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A detailed analysis of electricity consumption at the University of Castilla-La Mancha (Spain)

Paula Bastida-Molina [a,*], Juan Torres-Navarro [b], Andrés Honrubia-Escribano [c], Inmaculada Gallego-Giner [d], Emilio Gómez-Lázaro [c]

[a] Institute for Energy Engineering, Universitat Politècnica de València, 46022 Valencia, Spain
[b] Institute for Industrial Development, Scientific Technological Park of Castilla – La Mancha, 2006 Albacete, Spain
[c] Renewable Energy Research Institute and Department of Electrical Engineering, Electronics, Automation and Communications, Universidad de Castilla-La Mancha, 02006 Albacete, Spain
[d] Department of Civil and Building Engineering, Universidad de Castilla-La Mancha, 13071 Ciudad Real, Spain

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ABSTRACT

The current energy crisis has drastically altered forecast electricity plans and budgets for European university campuses. This situation heightens the need to analyze their electrical consumption, with two main goals: identifying their patterns and promoting the development of renewable installations for these consumers. Previous research has focused only on aggregated demand data, with the studies being based on estimations and forecasts, and focused mainly on single buildings. Moreover, there is a lack of scientific papers that provide a replicable codebase for electricity analysis. Our work presents a novel methodology to overcome these research gaps, proposing the first comprehensive, replicable and scalable codebase to analyze electricity consumption in universities. It is based on three steps. The first comprises automated data collection of real electricity measurements at each electricity supply point. The second develops the complete analysis of electricity consumption. The last step parameterizes this consumption by identifying seasonal and daily profiles. The research was applied to the University of Castilla-La Mancha, campus Albacete (Spain) case study. The results revealed the 4 highest electricity-demanding buildings: Biomedical Complex, Higher Technical School of Industrial and Computer Engineering, Vicerectorate and Library, and Higher Technical School of Agricultural and Forestry Engineering. The results are thus of great value for other educational buildings.

1. Introduction

In recent years, causes including climate change, population growth and increased use of indoor thermal comfort equipment have led to a significant increase in buildings' electricity consumption [1]. Other major contributing factors to this rise in consumption are poor building envelopes and precarious energy conservation measures in public buildings or institutions [2]. Globally, around 20–45% of energy is demanded by buildings [3], which are considered to be the major energy-consuming sector [4], reaching energy demands even higher than those of industry and transport [5]. Considering cities exclusively, this number rises to 75% of total primary energy consumption and represents 39% of energy-related CO_2 emissions [6]. In the European Union, buildings accounted for 40% of total energy consumption and 30–36% of CO_2 emissions in 2020 [7,8].

This situation has heightened the need to analyze electricity consumption in buildings. The methods proposed in the literature review are general methodologies, and can thus be applied to any case study. However, the application to each different type of case study (residential, industrial or education) will provide diverse results and conclusions specific to each type of building. Data such as levels of load, contracted power, hours of use and schedules, among others, differ completely in residential, industrial or educational buildings. It is therefore essential to conduct an electricity analysis of each type of case study.

Although a broad range of research has tackled this issue over the last decade, most has focused only on residential buildings [9], for different reasons [10,11]. Firstly, users have direct and easy access to their electricity consumption data [12]. Secondly, residential electricity consumption profiles present multiple similarities in schedules, power peaks/valleys and accumulated values

* Corresponding author.
E-mail address: paubasmo@upv.es (P. Bastida-Molina).

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[13]. Finally, improvements in the electrical consumption of residential buildings generate direct economic benefits for residential customers' bills.

Nonetheless, the number of studies in electricity consumption for other types of buildings, i.e. industrial or educational, is much lower [14]. The latter (educational buildings), particularly, have been traditionally neglected despite their importance: Due to their mainly public use, improvements in electricity consumption did not have a direct economic impact on users, unlike private industries or residential customers [15]. Additionally, energy performance in such buildings depends on the institutions and public policies in question.

Regarding these educational buildings, the new global situation is increasing the need for the careful study of their electrical consumption. The current energy crisis, together with the exorbitant increase in electricity prices, has drastically altered forecast electricity plans and budgets for European university campuses, which represent nearly 50% of total building demand [16]. Thus, analyzing their electricity consumption has two main goals in addressing this issue. The first is to determine their current patterns and seek to improve them by reducing consumption or increasing electricity efficiency. The second is to enhance the development of renewable installations in university campuses in the near future, especially solar photovoltaic (PV) ones, for which the previous in-depth investigation of electricity consumption is essential [17].

Our exhaustive review of studies on electricity consumption analysis in university buildings revealed that many of them do not base their research on collected time data, but mainly focus on estimations and forecasts based on authentic parameters. For instance, Mendoza-Vela et al. estimated electricity demand areas and electricity consumption of air conditioning for one building at Salta National University (Argentina) according to electricity bill data [18]. Šoše et al. also based part of their research on electricity bill data to determine the accumulated monthly electricity consumption of the Faculty of Electrical Engineering in the University of Sarajevo [19]. However, this last research also collected real data on various loads over 8 months to show their daily load profiles. Following this trend, other studies also include the analysis of real electricity consumption data of single university buildings. Alam M. and Devjani M. R. also focused their study on just one building, at the University in Melbourne (Australia). In this case, they collected real power data, presenting the daily consumption profiles for each usage over one year with no analysis of accumulated electricity consumption [20].

As the above-mentioned studies reflected, most of the state of the art related to electricity consumption in universities is focused on just one building. However, higher educational institutions are usually composed of different buildings, grouped together on a university campus. Thus, having a global overview of the electricity consumption on the campus will enhance the achievement of the two main aims previously presented. Only a few studies have tackled this issue, including a general overview of the campus. Among them, Aguayo-Ulloa et al. analyzed accumulated hourly electricity consumption and annual use intensity considering the complete campus of the University of Bordeaux (France). However, the real datasets are not complete (between 3% and 43% of real data collected) and the analyzed buildings are clustered into three categories [21]. Gui et al. analyzed the data from each building on the campus of Griffith University (Australia), but with a low sampling period (weekly), presenting results for general annual and weekly electricity use intensity [22].

Our thorough analysis of the state of the art also revealed the incompleteness of the electricity consumption analysis in previous research, which is mainly focused on aggregated demand data with different scales (annual and monthly, mainly), presented directly as electricity energy consumption or use intensity results. Although such results present valuable information, they do not provide information on time of use patterns: peaks, valleys, base consumption, seasonality, etc. Such information is of utmost importance to fulfill the two energy goals described above: to determine current electricity profiles to improve them by reducing consumption or increasing electricity efficiency, and to enhance the development of renewable installations in university campuses in the near future.

Moreover, most of the previous studies directly presented the electricity analysis data and results, without providing the methodology used to be replicated by other researchers. For instance, Šoše et al. present the case study of the Faculty of Electrical Engineering (University of Sarajevo), and afterwards, the obtained outcomes [19]. The same happens for [18] or [21], which presented the results of the study cases of one building in Salta National University, and of the University of Bordeaux, respectively. Other studies presented equations specifically related to energy forecasting or probability, which provided valuable information but do not solve the real electricity analysis [22,23].

As a summary, Table 1 presents the main previous contributions on electricity consumption analysis for universities. As observed in the literature review, there is a lack of electricity consumption analysis in Spanish universities in general, while the previous contributions on European universities are also scant. None of them has provided a replicable codebase for electricity analysis.

Our paper presents a novel methodology to fill the previous research gaps and proposes a complete codebase to analyze electricity consumption, not only for universities but also replicable to any large company with several electricity supply points. The method is based on three clear steps: data collection, electricity consumption study and parametrization. The first involves automated data collection of real electricity measurements (real active and reactive power, together with electricity energy consumption) at each electricity supply point. The second develops the complete analysis of electricity consumption using energy indicators. Finally, the last step parameterizes this consumption by identifying seasonal and daily profiles. The proposed method becomes completely replicable and scalable to any case study for electricity consumption analysis, since the codebase is presented and the input variables/parameters eligible depending on the application.

The research was applied to the University of Castilla-La Mancha (UCLM) case study, specifically the campus located in Albacete, Spain (UCLM-AB) [24]. This institution is immersed in a profound energy transition towards a more energy-sustainable university, also supported by the recent Spanish financial regulation of new renewable installations [25]. This regulatory framework establishes financial funding for self-consumption and storage systems based on renewable resources in public institutions whose total annual self-consumed energy corresponds, at least, to 80% of the total produced annual energy [26]. Hence, for our selected case study, 16 electricity supply points of the UCLM-AB campus were analyzed, focusing mainly on the 4 buildings with the highest electricity demand. For this issue, real-time measurements of electricity energy consumption and real active and reactive power were collected over 1 year, with two different sampling periods: hourly and quarter-hourly.

The rest of the paper is organized as follows: section 2 presents the methodology proposed in this study, section 3 describes the case study, section 0 presents the results and discussion and, finally, our conclusions are outlined in section 6. Moreover, the whole codebase is provided in the Annex.

Table 1
Summary of the previous contributions focused on the analysis of electricity consumption in university buildings.

Reference	Year	Context	Codebase for electricity analysis	N° of analyzed buildings	Data collection period	Sampling period	Type of electricity consumption analysis	Pattern analysis
[4]	2020	University campus - Politecnico of Milano University (Italy)	Briefly described with Excel spreadsheet screenshots	2	2 years	1 h	Annual electricity power profiles, Monthly electricity use intensity	No
[21]	2018	University campus - University of Bordeaux (France)	Not provided	Three categories: teaching, research and administrative.	3 years. Datasets are not complete, varying between 3% and 43%	–	Annual electricity use intensity, Accumulated hourly electricity consumption per category.	No
[22]	2020	University campus - Griffith University (Australia)	Statistical model for the study of energy use, but electricity analysis codebase not provided.	122	2 years	Weekly	Annual and weekly electricity use intensity.	No
[27]	2019	University building - A general Higher Educational Environment (England)	Not provided	1	2 years. Only unregulated electricity consumption data are collected, i.e., server rooms, small power loads. . .	–	Annual electricity use intensity Accumulated monthly electricity consumption.	No
[18]	2021	University building - Salta National University (Argentina)	Not provided	1	Electricity bill data, over 6 years.		Estimation of electricity demand areas and electricity consumption for air conditioning	No
[23]	2018	University campus - From Anhui Province (China)	Multi-linear regression model for the study of energy use, but electricity analysis codebase not provided.	13	– Total electricity consumption and sub-entry electricity consumption data were collected. The length and the sample period are not detailed.	–	Normalized electricity use intensity	No
[19]	2019	University building – University of Sarajevo	Not provided	1	Electricity bill data, over 3 years. 8 months Not all loads	 15 min	Accumulated monthly electricity consumption. Daily load profiles. Monthly power peak (maximum and minimum).	No
[28]	2021	University dormitories – a Chinese university	Not provided	1	1 year	–	Daily electricity consumption.	Clusters related to daily electricity consumption.
[20]	2021	University building – a University in Melbourne (Australia)	Clustering equations, but electricity analysis codebase not provided.	1	1 year	5 min	No	Daily electricity consumption profile for each usage.
Our study	2022	University campus – University of Castilla-La Mancha, campus Albacete (Spain)	Completely described and provided	16, focused on 4	1 year	Hourly and quarter hourly	For each building: Annual and monthly electricity consumption. Monthly electricity use intensity. Hourly detailed electricity consumption per day and along the year.	Identification of detailed seasonal and daily electricity consumption patterns.

2. Methodology

The present study proposes a complete codebase to analyze electricity consumption in universities. It is based on three clear steps: data collection, electricity consumption study and parametrization. The first involves automated data collection of real electricity measurements (real active and reactive power, together with electricity energy consumption) at each electricity supply point. The second develops the complete analysis of electricity consumption by means of energy indicators. Finally, the last step parameterizes this consumption by identifying seasonal and daily profiles.

The proposed method becomes completely replicable and scalable to any case study for electricity consumption analysis, since the codebase is presented and the input variables/parameters eligible depending on the application.

In this section, we describe the three stages that compose this methodology (2.1 to 2.3). Moreover, the codebase, which has been developed in Phyton software, is described in detail in subsection 2.4. This code is completely provided in the Annex.

2.1. Data collection

The electricity data collection comprised the first stage of the study, the main features of which are detailed as follows:

1. Real-time electricity consumption data for the entire UCLM-AB were collected for the period between January 2021 and December 2021, inclusive.
2. Electricity measurements corresponded to real active and reactive power, together with electricity energy consumption.
3. The above-mentioned measurements were taken at each electricity supply point of UCLM-AB, making a total of 16. Powerful data meters were installed at each point of supply for this issue.
4. Data were collected over the whole year of 2021, with two different sampling periods: hourly and quarter-hourly.
5. Data were stored in an online platform and subsequently processed with Python, as described in subsection 2.4.

The last row of Table 1 ("Our study") summarizes the characteristic of the data collection for our research.

2.2. Electricity consumption indicators

The second stage of the method corresponds to the analysis electricity database for the complete year. To this end, different electricity indicators were developed.

3. Electricity consumption

On the one hand, annual electricity consumption (E_a) quantifies the complete electricity consumption over the year and location in question, as equation (1) indicates:

$$E_a = \sum_{d=1}^{d=365} \sum_{h=1}^{h=24} P_{hd} \cdot t \tag{1}$$

where P_{hd} represents the active power consumption at each hour (h) of the day (d) across the year under study, whereas t corresponds to the sampling period.

On the other hand, monthly electricity consumption (E_m) focuses on the electricity consumption that takes place in a specific month of the location under review, as equation (2) reflects:

$$E_m = \sum_{d=1}^{d=m} \sum_{h=1}^{h=24} P_{hd} \cdot t \tag{2}$$

Being m the number of days of the month under study, specifically: 28 or 29 for February, and 30 or 31 for the other months.

4. Electricity use intensity

The electricity use intensity indicator relates the electricity consumption of the location in question to its surface area. Equation (3) reflects this indicator, on a monthly basis (UI_m):

$$UI_m = \frac{\sum_{d=1}^{d=m} \sum_{h=1}^{h=24} P_{hd} \cdot t}{A} \tag{3}$$

where A corresponds to the net surface area of the building in question.

4.1. Electricity parametrization

The last stage of the method parameterizes this consumption by identifying seasonal and daily profiles.

4.1.1. Seasonal electricity patterns

The method aims to identify possible seasonal electricity patterns across the entire period of study. For this research the period corresponds to one year, according to the year database collected (section 0). The loop algorithm in equation (4) can be applied to the electricity consumption year database and identifies such patterns according to hourly electrical energy differences and the maximum stablished tolerance:

$$\frac{\left|\sum_{d=1}^{d=365} \sum_{h=1}^{h=24} \left(E_{hd} - E_{h(d+1)}\right)\right|}{E_{hd}} \leq x \tag{4}$$

Being E_{hd} the electricity consumption at hour h for day d, and x the tolerance factor.

4.1.2. Daily electricity patterns

Once seasonal electricity patterns are identified, the method also allows daily electricity patterns to be identified. For the electricity consumption data of each seasonal pattern, algorithm of equation (5) is applied:

$$\frac{\left|\sum_{d=1}^{d=s} \sum_{h=1}^{h=24} \left(E_{hd} - E_{h(d+1)}\right)\right|}{E_{hd}} \leq y \tag{5}$$

Being s the specific number of days for each seasonal pattern, whereas y represents the corresponding tolerance factor.

4.2. Codebase

The electricity consumption data is provided monthly as csv files. Depending on the month, the data can be clustered in a single file or separated into different files according to the CUPS (Universal Supply Point Code). In both cases exist, at least, the following columns: CUPS, date, hour, AE, R1, R2, R3 and R4, where CUPS represent the code of the supply point, date comprises the day, month and year of the reading, hour stores the hour and minute of the reading, AE represents the active power and R1-R4 are readings of the reactive power. Additionally, an excel sheet is archived with the columns: Campus, Location, CUPS and Area, where Campus is a 2-letter code that represents the campus which the building belongs to, Location represents the building name where the CUPS is located, CUPS is the supply point and Area is the area that encompasses the building.

The processing of the data has been undertaken using Python and several publicly available libraries: pandas, openpyxl, meteostat and matplotlib. The library pandas is a data analysis and manipulation tool [29]. It allows to create in-memory datasets and execute batch operations in all data (or subsets of them) at once. This data can be created by code, read from files or requested from The Internet. The use of openpyxl [30] is needed to endow python with the ability of interacting with excel sheets. In our program, this library is utilized to make pandas able to read the excel sheet where the information of CUPS, buildings' names and areas are stored in. In-code access to weather data is achieved through meteostat [31] library. Lastly, matplotlib [32] is the visualization tool selected to represent the data.

The software has been developed using Object-Oriented Programming (OOP), emphasizing the scalability of the project to be extensible to the data provided by any marketer or institution. The UML (Unified Modeling Language) class diagram is shown in Fig. 1, where black arrows indicate dependency relationships,

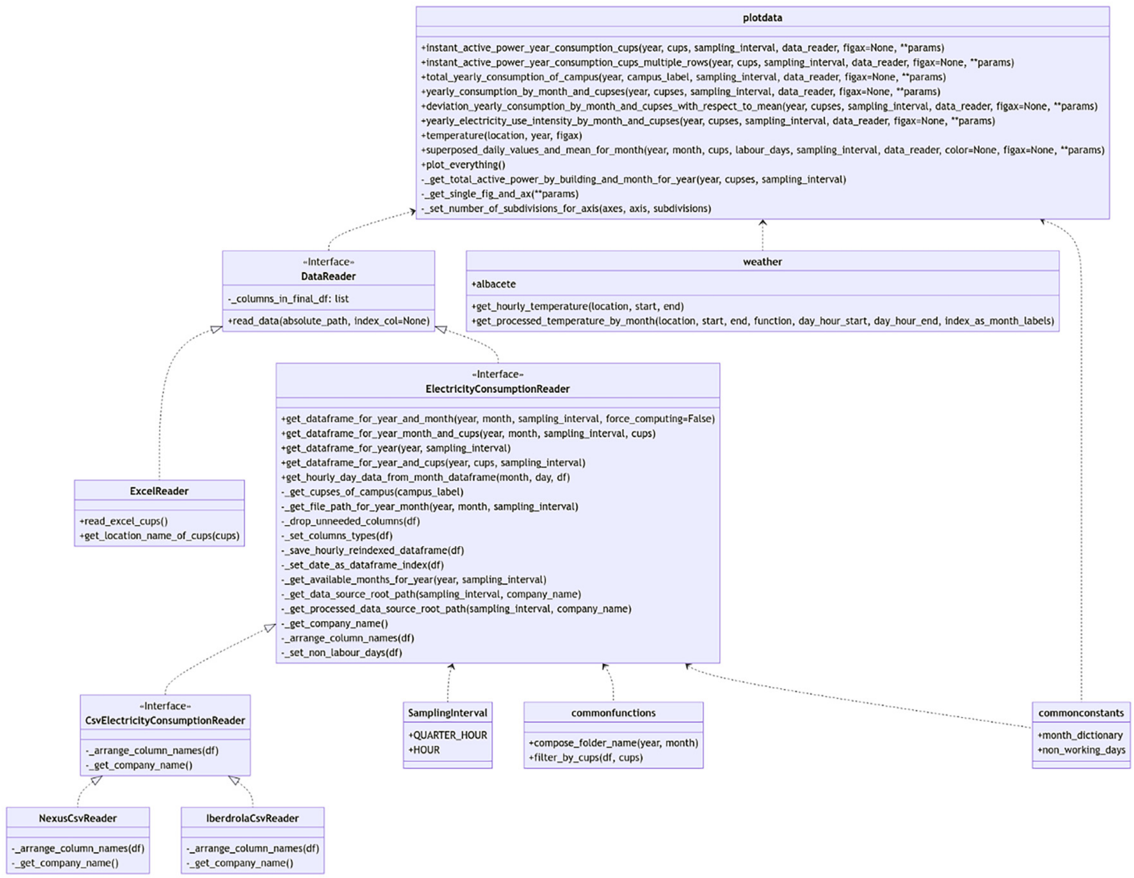


Fig. 1. Class diagram of the developed codebase.

while white arrows represent interface realization relationships. Moreover, the different insights of the code and its extension are presented after Fig. 1.

Probably the most important class is the interface DataReader, which is designed to have one attribute to specify the columns that will be present in the final dataset (_columns_in_final_df), and the method read_data, responsible for providing the dataset whose data is going to be analyzed. Two different classes implement the DataReader interface: ExcelReader and ElectricityConsumptionReader. ExcelReader, as its name suggests, is the class used to read all the information regarding the previously described excel sheet. In contrast, ElectricityConsumptionReader is another interface designed to be extensible to read any kind of format in which the data is provided. This interface does implement a great percentage of its defined methods, since their behavior will be exactly the same even in the case when the data sources have different formats. The public methods of ElectricityConsumptionReader are those that return the dataset that is wanted to be retrieved at any time, whereas the private methods take care of the consistency of the data, time optimizations when reading data and performing file system operations. This interface has 3 dependencies: commonconstants, SamplingInterval and commonfunctions. The classes commonconstants and commonfunctions are two modules that store useful information and functionality that are needed in different sections of the codebase. It has been decided to be implemented in this manner to keep the code DRY (Don't Repeat Yourself). Meanwhile, SamplingInterval is an enumeration to specify what type of resolution is desired to be used to read the data: hourly or quarter hourly. This is due to the fact that the data are stored in different files located in different directories depending on their resolution. Apart from these 3 dependencies, ElectricityConsumptionReader is implemented by another interface called CsvElectricityConsumptionReader. This interface takes the responsibility of reading data that comes in csv format. To finish with the reading data section, NexusCsvReader and IberdrolaCsvReader are classes that implement CsvElectricityConsumptionReader. They specialize the functionality of their parent classes to read the csv files that provides "Nexus Energía" and "Iberdrola", our electricity marketer and DSO (distribution system operator), respectively. Extending CsvElectricityConsumptionReader or ElectricityConsumptionReader is the way to endow the software with the ability to read any file containing data to analyze. Lastly, the classes weather and plotdata allow to retrieve weather information, and plot the read data, respectively.

5. Case study: University of Castilla-La Mancha, campus Albacete

The UCLM is a Spanish public university, founded in 1982. It comprises four main campuses located in different cities in the Spanish Region of Castilla-La Mancha (Albacete, Ciudad Real, Cuenca and Toledo), as well as two other satellite campuses in Almadén and Talavera de la Reina [24].

The UCLM is currently immersed in a profound transition towards a more energy- sustainable university. This plan, led by the Vice Rectorate of Sustainability and Infrastructures, started at the beginning of 2021 with a clear aim: to monitor and supervise the detailed electricity consumption of each building on each campus, in order to analyze electricity efficiency and evaluate the possibility of including solar PV generation in the most suitable buildings on each campus. This aim is in line with the new Spanish financial regulation to enhance the development of renewable installations [25].

The Albacete campus of the UCLM (UCLM-AB) was selected as a case study for this research, since it is the university's largest. It is also highly representative of the Spanish University system, since:

- It offers the three possible levels of university studies in Spain: BSc, MSc and PhD studies.
- It offers studies in four different disciplines: arts and humanities, pure sciences, health sciences, social and legal sciences, and engineering and architecture. Moreover, the campus includes 11 educational centers at which these disciplines are taught:
  - o Faculty of Economics and Business Administration.
  - o Faculty of Law.
  - o Faculty of Labor Relations and Human Resources.
  - o Faculty of Education.
  - o Higher Technical School of Industrial Engineering.
  - o Higher School of Computer Engineering.
  - o Higher Technical School of Agricultural and Forestry Engineering.
  - o Faculty of Nursing.
  - o Faculty of Humanities.
  - o Faculty of Pharmacy.
  - o Faculty of Medicine.
- The number of students enrolled for the 2021/2022 academic year was 7559, of whom 6155 were BSc students, 423 were MSc students and 981 were engaged in PhD studies.
- The number of teaching staff in the 2021/2022 academic year was 737.
- The number of administration and services staff during this course 2021/2022 was 337.

Moreover, this campus includes high electricity-demanding laboratories and research centers, where technical and scientific degrees are studied (they have high electricity needs due to the equipment used).

Fig. 2 shows all the buildings of UCLM-AB:

5.1. Buildings with highest annual electricity demand

A first approach to the electrical demand of UCLM-AB (Eq. (1)) revealed the annual electricity consumption for each supply point on the campus during 2021, as presented in Fig. 3. The buildings in the first quartile with the highest electrical demand include the Biomedical Complex, and the Infante Don Juan Manuel, José Prat and Manuel Alonso Peña buildings. Hence, these centres were selected for our case study research. The annual electricity consumption of the Biomedical Complex (Fig. 3) stands out greatly from the others, representing 41% of the entire UCLM-AB electricity consumption in 2021, which accounts for around 12% of the whole UCLM electricity consumption.

In order to give more context to the buildings chosen for our case study, the details of each one are described in the following subsections (3.1.1 to 3.1.4).

5.1.1. Biomedical Complex

The Biomedical Complex is an enormous facility focused on medical science education and research. It includes two educational institutions and three research centers. The Medical school [33] and the Faculty of Pharmacy [34] are the educational institutions comprising the Biomedical Complex, while the Biomedical Research Centre (CRIB, in its Spanish acronym) [35], the Animal Laboratory [36] and the Spin-off Incubator [37] conform the research centers. Moreover, it has a total surface area of 25,875 m^2, with the above-mentioned buildings being built in 2003, 2017, 2006, 2006 and 2014, respectively.

Regarding the educational buildings, the BSc Degree in Medicine and BSc Degree in Pharmacy are taught in each faculty. Both institutions stand out due to their powerful laboratories, with cutting-edge medical equipment and cold rooms for medical experiments and corpse conservation that have a high electricity demand [33,34].

In line with their educational use, attendance of students and professors follows the Academic Calendar of UCLM-AB. In general terms, the academic year begins at the start of September and finishes at the end of July. Over this period, lectures take place on morning or afternoon schedules, from 8 to 14 and from 15 to 21 approximately. Ordinary session exams are held in January and June, while extra session exams are sat in July. August is the holiday month for both students and professors. Moreover, during Christmas and Easter holidays, the building also remains closed.

With respect to research centers, their laboratories again include powerful equipment related to in-vitro and in-vivo studies, spectroscopy, proteomics or biotechnology units [35–37]. The Animal Laboratory stands out from the others: it needs to maintain optimal temperature and humidity conditions 24 h a day over the whole year, which leads to extremely high electricity consumption. Investigators from these research centers do not wholly follow the academic calendar. Although their main work activity does, experiments or project deadlines mean researchers attend these centers on more days to follow experiments.

Finally, air conditioning in the entire Biomedical Complex depends on gas boilers and electric air conditioning units. In general terms, gas boilers are used mainly during the cold season, while electric air conditioning units operate during the warm ones. Only the Faculty of Pharmacy runs electric air conditioning systems for both uses.

Table 2 summarizes the constructional features, together with the main equipment used for the adequate environmental conditions of each building in the Biomedical Complex.

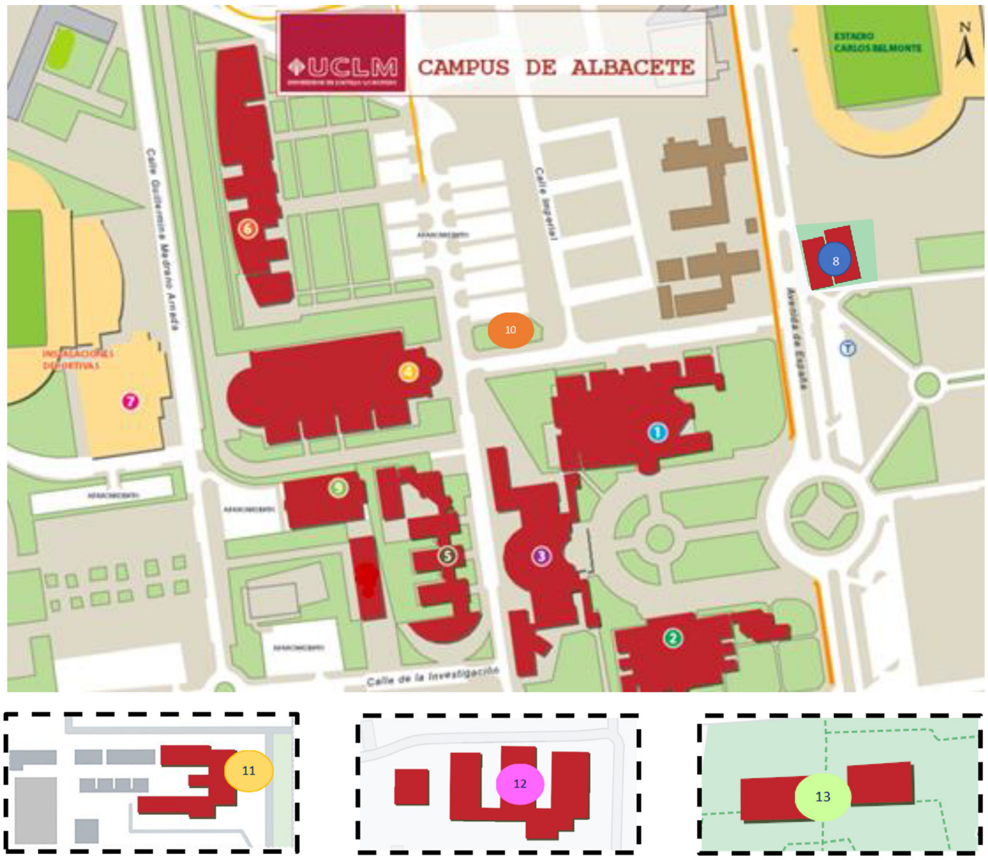
5.1.2. Infante Don Juan Manuel

The Infante Don Juan Manuel building is an educational building, which encompasses both the Higher Technical School of Industrial Engineers [38], and the Higher School of Computer Engineering of UCLM-AB [39], where the following degrees are taught: BSc Degree in Mechanical Engineering, BSc Degree in Industrial Electronics and Automatics Engineering, BSc Degree in Electrical Engineering, BSc Degree in Computer Science and MSc Degree in Industrial Engineering. It was built in 1990 and has a total surface area of 15,798 m^2.

The different rooms and services of this building, which includes also a bar-restaurant are detailed in Table 3. Due to the technical and computer degree courses taught in the Infante Don Juan Manuel, the building houses cutting-edge technological equipment, together with 2 data center rooms. The computer equipment and refrigeration systems of these data centers remain on 24 h a day across the whole year.

Since it is an educational building, the attendance of students and professors follows the same trend as that explained before for the educational buildings in the Biomedical Complex (3.1.1).

Furthermore, the air conditioning in the Infante Don Juan Manuel also depends on gas boilers and electric air conditioning units. In general terms, gas boilers are mainly used during the cold season, while electric air conditioning units run during the warm ones. Table 3 summarizes the main equipment used for the adequate environmental conditions of the building.



B1. Melchor de Macanaz
Faculty of Economics and Business Administration
Faculty of Law
Faculty of Labor Relations and Human Resources.

B2. Simón Abril
Faculty of Education

B3. José Prat
Offices of the Vice-Rectorate
Library
Students unit

B4. Infante Don Juan Manuel
Higher Technical School of Industrial Engineers
Higher School of Computer Engineering.

B5. Manuel Alonso Peña
Higher Technical School of Agricultural and Forestry Engineering

B6. Benjamín Palencia
Faculty of Nursing
Faculty of Humanities

B7. Sports Hall 1

B8. Sports Hall 2

B9. Regional Development Institute

B10. Multipurpose University Building
BSc in Biotechnology
Academic Management
Center for Information and Promotion of Employment
International Relations Office
Sports and University Extension.

B11. Biomedical Complex
Faculty of Medicine
Faculty of Pharmacy
Biomedical Research Centre
Animal Laboratory
Spin-off Incubator

B12. Francisco Jareño y Alarcón
Higher Technical School of Agricultural and Forestry Engineering

B13. Botanical Garden Research Institute

B14. Warehouse Aguas Nuevas

Fig. 2. Buildings of UCLM-AB.

5.1.3. José Prat

The José Prat is an administrative building, which encompasses the library, auditorium and Vice-rectorate offices of the university, together with a refectory. It was built in 1992 and has a total surface area of 9393 m^2.

Table 4 reflects the infrastructure of this building.

Due to its administrative use, employees are at the building not only on teaching days, but also on other days to work on administrative processes. For instance, during the first and last weeks of August, a quarter of the staff are working in the offices of the Vice-rectorate, and during exam months (January, June and July), the library remains open at the weekends. Regarding daily opening hours, the staff schedule at the Vice-rectorate offices is from 8 to 15 h. The library schedule, however, reproduces that of the educational buildings in order to provide for students. Finally, the greatest occupation at the refectory is at midday for lunch.

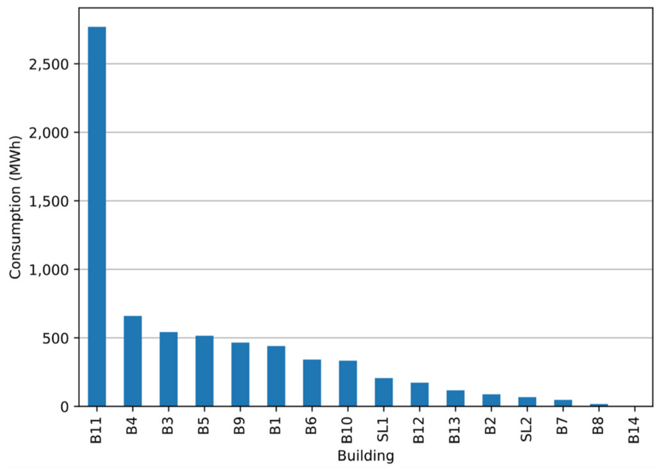


Fig. 3. Annual electricity consumption for each UCLM-AB electricity supply point. *SL1 and SL2: Street lighting 1 and 2.*

Table 2
Constructional features and equipment for adequate environmental conditions of the Biomedical Complex.

Building	Year of construction	Surface area (m^2)	Use
Medical School	2003	15618 m^2	Educational
Faculty of Pharmacy	2017	6231 m^2	Educational
Biomedical Research Center	2006	1256 m^2	Research
Animal Laboratory	2006	1125 m^2	Research
Spin-off Incubator	2014	1645 m^2	Research
Infrastructure			
2 educational buildings with 14 classrooms, 2 computer classrooms, 20 seminar rooms, 1 multimedia room, 5 assembly halls, 40 laboratories, 2 videoconference rooms, 3 cold rooms, 1 library. Research buildings with: 1 cold room, 30 laboratories, 1 instrumentation room, 2 analysis rooms, 1 reagent warehouses, 4 material warehouses, 3 general warehouses, 2 animal feed warehouse, 8 offices, 12 animal holding cells, 1 animal quarantine cell, 2 animal operating rooms + 1 surgery preparation room, 1 animal morgue, 10 stables, 1 washing area, 12 changing rooms.			
Equipment for environmental conditions adequacy			
2 condensed water coolers, 3 steel plate boilers with gas burner, 11 water circulation pumps, 76 air conditioners for air treatment, 124 horizontal fan coils without enclosure, 15 heat pumps, 4 corpse preservation chambers, 1 freezing chamber, 1 extraction system, 12 outdoor units with heat recovery, 25 ducted indoor units, 1 exhaust system, 2 water chiller, 3 humidifiers, 1 steam boiler, 1 volumetric water softener, 1 VRV unit, 19 ceiling fan coils, 9 splits, 5 in-line extractors, 1 indoor unit, 99 indoor duct pressure units, 8 main controllers, 4 secondary controllers, 6 recovery units.			

Furthermore, the air conditioning in the José Prat relies on gas boilers and electric air conditioning units. In general terms, the gas boilers are mainly used during the cold season, while the electric air conditioning units run during the warm ones. Only the refectory uses electric air conditioning machinery for both periods. Table 4 summarizes the main equipment used for the adequate environmental conditions of the building.

5.1.4. Manuel Alonso Peña

The Manuel Alonso Peña building is an educational building, which includes the Higher Technical School of Agricultural and Forestry Engineering of UCLM-AB, in which 5 different bachelor and master's degrees are taught: BSc Degree in Agricultural and Agri-food Engineering, BSc Degree in Forestry and Environmental Engineering, BSc Degree in Biotechnology, MSc Degree in Agronomic Engineering and MSc Degree in Forestry Engineering. It was built in 1993 and has a total surface area of 7871 m^2.

Table 3
Constructional features and equipment for adequate environmental conditions adequacy of the Infante Don Juan Manuel building.

Year of construction	Surface area (m^2)	Use
1990	1598 m^2	Educational
Infrastructure		
31 classrooms, 10 computer engineering laboratories, 17 industrial engineering laboratories, 1 computer room, 1 study room, 1 meeting room, 1 students' delegation service, 2 data centers, 1 reprography service, 151 offices, 1 bar-restaurant.		
Equipment for environmental conditions adequacy		
21 cassette heat pumps, 4 split heat pumps, 2 condensed water coolers, 77 floor fan coils with enclosure, 5 water circulation pumps, 22 single split conditioning units, 26 multiple split conditioning devices, 60 ceiling fan coils without enclosure, 2 autonomous precision units with ducted unit to false ceiling equipped with humidifier + telephone pager, 4 outdoor units heat pump-VRV system, 30 cassette-type indoor units, 1 air conditioner, Cast-iron radiators + black welded steel pipe network.		

Table 4
Constructional features and equipment for adequate environmental conditions of the José Prat.

Year of construction	Surface area (m^2)	Behavior
1992	9393 m^2	Administrative
Infrastructure		
2 study rooms with 890 study places, 1 reading room, 1 social council room, 1 newspaper library, 1 videoconference room, 1 book archive, 6 book storage units, 1 International PhD School, 81 offices, 1 refectory.		
Equipment for environmental conditions adequacy		
3 heat pumps, 2 condensed water chillers, 1 stand-alone gas boiler, 3 water circulation pumps, 1 gas leak detection device, 6 motor pump units, 2 rooftop air conditioners, 1 cassette console type split conditioning unit, 16 air treatment conditioners, 119 floor fan coils with enclosure, 1 ceiling fan coil without enclosure, 6 ducted fan coils, 8 cassette fan coils, 8 split conditioning units, 2 centrifugal extractors, 1 ventilation box, 1 plate heat exchanger for fan coil circuit.		

The different rooms and services of this building are detailed in Table 5. It can be observed that the Manuel Alonso Peña presents a low teaching capacity, with only 10 classrooms. However, the bachelor's and master's degrees of this Technical School are focused on scientific research, which means that a significant number of laboratories are included.

The presence of students and professors at the Manuel Alonso Peña is the same as that at the Infante Don Juan Manuel's (subsection 3.1.2), since both buildings are used for educational purposes and their schedules follow the Academic Calendar of UCLM-AB.

Finally, the air conditioning in the Manuel Alonso Peña relies only on electric air conditioning units, which are thus used during both cold and warm seasons. Table 5 reflects the main equipment used for the adequate environmental conditions of this building.

6. Results and discussion

This section presents the results of applying the above-described methodology on the UCLM-AB campus, specifically to the four buildings with the highest electricity demand: the Biomedical Complex and the Infante Don Juan Manuel, José Prat, and Manuel Alonso Peña buildings.

6.1. Monthly electricity consumption

Fig. 4 represents the electricity consumption per month in each of the four UCLM-AB buildings with the highest electrical demand during 2021, as described in subsection 3.1. Furthermore, Fig. 5

Table 5
Constructional features and equipment for adequate environmental conditions of the Manuel Alonso Peña.

Year of construction	Surface (m^2)	Use
1993	7871 m^2	Educational
Infrastructure		
15 classrooms, 20 technical laboratories, 2 computer rooms, 3 meeting rooms, 1 assembly hall, 69 offices.		
Equipment for environmental conditions adequacy		
17 single split conditioning units - heat pump, 1 single split conditioning equipment wall console, 4 multiple split conditioning units 2x1-wall console type, 23 outdoors units-VRV system, 81 indoor units (ducts)-VRV system, 54 indoor units (cassette)-VRV system, 96 individual remote control, 4 ventilation and energy recovery units and 1 central management system.		

presents the monthly deviation from the annual average electricity consumption for each of these four buildings, while Fig. 6 shows the temperature data in Albacete during 2021.

Firstly, the Biomedical Complex stands out from the rest due to its high electricity consumption, with average differences of 220,000 kWh per month compared to the other buildings. The main reason for this absolute difference lies in its extension (25875 m^2 with 5 different buildings, as detailed in subsection 2.4.1) and the high electricity demand needs of some of these buildings. Specifically, the animal laboratory refrigeration units and the freezing conservation chambers remain on over the entire year, which leads to an exceptional base consumption in the complex. Moreover, the air conditioning in the Biomedical Complex depends on gas boilers and electric air conditioning units. In general terms, the gas boilers are used mainly during cold season, while the electric air conditioning units run during the warm ones.

Thus, some seasonal trends could be observed in this complex, also affected by the heterogeneous uses of the complex: students attend classes in the Medicine School and Faculty of Pharmacy faculties during the academic year, while staff from the spin-off companies and scientists from the CRIB also work through July and part of August, as explained in subsection 3.1.1.

The highest electricity consumption occurs in July (303795 kWh). This month is the working one with the highest temperatures in Albacete (38 °C was reached in 2021), as Fig. 6 reflects, thus generating significant cooling needs. June also presents high temperatures, albeit not such extreme ones as in July. August, meanwhile, is the standard holiday month, so low consumption data would be expected. However, during this month, consumption was 220,425 kWh, which represents a decrease of only 2% compared to the average values of this month. The trend reflects

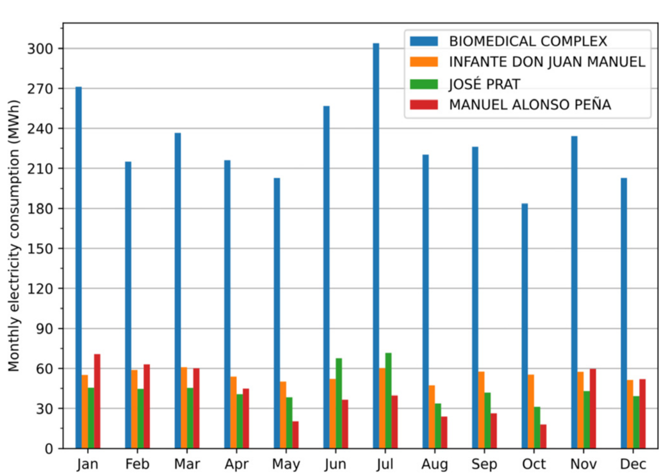


Fig. 4. Monthly electricity consumption.

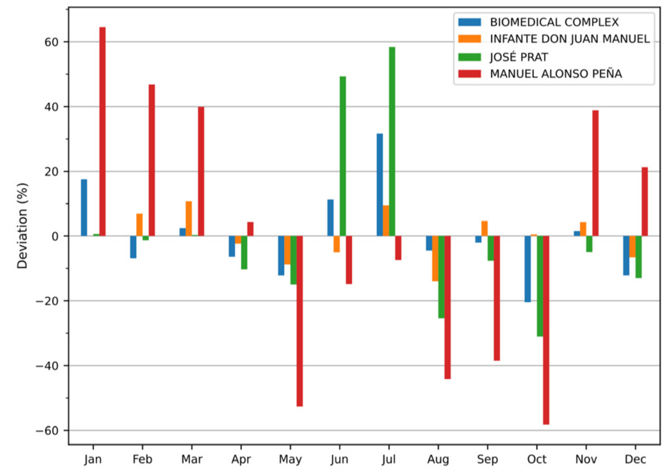


Fig. 5. Monthly deviation from the annual average electricity consumption.

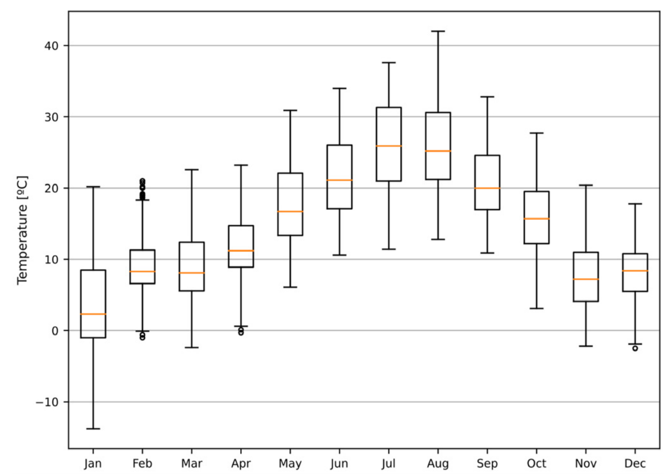


Fig. 6. Temperatures in Albacete, 2021.

the previously described behavior of the building, since cold air conditioning for the warm season depends only on electric units and staff from the spin-off companies and scientists from CRIB also work during part of August.

The cold months (November, December, January and, February, average 230,884 kWh) present, on average, lower values than those in hot working months (June and July, average 280,321 kWh), which is motivated by air conditioning usage. January stands out from the other cold months, since consumption increases by 17.52% compared to the annual average values for two reasons: it is the coldest month of the year (Fig. 6, −15° was reached in 2021), and, despite gas boilers being the main conditioning mode for this building, the Faculty of Pharmacy depends only on electric units and extra electric units are also used in the Medical School. Moreover, staff and students return from Christmas holidays and exams take place in both faculties.

Regarding the educational buildings, the Infante Don Juan Manuel and Manuel Alonso Peña present remarkable electricity trends despite their educational functions.

Firstly, the Infante Don Juan Manuel stands out due to its homogenous annual electricity consumption (13.96 % maximum deviation compared to annual average values, Fig. 5). This trend corresponds to two remarkable base loads, which remain on 24 h a day during the whole year: the bar-restaurant's freezers and fridges and the 2 Data Center Rooms with computer services, as described in subsection 3.1.2.

Moreover, the air conditioning and the educational function of the building also contribute to its homogeneous consumption. On the one hand, the air conditioning in the Infante Don Juan Manuel depends on gas boilers and electric air conditioning units. In general terms, gas boilers are mainly used during cold season, while electric air conditioning units run during the warm ones. On the other hand, students and staff are present in the building following the academic calendar presented in subsection 3.1.2. Hence, both features lead to the homogenous electricity consumption of the building: refrigeration needs during the cold months are covered with gas boilers and, hence, no remarkable electricity consumption increases are detected in these months. Cooling during summer months is covered by using air conditioning units. However, only July increases electricity consumption with respect to the average values by 9.52 % (higher attendance due to the exam period, Fig. 5), while August presents the highest electricity (13.92%) decrease since it is the holiday month for both professors and students.

In contrast, the Manuel Alonso Peña presents high monthly variations in electricity consumption over the year. Unlike the Infante Don Juan Manuel, the air conditioning in the Manuel Alonso Peña depends only on electric air conditioning units, and so are used during both cold and warm seasons. In line with the climatology of Albacete and the academic calendar, the highest electricity demand occurs during the winter months, especially in January (70713 kWh, which represents a 64.52 % increase with respect to the average values, (Fig. 4 and Fig. 5) when exams take place and extreme low temperatures are reached (up to −15 °C in 2021, Fig. 6). The lowest consumption values are in the mild months, such as May or October, when no air conditioning is needed. During the summer months, electricity consumption increases again, due to cooling needs. July is the hottest working month, but consumption does not increase excessively in this month because student attendance is low: only some extra session exams take place. In this regard, the August data may initially seem surprising. Despite being the holiday month, the electricity demand data during this month (24012 kWh) was similar to that of September 2021 (26451 kWh), a working month. This high consumption during August 2021 corresponded to the rental of Manuel Alonso Peña during this month to a medical academy.

Finally, the air conditioning in the José Prat building depends on gas boilers and electric air conditioning units. In general terms, gas boilers are used during the cold season, while electric air conditioning units run during the warm ones. This situation leads to an increase in electricity consumption during the summer months, as explained before for the Biomedical Complex and the Infante Don Juan Manuel building. Unlike these buildings, the function of the José Prat is administrative, and so working summer months do not experience a decrease in occupation because the administrative staff continue doing their jobs during working hours. Furthermore, the library opening hours are extended during June and July due to exams. Both situations lead to the highest electricity demand in these months (67540 kWh and 71,637 kWh, respectively, Fig. 4), which increases up to 49.31% and 58.37% (Fig. 5), respectively, compared to the annual average values. August is the summer month with the lowest data due to it being a holiday month. It does not, however, present the lowest annual figures (for instance, 31,181 kWh was consumed in October compared to 33,736 kWh in August 2021). In this month, some staff from the library and the administrative building continued working to maintain bureaucratic procedures.

6.2. Monthly electricity use intensity

Fig. 7 represents the monthly electricity use intensity of each UCLM-AB building analyzed. The Biomedical Complex stands out from the other buildings again, since it presents the highest electricity use intensity over the year, as described in 4.1 (the animal laboratory refrigeration units, and the cold rooms remain on during the whole year).

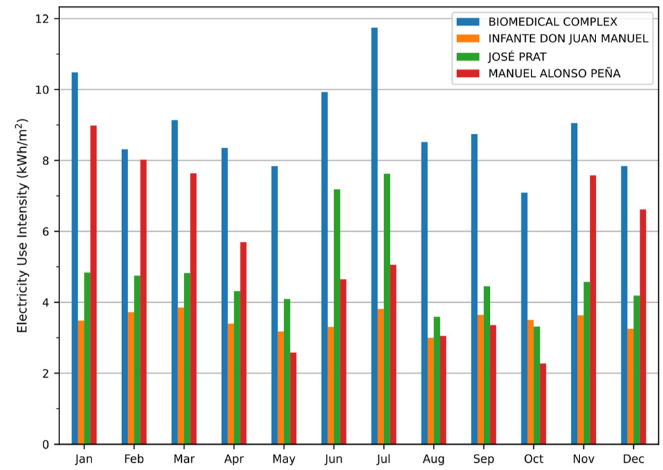


Fig. 7. Monthly electricity use intensity.

During the cold months, the Manuel Alonso Peña building shows the second highest data for electricity use intensity. This building is the only one that completely uses electric air conditioning units during the cold season, which leads to a notable electricity use during these months. For instance, in February its electricity use intensity values are almost the same as those of the Biomedical Complex (8.31 kWh/m^2 and 8.02 kWh/m^2, respectively).

However, during the summer, the José Prat building presents the second electricity use intensity (after the Biomedical Complex). This situation derives from the administrative function of this building; whereas the occupation of educational buildings decreases during the summer working months, that of the administrative staff remains constant, and the library hours increase due to exams. During August, this increase is not so notable, since some administrative staff continue to work in the José Prat, but the Manuel Alonso Peña is used by students from a medical academy, and the Infante Don Juan Manuel has the load base generated by the 2 data center rooms and the freezers and fridges of the bar, and, hence, the rates of electricity use intensity show similar values (3.59 kWh/m^2, 3.05 kWh/m^2 and 3.00 kWh/m^2, respectively).

6.3. Electricity patterns

This section presents the seasonal and daily patterns identified for the four selected buildings in our UCLM-AB case study.

Fig. 8 and Fig. 9 represent the hourly electricity consumption over the complete year of 2021 in the four selected buildings of UCLM.

Firstly, Figs. 11 and 12 clearly reflect the constant annual base load of each building. On the one hand, the José Prat and Manuel Alonso Peña buildings present a low base demand (15 kWh approx.), caused mainly by stand-by loads and similar. On the other hand, the Biomedical Complex and the Infante Don Juan Manuel present a substantial base demand, quantified at around 30% of their total average electrical consumptions: 200 kWh and 60 kWh, respectively. For the Biomedical Complex, this load demand corresponds to the animal laboratory refrigeration units and the cold rooms, which remain on 24 h a day over the whole year. For the Infante Don Juan Manuel building, the base demand corresponds mainly to the 2 data center rooms with computer services and the bar's freezers and fridges, which also remain on 24 h a day over the whole year.

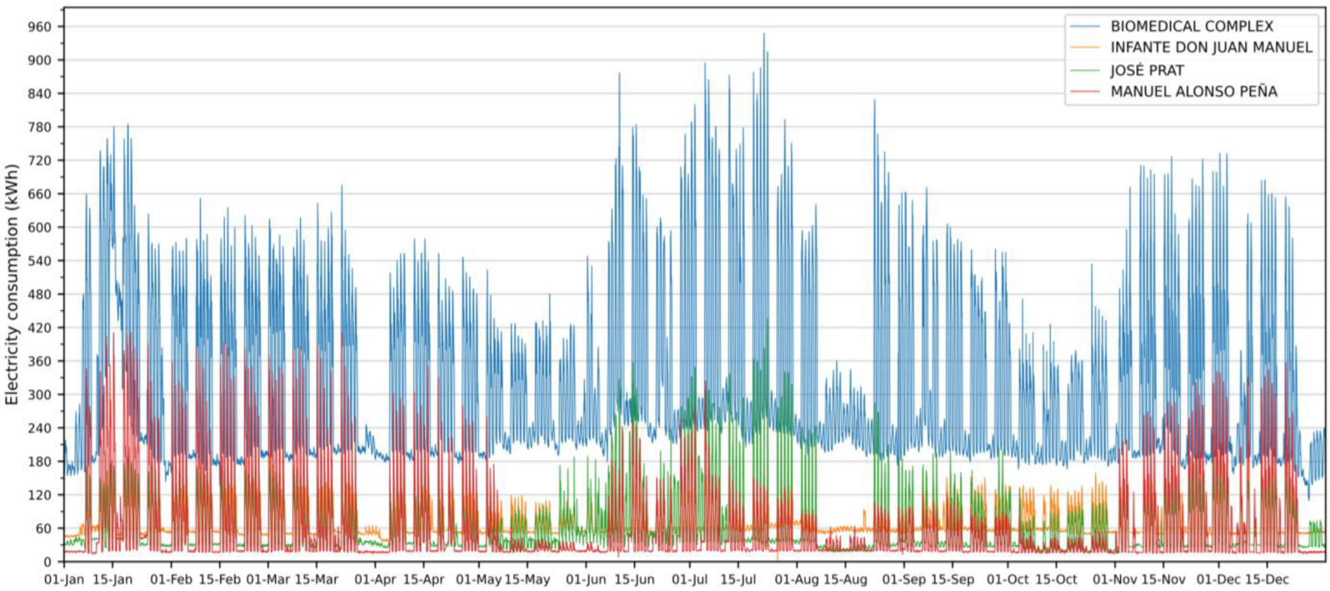


Fig. 8. Hourly electricity consumption over the complete year of 2021 for the selected buildings in UCLM-AB.

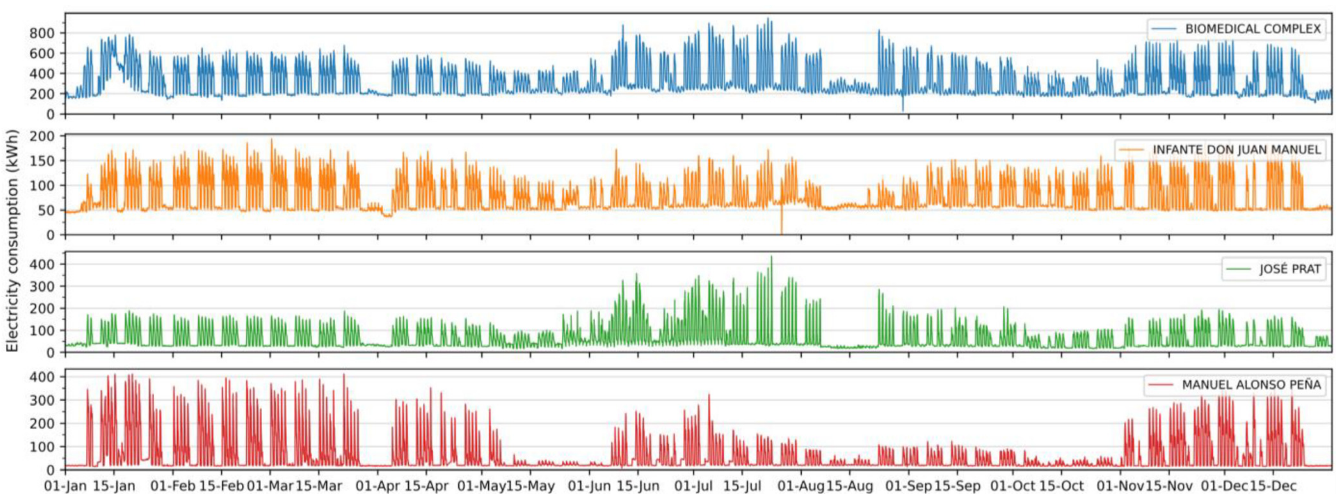


Fig. 9. Hourly electricity consumption over the complete year of 2021 for the selected buildings in UCLM-AB.

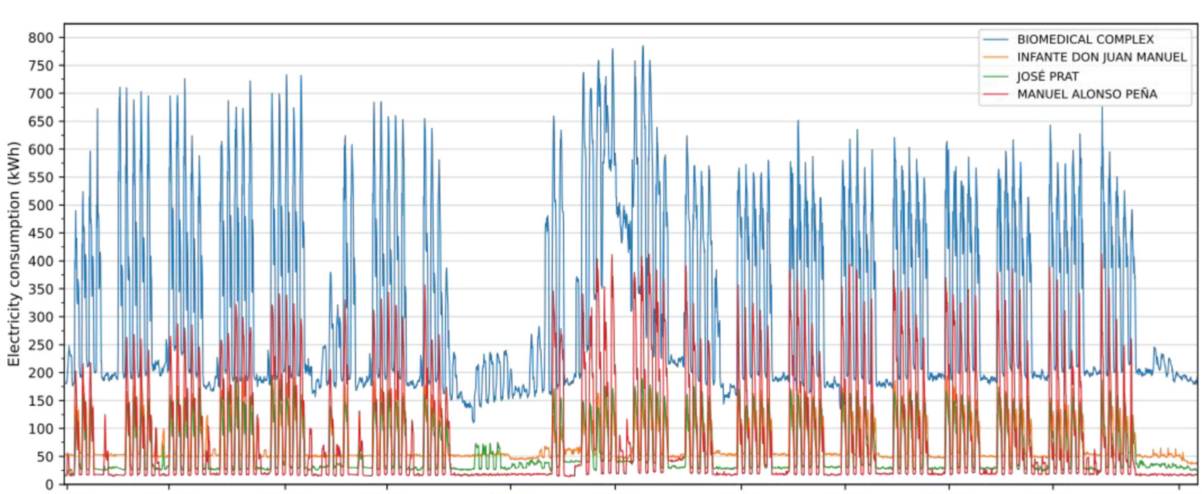


Fig. 10. Winter Seasonal pattern: November to March.

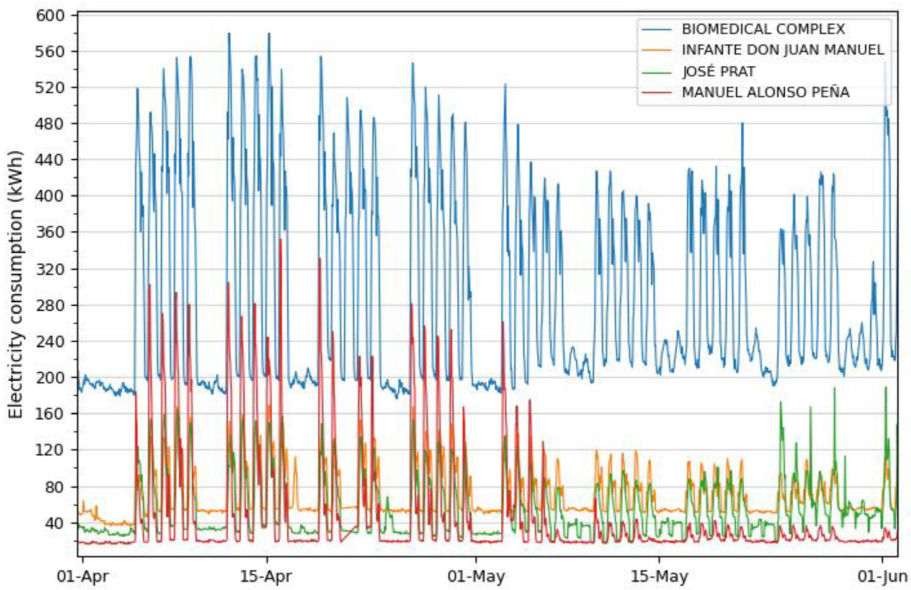


Fig. 11. Spring Seasonal Pattern: April and May.

Secondly, the daily electricity consumption shown in Figs. 11 and 12 reveals 5 different seasonal patterns across the year: winter (from November to March), spring (from April to May), summer working season (from June to July), summer holiday season (August) and autumn (from September to October).

Furthermore, base load distribution also determines two daily patterns: working days and non-working days. For non-working days, the base load remains constant through the day. However, on working days, these base loads occur at certain hours (evening and night), while the highest consumption profiles occur during the day.

To conduct a detailed analysis of the electricity patterns, two studies were performed, as follows: seasonal and daily.

7. Seasonal patterns

Fig. 10 to Fig. 14 show the 5 seasonal patterns previously identified.

The winter seasonal pattern is the longest one, in line with the climatology of Albacete (Fig. 10). These daily distributions verify the functions of the different buildings previously described: on non-working days, the educational buildings' consumption matches the base load (students and professors do not attend lectures), whereas the Biomedical Complex presents an erratic distribution due to the non-conventional schedules of experiments, as well as spin-off projects. The long weekend of 6th and 8th December (Spanish bank holidays) and the Christmas period reflect this situation, in which the José Prat building was also open because the library and administrative offices continued to function.

The peak average values of the Manuel Alonso Peña stand out in this period (350 kWh), being almost half those of the Biomedical Complex (650 kWh). The José Prat and Infante Don Juan Manuel present similar peak average values in this period (140 kWh).

During the spring seasonal pattern, as shown in Fig. 11, the consumption values in the Manuel Alonso Peña building decrease greatly in May, where peak values almost coincide with base load

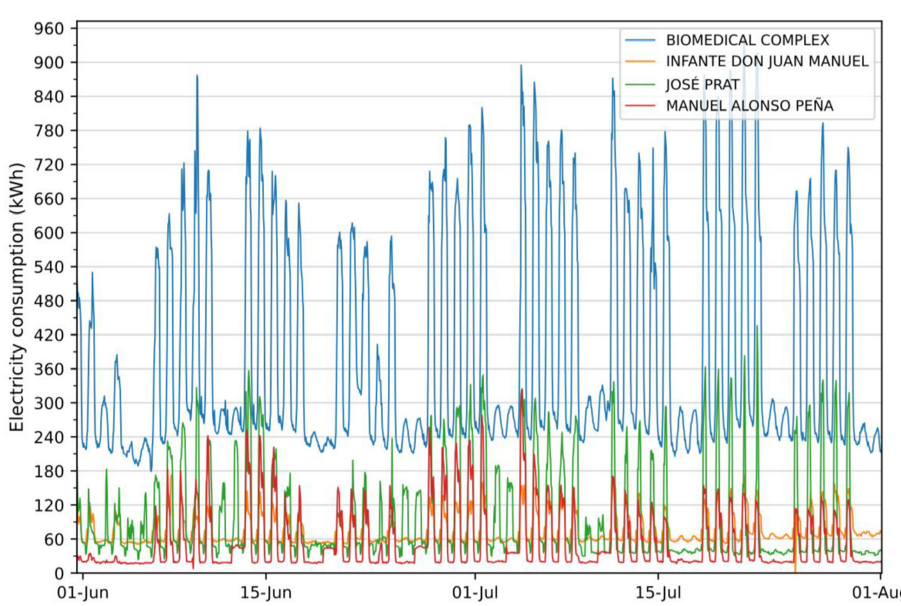


Fig. 12. Summer Working Seasonal Pattern: June and July.

ones (40 kWh vs 15 kWh). Moreover, during these months, the Biomedical Complex presents a smooth profile on conventional non-working days, which continues during the summer pattern.

During summer, exams take place in the educational buildings. This situation is reflected in Fig. 12, where the Manuel Alonso Peña and Infante Don Juan Manuel buildings follow almost the same trend due to the academic exam calendar. Hence, some conventional working days with no exams present base load consumption in these educational buildings, while the Biomedical Complex and the José Prat follow conventional working day profiles (beginning of June). Moreover, attendance at the José Prat library increases during this period due to exams, which results in higher consumption peak values on working days (300 kWh average) and the appearance of demand profiles on non-working days due to the extended opening hours.

August presents clear daily patterns, as observed in Fig. 13. During the first and the last weeks of the month, there is still some activity on the campus: a number of professors prepare materials for the coming academic year in the educational buildings, administrative staff work to update bureaucratic processes in the José Prat and various scientists and workers from the Biomedical Complex continue to work on their projects. Although a working profile is detected during these weeks, peak average values are considerably lower than those in the working summer period (80 kWh compared to 140 kWh in the Infante Don Juan Manuel, 75 kWh compared to 180 kWh in the Manuel Alonso, 150 kWh compared to 300 kWh in the José Prat, and 600 kWh compared to 850 kWh in the Biomedical Complex). However, the two central weeks of August present non-working days profiles for all the buildings except for the Biomedical Complex, where a lower working profile of 350 kWh peak average is detected.

In the autumn seasonal pattern, Fig. 14, working and non-working day profiles increase markedly again with the beginning of the new academic year. A sharp drop in electricity consumption appears in October, which is a mild month where no air conditioning is required.

7.0.1. Daily patterns

Fig. 15 represents the daily electricity consumption patterns for both working and non-working days in the four UCLM-AB buildings selected. Each plot includes electrical consumption for each day (thin lines), together with average daily consumption for each month (bold line). It also shows that the highest consumption profiles of each building approximately coincide, although with some differences according to the different function and use of the buildings, as explained in subsection 3.1.

Regarding working days, those in the winter months present base consumption from 22 h to 6 h approx. The highest electricity consumption in the Biomedical Complex, and the Infante Don Juan Manuel and José Prat buildings occurs in the morning (mainly at midday), while that for the Manuel Alonso Peña is registered in the early morning (6–8 h), when the air conditioning starts working to heat the classrooms. During these months, the Infante Don Juan Manuel and José Prat buildings present very similar profiles, since their electricity consumption does not include air conditioning (heating runs on gas boilers).

In spring months, especially in May, these trends change: in the Manuel Alonso, electricity consumption decreases from 240 kWh peak in April to 60 kWh peak in May. Subsequently, in the summer months, the highest electricity consumption in the four buildings occurs during the morning and early afternoon, from 8 h to 16 h, although base consumption is achieved at 21 h approx. In these seasons, both educational buildings present a similar behavior, although the José Prat presents the second highest values, only surpassed by the Biomedical Complex. Finally, the pattern in the autumn months is similar to that in spring.

With respect to non-working days, these present flat profiles, which mainly reflects the base load for each building. As explained, the Biomedical Complex presents a smooth profile on this type of day, especially for summer months, due to its non-conventional schedule (experiments, spin-off projects, etc.). Hence, from June to September, non-working days present lower values from 8 h to 22 h approx., reaching around 260 kWh at peak slots (15 h). The José Prat building also exhibits a moderate electricity demand profile during the non-working days of June and July, when the library extends its opening hours. This profile covers from 8 h to 21 h and reaches peak values of 100 kWh.

8. Future work

Having thoroughly analyzed the electricity consumption of the UCLM-AB, our future work is designed to go two steps further.

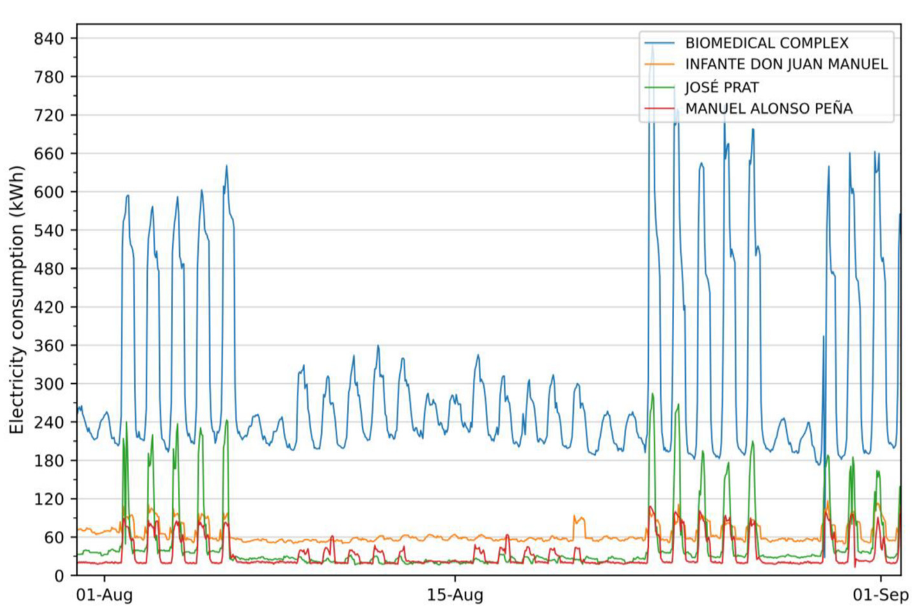


Fig. 13. Summer Holiday Seasonal Pattern: August.

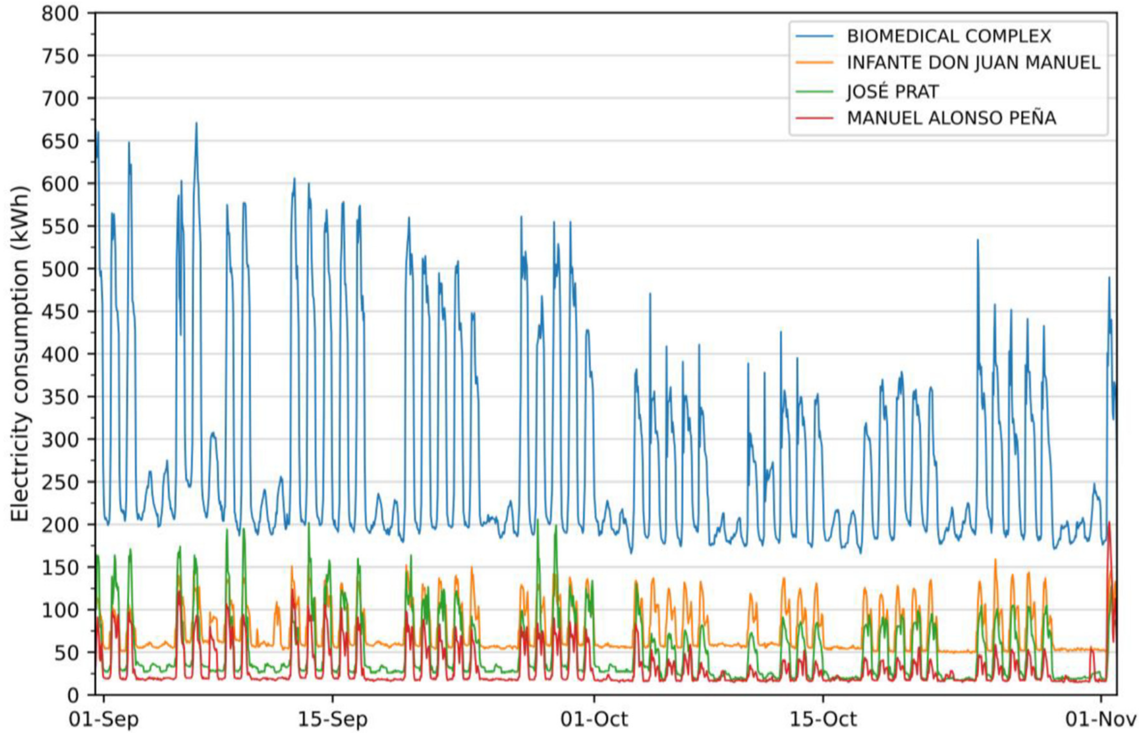


Fig. 14. Autumn Seasonal Pattern: September to November.

First, we will assess the effects of the current energy crisis in university buildings, the plans and budgets of which have been drastically modified. This future research will address not only the effect of such energy constraints on usage, but also their economic impact. The case study for this future research will embrace the whole UCLM.

A second future research could be focused on the suitability of including renewable energy generators, such as solar PV installations, for the university buildings according to their daily and seasonal load profiles, as well as the implementation of new electricity efficiency measurements. Again, our case study will correspond to UCLM. Following these studies, the UCLM will be prepared for a true sustainable energy transition.

9. Conclusions

The current energy crisis, together with the exorbitant increase in electricity prices, has drastically altered forecast electricity plans and budgets for European university campuses, which represent nearly 50% of total building demand. Hence, this new global situation magnifies the need to carefully study electricity consumption in university buildings, something which has traditionally been neglected despite the importance of these constructions.

Our work presents a novel methodology to tackle this issue, and proposes for the first time a complete codebase to analyze electricity consumption in universities. The method is based on three clear steps: data collection, electricity consumption study and parametrization. The first involves automated data collection of actual electricity measurements (real active power, together with electricity energy consumption) at each electricity supply point. The second develops the complete analysis of electricity consumption using energy indicators. Finally, the last step parameterizes this consumption by identifying seasonal and daily profiles. The proposed method becomes completely replicable and scalable to any case study for electricity consumption analysis, since the codebase is presented and the input variables/parameters eligible depending on the application.

The research was applied at the University of Castilla-La Mancha, specifically on the campus located in Albacete (Spain). Hence, for our selected case study, 16 electricity supply points of the UCLM-AB campus were analyzed. To this end, real-time measurements of electricity consumption and real active power were collected over 1 year (2021), with two different sampling periods: hourly and quarter hourly.

The COVID-19 crisis did not affect energy usage at UCLM-AB. The selected teaching system of "maximum" attendance led to neither a decrease nor an increase in energy usage at UCLM-AB. The classrooms used were the same as those in non-pandemic years, as they have the capacity to accommodate all the students enrolled at individual desks. Moreover, no forced ventilation was required, since all the buildings presented natural refrigeration. Finally, webcams with microphones were the only extra resource implemented to broadcast lectures by TEAMS for students that were unwell, neither of which involve a change in energy usage.

The results revealed the 4 buildings on campus with the highest electricity demand, in the following order: the Biomedical complex (research and educational building), Infante Don Juan Manuel (educational building), José Prat (administrative building) and Manuel Alonso Peña (educational building). The Biomedical Complex stands out from the rest due to its high consumption: 2,769,861 kWh/year, which represents 41% of the whole UCLM-AB electricity demand. This center includes the Medical School and the Faculty of Pharmacy, a Biomedical Research Center, a spin-off incubator and an animal laboratory. This last facility requires constant optimal temperature and humidity conditions 24 h a day during the whole year, which leads to a high annual base consumption.

The monthly electricity consumption outcomes reflect how the air conditioning systems affect accumulated values. The Manuel Alonso Peña presented high electricity consumption monthly variations over the year, since it depends solely on electric air conditioning units, which are used during both cold and warm seasons. These high values led to an elevated electricity use intensity in this building (despite being the building with the lowest annual electricity consumption of the four selected) during these months, almost comparable to the Biomedical Complex. However, the Biomedical Complex, and the Infante Don Juan Manuel and José Prat buildings did not present notable increments in consumption during the cold months, despite the low temperatures in Albacete. This situation responds to the existence of gas boilers and electric air conditioning units in these buildings, with the former being those primarily used during the cold seasons.

Base consumption and the different behavior of the buildings also had a direct impact on aggregated values. The Infante Don Juan Manuel includes two data center rooms with a constant 24 h demand over the whole year, together with that of the animal laboratory in the Biomedical Complex, as mentioned above. Thus, the variation in their monthly electricity consumption presents homogeneous trends, with slight variations compared to average values (average 10.6% and 6.2%, for the Biomedical Complex and the Infante Don Juan Manuel, respectively). Moreover, the different nature of the buildings (research, educational and administrative) could be visualized in the outcomes for electricity use intensity. For instance, during June and July the electricity use intensity of the José Prat records the second highest values after the Biomedical Complex, since it is the exam period and the library extends its opening hours.

Nonetheless, the detailed annual electricity consumption per hour clearly reflects the previous aspects. Firstly, the José Prat and Manuel Alonso Peña buildings present a low base demand (15 kWh approx.), caused mainly by stand-by loads or similar, while the Biomedical Complex and the Infante Don Juan Manuel exhibit a notable base demand, quantified at around 30% of their total average electrical consumptions: 200 kWh and 60 kWh, respectively. Secondly, daily electricity consumption reveals 5 different seasonal patterns across the year: the winter season (from November to March), the spring season (from April to May), the summer working season (from June to July), the summer holiday season (August) and the autumn season (from September to October). In these seasons, base load distribution also determines two daily patterns: working days and non-working days. For non-working days, base load remains constant over the day. However, during working days, these base loads occur during certain hours (evening and night), while the highest consumption profiles are exhibited during the day, especially at midday.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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We are grateful to the Infrastructure Management Office of the UCLM and Mr. Jose Jaén Cebrián (Technician of Infrastructures for UCLM-AB) for providing information about the campus equipment related to this research. This work was partially supported by the Ministry of Science and Innovation, the European Union (Next GenerationEU), the AEI through project PID2021-126082OB-C21 and by the Council of Communities of Castilla-La Mancha (Junta de Comunidades de Castilla-La Mancha, JCCM) through project SBPLY/19/180501/000287.

Annex

The code of the software can be found at the following link: https://github.com/JuanTorresPctClm/paper-codebase.

Daily electricity patterns (subsection 4.3) are presented in Fig. 15:

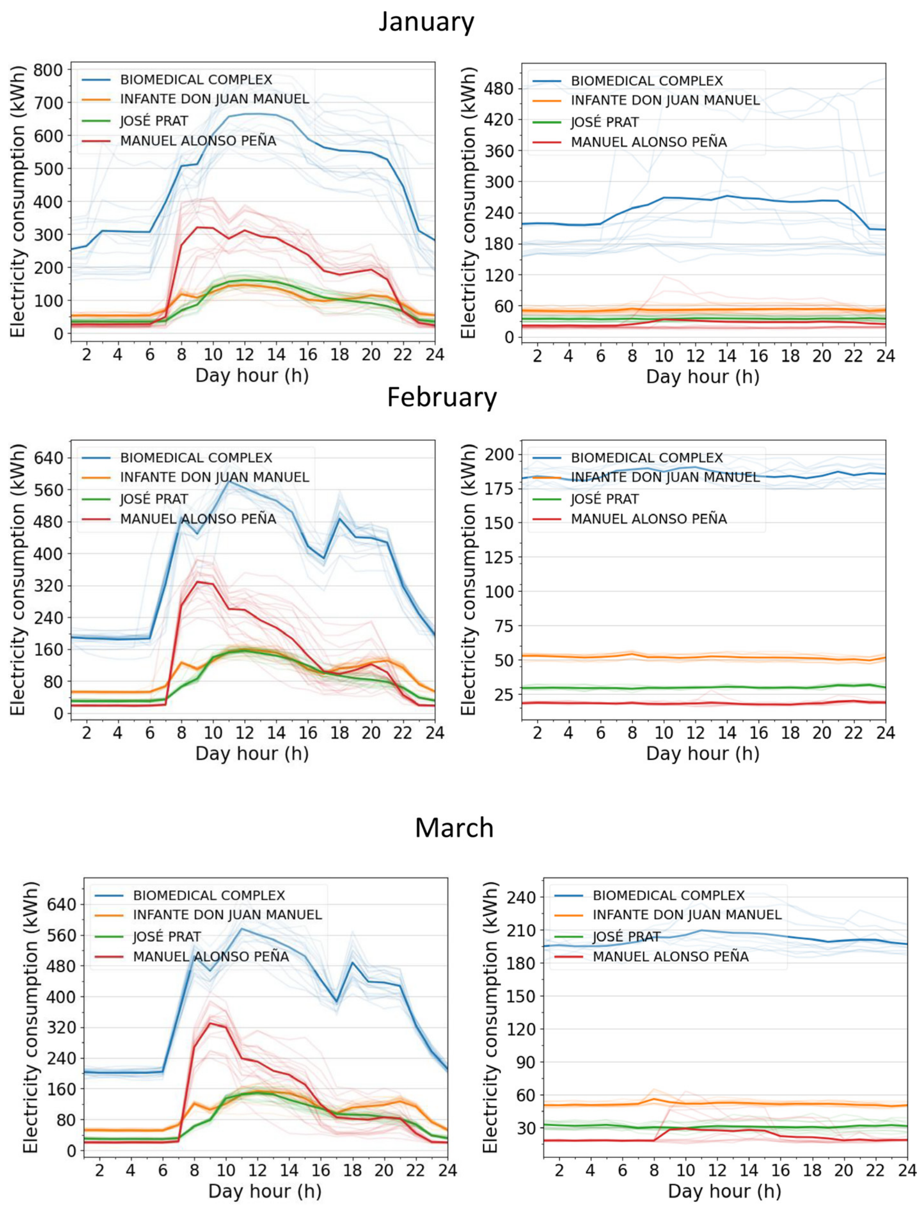


Fig. 15. Daily electricity patterns. (a) Working days. (b) Non-working days.

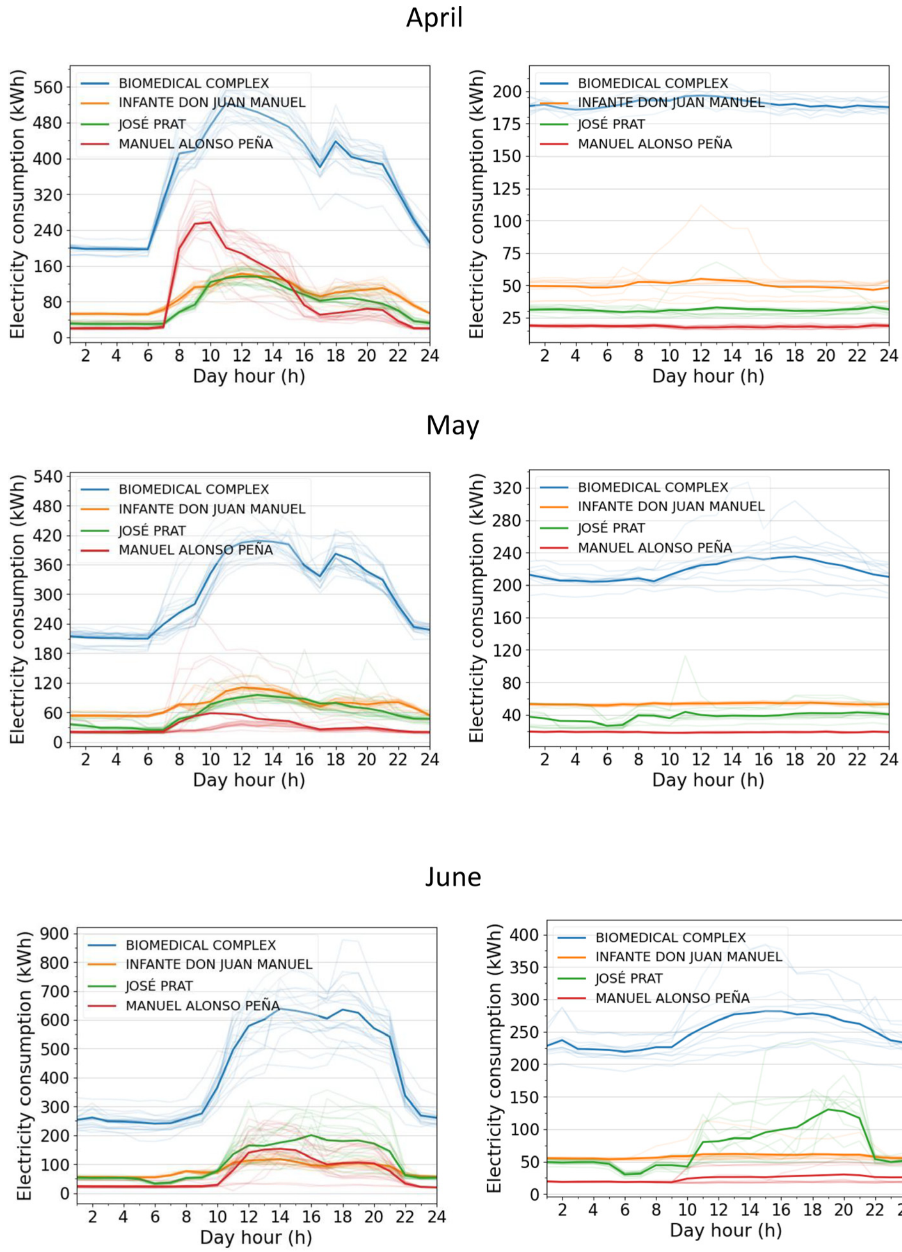
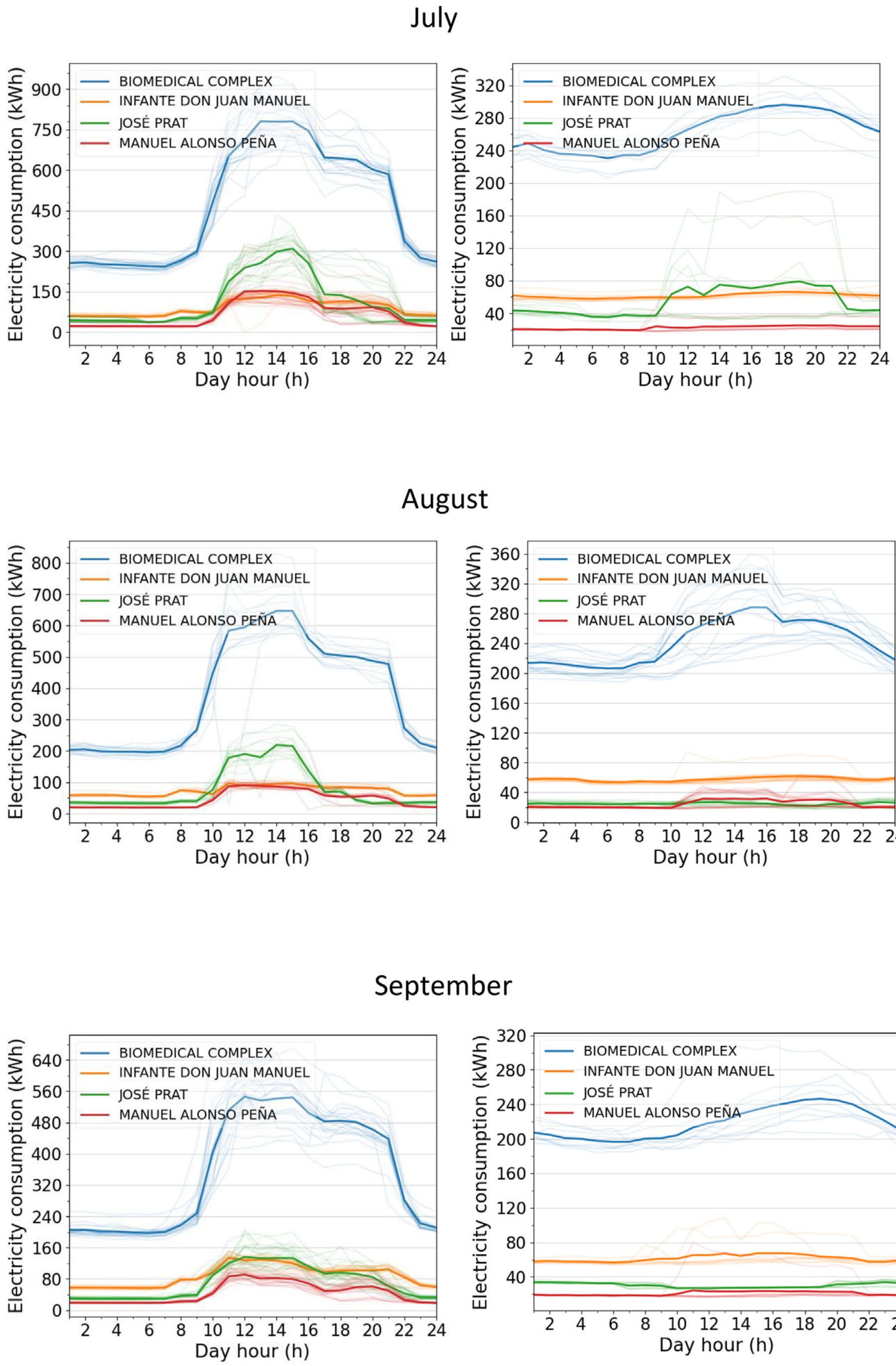


Fig. 15 (*continued*)



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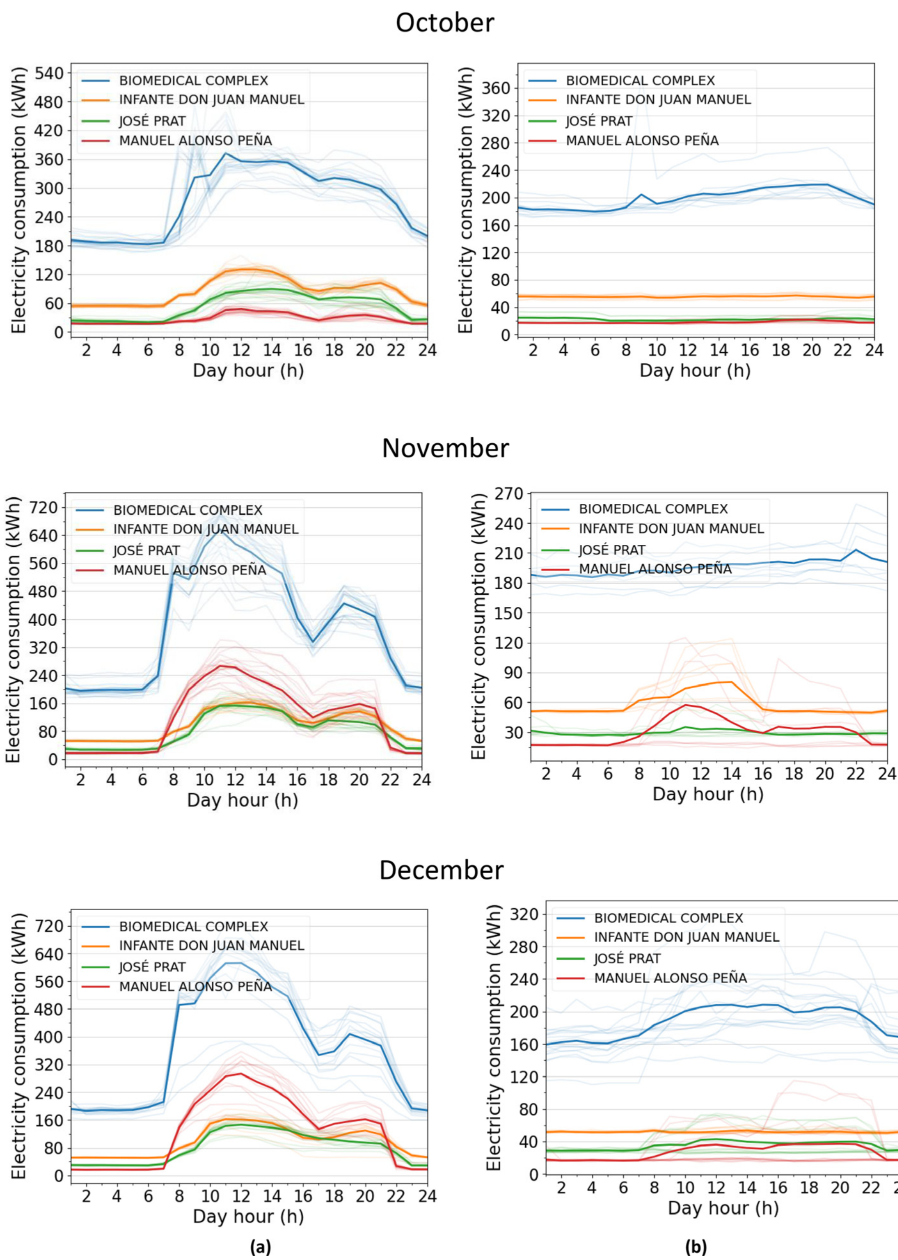

Fig. 15 (*continued*)

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