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APPLICATION OF ENERGY EFFICIENCY EVALUATION METHODS FOR COMMERCIAL BUILDINGS IN AGRIBUSINESS

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KEYWORDS

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ABSTRACT

Agribusiness and commerce are two major sectors that consume electricity. Agribusiness can generate energy but not enough to meet its needs. Thus, energy efficiency is fundamental for the sector's sustainability. This study aimed to apply PROCEL energy evaluation methods in a Brazilian agribusiness company, specifically in the meat retail sector, located in the Alta Paulista region. This research has a quantitative approach, and PROCEL's RTQ-C manual, bibliographical research on the energy issue, and the functioning of the company's environment were used. The commercial establishment received the B classification index, which can be considered good but has several points of improvement, mainly on air conditioning, which provides better energy efficiency to the company. Therefore, the company can obtain economic and environmental returns by improving such areas, and the present research serves as a basis for evaluating energy efficiency in other companies in the same sector.

INTRODUCTION

New technologies are increasingly present in our daily lives through electronic devices and household appliances, among others. An increase in electrical energy consumption has been observed with the higher use of this equipment. Thus, energy supply also needs to accompany this growth, but it is not something simple (Iwaro & Mwasha, 2010).

Agribusiness is not one of the largest consumers but still contributes significantly to the increase in electrical energy consumption, thus contributing to an increase in the global demand for this input in Brazil and the world (Montoya et al., 2019).

Therefore, consciously using energy has been becoming more and more of a basic need, which can be met by applying and paying attention to energy efficiency issues.

According to Souza et al. (2020), energy efficiency is the way of carrying out a task or activity, not using more than necessary or using as little energy as possible. According to the authors, savings can be generated using technologies that allow control or lower energy use or the exchange of equipment with a high energy expenditure for more efficient ones. This responsibility must be shared between the government, companies, and society (Labanca & Bertoldi, 2018).

Regarding built environments, energy efficiency has gained great prominence, as relatively simple changes, or preparations, if planned in advance or altered, can lead to energy efficiency with a considerable cost-benefit ratio (Ceballos-Fuentealba et al., 2019). Other authors have studied the efficient use of electrical energy in agribusiness, such as Cremasco et al. (2010) in laying hen companies.

Other agribusiness sectors, such as the meat retailer, can also benefit from these issues, as they are linked to two major consumers of electrical energy: agriculture and commercial activities.

Brazil had great prominence on the world stage in meat production, specifically beef, in a market that remains

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in continuous development, with signs for further expansion given the improvement of its production in quantity and quality. Beef alone generates revenue of approximately 6.55 million for Brazil in exports and many consider it as the main national commodity in terms of value. In addition, Brazil is on the way to becoming the world's main supplier of this input with its large herd (Rodrigues & Marta-Costa, 2021).

The increase in production also leads to an increase in energy demand. Therefore, energy efficiency is fundamental for the sustainability of this sector.

One of the ways to assess energy efficiency in built environments is using the Technical Quality Regulation for the Energy Efficiency Level of Commercial Buildings and Public Services (RTQ-C) of 2017, developed by the National Electrical Energy Conservation Program (PROCEL), which allows an analysis through three points: building envelope, lighting, and air conditioning, and can be applied to different types of buildings (Wong & Krüger, 2017).

Regulated by the Brazilian National Institute of Metrology, Standardization, and Industrial Quality (INMETRO) in 2009, the RTQ-C became mandatory from 2014 onwards for all public service buildings, evaluating buildings using two methods: Simulation Method (performed by software) and Prescriptive Method (performed through equations). Initially, it was well criticized but after several improvements, the 2017 version has been considered a well-structured and valid method (Garcia & Souza, 2017).

Therefore, this study aims to evaluate the energy efficiency level of the building envelope, lighting, and air conditioning through the RTQ-C manual in a meat retailer located in the Alta Paulista region, in the municipality of Bastos-SP, Brazil. The possible hypotheses are that the level of energy efficiency is considered good, medium, or bad, with an efficiency rating ranging from A to E.

This study can be of vital importance for the study of energy efficiency in agricultural and agroindustrial production, as there is not a large amount of research related to the use of RTQ-C in agribusiness.

MATERIAL AND METHODS

This is exploratory and descriptive research regarding the objectives, with a quantitative approach, whose unit of analysis is a company in the agribusiness sector, that is, a retail butcher shop located in the municipality of Bastos-SP, Brazil.

The collected data allowed the use of previously existing equations in the literature to obtain evaluation and classification indices. Moreover, the data for each sector of the analyzed industry allowed a descriptive statistical analysis.

The butcher shop has four employees, one of whom is responsible for customer service and the others focused on preparing the cuts of meat. It sells an average of 4000 kg of meat per month.

The company's field of action is the municipality of Bastos and other municipalities in the region. The butcher shop is only responsible for the preparation and sale of products since the animals are slaughtered outsourced. Regarding infrastructure, the establishment has a total area of 211.61 m^2.

The prescriptive method of the RTQ-C manual for the Energy Efficiency Level of Commercial Buildings and Public Services version 2017 was used to assess the energy efficiency of the object of study. For this, a thorough study of the manual was necessary to understand its concepts and procedures, in addition to researching application cases in other objects of study to better understand its practical application.

After analyzing the floor plan, a semi-structured interview was required to obtain information about the company's operation and its activities. Structural data about the unit, inherent to the constructed area of the studied building and the climate zone in which the company is located, were also collected to determine the calculations for the energy efficiency level.

Three points described in the efficiency manual were calculated separately to determine energy efficiency: building envelope efficiency, lighting efficiency, and air conditioning efficiency. Finally, the partial calculations were combined into a final equation, which determines the overall efficiency level.

According to the RTQ-C manual (Programa Nacional de Conservação de Energia Elétrica, PROCEL, 2017, p. 38), the building envelope "is the set of constructive elements that are in contact with the outside environment, that is, that make up the closures of the internal environments relative to the external environment."

The bioclimatic zone in which the studied environment is located was initially defined to calculate the efficiency of this point (Krüger & Mori, 2012). In this case, according to NBR 15220-3, the area of the Alta Paulista region is in Bioclimatic Zone 6, as shown in Figure 1.

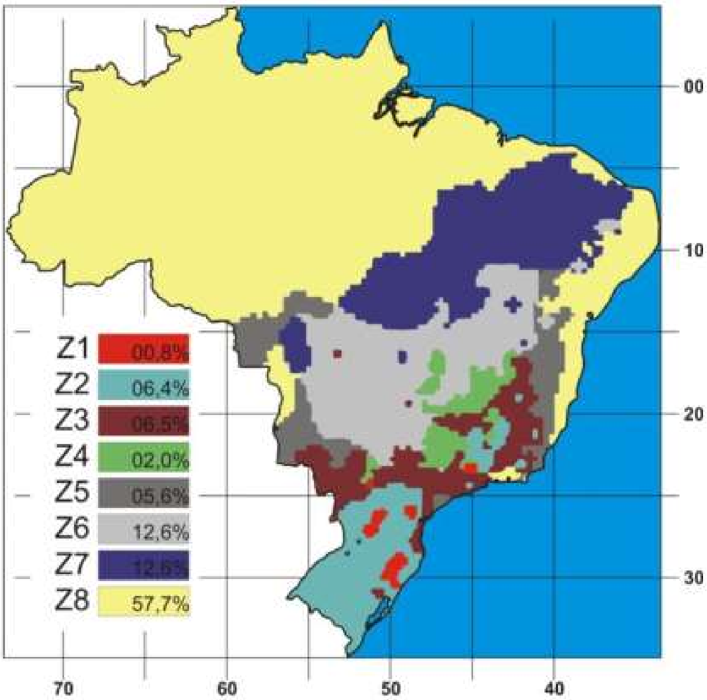

FIGURE 1. Map of Brazilian Bioclimatic Zones (PROCEL, 2017).

This point is important for choosing the building envelope formula and reaching the final classification of the energy efficiency level. The classification ranges from A to E, in which A is the most efficient and E is the least efficient.

The thermal transmittance of the glazing, walls, and roofs, that is, "heat transmission in a unit of time and through a unitary area of a building element or component, in this case, opaque components of the facades (external walls) or toppings" (PROCEL, 2017) was also evaluated.

The weighted mean of this factor was calculated because there may be material variations in the same construction. Thus, the Brazilian Standard 15220-2 was used to determine this index for each type of material. This standard also provides the surface absorption value according to the color of the building, which is another important factor for efficiency classification.

Finally, the building envelope consumption indicator ($CIenv$) was calculated by [eq. (1)], as the building projection area (BPA), calculated according to the RTQ-C 2017 manual, is lower than 500 m^2. This calculation depends on the roof of the studied environment, the number of floors, and the regularities of these floors. Thus, the building envelope indicator for bioclimatic regions 6 and 8 for buildings with less than 500 m^2 of BPA is given by:

$$CIenv = 454.47.FH - 1641.37.FS + 33.47.POTF + 7.06.FSun + 0.31.VSA - 0.29.HSA - 1.27.POTF.VSA + 0.33.POTF.HSA + 71 \quad (1)$$

with:

$$FH = \frac{Arp}{Atot} \quad (2)$$

$$FS = \frac{Aenv}{Vtot} \quad (3)$$

where:

FH is the height factor;

Arp is the roof projection area;

$Atot$ is the total area;

FS is the shape factor;

$Aenv$ is the building envelope area;

$Vtot$ is the total volume;

$POTF$ is the percentage of openings on the total facade: mean percentage of existing openings;

$FSun$ is the solar factor;

VSA is the vertical shading angle, and

HSA is the horizontal shading angle.

Table 1 was used to define the level of the calculated value. Equation (1) was used to calculate $CImax$ and $CImin$, but with the following parameters for $CImax$: 0.6 for $POTF$, 0.61 for $FSun$, and 0 for VSA and HSA; and the following parameter for $CImin$: 0.05 for $POTF$, 0.87 for $FSun$, and 0 for VSA and HSA. The i index is calculated by the equation $i = CImax - CImin/4$.

The building envelope efficiency index is obtained by completing Table 1 with the collected variables and comparing it with the value obtained in [eq. (1)].

TABLE 1. Building envelope efficiency classification.

Classification	Efficiency	
	Minimum	Maximum
A	-	$Icmaxd - 3i$
B	$Icmaxd - 3i + 0.01$	$Icmaxd - 2i$
C	$Icmaxd - 2i + 0.01$	$Icmaxd - 1$
D	$Icmaxd - i + 0.01$	$Icmaxd - i + 0.01$
E	$Icmaxd + 0.01$	-

Source: PROCEL, 2017.

The method of activities per building environment was used to calculate lighting efficiency. It allows verifying the value required to carry out a certain activity, with a classification from A to E depending on the activity of each environment, as proposed in the RTQ-C manual (PROCEL, 2017):

- Identify all illuminated environments.
- Identify the main activities of each environment and determine which of the activities present in the manual's list fits each one.
- Determine the maximum and minimum levels for each activity per m^2 of each of the illuminated environments.
- Determine the illuminated area of each environment.
- Check the limit for each environment according to its size, multiplying the area of the environment by its maximum and minimum parameters for each efficiency level.
- Add the Limit Lighting Power Density ($LLPD$) (W m^{-2}) – $LLPD$ of all lamps and lighting systems in each environment.
- Add the maximum and minimum parameters of each environment in each efficiency classification, forming a table.
- Condense in a table the values obtained from all the lamps used in all the company's environments and compare them with the parameters stipulated by the manual.

Initially, all air conditioners in the studied space were mapped to calculate air conditioning efficiency. In addition, the air conditioning equipment outlets were checked to ensure that they were not obstructed. If so, the air conditioner loses points when carrying out its efficiency classification, according to the manual.

The efficiency indices of each air conditioning model were collected, according to the calculation by INMETRO. This value may be present on the product or may be consulted on the INMETRO website.

Subsequently, the power (in BTUs) of the air conditioners was collected for each environment. This value can also be checked on the device or the INMETRO website.

Thus, the weighted efficiency mean was calculated according to the number of BTUs of each device, and each efficiency level had a numerical correspondent. Therefore, this value is compared to the parameters of the RTQ-C manual to determine the energy efficiency level of air conditioning.

A general table with the limit power per environment was generated and the mean of all environments for all indicators was calculated.

Equation (4) (PROCEL, 2017), which consists of the total energy efficiency score, was applied to obtain the overall classification:

$$Pt = 0.3\left(EqNumEnv * \frac{AC}{UA} + \frac{TSE}{UA} * 5 + \frac{ANC}{UA} * EqNumV\right) + 0.30 * EqNumLPD + 0.4\left(EqNumAC * \frac{AC}{UA} + \frac{TSE}{UA} * 5 + \frac{ANC}{UA} * EqNumV\right) + b \quad (4)$$

in which:

Pt is the energy efficiency index;

$EqNumEnv$ is the numerical equivalent of the building envelope;

$EqNumLPD$ is the numerical equivalent of the lighting system, identified by the acronym *LPD*, that is, lighting power density;

$EqNumAC$ is the numerical equivalent of the air conditioning system;

$EqNumV$ is the numerical equivalent of non-air-conditioned and/or naturally-ventilated environments;

TSE is the useful area of transient stay environments if they are not air-conditioned;

ANC is the useful area of non-air-conditioned environments for a prolonged stay, with proof of percentage of occupied hours of comfort by natural ventilation (*POC*) through the simulation method;

AC is the useful area of air-conditioned environments;

UA is the useful area, and

b is the score obtained by the bonuses, which varies from zero to 1.

Thus, the final value is obtained, allowing the classification of the energy efficiency of the object of study, according to the manual's parameters.

RESULTS AND DISCUSSION

First, the minimum requirements for classification were verified using the RTQ-C guidance, which recommends the use of NBR 15220 (2005) – Part 2 and provides the thermal properties of various materials. The web system Projetando Edificações Energeticamente Eficientes (Projeteee, 2021), which has a data catalog and tools to assist in the calculation of information, was also used.

Each of the indices necessary to obtain the building envelope efficiency indicator was also calculated. The building envelope area of each of the building's facades and openings (doors and windows that allow light to enter) was calculated using data taken from the floor plan of the building and obtained from the company's view. Thus, the percentage of facade opening (PFO) was obtained.

The VSA and HSA data from all openings were determined using the software AutoCAD, after which a weighted mean was calculated according to the size of each opening.

The solar factor data were also obtained through the glass catalog of the Projeteee web system (2021), which has data on several types of glassware for construction, as the exact brand of glass used in the building was not known.

Thus, the variables applicable to the building envelope efficiency equation were calculated (Table 2).

TABLE 2. Variables for calculating the building envelope efficiency.

Variable	Abbreviation	Definition	Value
Roof projection area	Arp	Horizontal projection area of the roof, including covered or uncovered terraces and excluding eaves, marquees, and roofs over balconies – the latter as long as it is out of line with the building.	211.64 m^2
Total area	$Atot$	Sum of the floor areas of the building's closed environments, measured externally.	253.878 m^2
Building envelope area	$Aenv$	Sum of areas of facades, gables, and roof, including openings.	660.263 m^2
Total volume	$Vtot$	Volume delimited by the external closures of the building (facades and roof), except for uncovered internal courtyards.	1777.146 m^3
Height factor	FH	Ratio between the roof projection area and the total built area ($Arp/Atot$), except for basements.	0.833629
Shape factor	FS	Ratio between the building envelope area and the total volume of the building ($Aenv/Vtot$).	0.37153
Percentage of facade opening	PFO	Ratio between the sum of the glazed opening areas or with transparent or translucent closing of each facade and the total facade area of the building.	3%
Solar factor	FS	Ratio between the heat gain that enters an environment through an opening and the solar radiation incident on this same opening.	0.87
Vertical shading angle	VSA	Angle formed between two planes that contain the base of the opening.	3.08756
Horizontal shading angle	HSA	Angle formed between two vertical planes.	12.43007

Source: Descriptions according to RTQ-C and data calculated by the authors.

The building envelope efficiency index of 491.647 was obtained by applying these values in [eq. (1)]. Thus, the i, $ICMax$, and $ICMin$ values could be calculated, and the following classification was obtained:

- Level A if ≤ 499.
- Level B if ≤ 503.14 and ≥ 499.01.
- Level C if ≤ 507.29 and ≥ 503.15.
- Level D if ≤ 511.43 and ≥ 507.30.
- Level E if ≥ 511.44.

Finally, relating the efficiency index value with the classification, the building envelope is classified as A. However, the transmittance of the roof and walls exceeded the recommended limit for the A classification, as the suggested value would be up to 1.00 W m^{-2} K^{-1} for artificially air-conditioned environments and 2.00 m^{-2} K^{-1} for non-air-conditioned environments. Therefore, a study on the materials used is suggested so that these factors can be improved, as the thermal transmittance is within the limit of ≤ 0.5.

Therefore, the studied establishment has a satisfactory building envelope efficiency but there are still points to be improved regarding thermal transmittance.

Regarding lighting, we verified initially which of the activities arranged in the RTQ-C best suited each environment of the butcher shop. Thus, the $DPil$ limit could be determined for each of the establishment's activities.

Data on the illuminated areas of the establishment, related to the lighting area, power, and type of lamps, were also collected.

Therefore, the total installed power in the establishment is 640 W, resulting from the sum of the lighting powers installed in each environment. Therefore, the limits of each environment for each classification are found by multiplying the areas by the limits. The general limits of the establishment for each classification are found by adding the limits of all environments, thus allowing to establish Table 3.

TABLE 3. Limit power per environment.

Local	Power (W)	Area (m^2)	Dpil (W m^{-2})	Environment score	Limit A (W)	Limit B (W)	Limit C (W)	Limit D (W)
Sales area	144	28.4	5.07	A	514.07	616.88	719.7	822.51
Frozen room	72	12.31	5.85	B	61.56	73.87	86.18	98.5
Men’s restroom	54	5.32	10.15	D	26.61	31.93	37.25	42.57
Women's restroom	54	5.32	10.15	D	26.61	31.93	37.25	42.57
Cutting room	28	8.78	3.19	A	93.89	112.67	131.45	150.23
Deboning room	72	15.9	4.53	A	170.12	204.14	238.17	272.19
Antechamber	72	19.3	3.73	A	137.02	164.42	191.82	219.23
Utensils/ kitchen washing	72	8.74	8.24	A	93.48	112.17	130.87	149.56
Seasoning room	72	7.76	9.27	A	83.08	99.7	116.32	132.93
Total	640	111.8	60.18	-	1206.4	1447.7	1689	1930.3
Mean	71.1	12.4	6.69	-	134	160.9	187.7	214.5

Source: Prepared by the authors.

The butcher shop obtained an A classification in terms of lighting, as the obtained score of 640 W is lower than the A limit score, which is 1206.4 W. The building also has a general performance considered satisfactory, but there are still environments in which it can be improved, such as the frozen room, which obtained the B classification. Therefore, small changes can lead to a better index.

Another point that needs improvement is the restrooms, which obtained the D classification, which is the lowest for this type of efficiency. Therefore, this classification could be improved even considering that restrooms are not one of the company’s focus areas, which may lead to greater well-being for employees, among other factors.

The classification of air-conditioning efficiency requires the verification of the efficiency index of the device and compare it with the INMETRO classification. However, some devices did not have an official INMETRO classification. In this case, we needed to calculate the seasonal coefficient of performance ($SCOP$) and the coefficient of performance (COP), according to the ASHRAE Standard 90.1-2010, as recommended by RTQ-C.

COP is calculated by the ratio between the energy capacity of an air conditioner and its energy consumption, while $SCOP$ is calculated by the ratio of the seasonal average capacity and the consumption.

Thus, the data for air conditioners that fall into the VRF category were obtained through the manufacturers’ catalogs.

According to RTQ-C (PROCEL, 2017), air-cooled VRF air conditioners with less than 19 kW of power must have a minimum efficiency of 3.81 SCOP to be considered level A; otherwise, the classification is E.

Therefore, both air conditioners have obtained the E classification. AHRI 340/360 is used for split-type devices. Thus, the data were obtained for the device of this type. Considering a COP of 3.03, the classification for this device under RTQ C is C.

The other device in the establishment already had an INMETRO classification (A classification). Table 4 shows this configuration of butcher shop air conditioners.

The air-conditioning efficiency index of the establishment is verified through the calculation of the average of numerical equivalents weighted by the power that the device represents for the establishment (Table 4).

TABLE 4. Air conditioning equipment in the establishment and its weighted mean efficiency.

Environment	Type	Efficiency	Power (BTU h^{-1})	Weighting coefficient	Numerical equivalent	Weighted result
Sales area	Split	A	30000	36%	5	1.8072289
Cutting room	Forced	E	12000	14%	1	0.1445783
Deboning room	Split	C	30000	36%	3	1.0843373
Cold chamber	Forced	E	11000	13%	1	0.1325301
Total			83000	100%		**3.1686747**

Source: Prepared by the authors.

The company's air-conditioning classification index is reached by comparing the value obtained in Table 4 (3.1686747) with the following classification:

- Level A if ≥ 4.5.
- Level B if ≤ 4.4 and ≥ 3.5.
- Level C if ≤ 3.4 and ≥ 2.5.
- Level D if ≤ 2.4 and ≥ 1.5.
- Level E if ≤ 1.4.

Thus, the energy efficiency classification of air conditioning received a C score. One of the reasons that may be associated with this low performance is that 75% of the butcher shop's air conditioners do not have the INMETRO classification seal. The only certified device represents 36% of the entire refrigeration capacity of the establishment. However, it is not enough to improve performance and the score would probably be even lower if it did not exist.

Reviewing the choice of equipment would be interesting for the owner, giving priority to those with the best efficiency index when they are changed.

NR-17 (Brazilian Regulatory Standards) (Associação Brasileira de Normas Técnicas, 1990) was used as a basis to analyze the numerical equivalent of non-air-conditioned environments, that is, environments that do not use artificial air conditioning (in this case, kitchen, seasoning room, antechamber, and restrooms), compared to the data and information collected during visits to the company. Importantly, the area for future expansion was not considered in the calculations, as it was closed and unusable despite being part of the establishment. In addition, it is not yet known whether it will be an air-conditioned area or not.

NR-17 determines a temperature between 20 and 23 °C, air velocity of up to 0.75 m s^{-1}, and air humidity of up to 40%, and, therefore, the percentage of hours in comfort was approximately 60%, reaching the C score.

Moreover, the establishment did not meet any of the points to consider for bonuses, which involve a series of additional factors (water consumption control, use of sustainable energy sources, and water heating, when necessary, among others), and the established value was zero.

Thus, all the necessary indices were available for the final calculation of the energy efficiency of the building (Table 5). Importantly, the environment for future expansion was not considered a useful area, as it is not yet used by the company. Moreover, all extended stay environments are air-conditioned. Therefore, ANC was considered equal to zero.

An index equal to 3.9 was obtained by applying the values in Table 5 to [eq. (4)]. Thus, the company's overall energy efficiency classification is B, according to the following classification:

- Level A if ≥ 4.5.
- Level B if ≤ 4.4 and ≥ 3.5.
- Level C if ≤ 3.4 and ≥ 2.5.
- Level D if ≤ 2.4 and ≥ 1.5.
- Level E if ≤ 1.4.

TABLE 5. Variables for general efficiency calculation.

Variable	Description	Value
$EqNumEnv$	Numerical equivalent of the building envelope	5
AC	Useful area of air-conditioned environments	71.055
UA	Useful area	148.361
TSE	Useful area of non-air-conditioned transient stay environments	46.818
ANC	Useful area of non-air-conditioned environments for a prolonged stay	0
$EqNumV$	Numerical equivalent of non-air-conditioned and/or naturally-ventilated environments	3
$EqNumLPD$	Numerical equivalent of the lighting system	5
$EqNumAC$	Numerical equivalent of the air-conditioning system	3
b	The score obtained by the bonuses	0

Source: Prepared by the authors, with descriptions of RTQ-C (PROCEL, 2017).

Thus, the establishment still achieves an energy efficiency assessment considered satisfactory with some indices in the maximum score, being in the second-best classification level.

However, there are several points of possible improvement so that the enterprise can reach a higher energy efficiency index, mainly regarding air conditioning.

CONCLUSIONS

The establishment has a satisfactory efficiency classification, which does not mean that it does not have clear points for improvement.

Initially, a major bottleneck in the issue of air conditioning can already be seen, as it was the index that most compromised the company's overall energy efficiency among the three main indices.

A need for change is evident at this point, as several devices used by the establishment do not have the INMETRO evaluation and verification seal, which already indicated that they might not have an adequate energy performance, confirmed by the research.

Thus, an investment in this area would bring several benefits to the company, generating considerable energy savings. However, confirmation would only be obtained by applying the changes and monitoring the behavior of energy consumption.

Another interesting point to be improved would be the issue of bonuses, with investment in alternative forms of energy, such as solar, and carrying out a control of water use, among other factors.

Building envelope and lighting presented satisfactory indices but some illuminated environments were considered inefficient. Therefore, these points need to be better considered and the equipment needs to be replaced, when necessary, by more suitable ones. Equipment with a lower power would be better for these environments, as RTQ-C analyzes $DPil$.

Importantly, the lighting parameters of RTQ-C are quite limited, with no specific parameters for the activities in the cutting and deboning rooms, which are activities dealing with cutting equipment. Thus, exaggerated, or missing lighting can jeopardize the health of employees.

Finally, the establishment has a good energy efficiency index despite some problems, with several points that can be improved relatively easily to achieve a better classification. These changes would help the company to obtain not only financial savings but also a positive impact on the environment by instigating other companies with similar characteristics to carry out these best practices.

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