Characterization and Modelling of electricity consumption on services buildings:

The case study of NOS building

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Abstract

Since sustainability and energy efficiency are becoming increasingly significant as economic and social concepts, it is important, more than ever, to reduce energy consumption in every economic sector. The service sector, mainly represented by the service building sector, is responsible for about 13% of the final energy consumption in Europe as in Portugal. Energy audits are the foundational factor to establish a good set of measures that allow energy optimization in this kind of buildings. The main obstacle to this procedure is to obtain all the data that is need, set as the occupancy and the equipment details. This work focuses specifically on identifying an indicator of energetic intensity by area and occupant, to systematically define the consumed energy by standard type of working area on a service building. For that, an indicator of energy intensity was created which allows to model the energy demand of a service building in its design phase. For this work, the study models were two buildings which belong to NOS, the head office (placed in Campo Grande) and "Edifício América". At first, the developed model had a significant percentage of error. However, after calibration, which consisted in adjusting the equipment consumption and estimate the theoric occupancy with the real occupancy of the building, the model revealed to be highly reliable. With this study is was possible to recognize which spaces consume more either by area or by occupancy, Finally, the model was applied to the future NOS building, which is yet in project phase.

Keywords: Energy Efficiency, Energy Audit, Energy Indicator, Services Building

Introduction

Energy has a great importance in economic growth, progress and development of a society, as well as in the eradication of poverty, security and the capacity of supplying a nation. Uninterrupted access and supply of energy is therefore a vital requirement for all developed countries, with per capita energy consumption being one of the measurement indices of a wealth country [1]. Demand for primary energy is increasing worldwide and it is estimated that the growth tendency will intensify, considering the rise of new economic powers (the so-called BRICS - Brazil, Russia, India, China, South Africa) [2]. The increasing global use of energy has already raised concerns about supply difficulties, depletion of energy resources and heavy environmental impacts (ozone depletion, global warming, climate change, etc.). The overall contribution of buildings to both residential and commercial energy consumption has been increasing, reaching between 20% and 40% in the developed countries, having surpassed the other main sectors: industrial and transport [3]. Due to increased use of electricity, energy management is essential, especially in buildings, which implies a better understanding of the energy consumption profile. Although there are many studies on the understanding and prediction of energy demand, studies on the profile of electric energy consumption of buildings are scarce [4]. However, in recent years there has been a great development in the application of methods of evaluation and energetic classification, in which many methodologies are used. National energy assessment programs for new or existing buildings are very useful tools in energy audits [4].

Building stock modelling can be complex and time consuming due to the extensive information required. In the literature, there are two different approaches related to stock modelling: top-down and bottom-up [5].

Top-down models are based on statistical disaggregation models. These consist of disaggregating the power profiles consumed to identify various devices. Diversity is not modeled because it is included in a deterministic way in the measured data. They are therefore applied to an entire building sector, such as the residential sector. They make use of national energy statistics, interpolating for example the consumption of electricity to something smaller, such as a building [6] [7].

Grandjean et al. [8] divide bottom-up models as statistical random model, probabilistic empirical model and time of use based models, and consist of predicting energy consumption for typical representative spaces, then extrapolating to a larger universe of same typology.

The statistical random models are based on statistical data. Alves et al [5] state that they use monitored data from buildings to produce models that estimate the behavior of a building. In the literature, the regression models and artificial neural networks (ANN) are identified as the main statistical methods. The advantages of these methods are the ability to predict typical power consumption profiles. However, they fail to adjust the results to some change in human behavior or appliances within the building.

Probabilistic empirical models collect real data such as household habits and then apply probabilistic procedures.

Time of use based models guarantee the diversity of the results when analyzing data about the time of use of the equipment.

One is example of a bottom-up model is the model created by Richardson et al. [9]. Is also a time of use based model, since the authors apply the model to specific household equipment and people's habits that were obtained through surveys. The authors also used statistics on penetration ratios and annual consumption of housing and household appliances. In addition, they measured energy consumption patterns, and when it was not possible to measure, they assumed constant consumption. To validate the model, the authors compare the results obtained with those measured in 22 dwellings.

The authors concluded that:

- they did not include electrical heating due to their low penetration rate;

- For one year of validation, energy consumption corresponded to reality, however, the standard deviation was lower than the real one;

- The seasonality was under valuated;

- The model underestimates energy consumption at night and the morning peak occurs later than the real. These errors can be related to the fact that validation is done only for 22 houses and not for national level;

- Tendencies in the consumption profile from the model to the real are very similar.

Another example is the model created by Buso et al. [7] where a methodology is proposed for the creation of multifunctional buildings models. The authors separate the thermic spaces, where the temperature must be maintained and extra spaces. They only consider the thermic spaces to detect consumption tendencies. It was only considered the factors that have the most impact in the building consumption. The authors applied the methodology to a hotel and get the following conclusions:

- The model evidenced one of the biggest problems of the bottom-up models, the scarcity of data. ~
- The lack of statistical information on the hotel sector led to the definition of assumptions by the authors.
- The extra spaces, although representing a small area (6%), represent 20% of the hotel's primary energy consumption.
- The results were compared with other hotel studies. The comparison showed how difficult it is to define valid benchmarks for the various categories of buildings.

In literature we also can find hybrid models that are Statistical Engineering models that use data such as housing characteristics, site meteorology, penetration ratios, etc. They are a combination of top-down and bottom-up method.

When evaluating the energy performance of buildings, the term 'benchmarking' is used to refer to comparisons between energetic performances of similar buildings, although the term ‘benchmarking’ applies more generally to any level of standardized performance and serve as a basis for evaluation or comparison. According to Wang [10], benchmarking is "a simple method for decision makers, with a relative level of energy performance, comparing the energy performance index of the whole building with the pre-established indices."

As Hong notes [11], there isn´t an investment to calibrate top-down and bottom-up benchmarking methods, which makes the methods weaker. In addition, there is no measure of validation of their models, despite the existence of much research on the subject. An effective benchmarking framework is important for an analytical perception of performance.

Starting from this consideration, this paper presents a framework to obtain a method to estimate and forecast the electricity consumption of a service building. It will be created an indicator by area and by occupancy for some representative spaces of a service building. After that, the results of the spaces will be extrapolated to all building to obtain the daily electrical consumption.

Methodology

The methodology used in this electric consumption prediction model for service buildings was based on the bottom-up method according to the times of use. Afterwards, the methodology for the application of the model in a service building that is in the project phase is presented.

The methodology follows the steps shown in figure 1.

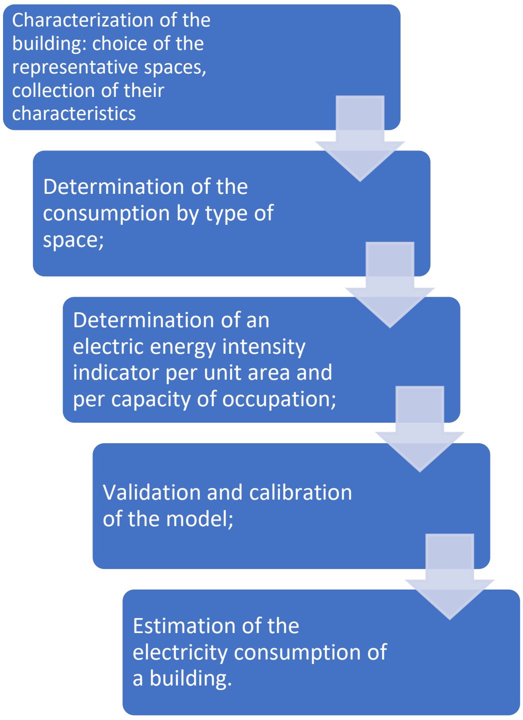

Figure 1 –Methodology’s steps

The model was based on the definition of the activity spaces and the equipment use, to create daily consumption profiles with hourly spaced intervals. Thus, considering the characteristics of the electrical equipment present in that same space, it was possible to study the consumption of more specific and typical spaces of a service building. The main factors in the characterization of the equipment are their power and time of use. Finally, by adding all the constituent spaces of the building it was calculated the building's total electrical consumption.

In the first phase it was necessary to define the typical spaces of a service building. This definition was based on the spaces that occupy almost the whole of the building and which are, as a rule, typical spaces that are part of service buildings. Spaces that have no impact on energy consumption have not been counted. The area was calculated using the computer tool, Autocad ®, based on the design of the building. Subsequently, a characterization of each type of space was made, making a survey of the electrical equipment and its nominal power.

The power can be checked on the labels of their equipment, on the manufacturer's website or, in the absence of specific information, in the literature.

The hourly consumption by type of equipment, Et_{eq} , was calculated using the following equation:

$$Et_{eq} = P * \Delta t * Q \qquad (1)$$

Where:

- P is the power of the equipment;
- Δt is the real electric consumption time, calculated as a percentage of maximum usage in one hour, i.e. considering maximum exploitation of this machine in one hour; and
- Q is the number of the type of equipment in that type of space.

To determine the energy by type of equipment, it was necessary to calculate the energy consumed by type of space, Ees. To achieve this. It was made the sum of the energy consumed of all the equipment in that type of space.

It was calculated the energy consumed by type of maximum space, that is, considering the maximum exploitation of all equipment. Nevertheless, it is known that for a day not all equipment consumes energy during 24 hours so it is necessary to adjust this indicator depending on the real operation of the equipment.

There are two types of equipment: those that are effectively consumed uninterruptedly and those that have a variable consumption related to its use. In order to calculate theoretical hourly consumption for one day, two methodologies, A and B, were used. Methodology A was used in most types of spaces, when energy consumption is directly related to the occupation of space. In this methodology the equipment's use was related with the occupation of the space so, to calculate the theoretical consumption every hour, equation 3 – where the consumption is equal to the fixed consumption independently of the occupation plus the variable consumption dependent of the occupation – was applied. Considering the percentage of occupancy of a given hour (%Ocup), the theoretical hourly consumption (Eth) of this hour is given by the following expression:

$$Eth(i) = \%Ocup(i) * Etvar + Etfixo \qquad (2)$$

Where:

- %Ocup(i) is the occupation percentage at time I;
- Etvar is the theoretical energy consumed at a time that depends on the occupation;
- Etfixo is the theoretical energy consumed in an hour that does not depend on the occupation.

In order to determine the daily occupancy profile of each space, the standardized profiles of the RECS were used, and in spaces where the RECS does not contemplate, the observation and inquiries of space users were used.

Methodology B was used to calculate the hourly profile of theoretical daily consumption in cases where it is not appropriate to make an occupation relation with the energy consumption, as is the example of the canteen.

In this methodology, the daily consumption profile of this type of space was obtained in the literature. Obtaining the consumption in percentage for the 24 hours of the day, %C. Multiplying the result obtained by the theoretical maximum hourly consumption, Ees, as described in equation 3, calculates the theoretical consumption for each hour of the day, Eth.

$$Eth(i) = \%C(i) * Ees \qquad (3)$$

Once the hourly consumption is known, regardless of the methodology used, it is necessary to determine the daily consumption, Etd, by the following expression:

$$Etd = \sum_{i=1}^{24} Eth(i) \qquad (4)$$

Finally, the daily energy indicator was calculated by unit of area, Ia, or by capacity of occupation, $Iocup$ by equations 5 and 6 respectively.

$$Ia = \frac{Etd}{A} \qquad (5)$$

$$Iocup = \frac{Etd}{Ocup} \qquad (6)$$

Where A is the area and $Ocup$ is the number of occupant stations that the space being studied can reach.

The data was obtained in a first phase defining representative areas of activity of the various buildings of the NOS and later characterizing the various spaces of activity through the following points:

- Accounting for equipment;
- Obtaining its power;
- Measuring your area and / or occupation;
- Calculating maximum hourly electrical consumption;
- Relating this consumption to the occupation or directly to a consumption profile;
- Obtaining a daily energy indicator.

After obtaining the energy indicator for each type of space, it was necessary to validate the model. This validation was performed comparing the theoretical consumption calculated in the model with the actual consumption, measured in the installations. Thus, the theoretical consumption was obtained, being necessary to know the real consumption to validate this model. Then the percentage of hourly and daily error was calculated using equation 7, respectively.

$$E_h = \frac{Chreal - Chteórico}{Chreal} * 100 \qquad (7)$$

The daily error, E_h, was calculated in the same way as the time error, but with daily consumptions instead of hourly consumption.
If the valid model is not verified, a calibration is necessary. This calibration should be made based on adjustments that are considered rational, reasonable and based on empirical data.

Once the energy intensity indicators are calculated and obtained by type of space, they are used to estimate the consumption of a building in a global way. In this way, the model can be applied to calculate building energy consumptions, having access to the total area or allowed occupancy of each type of space, as described in the equation 8. The total theoretical consumption of a building is then given by the sum of the consumption of the various areas.

$$Etd = Ia * A = Io * Ocup \qquad (8)$$

Case study

To characterize a service building, it was used as a model two building of NOS: the head office (placed in Campo Grande) and "Edifício América". In the end it will be calculated the consumption of a new building of NOS that is in project phase at the moment.

The head office is an essentially administrative building, where are included several types of services. This building is mainly constituted by open-space, meeting rooms, offices, technical areas, facility corner, lounge spaces and canteen. These are the types of spaces that will be studied in this work.

The "Edifício América" is a support building of NOS which is mainly made up of Call Center rooms. Then, as the new building will also have Call Center spaces, data was collected from this building to create the model.

Spaces that did not represent significant consumption in the total consumption of the building were not considered, as is the example of the bathrooms, parking lots and the reception, since lighting is the only electric consumption in the bathrooms and parking lots. In the case of the reception, the low consumption is justified by small area that it has comparing to the whole building.

Three spaces were characterized: “sala Lima” of “Edifício América” which represents the call center room; the canteen and the level 4 east side of the Campo Grande building. In this last space were included: open-spaces, meeting rooms, offices, technical zones, facility corner and lounge space. The characterization consists in taking into account the whole equipment presents in each space, it’s power and its real electrical consumption time. It was also needing to obtain the area and the occupation capacity of each space.

Subsequently the occupation profiles were obtained through two different ways. In one hand, the occupation of the Open Space, meeting rooms and offices was obtained through the RECS offices occupations. On the other hand, the Call Center space was obtained by an observation analysis and verbal inquiry since there was an absence of an occupation profile.

The occupation profile of the lounge space was obtained through the ”pronto-a-comer” profiles of the RECS but only until 6 pm, since after that time the occupation of the building is almost nil.

The occupation profile of the facility corner is not presented in the RECS, however by observation it was possible to verify that it is closely related to the occupation of the Open Space. It was estimated that the occupation is about 25% of the occupation of the Open Space, as it shown in figure 1. For the technical zone it was verified that its occupation is 0 being its consumption only due to equipment of fixed consumption. It was used the methodology B for the canteen so there was no need to obtain his occupation profile. The results are represented in figure 2

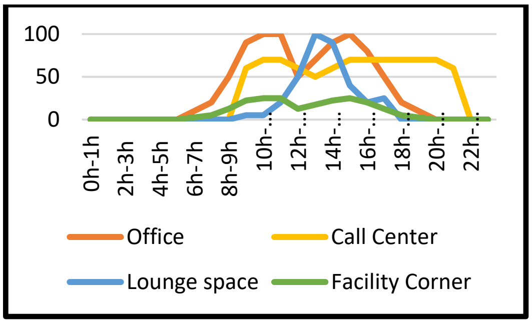

Figure 2 - Occupation of representative spaces in a working day

It was obtained also the consumption profile of the canteen as it is required by the methodology B. It is shown in figure 3.

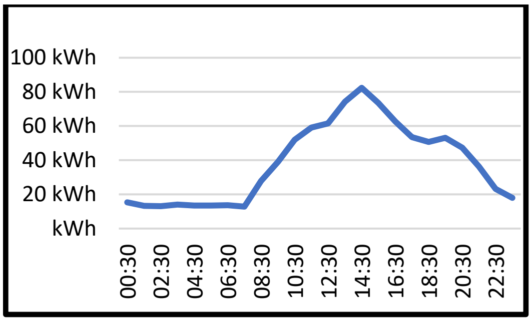

Figure 3 - Energy consumption in a canteen in a working day (%)

By collecting and comparing the data of the electric consumption in the summer versus in the winter and in the west side versus in the east side, it was concluded that the electric consumption barely varies.

Results and discussion

Results

To obtain the first results was considered that the Δt is equal to 100% so it was assumed that all the equipment is exploited to the maximum.

The figures 4 to 6 are represent the theoretical consumption obtained when applied the methodology to the case study, and the real consumption to validate the results.

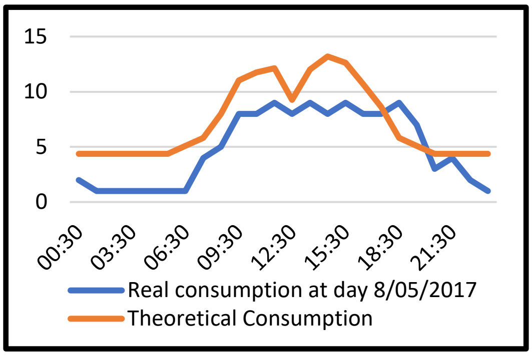

Figure 4 - Real consumption vs Theoretical consumption of level 4 east side of the Campo Grande building (kWh)

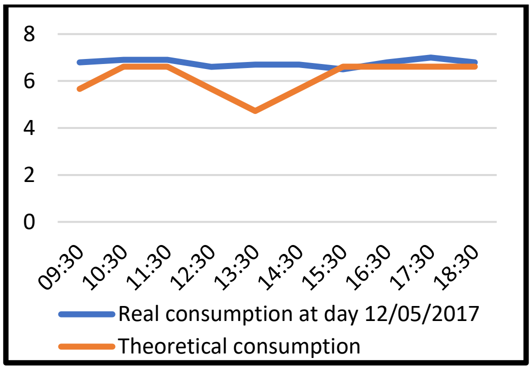

Figure 5 - Real consumption vs Theoretical consumption of "Sala Lima" at "edifício América" (kWh)

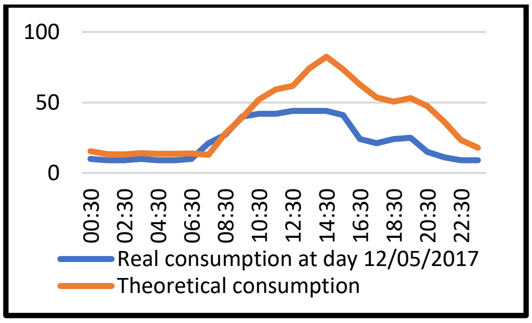

Figure 6 - Real consumption vs Theoretical consumption of canteen of the Campo Grande building (kWh)

After validation, with considerable error rates, it is clear that a calibration is required, which was then applied considering type of space.

Calibration

Level 4 east side of the Campo Grande building

The first change to make was the occupation of the offices floor, in order to be coherent with the work routine of the employees which is until 6 to 6:30 pm. The occupation to decrease only from 6 pm. The occupation was extended to two extra hours in the evening so that the model is in accordance with the effective schedule of the company's employees. It was also noted that there are always 5 to 7 employees leaving the building at around 10 pm. The Facility Corner occupation has been modified since it represents a quarter of the occupation of the Open Spaces.

The effective consumption of the machines that work with fluorinated gases in the lounge space and the technical area were rectified. The indicated power is related to the refrigeration cycle and more specifically to the work of the compressors. Since these are not always working even when the machine is running, it is necessary to find a percentual value of the time the compressor works, which is approximately equal to the time of consumption of the equipment. To obtain the estimated time, a comparison of theoretical consumption with the actual consumption at night was made. Knowing that in those hours these are the only working equipments, we can determine the time of consumption so that the theoretical consumption is equal to the actual consumption. Therefore, in the lounge space and in the Technical Pole, for the machines that work with fluorinated gases, it was considered that the electric consumption time, Δt of equation 1 is 30%.

Another nonconformity factor of this model is the lunch hour where a predicted decrease in consumption does not happen in reality. The reason for this to happen is that the employees do not turn off their computers when they go to lunch. The fact that there is no fixed lunch break schedule common to all employees, means that the lighting cannot be switched off during this period too. Therefore, the apparent desertion of the 4th floor is, in fact, non-existent in terms of electric consumption. For this reason, it was considered that the occupancy profile will not represent the "lunch hour", considering that the occupation between morning and afternoon is constant.

Finally, it was verified the cause of the superior theoretical consumption in the afternoon. It was found that this consumption comes from the lounge space and, more specifically, from the coffee machine which has a high power. Further analysis allowed the conclusion that it is not reasonable to assume that it has 100% consumption time, because even if the lounge space is full the machine is not always running. After some observations, the consumption time was changed to 30%. Similar logic processes were applied for any other equipment and through questionnaires and observations it was concluded that the consumption time of the televisions of the offices and meeting rooms are about 50%.

"Sala Lima" at "edifício América"

The only calibration made to the Call Center room was the cancellation of the room vacancy forecast at "lunch time".

Canteen of Campo Grande building

Recalling that the methodology applied in this space was different since it was related to a consumption profile and not to an occupation profile. The consumption profile was adjusted because the canteen serve breakfast. Therefore, it was assumed a continuity of consumption between 9am and 12am.

Following the same method of level 4 east side, consumption times were set for 60% to fluorinated gas equipment, except for the hot / cold water machine which was considered to have a consumption time of 30% because it was the same as the machine of the lounge space of the 4th floor.

Resorting to surveys it was concluded that kitchen equipment such as vegetable cutters, cutting saws, beaters, fryers and electric insect traps have a consumption time of 50%, while dishwashers have one of 70% and coffee machines 10%.

The schedule of the canteen of Campo Grande stars and finishes one hour earlier than the canteen in the model.

The figures 7 to 9 presents the results after the calibration.

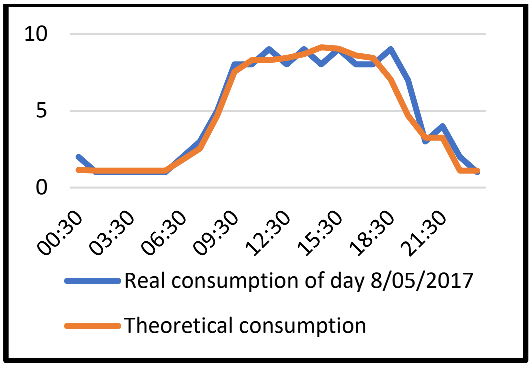

Figure 7 - Real consumption vs Theoretical consumption of level 4 east side of the Campo Grande building after calibration (kWh)

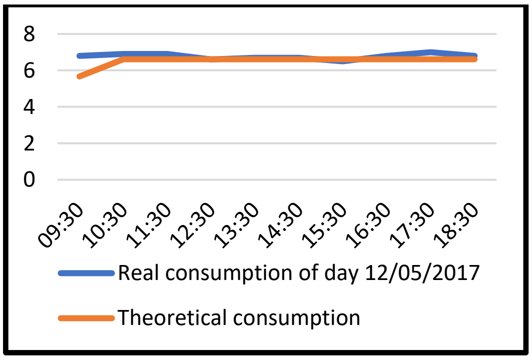

Figure 8 - Real consumption vs Theoretical consumption of "Sala Lima" at "edifício América" after calibration (kWh)

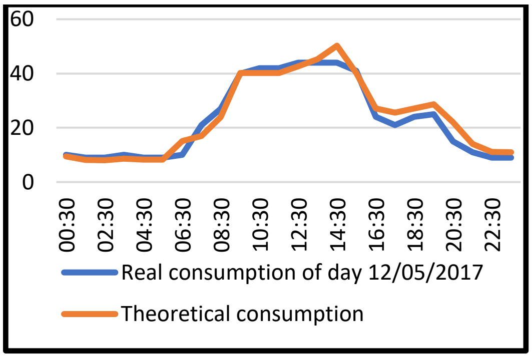

Figure 9 - Real consumption vs Theoretical consumption of canteen of the Campo Grande building after calibration (kWh)

In figure 10, with the calibration of the model, it can be seen a decrease in the error percentage and greater reliability.

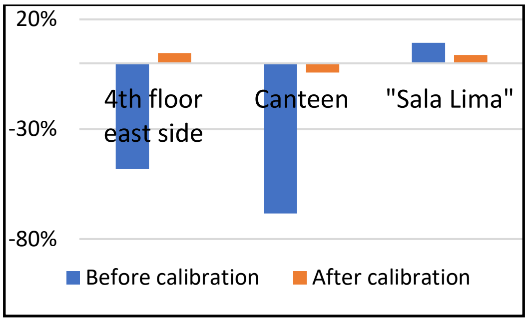

Figure 10 Error percentages before and after the calibration

The indicators for the final model are presented in figure 11 and 12, for area and for occupation respectively.

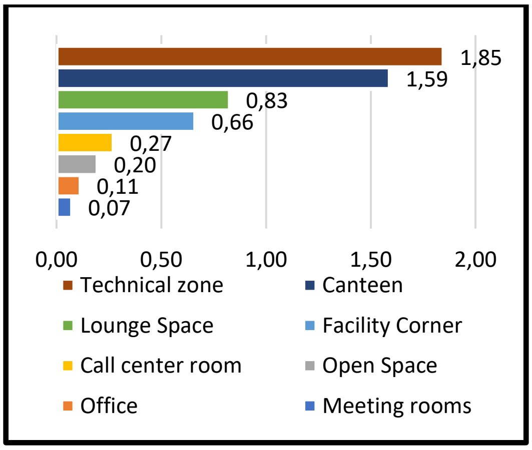

Figure 11 - Energy indicator by area of representative types of space in kWh/m2

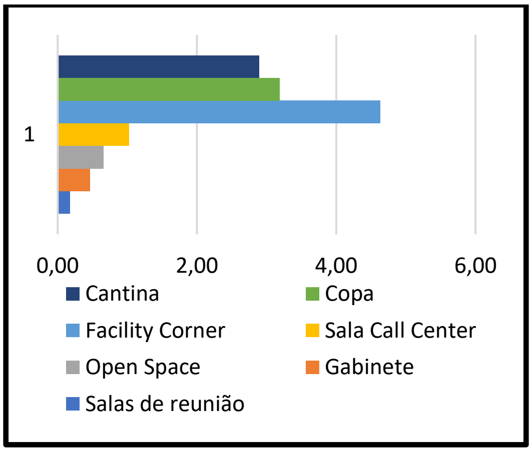

Figure 12 - Energy indicator by maximum occupation of representative type of space in kWh/m2

As it was proven, the technical area takes up to 33% of the energy consumption, making it the largest consumer per area.

The canteen, while being the second highest indicator by area, it is only the fourth biggest consumer per occupation. This points out the great density of people that the space can take.

On the contrary, the facility corner which has the fourth highest indicator in consumption per area, is the space that consumes the most energy per occupation. This result is due to its low occupancy, average of a single person. The lounge space is the third most energy consuming space given the two indicators which means that eating/drinking spaces are amongst the highest consuming zones. Then, with smaller indicators, the call center room is above the open space. With the lowest indicators are the offices and, lastly, the meeting rooms.

The theoretical diary electricity consumption, was calculated based on the indicators per area of the Campo Grande building. The same applies to the new building of NOS that is in project phase. His area was assumed based on a study that, at that moment, was the most reliable. The results are displayed in table 2.

Campo Grande building have an electricity consumption of 3650 kWh and the new building will have a consumption of practically 3000 kWh in a working day. Comparing the two buildings, the new building consumes a little less. Nevertheless, the indicator per area is a little higher in new building than the Campo Grande building.

- 0,244 kWh/m2 to Campo Grande building
- 0,269 kWh/m2 to the new building.

This difference may be due to the fact that half of the new building is a support building and have much call center area which has a higher indicator than open space. However, the fact that there is no canteen in the new building make the indicators very similar

Nevertheless, in this calculated theoretical consumption, the main AVAC equipment and the Data Center in the Campo Grande building are not taken in account, neither is the AVAC equipment in new building.

Table 1 - Theoretical consumptions of Campo Grande building and new building in kWh

Buildings	Open Space	Technical Area	Meeting Rooms	Office	Call Center	Facility Corner	Lounge Space	Canteen	TOTAL
Campo Grande	2387,0	144,1	97,0	64,1	-	57,2	235,0	642,7	3658,7
New Building	1016,1	331,9	53,1	-	1217,4	15,5	300,1	-	2934,2

Conclusion

This paper presents a framework to estimate the energy intensity baseline of a service building based on the *"NOS Comunicação"* buildings.

A Bottom-Up Model based on the Time of Use Based Models was used. The approach followed for the modeling of the Consumption Profiles was the empirical modeling that took into account the power and use of the equipment of representative spaces in a service building. The model was then validated with the consumptions obtained by measuring the electric switchboards or GTC.

The model that was created presented initially high errors, but after making calibrations that consisted in adapting concrete and scientific facts to the consumptions of the equipment and adjusting the theoretical occupation with the real occupation of the building, it turned out to be a highly reliable model, with daily errors below 5%. With this study, it was also possible to understand which spaces per area or work station consume more energy, thus verifying that the technical areas, facility corners, canteen and lounge spaces have the highest indicators.

Last of all, the model was applied to the new building of NOS and it was possible to predict its consumption.

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