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Quantifying the effect of tree shading on buildings during the summer

Quantificando o efeito do sombreamento de árvores em edifícios durante o verão

Cuantificar el efecto del sombreado de los árboles en los edificios durante el verano

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RESUMO

No Brasil, aproximadamente 50% da energia elétrica gerada é consumida em edificações, portanto adotar estratégias para reduzir o consumo de energia é uma maneira eficaz de alcançar maior eficiência energética.As edificações podem ser aprimoradas por meio da substituição de materiais isolante, bem como pela modificação de sua forma. No entanto, para edifícios antigos, as estratégias devem ser aplicadas em seu entorno. Uma opção viável é a plantação de árvores, que, por meio do sombreamento, filtram a radiação solar, alterando assim o balanço térmico. Nesse contexto, o objetivo deste estudo é quantificar o impacto do sombreamento proporcionado por espécies arbóreas no consumo de energia para condicionamento do ar em cidade de baixa densidade populacional. Para alcançar esse objetivo, foram seguidos procedimentos metodológicos que envolveram a coleta de dados empíricos durante três dias de verão. Esses dados foram posteriormente inseridos em um modelo de simulação no software Energy Plus TM. A variável desejada foi a carga térmica da edificação. Os resultados obtidos indicam que o sombreamento proporcionado pelas árvores reduz significativamente a carga térmica. Esse efeito é mais pronunciado às 16:00 horas, com redução de 11,87% ,14 ,92% e 12,55% .Além disso, observou-se uma redução significativa no consumo de energia, sendo de 14,33% para um sistema de ar-condicionado com um coeficiente de desempenho (COP) de 2,60. Assim, conclui-se que o sombreamento na fachada oeste durante o final da tarde no verão reduz o consumo de energia de forma mais eficaz do que o sombreamento pela manhã ou no início da tarde.

PALAVRAS-CHAVES: Eficiência energética. Sombreamento. Espécies arbóreas. Carga térmica. Consumo de Energia.

ABSTRACT

In Brazil, approximately 50% of the electricity generated is consumed in buildings, so adopting strategies to reduce energy consumption is an effective way of achieving greater energy efficiency. Buildings can be improved by replacing insulating materials, as well as by modifying their shape. However, for older buildings, strategies must be applied to their surroundings. One viable option is the planting of trees, which, through shading, filter out solar radiation, thus altering the thermal balance. In this context, the aim of this study is to quantify the impact of shading provided by tree species on energy consumption for air conditioning in a city with a low population density. To achieve this objective, methodological procedures were followed that involved collecting empirical data over three summer days. This data was then entered into a simulation model in the Energy Plus TM software. The desired variable was the building's thermal load. The results indicate that the trees' shading significantly reduces the thermal load. This effect is most pronounced at 4 p.m., with a reduction of 11.87% ,14.92% and 12.55%.In addition, there was a significant reduction in energy consumption of 14.33% for an air conditioning system with a coefficient of performance (COP) of 2.60. Therefore, shading on the west façade during the late afternoon in summer reduces energy consumption more effectively than shading in the morning or early afternoon.

KEYWORDS*: Energy efficiency. Shading. Tree species. Thermal load. Energy consumption.*

RESUMEN

En Brasil, aproximadamente el 50% de la electricidad generada se consume en los edificios, por lo que adoptar estrategiaspara reducir el consumo de energía es una forma eficaz de lograr una mayor eficiencia energética. Los edificios pueden mejorarse sustituyendo los materiales aislantes y modificando su forma. Sin embargo, en el caso de los edificios más antiguos, las estrategias deben aplicarse a su entorno. Una opción viable es la plantación de árboles que, mediante el sombreado, filtran la radiación solar, alterando así el equilibrio térmico. En este contexto, el objetivo de este estudio es cuantificar el impacto del sombreado proporcionado por especies arbóreas en el consumo de energía para climatización en una ciudad con baja densidad de población. Para alcanzar este objetivo, se siguieron procedimientos metodológicos que implicaron la recogida de datos empíricos durante tres días de verano. A continuación, estos datos se introdujeron en un modelo de simulación en el programa informático Energy Plus TM. La variable deseada era la carga térmica del edificio. Los resultados obtenidos indican que el sombreado proporcionado por los árboles reduce significativamente la carga térmica. Este efecto es más pronunciado a las 16.00 horas, con una reducción del 11,87% ,14,92% y del 12,55%. Además, se produjo una reducción significativa del consumo energético del 14,33% para un sistema de aire acondicionado con un coeficiente de rendimiento (COP) de 2,60. Por lo tanto, puede concluirse que el sombreado de la fachada oeste a última hora de la tarde en verano reduce el consumo de energía de forma más eficaz que el sombreado por la mañana o a primera hora de la tarde.

PALABRAS CLAVE*: Eficiencia energética. Sombreado. Especies arbóreas. Carga térmica. Consumo energético.*

1. INTRODUCTION

In Brazil, according to the Atlas of Energy Efficiency 2022 published by the EPE, buildings lead electricity consumption, accounting for around 50% of the country's total consumption. The importance of adopting energy efficiency measures by planners, builders and urban planners is therefore clear.

In cities, energy efficiency can be achieved through the integration of urban vegetation, which also contributes to reducing heat stress in urban areas. Various green strategies can be implemented, including the use of lawns, green roofs and walls, as well as the establishment of urban forests.

Planting trees is one of the ways to improve the urban thermal environment. The shading provided by trees plays a crucial role in this process, as it filters out solar radiation. The effectiveness of this shading is influenced by the shape and density of the canopy, as well as the density of the branches and leaf cover.

One of the beneficial results of shading trees is a reduction in energy consumption in buildings. In hot climates, shading building surfaces can significantly reduce the need for air conditioning. This, in turn, results in a reduction in the cooling load, as highlighted by (SIMÁ et al., 2015a).

Studies that seek to analyze the potential of tree shading in reducing energy consumption with cooling load can be conducted both experimentally, based on empirical data, and by means of thermo-energy simulations. In the work by Huang et al. (1987), a simulation approach was adopted to demonstrate the economic benefits of shading provided by trees. In this study, by increasing tree cover by 25%, a 40% reduction in cooling load was observed in the city of Sacramento, USA. On the other hand, the experimental study carried out by Ogueke et al. (2017) employed a practical method. In this study, the authors used dry wood piles, each equipped with two galvanized steel sheets. These plates were installed at different distances from the tree trunk, in the east, west, north and south directions. This arrangement made it possible to measure the temperatures of the galvanized steel plates and subsequently quantify the amount of energy absorbed. The results of the study concluded that proper tree planting can result in a reduction of more than 1050 kWh/year in the cooling load, which corresponds to 22% of annual energy consumption.

The research carried out by Simpson and Mcpherson (1996) showed that the western direction of houses provides greater energy savings in relation to the cooling load. They found that by adding a shade tree on the west side and another on the east side of a house, the annual cooling costs of the house can be reduced by a range of 10% to 50%, depending on the location in the hemisphere of study. This highlights the importance of vegetation, particularly shade trees.

Furthermore, in the study by Wang et al. (2016), the biophysical effects of trees and urban lawns in reducing energy consumption were highlighted through simulations. The results indicated that radiative shading (reducing direct radiation on solid urban surfaces) is more effective in reducing ambient temperature than urban lawns. Therefore, the appropriate placement of trees near or around buildings can reduce the need for air conditioning in hot climates, resulting in a reduction in energy consumption.

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In a city in Australia characterized by hot, dry summers, often marked by heat waves, and mild, wet and windy winters, a study was conducted to identify the ideal arrangement of residential trees. The results obtained for the region revealed that two arrangements of deciduous trees provide a 15% saving in energy consumption for cooling when located to the east or west of homes, and a 7% saving when positioned to the north. This highlights the influence of climatic and geographical characteristics and tree species in reducing energy consumption (ROUHOLLAHI et al., 2022a).

In a study carried out in Brazil, in a city with a subtropical climate, the simulation methodology was used to evaluate the cooling effect of trees in different configurations in a densely populated urban environment. The results showed that the cooling effect of vegetation is more significant when trees are planted along streets, compared to scenarios without the presence of vegetation, especially during the month of February (DUARTE et al., 2015).

It is therefore notable that several empirical and modeling studies have demonstrated that shade trees can provide significant energy savings in summer when strategically located and maintained close to buildings (AKBARI et al., 1997; SIMPSON, 2002).

Two systemic reviews (Roy; byrne; pickering, 2012; shao; kim, 2022) examined the geographical distribution of research on the effect of trees on urban microclimate and building-tree integration. These reviews highlighted that the majority of studies (64% of studies) were conducted in North America, with a focus on the United States (US) and Canada. In addition, there was a considerable focus on publications in the regions of the People's Republic of China, the USA, Australia, Germany and Italy. However, there is a notable lack of research related to this methodology and investigation in South American cities, especially in Brazil. Although there are studies aimed at high-density cities, as seen in the studies by (ABREU; LABAKI, 2010; BAPTISTA, 2014; DUARTE et al., 2015; KRÜGER et al., 2021), there is a pressing need to investigate the impact of shading provided by tree species on air conditioning energy consumption in low-density cities. These areas often face heat stress due to inadequate urbanization and a lack of proper urban infrastructure planning. Therefore, this research gap motivates the aim of this study, which is to quantify the impact of shading provided by tree species on air conditioning energy consumption in a low-density city.

2. MATERIAL AND METHODS

The methodological procedures employed in this study involved a combination of collecting empirical data and then inserting it into a simulation model. We therefore worked with observed data and simulated data (Output: Variable), as illustrated in the step-by-step diagram in Figure 1. Two simulation models were developed: one representing the real condition (with tree shading) and the other representing a hypothetical condition (without the presence of tree shading). The aim was to quantify the difference between these two conditions.

To model the real condition, it was necessary to obtain information on the trees' dendrometric variables. To do this, data was collected in the field using a Dji Phantom 4 Unmanned Aerial Vehicle (UAV). 48 images representing the treetops were captured. These images were processed to extract the height of the trees by creating a Digital Terrain Model

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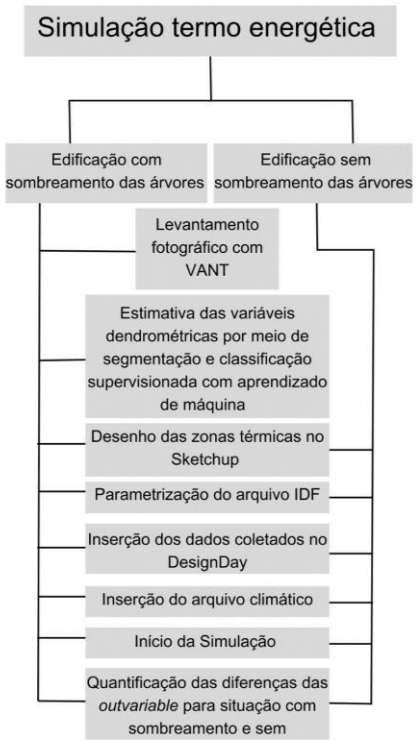
(DTM) and a Digital Surface Model (DSM). Machine Learning techniques were used for the other variables. Initially, Label me software was used to create representative polygons of the trees and then the Python programming language was used to segment and perform supervised classification with the Random Florest algorithm. The resulting metrics were obtained in the R language using the Pliman package, which specializes in image analysis, especially of plants.

The thermal zones were created in Sketchup, as shown in Figure 2, for both the real and hypothetical conditions. The room to be simulated was identified with a red dot. The model was then parameterized with the data collected in the field, including information on the dry bulb and wet bulb temperatures for the typical days of February 27, 2023, March 1, 2023 and March 3, 2023. The IDF file corresponding to these parameters is in the supplementary material. In addition, the appropriate climate file was selected, which corresponds to a distance of 50 km from the study region, as indicated in the additional information of the climate files provided by Energy Plus. The output variables requested for the simulation included:

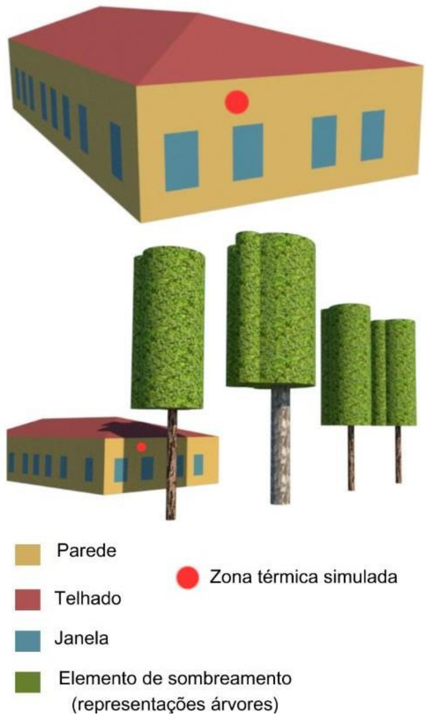
- *Zone Ideal Loads Zone Total Cooling Rate: Total cooling rate (sensible and latent) removed from the zone;*

Figure 1- Methodological scheme for thermo-energy simulation of the real and hypothetical situation



Source: Author ,2023

Figure 2 - Thermal zones of the building constructed for hypothetical and real situations (with tree shading)



Source: Author ,2023

The differences between the conditions were quantified using programming in the R language, and the corresponding script can be found in the supplementary material.

2.1 Study Area

The building under analysis is located in the city of Campo Belo in the southern region of the state of Minas Gerais, in southeastern Brazil. Its geographical coordinates are 20°53'32.3" S latitude and 45°16'17.0" W longitude. Campo Belo has an estimated population of 54,338 (IBGE, 2020), and a population density of 97.56 inhabitants/km². This region was chosen because it represents the reality of approximately 90% of the municipalities in Minas Gerais. In addition, this region of southeastern Brazil is facing a rising temperature trend, estimated at between 3 °C and 3.5 °C, which makes it especially relevant for studies on climate change adaptation and mitigation. Cities with low population density, such as Campo Belo, are becoming increasingly vulnerable to variations in microclimatic conditions due to the lack of adequate adaptation and mitigation measures. This reflects the reality of between 2% and 90% of municipalities in the state of Minas Gerais with a population of up to 50,000 inhabitants. In terms of climate, the Campo Belo region is classified as humid subtropical, with an altitude of 945 m above sea level. The average annual rainfall is 1,250 mm, while the average annual temperature is around 23.5

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°C. The predominant vegetation in the area combines elements of the Cerrado and the Atlantic Forest (SANTOS; BELO; ALBERICO, 2015), which makes it even more interesting for studies related to the impact of vegetation on the regulation of the urban microclimate.The trees that are exposed to the building are described in Chart 1.

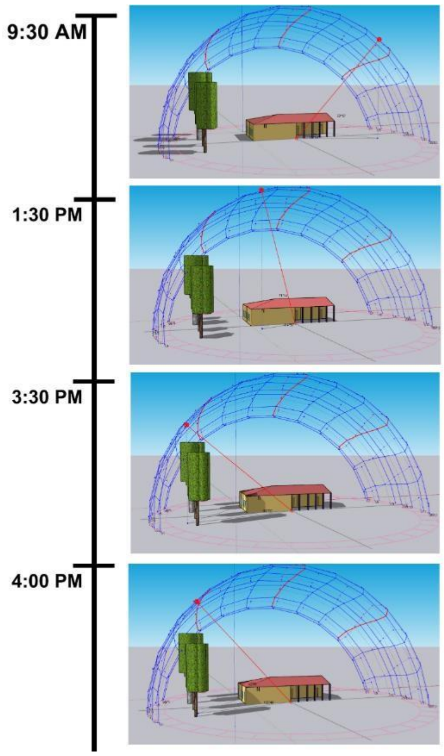
Chart 1- Tree Species in the wooded site

Tree species	*Caesalpinia leiostachya*	*Licania tomentosa*	*Ficus benjamina*	*Archontophoenix alexandrae*
Urban areas	Cônego Ulisses Square	Cônego Ulisses Square	Cônego Ulisses Square	Cônego Ulisses Square

Source: Plantnet and Embrapa ,2003;2004

The tree species were characterized using the Plantnet tool (https://identify.plantnet.org/pt-br), as well as on the basis of Embrapa's collection of books (2003, 2014) called "Brazilian Tree Species", which includes volumes 1 and 5. This approach allowed for precise identification of the species studied. As for the solar diagram of the site studied, the results are shown in Figure 3. It can be seen that during the morning, the projected shadow follows a direction opposite to the building. However, in the afternoon, the shadow moves in the direction of the building. This variation throughout the day is fundamental to understanding the behavior of the shadow in relation to the building and its implications for the local microclimate.

Figure 3 - Solar diagram for a typical day in the morning and afternoon for the city of Campo Belo, Minas Gerais, in the study building.



Source: Author ,2023

2.3 Collection of empirical data

Data was collected both inside the building and outside, as shown in Figure 5. Measurements took place between 09:30 a.m and 4 p.m, with a break during lunchtime when there was no occupancy in the room and no measurements were taken during this period. A TGD-400 thermal stress meter was used to take the measurements, the technical specifications of which can be found in Table 1. Before starting the measurements, it was necessary to wait for the equipment to stabilize, which took 25 minutes. The height of the equipment was 1.30 m (chest height). The sampling rate was 1 minute. The method of combining simulation and empirical data collection is based on the methods of Wang et al. (2016) , Hes et al. (2011) and Simá et al. (2015). The main data of interest for input into the Energy Plus software included dry bulb and wet bulb temperature measurements.

Figure 4- Location of the measuring equipment in the external and internal areas

Source: Author ,2023.

Table 1- Description of the parameters of the TGD 400 thermal stress measuring device

	TGD-400 Thermal Stress Meter			
Technical specifications	Display: Dual liquid crystal display (LCD) with 3 ½ digits	Anemometer	Dew Point	Operating humidity
Scale	-10~150ºC	0 - 20m/s	5º a 60ºC	0 a 85% UR
Resolution	0.1°C	0.1m/s	----------	----------
Precision	± 0.5°C	±4% + 0.1m/s	----------	----------

Source: Instrutherm ,2020

3. RESULTS AND DISCUSSIONS

The results and discussions have been organized into three separate sections. The first section presents the results of the photographic survey of tree species on the building, carried out using a UAV. The second section deals with the estimation of dendrometric variables, which are then inserted as shading zones in the simulation model. Finally, the third section presents the results obtained with the output variable requested from Energy Plus.

3.1 Photographic survey with UAV

The survey was carried out in November 2022, resulting in a total of 48 images, which are available for consultation in the supplementary material. These images were processed using the ODM web platform in order to generate the Digital Terrain Model (DTM) and the Digital Surface Model (DSM). Subsequently, a difference operation was performed between these models, resulting in the creation of the Digital Elevation Model (DEM). The results obtained from the DEM show a variation in the range -5.08 to 20.69. These values are related to the elevation of the tree canopy and therefore represent the height of the cluster of trees under study.

3.2 Estimation of dendrometric variables

Information on the tree canopy was obtained as shown in Table 2. Initially, this information was obtained by analyzing the annotated images, as shown in Figure 5, followed by identifying the RGB bands. Notably, the combination of the GR, R and G bands (Figure 5) showed a segmentation that was more in line with the original image. Therefore, these bands were used to extract the information related to the treetops.

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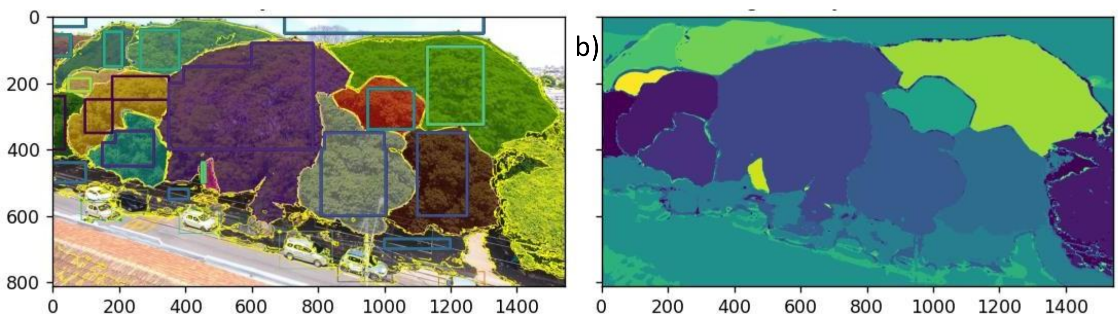
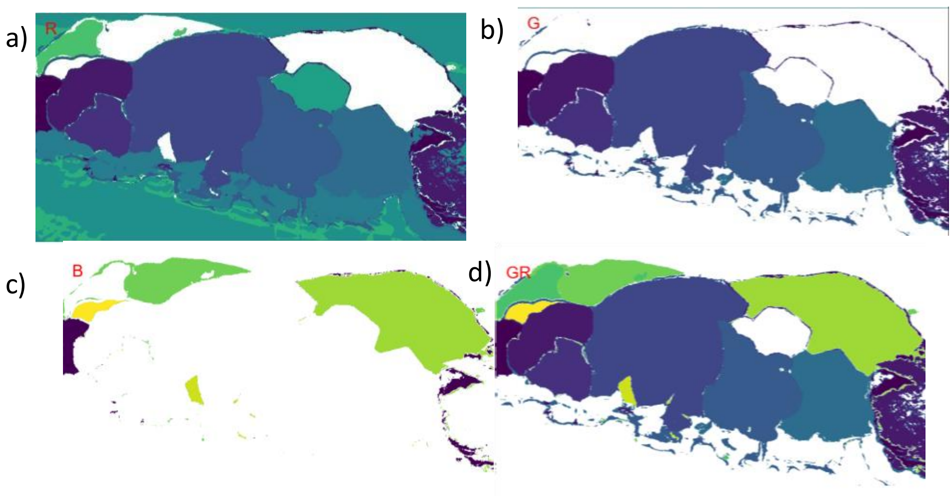
Figure 5 a) Images with band annotation performed in Labelme and Python to annotate the bands b) Image with segmentation using supervised classification with RandomFlorest algorithm



Source: Author ,2023

Figure 6 a) Segmentation using R-band RGB b) Segmentation using G-band RGB c) Segmentation using B-band RGB d) Segmentation using GR- band RGB



Source: Author ,2023

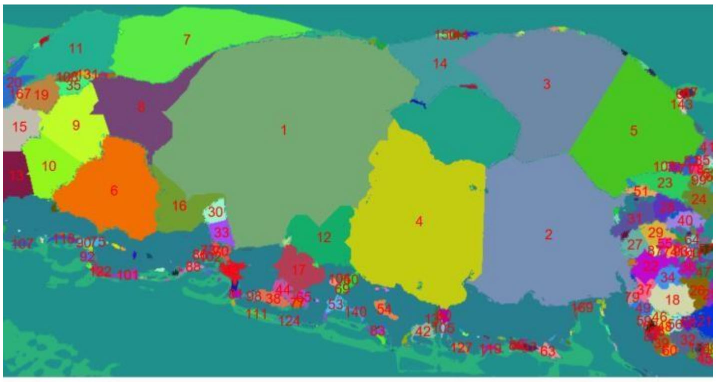
The development of the metrics made use of the Pliman package in the R language to determine the characteristics of the canopies. This resulted in the identification of the image bands that estimated the canopy variables of interest, based on the GR index (Figure 7).

Table 2 - Metrics for the canopy

ID/Métricas	1	2	4	6	8	9	10	12	13	15	16	17	19	30	33
area	23.53	11.76	11.43	4.37	3.27	2.11	1.48	1.71	0.76	0.89	1.47	0.94	0.68	0.26	0.28
diam_mean	5.51	3.91	3.85	2.35	2.29	1.64	1.39	1.53	1.01	1.07	1.51	1.09	0.95	0.58	0.62

Source: Author ,2023

Figure 7 - Identification of the image bands for estimating the canopy variables of interest using the GR index



Source: Author ,2023

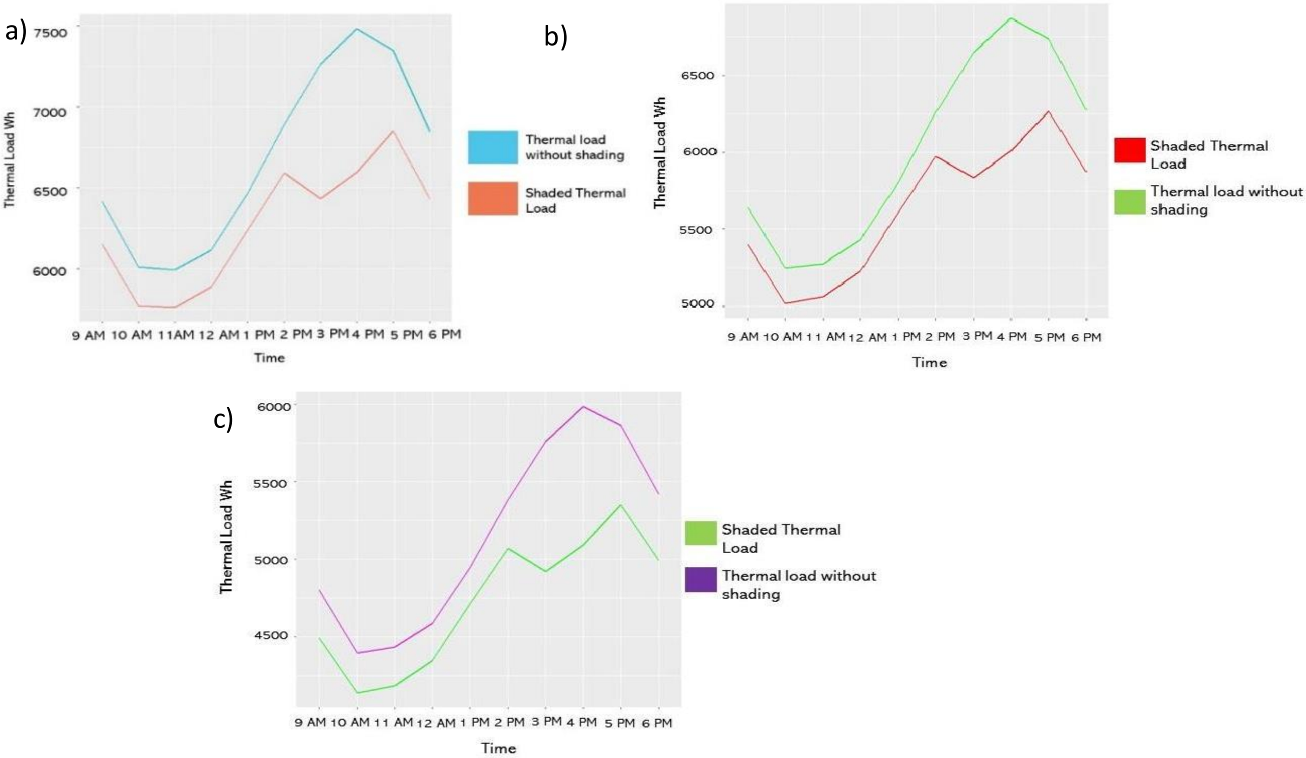
These values were validated in the field by measuring the shadow on the floor surface.

3.3. Thermo-energy simulation

3.3.1 Optimal total zone cooling loads

The cooling load was calculated through the heat balance, using the Conduction Transfer Function (CTF) algorithm for the days on which the data was collected, considering them as reference days. Thus, the two models, both the real and hypothetical conditions, showed differences over three days. These differences were evident througho ut the building's occupancy period, with the peak thermal load occurring at 4pm in the hypothetical condition (without tree shading) and at 5pm in the real condition, which includes tree shading. This discrepancy can be explained by the fact that, at 4pm, the sun is shining directly on the surface of the west wall and on the windows, increasing heat transfer by thermal conductivity through the materials, as well as by solar radiation. On the other hand, in the presence of shading during peak sunlight hours, heat transfer is reduced, resulting in a peak thermal load at 5pm. This phenomenon can be attributed to thermal lag, and shading acts as a way of altering this thermal lag of the materials. In this context, shading proves to be beneficial, since at 5 p.m., the time closest to the end of the building's occupation, the thermal load is reduced. The results reveal an advantageous interaction between the time of greatest exposure to solar radiation and the presence of shading, which contributes to a reduction in energy consumption. In other words, shading is an effective strategy for increasing a building's energy efficiency, especially in reducing the energy consumption associated with air conditioning systems. Therefore, this satisfactory interaction between exposure to solar radiation and shading results in a remarkable thermal inertia in the building.

Figure 8- a) Thermal load with the presence of shading and without over the study room for February 27, 2023 b) Thermal load with the presence of shading and without over the study room for March 1, 2023 c) Thermal load with the presence of shading and without over the study room for March 3, 2023



Source: Author ,2023

Figures 8 (a), (b) and (c) show the differences between the hypothetical and real conditions. The greatest reduction in thermal load occurred at 16:00 hours, corresponding to 11.87%, 14.92% and 12.55% for the respective measurement days. The reductions at the other times are detailed in Table 3.

This reduction is related to the age of the trees providing shade, since older trees tend to have larger canopies. If the trees were younger, the shading might not reach the wall surface (SIMPSON; MCPHERSON, 1996).

The reduction in thermal load has also been observed in other studies, such as (AKBARI et al., 1997; CHAGOLLA et al., 2012; HUANG et al., 1987a; ROUHOLLAHI et al., 2022b; SIMÁ et al., 2015b; SIMPSON, 2002; SIMPSON; MCPHERSON, 1996) . In these studies, the reduction is linked to the annual energy consumption of the buildings, obtained through simulation and on-site measurement. It was therefore expected that tree shade would reduce energy consumption by reducing exposure to solar radiation. In addition, some of these studies have also highlighted the effect of evapotranspiration, which is satisfactory for reducing the thermal load. It is important to note that the reduction in thermal load, through shading, is more noticeable in older houses, due to the lower thermal integrity, according to our study condition (HUANG et al., 1987a). Our study showed that shading begins to affect the façade from 3pm, with the reduction in thermal load occurring during this period. However, for the real condition, we also observed a reduction in the morning. This pattern is consistent with the study by Donovan and

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Butry (2009), which showed that shading in the late afternoon on the west façade of a property in summer reduces energy consumption more than shading in the morning or early afternoon.

Table 3 - Thermal load for the hypothetical condition, the real condition and the difference between the two

Date	Time	Thermal load Wh (hypothetical condition)	Thermal loadWh (actual condition)	Difference Thermal load (%)
27/02/2023	9 a.m	6154.44	6417.56	4.1
27/02/2023	10 a.m	5771.53	6011.93	4.0
27/02/2023	11 a.m	5761.96	5995.32	3.89
27/02/2023	12 p.m	5888.14	6117.23	3.74
27/02/2023	1 p.m	6237.1	6463.02	3.5
27/02/2023	2 p.m	6592.7	6890.79	4.33
27/02/2023	3 p.m	6432.94	7263.17	11.43
27/02/2023	4 p.m	6593.96	7482.2	11.87
27/02/2023	5 p.m	6851.91	7347.67	6.75
27/02/2023	6 p.m	6428.33	6844.81	6.08
01/03/2023	9 a.m	4800.88	4493.84	6.4
01/03/2023	10 a.m	4394.62	4137.38	5.85
01/03/2023	11 a.m	4433.01	4184.36	5.61
01/03/2023	12 p.m	4586.28	4347.32	5.21
01/03/2023	1 p.m	4946.36	4712.02	4.74
01/03/2023	2 p.m	5382.7	5071.08	5.79
01/03/2023	3 p.m	5760.22	4919.74	14.59
01/03/2023	4 p.m	5985.15	5092.31	14.92
01/03/2023	5 p.m	5864.95	5352.79	8.73
01/03/2023	6 p.m	5418.02	4990.99	7.88
03/03/2023	9 a.m	5642.55	5403.48	4.24
03/03/2023	10 a.m	5247.51	5014.61	4.44
03/03/2023	11 a.m	5275.08	5060.06	4.08
03/03/2023	12 p.m	5432.06	5229.54	3.73
03/03/2023	1 p.m	5806.83	5611.86	3.36
03/03/2023	2 p.m	6260.17	5973.8	4.57
03/03/2023	3 p.m	6649.63	5834.28	12.26
03/03/2023	4 p.m	6874.08	6011.28	12.55
03/03/2023	5 p.m	6735.03	6267.52	6.94
03/03/2023	6 p.m	6274.76	5872.17	6.42

Source: Author ,2023

It is seen that the shading provided by trees not only reduces the right solar gain reaching the building envelope, but also has the effect of reducing the diffuse light reflected from the sky and surrounding surfaces (HUANG et al., 1987b).

3.3.2 Saving energy consumption

Reducing the thermal load has a significant impact on energy savings, especially air conditioning consumption, as is already well known. Considering a commercial air conditioning system with a coefficient of performance of 2.60 (INMETRO, 2021), we can evaluate the reduction in daily consumption as shown in Table 4. In terms of cost, the savings are 1.57 R$, 1.59 R$ and 1.46 R$ for the respective days analyzed. This means that if the behavior is similar over the course of the months, the accumulated savings would be R$46.20, R$47.70 and R$43.60 in total energy consumption.

Comparing our study with the work by Rouhollahi et al. (2022c), it can be seen that, as in our study, the author, in a location also in the southern hemisphere, highlights the positive influence of planting trees on the west façade. This results in reduced exposure to shortwave radiation during summer afternoons, which in turn cools the façade surface creating an evaporative cooling effect. Therefore, compared to a situation without trees, planting trees to the west shows a greater effect on energy efficiency, controlling daytime heat transfer and heat retention at night.

Table 4- Energy consumption for an air conditioner with COP 2.60 for the hypothetical, actual and difference conditions.

Date	time	no shading	shading	Difference
27/02/2023	9 a.m	1719.2	1643.0	76.2
27/02/2023	10 a.m	1601.5	1541.0	60.5
27/02/2023	11 a.m	1612.1	1554.2	57.9
27/02/2023	12 p.m	1655.9	1600.0	55.9
27/02/2023	1 p.m	1755.7	1700.0	55.7
27/02/2023	2 p.m	1883.2	1801.7	81.4
27/02/2023	3 p.m	2001.8	1779.4	222.4
27/02/2023	4 p.m	2118.2	1835.5	282.8
27/02/2023	5 p.m	2152.7	1998.5	154.1
27/02/2023	6 p.m	1662.6	1519.6	143.0
01/03/2023	9 a.m	1846.49	1728.4	118.09
01/03/2023	10 a.m	1690.24	1591.3	98.94
01/03/2023	11 a.m	1705	1609.37	95.63
01/03/2023	12 p.m	1763.95	1672.05	91.91
01/03/2023	1 p.m	1902.45	1812.32	90.13
01/03/2023	2 p.m	2070.27	1950.42	119.85
01/03/2023	3 p.m	2215.47	1892.21	323.26
01/03/2023	4 p.m	2301.98	1958.58	343.4
01/03/2023	5 p.m	2255.75	2058.77	196.98
01/03/2023	6 p.m	2083.85	1919.61	164.24
03/03/2023	9 a.m	2170.21	2078.26	91.95
03/03/2023	10 a.m	2018.27	1928.7	89.58
03/03/2023	11 a.m	2028.88	1946.18	82.7
03/03/2023	12 p.m	2089.25	2011.36	77.89

Date	time	no shading	shading	Difference
03/03/2023	1 p.m	2233.4	2158.41	74.99
03/03/2023	2 p.m	2407.76	2297.62	110.14
03/03/2023	3 p.m	2557.55	2243.95	313.6
03/03/2023	4 p.m	2643.88	2312.03	331.85
03/03/2023	5 p.m	2590.4	2410.58	179.81
03/03/2023	6 p.m	2413.37	2258.53	154.84

Source: Author ,2023

Another relevant study for comparison is that of Hsieh et al. (2018), in which they carried out Energy Plus simulations considering tree shading at distances of 6 and 3 meters from the building. In this study, a reduction in cooling load of 15.2% was observed at distances of 3 meters from the building, and 12.4% and 10.3% at distances of 6 meters, the latter being the current scenario. In our study, the reductions for the three days were in between 8.02% and 6.31%. However, there are some notable differences. Firstly, the trees in our study are located at a greater distance, around 14 meters from the building. In addition, the characteristics of the trees, such as crown height, crown density and tree height, are different. The shape of the trees also plays an important role, as it is related to the projection of shade. Trees with less dense canopies tend to provide less shade. In addition, the characteristics of the building itself also have an influence, such as the number of storeys and the thermal conductivity of the materials. Therefore, the difference in daily reductions can be explained by these variations. Another study by Calcerano and Martinelli (2016), which also used Energy Plus simulation, showed a potential reduction in energy consumption of 10.7% by inserting a tree on the west façade. In this case, the tree's characteristics included a height of 8 m and a crown diameter of 6 m for a single-storey building. Again, the similarity between this study and ours lies in the diameter of the tree canopy, which results in close energy reduction values. However, the distance from the building is different, since the authors considered a distance of 3 meters in their study. It is important to note that geographical location also plays an important role, as the authors' city is in the northern hemisphere, which affects the direction of solar radiation. In the southern hemisphere, as in our study, the western façade tends to show a greater reduction during the afternoon, due to the more intense exposure to the sun.

4. LIMITATIONS OF STUDY

The study aimed to quantify the impact of tree shading on buildings, but it is important to note that although it was possible to carry out the simulation, there may still be some discrepancies with the real situation. This is because the simulation does not take into account the biophysical effect of evapotranspiration from trees, nor does it cover the complete thermal dynamics of a city, including its surroundings. In addition, the geometry of the trees has been simplified, not taking into account details such as the shape of the leaves and branches, which means that the representation of the trees in the simulation does not accurately correspond to reality. However, the results obtained were satisfactory in demonstrating the positive impact of shading in reducing the thermal load on buildings. In order to improve the representation of the trees, we tried to approximate their geometry based on images taken by the VAP at the study site. It is important to emphasize that the aim of this work was to explore the effect of shading on the surface of exposed walls, and not to carry out a complete characterization of the urban environment or an accurate representation of real trees.

5. CONCLUSION

The research revealed that shading provided by trees is an effective strategy for reducing energy consumption in buildings, resulting in significant savings of 20.52% when considering the two typical summer days. This saving indicates that, if this trend persists throughout the month, energy costs could be reduced by approximately R$ 47.70 for the buildings studied, with a total saving of R$ 43.60 in energy costs.

These results highlight the importance of implementing a green urban infrastructure, with a special focus on buildings with lower thermal integrity, such as old houses, as a fundamental measure to improve energy efficiency. It is important to note that the study did not quantify the effect of evapotranspiration from trees, which represents a limitation in our understanding of the complete thermal dynamics. However, the main objective of the research was to quantify the impact of shading, and in this respect, the results were satisfactory.

The research findings clearly demonstrate that the introduction of trees on old buildings plays a crucial role in improving thermal conditions and reducing air conditioning consumption during the summer months. This not only contributes to energy savings, but also promotes a more sustainable and comfortable urban environment. Therefore, the incorporation of green areas into urban planning strategies should be encouraged as an effective measure to address the challenges of energy efficiency in buildings. This study provides a solid basis for future research and urban design practices aimed at promoting energy sustainability and thermal comfort.

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