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# ENERGY AUDITS IN UNIVERSITY BUILDINGS IN A TROPICAL CLIMATE: ASSESSMENTS OF AIR CONDITIONING CONSUMPTION

**Maria Lívia Costa*[1], Saara de Carvalho Boteon[1], Kleber Freire da Silva[2], Marcia Rebouças Freire[3] and Francisco Gaudêncio M. Freires[1]**

[1]Federal University of Bahia. Polytechnic School. Salvador, Bahia. Brazil
[2]Federal University of Bahia. Polytechnic School. Masters in Electrical Engineering. Salvador, Bahia. Brazil
[3]Federal University of Bahia. Faculty of Architecture. Environmental ComfortLaboratory. Salvador, Bahia. Brazil

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***Corresponding author: Maria Lívia Costa,***

## ABSTRACT

We evaluated aspects of energy consumption by air conditioning units in the Polytechnic School (PS) and the Faculty of Architecture (FA) of the Federal University of Bahia (UFBA), Brazil. The methodology involved a Level I energy audit based on energy consumption data in those two departments, information concerning the efficiencies of air conditioning units in operation between 2013 and 2018, and interviews with management agents and users. We encountered mid-level indicators of energy use, corresponding to 58 kWh/m²/year in the PS and 40 kWh/m²/year in the FA. Energy consumption for airconditioning represented 36% of the total electrical energy consumed by the PS, and 19% of the total consumed by the FA. This research is innovative as it contributes to determining air conditioning energy use indices that can serve as benchmarks for other universities in tropical climates. The study also demonstrated the importance of incentivizing the use of natural ventilation to reduce energy consumption while providing comfort-level thermal exchanges. The results of this investigation can be used to elaborate management plans for rational electrical energy consumption in different university departments.



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# INTRODUCTION

The world is facing a major crisis related to environmental issues, a situation aggravated by everincreasing demands for electrical energy; and projected climate changes may also worsen indoor comfort conditions. Economic and population growth as well as changes in consumption patterns translate into increases in energy consumption that can drain financial resources from other activities (Kiperstok and Kiperstok, 2017; Worldwatch Institute, 2015). The Brazilian government created the Brazilian Labeling Program (PBE) in 1984 in one of its first moves to promote the efficient use of electricity,combat waste, and minimize environmental problems. The National Energy Efficiency Label (ENCE), an integral part of the PBE, classified the energy performances of equipment, buildings, and light vehicles according to their consumption and efficiency. The ENCE for buildings appeared in 2009 and, in 2014, Normative Instruction No. 02 was published, making it mandatory that new federal public buildings (as well as renovations of areas greater than 500 m²)to have an “A”rating of the National Energy Conservation Program (Procel). The “A” classification adopted by the ENCE

Soares et al. (2015) urged the higher education sector to assume an important role in adopting measures aimed at reducing energy consumption throughboth teaching and research activities, andby acting as an opinion-forming agent. The results of their research pointed to the importance of making users aware of the need to reduce energy consumption, and that universities must treatoperational energy performanceas a priority. The world has recently faced a grave crisis because of the Covid pandemic, which has emphasized the importance of natural ventilation for thermal exchange within buildings. Congedo et al. (2021) pointed out the importance of natural ventilation for providing thermal exchange, but also predicted that controlled mechanical ventilation systems would increase in the near future and consequently increase energy consumption. This research demonstrates that universities in tropical climates should better manage their installations and actively promote the use of natural ventilation instead of installing air-conditioning units, which would reduce energy consumption as well as provide more healthy environments. This study also contributed to the collection of energy consumption indices and data on energy consumption by air-conditioning units in universities established in tropical climates that can serve as benchmarks for other schools and public buildings. We therefore investigated aspects of energy management at the Federal University of Bahia, focusing on the electricalenergy consumed by air conditioning, by carrying out a level I energy audit in two of its departments, the Faculty of Architecture (FA) and the Polytechnic School (PS), whose teaching, research, and extension objectives are directly related to structural environments.

***Energy Consumption by Universities:*** Many studies of energy efficiency, sustainability, and environmental management in institutions of higher learning have been carried out, including those by Tauchen and Bradli (2006), Ahmad & Hassan, et al. (2012), Escobedo et al. (2014), Too and Bajracharya (2015), Soares et al. (2015), Maistry and Annegam (2016), Maistry and McKay (2016), and Allen and Marquart-Pyatt (2018). Many of those studies generated energy efficiency plans and proposed measures to reduce energy consumption, such as Jamaludin et al. (2013), Domenica et al. (2013), Soares et al. (2015), Gul and Patidar (2015), Too and BhishnaBajracharya (2015), Hopkins (2016), Weber et al. (2017), and Chen et al. (2018). Machado et al. (2013) studied environmental management practices in Brazilian universities and reported that the main barriers to energy efficiency were related to the lack of human and financial resources, awareness of those involved, and the lack of interest shown by the educational institutions themselves. Only 3.21% of the 75 universities surveyed had control over their energy consumption (which was also one of the items with the lowest adherence). Lamberts et al. (2014) point out that in a country like Brazil, where energy costs have been growing in recent years, those outlays contributed to considerable increases in university budgets, while the pursuit of energy efficiency provided cost savings.

**Table 1. Energy use indicators by Universities**

| Location of the building | Climatic zone | **Electric use** (kWh/m²/year) | **Authors** |
|---|---|---|---|
| **Tokyo, Japan** | Cfa | 126.96 | Ma *et al.*, 2015 |
| **Osaka, Japan** | Cfa | 138.13 | |
| **Pittsburgh, USA** | Dfa | 88.39 | |
| **Sheffield, UK** | Cfa | 58.81 | Altan, *et al.*, 2014 |
| **Madrid, Spain** | Csa | 71.60 | Isabel *et al.*, 2010 |
| **Bourdeaux, France** | Cfb | 96.60 | Valderrama *et al.*, 2011 |
| **Bangkok, Thailand** | Aws | 87.57 | Orrawan*et al.*, 2015 |
| **Parit Raja, Malaysia** | Af | 116.00 | Jamaludin*et al.*, 2011 |
| **Kuala Lumpur, Malaysia** | Af | 78.59 | Ahmad *et al.*, 2012 |
| **Tangshan, China** | Dwa | 174.00 | Han *et al.*, 2015 |

Source: Self elaboration (2019)

The authors went on to explain that those costs needed to be managed, so that investments in education, research, and infrastructure would not be harmed. Likewise, studies carried out by Wachholz and Carvalho (2015) to assess the sustainability of Latin American universities (with the participation of universities in southern and southeastern Brazil) produced an overview of the environmental performance of those institutions and presented ideas for possible improvements and proactive changes. Among the topics studied was energy management. A survey carried out by the Brazilian Electric Company– Eletrobrás (Procel, 2008) on the ownership of equipment and use-habits of the commercial sector, indicated that the electrical energy consumption by educational institutions was distributed as follows: 43% for air conditioning, 26% for lighting, 17% for office equipment, 3% elevators, 1% pumping, and 10% other loads. Air conditioning and lighting therefore accounted for 69% of the electrical energy consumed in educational institutions. Fully 46.8% ofall of the energy used in northeastern Brazil is consumed by air conditioning – so that the use of air-conditioners and electric fans to promote thermal comfortincreasingly contribute to growing global demands for energy (IEA, 2018). Table 1 lists the energy use indicators of ten universities located in different climatic zones (and therefore having different requirements in regards tothe use of electrical energy for thermal comfort). The climatic zones follow the Köppen-Geiger classification: tropical (Af), savanna (Aws), humid subtropical (Cfa), temperate oceanic (Cfb), temperate Mediterranean (Csa), humid continental (Dfa) and continental (Dwa).

Those energy uses had an average value of 103.67 kWh/m²/year, and a standard deviation of 33.23, which indicated a high degree of heterogeneity among the samples. Although the data do not provide a precise reference value, qualitatively or quantitatively, they make it possible to determine an order of magnitude for energy use by institutions of higher education. It can be seen in Table 1 that there is very little data available concerning energy consumption by universities in tropical (Af) climates. The collection of such data would aid those academic communities by providing background statistics that could be studied and compared. A Level I energy audit was therefore undertaken to determine energy consumption levels in the two faculties studied and to obtain data concerning the statuses of their current air conditioning units.

**Energy Audits:** According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2011) and ISO 50002 (ABNT, 2014), energy audits can be defined as processes to identify and indicate opportunities to improve the energy efficiency of the building by developing measures to reduce energy use and/or operating cost and improve internal environmental quality for occupants. Also according to Isabel et al. (2010), who developed an Energy Audits Guide for teaching centers in Madrid, energy audits are comprehensive studies used to analyze energy situations in architectural assemblages of buildings and their facilities, reduce consumption, improve services, increase the durability of the equipment, and increase the sense of user comfort. According to ASHRAE Standards (2011), energy audits can be classified as levels I, II or III. This article focuses on level I auditing, analyzing electrical consumption by air conditioning units in university buildings, considering both human occupation and use. Level I audits includeon-site technical visits to observe the characteristics of the building and their environments, monitor the equipment, and verify their capacities, as well as their times of use, through interviews with the building staff, as well as other direct observations. Comparisons with benchmarks of energy efficiency indicators of similar buildings are subsequently carried out, followed by the identification of efficiency measures that could reduce consumption.

***Characterization of the Study Objects:*** The city of Salvador is located innortheastern Brazil (12º 58'16" S and 38º 30'39" W), at sea level. According to the NBR 15220 classification system (ABNT, 2005), it is situated in Bioclimatic Zone 8, and is characterized by having an Atlantic tropical climate (hot and humid), with relatively constant temperatures throughout the year. According to NBR 15575, the typical austral summer day in the city of Salvador has an air temperature range of 6.1°C, with a maximum of 31.6°C, and a daily winter range of 5°C, with a minimum temperature of 20º C (ABNT, 2013). The mean annual temperature there is 25.2º C, with 76.97% relative humidity, and wind speed of 3.1 m/s (LABEE/INMET, 2016). The Federal University of Bahia (UFBA) is a public institution of higher education, located in the city of Salvador, Brazil. It was created in 1950 through the integration of pre-existing higher education institutions, with the institution of new courses (UFBA, 2000). The University covers an area of 5.8 km² and houses 31 departments and nine classroom units, in addition to hospitals, museums, daycare centers, sports centers, restaurants, libraries, university residences, and supplementary buildings. The teaching departments selected as the objects of this study were the Polytechnic School and the Faculty of Architecture, as they are familiar to the authors and carry out similar activities. Both are part of the Federation/Ondina campus of the Federal University of Bahia, and are located on a ridge approximately 60 meters above sea level, and distant approximately 500 meters from each other. The construction of the two buildings dates to the 1960s, with the original projects being designed by the architects DiógenesRebouças, Américo Simas, and Oscar Caetano Silva. Their architectures are modernist-inspired, with the premise of taking advantage of natural ventilation and lighting, with elongated sectors perpendicular to the prevailing winds, allowinginternal cross ventilation. The two faculty buildings were constructed using reinforced concrete, ceramic bricks, aluminum and glass windows, and hollowed elements facing corridors providing shade (refer to Figures 1, 2A and 2B).

Source: Self elaboration (2019)

**Figure 1. Polytechnic School**

Source: Self elaboration (2019)

**Figura 2A e 2B – Faculty of Architecture**

The occupation of those two buildings has also been similar, as they are used for teaching architecture and engineering; descriptions of their internal environments are provided in Table 2.

**Table 2. Characteristics of the study buildings**

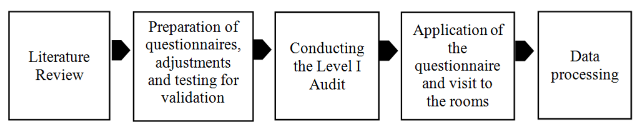
| Infrastructure aspects | Polytechnic school | Faculty of architecture |
|---|---|---|
| Pavements | 8 | 5 |
| Total area | 16.300 m² | 4.800 m² |
| Private area | 8.200 m² | 3.500 m² |
| Undergraduate courses | 11 | 2 |
| Number of students | 5500 | 1100 |
| Equivalent population | 994 | 220 |
| Classrooms | 44 | 20 |
| Faculty offices | 96 | 1 |
| IT laboratories | 9 | 2 |
| Research/experimental laboratories | 53 | 0 |
| Administrative offices | 54 | 14 |
| Library | 1 | 1 |
| Auditoriums | 2 | 3 |
| Elevators | 2 | 1 |
| Snack bars | 1 | 1 |
| Storerooms | 6 | 2 |

Source: Self elaboration (2019)

The Polytechnic School is larger than the FA but, proportionally, both carry out similar activities and have very similar structures. The greatest difference between them is the presence of engineering research laboratories in the PS with their significant consumption of electricity, due to the use of both air conditioning and laboratory equipment (some of which cannot be turned off). At the time of this study, only one elevator was in operation in the PS, while the only elevator in the FA was disabled. The elevator in use in the PS has an average consumption of 360 kWh/year.

# METHODOLOGY

The research plan was to conduct a level I energy audit in both the PS and FA. A literature search was carried out focusing on energy consumption in school buildings, preferably in tropical climate zones. Despite its relevance, searches on those topics revealed a general lack of publications. A database of the air conditioners installed in the two schools was compiled after the on-site technical visits (with the assistance of the SUMAI), with information about the models and their locations. The inspection of rooms equipped with air conditioning was preceded by the elaboration of a questionnaireapplied to teachers, civil servants, outsourced employees, and students in the PS and FA. In addition to conferring the air conditioning units, the technical visits allowed direct observations of the characteristics of the buildings and their environments. The literature review made it possible to determine which points should be addressed in the questionnaire, including air conditioning use and user behavior patterns, always considering the particularities of the tropical climate and the nature of the activities undertaken in the two buildings. An initial trial to validate the questionnaire indicated the need for certain adjustments to some questions that could generate ambiguous interpretations; it was then applied from April to September/2019to the users of five rooms in the FA. A total of 273 air conditioning units were inspected in the Polytechnic School, and 80 questionnaires were applied to their occupants; 17 air-conditioning units were inspected in the Faculty of Architecture, and 13 questionnaires applied to their occupants.




Source: Self elaboration (2019)

**Figure 3. Flow diagram of the methodology used**

Information on energy consumption at the University (from 2016 to 2018) and at the PS and FA (from 2013 to 2018) was obtained from SUMAI, and from reports provided by the Electricity Company of Bahia State, COELBA.Interviews were conducted in April/2019 with SUMAI's energy, maintenance, and planning managers for projects and works to identify actions related to the management of energy consumption and its reduction at the University. Equation (1) was used to estimate the energy consumed by air conditioners:

$$C = P \cdot t \qquad (1)$$

where: C is the device consumption [kWh];
P is the power of the device [kW];
t is the usage time of the device [h].

The power values of the devices were obtained from their respective manuals and from the Inmetro Table, and data regarding the length of time oftheir use were collected during interviews with users. The air conditioning units were considered to operate 75% of the time, according to data from the Ministry of Mines and Energy (EPE, 2018). Nogueira, et al. (2015) also used that simplified approach to approximate use conditions and to estimate air conditioner energy consumption (in kWh), considering operation at 70% of the nominal capacity, as suggested in the rules of the Brazilian Labeling Program. This work adopted 75% operating time, as itappeared to be a safer

# RESULTS AND DISCUSSIONS

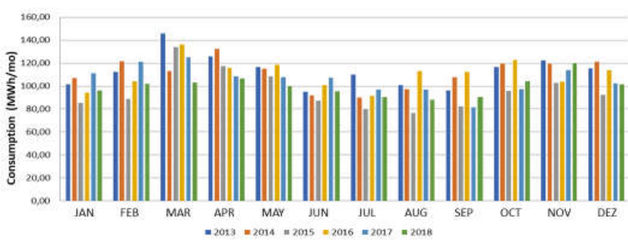
**Electric Energy Consumption in the Study Buildings:** Data concerning the total electrical consumption by the PS and FA buildings for each month of the period between 2013 and 2018 were obtained from SUMAI. To better analyze the influence of teaching activities on energy consumption, arithmetic means and standard deviations were calculated separately for the different months of the academic year and recess periods. Consumption recorded during recess months was, on the average, 10% and 14% lower than during the months of academic activity at PS and FA respectively. The standard deviation of PS consumption was higher than that of FA, indicating that the monthly consumption of electricity at the former was less regular than at the latter.

**Table 3. Comparisons between electrical consumption during classes and in recess periods**

| Mean and standard deviation | Polytechnic school | | Faculty of architecture | |
|---|---|---|---|---|
| | During classes | Recess period | During classes | Recess period |
| Monthly mean (MWh/mo) | 108.3 | 97.5 | 16.7 | 14.4 |
| Monthly standard deviation (MWh/mo) | 13.4 | 14.7 | 3.6 | 4.2 |

Source: Self elaboration (2019)

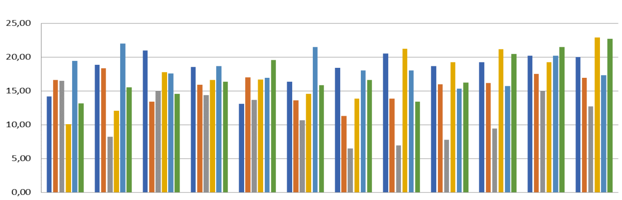
It is possible to observe in the graphs that monthly consumption followed a seasonal trend over the years at PS (Figure 3), being lower during recess periods (July and the austral summer). This is an indicator that electrical consumption at the PS reflects activities other than teaching, such as administrative and research activities (including the functioning of laboratories).




Source: SUMAI, 2018

**Figure 3. Monthly electrical consumption at the Polytechnic School (2013-2018)**

The Faculty of Architecture did not, however, show any evident consumption pattern in the period considered, with its electrical use being irregularly distributed over the years, indicating the need for a more in-depth analysis to determine its consumption profile. (Figure 4). Of the 17 air-conditioned rooms in the FA, only seven are in classrooms, so the impact of reducing consumption during recess periods would not necessarily be significant.




Source: SUMAI, 2018

**Figure 4. Monthly electrical consumption at the Faculty of Architecture (2013-2018)**

By analyzing the annual energy consumption per m², an average energy efficiency index of 58 kWh/m²/year was obtained for the Polytechnic School, and 40 kWh/m²/year for the Faculty of

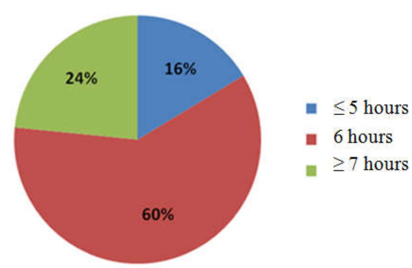
**Table 4. Indicators of electrical energy efficiency**

| Year | Faculty of Architecture (kWh/m²/year) | Polytechnic School (kWh/m²/ year) |
|---|---|---|
| 2013 | 45.88 | 62.60 |
| 2014 | 39.10 | 61.62 |
| 2015 | 25.50 | 49.36 |
| 2016 | 43.03 | 61.15 |
| 2017 | 46.24 | 58.55 |
| 2018 | 43.11 | 55.21 |
| Mean | 40.48 | 58.08 |
| Standard dev. | 7.09 | 4.59 |

Source: SUMAI, 2018

For comparison, the consumption of kWh/m²/year at the Polytechnic School is equivalent to those of university buildings in Malaysia, a country with a tropical climate. Ahmad et al. (2012) reported that the energy efficiency index for university buildings with classrooms and laboratories in Malaysia varied between 45 and 60 kWh/m²/year. Siti Birka et al (2021), on the other hand, reported energy consumption values ranging from 54.01 kWh/m²/year to 63 kWh/m²/year in that same country.

***Estimated Consumption of air Conditioning Appliances:*** While applying the questionnaires, we noticed that the methodology did not accurately define the times of use of air conditioning devices in environments where there use did not follow a fixed routine as, for example, in auditoriums. As such, this study considered only consumption referring to devices that remained in use with routine schedules. For obvious reasons, devices that were not used, or that were nonfunctional, were also excluded. As such, our calculations considered 256 devices at the Polytechnic School (78%, out of a total of 330) and 17 at the Faculty of Architecture (71%, out of a total of 24). To determine the proportions of total electrical consumption corresponding to air conditioning use, the time of use of each appliance was considered, as informed by the occupants of the room at the time of our inspection. At the Polytechnic School, 60% of the air conditioning units remain on for 6 hours a day, with only 24% of them exceeding six hours of use each day (Figure 5); at the Faculty of Architecture 41% of the air conditioning units exceeded nine hours of daily use (Figure 6).




Source: Self elaboration (2019)

**Figure 5. Duration of air conditioner use, in hours/day, at the Polytechnic School**

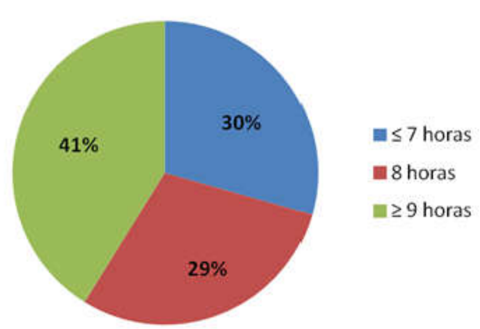
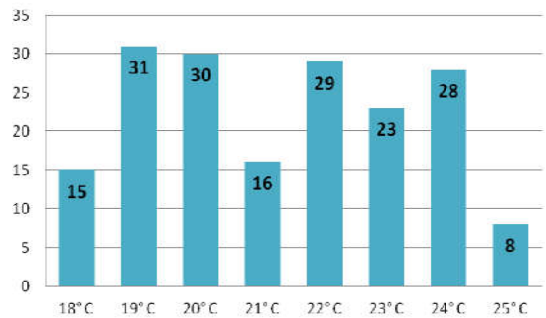


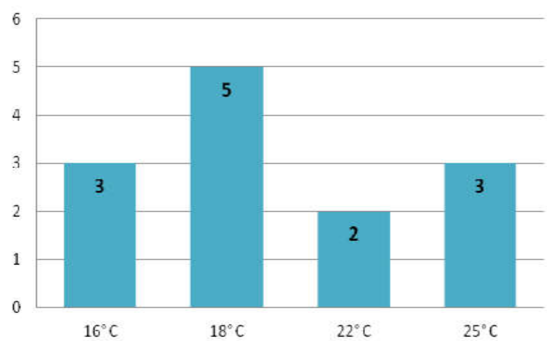

**Figure 7. Duration of air conditioner use, in hours/day, at the**

The official standard for air-conditioning installation, NBR 16401 (ABNT, 2008), lists the recommended comfort parameters for summer operating temperatures of artificially climate-controlled environments as between 22.5º C and 25.5º C (considering that a person will be wearing a typical summer outfit with 0.5 clo). During the data collection phase, it was found that 77% of the air conditioners at the FA (Figure 8) were programmed to temperatures below recommended levels; the same was true for 67% of the PS appliances (Figure 7). During our visits to air conditioned spaces, we observed that the occupants themselves set the air conditioners to lower temperatures, even if they then needed to wear heavier clothes (such as coats and long-sleeved shirts) to maintain their body temperatures.



Source: Self elaboration (2019)

**Figure 8. Observed temperature settings of air-conditioners in the Polytechnic School**



Source: Self elaboration (2019)

**Figure 9. Observed temperature settings of air-conditioners in the Faculty of Architecture**

The estimated mean energy consumption by air conditioning units at the Polytechnic School was 35.72 MWh/month. The overall energy consumption by the PS based on the year 2018 was 1200 MWh, which gives an average energy consumption of 100 MWh/month. As such, the energy consumption by air conditioning use was equivalent to 36% of the total electrical energy consumed – a value within the range identified in a theoretical framework for educational institutions (Procel, 2018). In terms of the Faculty of Architecture, the estimated energy consumption by air conditioning was estimated to be 3.30 MWh/month. The overall energy consumption of the FA based on the year 2018 was 205.69 MWh, which gives an average consumption of 17.14 MWh/month.

As such the energy consumption by air conditioning use was equivalent to 19% of the total electrical energy consumed, which is well below the value found for the Polytechnic School. A rating system for labeling equipment (such as air conditioning units) was also created, classifying their energy performances. The National Energy Efficiency Rating (ENCE) considered five efficiency classes (A, B, C, D and E), with class A being assigned to the most efficient models, and the classes descending to E indicating less efficient equipment.

**Table 6. Numbers of air-conditioning units in each efficiency class according to the Procelrating**

| PROCEL labels | PS | FA |
|---|---|---|
| A | 140 | 16 |
| B | 95 | - |
| C | 59 | 7 |
| D | 36 | - |
| Without tag | - | 1 |

Source: Self elaboration (2019)

As the use of more efficient air conditioners would contribute to the reduction of energy consumption, a survey of the rating classes of all of the air-conditioning units installed in the two buildings was undertaken. The results are presented in Table 6; with A ratings found for 42% of the units installed in the PS, and 67% of those in the AF.

***Building use and Operation:*** Santo, Nico-Rodrigues and Alvarez (2016) observed that, due to the popularization of artificial HVAC systems and the lack of concern about energy consumption, designers and managers were ignoring the importance of window frames and their maintenance. Taking into account their fundamental roles as promoters of thermal comfort, windows need to be maintained in good working order to allow users to control ventilation. The use of air conditioning in various environments at the UFBA has increased over the years, without any planning. Research carried out by Costa et al. (2019) demonstrated a growing adherence to artificial air conditioning in the administrative offices of the Faculty of Architecture, but without first adopting simple measures to improve their thermal performances through passive measures. The option of using individual air conditioning units created inefficiency in the system. Hernandez and Romero (2001) pointed out that central air conditioning units are 20 - 30% more efficient than window units, and 15% more efficient than split models. Window-type air conditioning units are only recommended for acclimatizing rooms having floor areas less than 70m² (CREDER, 2004). For more ample environments, such as University buildings, the preparation of a HVAC project would be recommended, so that the choice of any airconditioning system would be technically well-founded. In the case of the two building evaluated here, their architectural designs and constructions allowed for ample ventilation. Costa et al. (2019) reported good ventilation potentials of the windows in the Faculty of Architecture, although some of them, as well as their states of conservation, often impaired optimal thermal performances. The deterioration of the window frames, for example, allowed the entry of external hot air, causing the air conditioning units to operate with significant energy losses.The poor states of conservation of the window frames in the FA left some impossible to open, while the users chose to permanently close others. Similar situations were likewise observed at the Polytechnic School.

**Aspects Related to the use of air conditioning by the academic community:** Research by the Chartered Institution of Building Services Engineer (CIBSE) focusing on energy efficiency in university buildings pointed out that building users themselves can have large impacts on energy consumption, depending on their lengths of permanence in the classrooms and the types of activities undertaken (CIBSE, 2012). Ricciardi and Burratti (2018) noted that environmental comfort is not only based on objective parameters, as behavior can greatly influences energy use. Pan et. al (2017) noted that the behavior of building occupants and how they use it represent important factors when assessing energy performance. To better understand user behavior patterns in relation to air conditioner use, interviews were conducted during our visits. The results, based on responses to those question are presented in Table 7. Two thirds of the occupants of rooms inspected in the Faculty of Architecture said that they preferred the use of natural ventilation, but 60% of them replied that the room they were occupying could not be ventilated naturally. At the Polytechnic School, on the other hand, just over half of respondents (51%) replied that they preferred air conditioning, and only 12% of them believed that the room could be naturally ventilated; 88% considered the use of mechanical ventilation essential in that environment.

**Table 7. Tabulation of the questionnaire data**

| Questions | FA | | PS | |
|---|---|---|---|---|
| | Yes | No | Yes | No |
| 1. Is the air-conditioning functioning? | 88% | 13% | 85% | 15% |
| 5. Do you consider the use of air-conditioning better than natural ventilation? | 33% | 67% | 51% | 49% |
| 6. Do you think that the room could be naturally ventilated? | 40% | 60% | 12% | 88% |
| 7. Do you think that the occupants of this room are concerned about energy consumption by air-conditioning? | 80% | 20% | 82% | 18% |
| 8. Do you think that the occupants of this room are concerned about the financial costs of air-conditioning to the UFBA? | 53% | 47% | 82% | 18% |
| 9. Do you think that the occupants of this room make rational (economic) use of energy resources? | 80% | 20% | 76% | 24% |
| 10. In your opinion, would the occupants of this room be inclined to adhere to a campaign to reduce the use of air-conditioners? | 87% | 13% | 59% | 41% |

Source: Self elaboration (2019)

Costa et al, (2019) evaluated the use of natural ventilation in the Faculty of Architecture, and Mishra and Ramgopal (2015) evaluated 5 classrooms with natural ventilation and 3 rooms with air conditioning at a University in India (located in a tropical climate zone), and both reported that the occupants of those classrooms stated that they were comfortable, even with the internal temperatures of those environment varying between 24 and 30º C, and that they could easily adapt by using appropriate clothing, opening the windows, or using a fan. The users of both the PS and FA buildings stated that they were concerned about energy consumption by air conditioners and the financial expenses involved. They largely considered (80% at FA and 76% at PS) that the occupants of the rooms should practice the rational use of energy. Finally, the majority of respondents were willing to join campaigns to reduce the use of air conditioning, although that percentage was much higher at the FA (87%) than at the PS (59%). In the aforementioned research carried out by Costa et al. (2019) on the thermal sensations of users in naturally ventilated classrooms in the Faculty of Architecture, 53% of respondents stated that they felt comfortable. That result was important, as it was a critical summer period in Salvador at the time and the building was not fully potentialized for cooling its internal spaces by passive means as many of the window frames did not allow easy control over natural ventilation.

**Electrical energy Management at the University:** Information on the management of electrical energy at the Federal University of Bahia was obtained from SUMAI to verify actions related to the management and reduction of energy consumption at the University.

In terms of energy management, actions are routinely carried out to analyze the accounts of all buildings, and specific maintenance and improvement actions are taken when there is an imminent need, although no structured management plan was presented with proactive preventive actions and improvements planned for the current year. Consumption measurements were only made for buildings as a whole, without the installation of individual meters in the different departments or sectors, making it difficult to target actions to reduce consumption. Regarding new projects for classroom buildings and compliance with Normative Instruction No. 2 (the need for public buildings to comply with PROCEL Edifica norms) – the responsible sector stated that they were not aware of that requirement, so bids for building were being held without complying with the Normative Instruction of the Federal Government. The University's energy manager is knowledgeable about energy efficiency and has sought to carry out improvements, although hampered by the lack of resources and a strategic management plan.

# CONCLUSIONS

Based on the energy audit and the analysis of the energetic efficiencies of the two buildings studied, our conclusions are as follow:

- We encountered mid-level indicators of energy consumption, corresponding to 58 kWh/m²/year in the Polytechnic School and 40 kWh/m²/year in the Faculty of Architecture.
- The estimated energy consumption by air conditioning units in the PS was 35.72 MWh/month. Based on the overall energy consumption in 2018 (1200 MWh), the mean monthly consumption of electrical energy was 100 MWh/month.
- The estimated energy consumption by air conditioning units in the FA was estimated to be 3.30 MWh/month. Based on the overall energy consumption in 2018 (205.69 MWh), the mean monthly consumption of electrical energy was 17.14 MWh/month.
- The percentage energy consumption by air conditioning in the PS was 36%, and 19% in the FA.
- The energy consumption values of those two faculties were within the theoretical values for other institutions of higher learning in Brazil.
- In terms of the energy efficiency of the air-conditioning units installed in the PS, 42% were designated with an A ratings; 67% were designated with an A rating in the FA.
- Consumptions during recess months were, on the average, 10% and 14% below consumption levels during the active school year in the PS and FA respectively. Most energy consumption therefore does not appear to be related to classroom activities, but rather to administrative and research activities, including energy use in laboratories (which continues during university holidays and breaks).
- We observed that the occupants of classrooms with air conditioning units tended to regulate environmental temperatures below the comfort levels of between 22.5º C and 25.5º C with 77% of the units in the FA and 67% of the units in the PS – even if that obliged the occupants to use heavy clothing to regulate their body temperatures.
- The promotion of air-conditioning to guarantee thermal comfort has produced a culture that prefers artificial thermal regulation – thus generating considerable levels of electrical energy consumption and accompanying outlays for the acquisition and maintenance of air-conditioning units. That situation has become increasingly troublesome for the maintenance of public universities.
- Buildings in tropical climates require special attention in terms of their thermal efficiency, including openings for natural ventilation that can reduce energetic costs and create healthy environments. Windows have primary roles in the ventilation and illumination of internal environments, and their dimensions and positioning, as well as their systems of control (opening and closing), can be the principal factors determining the quality of air circulation and thermal comfort.
- It is hoped that the data collected here can serve as a basis for analyzing consumption in other departments of UFBA and other universities in tropical climates, as well as contribute to energy conservation.

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