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# Electricity consumption analysis for university buildings. Empirical approach for University of Castilla-La Mancha, campus Albacete (Spain)

Paula Bastida-Molina[1-2*], Juan Torres-Navarro[2], Andrés Honrubia-Escribano[2] and Emilio Gómez-Lázaro[2]

[1] Universitat Politècnica de València
46022 Valencia, (Spain)
Corresponding author*: paubasmo@upv.es

[2] Renewable Energy Research Institute, Universidad de Castilla-La Mancha
02006 Albacete (Spain)
Paula.Bastida@uclm.es, Juan.TorresNavarro@uclm.es, Andres.Honrubia@uclm.es, Emilio.Gomez@uclm.es

## Abstract

New global situation is boosting the necessity of analysing electricity consumption of university buildings, mainly motived by the exorbitant increase in electricity prices. In this regard, knowing such demand aims at three goals: i) to reduce their consumption, ii) to increase energy efficiency and iii) to develop solar PV installations. Very few research has previously analysed aggregated energy data for educational buildings, and none have studied detailed real electricity consumption in terms of hourly data, which results of utmost relevance, especially for the development of solar PV installations in these environments. Our research tackles this issue and provides a complete methodology to analyse electrical energy and hourly data consumption in university buildings, based on electricity indicators and patterns. The research has been applied to the University of Castilla-La Mancha, in Spain. A complete year data base (2021) of real power and electrical energy consumption of the whole campus has been collected and analysed, with an hourly scale. Results revealed that Biomedical Complex corresponds to the highest load demanding building of the campus (2770 MWh, 43% of the total campus). Outcomes also disclosed an annual high consumption base of 250 kWh for this building, together with 6 different seasonality patterns and 2 annual daily patterns.

## Keywords

Electricity consumption, university buildings, real electricity hourly data, electricity patterns, electricity energy indicators.

## 1. Introduction

The increasing development of new solar photovoltaic (PV) projects has boosted the necessity of analysing electricity consumption data, due to power balance requirements of such installations [1].

In this regard, a wide range of research related to residential buildings consumption has been performed for different reasons [2]–[4]. Firstly, consumers have direct access to these data. Secondly, economic benefits of installing solar PV resources in households have straight impact on user's invoices. Additionally, residential electricity consumption patterns present numerous similarities. For instance, Escobar et al. modelled electricity consumption profile of the residential sector in Spain according to most common appliances and house lighting [5]. Vassileva et al. developed a similar research for rented apartments, considering also behavioural characteristics of Swedish households [6].

However, the number of investigations for electricity consumption in other type of buildings, i.e. industrial [7] or educational, turns out to be much lower.

With regard to educational buildings, new global situation is boosting the necessity of analysing their electricity consumption, mainly motivated by the exorbitant increase in electricity prices [8]. Thus, knowing such electricity demand aims at three goals: to reduce their consumption, to increase energy efficiency and to develop the above-mentioned solar PV installations [9].

Previous research for educational buildings in this topic mostly analysed aggregated energy data. Thus, Medrano et al. provided an energy analysis for the whole university campus of Lleida (Spain), distinguishing between electricity and gas energy consumption for each building [10]. Gui et al. studied the impact of academic calendars on Griffith University campuses (Australia) in terms of electricity energy consumption, clustering buildings according to their main use: research, academic, sports, administrative…[11]. Nonetheless, very few studies include analysis of real power data consumption. Aguayo-Ulloa et al. presented a brief description of daily power consumption at the campus “Sciences et Technologies” of the University of Bordeaux (France), although data are represented in terms of aggregated consumption [12]. Ferrari et al. described a consumption data base to analyse energy consumption in tertiary buildings, taking as a case study one building of the campus Politecnico of Milano (Italy) [13].

Despite the importance of studying aggregated electrical energy demand for university buildings, electricity patterns analysis results of utmost relevance, especially for the development of solar PV installations in these environments. However, to the best of the authors knowledge, no previous studies have analysed electricity consumption in terms of hourly data in university buildings.

Our research tackles this issue and provides a complete methodology to analyse electrical energy and hourly data consumption in university buildings, based on electricity indicators and patterns: annual, seasonal and daily. The research has been applied to the campus of Albacete of the University of Castilla-La Mancha (UCLM-AB), in Spain. A complete year data base (2021) of real power and electrical energy consumption of the whole campus has been collected and analysed, with hourly scale.

The rest of the paper is organized as follows: section 2 presents the materials and methods of the study, section 3 describes the case study and section 4 provides the results and discussion of the research. Finally, the paper conclusions are outlined in section 5.

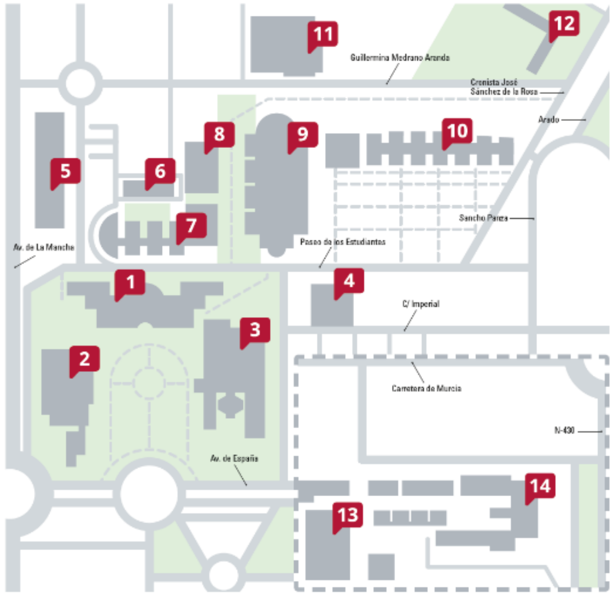
## 2. Materials and methods

This research presents a detailed methodology to analyse electricity consumption in high demand load university buildings. The method focuses not only on traditional energy indicators such as energy per month (kWh/month) or energy use intensity (kWh/m$^2$), but also on hourly data. Hence, the research provides electricity patterns analysis.

### *A. Data collection*

The method has been applied to University of Castilla-La Mancha (Spain). This university is divided in 4 different campuses of the Spanish Region of Castilla-La Mancha: Albacete, Ciudad Real, Toledo and Cuenca. In addition, UCLM has two satellite campuses in Almadén and Talavera de la Reina. Our study focuses on Albacete Campus, which is one of the main campus of UCLM.

This campus was founded in 1982 and currently incorporates more than 7000 students. Fig. 1 represents the general campus distribution.




*1. Vice-rectorate Building, 2. Education Faculty, 3. Economics and Business Sciences Faculty, 4. Multipurpose Building, 5. Renewable Energy Institute, 6. Computer Research Institute, 7. Technical School of Agronomists and Forestry Engineers, 8. Regional Development Institute, 9. Technical School of Industrial and Computer Engineering, 10. Nursing Faculty, 11. Sports Center, 12. Residential Apartment, 13-14. Pharmacy and Medicine Faculty and Biomedical Research Institute, normally called Biomedical complex.*

Fig. 1. University of Castilla-La Mancha. Campus Albacete.

A complete year data base (2021) of real active and reactive power consumption, together with electricity energy consumption of the whole campus has been analysed, with hourly scale. Python software was used for this aim.

### *B. Electricity energy indicators*

Three electricity energy indicators were developed for this research.

Firstly, annual electricity consumption ($E_a$) quantifies the whole electrical consumption during the year in question.

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

Where $P_{hd}$ represents the power consumption at each hour of the day in question, and t corresponds to the time period (1 hour according to this case study).

Monthly electricity consumption ($E_m$) makes a higher distinction and quantifies the whole electrical consumption during the month in question.

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

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

Finally, monthly electricity use intensity ($UI_m$) relates monthly consumption to surface area.

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

*C. Electricity patterns*

This study aims to identify electricity patterns along one year of data collection. With a powerful loop algorithm developed in Python, hourly electricity data were analyzed to identify remarkable patterns in the Biomedical complex along the year under study. This loop identifies differences between electricity power data, as equation (4) reflects:

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

Where x is the tolerance factor: if electricity power consumption of time h differs in x% to the same value of the previous day, the loop identifies a new pattern.

## 3. Case study

Fig. 2 shows the yearly electricity demand of the main buildings of UCLM-AB. In this regard, it is possible to observe that buildings 13-14 (they act as a unique building) have the highest annual consumption: 2770 MWh, which represents 43% of the total campus. This group corresponds to Pharmacy and Medicine Faculty and Biomedical Research Institute, normally called Biomedical complex. This complex embraces a total area of 25878 $m^2$.

Table I summarizes the main equipment used for environmental conditions adequacy of such complex. On the one hand, the building has an educational behaviour, where medical and pharmacy students attend lectures and practice in laboratories. These laboratories include high electricity demanding machinery for ventilation, refrigeration, and conservation of medical experiments. Moreover, Pharmacy Faculty employs only electrical equipment for air conditioning.

On the other hand, the building also incorporates a research centre with an enormous animal laboratory. This animal laboratory should maintain optimal temperature and humidity conditions during the whole year, which leads to an extremely high electricity consumption. Moreover, the complex incorporates a building for spin-off companies.

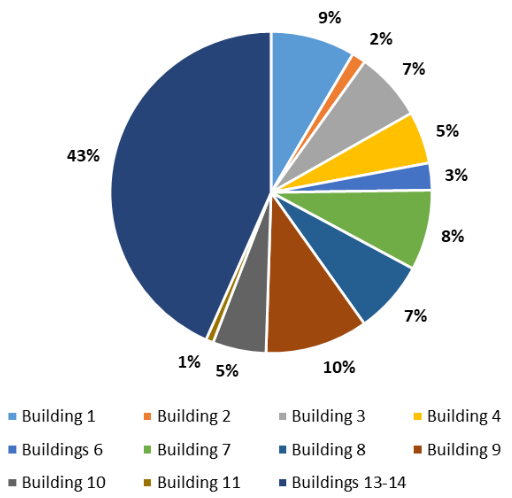



Fig. 2. Distribution of the annual electricity consumption distribution of UCLM-AB, per building.

Table I. Equipment for environmental conditions adequacy of Biomedical complex.

| **Medicine faculty** |
|---|
| 2 coolers, 3 boilers, 11 water circulation pumps, 47 air conditioners, 115 horizontal fan coils, 15 heat pumps, 4 carcass preservation chambers, 1 freezing chamber, 2 extraction systems, 20 conditioning equipment, 2 outdoor units with heat recovery, 25 ducted indoor unit. |
| **Pharmacy faculty** |
| 10 outdoor units, 1 indoor cassette units, 99 indoor duct pressure units, 3 air conditioning units, 8 main controllers, 4 secondary controllers, 6 recovery units. |
| **Animal laboratory** |
| 1 water chiller, 4 air conditioners, 9 fan coils, 3 humidifiers, 1 steam boiler, 1 volumetric water softener. |
| **Research centre** |
| 1 water chiller, 1VRV unit, 2 air conditioner, 19 ceiling fan coils, 2 splits. |
| **Spin-off department** |
| 7 splits, 5 in-line extractors. |

Regarding schedules, university course begins in September and finishes in June. During July, the whole university staff (professors, researchers, administrative workers…) continues working, but students do not attend classes. Finally, August is the holiday month where university remains closed during the second and third week: only authorized employees can stay there during these two weeks.

## 4. Results and discussion

*A. Electricity energy indicators*

Annual electricity consumption for the biomedical complex during 2021 increased up to 2770 MWh, as mentioned in section 3. Fig. 3 reflects this consumption per month.

The highest electricity demand takes place in July. This is the working month with highest temperatures in Albacete (38 ºC were reached in 2021). Such increase in the electricity consumption derives from the continued use of refrigeration systems during working hours to achieve adequate climate conditions for university staff. These units are 100% electricity dependent.

Other months could firstly seem more restrictive than July. For instance, January was the coolest month of 2021, achieving until -12 ºC, and during this month both students and university staff attended the university. Although high electricity rates were achieved in January, this month has the second highest values after July. Main reason for this lies in the refrigeration units for cold cooling, which are not exclusively dependent on electricity: medicine faculty or the research centre include boilers.

This behaviour repeats for the other winter and summer months, with some observations. Regarding winter months, November and December presented similar weather conditions, but demand in December was reduced due to Christmas holidays. Referring to summer months, August is the hottest month of the year for Albacete where the university remains closed during the central weeks due to summer holidays. Despite being closed, electricity rates presented high values, even higher than some working months as October or May. This was caused for two reasons. On the one hand, the first and fourth week of August, refrigeration necessities were really high due to the extreme warm temperatures (up to 42 degrees in 2021). On the other hand, animal laboratory needs to maintain optimal conditions of humidity and temperature 24 h during the whole year, which leads to a continued annual electricity base consumption.

An appreciable decrease takes place during mild months, where mainly lighting needs and consumption base should be covered.

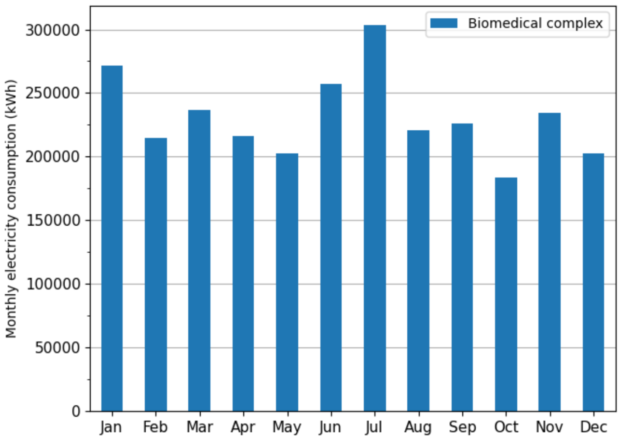



Fig. 3. Monthly electricity consumption. Biomedical complex.

Fig. 4 also represents monthly electricity use intensity for the biomedical complex. Although this analysis does not provide extra information for this research, authors consider of utmost importance its study for further research, when electricity consumption for different buildings of UCLM-AB will be analysed.

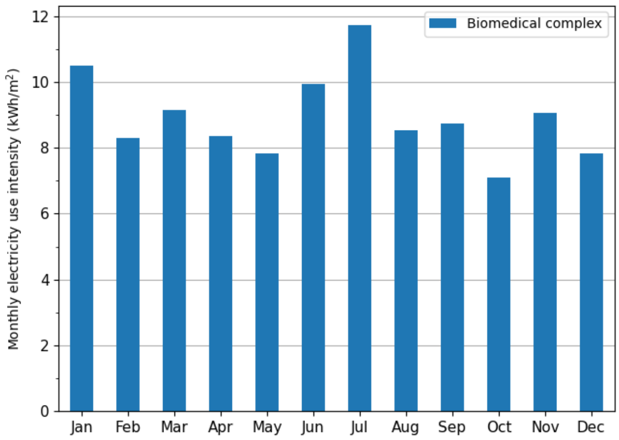



Fig. 4. Monthly electricity use intensity. Biomedical complex.

*B. Electricity power patterns*

Fig. 5 reflects hourly data electricity consumption along 2021 for the Biomedical complex. Different power patterns could be recognized.

Firstly, a high a continued demand base of around 200 kWh takes place. This consumption matches all electricity consumption that occurs uninterruptedly annually. It mainly relates to the laboratories of the Medicine Faculty, with 4 carcass preservation chambers and 1 freezing chamber, and specially to the animal laboratory. All the elements for environmental conditions adequacy of this animal laboratory (Table I) remain annually connected in order to obtain optimal humidity and temperature conditions, which leads to a high electricity consumption. During summer months, this base load increases in 50 kWh since cold refrigeration conditions are completely electricity dependent.

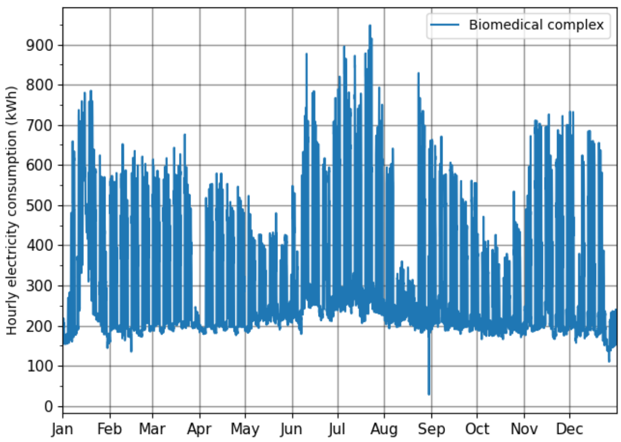



Fig. 5. Hourly electricity consumption. Biomedical complex.

This electricity consumption base takes place during not working hours (normally between 21 h and 8 h) for working days, and during not working days. During working days, it is added to the rest of the daily consumption. Hence, a new pattern could be recognized: working and not working days.

Finally, electricity consumption for working days does not behave the same along the year, so 6 seasonality patterns are identified. Table II describes them:

Table II. Seasonality patterns. Biomedical complex.

| Period | Description | Hourly min-max consump. (kWh) |
|---|---|---|
| September - October | Beginning of the new course. High refrigeration requirements at the beginning, which gradually decrease. | 650 – 400 |
| November - December | Temperatures start decreasing, so air conditioning requirements increase (not completely dependent on electricity). Decrease in electricity requirements due to Christmas holidays could be observed at the end of December. | 700 – 225 |
| January-March | Remarkable increase in electricity consumption in January due to the start of the lessons and low temperatures. February and March present a similar pattern. | 790 - 600 |
| April-May | Mild months, so air conditioning requirements gradually decrease. Moreover, lighting requirements also decrease due to the increase in days length. | 560-410 |
| June-July | Extreme high temperatures. Although lectures do not take place in July, refrigeration units are 100% electrical. The highest consumption is achieved in July | 600-940 |
| August | Extreme high temperatures. However, almost all the staff is off during central weeks, and during the first and fourth weeks only a 25% of them are working. | 300-800 |

## 5. Conclusions

New global situation is boosting the necessity of analysing electricity consumption in university buildings, mainly motivated by the exorbitant increase in electricity prices. In this regard, knowing such electricity demand aims at three goals: to reduce their consumption, to increase energy efficiency and to develop solar PV installations.

This research focuses in UCLM-AB, which has collected hourly and quarter hourly electricity consumption data for the whole campus for one year: 2021.

Pharmacy and Medicine Faculty and Biomedical Research Institute, generally called Biomedical complex, outstands among the 14 buildings of this campus due to its noteworthy electricity consumption: 2770 MWh, which represents 43% of the total campus. The complex occupies a considerable surface of the campus: 25878 $m^2$.

Results also revealed its monthly electricity distribution and patterns. Firstly, highest electricity demand took place in July, followed by January. Although students do not attend classes in July, refrigeration necessities in such month are certainly high for Albacete, being conditioning equipment completely electricity dependent. January could seem more restrictive at first sight, since both students and staff attend university, and climate temperatures are the lowest. However, conditioning equipment is some areas, i.e. medicine faculty, is supported by water boilers, which decreases electricity demand in winter months.

Hourly electricity consumption results were also analysed, providing an outstanding novelty in such kind of research: only aggregated values of electricity consumption were previously studied for university campuses. From such study, it has been possible to identify annual and seasonal, and daily electricity patterns of the Biomedical complex. Firstly, a high continued demand base of around 200 kWh takes place annually. It mainly relates to the laboratories of the Medicine Faculty, with 4 carcass preservation chambers and 1 freezing chamber, and specially to the animal laboratory. All the elements for environmental conditions adequacy of this animal laboratory remain annually connected to obtain optimal humidity and temperature conditions, which leads to a high electricity consumption base.

Secondly, this electricity consumption base takes place during not working hours for working days, and during not working days. During working days, it is added to the rest of the daily consumption. Hence, a new pattern could be recognized: working and not working days.

Finally, electricity consumption for working days does not behave the same along the year, so 6 seasonality patterns are identified. The most remarkable one corresponds to August, where students do not attend classes and most of the staff are on holiday, especially during the two central weeks. Despite this low occupancy, high refrigeration requirements lead to hourly values up to 850 kWh during the fourth week (double the average values of May). Nonetheless, during the two central weeks, the Biomedical complex achieves the lowest hourly values along the year.

Further studies will also focus on specific daily electricity consumption distribution for working and not working days for each identified seasonality. Moreover, a detailed comparison among Biomedical complex and other high demanding buildings of UCLM-AB will be addressed by the authors.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