with an increment (Tomax,$UH,real \leq$ Tomax,$UH,ref + \Delta$Tomax).

This increase in operating temperature, based on the reference model result, is equal to 2 °C, considering that the present case study concerns a single-family, ground-floor housing unit (Figure 5). As the residence will be built within ZB-7, it is not necessary to check the Tomín$_{UH}$.
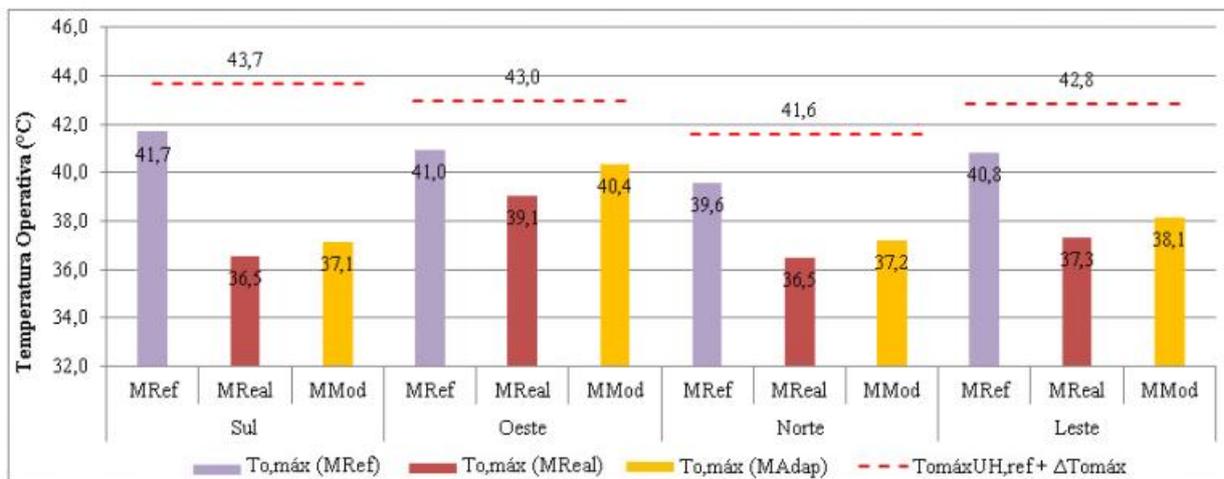

Figure 5. Operating temperature reached in the models

(Source: Prepared by the authors themselves.)

All evaluated models passed the first criterion. In all cases, the maximum operating temperature (To,max) was observed in the room. This was expected, given that this is the APP most occupied in the afternoon, i.e., when the highest TBS occurs. Depending on the project's orientation, the reference limit for this parameter (To,max) will vary, but this variation is not necessarily proportionally reflected in the maximum operating temperature observed in the storage units.

By way of illustration, comparing the Southern and Northern scenarios, it is observed that the real models and the modified models have respective To,max values close to 36.5°C and 37.1°C. However, the reference limits for evaluating these models have a difference greater than 2 °C. Thus, it is stated that the parameter adopted to evaluate the UH in the northern scenario ends up being more rigorous as the MRef has a lower To,max.

The result obtained shows that both models meet the criterion for the maximum operating temperature of the UH, without the need to consider the 2 °C increase over the reference model, and the lowest To,max occur in the MReal, South and North scenarios, and the highest To,max in the MMod West and East scenarios.

The second criterion analyzed was the percentage of occupancy hours during which the models are within the operating temperature range (PHFT). In this case, only ToAPP values below 28 °C were counted, for the times when the APPs should be occupied. Table 1 shows the number of hours each APP is occupied and has an operating temperature within the temperature range (NhFT).

Table 1. NhFT and PHFTAPP values for the APPs of the 3 models analyzed

Modelo	MRef	MReal	MMod	MRef	MReal	MMod
Cenário		Sul			Norte	
NhFT sala	41	460	338	38	439	283
PHFTsala	1,4%	15,8%	11,6%	1,3%	15,0%	9,7%
NhFT quarto 1	2027	3106	3074	1273	2759	2686
PHFT quarto 1	55,5%	85,1%	84,2%	34,9%	75,6%	73,6%
NhFT quarto 2	1408	2857	2788	1930	3061	3034
PHFT quarto 2	38,6%	78,3%	76,4%	52,9%	83,9%	83,1%
Cenário		Oeste			Leste	
NhFT sala	28	268	166	44	422	276
PHFT sala	1,0%	9,2%	5,7%	1,5%	14,5%	9,5%
NhFT quarto 1	1234	2476	2336	1980	3014	2922
PHFT quarto 1	33,8%	67,8%	64,0%	54,2%	82,6%	80,1%
NhFT quarto 2	1975	2946	2847	1270	2624	2498
PHFT quarto 2	54,1%	80,7%	78,0%	34,8%	71,9%	68,4%

Source: Prepared by the authors themselves

Based on the data above, the percentages of hours within the operational range for the PHFTUH housing units were calculated, as well as the reference limit for evaluating compliance with the minimum level (dashed red line). Figure 6 shows the results for the analysis of this parameter.
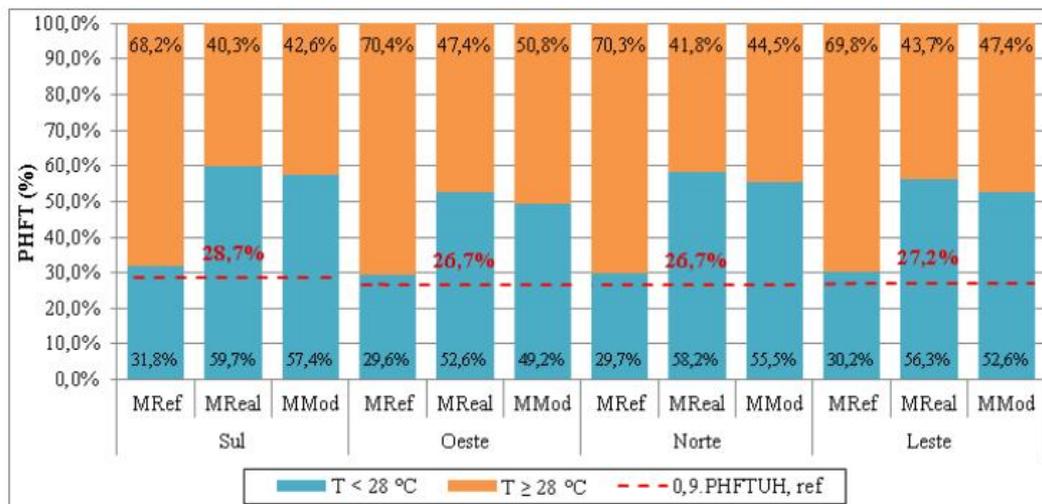

Figure 6. Compliance with the PHFT criterion (Source: Prepared by the authors themselves.)

It is observed that the PHFT$_{UH,ref}$ underwent a small variation between scenarios; consequently, the parameters for evaluation also had a low variation when rotating the building, remaining between a minimum of 26.7% (West and North) and a maximum of 28.7% (West). The graph highlights that the evaluated models (MReal and MMod) meet the PFHT criterion, reaching values well above 90% of the PHFT$_{UH,ref}$.

Once again, the best scenario was the MReal with the main facade facing South. In second place was the same model in the North scenario, even surpassing the MMod with the main facade facing South. This fact highlights the superior capabilities of the SVVE, made of cast-in-place reinforced concrete, over the conventional system made of ceramic brick masonry. The worst situation is represented by the MMod in the West scenario, followed by the MReal in the West scenario and the MMod in the East scenario, which obtained the same PHFT value.

Since the two criteria relevant to the evaluation of minimum thermal performance were met, it is affirmed that the models studied are in accordance with the mandatory normative parameters as determined by the new thermal performance evaluation procedure. The data corroborate the confirmation that MReal, despite the thermal properties of its SVVE not meeting some indications for ZB-7, can be used in such a way that the minimum thermal performance measures are satisfied.

Meeting the intermediate and superior levels is only verified when the minimum thermal performance is achieved. To meet these levels, the ability of the evaluated model to achieve increments in the percentage of hours within an operating temperature range (ΔPHFT) and the reduction of the total thermal load (RedCgTT) of the evaluated model in relation to the reference model is verified, which must subsequently be compared with minimum values (ΔPHFTmin and RedCgTTmin). For the calculation of the thermal load, it should be noted that the models are simulated without natural ventilation.

In situations where PHFT$_{UH,ref}$ is less than 70%, as calculated, the ΔPHFTmín must be determined by calculation and must be exceeded in order to reach the intermediate level of thermal performance (Table 2).

Table 2. Compliance with the incremental criterion in PHFT

Scenario	ΔPHFTmín	ΔPHFTReal	Satisfaction	ΔPHFTMod	Satisfaction
South	26,5%	27,9%	Satisfied	25,6%	Not Satisfied
West	27,8%	22,9%	Not Satisfied	19,6%	Not Satisfied
North	27,8%	28,5%	Satisfied	25,8%	Not Satisfied
East	27,5%	26,1%	Not satisfied	22,5%	Not Satisfied

Source: Prepared by the authors themselves.

Regardless of the scenario, the MMod does not have a ΔPHFTMod greater than the ΔPHFTmin; consequently, it does not meet the present criterion. The Southern scenario of this model was the closest to the limit. On the other hand, it is noted that the MReal, in the Southern and Northern scenarios, has percentage increase values for hours within the operating temperature range that are greater than the minimum; therefore, they satisfy the reference parameter, meeting the first criterion necessary to obtain the intermediate thermal performance level.

The second criterion, calculated to verify compliance with the aforementioned intermediate thermal performance level, was the total thermal load of the housing unit (CgTT$_{UH}$). The total thermal load, in this case, is equivalent to the cooling thermal load (CgTR$_{UH}$), since artificial heating systems are not considered for buildings located in the city of Paulo Afonso-BA.

Figure 7 details the total thermal loads for each of the three simulated models and the values of the ratio of the total thermal load to the sum of the areas of the prolonged occupancy environments that were evaluated in the simulation. As can be observed, the reference model has a total thermal load requirement that varied, according to the scenario, between a minimum of 12,469.6 kWh/year (East) and a maximum of 13,082.6 kWh/year (West).
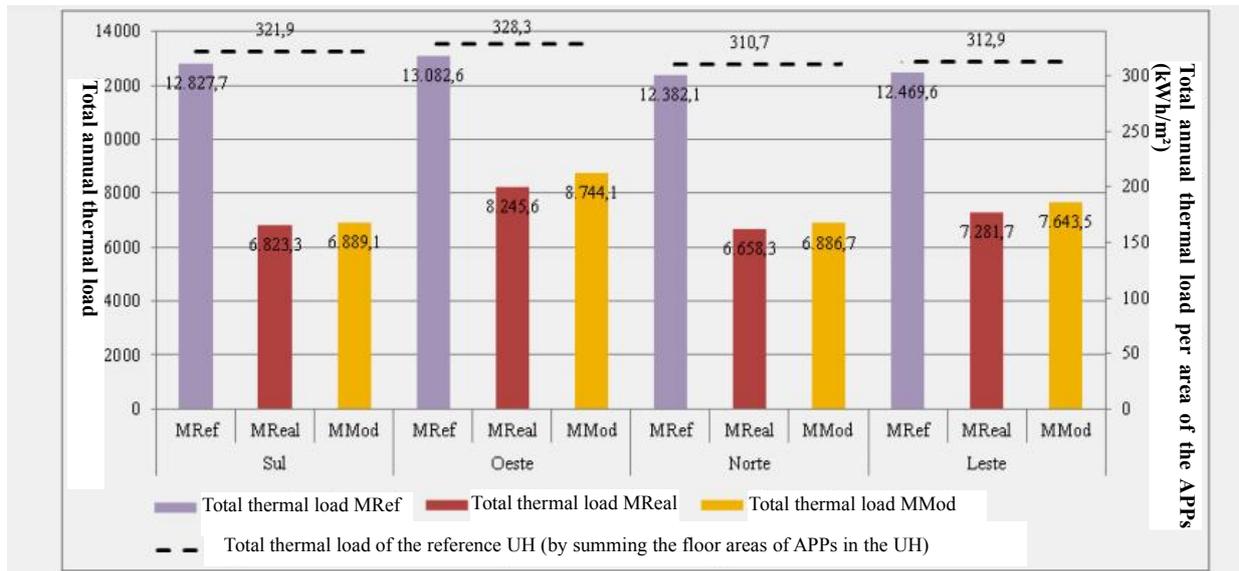
Figure 7. Compliance with the PHFT criteria

(Source: Prepared by the authors themselves.)

On the other hand, the evaluated models obtained a demand that varied between 6,658.3 kWh/year (MReal in the North scenario) and 8,744.1 kWh/year (MMod in the West scenario) for cooling the housing unit. It is noteworthy that, this time, the MReal in the South scenario was not the one that obtained the best result among all the variables that have been presented so far.

Considering that in the present study the ratio between $CgTT_{UH,ref}$ and the floor area of the UH (Ap_{UH}) is greater than 100 kWh/m^2, and that $PHFT_{UH,ref}$ was less than 70%, it is established that the $RedCgTT_{mín}$ is 0% for intermediate thermal performance. Table 3 shows the reduction in thermal load that each evaluated model obtains in relation to the reference model, highlighting whether the criterion is met or not.

Table 3. Compliance with the CgTT reduction criterion for intermediate thermal performance

Scenario	RedCgTTmín	RedCgTTMReal	Satisfaction	RedCgTTMMod	Satisfaction
South		46,8%	satisfies	46,3%	satisfies
West	0%	37,0%	satisfies	33,2%	satisfies
North		46,2%	satisfies	44,4%	satisfies
East		41,6%	satisfies	38,7%	satisfies

Source: Prepared by the authors themselves.

The evaluated models obtained a RedCgTT value higher than the $RedCgTT_{min}$ value; therefore, it is stated that the criterion is met by all of them. The greatest reduction in thermal load is observed in the MReal model, in the Southern scenario, while the smallest reduction is observed in the MMod model, in the Western scenario. This means that the first model is the one that will be able to minimize energy consumption with the cooling system more efficiently when compared to the reference model. Although all models easily exceeded the RedCgTTmin limit, only the real model, in the Southern and Northern scenarios, achieved intermediate thermal performance, as they were the only ones to satisfy both criteria relevant to this performance level.

Once the intermediate level is met, the models that satisfied this level are analyzed for the superior level. The $\Delta PHFT_{mín}$ and $RedCgTT_{mín}$ values must be recalculated. According to the standard, it is established that if the $PHFT_{UH,ref}$ for the model evaluated in this study is greater than 70%, the $\Delta PHFT_{mín}$ remains equal to the values calculated for the intermediate level. Thus, it is stated that the first criterion evaluated, for the analysis of superior thermal performance, is

satisfied only by MReal, in the South and North scenarios.

Regarding the reduction of total thermal load, through $PHFT_{UH,ref}$ and the ratio between $CgTT_{UH,ref}$ and $Ap_{,UH}$, it is determined that, to meet the superior level, the evaluated models must exceed or reach the $RedCgTT_{mín}$ of 55%. In these terms, since the RedCgTT of the respective MReal models in the South and North scenarios do not exceed the aforementioned limit, it is concluded that the two evaluated projects do not meet the superior thermal performance.

In view of the above, it is confirmed that, for this case study, although the SVVE made of reinforced concrete cast in situ does not have a thermal transmittance value within the ranges established by standards for ZB-7, it can be used without impairing the thermal performance of the building to the point of preventing the housing unit from achieving intermediate thermal performance. It should be noted that the orientation of MReal affects its thermal performance, causing it, for example, to reach the lower level in the West and East scenarios. This corroborates the observations of Oliveira et al. (2015) when applying the old evaluation method.

The results obtained in this study differ from the findings of, for example, Ferreira and Pereira (2012), who, when applying the old method of evaluating (computational simulation) thermal performance, concluded that, for ZB-7, specifically the city of Petrolina-PE, the thermal performance of a UH made of reinforced concrete with a 10 cm wall was unsatisfactory. They realized that only by increasing the wall thickness to 12 cm was it possible to achieve the minimum thermal performance, the same level of performance as a ceramic brick masonry wall.

5 Conclusion

Depending on the design orientation, the models achieved minimum or intermediate thermal performance, which contributes to the conclusion that the studied sealing systems can be used in buildings located in semi-arid climates, such as Paulo Afonso-BA.

A cast-in-place reinforced concrete wall, evaluated in isolation in terms of thermal transmittance (U), is not considered suitable for this region. However, when analyzing its performance within the model of a building, considering all the architectural and usage properties of the dwelling, this system can meet the minimum thermal performance criteria. This fact shows that, although cast-in-place reinforced concrete walls have a thermal transmittance value above the normative limit, other aspects of the building design, such as orientation, can positively impact the thermal performance of the model, leading it to achieve acceptable thermal behavior and even superior to that of ceramic brick masonry buildings.

This study should generally assist construction professionals in the development of bioclimatic architectural projects. Above all, it will help in proposing buildings that are suitable for the realities of hot and dry regions in Brazil. This study is limited to a specific project. Therefore, future research suggests making changes to the architectural properties and materials of the building design to verify the possibilities of achieving superior thermal performance compared to that obtained in this case study.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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