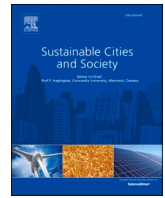




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Addressing the impact of COVID-19 lockdown on energy use in municipal buildings: A case study in Florianópolis, Brazil

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ABSTRACT

COVID-19 has spread quickly to several countries following the initial outbreak of the disease. As a consequence, several measures have been taken to mitigate the virus spread worldwide. In the city of Florianópolis, in southern Brazil, a strict lockdown was implemented on 16 March 2020. Although commercial activities were allowed to resume 21 April, a complete lockdown of municipal public buildings (e.g., administrative buildings and schools) lasted up to 5 August 2020. Reports in the literature emphasize the influence of occupant presence and actions on energy use in buildings. Therefore, the objective of this study was to assess the impact of the COVID-19 lockdown on the electric energy use of municipal buildings in Florianópolis. A large database with monthly electric energy use data was provided by the City Hall and analyzed. Firstly, the consumer units were grouped into three categories: systems, services and buildings. This revealed that buildings were directly affected by the lockdown measures, but systems and services were not. Therefore, an in-depth evaluation of health centers, administrative buildings, elementary schools and nursery schools was conducted and mean electric energy reductions of 11.1 %, 38.6 %, 50.3 %, and 50.4 %, respectively, were observed. Although it may initially seem unexpected, municipal health centers had a small electric energy use reduction, because they were not directly responsible for COVID-19 treatment, as patients were forwarded to specific facilities. Walkthroughs and energy audits were performed in an administrative building, an elementary school, and a nursery school, to gain a deeper understanding of the consumption trends. It was observed that municipal buildings present a basal energy use intensity even when the buildings are unoccupied. Energy audits verified that stand-by loads and vital loads, such as lighting for safety and computer servers, play a key role in this share of energy use.

1. Introduction

The outbreak of COVID-19 was first reported in late 2019, and the disease had spread to many countries by early 2020. Considering this scenario, the World Health Organization (WHO) announced on 11 March 2020 that COVID-19 should be characterized as a pandemic (WHO, 2020). Several countries took measures aimed at mitigating the virus spread. Schools were closed, physical interaction between people was limited, public events were canceled and, in some places, strict lockdowns were implemented. According to the International Energy Agency (IEA), such measures had a direct effect on energy demand worldwide. Up to mid-April, countries in full lockdown experienced a decline of around 25 % in the weekly energy demand and those in partial lockdown experienced an average decline of 18 % (IEA, 2020). The IEA

also highlighted that daily data collected in 30 countries up to 14 April confirmed that this reduction is related to the period and stringency of the lockdowns. Aruga, Islam, and Jannat (2020), for instance, showed that lockdown measures directly reduced energy consumption in India. The authors showed that the number of COVID-19 cases positively influenced the Indian energy consumption, i.e., the energy consumption increased as the lockdown was relaxed.

The literature highlights the impact of occupant presence and actions (OPA) on building energy use. Comprehensive efforts have been made to better understand this relationship, considering both assessment and simulation approaches (Yan et al., 2017). According to the IEA EBC Annex 53 “Total energy use in buildings: Analysis and evaluation methods”, there are six main influencing factors regarding energy use in buildings: climate, building envelope, building services and energy systems, building operation and maintenance, occupant activity and

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Nomenclatures

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMR	Basal Metabolic Rate
CBCS	Brazilian Council for Sustainable Construction (from Portuguese “Conselho Brasileiro de Construção Sustentável”)
EBC	Energy and Buildings Communities
EEB	Elementary School (from Portuguese: “Escola de Educação Básica”)
EUI	Energy Use Intensity
GDP	Gross Domestic Product
ICS	Climate and Society Institute (from Portuguese: “Instituto Clima e Sociedade”)
IEA	International Energy Agency
LabEEE	Laboratory of Energy Efficiency in Buildings (from Portuguese: “Laboratório de Eficiência Energética em Edificações”)
NEIM	Nursery School (from Portuguese: “Núcleo de Educação Infantil Municipal”)
OPA	Occupant presence and actions
SMDU	Municipal Office for Urban Development (from Portuguese: “Secretaria Municipal de Desenvolvimento Urbano”)
TM	Technical Memorandum
UFSC	Federal University of Santa Catarina (from Portuguese: “Universidade Federal de Santa Catarina”)
WHO	World Health Organization
ZEB	Zero Energy Buildings

behavior, and indoor environmental quality (Yoshino, Hong, & Nord, 2017). According to the authors, physical and technical factors provide a background to estimate building performance, while human-influenced factors lead to the actual energy use. On this basis, one may argue that unoccupied buildings tend to present low energy use levels. However, there is evidence for both commercial (Masoso & Grobler, 2010) and residential buildings (Al-mumin, Khattab, & Sridhar, 2003) that a relatively high amount of energy may be used when spaces are unoccupied. Focusing on office spaces, Masoso and Grobler (2010) found in a case study that around 56 % of the energy was used during non-working hours, partly due to lights and equipment being left on at the end of the day.

Studying the actual energy performance of buildings is a constant concern, especially due to the evident energy performance gap reported in the literature: the difference between predicted and measured energy performance of buildings (De Wilde, 2014). Occupancy in buildings already proved to be the main cause for uncertainties regarding the energy performance of buildings (D’Oca, Hong, & Langevin, 2018) – opening a lack for research of actual energy performance of buildings (Bavaresco, D’Oca, Ghisi, & Lamberts, 2020; Geraldi & Ghisi, 2020). Optimizing such energy use in buildings is also denoted as a key aspect to boost the economic and environmental indices regarding the energy sector worldwide (Chamandoust, Derakhshan, Hakimi, & Bahramara, 2019; Chamandoust, Derakhshan, & Bahramara, 2020). Along these lines, the abnormal unoccupancy of buildings caused by the measures taken to deal with COVID-19 provides an opportunity to improve evaluations of energy use in buildings and investigate what the main factors that impact it are. The Municipality of Florianópolis, the capital city of Santa Catarina State, Southern Brazil, also established regulations to tackle the pandemic. The aim of an ongoing project in this city, denominated “Cidades Eficientes” (Efficient Cities), performed by the “Conselho Brasileiro de Construção Sustentável” - CBCS (Brazilian

Council for Sustainable Construction), is to study the actual scenarios in the municipal buildings and propose actions to make them more energy and water-efficient. In one of the subtasks of this project, the municipal building portfolio was raised and described. Building features and occupancy behavior were associated with the energy consumption data, individually, and all of the information gathered was then inputted into a digital hub. This provides a transparent snapshot of the Florianópolis municipal building portfolio.

With the COVID-19 pandemic outbreak, there is an evident need to investigate the impact of the lockdown period and the social-distancing measures on electric energy consumption in buildings. On considering the data available for Florianópolis and exploring its relationship with the lack of occupancy of municipal buildings (such as schools, administrative buildings and health centers) the following questions can be addressed: Does an unoccupied building present a near-zero consumption? If not, what are the building features or systems that lead to this energy use? Lastly, what portion of the energy consumption is related to occupant presence? Such still unanswered questions may be a starting point to build comprehensive knowledge on the energy use intensity of unoccupied buildings and may guide further actions regarding building design, operation and maintenance. In fact, other concerns evidenced by the COVID-19 crisis like occupants’ safety during occupation may lead to increased energy use due to higher ventilation rates required (Ibn-Mohammed et al., 2021). If the building stock is wasting energy during unoccupied hours, such worry should be put in a paramount position to guide building design and operation. The literature supports that policymakers, planners, and architects should think out of the box to achieve antivirus-built environment (Megahed & Ghoneim, 2020), but energy efficiency concerns as well as CO₂ emissions cannot be disregarded.

In this panorama, the objective of this paper is to assess the impact of the lockdown imposed to deal with the COVID-19 emergency on the electric energy use of municipal buildings in Florianópolis, Brazil. The motivation was to comprehend current user-related conditions of municipal buildings that were limited during this pandemic. Aiming to provide valid, representative, and generalizable results for pre- and post-pandemic scenarios, this study is based on recommendations provided by Fell et al. (2020). We took the proposed “core and consider” approach to account for the influence of the pandemic on research validity. Our “core variables” are the government restrictions imposed on the city, as well as objective measurement of the electric energy consumption of municipal buildings that were directly influenced by changes in daily routine caused by the restrictions. Other “considered” variables herein encompass a general profile of the municipality electric energy use, adopting a broader scope where spaces other than buildings were included.

The main contribution of this study is the comprehensive analysis of the impact of the lockdown measures to contain COVID-19 spread in public buildings. Specifically, the monthly electric energy use intensity of the buildings during the pandemic was compared with the same period in previous years. The aim was to explore how the building electric energy consumption is responding to the unprecedented situation of an almost complete lack of occupancy. Connections between an energy use reduction and building features were explored, and semi-structured interviews were performed with key people in the municipality, to clarify some questions regarding the operation of buildings during this period. Finally, individual buildings were analyzed using energy audits in order to qualify, assess and understand the basal energy consumption of these buildings.

2. Context and overview

Florianópolis is located in southern Brazil and has a humid subtropical climate (classified as Cfa according to Köppen-Geiger system). Florianópolis is classified as climatic zone A2 according to the ANSI/ASHRAE Standard 169–2013 (ASHRAE, 2013). It is considered a medium-sized city in Brazil, with a population of 477,798 in 2016 and a

Gross Domestic Product of US\$ 6.9 billion in February 2015 (IBGE, 2016). The Human Development Index (HDI) is 0.847 (United Nations Programme Development, Atlas of Human Development, 2013).

The project “Cidades Eficientes” (Efficient Cities) carried out by the “Conselho Brasileiro de Construção Sustentável” - CBCS (Brazilian Council for Sustainable Construction) started in 2018, with the goal of supporting municipal governments in promoting actions targeting reductions in greenhouse gas emissions, mainly related to energy and water consumption, with a focus on municipal buildings. Three cities in Brazil were chosen to participate in the initial phase of the project (second semester of 2018), including Florianópolis. The project is funded by the “Instituto Clima e Sociedade” - ICS (Society and Climate Institute). In September 2019, the project was renewed for one more year, and Florianópolis was selected as the main case study. The Municipal Administration of Florianópolis thus created the “Programa Floripa Cidade Eficiente” (Floripa Efficient City Program). A partnership between CBCS and the Laboratory of Energy Efficiency in Buildings (LabEEE) of the Federal University of Santa Catarina (UFSC) was also set up for collaboration on the project. Three main subtasks were established: (a) the development of an integrated platform for electric energy and water management of the municipal building portfolio; (b) training municipality staff members; and (c) analysis of the existing legislation related to sustainable buildings and suggestions for an energy building code to increase efficiency in third party buildings.

The first subtask front focused on the development of an online platform that provides a dashboard to analyze performance building by building. To build this platform, a stock analysis was undertaken by identifying the stock information and relating it to the electric utility database. This stock analysis framework started a current of communication between the municipality and the electric utility company, which provides monthly updates of the energy consumption related to the municipal administration. It was a challenging task, since the information available was spread out and not well structured. The municipality of Florianópolis has access to up-to-date information on their buildings in an online environment now implemented by the project. The platform displays indicators including the energy use intensity (EUI), consumption rated by occupancy, cost indicators and greenhouse gas emission estimations. Additionally, the information available was used to develop a statistical benchmarking tool to provide a building performance evaluation reference at stock-level. All information used to conduct the analysis in this article is available in (CBCS (Conselho Brasileiro de Construção Sustentável) (2020)).

Through this process, information on all electric energy consumers contracted by the city administration was also made available – including public lighting, traffic lights, and so forth. Thus, we can provide an overview of the city’s energy consumption, giving a general perspective of the amount of energy consumed by the municipal administration. This information is important as it provides a reference of the city size and its consumption profile. The total amount of energy consumed was 48,403 MW h in 2019, this being considered as the reference year. The total energy consumption was divided into three sectors:

- Systems: Public Lighting, Security cameras, Street clocks, traffic lights;
- Services: Cemeteries, Recycle centers, Landfills, Others; and
- Buildings: Elementary Schools, Nursery Schools, Health Centers, Social Assistance Services, Community Centers, Administrative buildings, and others.

It is important to highlight that Florianópolis does not operate any type of electric public transportation. The only public transportation system is regular buses. Also, the municipality of Florianópolis does not have any electric vehicles.

The characterization of the electric energy use profile of municipal consumers for the city of Florianópolis is shown in Fig. 1. This approach illustrates the contribution of different types of energy use to the total energy consumption associated with the municipal government.

The central chart represents the portion of energy used by systems, services and buildings while the others illustrate specific portions associated with each category. The first observation is the expressive impact of systems on the total energy use of the city. In this regard, public lighting plays the main role, followed by traffic lights. Similarly, the other two cities in the project Efficient Cities also point out public lighting as a major energy consumer for their municipalities. This result evidences the need to comprehensively assess this contribution and provide guidelines to increase the energy efficiency of these municipal systems. Although worthy of investigation, this topic lies outside the scope of the present study because energy use by systems was not directly affected by the lockdown measures adopted in Florianópolis. Considering the other categories, services may be affected by social-distancing measures; however, they represented less than 1 % of the total energy consumption managed by the municipal administration. Table 1 shows the energy consumption for both systems and services

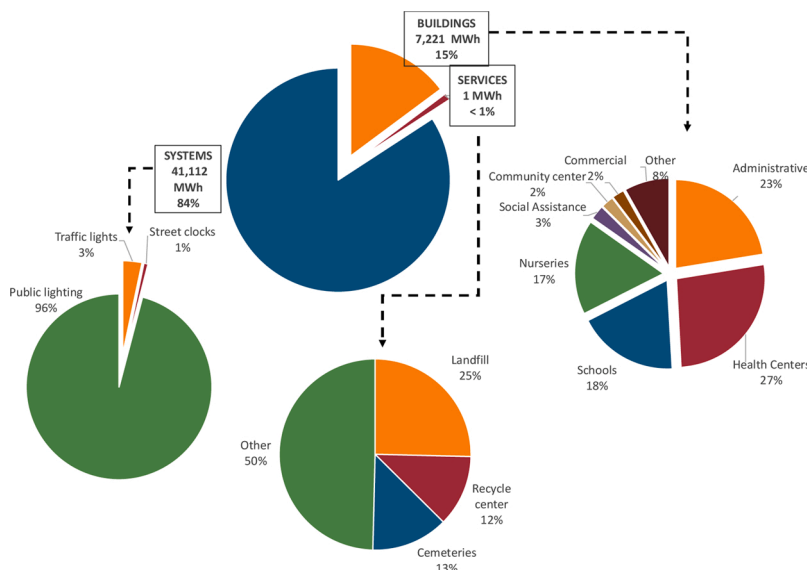


Fig. 1. Energy use profile for the municipal administration of Florianópolis during 2019.

Table 1

Electric Energy consumption of the Florianópolis City Hall from April to July, for 2019 and 2020, and its reduction due to the lockdown period.

Sector	Electric Energy Consumption from April to July (MWh)		Reduction during lockdown period (%)
	2019	2020	
Systems	16,939	16,737	1
Services	46	41	11
Buildings	2,560	1,721	33

from January to July of 2019 and 2020.

It is possible to observe a slight difference in energy consumption during the lockdown period in both the systems and services sectors. However, this analysis focused on municipal buildings, exclusively, as they accounted for around 15 % of the total energy use and were directly affected by the lockdown and work-from-home policies. Administrative buildings, elementary and nursery schools, and health centers are the typologies that have the most significant impact on the total energy consumption of municipal buildings (around 85 %). Thus, all subsequent analysis was conducted considering these four typologies. In fact, social assistance buildings and community centers play a social role by acting in supporting the community in which they are located, serving as hosts for decision-making meetings or reference points for food distribution, among other social functions. These buildings were therefore excluded from the analysis as they present an unusual occupation during the pandemic.

The pandemic reached Florianópolis on 22 February 2020, when the first COVID-19 cases were confirmed (Prefeitura de Florianópolis, 2021). At this time, many actions were taken to avoid the spread of the virus and manage the effects of the pandemic. In order to provide a clear perspective of the actions taken and explain the timeframes chosen for the analysis, we organized these actions into a timeline, as shown in Fig. 2.

Based on the “core and consider” approach suggested by Fell et al. (2020), Fig. 2 illustrates the timeline of actions taken to deal with the COVID-19 emergency in Florianópolis, since the government restrictions represent core variables in this analysis. All of the information provided on the timeline is based on governmental sources and databases (Prefeitura de Florianópolis, 2021).

On 11 March 2020, the World Health Organization (WHO) declared that the Coronavirus outbreak should be considered as a pandemic. The

growing trend of confirmed cases then led to a municipal lockdown being implemented on 16 March, with widely publicized instructions for the public to stay at home. The Municipal Decree 21.347 (Prefeitura de Florianópolis, 2020) established measures that included: cancelling classroom teaching, implementation of a remote work policy, and lockdown in the whole city, except for essential services. During the same week, two other Decrees were launched: 21.352, declaring a State of Emergency in the city; and 21.357, extending the lockdown measures by prohibiting access to beaches, parks and other public spaces, as well as freezing public transport services. Although some commercial activities were allowed 46 days after this lockdown (Prefeitura de Florianópolis, 2020), it is important to highlight that in the case of municipal buildings the strict lockdown and work-from-home policy remained in place until 5 August (Prefeitura de Florianópolis, 2020). Therefore, during the period of analysis considered in this study (16 March to 31 July), all of the municipal administrative buildings, elementary schools and nursery schools were expected to be nearly unoccupied.

3. Method

3.1. Data and information

The dataset was gathered by the Efficient Cities project mentioned above, a partnership between the Municipal Administration of Florianópolis and CBCS with the collaboration of LabEEE. One objective of this project was to establish a standard framework to manage energy and water data related to the municipal buildings for 2018, 2019 and 2020.

Data on a portfolio of 289 municipal buildings was available, as detailed in Table 2, which formed the basis of this study.

Table 2
Summary of the dataset.

Typology	Buildings in portfolio
Administrative Buildings	20
Elementary schools	44
Nursery schools	80
Health Centers	54
Social Assistance Services	21
Community Centers	17
Others (Public Gymnasiums, Shelters, among others)	53
Total	289

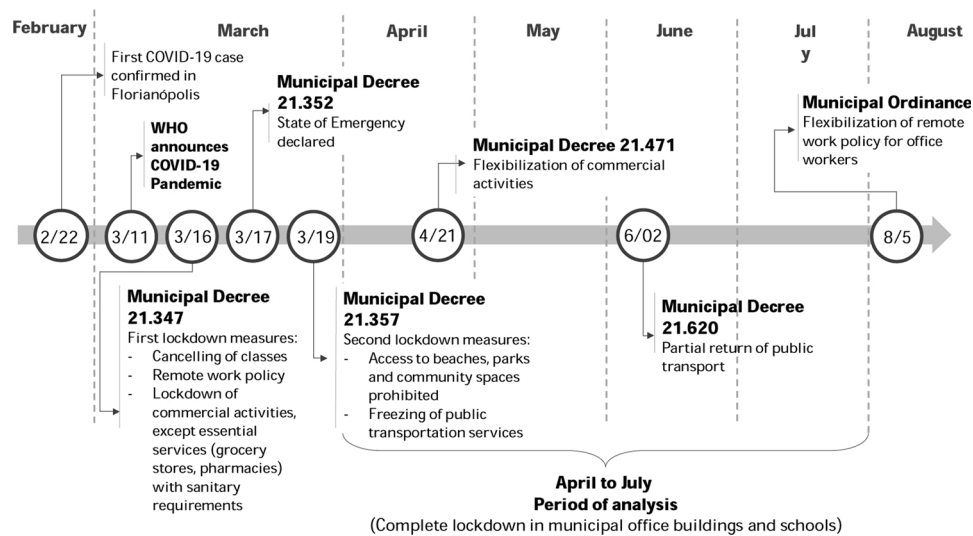


Fig. 2. Timeline of actions taken to tackle pandemic in Florianópolis during March to August of 2020.

Sources: (Prefeitura de Florianópolis, 2021, 2020; Prefeitura de Florianópolis, 2020, 2020; Prefeitura de Florianópolis, 2020, 2020; Prefeitura de Florianópolis, 2020).

Importantly, since the analysis was based on energy bills, the reference date of each month was adjusted to refer to the actual period when the energy was consumed. An energy bill for March, for instance, usually relates to the consumption in February, but in this study the February consumption actually corresponds to the energy consumed in February.

3.2. Analysis of the energy consumption variations

The analysis of the energy consumption variables was performed by the examination of the sum of differences between the energy consumption during the lockdown period and the average energy consumption of the same period in the last two years, divided by the average energy consumption of the same period in the previous two years (Eq. (1)). This equation indicates how much the energy consumption during the lockdown was higher (positive variation) or lower (negative variation) than the average of the same period in the last years.

$$V = \sum_{i=1}^n \left\{ \left[E_{2020} - \left(\frac{E_{2018} + E_{2019}}{2} \right) \right] / \left(\frac{E_{2018} + E_{2019}}{2} \right) \right\} \times 100 \quad (1)$$

where:

V is the variation in the energy consumption during the lockdown period, in %;

E_{2020} is the energy consumption from March to July of 2020 (lockdown period), in kWh;

E_{2019} is the energy consumption from March to July of 2019, in kWh;

E_{2018} is the energy consumption from March to July of 2018, in kWh;

n is the number of buildings of a given typology;

i represents the months, starting from March (1) to July (5).

A building stock-level approach is used to analyze various aspects of a group of buildings (Geraldi & Ghisi, 2020). In this study, the results were expressed in boxplots and tables to present the statistic measures for each typology studied.

3.3. Identifying the basal energy use intensity

Based on the analysis of the data available for the portfolio of municipal buildings, a remaining energy consumption was identified even though the buildings were supposed to be unoperated, regarding the official orientation. This was unexpected since the buildings were not operating; the energy consumption should be zero; however, this was not what happened in practice. In addition, it is reasonable to state that the remaining energy consumption is unnoticeable in regular operation but become evident in cases of restrict operation, such as during the first lockdown due to the pandemic.

Based on a similar idea related to a human body, of a basal metabolic rate (BMR), which is the minimum energy required to keep this organism functioning at rest (Henry, 2005; Schofield, 1985), we proposed the term "basal energy use intensity" (basal EUI), that is, the minimum energy needed to maintain the building operating at minimal conditions. It is important to explain that these minimal conditions are different than inactivated buildings: buildings that are inactivated are not being used anymore, and their energy consumptions will be zero, while minimal conditions imply that buildings are no operating during a short or uncertain period, and must be ready to operate anytime.

In order to measure this basal EUI, Eq. (2) was used to calculate the simple average EUI for the target building during the months of complete lockdown (sum of EUI's divided by the number of months). Still, an interval of confidence was calculated for this period, to consider variations. The Interval of confidence is considered by adding and subtracting the average basal EUI a part calculated by quotient between the standard deviation of the EUI, the root squared number of months and multiplying by the statistic "t" from the Student t-test, in this case, considered with a significance level of 10 % (90 % of confidence).

$$B = \frac{\sum_{i=1}^m \mu_i}{m} \pm \left(t_{90\%} \times \sigma / \sqrt{m} \right) \quad (2)$$

where:

B is the basal EUI of the target building, in kWh/m²;

μ is the monthly EUI of the target building, in kWh/m²;

m is the number of lockdown months that affected the target building;

$t_{90\%}$ is the statistic "t" from the Student t-test with a significance level of 10 %;

σ is the standard deviation of the EUI during the lockdown months that affected the target building, in kWh/m²;

i represents the months, starting from March (1) to July (5).

Hypothetically, many factors could account for this basal EUI; e.g., stand-by loads, vital loads, inefficiency, and so forth. In practice, although the municipal legislation restricted the occupancy in their buildings during the lockdown, some occupants might have been visiting buildings for different reasons. To investigate this basal EUI, one building of each typology studied (an administrative building, an elementary school and a nursery school) was selected to receive *in-situ* visits, aiming to investigate specific cases. Health centers were not visited for safety reasons in view of the pandemic.

A combination of the ASHRAE Energy audit level 2 (ASHRAE, 2011) and semi-structured interviews was applied to gather information related to the building occupancy during the pandemic and outline the basal EUI. Interview questions were answered by a building staff member. The main questions were:

- 1 Are the buildings occupied during the lockdown period?
- 2 If so, who are the main occupants?
- 3 What is the frequency of this occupation?
- 4 What is the purpose of this occupation?
- 5 How long is this occupation (in h/day)?

The findings of the interviews helped to outline the possible causes for the remain energy consumption of the buildings. Regarding the energy audits, a careful observation of appliances and systems in each building was performed. This provided a comprehensive identification of systems that are still operating even though the occupation was severely reduced. The accompanying building staff member explained the operational needs that lead to systems being turned on or off.

The monthly EUI was then estimated using the TM22 spreadsheet method (Field, 2006). Technical Memorandum 22 (TM22) is a document developed by the CIBSE (Chartered Institution of Building Services Engineers of the United Kingdom) (Chartered Institution of Building Services Engineers (CIBSE) (2006)). This document defines a method for assessing the energy performance of a building based on energy use. TM22 provides a standard approach to quantify the energy use according to the existing systems and energy consumers in the building and their usage pattern. A spreadsheet is used to quantify the installed power density of plug loads, HVAC, lighting and special systems specification. The estimated energy consumption is obtained from installed power and the hour of usage of each item raised in an *in-situ* visit. In summary, the power of each piece of equipment identified was multiplied by an estimated number of hours of usage, known as the use factor. Lastly, the energy consumption of refrigerators was measured using a specific energy meter.

4. Results

4.1. Energy consumption variations

With regard to the impact of lockdown on the energy use of municipal buildings, substantial variations were found during the period

of analysis. As shown in Fig. 3, all categories of buildings showed a reduction in energy use during these months.

The decrease in energy use at health centers may initially seem inconsistent with a period in which these facilities are expected to be overused. However, the Florianópolis administration encouraged people to use a telemedicine service instead of visiting clinics to reduce the risk of contagion (Prefeitura de Florianópolis, 2020). Also, small health centers were not directly responsible for attending COVID-19 patients, as specific reference centers were established. Considering the other typologies (administrative buildings and elementary and nursery schools), expressive reductions were found during the lockdown. Thus, from April to July a basal energy use is evident.

It is important to highlight that the summer in this city ranges from December to March, and air conditioning systems are often used in this period, which explains the decrease in the historical average (lines) energy consumption from January to July. Air conditioning for heating is not common and does not seem to have an effect in this context since Florianópolis has mild winters. In the case of schools, the historical average EUI is lower in December and January due to the summer vacation period.

Focusing on administrative buildings and schools, which were strongly affected by the lockdown measures, interesting findings were obtained. It was noted from this analysis that the basal energy use of these buildings represents a considerable portion of the historical average, ranging from 46 % (nursery schools in July, which consumed 47.6 MW h compared to the historical average of 103.1 MW h) to 66 % (administrative buildings in July, which consumed 60.1 MW h compared to the historical average of 90.9 MW h). In the case of administrative buildings, mostly offices, this value is surprising as the historical average is expected to drop during the winter (from June to

September), considering that HVAC systems are mostly used during the summer in Florianópolis (De Vecchi, Candido, de Dear, & Lamberts, 2017; Rupp, de Dear, & Ghisi, 2018). This trend raises some questions about the impact of occupant presence and actions (OPA) on the total energy use in these buildings. While the literature supports that energy-efficient facilities, especially zero energy buildings (ZEB), are highly influenced by OPA (Nord, Tereshchenko, Qvistgaard, & Tryggestad, 2018), our results led to some intriguing conclusions. For instance, it seems that for municipality buildings in Florianópolis, a significant portion of energy use is not necessarily driven by the presence of occupants. Our results suggest that occupant presence could influence around 38.6 % of total energy use in administrative buildings. This is a compelling reason to conduct further monitoring and evaluations in these buildings, as high energy use when occupancy is diminished may indicate possible waste patterns.

Key descriptive statistics were calculated considering the variations in energy use between 2020 and the historical average, to provide a deeper understanding of the trends. Importantly, the interval considered for this analysis was April to July. The variations in energy consumption can be seen in Table 3, and Fig. 4 shows a summary for each typology in a boxplot. Reductions are expressed as negative values and increases as positive values.

As expected, based on the previous evaluation, health centers presented smaller reductions during the lockdown, although for more than half of these buildings the energy consumption reduced by at least by 15 %. Expressive reductions were observed for the other typologies. The upper quartiles in the boxplots confirm that for at least 75 % of the administrative buildings, elementary schools and nursery schools the energy consumptions reduced by 24.4 %, 35.1 %, and 35.9 %, respectively.

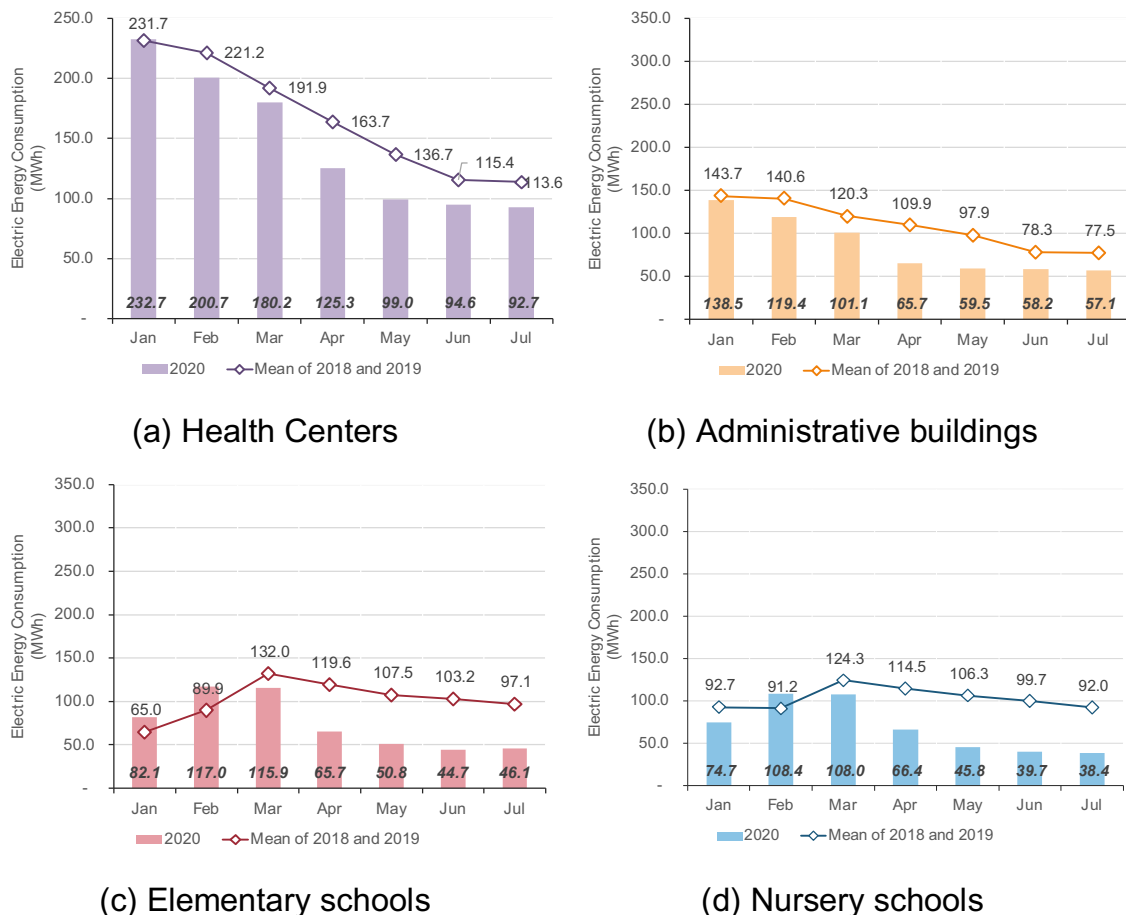


Fig. 3. Energy consumption from January to July 2020 in comparison to the average of the same period in 2018 and 2019.

Table 3

Summary of the variations* in the energy consumption of municipal buildings in Florianópolis due to lockdown from March to July of 2020.

Parameters	Administrative Buildings	Elementary School	Nursery School	Health center
Minimum (%)	-73.0	-100.0	-100.0	-90.5
Lower Quartile, 25 % (%)	-47.5	-68.6	-70.0	-32.1
Median, 50 % (%)	-42.0	-54.7	-54.0	-17.5
Standard deviation (%)	18.3	26.9	27.1	36.3
Upper Quartile, 75 % (%)	-24.4	-35.1	-35.9	4.3
Maximum (%)	-9.1	45.1	69.0	97.8
Mean (%)	-38.6	-50.3	-50.4	-11.1
Interval of	-35.5 to	-47.4 to	-48.4 to	-7.7 to
Confidence (%)	-41.6	-53.2	-52.4	-14.5

* Comparison of mean consumption values for 2018 + 2019 and for 2020, considering the period of April to July (pandemic).

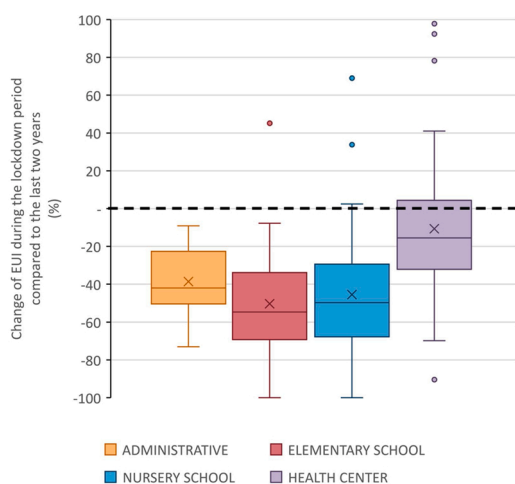


Fig. 4. Boxplot of the variations in energy consumption of the administrative buildings, elementary schools, nursery schools and health centers.

It is important to highlight that the mean variation is always negative (reduction), and it was possible to determine a confidence interval considering the standard deviation and the size of the building stock for each typology. In other words, this outcome explains how much the energy consumption decreased due to lockdown measures in the case analyzed, according to different typologies.

The maximum change in energy consumption observed was 100 %, which means that some buildings presented zero energy consumption, probably due to the deactivation of the power supply. On the other hand, for all typologies, some buildings showed an increase in energy consumption (maximum positive values) and these should be investigated in further analysis.

Results evidenced expressive reductions in some municipal buildings caused by the lockdown, but it also revealed that many facilities consumed a high amount of electricity with occupancy reduced. Therefore, a path towards understanding this scenario is needed to guide future decision making related to energy efficiency in buildings. According to Steffen, Egli, Pahle, and Schmidt (2020), energy and climate policies need to encompass criteria to deal with new circumstances arising during the COVID-19 crisis. The authors note that although reductions in energy consumption and CO₂ emissions have been observed throughout the world during the short-term response to this crisis, long-term scenarios will be highly dependent on whether structural changes are introduced in the sector. Considering a potential perspective for the post-crisis scenario, Kuzemko et al. (2020) emphasized that the

path to economic recovery presents an opportunity to stimulate green growth. In other words, policy interventions may accelerate the decarbonization of energy systems as well as enhance the requirements related to energy efficiency and the indoor quality of built environments.

4.2. Basal energy use intensity

Evaluations in one building of each category were conducted to understand the possible causes of the high basal energy consumption during the unoccupied period. A combination of ASHRAE Energy Audit level 2 and semi-structured interviews were the methods used to obtain more information. Table 4 contextualizes each building evaluated and shows the observed reduction of energy use during the lockdown.

All buildings had a significant reduction in energy consumption during the lockdown. For the administrative building evaluated, the average energy consumption reduction was 40.5 %, compared to the historical average. The calculated basal consumption ranged from 2.22 to 2.30 kW h/m².month, considering the confidence interval. Possible causes for the remained energy consumption of the buildings visited were outlined from the interviews accompanied by the *in-situ* visits. The visits revealed the presence of several data processing rooms with servers and racks that were continuously operating, since this building is the hardware hub of the municipal administration's online environments. Also, equipment such as computer screens and other computer hardware were left in stand-by mode. Some specific lighting (such as in corridors, garages and external areas) remained on for safety reasons. This building has two lifts, which probably contributes for a high portion of the energy consumption, since stand-by lift energy consumption often represents an expressive percentage (about 80 %) of the total consumption of this end use in a building (Patrão, De Almeida, Fong, & Ferreira, 2010).

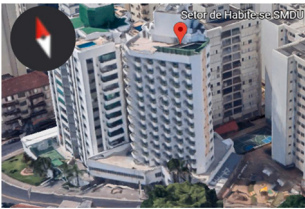


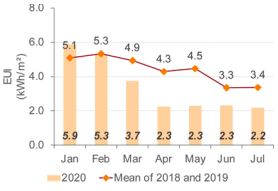
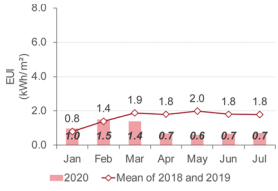
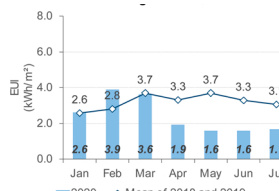
Regarding the elementary school evaluated, much of the consumption observed was attributed to refrigerators and stand-by plug loads. Lighting for safety was also identified, especially in the external areas. Sporadic visits from staff members were reported, especially for cleaning purposes toward the end of lockdown. Similar results were observed for the nursery school visited. Table 5 provides the estimated breakdown of the basal EUI for each building audited, using the TM22 method.

Table 5 shows the estimated EUI for each building audited. There is a difference between the estimated and actual basal EUI calculated from the energy bills. By estimating the EUI it was possible to identify a portion of the actual EUI that is related to each end use verified. The SMDU building resulted in an estimated EUI of 1.77 kW h/m².month, while the actual basal EUI was 2.22 ± 0.04 kW h/m².month. The difference (around 0.45 kWh/m².month) could be attributed to the uncertainty and variations that occur in practice and are not considered in the model used (TM22 spreadsheet). The same scenario was observed for the elementary school (estimated 0.61 but actual 0.66 ± 0.03 kW h/m².month) and for the nursery school (estimated 1.12 but actual 1.7 ± 0.12 kWh/m².month). The extra energy could be related to visits from the staff members for different reasons (cleaning or accessing files and computer programs that are only available on the office computers).

For the city of Florianópolis, the average breakdown of the energy consumption for a school with air conditioning is: 30 % for air conditioning; 48 % for lighting and 21 % for plug-loads (mainly refrigerators and computers) (CBCS (Conselho Brasileiro de Construção Sustentável) (2021)). However, it is important to highlight that air conditioning is not often present in these buildings – In fact, only 25 % of the elementary and nursery schools have the system in the classrooms (CBCS (Conselho Brasileiro de Construção Sustentável) (2020)). The breakdown for a school without air conditioning in Florianópolis is: 69 % for lighting and 31 % for plug loads (refrigerators and computers) (CBCS (Conselho Brasileiro de Construção Sustentável) (2021)).

It is important to highlight that a significant portion of this basal EUI could be reduced, especially by avoiding unnecessary stand-by plug

Table 4
Case studies with one example building of each typology.

Building type:	Administrative building	Elementary School	Nursery School
Name:	SMDU	EEB Beatriz de Souza Brito	NEIM Costeira do Pirajubáé
Street view:			
	Source: Google Earth, 2020.	Source: Google Earth, 2020.	Source: Google Earth, 2020.
EUI Profile:			
Area (m ²):	5,864.91	2,183.44	446.77
Average energy consumption reduction during pandemic (%):	40.5%	63.9%	48.9%
Basal EUI (kWh/m ² .month):	2.26 ± 0.04 (CI = 2.22 to 2.30)	0.66 ± 0.03 (CI = 0.63 to 0.70)	1.70 ± 0.12 (CI = 1.58 to 1.82)
Standard deviation (kWh/m ²):	0.06	0.05	0.16
Possible causes of the remain energy consumption:	<ul style="list-style-type: none"> - Data processing centers; - Some lights remain on for safety reasons; - Elevators (stand-by); - Stand-by plug loads. 	<ul style="list-style-type: none"> - Periodic visits by cleaning staff lights and HVAC usage); - Refrigerators and freezers remain on; - Some lights remain on for safety reasons; - Stand-by plug loads. 	<ul style="list-style-type: none"> - Periodic visits by cleaning staff (lights and HVAC usage); - Refrigerators and freezers remain on; - Some lights remain on for safety reasons; - Stand-by plug loads.

*CI = Confidence interval.

Table 5
Breakdown of estimated basal EUI for each typology from energy audits.

Typology	Building	Area (m ²)	End use	Units	Power installed (W)	Break-down of power installed	Motivation (reason for end use)	Average Estimated Monthly Energy Consumption (kWh)	Break-down of remained consumption	Whole-building EUI estimated by TM22 (kWh/m ² /month)
Administrative Building	SMDU	5,864.91	Lighting systems for security (external areas, corridors, etc.)	68	1,020	1 %	Security reasons	520	5%	1.77 (actual 2.22)
			Data processing centers	10	30,000	40%	Server for municipal sites	7,650	74%	
			Computers in stand-by mode	289*	43,350	58%	Inefficiency and/or work-from-home needs	2,211	21 %	
Elementary School	EEB Beatriz de Souza Brito	2,183.44	Lighting system for security (external area, corridors, etc.)	147	8,708	86 %	Security reasons	639	48 %	0.61 (actual 0.66)
			Refrigerators	5	423	4%	Maintain operation (even when empty)	190	14%	
			Computers in stand-by mode	37	975	10 %	Inefficiency	510	38 %	
Nursery School	NEIM Costeira do Pirajubáé	446.77	Lighting system for security (external areas, corridors, etc.)	17	2,200	81 %	Security reasons	110	22 %	1.12 (actual 1.70)
			Refrigerators	5	310	11 %	Maintain operating (even when empty)	226	45%	
			Computers in stand-by mode	4	212	8%	Inefficiency	163	33 %	

* Total number of computers in the building considered in stand-by mode.

loads, such as computers. The reduction could reach around 22 % (0.37 kW h/m².month) for the administrative building, 38 % (0.23 kW h/m².month) for the elementary school and 33 % (0.36 kW h/m².month) for the nursery school. Also, empty refrigerators could be turned off, notably at the nursery school evaluated, since this system had the highest share of basal energy use.

Another important aspect is related to high-demand contracts. Higher consumption clients (such as the SMDU building) have a contract known as 'energy on demand': the municipality has an annual contract with a fixed energy demand per month and pays the energy consumption bill monthly. If the building uses more energy than this fixed value, a higher amount is charged for the extra energy demand. If the building uses less energy than the contract value, the agreed amount is charged. During this pandemic period, the SMDU building, for example, had a lower energy demand (average 35.5 kW) than the amount fixed on the contract (70 kW), and the municipality is paying for this unused demand. The context of this research represents an unpredictable situation, with the building being unoccupied for a long period. However, knowing the basal EUI and taking measures to decrease it could allow the municipality to adjust its energy contracts and save resources in the long term. As a consequence, lessons learned during this challenging period can be implemented in post-pandemic scenarios and help to decarbonize the public building stock in Florianópolis.

5. Discussion

According to [Bashir, Ma, and Shahzad \(2020\)](#), socio-economic and environmental impacts resulted from the measures taken to deal with the COVID-19 emergency. The world is observing severe demographic changes, high unemployment rates, and reductions in economic activities. Energy-related research is also highlighting many aspects including reductions in total energy consumption ([Aruga et al., 2020](#); [IEA, 2020](#)), CO₂ emissions ([Le Quéré et al., 2020](#); [Shehzad, Sarfraz, Ghulam, & Shah, 2020](#)), and other air pollution indicators ([Kumar et al., 2020](#); [Shakil, Munim, Tasnia, & Sarwar, 2020](#); [Wang & Li, 2021](#)) worldwide. However, [Bashir et al. \(2020\)](#) also noted that COVID-19 should not be considered as a driver for these positive variations, especially considering that the environmental changes and reductions on pollution levels will not be long lasting. Nevertheless, the availability of previously unseen patterns allows the assessment of specific aspects that must be studied and improved in the future. Magahed and Ghoneim argued that responses to this crisis might shape the design of antivirus-built environments relying on multidisciplinary efforts ([Magahed & Ghoneim, 2020](#)). Evidence supports that climate conditions may boost coronavirus spread, and such information may provide guidelines for building design. In fact, low-humidity areas imply in higher mass transfer potential, which may dry and reduce the size of respiratory droplets – increasing their spread ([V, R, & Haghghat, 2020](#)). However, the literature also supports that both built and social environments influenced the dissemination of COVID-19 in Washington D.C., USA ([Hu, Roberts, Azevedo, & Milner, 2020](#)).

In a current perspective, measures to reduce the spread of COVID-19, like adopting lockdown and work-from-home policies, showed that authorities can respond quickly to evident threats. However, other notable issues, like climate change, seem to be somewhat disregarded by building stakeholders ([Pike, 2020](#)). Along these lines, the literature evidences a two-fold relationship between climate change and the building sector. Firstly, buildings are responsible for a high portion of energy use worldwide ([GABC, 2018](#)) with a direct impact on greenhouse gas emissions and climate change ([IEA, 2020](#)). Secondly, climate change itself is expected to increase the energy demand of buildings ([da Guarda et al., 2020](#); [Li, Yang, & Lam, 2020](#); [Triana, Lamberts, & Sassi, 2018](#)). Additionally, as argued by Mohammed et al. ([Ibn-Mohammed et al., 2021](#)) COVID-19 also evidenced some needs in further design and operation of buildings. For instance, authors argued that higher ventilations rates will be necessary, which increases the energy use in

buildings.

Reports in the literature highlight that increasing energy efficiency is an important strategy to prevent a rebound effect on carbon emissions in a post-COVID scenario ([Wang & Wang, 2020](#)). Therefore, implementing energy-efficiency strategies in buildings in Florianópolis' is vital, since our results indicate that most municipal facilities had high levels of energy use during lockdown. These values may be considered as a basal amount of energy consumed regardless of the presence of occupants, that is, the basal energy use intensity (BEUI).

In the case of Florianópolis, the monthly average energy use of municipal buildings from April to July ranged from 49.6 % to 61.4 % of the historical average, which is a large portion considering the abnormal lack of occupancy. Similar outcomes were presented for University buildings in the UK, where 46.6 % electricity reduction was found comparing energy use previous and during the lockdown ([Birch, Edwards, Mander, & Sheppard, 2020](#)). Other countries report different reductions. In Italy, reductions in electric energy consumption were around 37 % ([Ghani, Galici, Mureddu, & Pilo, 2020](#)), compared to the same period last year. In Spain, office buildings reported a reduction of 14.53 % during workdays and 10.62 % in weekends ([Santiago, Moreno-Munoz, Quintero-Jiménez, Garcia-Torres, & Gonzalez-Redondo, 2021](#)). In China, the estimated carbon reduction was 23.9 % for constructions than in the same period in the past year ([Wang, Lu, Bai, & Wang, 2020](#)). The building stock responds differently along with the country reality – not only according to the building practices but, in this case, also according to the actions took to deal with the pandemic situation. In fact, the energy performance of buildings is largely affected by the cultural and social aspects ([fei Chen et al., 2020](#)).

An unintended consequence of the lockdown is that it allowed the baseline scenario to be evidenced, revealing that buildings remained with some systems turned on as if they were occupied. As stated by the building coordinators in Florianópolis, in several cases this was due to uncertainties related to the return of activities. For example, in schools (elementary and nursery), refrigerators were empty but remained on. Similarly, stand-by computer loads were observed in all the typologies evaluated in depth. This demonstrates that basal consumption is also present during the normal operation period since the refrigerators are turned on and stand-by loads are present constantly. In a planned unoccupied period (which was not the case of the lockdown situation), all of these systems could be turned off.

This basal consumption was classified into four main causes: sporadic activity of the staff; inefficiency; stand-by loads; and vital loads. Stand-by loads and inefficiency represent a portion of consumption that could be avoided, and often resulted from an employee inadvertently leaving a piece of equipment turned on (e.g., a computer), or could be managed (e.g., in larger systems such as lifts). Vital loads are a portion of the energy consumption that is always present in the building and could be related to refrigerators and some locations that require lighting for security purposes. Identifying and understanding this basal EUI is important, since actions aimed at its reduction can then be outlined. The basal EUI seems to be related to the organizational culture of the building rather than the presence of the occupants. Thus, when switching off computers and equipment every day after the work is a trait of the organizational culture, the stand-by loads are reduced ([Li, Xu, fei Chen, & Menassa, 2019](#)). Further investigations on organizational culture could ensure that some findings reported herein lead to impactful changes in building operation and maintenance.

The typical monthly EUI for administrative buildings in Florianópolis is 4.94 kW h/m²/month, for elementary schools is 2.24 kW h/m²/month, and for nursery schools is 2.29 kW h/m²/month. Whilst, the basal EUI for administrative buildings observed in Florianópolis is 3.04 kW h/m²/month (61.4 % of the regular monthly EUI), for elementary schools is 1.13 kW h/m²/month (49.7 %), and for nursery schools is 1.13 kW h/m²/month (49.6 %).

In terms of Building-Integrated Photovoltaics, the only case of the City Hall is a nursery school called "Creche Hassis", which is equipped

with a 21 kWp photovoltaic system. This nursery is a pilot project of the City Hall regarding sustainable construction. It is LEED Platinum certified and its photovoltaic system is on-grid. During the lockdown period, the Creche Hassis consumed 11.131 kW h and generated 16.067 kW h that was injected on the grid. Thus, this building was a net-positive building in terms of generation. However, it is important to notice that even though there is a generation capacity, the facility still consumed residual energy. Then, we visited this building to prospect responses for this residual consumption. In this specific case, the residual energy consumption during the pandemic could be attributed to the use of the building as a strategic point for the community to collect donations and supplies. So, equipment such as computers, refrigerators and lighting remained in use, even though the main function of the building (caring of infants) was not happening.

In this context, [Kuzemko et al. \(2020\)](#) argue that the economic and social impact of COVID-19 will contribute in shaping sustainable energy transitions. Additionally, [Steffen et al. \(2020\)](#) provided a structure to guide energy policymakers towards clean energy transitions during and after the COVID-19 crisis. According to the authors, three main horizons must be taken into account: short-term (months), mid-term (years), and long-term (decades). Our analysis focused on the short-term horizon (when severe measures were undertaken to deal with COVID-19), and the buildings evaluated had their occupancy drastically reduced. However, considering a broader picture of this scenario, building stakeholders will need to deal directly with challenges during subsequent stages; i.e., mid-term and long-term horizons. After the first few months of the severe crisis, for instance, some occupants are expected to return to their workplaces. Besides the aim of achieving the energy-efficient operation of buildings, another paramount need is guaranteeing the safety of the employees. Finally, the long-term horizon also features significant challenges for the building communities. Considerable effort will be needed to guarantee resilience against similar shocks in future, based on the lessons learned.

Along these lines, our results highlight the important role of setting strategies to mitigate energy wastage in buildings based on real-world information. This sheds light on the need to drive the necessary changes in building-related policies, especially in Brazil, considering that Energy Performance Certificates are still optional, except for federal buildings. An in-depth knowledge of these aspects, along with understanding and rating the building performance throughout its operation, is also fundamental. As discussed by [Yoshino et al. \(2017\)](#), a lack of knowledge regarding the primary factors that influence building energy use is a substantial barrier to improving energy efficiency. In this regard, our results verify that a significant portion of the building energy consumption is related to the presence of the occupant, such as air conditioning, lighting and plug loads. In the context analyzed in this paper, it was possible to quantify a portion of energy that could be saved with strategies to reduce the total energy consumption of a building. In the administrative building analyzed, for example, adopting work-from-home policies in the post-pandemic scenario could reduce the SMDU's energy consumption by up to 40.5 %, considering zero occupancy for one month. On this basis, scenarios could be tested to specify and outline such a policy. In fact, the records of energy consumption of Florianópolis obtained from the electric utility ([CELESC, 2018](#)) reported an increasing in electric energy consumption in residential sector but an expressive reduction in commercial sector. Comparing the total electric energy consumption from March to July of 2020 with the same period of 2019, the residential sector had an increasing of 4.4 % (around 8,806.83 MW h), while the commercial sector had a reduction of around 19 % (26,237.05 MW h). If such a trend is maintained in the so-called "new normal", further energy efficiency measures for the residential sector will be discussed and presented. Therefore, policymakers are recommended to carefully evaluate underlying effects on the energy use of residential buildings ([Balezentis, 2020](#)), as well as possible rebound effects when energy efficiency measures are adopted ([Balezentis, Butkus, Štreimikienė, & Shen, 2021](#)).

Finally, another aim of this study was to present to the building community meaningful information that may encourage changes considering both the mid- and long-term horizons. In this context, [Fell et al. \(2020\)](#) presented a general overview of good practices regarding the validity of energy-social research during and after the COVID-19 emergency. The authors stressed that conclusions drawn from data collected during this period should be valid, representative and generalizable to a post-pandemic world, as well as comparable to the pre-pandemic scenario. Indeed, these aspects are key to extracting lessons from this situation and implementing good practices in this field. Considering the energy consumption of municipal buildings in Florianópolis, the unprecedented lockdown evidenced that many buildings may be wasting energy throughout the year, and this trend is generalizable to both pre- and post-pandemic scenarios. Additionally, this study reinforces the need for a workgroup formed of municipal administration staff that would be responsible for measuring the building performance of their portfolio and propose energy efficiency actions. This study represents a first step to understanding the performance of these patterns and identifying the reasons for their occurrence. Further research will focus on performing a comprehensive energy consumption breakdown for the buildings in the portfolio of the municipality.

6. Conclusions

This study focused on the short-term influence of the lockdown undertaken to deal with COVID-19 emergency on the energy use of municipality buildings in Florianópolis, Brazil. The main conclusion was that buildings consumed an expressive amount of energy during this period. Also, an expressive scientific outcome could be drawn from this study: buildings present a remaining energy consumption that is unnoticeable in regular operation, but become evident in cases of restrict operation, such as during the first lockdown due to the pandemic. We found that this remaining energy consumption exists because of a sum of vital loads and/or stand-by loads (that were kept in this way for the eminent return of the operation). Hence, we compared this state with the Basal Metabolic Rate – which is the minimum energy required to keep a human body functioning at rest. Drawing this parallel, we proposed the term "basal energy use intensity", associating both concepts of Basal Metabolic Rate and the Energy Use Intensity.

Additionally, specific typologies (administrative buildings and elementary and nursery schools) were evaluated from the building and stock-level perspectives, and the following conclusions can be outlined:

- During the lockdown, the energy use of administrative buildings, elementary schools and nursery schools reduced by around 38.6 %, 50.3 % and 50.4 %, respectively, compared to the same period in the last two years, revealing that almost unoccupied buildings do present considerable energy consumption. Hence, half of the energy consumption of the typologies addressed is not related to the continuous presence of occupants.
- The Basal EUI corresponds to an expressive fraction of the regular energy use was evident during the lockdown. Thus, future studies should examine to what extent this basal energy use is due to system inefficiency, building management, and organizational culture.
- Energy audits were performed on a sample of buildings to identify the source of this basal EUI. Stand-by loads and vital loads (such as lighting for safety and server rooms) were identified as the main contributors. Thus, the basal EUI could be reduced with behavioral changes and more efficient systems being installed.

These outcomes support the need for making energy-related policies stricter, to reduce the basal energy use intensity. Considering mid-term and long-term horizons might help us to understand several challenges associated with building operation, considering all of the changes that this pandemic period has brought to our society.

Declaration of Competing Interest

The authors report no declarations of interest.

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