Adaptive comfort assessment for different thermal insulations for building envelope against the effects of global warming in the mid-western Brazil

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Abstract. The consequences of global warming have gained worldwide importance, also in the scope of built environment when related with the thermal comfort conditions of users. In this way, the objective of this research is to analyse the effects of global warming on the hours of thermal comfort of dwellings, with different thermal insulators in the external walls, considering the emission scenario A2 of the Fourth Assessment Report (AR4) of the IPCC. The methodological procedures consist of four stages: preparation of climate files for Future Scenarios (2020, 2050 and 2080) from the base climate file (base scenario); definition of a dwelling for study object (Tbase); preparation of thermal insulating intervention proposals, such as: EPS (T1), rock wool (T2) and glass wool (T3) and evaluation of thermal comfort conditions using the adaptive thermal comfort method. The results indicate that the air temperature increases by 21.5% and the relative air humidity reduces by 22% until the 2080 scenario if compared to the base scenario. From these new conditions, the percentages of Tbase comfort hours suffer a reduction of 63.61%, increasing the hours of heat discomfort by 98.48%, in the scenario of 2080 in relation to the base scenario.

With the adoption of insulation, the T1 typology presented comfort hours of 58.4%, reducing to 17.9%. However, typologies T2 and T3 presented similar behaviour, with 27.2% of hours in comfort and 67.4% of hours in heat discomfort, in the 2080 scenario in relation to the baseline scenario. Therefore, it can be concluded that typologies T2 and T3 presented greater resilience to the effects of global warming, but it is necessary to incorporate constructive interventions to absorb the impacts of climate changes and provide better conditions of thermal comfort.

Keywords: Climate changes. Built Environment. Thermal comfort.

1. Introduction

Scientific research evidences a progressive increase of terrestrial temperature as one of the present transformations of the planet. Different studies, such as Duursma [1], point out that between the end of the 19th century and the beginning of the 20th century, the temperatures showed quite invariable behaviour. Marengo and Soares [2] estimated an addition of 0.85°C, every 100 years, in the Amazon region. Casagrande and Alvarez [3] points out that since the 1920s, there has been an increasing trend...
of temperatures, with an addition of 0.8 °C in the year 2000, compared to the averages of the period 1961-1990.

Knowledge about climate change, motivated by anthropogenic actions and based on greenhouse gas (GHG) emissions, has been developed by the Intergovernmental Panel on Climate Change (IPCC). The IPCC has published scientific reports, on which scientists from a wide range of fields base their research on the behaviour of terrestrial ecosystems. In 2007, IPCC released the results of its Fourth Climate Change Assessment Report (AR4). The results are based on three working groups, which elaborate models of GHG emissions and their respective impacts on global warming. The scenarios are divided into four families, called A1, A2, B1 and B2, where 'A' and 'B' mean low (pessimistic) and high (optimistic) commitment to sustainable development, and '1' and '2 ', regional integration or fragmentation, respectively [4]. The GHG emissions scenarios developed by the IPCC are future conditions with similar demographic, social, economic and technological histories. This report highlights that most of the temperature increase events observed in the last 50 years were caused by anthropogenic actions, and alert for 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 [4].

It is known that the thermal energy performance of buildings depends on the climate they are exposed [5] and new climatic conditions influence and impose new impacts on buildings and user thermal comfort [6]. Considering that the useful life of a building is 50 to 75 years [7], it is inferred that the performance of the current buildings will be affected by the expected climate changes for the coming decades. Nico-Rodrigues et al. [8], suggest that adopting guidelines that consider the relationships between climate and humans is essential to define dwellings with adequate thermal comfort. Therefore, it is necessary to update the climatic data from the survey by IPCC emission scenarios and verify the current performance of buildings in the future environmental conditions. Thus, researches that address climate change have acted in the simulations of thermal and energetic performance of buildings through the effects of heating, obtaining as a result conditions of comfort of the internal environments, consumption of electric energy [9,10] and passive design strategies to provide better housing conditions [11,12,13].

In this way, the mitigation of climate change effects has been a guideline of public policies in many countries and, researches to adapt the buildings to the new climatic scenarios has been developed in several areas of construction field. Therefore, this work has as general objective to analyse the effects of global warming on the hours of comfort and thermal discomfort of the dwellings with different thermal insulation, for mid-western Brazil.

2. Methodology

2.1. Elaboration of future climate files

The survey of published researches, on scientific platforms on studies of future climate projections, made possible the knowledge of the methodology indicated by the IPCC for the elaboration of climatic archives, with influence of global warming [9, 10, 11, 12, 13 14]. By means of these literature the morphing methodology published by Belcher, Haker and Powell [15] for the elaboration of the future climate archives was chosen. This methodology modifies a set of historical climatic variables (1961-1990) of 8,760 hours per year, without the influence of urbanization and incorporates the effects of global warming on the climatic archives, thus obtaining projections of future climatic data. The process used by this method evidenced the complexity in developing future climate scenarios with the vision of application in simulation software for buildings. In order to facilitate and consolidate the aforementioned algorithmic operations, the Sustainable Energy Research Group (SERG) from the University of Southampton in the United Kingdom has developed the "Climate Change World Weather Generator" (CCWorldWeatherGen) tool incorporated into Excel Software. This tool uses the emission scenario A2 from the IPCC Fourth Report (AR4), for time-slice 2020 (period 2011-2040), 2050 (period 2041-2070) and 2080 (period 2071-2100).
2.2. Definition of the study object

A standard single-family housing (Tbase), located in the city of Cuiabá, Brazil, with a total area of 39.18 m², containing the Living Room/Kitchen (17.44 m²), Bedroom 1 (7.78 m²), Bedroom 2 (7.57 m²) and Bathroom (1.75 m²) as shown in Figure 1. The house has a gable roof with eaves of 30 cm. The ceiling is 3.00 m high.

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 1.10 m (living room), 1.20 x 1.10 m (Bedrooms 1 and 2) and 1.20 x 1.10 m (Kitchen). The external doors are made of metal sheet and the internal doors are made of wood. The vertical and horizontal closures were defined by the Brazilian standard NBR 15.220 [16], 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.

![Figure 1: Study object (Tbase)](image)

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

Proposals for constructive interventions were inserted in Tbase, with the purpose of analysing the influence of thermal insulation on thermal comfort. Without modifying the Tbase cover materials,
thermal insulation was inserted inside the outer walls, with Expanded Polystyrene (EPS) composing T1, Rock wool in typology T2 and glass wool in typology T3, all of them with thickness of 2.50cm.

2.3. Adaptive comfort conditions according to De Dear and Brager methodology (1998)

Standard 55 (ASHRAE, 2013) presents an index based on the studies of adaptive thermal comfort proposed by De Dear and Brager [17]. The method can be applied to naturally ventilated buildings, considering occupancy and internal sources of heat to better represent the users comfort condition in the buildings. The comfort levels are established by the ideal indoor operative temperature or the monthly neutral temperature (Tn, in °C) related to the monthly averages outdoor temperature (TEmed., in °C), according to Equation 01. It is emphasized that the equation is valid for TEmed between 10.0°C and 33.5°C.

\[ Tn = 17.8 + 0.31 \times TE_{med} \]  

Equation 01

After determining the neutral temperature, ASHRAE establishes a comfort temperature range for 80% or 90% of satisfied users. The bands are determined by upper and lower limits given by Tn+Tolerance and Tn−Tolerance, respectively and the indoor operative temperature (Top), representing the interval for 80% of satisfied users of Tn−3.5 and Tn + 3.5 and to 90% of satisfied users of Tn−2.5 and Tn+2.5. With the monthly ideal indoor operative temperatures, it is possible to quantify the hours of discomfort by heat or cold and thermal comfort inside the building, for the current scenario and future climate projections. Therefore, this study considered the range of 90% of satisfied users, as well as Alves [16], and Tateoka and Duarte [18]. In addition to these studies, Sánchez-García et. al [19] used this methodology to investigate adaptive comfort in Southern Spain.

3. Results

3.1. Air temperature and relative humidity

For Cuiabá, the results of simulations showed that future climatic effects caused an increase in monthly temperature averages and a decrease in relative humidity, corroborating the studies from Triana, Lamberts and Sassi [20]. The average annual temperature increased by 21.50% up to the 2080 scenario, when compared to the Base Scenario. The average annual temperature in the current scenario is 26.73 °C, going to 28.24 °C in the 2020 scenario, to 29.90 °C in the 2050 scenario and to 32.48 °C in the 2080 scenario (Figure 2-a). Relative annual air humidity decreased by 22% from the Base Scenario for the 2080 scenario. The annual average base is 69.08%, rising to 64.75% in 2020, 60.41% in 2050 and 53.67% in 2080 (Figure 2-a and b).

![Figure 2: a) Dry bulb temperature (°C) and b) Relative humidity (%)](image-url)
The increase in mean annual dry bulb temperatures was estimated at 1.51°C in the 2020 scenario, 3.17°C in the 2050 scenario and 5.75°C in the 2080 scenario. Annual average relative humidity decreased by 4.33% in the 2020 scenario, 8.67% in the 2050 scenario and 15.40% in the 2080 scenario. It has been found that the increase of dry bulb temperature is more significant between the 2050 and 2080 scenarios, as well as the reduction of relative humidity.

3.2. De Dear and Brager scenarios: Base (1961-1990) and Future (2020, 2050 e 2080)

The annual percentages of satisfied and unsatisfied hours by cold and heat were quantified for the four typologies of dwellings and for the four study scenarios. The base typology (Tbase) presented increased hours of heat discomfort and reduced hours of cold discomfort, as well as the hours of comfort for the 2080 scenario. In this way, Tbase showed a variation of +35.15%, +65.88% and +98.48% of the hours of heat discomfort, -21.22%, -37.95% and -59.46% of the hours of cold discomfort and -22.71%, -42.99% and -63.61% of the comfort hours, respectively, in the scenarios of 2020, 2050 and 2080, demonstrating the need to adapt the dwellings for mitigation effects of global warming (Figure 3).

By adopting the thermal insulation and comparing with the base case, the dwellings presented higher satisfaction hours of comfort in the scenario of 2080 and, consequently, they obtained greater resilience to the increase of the outdoor temperatures. In the base scenario, the typologies with thermal insulation in the external walls, such as T2 and T3, presented higher satisfaction hours of comfort, 5,242 (59.8%) and 5,242 (59.8%), reducing both 2,383 (27.2%) hours in the 2080 scenario. It should be noted that the rock wool and glass wool insulators did not show differences in the percentages of comfort hours, as well as in the hours of heat and cold discomfort, presenting similar results for the four scenarios analysed. The typology with thermal insulation of EPS (T1) presented 5,151 (58.4%) of satisfied hours for comfort, reducing to 2,179 (24.9%) in the 2080 scenario.

Figure 3: Hours of comfort and discomfort for dwellings: a) in the Base Scenario, b) 2020, c) 2050 and d) 2080.
By means of the neutral temperatures obtained from the monthly averages of Te,med, for the Base Scenario and the scenarios of 2020, 2050 and 2080, it was possible to verify the thermal comfort temperature ranges, considering the satisfaction band of 90% of the users. In the Base Scenario, the adaptive comfort range ranged from 22.54°C to 29.26°C. Thus, the thermal comfort conditions of Tbase were above the tolerance range for 90% of users, presenting discomfort in 16.6% of the year. It is noteworthy that Tbase average indoor temperature was higher than 29.2°C in the months of October and December. The other typologies accompany the behaviour of the comfort range, remaining between the upper and lower limits (Figure 4-a).

![Figure 4: Building comfortable temperatures ranges: a) in the Base Scenario, b) 2020, c) 2050 e d) 2080.](image)

In the 2020 scenario the comfort range increased by +0.58°C compared to the current scenario, changing from 23.01°C to 29.84°C. Tbase presented conditions of thermal discomfort in 58.3% of the year, increasing by +40% in relation to the Base Scenario. With the increase of TE,med, T1 presented conditions of thermal discomfort in 41.66% of the year, being more representative in the month of October with Ti,med of 30.55 °C. The other typologies (T2 and T3) presented thermal discomfort in 25% of the year (Figure 4-b). In 2050, the comfort range increased by +1.15°C compared to the Base Scenario, rising to 23.51 °C at 30.41 °C. Tbase's annual thermal discomfort increased by +78% from the Base Scenario to 91.6% of the year. This increase is also verified in the other typologies, presenting discomfort in 58.3% in T1 and 50% in T2 and T3 in the scenario. It should be noted that Tbase provided
thermal comfort conditions only in June and July (Figure 4-c). Finally, in the scenario 2080 (2071-2100), the comfort range increased by +1.50°C, when compared to the Base Scenario, from 24.41°C to 30.76°C. It was verified that in this scenario, T_base presented thermal discomfort during all year, except for the month of July. The other typologies presented thermal discomfort of 66.6% of the year, providing thermal comfort only in the months of May, June, July and August (Figure 4-d). This increase in the thermal discomfort of the typologies can be justified by the significant increase of T_e,med over +5.5°C, directly affecting the comfort conditions inside the dwellings, resulting in T_i,med above 30.0°C in the scenario.

4. Conclusions
The effects of climate change due to global warming have affected habitability and thermal comfort. In this way, the climatic data of the building implantation is an important parameter to evaluate its behaviour, also, the climatic forecast is significant for habitability planning and conditions of thermal comfort.

By means of the De Dear and Brager [17] model for naturally ventilated buildings, the behaviour of comfort and discomfort hours were similar, presenting an increase in the discomfort from heat and reduction of the discomfort from cold, as well as the reduction of the hours of comfort until the scenario of 2080. The hours of heat discomfort increased and cold discomfort reduced until the scene of 2080, when compared to the Base Scenario. The T_base typology, did not obtain conditions of thermal comfort in the scenario of 2080, due to the increase of outdoor temperatures. The typologies T1, T2 and T3 obtained better conditions of thermal comfort in the scenario of 2080, with 24% of hours of comfort. It is concluded that the adaptation of the typologies by means of constructive interventions becomes important to achieve thermal resilience and provide comfort conditions until the scenario of 2080.

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