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GREEN ROOFS: ANALYSIS OF THE THERMAL PERFORMANCE OF AN EXTENSIVE SYSTEM COMPARED TO A ROOF WITH CERAMIC TILE IN THE CITY OF PALMAS-TO

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ABSTRACT

This study compared the thermal performance of green roofs and ceramic tiles, evaluating thermal transmittance and thermal comfort in accordance with the ABNT NBR 15.575-5:2013 and ABNT NBR 15.575-1:2013 standards. The analysis was carried out using the simplified procedure, with the calculation of thermal transmittance in both roofs, and the on-site measurement procedure, which involved collecting the air temperature in the prototypes for three consecutive days. In addition to the methods provided for by the standard, the parameters of relative humidity and the temperature of the black globe were also analyzed, through the interpretation of graphs with the data collected during the measurement period. The results showed that the green roof had a lower thermal transmittance compared to the ceramic tile, indicating better thermal insulation. However, both coverages did not meet the minimum performance requirements of the standard. The in-situ measurement revealed that, although the green roof provides greater thermal comfort, no model was able to guarantee internal temperatures lower than external temperatures during the entire

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collection period. The research suggests that optimizing materials, such as increasing the thickness of components such as plywood, could improve results and meet the criteria required by the standard.

Keywords: Green Roof, Thermal Performance, Ceramic Tile, Civil Engineering, Architecture and Urbanism.

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INTRODUCTION

The phenomenon of urbanization is a global trend characterized by the exponential growth of urban areas and the imposition of an inevitable expansion over territories not yet explored. This movement demands a profound reconfiguration of cities, as well as their urban policies, with the purpose of mitigating the growing environmental challenges that arise as a result of this process (Coelho, 2019).

Among the environmental problems resulting from the scenario mentioned above, the increase in air temperature in urbanized areas stands out. Regarding the above, Coelho (2019) states that this phenomenon is due to the presence of vast areas with impermeable coatings, such as roads, sidewalks, vertical structures and building surfaces. Santos (2012) corroborates the above by stating that with the expansion of urban centers, there is a reduction in green spaces, which are replaced by concrete and steel structures, retaining more heat throughout the day.

With the emergence of new environmental problems, concepts and demands, the civil construction area identified the need to adapt its planning and execution methods, its project models and its standards, to reverse the consequences of great urbanization. In relation to the critical increase in air temperature, Almeida (2019) points out that ABNT NBR 15.575:2013 - Residential buildings - Performance, in its parts 1, 4 and 5, addresses how thermal performance is an important requirement to keep the building habitable, directly interfering with the well-being of the user.

With the increasing emphasis on the thermal performance of buildings and the urban environment, it seeks to employ sustainable solutions that positively influence both the comfort of building occupants and the well-being of the population in general. As defended by Coelho (2019), green roofs emerge in this scenario as an ecological alternative to conventional roofs, due to their proven ability to reflect most of the heat that falls on them.

From an environmental point of view, green roofs contribute significantly to the improvement of air quality, the reduction of the effects of urban heat islands, and the minimization of river flows (Baldessar, 2012). This statement confirms that the green roof system has economic advantages, sustainable interferences in the urban scenario, and advantages in the global ecosystem in the long term.

To explore the performance of a construction system, Caldas and Carvalho (2018) suggest the comparison between two materials, models or methods for an effective analysis, since this type of evaluation is considered assertive and is recurrently used. Thus,

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in order to explore the thermal behavior of the green roof system, it was decided to compare it with a ceramic tile roof, which, according to Lopes (2007), is among the three most used types of roofs in Brazil.

The data collection region chosen for this study was the city of Palmas, in the state of Tocantins. Despite being the youngest among Brazilian capitals and holding the title of "Ecological Capital", its green areas were neglected both in urbanization and in the city's expansion process (Paz, 2009).

Freitas and Souza (2016) in their study on the climate of Palmas-TO concluded that the city presents climatic variations with a tendency to the prevalence of high temperatures during the dry season. This result justifies the interest of the study in the region, as it demonstrates the importance of understanding local climatic characteristics for the development of strategies for adaptation and improvement to climate change.

In view of the above, the objective of this work is to analyze the thermal performance of extensive green roofs and conventional roofs with ceramic tiles in Palmas-TO, in order to verify which construction system provides better performance, according to the analysis of the collected data comparing them with the minimum requirements established in ABNT NBR15.575:2013.

METHODOLOGY

In order to analyze the thermal performance of the roof in prototypes with green roofing and with ceramic roofing, according to the ABNT NBR 15575:2013 Performance Standard, this chapter presents the methodological procedures carried out in the research.

GREEN ROOF CONSTRUCTION

To carry out the data collection, two existing prototypes located at the Federal University of Tocantins campus of Palmas were used, which are framed in figure 1A and visible in figure 1B.

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Figure 1: Location of the prototypes.

Source: Authors (2024) adapted from Google Maps.

The prototypes were built by Gonçalves, Oliveira and Omena (2022) for the development of the article "Comparisons in thermal performance between ceramic tile prototypes and concrete tiles in Palmas-TO", published in the magazine Sítio Novo in 2022. According to Gonçalves, Oliveira and Omena (2022, p.142):

> The prototype project has internal dimensions, in plan, of 1.5 x 1.50 m, (area of 2.25m²) and height of 1.5 m, which results in an internal volume of approximately – 3.4m³ (figure 2). The walls were built with eight-hole ceramic brick with dimensions 9 x 19 x 19 cm, laid with common mortar in 1/2 time, covered with mortars on the internal and external sides, and with a concrete subfloor 5 cm thick (Gonçalves, Oliveira, Omena, 2022, p.142).

The two existing prototypes have the same solar orientation, to the north, a distance of 5 meters from each other and no incidence of shadow (Gonçalves, Oliveira, Omena, 2022). The doors had to be remanufactured and were made with wood, to avoid any external interference on the measuring device during the registration period. In both prototypes there is a metal structure built, and in the prototype where there were the concrete tiles, all of them were removed for the installation of the green roof.

For the construction of the green roof, the dimensions of the existing prototype were measured, with this it was possible to verify that the metal structure where the box would be installed is 1.90 wide by 1.90 long. The 55 boxes presented in figure 15 were then built, for which wooden boards were used, totaling 1.90 wide by 1.90 long and 20 cm high.

After the assembly of the box, it was also waterproofed using a white rubberized liquid blanket for roofs and slabs of the Hydronorth brand. 3 coats of the product were applied, respecting the drying time between the layers and the final curing time before starting the assembly of the cover inside the box.

After the installation of the box, the assembly of the green roof layers began. The drainage layer was executed using expanded clay. Then the filter layer was installed, which

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was developed using a bidim geotextile blanket, covering all the expanded clay. With the filter layer properly installed, the penultimate layer of substrate was disposed.

For an optimal result in the planting of emerald grass, a survey was carried out among the gardening companies operating in the city, and it was concluded that the premium Mogifertil substrate would be a great option. The soil was then poured and spread evenly over the entire length of the bidim blanket, forming a 5-centimeter layer. Finally, emerald grass was planted on the substrate.

Figure 2A shows the installation of the vegetation cover in the prototype, along with the representation of the door in plywood, produced to improve safety and accuracy in data collection. In the second prototype, which has a ceramic roof, the installation of the door in plywood was the only intervention needed, as can be seen in figure 2B of the prototype with ceramic tiles.

Figure 2: Prototypes of the study.

Source: Authors (2023).

ON-SITE MEASUREMENT

Data collection inside the prototypes was carried out using two digital globe thermometers with Datalogger, model HMTGD-1800, from Highmed. The devices comply with ISO 7243:2017 standards - Ergonomics of the thermal environment - Evaluation of thermal stress using the WBGT index (wet bulb and globe temperature) and ISO 7726:1998 - Ergonomics of the thermal environment - Instruments for measuring physical quantities.

Both devices were calibrated and configured before data collection, and according to the instructions of ABNT NBR 15.575:2013. It should be noted that the devices were

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centered inside each prototype at a height of 1.20m with the aid of a tripod. For data storage, the equipment's own software, named Heat Stress WBGT Meter, was used.

As instructed by ABNT NBR 15.575:2013, the measurement was carried out for three consecutive days. The data from the first two days served as validation of the similar characteristics and those from the third day were actually analyzed and compared with the external values. The external temperature data were made available by LabMET/UFT - Meteorology and Climatology Laboratory of the Federal University of Tocantins.

The measurements were carried out from October 2 to 4, 2023, from 6:40 am to 7:10 pm, with a 30-minute interval between each record. The choice of the collection date was due to the occurrence between September 17 and 28 of a heat wave driven by *El Nino* that generated high temperatures and variations in climatic characteristics. Therefore, it was decided not to perform the measurement during this period and waited another 3 days, to then collect the necessary data.

For the analysis of the thermal performance of the roofs, the indoor air temperature (AT) data collected by the thermometers were compared with the outdoor air temperature values collected and provided by LabMET/UFT. The results were analyzed according to the summer conditions, stipulated by ABNT NBR 15575-1:2013.

For the enrichment of the work, the data of Relative Humidity (% RH) were also compared and analyzed with the values of Black Globe Temperature (TG) collected. The evaluation of the results was not based on specific standards, but on the application of concepts related to the interactions between thermal parameters and on the thermal comfort studies that were conducted during the elaboration of this research.

SIMPLIFIED PROCEDURE

The simplified procedure is carried out by calculating the thermal transmittance (U) for roofing, which is a horizontal sealing system. The materials used in the construction of the green roof were then detailed and especially for the canvas and waterproofing elements, the approximate value of 1 mm thickness was considered.

To calculate the thermal transmittance in the green roof, its layers and respective thermal conductivities of each material used were considered, with the exception of the vegetal layer composed of emerald grass. This is because the thermal conductivity value was not found in any NBR or ISO neither for emerald grass itself, nor for grasses in general nor for vegetation.

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Table 1: Thicknesses and thermal conductivity of green roof materials.

Madeira compensada	
e - Espessura de material sólido homogêneo (mm)	6
e - Espessura de material sólido homogêneo (m)	0,006
λ - Coeficiente de condutividade (W/m.K)	0,12
Impermeabilizante a base de resina acrílica	
e - Espessura de material sólido homogêneo (mm)	1
e - Espessura de material sólido homogêneo (m)	0,001
λ - Coeficiente de condutividade (W/m.K)	0,20
Lona preta (Polietileno de baixa densidade)	
e - Espessura de material sólido homogêneo (mm)	1
e - Espessura de material sólido homogêneo (m)	0,001
λ - Coeficiente de condutividade (W/m.K)	0,40
Argila expandida	
e - Espessura de material sólido homogêneo (mm)	30
e - Espessura de material sólido homogêneo (m)	0,03
λ - Coeficiente de condutividade (W/m.K)	0,16

Manta geotêxtil bidim (Poliéster)	
e - Espessura de material sólido homogêneo (mm)	3
e - Espessura de material sólido homogêneo (m)	0,003
λ - Coeficiente de condutividade (W/m.K)	0,40
Substrato (Terra úmida)	
e - Espessura de material sólido homogêneo (mm)	50
e - Espessura de material sólido homogêneo (m)	0,05
λ - Coeficiente de condutividade (W/m.K)	0,60
Vegetação (Grama esmeralda)	
e - Espessura de material sólido homogêneo (mm)	40
e - Espessura de material sólido homogêneo (m)	0,04
λ - Coeficiente de condutividade (W/m.K)	-

Source: Authors (2023).

Despite the impossibility of calculating the thermal transmittance of the vegetal layer, comparative studies such as that of Pereira and Masiero (2023) prove that the presence of this layer considerably influences the improvement of the thermal performance of the roof as a whole, through the absorption of heat and radiation and also due to the evapotranspiration process that the vegetation performs.

For the ceramic tile roof, the data presented in Chart 2 were considered. The calculation of the thermal transmittance was performed using the thickness of the tile measured in the field, which was 12 millimeters and the conductivity coefficient of 1.05 specified by ABNT NBR 15220-2:2005.

Table 2: Thicknesses and thermal conductivity of the green roof.

Telha cerâmica tipo plan	
e - Espessura de material sólido homogêneo (mm)	12
e - Espessura de material sólido homogêneo (m)	0,012
λ - Coeficiente de condutividade (W/m.K)	1,05

Source: Authors (2023).

According to the normative criteria, the maximum thermal transmittance value allowed for bioclimatic zone 7 is less than or equal to 2.3 W/m². K, for the case where the absorption to solar radiation of the external surface is less than or equal to 0.4, and less than or equal to 1.5 W/m². K, for the case where the absorption to solar radiation has a value greater than 0.4. These criteria are presented in table 3 presented above and represent a minimum coverage performance.

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According to ABNT NBR 15575-1:2013, the absorption value must be defined for the roofs according to the color of the external surface specified in the project. For the case of ceramic tile roofing and green roofing, the value of α = 0.3 will be used, referring to light colors. For the calculation, the values of internal and external surface thermal resistance shown in table 3 were also considered:

Table 3: RSI and RSE values.

Resistência superficial m²·K/W	Direção do fluxo de calor		
	Ascendente	Horizontal	Descendente
R_{si}	0,10	0,13	0,17
R_{se}	0,04	0,04	0,04

NOTA 1 Os valores de resistência superficial se aplicam às superfícies em contato com o ar. Nenhuma resistência superficial se aplica às superfícies em contato com outro material.

NOTA 2 Os valores de resistência superficial interna são calculados para $\varepsilon = 0,9$ e com h_{r0} avaliado a 20 °C. Os valores de resistência superficial externa são calculados para $\varepsilon = 0,9$, h_{r0} avaliado a 10 °C, e para $v = 4$ m/s.

Fonte: ABNT NBR 15220-2 (2023, p.13).

ANALYSIS OF THE RESULTS

SIMPLIFIED PROCEDURE

According to ABNT NBR 15.575-5:2013, if the thermal transmittance requirements and the minimum level of thermal performance are not met after on-site measurement, adaptations to the building must be made. Thus, it was observed throughout the development of the research that, because the prototypes only serve as a support to simulate a building and then be able to compare the performance between the green roof and the ceramic, the thermal transmittance value less than or equal to 2.3 served only as a reference for the calculations, and not as a guarantee of compliance or not with the standard.

Thermal Transmittance Calculation- Ceramic Tile

With the use of the data of thickness and conductivity coefficient of the ceramic tile, the calculations of thermal resistance (R) were first performed and then the calculation of thermal transmittance (U) for the ceramic tile. The respective results are summarised below:

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The thermal resistance value found was R = 0.011 m²· K/W; the calculation of total thermal resistance considering Rsi and Rse resulted in the value of RT = 0.221m². K/W; the calculation of thermal transmittance resulted in the value of U = 4.525 W/(m². K).

The result obtained was considerably close to the value of U = 4.55 W/m². K), thermal transmittance given by ABNT NBR 15.220-3:2005. The calculation was carried out in order to confirm the methodology and obtain a more precise value for comparison with the green roof, since the standard presents the generalized reference value independent of the ceramic tile model, and consequently, without specifying its thickness.

Calculation of thermal transmittance- Green cover

With the data of each component material of the green roof, it was possible to calculate the thermal resistance (R) of each material and later the calculation of thermal resistance (U) of the whole set forming the green roof. The results obtained are summarized below:

The calculation of total thermal resistance considering Rsi and Rse resulted in the value of RT = 0.385 m². K/W; the calculation of thermal transmittance resulted in the value of U = 2.597 W/(m². K).

Comparison between the thermal transmittance results obtained

Analyzing the results obtained, it was possible to affirm that the green roof provides greater thermal comfort in relation to the ceramic roof, justified by the fact that between the green roof and the ceramic tile, the former presented the lowest thermal transmittance (U = 2.597 W/m². K). As thermal transmittance expresses the rate of heat transfer through the element, the lower its value, the greater the comfort that that cover can provide.

Although the results show that the green roof favors an improvement in thermal comfort compared to the ceramic tile roof, neither of the two roofs met the minimum performance criterion according to ABNT NBR 15.575-5:2013. In order for the standard to be met, the thermal transmittance value, considering the absorption to radiation less than or equal to 4 and the bioclimatic zone 7, should have been less than or equal to 2.3 W/m².K.

It was observed during the calculations that plywood and substrate have the highest thermal resistance values, so by increasing the thickness of these materials it would be possible to reach a thermal transmittance value that meets the minimum performance criterion according to ABNT NBR 15.575-5:2013, as well as Misaka (2021) in his

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experiment to evaluate a green roof arrived at the thermal transmittance value U = 1.129 W/m². K, which fits the required parameters.

It is also noteworthy that during the calculation of thermal transmittance, the vegetal layer was not considered due to the absence of the conductivity coefficient for the calculation of thermal resistance. However, as previously mentioned, Pereira and Masiero (2023) proved in their study that the presence of vegetation contributes to increasing the thermal performance of the green roof. Therefore, the thermal transmittance value would have been even lower if this layer had been considered in the calculation, contributing to an even more favorable and assertive result.

ON-SITE MEASUREMENT

The in-situ measurement was carried out for three consecutive days as requested by ABNT NBT 15.575-1:2013 and data on internal air temperature, internal relative humidity, black globe temperature, dew point and wet bulb temperature were collected in each prototype, in addition to the external data made available by LabMET/UFT. However, to verify the conformity of the results obtained with the criteria requested by the standard, only the air temperature data from the third day of collection were used.

For a better visualization of the analyzed content, the values recorded on October 4 were inserted in graph 1, where the y-axis represents the amplitude of internal and external temperatures obtained in degrees Celsius and the x-axis represents the moment when the data was recorded.

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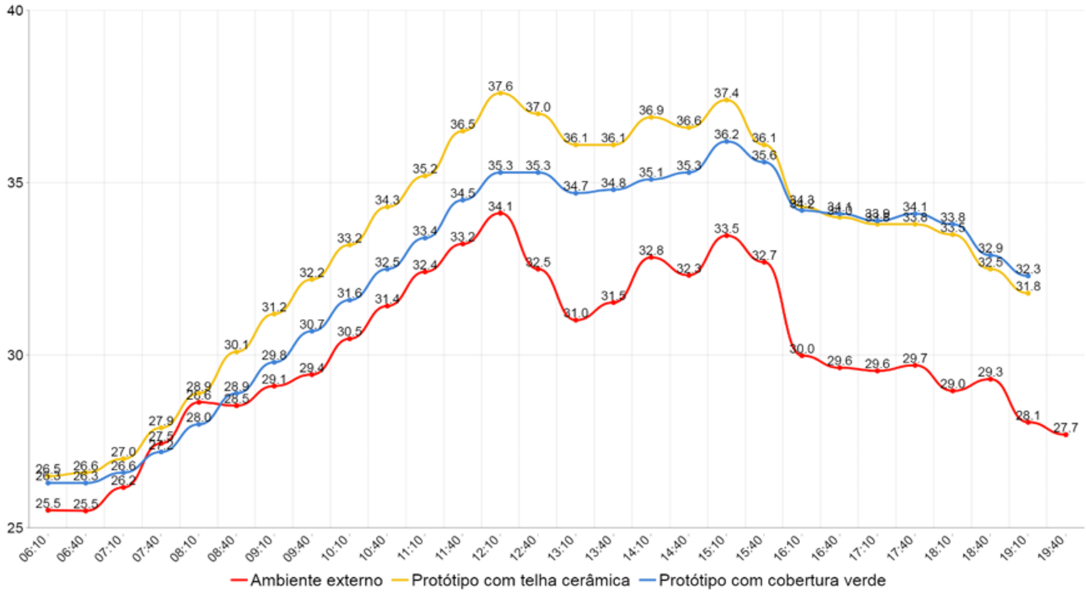
Graph 1- Air temperatures measured on October 04, 2023.



Source: Authors (2023).

According to ABNT NBR 15.575-1:2013, the requirement for a roof to minimally perform its thermal insulation function is that the air temperature inside the enclosures where there is greater permanence throughout the day is less than or equal to the maximum daily value of the outdoor air temperature.

On October 4, the maximum recorded in the external environment was 34.10 ºC at 12:10 pm. In the prototype with ceramic tile roofing, the internal maximum recorded was 37.60 ºC, also at 12:10 pm, while in the prototype with green cover, the maximum reached was 36.20 ºC at 3:10 pm.

Since the internal temperature in both prototypes remained higher than the external temperature for most of the collection period, with the exception of a period between 07:40 hours and 08:40 hours where the internal temperature of the prototype with green cover remained below the external temperature, the thermal performance of both roofs was evaluated as unsatisfactory, because none of them could satisfy the condition of minimum summer performance where Ti,max. ≤ Te,max.

TEMPERATURE, HUMIDITY AND AMPLITUDE ANALYSIS

The air temperature data for the 2nd, 3rd and 4th are respectively displayed in graphs 2, 3 and 4. Graph 4 has the same data previously presented in graph 1, however, as these are different analyses, it was decided to include it again in this topic to facilitate the projection of comments.

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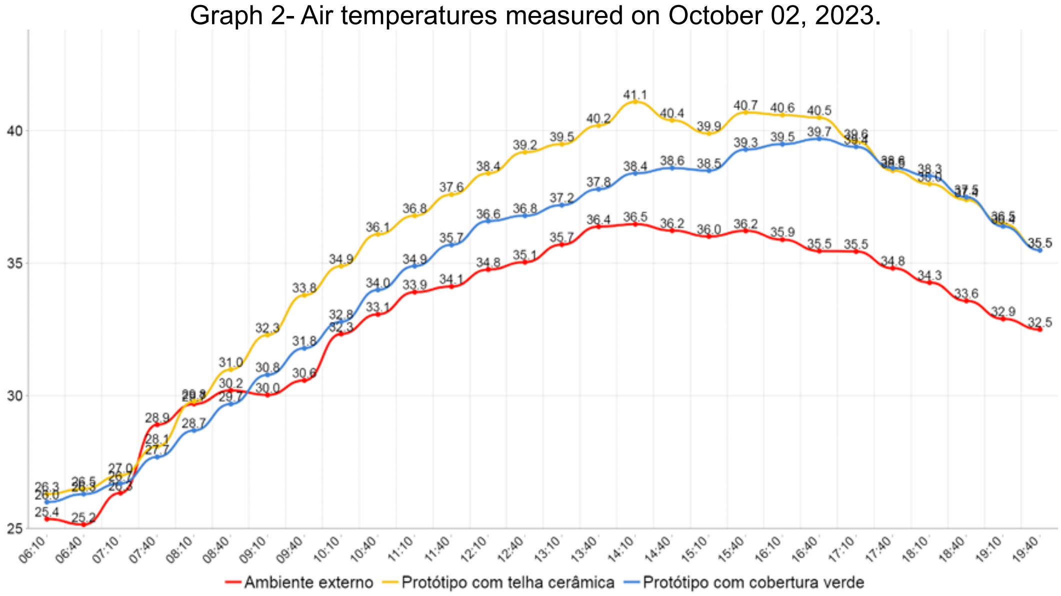
Graph 2- Air temperatures measured on October 02, 2023.



Source: Authors (2023).

On the first day of measurement, data collection began at 6:10 a.m. and ended at 7:40 p.m., on the second day data collection began at 6:40 a.m. and ended at 7:10 p.m., and on the third and last day of data collection, data began to be recorded at 6:10 a.m. and ended at 7:10 p.m. Such variation occurred due to external motivations, so for a correct analysis by data comparison, only the records of the period between 6:40 am and 7:10 pm were considered on all days.

On the first day of measurement (10/02/2023) there was the highest external temperature recorded among the three days, this occurred at 14:10 and had a value of 36.5 ºC. While the prototype with ceramic tile followed the increase in parallel, reaching a maximum internal temperature of 41.10 ºC also at 14:10, the prototype with green cover continued to increase its internal temperature with less aggressiveness, so that the highest temperature recorded occurred just two and a half hours later, at 4:40 pm, with a value of 39.7 ºC.

The lowest maximum temperature was recorded on the second day of measurement (10/03/2023) at 1:10 pm with a value of 33 ºC. The graphs show that the hottest day was also the one that maintained the highest linearity with less temperature variation throughout the day, while the third and fourth days of measurement had temperature peaks and declines varying after 11:40 am.

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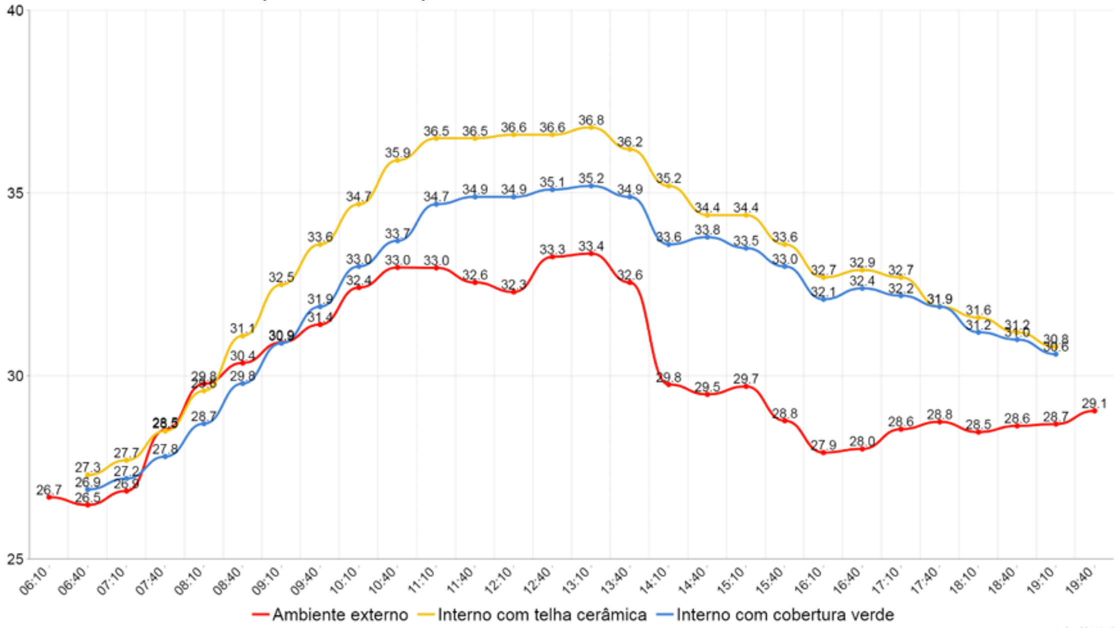
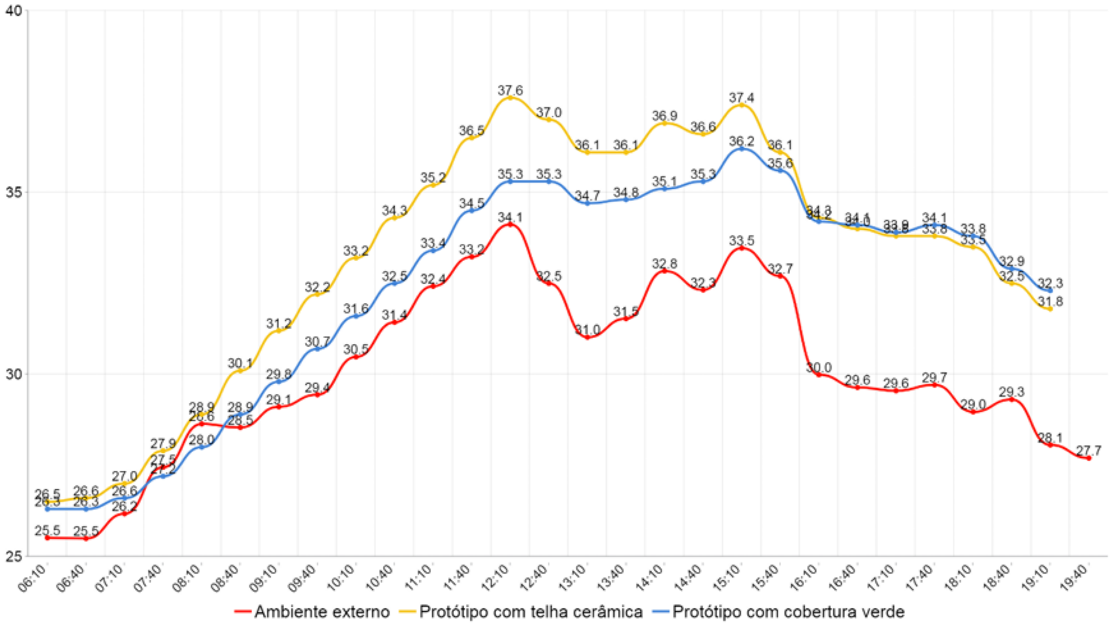
Graph 3 - Air temperatures measured on October 3, 2023.



Source: Authors (2023).

By analyzing the graphs, it was possible to identify three periods in which distinct behaviors occur and that are directly related to the physical characteristics of each cover and how they respond to external environmental variations. The first period occurs from 6:40 am to approximately 9:10 am, the second period runs from 9:10 am to 5:10 pm and finally the third period extends from 5:10 pm to 7:10 pm.

Graph 4- Air temperatures measured on October 04, 2023.



Source: Authors (2023).

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In this first period, the green roof was able to provide greater thermal comfort than the roof with ceramic tiles, due to the low amplitude it had in relation to the external temperature variation. While the internal temperature of the prototype with ceramic tile roofing varied by 1ºC more than the external environment, the one with a green roof managed to keep its amplitude always below the external temperature.

The second period is characterized by a high incidence of solar radiation, so that the internal temperatures in the prototypes rise considerably. In this time range, the greater the thermal transmittance of the roofing component material, the greater the heat transmission to the interior of the building, so it is desirable that the roof also has a good emissivity, so that there is a balance. As it is a longer period, it is common for the temperature to present variations, such as those that occurred on the 3rd and 4th, with peaks and falls, resulting from the variation in humidity and the action of the winds.

When comparing the two roofs during the second period, it was observed that the prototype with ceramic tile had a higher temperature compared to the prototype with green roof. This difference can be explained by the significantly lower thermal transmittance of the green roof compared to the ceramic tile.

That said, it was possible to observe through the graphs that the ceramic roof carried out the process of releasing heat from the internal environment to the external environment more quickly, so that the internal temperature of the prototype dropped very quickly. Meanwhile, the green cover also released the heat from the interior of the prototype to the external environment, but with less aggressiveness, retaining part of it.

To perform the analysis of the thermal amplitude during the complete measurement period, considering that the data collected in the three days are similar, graph 5 was developed, which shows the averages of the internal temperature values collected in the prototypes with green roof and ceramic tile roof, and the averages of the external temperature made available by LabMET/UFT.

The temperature range is determined by the difference between the maximum and minimum temperature recorded during a given period. The greater this variation, the less efficient the roof is in insulating heat transfer from one room to another. To optimize performance and thermal comfort, it is desirable that the thermal amplitude of the roof be reduced, since high amplitudes result in more abrupt and rapid temperature changes, making the indoor environment less comfortable.

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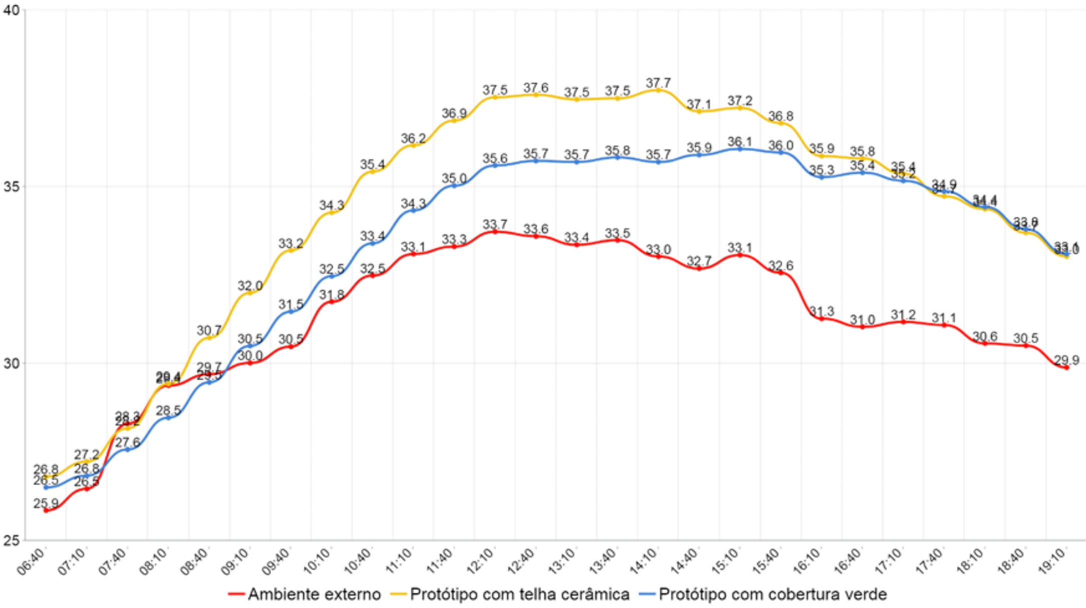
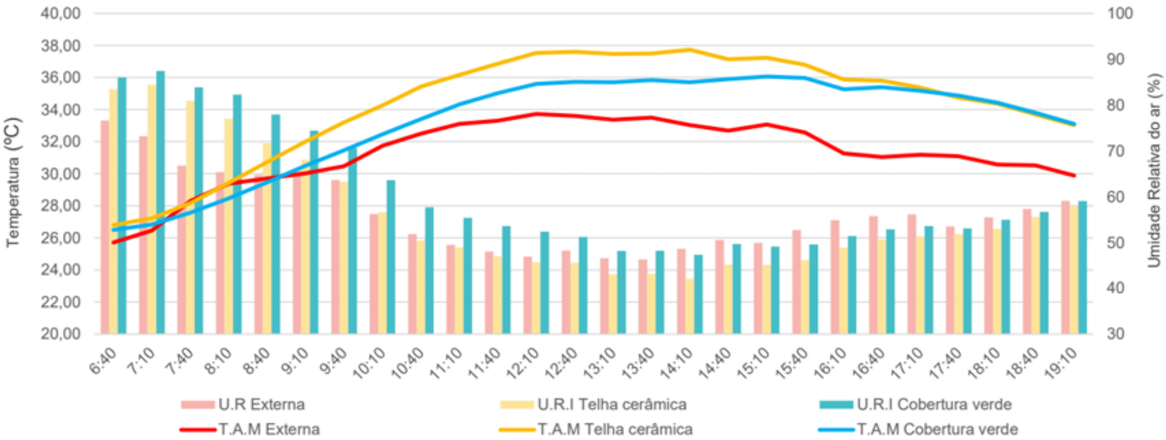
Graph 5- Data referring to the average internal temperatures (Prototype with ceramic tile and prototype with green roof) and external temperatures measured on October 02, 03 and 04, 2023.



Source: Authors (2023).

The relative humidity data (% RH) were also analyzed on the three days of measurement. To understand the behavioral relationship between air temperature and humidity, the average humidity of the three days (External U.R., U.R.I Ceramic Tile and U.R.I Green Roof) were made and their data were inserted in Graph 6 together with the data of external (External T.A.M) and internal (T.A.M Ceramic Tile and T.A.M Green Roof) average air temperature.

Graph 6 - Data referring to average indoor temperatures and humidity (Prototype with ceramic tile and prototype with green roof) and external measured on October 02, 03 and 04, 2023.



Source: Prepared by the authors (2023).

It can be seen in graph 6 that the external relative humidity remained lower than the internal humidity until 09:10 hours, when the second period with the highest incidence of solar radiation began. From the second period onwards there is a considerable drop in relative humidity, following the increase in temperature, so that in the prototype with ceramic tile the U.R values are always below those corresponding to the prototype with green roof.

Between 6:40 a.m. and 1:40 p.m., there was a progressive decrease in the external RH, reaching a reduction of 40.26%. Parallel to this drop there was an increase in external and internal temperatures, the thermal increase in the prototype with ceramic tile reached 40% of the initial temperature while in the prototype with green roof the increase was 35%.

After 1:40 p.m., when a slight variation in air temperature begins with interspersed increases and decreases, an increase in the external and internal U.R values is verified, with the external values standing out the internal values in the prototypes. This event is justified by the fact that while the external environment undergoes the alteration of both indicators simultaneously, the internal environments are still retaining the heat accumulated throughout the day, thus, right after 5:10 pm, it is noticed that gradually the internal humidity in both prototypes returns to its behavior of the beginning of the day.

FINAL CONSIDERATIONS

The comparative study between the extensive green roof and the ceramic tile roof, seeking to analyze which performs its thermal insulation function better, allowed us to conclude that the green roof is the alternative that provides better thermal comfort when compared to the ceramic tile. The combination of the three evaluative procedures used was essential for the analysis of the results, because only by the normative methodology would both coverages have their use considered unfeasible.

The first evaluation method was the simplified procedure that uses thermal transmittance values as a performance parameter stipulated by NBR 15.575-5:2013. Neither the green roof nor the ceramic roof met the required normative standard, however, among the two values of thermal transmittance calculated, the green roof was the one that came closest to the requirement of the standard. It is also noteworthy that it was not possible to consider the interference of the grass in the calculation and that the thickness of the substrate, if greater, could have resulted in compliance with the standard.

The in-situ measurement was carried out both because of the non-compliance with the standard by the simplified method and because of the interest in evaluating the

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coverage by its minimum performance requirement. Again, neither of the two coverages met the normative criterion. However, it should be noted here that both prototypes were already built and are considered unsuitable for in-situ measurement because they do not have windows. However, as Gonçalves, Oliveira and Omena (2022) explained, these prototypes (which were also used in the present study) are considerably close to the construction models used in Palmas-TO, especially for the low-income population

With the on-site measurement, it was also possible to identify the difference in the behavior of the roofs in terms of heat absorption and transfer of absorbed heat to the interior of the prototype, as well as the loss of heat from the internal to the external environment. In accordance with the values obtained for thermal transmittance, it was observed that the green roof better controls the absorption and transfer of heat to the internal environment, generating greater comfort to the user, since heating and cooling happen gradually.

It was also possible to identify through the collection of data on relative humidity and black globe temperature that compared to the ceramic tile, the green roof kept the internal humidity of the environment higher, which helps to regulate heat loss from the internal to the external environment. In terms of temperature and thermal amplitude, the green roof managed to keep the internal values reduced and also obtained a low variation compared to the ceramic tile.

All the results obtained show that, in terms of thermal comfort, the green roof offers advantages over the roof with ceramic tile. Even though it did not fully meet the normative criteria, the results obtained were still closer to the desirable parameters when compared to the ceramic tile roof.

Considering that the city of Palmas-TO is characterized by its high temperatures, low humidity and a high thermal amplitude, it becomes complex and difficult to solve thermal comfort problems by investing in only one material or one solution. That said, it should be noted that the green roof is a multi-layer system and there is the possibility of improving and including other layers, within the needs, the correct sizing and thermal insulation solutions.

It is also pointed out that due to the configurations of the prototype it is possible that in other researches, using full-size buildings, different results will be obtained from the current investigation. Likewise, for the green roof, it is possible that, with changes in the thickness of the various layers and the adoption of other drainage and filtering systems, it will be possible to obtain results that fit the requirements of the standards presented.

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That said, it is relevant to emphasize that this study focuses on the isolated analysis of the roofing system, using two prototypes in the same configurations. In view of this, it is also emphasized that the incorporation of other elements in the building, such as ceilings and insulating blankets, could significantly improve the performance of roofs in terms of thermal insulation.

In view of the above, it is possible to conclude that the green roof is a viable alternative to the thermal improvement of a building, and can be adapted to the different climatic scenarios and environmental variables in which it is found. In addition to being an ecological and sustainable alternative, with low maintenance in the long term, it also contributes to the increase of green areas in the urban region and the reduction of impacts in rural regions.

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REFERENCES

1. Almeida, V. G. de. (2019). A utilização da tecnologia BIM para análise de desempenho térmico de edificações habitacionais (Dissertação de Mestrado, Curso de Arquitetura e Urbanismo). Universidade de São Paulo, São Carlos-SP, 131 f.

2. Associação Brasileira de Normas Técnicas. (2005). NBR 15220-2: 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. ABNT. 34 p.

3. Associação Brasileira de Normas Técnicas. (2023). NBR 15220-2: Desempenho térmico de edificações Parte 2– Componentes e elementos construtivos das edificações — Resistência e transmitância térmica — Métodos de cálculo (ISO 6946:2017 MOD). ABNT. 47 p.

4. Associação Brasileira de Normas Técnicas. (2013). NBR 15575-1: Edificações habitacionais — Desempenho Parte 1: Requisitos gerais. ABNT. 71 p.

5. Baldessar, S. M. N. (2012). Telhado verde e sua contribuição na redução da vazão da água pluvial escoada (Dissertação de Mestrado, Curso de Setor de Tecnologia, Programa de Pós-Graduação em Engenharia de Construção Civil). Universidade Federal do Paraná, Curitiba, 125 f.

6. Caldas, L. R., & Carvalho, M. T. M. (2018). Avaliação do desempenho de vedações verticais utilizando o Processo de Análise Hierárquica na tomada de decisão. Parc Pesquisa em Arquitetura e Construção, 9(2), 109-121. http://dx.doi.org/10.20396/parc.v9i2.8651552.

7. Coelho, K. de S. D. (2019). Avaliação de um sistema modular de cobertura verde: Comportamento térmico, hídrico e acústico (Dissertação de Mestrado, Curso de Energia Para A Sustentabilidade, Especialização em Edifícios e Ambiente Urbano). Universidade de Coimbra, Coimbra, 83 f.

8. Freitas, T. P. F., & Souza, L. B. e. (2016). Aspectos do clima urbano de Palmas-TO no episódio de outono-inverno. Caminhos de Geografia, 17(59), 103-125.

9. Gonçalves, T. B., Oliveira, M. C. A. de, & Omena, T. H. (2022). Comparações no desempenho térmico entre protótipos de telha cerâmica e telha de concreto em Palmas-TO. Sítio Novo: Instituto Federal do Tocantins, 6, edição especial, 139-148, 09 mar.

10. International Organization for Standardization. (2017). ISO 7243: Ergonomics of the thermal environment Assessment of heat stress using the WBGT (wet bulb globe temperature) index (3ª ed.). 18 p.

11. International Organization for Standardization. (2017). ISO 6946: Building components and building elements- Thermal performance of windows, doors and shutters-

Calculation of thermal transmittance. Geneva: International Organization for Standardization.

12. International Organization for Standardization. (2017). ISO 7726: Ergonomics of the thermal environment- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva: International Organization for Standardization.

13. Lopes, D. A. R. (2007). Análise do comportamento térmico de uma cobertura verde leve (CVL) e diferentes sistemas de cobertura (Dissertação de Mestrado, Curso de Engenharia, Programa de Pós-Graduação em Ciências da Engenharia Ambiental). Universidade de São Paulo, São Carlos-SP, 145 f.

14. Misaka, B. L. S. (2021). Avaliação do conforto térmico entre os sistemas de telhado verde, ecológico e convencional (TCC de Graduação, Curso de Engenharia Civil). Universidade Federal do Pampa, Alegrete, 85 f.

15. Paz, L. H. F. (2009). A influência da vegetação sobre o clima urbano de Palmas-TO (Dissertação de Mestrado, Departamento de Pós-Graduação da Fau-Unb do Curso de Arquitetura e Urbanismo). Universidade de Brasília, Brasília, 169 f.

16. Pereira, B. dos R., & Masiero, É. (2023). Caracterização do comportamento térmico de um sistema de telhado verde. In Encontro Nacional de Conforto no Ambiente Construído (17.), Anais [...]. 1-9.

17. Santos, D. J. P. (2012). Desempenho térmico de uma cobertura verde num edifício solar passivo (Dissertação de Mestrado, Curso de Engenharia do Ambiente, Departamento de Ambiente e Ordenamento). Universidade de Aveiro, [S.I.], 79 f.