Use of thermal insulation in the envelope to mitigate energy consumption in the face of climate change for mid-western Brazil

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Abstract. As scientific research shows a progressive increase in Earth temperature, climate change is recognized as a key global challenge for the 21st century. Studying the consequences of this phenomenon has gained worldwide importance, including in the field of buildings. It starts from the problematic that comes from the housing models that, at present, are already built with inadequate thermal insulation, questioning what internal conditions will bring benefits in these future heating scenarios. In places with hot climates such as in the Brazilian savannah, this subject is even more important because an effective countermeasure is necessary in reducing the cooling load of buildings. High temperatures lead to longer demand for air conditioning, which results in a significant increase in building energy consumption. In this way, this work has the general objective to analyze the effects of global warming on the consumption of buildings with different insulation in the envelope, in face of the climatic changes. The emissions scenario A2 of the Fourth Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) was considered. The methodological procedures consist of five steps: preparation of the climate files for Future Scenarios (time-slices 2020, 2050 and 2080) from the file without influence of global warming (1961-1990), called Base Scenario; definition of a dwelling for study object (Tbase); quantification of global warming impacts on building consumption; elaboration of intervention proposals in the object of study, defining four typologies (Tbase and T1 to T3) by adopting the use of insulation, in the first one (T1) was applied EPS, in the second (T2) rockwool and in the third (T3) glasswool, in the last stage, the energy consumption for cooling was estimated, considering the main facade as north for all cases. Under the effects of global warming, the results showed the annual average temperature and relative humidity of the external air of the Base Scenario from 26.73 °C to 32.48 °C (+5.75 °C) and 69.08% to 53.67% (-22%), up to the 2080 scenario, respectively. Energy consumption is directly influenced by the effects of global warming, Tbase's energy consumption in the current scenario presents increases for the 2080 scenario of 54.18%, the T1 was 40.73%, the T2 of 41.97% and the T3 ratio of 41.87%. With the use of insulation in the typologies T1 to T3, the energy consumption reduced in the base scenario by 30.58%, 30.62% and 30.64% respectively. This fact proves the importance and effectiveness of the use of more resilient envelopes as a strategy to mitigate climate change. It is concluded that considering the useful life of 50-year-old buildings, it is necessary to re-think the current constructive specifications, incorporating interventions to absorb the impacts of climate change, pointing out guidelines on how to build today, to provide better and more resilient climate habitability in future climate scenarios.

Key Words: Global Warming. Energy Efficiency. Tropical weather.
1. Introduction

As scientific research shows a progressive increase in the temperature in earth’s surface, climate change is recognized as a key global challenge for the 21st century. CO₂ emissions from anthropogenic activities increased by 54% in the period from 2002 to 2011, compared to 1990 (STOCKER et al., 2013). These increases in emissions have contributed directly to global warming, rising sea levels, increase intensity of extreme events and changes in precipitation and wind patterns. According to Stocker et al. (2013), this increase was 0.72°C in the period from 1951 to 2012. The study of the consequences of this phenomenon has gained worldwide importance, including in the scope of energy consumption of buildings.

The construction industry contributes directly to the emissions of greenhouse gases (GHG). Thus, this sector can contribute up to 30% of global annual emissions (IPCC, 2007). According to Cellura et al. (2018), the construction industry, within European buildings, generates about 36% of CO₂ emissions. Therefore, the European Union has made the construction sector an important mitigation tool for reducing GHG emissions. It is also considered that buildings consume about 40% of global energy consumption worldwide and are also responsible for CO₂ emissions (Flores-Larsen, Filippín and Barea, 2019).

Considering that the useful life of the buildings corresponds to the time scale in which, there will be substantial climate changes, the buildings constructed in the present days need to be resilient in the future. Therefore, obtaining knowledge about future climate changes motivated by anthropogenic actions and based on GHG emissions is a starting point for studies of the resilience and impact of global warming on buildings. In this way, the Intergovernmental Panel on Climate Change (IPCC) has published scientific reports, on which scientists from various fields base their research on the behavior of terrestrial ecosystems.

In 2007, the IPCC released the results of its Fourth Assessment Report on Climate Change (AR4) entitled "Fourth Assessment Report: Climate Change 2007". The models are divided into four families, called scenarios A1, A2, B1 and B2, in which ‘A’ and ‘B’ mean low and high commitment to sustainable development, and ‘1’ and ‘2’, integration or fragmentation, respectively (IPCC, 2007). The ‘A’ rating scenarios are considered 'pessimistic' and the 'B' rating scenarios are considered 'optimistic'. This publication specifically highlights that most of the temperature increase events observed in the last 50 years, were caused by anthropogenic actions and, warns about the average increase in global temperatures of 1.1°C to 5.4°C, reaching 6.4°C by the year 2100, if the population and economy continue to grow rapidly, with heavy consumption of fossil fuels (IPCC, 2007).

New climatic conditions impose changes in climatological variables, such as the increase of global mean temperature. It is known that the energy performance of buildings depends on the climate in which they are inserted (DE WILDE, COLEY, 2012). So, the problem arises from the housing models that are being built with inadequate thermal insulation, raising questions about what internal conditions will be provided in these future heating scenarios. Nico-Rodrigues et al. (2015) point out that adopting guidelines that consider the relationships between climate and human beings become important instruments for definitions of housing adequate to the conditions of thermal comfort.

In places with hot climates such as in mid-western Brazil, this issue is even more important, because an effective countermeasure is necessary to reduce the cooling load of buildings. High temperatures lead to longer demand for air conditioning, which results in a significant increase in the building’s energy consumption. In this way, this work has the objective of analyzing the effects of global warming on the consumption of buildings with different insulations in the envelope, facing the climatic changes. For this, the A2 emission scenario of the Fourth Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) was considered.
2. Methodology

2.1. Elaboration of future climate files

Initially, the morphing methodology published by Belcher, Haker and Powell (2005) was used for the preparation of future climate scenarios, as well as for the investigations of the studies of climatic projections (SABUNAS e KANAPICKAS, 2017; WANG, LIU e BROWN, 2017). The methodology modifies a set of historical climatic variables (1961-1990) of 8,760 hours per year and incorporates the effects of global warming on the climatic archives, thus obtaining projections of future climate data. In this way, the "Climate Change World Weather Generator" tool (CCWorldWeatherGen) was used. This tool is incorporated in Excel Software and was developed by the research group "Sustainable Energy Research Group" (SERG) of the University of Southampton in the United Kingdom. The interface is presented in the Figure 1.

The tool consists of a spreadsheet that integrates EPW extension files into the Hadley Center Coupled Model version 3 (HadCM3) Global Climate Model (GCM). This model consists of an ocean-atmosphere coupled model, with a resolution of 417km x 278km in the region of Ecuador, and 295km x 278km at the Latitude 45°, making up the scenario of emissions of scenario A2 of the Fourth Report (AR4) of the IPCC, for the time-slice 2020 (period of 2011-2040), 2050 (period of 2041-2070) and 2080 (period of 2071-2100).

2.2. Study object

The object of study is a single-family residential dwelling (Tbase), located in the Brazilian mid-west (latitude 15°36'56"S), in the city of Cuiabá-MT, belonging to three important Brazilian ecosystems, the Pantanal to the south, the Amazon Forest to the north and the Cerrado in its surroundings (CALLEJAS, 2012). The Tbase has 39.18m² and 34.54 m² of total and useful area, respectively, containing the Living Room/Kitchen (17.44m²), Bedroom 1 (7.78m²), Room 2 (7.57m²) and Bathroom (1,75m²) (Figure 2 and 3). The house has a gable roof with eaves of 30 cm. The ceiling is 3.00 m high (Figure 4). The main facade faces north (0°).
The vertical closures (walls) of the object of study are composed of six-hole ceramic bricks coated on both sides. The horizontal closure (roof) are made of ceramic tiles on Vinyl Polychloride (PVC). The vertical and horizontal closures were defined by the Brazilian standard NBR 15.220 (ABNT, 2005), with the thermal properties of building materials expressed in Thermal Resistance (R), Thermal Transmittance (U), Thermal Capacity (C) shown in Table 1. The thermal resistance of the air chamber is 0.21 m²K/W, high emissivity, thickness greater than 5 cm.

Table 1: Study object thermophysical properties (Tbase)

| Envelope   | Composition          | Thickness (cm) | R (m²K/W) | U (W/m²K) | C (J/m²K) |
|------------|----------------------|----------------|-----------|-----------|-----------|
| External walls | External mortar       | 2.50           |           |           |           |
| Tbase      | Ceramic brick         | 9.00           | 0.2991    | 3.34      | 166.87    |
| Tbase      | Internal mortar       | 2.50           |           |           |           |
| Roof       | Ceramic roof tile     | 2.00           | 0.4795    | 2.08      | 41.92     |
| Tbase      | PVC liner             | 1.00           |           |           |           |

Proposals for constructive interventions were inserted in Tbase, with the purpose of analyzing the effects of global warming on the energy consumption of buildings, using different insulation on the external walls. Considering that the external walls directly receive the direct solar radiation and are important constructive components in the energy consumption of the dwellings, the following interventions were proposed: Expanded Polystyrene (EPS) (T1), Rockwool (T2) and Glasswool (T3) (Table 2). It should
be noted that the thermal resistance of the Tbase, T1, T2 and T3 typologies is 0.21 m²K/W, high emissivity, thickness greater than 5 cm.

Table 2: Thermal properties of the constructive intervention (thermal insulation) in the typologies

| Typologies | Envelope                  | Composition | Thickness (cm) | R (m²K/W) | U (W/m²K) |
|------------|---------------------------|-------------|----------------|-----------|-----------|
| T1         | External walls            | EPS         | 2.50           | 0.909     | 1.10      |
| T2         |                           | Rockwool    | 2.50           | 0.840     | 1.19      |
| T3         |                           | Glasswool   | 2.50           | 0.840     | 1.19      |

The Bedrooms and the Living room window frames are metallic, Venetian type with glass, with four sliding panels (two fixed and two mobile). Their dimensions are 1.50 x 1.00 m (living room), 1.20 x 1.00 m (Bedrooms 1 and 2) and 1.00 x 1.00 m (Kitchen). The external doors are made of metal sheet and the internal doors are made of wood.

2.3. Computer Simulation

It was decided to use EnergyPlus software from the United States Department of Energy (DOE) because of the possibility of insertion of current and future climate archives, in addition to being validated by Standard 140-2004 (ASHRAE, 2004). The software uses the climate file (EPW) of the study site, containing a series of data, such as: soil temperature and geographic location in order to better represent the climate (RORIZ, 2012). It is also possible to insert the thermal properties of the building materials, as well as schedules of natural and artificial ventilation, occupation, equipment and lighting, and the insertion of data of the typical design day for Winter or Summer. This allows obtaining results of energy demand for cooling and heating, thermal performance of the building systems, ventilation capacity and natural light, calculation of thermal loads and performance of the whole building (DOE, 2016).

To model the geometry of the building, the Open Studio plug-in was used, where all the extended stay environments were defined as a thermal zone, including the attic. The walls, roof and external openings have been previously configured as surfaces exposed to the sun and wind and the walls and internal openings without exposure. The data of the thermal properties of the constructive materials (opaque and transparent) were also inserted. Eaves were represented in the model by a surface, characterizing shading of external walls (Figure 5).

![Figure 5: Computational simulation of study housing in the Open Studio plug-in](image)

Occupancy patterns and internal gains were taken from the Technical Quality Regulation for the Energy Efficiency of Residential Buildings (RTQ-R) (INMETRO, 2012), which specifies occupancy schedules for weekdays and weekends, as well as occupancy and use times for lighting and equipment. In this way, it was considered an occupation of two people in Bedrooms 1 and 2 and four people in the Living Room, with metabolic activity of 45W/m² (sleeping activity) and 60W/m² (sitting activity), respectively. The lighting schedules were configured only for extended stay environments, considering weekdays and
weekends (Table 3). The installed power density of the recommended lighting is 5.0 W/m² for dormitory rooms and 6.0 W/m² for living room (INMETRO, 2012). The internal loads of equipment should be modeled only for the Living Room, with the period of 24 hours and the power of 1.5 W/m² (INMETRO, 2012).

Table 3: Occupancy and lighting schedules for weekdays and weekends

| Bedroooms          | Living Room/Kitchen |
|--------------------|---------------------|
| **Occupancy**      | Weekdays  | Weekends  | Weekdays  | Weekends  |
| 9pm to 8am        | 9pm to 10am | 2pm to 9pm | 11am to 9pm |
| **Lighting**       | 9pm to 10pm | 9pm to 10pm | 5pm to 9pm | 11am to 12pm and 5pm to 9pm |

2.4. Relative Consumption of Electric Energy

The RTQ-R defines Relative Consumption (RC) as the annual energy consumption (in KWh/m²) required for ambient cooling during the daily period from 9am to 8pm, throughout the year, with temperature maintenance at 24°C (INMETRO, 2012). The methodology compares the relative consumption for refrigeration of extended stay environments with the level of efficiency of the housing when the building is artificially conditioned, of informative character only and used to obtain a bonus for air conditioning.

In this research, it was only taken into account the estimated annual and monthly electricity consumption of artificially conditioned environments in the standards established by RTQ-R (INMETRO, 2012). In order to obtain these consumptions, the simulations were performed in the artificially conditioned condition (HVAC), for the whole year (8,760 hours) considering people, equipment and lighting according to the standards of RTQ-R. Initially the total relative consumption was analyzed, adding the consumption of equipment and lighting and air conditioning. Finally, the HVAC system was analyzed, subtracting the consumptions related to lighting and the equipment of the total estimated consumption, in order to verify the energy demand for the future climate scenarios.

3. Results

3.1. Future Climate Files

After using the CCWorldWeatherGen tool, the climatic files were obtained in the EPW extension, referring to the three projections analyzed (2020, 2050 and 2080) for the city of Cuiabá. From these archives, it was possible to generate graphic elements of which climate variables would be most vulnerable to the effects of global warming. These variables are: Dry Bulb Temperature (DBT, in °C) and Relative Humidity (RH, in %). In Cuiabá, the results of the simulations showed that future climatological effects will cause an increase in monthly temperature averages and a decrease in relative humidity, corroborating the studies of Rubio-Bellido; Pérez-Fargalho and Pulido-Arcas (2016); Triana, Lamberts and Sassi (2018).

The average annual temperature increased by 21.50% up to the 2080 scenario, when compared to the Base Scenario (1961-1990). The annual average temperature in the current scenario is 26.73 °C, increasing to 28.24 °C in the time-slice 2020 (2011-2040), to 29.90 °C in time-slice 2050 (2041-2070) and to 32.48 °C in the time-slice 2080 (2071-2100). The hottest months are the months of October, December and January, with monthly averages of 28.89 °C, 27.70 °C and 27.55 °C, respectively, increasing to 30.78 °C (+6.53%), 28.87 °C (+4.16%) and 28.73 °C (+4.30%) in the time-slice 2020; to 32.62 °C (+12.89%), 30.26 °C (+9.21%) and 29.87 °C (+8.42%), in the time-slice 2050 and to 35.34 °C (+22.30%), 32.52 °C (+17.52%) and 31.81 °C (+15.47%) in the time-slice 2080, respectively (Figure 6).

The relative annual air humidity decreased by 22% from the Base Scenario to the 2080 scenario. The annual average base is 69.08%, increasing to 64.75% in 2020, 60.41% in 2050 and 53.67% in 2080. The months of March, February and January are the most humid in the Base Scenario, with relative humidity of 78.32%, 76.70% and 75.79%, respectively. In future projections, the humidity decreased to 74.33% (-5.08%), 74.68% (-2.63%) and 73.79% (-2.64%) in 2020, to 72.26 (-7.73%), 71.70% (-6.53%) and
71.79% (-5.28%) in 2050 and to 67.26% (-14.12%), 67.69% (-11.74%) and 68.76% (-9.28) in 2080, respectively (Figure 7). It should be noted that this reduction is directly related to the increase in mean air temperature.

Figure 6: Air temperature in the base scenario and future scenarios

These conditions are also found in Rubio-Bellido's work; Pérez-Fargallo and Pullido-Arcas (2016). The authors state that average annual air temperatures will increase by 4.0 °C and relative air humidity will decrease by 5% in all bioclimatic zones of Chile until the 2080 scenario. Comparing the results obtained between the authors and the present study, the difference between the average air temperature increases is 1.75 °C (5.75 °C in Cuiabá and 4.0 °C in Chile) and relative humidity is 11% (-16% in Cuiabá and -5% in Chile). Comparisons with other studies corroborate the results presented, generating reliability of the future climate files, showing that the methodology used has a reliable tendency in its applicability.

3.2. Relative Consumption of Base Housing for the Current Scenario (1961-1990) and Futures (2020, 2050 and 2080)

It was verified that the variation in the electric energy consumption occurred only in the demand for artificial air conditioning (HVAC), remaining constant the consumption of the lighting system and equipment. The total relative (monthly) consumption of the typologies was analyzed, when adding the consumption due to lighting, equipment and air conditioning. It should be emphasized that the consumption values are relative consumption, established based on the use and operation schedules of the RTQ-R, and therefore are not actual consumption.

The Tbase typology presented the highest values of energy consumption in the base scenario in relation to the other typologies, presenting total annual consumption of 4,363 kWh. In the base scenario, the months of December and July presented higher and lower values of energy consumption, being 451 kWh and 236 kWh respectively. These results are found in future climate scenarios, with an increase in energy consumption of 16%, 25% and 37% in December, for the scenarios of 2020, 2050 and 2080 respectively. In July, this increase in consumption was 8%, 23% and 52%, respectively (Figure 8).

With the reduction of the thermal transmittance of the external walls, the typology T1 presented total annual consumption of 3,499 kWh in the base scenario and 4,006 kWh, 4,286 kWh and 4,649 kWh in the 2020, 2050 and 2080 scenarios, respectively. Presenting a difference of 864 kWh in relation to Tbase, in the base scenario. As in the Tbase typology, the months of December and July presented higher and lower values of energy consumption, but with lower values in relation to Tbase. Thus, the month of December presented energy consumption of 382 kWh in the base scenario, increased by 12%, 18% and 22%, in the scenarios of 2020, 2050 and 2080. In July, energy consumption values of 183 kWh were obtained in the base scenario, increasing to 187 kWh in 2020, 199 kWh in 2050 and 241 kWh in 2080 (Figure 9). The T2 and T3 typologies had the same thermal transmittance values, being 1.19W/m²K in the external walls, thus, the energy consumption values were similar. In the base scenario, both typologies T1 and T2 presented values of total annual energy consumption of 3497 kWh. However, in
the scenarios of 2020, 2050 and 2080 the typologies presented differences in total annual consumption. The thermal insulation of rockwool (T2) presented lower values of energy consumption in relation to glasswool (T3), with values of 4,010 kWh and 4,005 kWh in 2020, 4,297 kWh and 4,298 kWh in 2050 and 4,692 kWh and 4,679 kWh in 2080 respectively. The months of December and July presented higher and lower values of energy consumption in the scenarios for both typologies. Thus the month of December presented consumption of 382 kWh in the base scenario, 428 kWh in 2020, 449 kWh in 2050 and 468 kWh in 2080, for both typologies. In July, typologies T2 and T3 presented similar values, of 182 kWh in the base scenario, 188 kWh in 2020 and 199 kWh in 2050. In the scenario of 2080, T2 presented consumption of 254 kWh and T3 of 243 kWh, obtaining a difference of 11 kWh (Figures 10 and 11).

This increase in the energy consumption in the typologies can be justified by the increase of the external air temperature, increasing consequently the values of the internal air temperature of the typologies. It is noteworthy that the month of December presents external air temperature of 27.7 °C in the base scenario, increasing to 32.56 °C in 2080. The month of July suffers the same influence of global warming, having a temperature of 23.36 °C in the base scenario, increasing to 29.41 °C in 2080. Analyzing only the energy demand of the air conditioning (HVAC), the constructive interventions obtained lower values of energy consumption, however, the typologies T2 and T3 presented similar values of energy demand. In the Tbase, HVAC energy demand at the base scenario was 3,693 kWh, increasing by 22% in the 2020 scenario, by 37% in the 2050 scenario and by 54% to 5,693 kWh by 2080 (Figure 12).
Figure 12: Energy demand of the air conditioning system (HVAC) in each typology

Considering the constructive interventions, the T1 typology presented HVAC energy demand of 3,499 kWh in the base scenario, increasing by 14%, by 22% and by 33%, in the scenarios of 2020, 2050 and 2080, to 4,006 kWh, to 4,286 kWh and to 4,649 kWh respectively. The T2 and T3 typologies presented similar behavior, with HVAC demand in the base scenario of 3497 kWh, rising to 4.697 kWh in 2080, increasing about 34% in both scenarios. However, the typologies T2 and T3 presented lower values of energy consumption of HVAC when compared to Tbase. The difference is 196 kWh in the base scenario and 1,014 kWh in the scenario of 2080.

In this way, the results show that the effects of global warming modified the energy consumption for all studied typologies. However, the insertion of the thermal insulation in the external walls (T1 to T3), presented lower values of consumption in the base scenario and in the future climatic projections, mainly the insulation of rockwool and glasswool.

4. Conclusions

The effects of global warming as well as climate change result in a potential threat to the energy behavior of buildings, directly affecting the conditions of habitability and thermal comfort. In this way, the climatic data of the place of implantation of a building are important parameters to evaluate this behavior. Future climate prospecting is also required to plan habitability, thermal comfort conditions and energy consumption.

The results showed that the dry bulb temperature increased by 21.51% in the 2080 scenario in relation to the baseline scenario and the relative humidity decreased by 22.31% in the 2080 scenario compared to the baseline scenario. Total energy consumption increased progressively in scenarios and typologies. The highest values and increases in consumption were in the Tbase typology, of 4,363kWh in the base scenario, increasing by 46% in 2080. With the constructive interventions there was a reduction of 864 kWh in the consumption of T1 in relation to Tbase for the base scenario and of 1,714 kWh for the 2080 scenario. The typologies T2 and T3, presented similar behavior in the scenarios and, consequently, similar reduction values. The air conditioning system (HVAC) has undergone variations in the scenarios, due to the increase of external temperatures and, consequently, internal temperatures. However, the insertion of the thermal insulation in the external walls showed a reduction in the energy demand of the typologies, mainly for the future climatic scenarios. Finally, by incorporating the effects of global warming, the current conditions are even more compromised, contributing negatively to the energy consumption of the typologies and, consequently, habitability. The proposed interventions for external walls resulted in improvements in energy consumption and energy demand. With the increase of the thermal transmittance, the typologies T1, T2 and T3 demonstrated better levels of adaptability in the future scenarios.
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