ANALYSIS OF WATER AND ENERGY CONSUMPTION IN A VERTICAL GREEN RESIDENTIAL BUILDING IN THE AMAZON

ANÁLISE DO CONSUMO DE ÁGUA E ENERGIA DE UMA CONSTRUÇÃO VERDE RESIDENCIAL VERTICAL NA AMAZÔNIA

ANÁLISIS DEL CONSUMO DE AGUA Y ENERGÍA DE UNA EDIFICACIÓN RESIDENCIAL VERTICAL SOSTENIBLE EN LA AMAZONÍA

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ABSTRACT
In the face of the global need to reduce resource consumption, environmental certifications emerge as a possibility for efficiency gains in the construction industry. This study aimed to assess the energy and water efficiency of a vertical multifamily green residential building located in Belém, in the Brazilian Amazon. The energy and water consumption data of two similar buildings were compared, with only one implementing mandatory green practices and technologies for Leadership in Energy and Environmental Design (LEED) Envelope and Core certification. As a result, water consumption was 30.64% higher than estimated. On the other hand, electricity consumption was 24.6% below the estimated project and 1.73% below the per capita consumption obtained for the building constructed without any green practices or technologies. These results demonstrate that the adopted green technologies were able to improve the energy efficiency of the studied building. However, they had low water efficiency, attributed to user behavior patterns and the LEED's inability to meet the region's water requirements. To address this issue, changes to certification criteria are suggested.

KEYWORDS
Green building; LEED; water; energy; construction industry.

RESUMO
Diante da necessidade global em reduzir o consumo de recursos, as certificações ambientais se apresentam como uma possibilidade de ganho de eficiência na construção civil. Este trabalho buscou avaliar a eficiência energética e hídrica de uma construção verde multifamiliar residencial vertical localizada em Belém, na Amazônia brasileira. Foram comparados os dados de consumo energético e hídrico de dois edifícios similares, onde apenas um deles implementou práticas e tecnologias verdes obrigatórias para a certificação ambiental Leadership in Energy and Environmental Design (LEED) Envoltória e Núcleo Central. Como resultado, foi obtido que o consumo de água foi maior que o estimado em 30,64%, por outro lado, o consumo de energia elétrica foi 24,6% abaixo do estimado em projeto e 1,73% abaixo do consumo por pessoa obtido para a edificação construída sem qualquer prática ou tecnologia verde. Estes resultados demonstram que as tecnologias verdes adotadas foram capazes de melhorar a eficiência energética do edifício estudado. No entanto, tiveram baixa eficiência hídrica. Isto foi atribuído ao padrão de comportamento dos usuários

e à incapacidade do LEED em atender as necessidades da região nos requisitos hídricos. Para melhorar esta questão sugere-se alterações nos critérios da certificação.

PALAVRAS-CHAVE

Construções verdes; LEED; água; energia elétrica; construção civil.

RESUMEN

Ante la necesidad global de reducir el consumo de recursos, las certificaciones ambientales se presentan como una posibilidad de ganar eficiencia en la construcción civil. Este trabajo buscó evaluar la eficiencia energética e hídrica de una construcción verde multifamiliar residencial vertical ubicada en Belém, en la Amazonía brasileña. Se compararon los datos de consumo energético y hídrico de dos edificios similares, donde solo uno implementó prácticas y tecnologías verdes obligatorias para la certificación ambiental Leadership in Energy and Environmental Design (LEED) Envolvente y Núcleo Central. Como resultado, se obtuvo que el consumo de agua fue mayor en un 30,64% que lo estimado. Por otro lado, el consumo de energía eléctrica fue un 24,6% menor al estimado en el proyecto y un 1,73% por debajo del consumo por persona obtenido para la edificación construida sin ninguna práctica o tecnología verde. Estos resultados demuestran que las tecnologías verdes adoptadas fueron capaces de mejorar la eficiencia energética del edificio estudiado. Sin embargo, tuvieron una baja eficiencia hídrica, atribuida al comportamiento de los usuarios y a la incapacidad del LEED para satisfacer las necesidades de la región en cuanto a requisitos hídricos. Para mejorar esta cuestión, se sugieren cambios en los criterios de la certificación.

PALABRAS CLAVE

Edificaciones sostenibles; LEED; agua; energía eléctrica; construcción civil.

1. INTRODUCTION

Historically, the construction industry is one of the sectors with the greatest environmental impact, primarily due to its consumption of natural resources. It accounts for 40% of global primary energy consumption (YUSOF, 2017) and natural resource consumption (ZHAO et al., 2019). In Brazil, construction consumes over 50% of the total extracted resources, also compromising the country's abundant mineral reserves (ROSADO et al., 2017)

This occurs because, despite the intense chase of progress, there was not sufficient concern for the conscious use of natural resources, which until the middle of the last century were seen as limitless (OLIVEIRA, 2007; SONDEREGGER et al., 2017). In an effort to develop a new relationship with the environment, the construction industry currently faces the challenge of reducing the consumption of natural resources and energy (AKHTAR, 2018)

With this purpose, the adoption of sustainable construction technologies and practices stands out, which are based on alternatives for minimizing waste production, as well as optimizing energy and water consumption (Sodiq et al., 2019), such as the use of solar panels, eco-friendly pavements, rainwater harvesting, and green roofs (SIVIRINO, 2021). Consequently, these measures allow for the preservation of the natural environment, enabling the construction industry to reduce environmental impacts, improve building efficiency, and construct buildings that meet users' needs (SANTOS et al., 2015).

Among these measures, green building labels (GBL) have already contributed to certifying over 850,000 green buildings worldwide (SANTANA et al., 2023). These green buildings labels are based on the encouragement and recognition of environmentally responsible projects in the construction industry, promoting sustainable design practices and stimulating green competition (PASSOS & BRUNA, 2019). In addition to encouraging waste reduction and the use of green materials, practices, and technologies throughout the construction production chain (ATANDA & OLUKOYA, 2019).

In this context, there are several green building labels, including AQUA-HQE, a French certification that assesses the effects of building or rehabilitating structures, analyzing the external environment, user comfort, and health throughout all phases of the project (VANZOLINI, 2023). The Casa Azul Plus label from Caixa Econômica Federal, granted to projects financed by Caixa Econômica Federal, aims to raise awareness about the social and economic benefits of sustainable construction. It also aims to reduce maintenance costs and monthly expenses for its users (SCHAMNE et al., 2021). In this context, the Leadership in Energy and Environmental Design (LEED) stands out as one of the most recognized and widely used certifications worldwide, with a broad portfolio across various types of projects (DARKO et al., 2019).

In Brazil, LEED stands out as the GBL with the highest number of certifications (Santana et al., 2023), leading a movement towards reducing the environmental impacts of constructions that has been gradually evolving in the country (GOMES, 2018). In the current scenario, many buildings are showing interest in adopting these GBL to contribute to the environment and, consequently, enhance the credibility of the project (SILVA & PARDINI, 2010; LIMA, 2019).

Knowledge about the performance of certified buildings in Brazil is limited, especially due to the confidential nature of the information, as a significant portion of certified buildings belongs to the private sector (USGBC, 2023). Additionally, the financial investiment needed to meet certification criteria might deem specific projects economically unfeasible, particularly considering the American certification standards within the Brazilian context (RECH et al., 2018). Furthermore, doubts persist regarding the actual performance of LEED buildings (ZHANG et al., 2018), as some studies yield negative results while others report positive efficiency outcomes for these constructions: in the United States, no significant performance improvements were observed when examining 465 federal green buildings and 11,006 conventional ones (CLAY et al., 2023; LUO et al., 2021); in India, a 34% higher energy efficiency was achieved for 4 LEED buildings (SABAPATHY et al., 2010); in Dubai, gains of 30% and 27% were observed for energy and water, respectively, in 9 schools (ELKHAPERY et al., 2021); in Brazil, values 30% and 200% higher for energy and water consumption, respectively, were obtained in a commercial LEED building with 11,000m² of constructed area (KERN et al., 2016). These factors raise questions about the true potential applicability and efficiency of this GBL in the Brazilian construction industry.

In order to contribute to this discussion and investigate the applicability of LEED in residential buildings in the Amazon region. This study aimed to assess the energy and water efficiency resulting from the implementation of mandatory requirements for LEED certification (Envelope and Core) in a vertical residential building located in the Amazon.

2. THEORETICAL FRAMEWORK

2.1. Construction Industry

The construction industry is a vital global sector, employing a significant number of people, generating income, and contributing to the development of many regions. It is a crucial sector for improving the quality of life for populations, regardless of a country's level of development (TABASSI et al., 2016). According to the U.S. Bureau of Economic Analysis (BEA, 2019), in just the third quarter of 2019, the construction industry in the United States generated over $650 billion and employed more than 7 million people. The Chinese construction industry, on the other hand, presented even more significant figures during the same period, with a contribution proportional to the size of its market. According to the National Bureau of Statistics of China (NBS, 2019), the industry was responsible for $6.7 trillion of the country's Gross Domestic Product (GDP), providing income for over 55 million people. In Brazil, albeit on a smaller scale, the construction industry remains one of the main economic drivers, creating jobs in various sectors of the economy and stimulating the domestic market (FIALHO et al., 2014). According to IBGE (2020), the construction industry in Brazil is recovering after years of crisis, generating more than 120,000 jobs in 2019 and surpassing 10 million employees, contributing R$14.2 billion to the Brazilian GDP.

Despite its fundamental importance, this industry is also responsible for high levels of environmental pollution in various regions worldwide (YUSOF et al., 2017). For example, the urbanization process of cities has led to environmental impacts such as wildfires, deforestation, soil, and river pollution due to the need for space for growth and infrastructure (GONÇALVES et al., 2014; HYDE et al., 2018).

In addition to the impact caused before and during construction, it is essential to assess the effects that the outcomes of this activity generate. Regarding waste, the study by Estanqueiro et al. (2018) exemplifies that the construction industry in Europe generates over 100 million tons of waste annually, many of which are poorly managed, causing environmental damage. For the authors, HUANG et al. (2018), who analyzed construction and demolition waste (CDW) in China, the amount reaches up to 40% of the total from all sectors combined. In Brazil, approximately 50% to 70% of solid waste found in urban environments comes from the construction industry (GOMES et al., 2021).

In addition to the visible waste generated on-site from demolition and construction activities, the construction industry also significantly impacts air pollution by emitting toxic gases, contributing to the greenhouse effect, particularly carbon dioxide (CO2) (AKAN et al., 2017). Carbon dioxide alone accounts for 72% of all emissions contributing to the worsening of the greenhouse effect, which, in 2015, proportionally led to a 1°C increase in average global temperatures (QIAO et al., 2019),and currently, the year 2023 is proving to be the hottest year on record, with an average temperature 0.85°C above historical measurenments (G1, 2023). While seemingly not a highly significant value, the constant acceleration of global warming disrupts ecosystems and, as a consequence, leads to a higher number of climate catastrophes around the world (HOEPPE, 2016). Adverse climate events, increasingly unpredictable and more frequent natural phenomena, pose challenges to engineering, demanding improved infrastructure and the development of new technologies.

2.2. Sustainability and Energy Efficiency

The notion that natural resources, even if widely extracted and used indiscriminately, would be inexhaustible regardless of the quantity consumed (OLIVEIRA, 2007) had its validation discredited decades ago (DI VITA, 2006). It is now widely acknowledged that uncontrolled management of these resources leads to their premature depletion, preventing nature from having sufficient time for replenishment (ABOU ZAHR DIAZ et al., 2019; LONGONI et al., 2018; MCKINLEY et al., 2017). Such excessive consumption, coupled with rapid exhaustion, directly impacts natural cycles, resulting in climate changes that affect air quality, water availability, energy supply, and food production in the directly affected regions and their areas of influence (ZAMAN et al., 2017).

The dilemma in the construction industry is the pursuit of more sustainable materials without giving due importance to the reuse of existing materials. The necessary change requires a mindset instilled from academic education to demonstrate that the development of new materials and technologies is not the sole path to a more sustainable construction (SIEFFERT et al., 2014). In this sense, it is essential to note that for sustainable construction to exist, attention must be given to the three pillars: ecological sustainability, economic opportunity, and social inclusion. This is crucialfor transitioning from a polluting society to a sustainable one (AWADH, 2017; BROMAN & ROBÈRT, 2017; LU & ZHANG, 2016).

Considering these aspects and following the global trend, sustainable construction has been a sector that needed to reshape itself in recent decades to align more with these concepts (TABASSI et al., 2016). In this context, the concept of Low-Carbon Neighborhoods and Cities emerges. These are urban clusters that, through conscious practices and the use of renewable energy sources, manage to reduce greenhouse gas emissions and minimize environmental and climate impacts. This approach aims not only to transform isolated developments but to change the lifestyle of entire communities, experiencing increasing demand in Brazil and other countries as an alternative in the construction process (ASSAF, 2011; BENITES et al., 2020).

2.3. Green Building Labels (GBL)

Shifting the production process in construction, though challenging, has become a global necessity, involving the more conscious and regulated use of natural resources. Ignoring this shift in principles may result in a high environmental and quality of life cost for nations (LU & ZHANG, 2016; MENDES, 2022). This change becomes viable only when the concepts of sustainable construction are understood and applied, internalizing the need to "think globally, act locally" (SIEFFERT et al., 2014). With this new reality, the first GBL aimed at the construction industry emerged, where green projects would be assessed for desired environmental criteria, reducing consumption and waste and serving as an official acknowledgment for builders contributing to the environment (HE et al., 2018).

GBL aims to balance the social, environmental, and economic pillars and discover new strategies to incorporate environmentally friendly concepts into people's daily lives. The goal is to bring about a process of change, not just achieve certification. GBL are particularly important in developing countries where the construction industry holds significant economic importance due to infrastructure and housing demands (AKAN et al., 2017). In these countries, building certification can not only contribute to sustainability but also attract international investments by utilizing globally recognized labels. The primary international GBL include the Building Research Establishment's Environmental Assessment Method (BREEAM), created in the United Kingdom, which established environmental assessment criteria for buildings and set standards for best sustainable practices (Ding et al., 2018), and the Leadership in Energy and Environmental Design (LEED), developed by the United States Green Building Council (USGBC), a non-governmental organization that created LEED to define, standardize, and promote sustainable projects in the United States (STEFANUTO & HENKES, 2013).

Being one of the first certifications established, LEED has transcended the boundaries of its country of origin and is widely accepted in many others, not just for residential certification but also for commercial buildings and public spaces (CANDAŞ & TOKDEMIR, 2019; LU & ZHANG, 2016). In addition to energy consumption reduction, LEED considers other factors such as water consumption, atmospheric impact, waste generation, human experience, and project location. The goal is to promote green competition and raise consumer awareness of the importance of environmental performance in buildings (PASSOS & BRUNA, 2019).

In this context, the World Green Building Council emerged to adapt LEED to the reality of various countries, currently having 21 members, including the Brazil Green Building Council, which adapted certification parameters to Brazil's social and construction context (FASTOFSKI et al., 2017). With this new trend, GBL spread worldwide, playing a significant role in stimulating a paradigm shift (OBATA et al., 2019). However, it's important to note that despite the benefits gained through the process, implementing the LEED certification initially incurs additional costs in construction. According to the estimate by Uğur and Leblebici (2018), this cost increase can vary between 4% and 11% of the total budgeted value, considering both the cost of implementing measures and the bureaucracy for project certification, depending on the project's scale and intended level.

3. METHODS

For the conception of this study, an exploratory research with quantitative analysis was conducted to achieve the objective of measuring the energy and water consumption of a vertical residential green building. In this context, a green building refers to a vertical residential structure that meets the mandatory requirements for LEED certification (Envelope and Core). To accomplish this goal, the research was divided into four stages, detailed as follows:

a) In the initial stage, the LEED requirements met by the studied green building were investigated, specifically those related to "Water Efficiency" and "Energy and Atmosphere."

b) Subsequently, the electric energy consumption of the green building was measured and compared with the consumption of a conventional building, possessing similar standards and characteristics to its counterpart but without the implementation of any green construction technologies.

c) Similarly, water consumption data were collected for the green building and compared with the consumption of the same conventional building.

d) Finally, the findings from the energy and water consumption comparisons were analyzed, considering the impact of green building technologies and practices on the overall efficiency and sustainability of the construction.

By systematically following these four stages, this research aims to provide valuable insights into the energy and water efficiency of green residential vertical buildings and their impact on resource consumption in comparison to conventional structures. The data collected and analyzed in these stages contribute to a comprehensive understanding of the potential benefits and challenges associated with sustainable construction practices, particularly as they pertain to the LEED certification criteria.

3.1. Description of the Green Building and Conventional Building

The evaluated green building is a residential structure consisting of 30 typical floors, with one apartment per floor, offering two floor plan options of 195.01m² and 200.64m² of private area, along with 96 parking spaces and three elevators - one for regular use, one for service, and one for emergencies. The building's communal area includes facilities such as children's and adult swimming pools, a gourmet space, a multipurpose court, a gym, a party hall, a sauna, a playroom, and a game room. This development is situated in Belém, in one of the neighborhoods with the highest per capita income in the entire metropolitan region (DA SILVA & LOBO, 2019).

With the goal of offering a distinctive product, the management of this project initially decided to pursue LEED certification for Envelope and Core, aiming to achieve the Silver level. This would make the building the first residential development in the entire northern region of Brazil to attain an GBL. However, during the construction phase, the construction company chose not to proceed with the certification process due to the high costs associated with paying the fees required by LEED.

While the initial intention was to achieve LEED certification and demonstrate the commitment to environmental sustainability, the decision to forgo the certification highlights the financial challenges and trade-offs that construction companies often face when pursuing green building initiatives. This case underscores the complex considerations involved in integrating sustainable practices into construction projects and the need to balance environmental goals with economic feasibility. Even so, several green building technologies were implemented in its construction, as shown in Table 01.

In Table 01, we also observe a comparison with the conventional building, investigated to enable a comparison with energy and water consumption data. According to Table 01, both buildings present very similar characteristics, such as area, purpose, common areas, number of floors, rooms, and bathrooms per apartment. However, they differ in the number of air-conditioned spaces and

Criteria	GREEN Building	Conventional building
Purpose	Residential	Residential
Area	195.01m² e 200.64m²	193.05m² e 200.64m²
Common area	Children's and adult swimming pools; Gourmet space; Sport court; Fitness space; Party hall; Spa; Playroom; Playground	Children's and adult swimming pools; Gourmet space; Sport court; Fitness space; Party hall; Playroom; Playground
Number of floors	30	30
Number of apartments	1	2
Number of bedrooms	3	3
Number of bathrooms	5	5
Number of elevators	3	3
Number of air-conditioned spaces	1 in each bedroom + 1 in the living room + 1 on the balcony, totaling 5	1 in each bedroom, totaling 5
Gourmet balcony	Yes	No
Use of porcelain tiles with a solar reflectance index between 55 and 45	Yes	No
Doors made of wood certified by the Forest Stewardship Council	Yes	No
Use of paints, sealers, and putty with fewer pollutants	Yes	No
Glass façade with Stick-type system	Yes	No
Change of cables in the electrical downcomer	Yes	No
Use of more economical crockery and metals	Yes	No
LED lamps in common areas	Yes	No
Elevators with more efficient energy consumption	Yes	No

Table 01: Comparison between the LEED building and the conventional building.
Source: Authors.

apartments per floor, resulting in higher electrical project demands for the Green building.

3.2. LEED REQUIREMENTS DIAGNOSIS

LEED, like many other GBL, operates on a scoring system, where there are mandatory requirements that all projects must meet, as well as optional ones that provide additional points for projects aiming to achieve higher levels of sustainability, such as Silver, Gold, or Platinum.

In order to attain the Silver level of LEED certification for Envelope and Core, the green building under study needed to earn points beyond the mandatory requirements. To achieve this, the construction company defined which requirements they would pursue and adopted various green construction practices and technologies with the aim of obtaining the certification.

However, with the inability to complete the certification process, some of these requirements might not have been fully implemented. As a result, this study conducted a thorough assessment of the requirements that were fulfilled by the green building.

The implementation diagnosis was carried out through document analysis and on-site inspections, involving a review of the implemented items in the "Water Efficiency" and "Energy and Atmosphere" categories. These categories are linked to the technologies and practices mandated by the certification, with the purpose of reducing the building's electricity and water consumption.

By rigorously evaluating the implementation status of these requirements, the study provides insight into the extent to which the green building adhered to the intended environmental goals and practices outlined by the LEED certification guidelines.

3.3. Energy Consumption

Next, an analysis of the energy savings achieved through the implementation of some of the LEED measures in the studied green building was conducted. This analysis aimed to verify the actual reduction in consumption in the building when compared to another building that followed conventional construction methods without any interventions aimed at GBL.

Through an examination of the green building's electrical design, the expected consumption for the residential units was identified based on average consumption and calculation methods established by the National Electric Energy Agency (ANEEL, 2015). The comparisson between the expected project consumption with the observed energy consumption is important because it allows considering distortions resulting from differences between the developments, such as the absence of air conditioning in the living room and balcony of the conventional building.

Next, was collected the energy comption of the buildingsin kilowatt-hours (kWh). The data was directly collected from the Individual Energy Meter (IEM) of each apartment and the communal area, collected over a period of 19 months, spanning from July 2019 to January 2021.

For the comparative analysis of the energy consumption, data regarding average consumption per inhabitant were utilized to avoid variations resulting from the number of inhabitants. Additionally, this analysis helped determine whether the expected consumption based on the design was in line with, below, or exceeded the actual consumption of the green building.

By performing this analysis, the study aimed to assess the tangible impact of LEED measures on energy consumption, thereby providing insights into the effectiveness of the green building's sustainable practices in contrast to a conventional building.

3.4. Water Consumption

In this phase, data regarding the monthly water consumption of each residential unit in the green building was collected, spanning from August 2020 to April 2021. This was achieved by tracking the recorded values directly from the water meter of each individual dwelling on a monthly basis, allowing for the identification of water usage patterns.

The key reference value, crucial for accurate result comparison, is set by the local water and sewage utility company, COSANPA, for new vertical buildings in the state of Pará. In the specific case under consideration, COSANPA establishes a total of 1,000 liters per day per residential unit with three or more bedrooms.

However, it was not possible to conduct a comparative analysis with the conventional building due to the absence of individual water meters in that particular structure. These meters were removed shortly after the issuance of the "Habite-se" document by the Fire Department, which is granted shortly after the building's delivery to clients.

Given the aforementioned limitations, two distinct comparisons can be made regarding this project:

(a) A comparison between the estimated consumption based on COSANPA's projections and the actual consumption obtained.

(b) A comparison of the overall reduction in water usage between the obtained data during the specified period and the LEED-predicted water usage reduction based on the employed water efficiency technologies.

Through these comparisons, the study aimed to evaluate the extent to which the green building's water consumption aligned with both local regulatory expectations and LEED-predicted reductions, shedding light on the building's water-saving practices and the effectiveness of implemented water-efficient technologies.

4. RESULTS AND DISCUSSION

The research produced significant results regarding the energy consumption of the green building in comparison to the structure that did not incorporate any green construction technologies. A significant improvement in electricity consumption was observed in the green building. However, it is worth noting that the water consumption of the green building exceeded that of the conventional building. These outcomes, alongside the diagnosis of the LEED requirements implemented in the green building, will be deliberated upon in the following sections.

The subsequent sections will delve into a comprehensive analysis of these findings, providing insights into the reasons behind the observed energy and water consumption patterns. Moreover, a detailed discussion will be presented on the extent to which the LEED requirements were successfully integrated into the green building, considering the factors that may have contributed to the divergent water consumption results.

By scrutinizing the data and the implementation of LEED standards, the study aims to offer a comprehensive understanding of the energy and water consumption dynamics, allowing for a nuanced interpretation of the observed outcomes. This analysis will facilitate a robust examination of the building's overall sustainability performance and provide valuable insights for future endeavors in green construction practices.

4.1. Results From The LEED Requirements Diagnosis

To provide a foundation for the research discussions, a diagnostic assessment was conducted to ascertain which green technologies were effectively implemented by the construction company in the "Water Efficiency" and "Energy and Atmosphere" categories, which are the focus of the study.

Through this diagnostic analysis, it was observed that all mandatory requirements in both categories were fulfilled by the construction company. Additionally, partial compliance was noted with the optional requirement to "optimize energy performance".

Concerning water credits, the mandatory criteria were met through the use of individualized meters and the selection of efficient fixtures and fittings with reduced flow rates, achieving the targeted 20% water savings for this category. Furthermore, the landscaping of the green building does not require a permanent irrigation system and is maintained at a low frequency, fully satisfying the mandatory LEED criteria for Envelope and Core.

Likewise, the requirements related to the "Energy and Atmosphere" category also encompassed the mandatory aspects. To achieve this, a specialized company was hired to conduct building commissioning and verification. Additionally, the building incorporated smart elevators, more efficient electrical cables, and an exterior cladding with higher reflectance index, enhancing thermal comfort and aiming for a 10% or greater reduction in electricity consumption. Moreover, all air conditioning units installed in common areas were selected to avoid refrigerants that harm the ozone layer, utilizing CFC-free options. Finally, as required by the electric utility company, individual energy meters were installed for each consumer unit.

In addition to the technologies implemented, these interventions enabled the partial achievement of the "Optimize Energy Performance" credit. According to the report from the company that conducted the LEED certification process, it was possible to achieve a 14% reduction in electricity consumption for the green building through computational simulations. This outcome highlights the successful integration of energy-efficient strategies and their positive impact on overall energy consumption, aligning with the goals of sustainability and environmental responsibility set by the LEED certification.

4.2. Results From Energy Consumption

The analysis of energy efficiency was conducted after identifying the implemented green technologies. For this, the project's energy consumption was estimated, and then the per capita consumption was measured to ensure that the data were not distorted by apartments with varying occupancy rates.

The project's energy consumption was calculated based on average consumption data established by the National Program for Electric Energy Conservation

(PROCEL, 2010) and updated with current appliances and equipment data obtained from the architectural projects of the buildings. As a result, a higher estimated energy consumption was obtained for the green building (913.63 kWh), mainly due to the cooling of the living room and gourmet balcony, which does not occur in the conventional building (604.69 kWh).

Regarding the energy consumption of the buildings. The data were collected on a monthly basis from the electricity bill statements, measured in kWh, over a period of 19 months, spanning from July 2019 to January 2021. Moreover, apartments with incomplete or no consumption data, as well as unoccupied units, were excluded from the analysis to prevent negative distortion of the obtained results. Table 02 presents the estimated consumption and the average of the measured consumption.

Descrição	Consumption of electrical energy (kWh)	
	Green building	Conventional building
Baseline project (PROCEL,2010)	913.63	604.69
Actual on-site measured average	688.84	506.81
Reduction in consumption compared to the baseline project	24.60%	16.19%

Table 02: Comparison between projected electricity consumption and measured average consumption.
Source: Authors.

The results demonstrate that the green building achieved a greater reduction in energy consumption (24.60%) compared to the project than the conventional building (16.19%), despite the conventional building having a lower average energy consumption.

This greater reduction in consumption compared to the project demonstrates the better energy efficiency of the green building, resulting from the technologies employed. Although the green building generated higher energy consumption values, these values were lower than expected considering the electrical project and the expected consumption patterns for both buildings.

To corroborate these results, the monthly energy consumption per person was calculated. Figure 01 reveals that the average per capita consumption of the two buildings is statistically similar, showing a minor variation over the period. Within this timeframe, the average energy consumption of the green construction was 211.25 kWh, compared to 214.91 kWh for the conventional building, resulting in a variation of 1.73%.

4.3. Results From Water Consumption

These results demonstrate that despite an expected higher consumption per person for the green building, both constructions exhibit similar consumption patterns. This can be attributed to the green technologies employed, which, in the studied case, were able to equalize energy consumption per person even when considering the more demanding consumption conditions adopted in the electrical project of the green building.

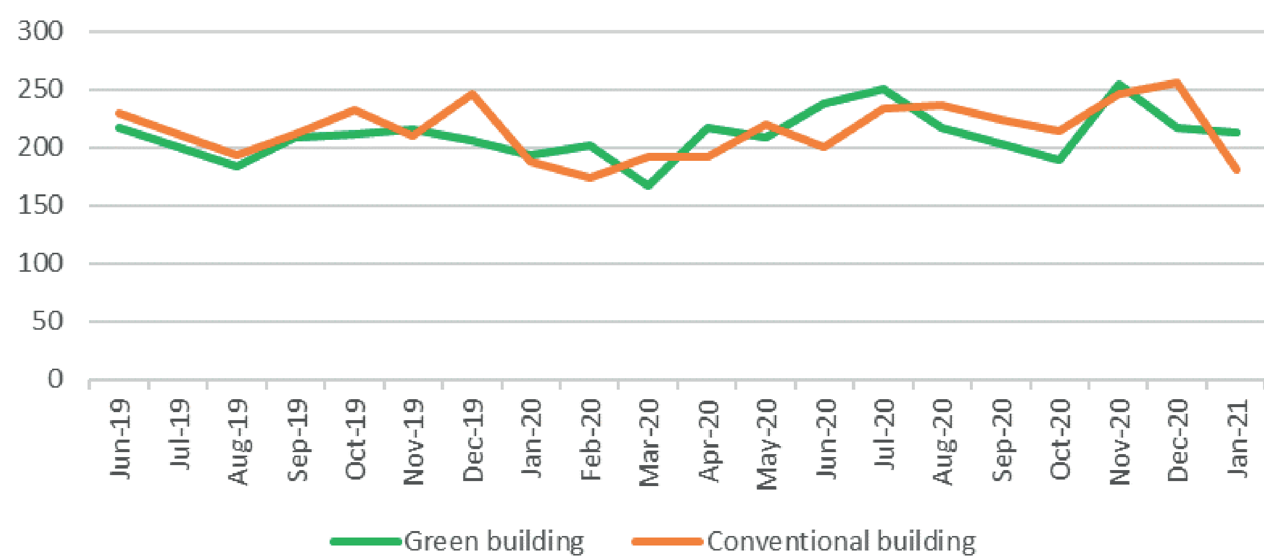

Figure 01: Comparison of monthly electricity consumption per person in kWh.
Source: Authors.

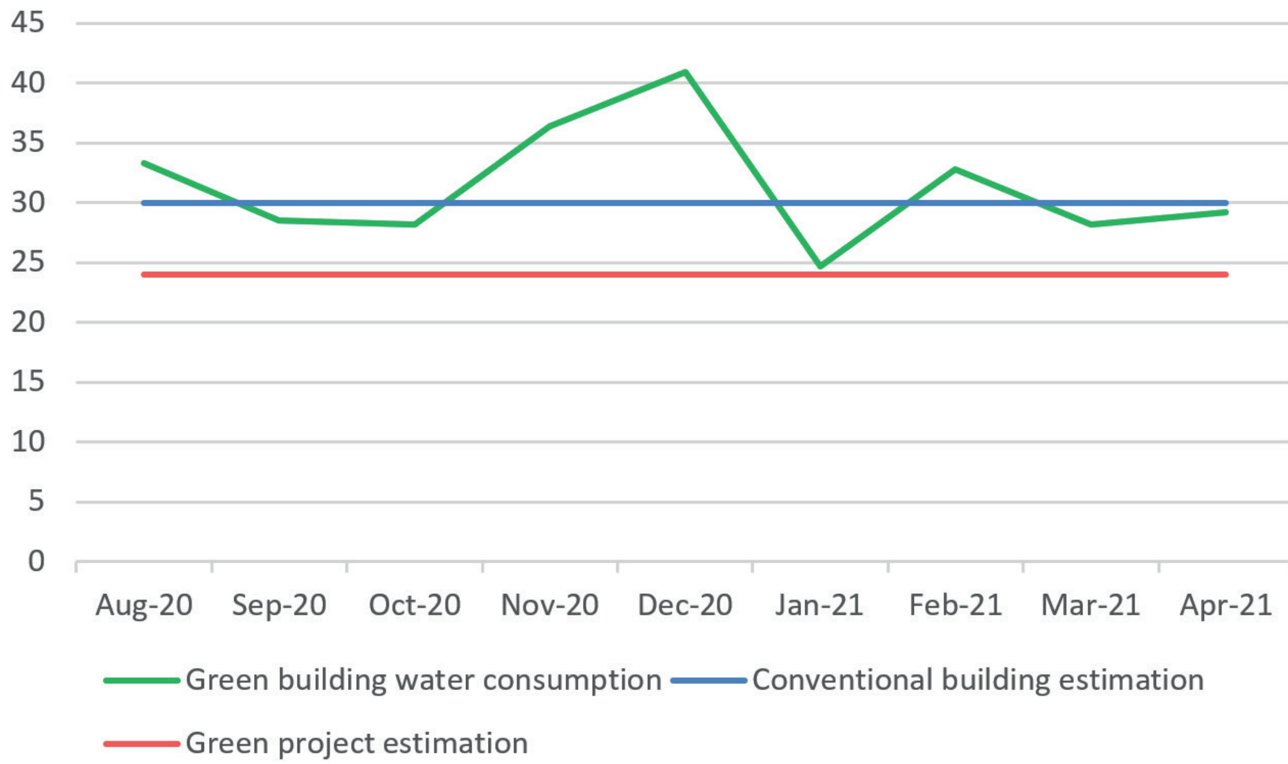

Figure 02: Comparison of monthly water consumption per person in kWh.
Source: Authors.

Another evaluated factor was the individual water consumption data of each housing unit, in order to investigate how they correlate with the project estimate and the anticipated reduction due to the adoption of green technologies.

This category, named "Rational Water Use," has a singular prerequisite: achieving a minimum 20% reduction in the overall consumption of this water resource. By doing so, it becomes possible to optimize efficiency and alleviate the burden on the local utility's water supply and sewage collection systems.

The construction company implemented several green technologies to attain this benchmark. Among these, the installation of dual-flush toilets, aerator-equipped faucets, and more efficient showers were introduced to achieve the desired water savings.

Considering the provided information, monthly consumption data per housing unit in cubic meters were gathered over the past nine months. These data points are displayed in Figure 02, alongside the reference line set by the water and sewage utility, as well as the minimum 20% reduction stipulated by LEED (Leadership in Energy and Environmental Design).

Figure 02 provides a clearer understanding of the water consumption pattern over the observed period. In general, the average water consumption of the green building apartments remained above the projected estimate, and consequently, above the LEED ideal. Over the nine-month period, an average of 31.35 cubic meters of water was consumed per unit, exceeding the estimated 30 cubic meters by COSANPA.

In percentage terms, the green construction recorded a water consumption 4.51% higher than the utility reference and 30.64% higher than the LEED certification projection. Throughout the nine months of observation, in five of them, the building's consumption values fell below COSANPA's estimate, yet still remained above the ideal reduction envisioned to attain LEED category credits.

On the other hand, in the other four months, the recorded value exceeded both the certification's expectation and the utility's estimate. Supporting these findings, Menassa et al. (2012) concluded that certification alone does not necessarily result in the proposed reductions in water and energy aspects. In the cases studied by the authors, most evaluated buildings were unable to even achieve the minimum result expected by the certification.

Another study conducted by Alborz and Berardi (2015) observed similar challenges in reducing water consumption in green constructions. The study assessed data from two hundred schools in the United States and observed that despite the implementation of green technologies, green constructions did not exhibit significant differences in water consumption compared to conventional ones. This phenomenon was partially attributed to a reduction in water consumption efficiency, amounting to around 5% over a total of five years.

However, there are authors who obtained different results. Kern et al. (2016) documented water consumption 31% lower than projected for a LEED-certified commercial building in Brazil. Similarly, Rodrigues et al. (2019) indicated a 70% reduction in water consumption due to LEED certification after the renovation of the Mineirão stadium.

This underscores that other factors must be influencing these variations in water consumption in green constructions. Aiming to identify this cause, Alborz and Berardi (2015) investigated the consumption habits of green construction users through post-occupancy surveys, revealing, for example, an average bathing duration 50% longer than estimated by LEED. These data suggest that the behavior of green construction users significantly influences the actual water consumption of the building and may even outweigh the superior efficiency of the employed technologies.

This reality might be even more pronounced in Brazil, particularly in the northern region of the country, given the abundance of water in the Amazon, where users are more prone to higher consumption and neglect in water resource management, resulting in high water loss rates during distribution (COSAMPA, 2020), disregard for basic sanitation infrastructure (IBGE, 2017), and water pollution (SANT'ANA, VITAL & SILVA, 2020).

Furthermore, the high water consumption of the green building can be attributed to the inadequacy of LEED requirements for constructions in the region. In fact, the lack of requirements adapted to the conditions of each locality is a criticized aspect of the certification (DEVINE, MCCOLLUM, 2019; SABBAGH, MANSOUR & BANAWI, 2019). A solution to this issue may involve adopting a greater number of requirements (ADEKANYE, DAVIS & AZEVEDO, 2020; FLOWERS, MATISOFF & NOONAN, 2019) and reducing mandatory requirements, without, however, reducing the required score. This strategy could favor constructions in climates entirely different from that for which LEED was created, and may even benefit lower-cost projects by allowing developers to choose requirements that provide greater benefits, such as favoring low cost, marketing, or environmental impact reduction, according to the project's objectives.

5. CONCLUSION

This study aimed to assess the energy and water efficiency resulting from the implementation of mandatory requirements for LEED certification (Envelope and Core) in a vertical residential building located in the Amazon. To achieve this, data on energy and water consumption were collected from a Green building and a conventional building with similar characteristics.As a result, this study found that the implementation of the mandatory LEED certification requirements led to a reduction in electricity consumption of 24.6% compared to the projected values, and an energy savings of 1.73% compared to the building constructed without any green technology implementations. This demonstrates that building certification and the adoption of green technologies are a viable path towards sustainability in the construction and operation of residential buildings.

On the other hand, the water consumption of the green construction was 30.64% higher than what would have been expected based on the LEED requirements met (Envelope and Central Core). In the study, this was attributed to higher water consumption behavior by users in the region, considering the warmer climatic zone that demands more water for personal hygiene, as well as a possible neglect of water due to its abundance in the Amazon region. This result highlights the importance of user awareness and behavioral change, as despite the implementation of green technologies for water efficiency, users are the primary drivers of performance.

Furthermore, the high water consumption of the green building can also be attributed to the inadequacy of LEED criteria for the Amazonian reality. This is a result of its inability to meet the realities of all locations. To address this issue, greater flexibility in the LEED certification process is crucial, such as adopting a greater number of requirements and reducing the number of mandatory requirements. This would favor the certification process for small businesses, allowing them to adopt sustainable construction practices compatible with local conditions, user behavior patterns, and their investment capacity.

As a suggestion for future research, it is recommended to investigate the factors that influence high water consumption in hot and tropical climates and their impact on the observed results.

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