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Analysis of electricity consumption in university buildings and possible improvements due to Spanish financial helps announcement. Study of the state of the art.

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Abstract. It is interesting to study electricity consumption in buildings due to the fact that it can lead to useful information that can help society as a whole. Lots of studies have been performed in residential buildings since every individual can have access to their electricity consumption. Even though these studies have a real use case and are really important to achieve high scale energy savings, the individual contribution of each residential building is not very high. For this reason, the research on more impactful infrastructure becomes of great interest, such as university campuses. This paper aims to perform a review of the state of the art regarding electricity consumption in university buildings. In this context, studies about electricity consumption in university buildings do exist but are much scarcer and tend to focus on a variety of topics such as prediction of future consumptions or assessment of the impact of people's behaviour in it.

Key words. Electricity consumption, university buildings, state of the art, real data, self-consumption, solar PV regulation.

1. Introduction

Technological growth of society has allowed for a rise in the quality of life, providing better buildings, services, commodities, etc. However, these benefits come at a cost. With the increase of population, energy demand is constantly growing, even reaching the point where concerns about energy supply difficulties, exhaustion of energy resources, and heavy environmental impacts have been risen [1]. In cities, buildings can consume up to 75% of total primary energy and produce 39% of energy-related carbon dioxide emission annually [2].

In this context, it becomes of great interest the study of energy consumption in buildings, with the objective of reducing energy waste. Some authors have already made advancements in this field. An analysis of gas and electricity consumption has been undertaken in [3], where three different schools of diverse ages were studied. Scientists in Australia and China have written about the impact of academic calendars in the energy use and energy use intensity [2]. Specifically, they have analysed consumption data of 122 campus buildings and two different academic calendars: one based on semesters and the other one based on trimesters. Other authors in Sweden [4] have carried out research on the consumption of households in rented apartments, concluding that the total household's income determines the consumer behaviour, which is related to higher electricity consumption. In Spain, a methodology for evaluating historical energy use and renewable energy production for all the buildings of a university, including hourly, daily and monthly data assessments is presented in [5]. Other contributions analyse the electrical consumption data in order to fit them under clusters, such as the case of [6].

The afore-mentioned contributions are the ones that more closely resembled the problem that we want to tackle. Most part of the literature focuses on residential buildings since their consumption data are easier to acquire. When dealing with corporations or public entities consumptions, considerable fewer studies have been carried out. Overall, electricity consumption data have been thoroughly studied. In some cases, room for improvement has been detected, but its impact in case of having applied a solution has not been studied, maybe due to a lack of financial support. Currently, in Spain exists an opportunity for investing in renewable energies for self-consumption, which can lead to interesting studies that analyse the electricity consumption pre and post installation of solar photovoltaic (PV) panels.

Spain's Official Gazette (BOE), on Wednesday 30th of June 2021, made an announcement for financing energy self-consumption and storage systems using renewable resources [7]. Six different funding programs can be found

Table 1. All different self-consumption programs announced in the Spain's Official Gazette.

Program	Objective	Target
1	Self-consumption and storage	Service sector
2	Self-consumption and storage in other productive sectors	Industry
3	Incorporation of storage in existing self-consumption facilities	Economic sectors
4	Self-consumption and storage	Residential, public and third sector
5	Incorporation of storage in existing self-consumption facilities	Residential, public and third sector
6	Air conditioning and domestic hot water using renewable energies	Residential sector, including public protected household

and each one of them has an objective and a target, as shown in Table 1.

University of Castilla – La Mancha (UCLM) is a public institution and currently has no self-consumption, so, the applicable program for it, is number 4. Currently, several projects are planned to include solar PV in some buildings of UCLM. Once finished, new data will be measured during a long enough period, which will allow us to compare the current electricity consumption data with the new ones using renewable energy for self-consumption. One key aspect of this announcement is that all built installations must be for self-consumption, being the recipient bound to consume, at least, 80% of the produced energy.

The rest of this paper is structured as follows: Section 2 describes the objective, in Section 3 a closer review of the most important references is undertaken, Section 4 establishes the main contributions of this paper and Section 5 describes the future work we plan to tackle.

2. Objective

The main objective of this research is to identify the state of the art in the matter of real electricity consumption data in university buildings, more precisely:

- Finding previous contributions that have already analysed real data of electricity consumption.
- Learning about methodologies that other authors applied to these data processing (whether they were real or estimated).
- Analysing scientific papers that, in case of having studied real electricity consumption data and proposed a solution for its improvement, it has been implemented and also studied.

Moreover, Spanish renewable energy funding programs are addressed with the objective of informing about the situation of UCLM regarding electricity consumption and its future improvement with self-consumption solar PV.

3. Literature review

An analysis of real-time electricity consumption in Canadian school buildings was carried out by Mohamed Ouf et al. in [3]. This study stated that, with the objective of achieving large scale energy reductions, it was needed to bring closer the expected and actual energy performance of buildings. All parameters that influence energy consumption must be considered, for example those related to occupancy and usage. The study focused on assessing the energy performance of school buildings in Manitoba, Canada. For this purpose, the authors analysed historical energy consumption in a random sample of 30 schools over 9 years. It was found out that electricity consumption in newer schools was higher than that of older ones, but gas consumption was lower. This fact made the authors consider that electricity consumption needed to be investigated in greater detail. Contribution [3] studied more closely the differences of 3 schools at the levels of building, classroom, gymnasium and other spaces in both: work and non-work hours. The study analysed gas and electricity consumption data, as well as billing costs, to assess the effect of building age on energy consumption. Electricity was monitored at 30 minutes intervals. Each of the 3 selected schools belonged to a different age category: old school (built before 1960), middle aged school (built between 1960 and 1989) and new school (built after 1989). In order to compute total energy consumption in kWh at building level, they multiplied gas consumption data in m^3 by a factor of 10.33, to later add it to electricity consumption. At building level, results showed that average annual electricity consumption was the lowest in the old schools, and the highest in the new ones, whereas gas consumption followed the opposite trend. Regarding base load consumptions, the middle-aged school presented the highest one in relation to its average daily load, followed by new and old schools. At classroom level, electricity consumption did not follow the same trend than at building level. Outcomes showed that the old school's classroom consumed more electricity for lights and plug loads, followed by new and middle-aged schools. These facts led the authors to the next conclusion: classrooms may not contribute to the higher electricity consumption of the new schools. At gymnasium level, consumption of the new school was the highest, while that of the middle-aged was the lowest. Electricity demand of lighting and plug loads in gymnasiums during non-work hours constituted a high percentage of electricity consumption, being their maximums 24.3% and 24%, respectively, in the old school case. This fact highlights the effect of occupancy on real-time electricity during work and non-work hours. Finally, at other spaces level, lighting and plug loads consumption during non-work hours was negligible in comparison with work hours. However, the authors claim that this situation may be due to the spaces not being used outside regular hours given the short duration of the study. As drawn conclusions, authors state that the analysis revealed a decrease in gas consumption for heating in newer schools but a statistically significant increase in their electricity consumption. Their results could not explain the higher electricity consumption of newer schools. These may be caused by more complex HVAC systems or other spaces in the schools with higher consumptions than those analysed. In addition, occupants' behaviour could explain the observed differences in electricity consumption [3].

Iana Vassileva et al. [4] assessed real monthly electricity data (which spanned 6 years) of two identical buildings. Differences were found in consumption of the two buildings: building 1 presented a stable consumption during the 6 years, while building 2 followed a gradual decrease during the first 3 years and a slight uptrend for the last 3 (still below than that of the second year). The study also analysed the energy use intensity (kWh/m^2), which was always lower for the second building, except for the year 2004. Nevertheless, if the energy use intensity per person (kWh/m^2/person) living in each building is considered, then, for building 2, is lower for every analysed year, leading to the conclusion that it is important to consider the number of residents and their behaviour when analysing electricity consumption in households. At some points of the analysed data, significant rises or falls were presented. These were caused by old tenants leaving the dwellings and new ones coming in. These rises and falls signalled the importance of residents' behaviour in electricity consumption and made the researchers go on to use survey results in which they inquired about different factors that may affect the final total energy consumption. The questionnaire was divided in three sets concerning different subjects such as: personal characteristics of the residents (family structure, time spent at home, education level, salary…), appliances (type, number and frequency of use) and energy consumption behaviour (careful use of equipment, purchase cheap vs purchase environmental, control behaviours…). Tenants who seemed to be more concerned about their electricity consumption and have a higher knowledge about energy related questions were more prone to execute simple measures for saving electric power. In addition, residents that already presented lower consumption did not appear to have interest in energy saving questions, probably because they were currently applying some of those to ensure their low consumption. On the other hand, people with high consumption and salary, did not want to change their electricity consuming habits. So, it is possible to find significant differences in electricity demand in households with similar characteristics where the main difference is the salary. The problem is how to encourage households with high income to reduce their energy consumption [4].

The contribution written by Xuechen et al. [2] investigated the impact that the academic calendar in high education buildings has on their energy consumption. The studied University was Griffith University, where they collected weekly energy data from 122 campus buildings, analysed them and compared them under two different academic calendars: semester and trimester. These buildings were of different types, belonging to the following categories: academic, administration, research, residential, retail, sports creation and teaching. The afore-mentioned contribution was the first one in analysing the occupancy condition of higher education buildings and stablish a connection with the energy consumption. Before 20th February 2017, Griffith University used to have a semester system, later they adopted a trimester one. Each system divided the academic year in 3 terms: Semester 1, Semester 2 and Summer Semester (in semester system) and Trimester 1, Trimester 2 and Trimester 3 (in trimester system). In addition, for both systems, between each term existed a break period. One year of each system is analysed as a typical academic year. During each term, the teaching activities were carried out regularly. In contrast, during the break period no classes were held, but academic staff and researchers might continue working. Results showed that academic buildings had a greater energy consumption, whereas research buildings presented the highest energy use intensity. In addition, there were no significant differences found between energy consumption and energy use intensity in each building category for the different academic calendars. Nevertheless, the authors highlighted some changes in these magnitudes for academic and research buildings. When the transition from semester system to trimester system was produced, energy consumption and energy use intensity in teaching buildings decreased, while those of research buildings increased. This fact seems to indicate that the semester system consumed more time in classes, whereas trimester system favoured research activities [2].

Marc Medrano et al. [5] proposed a methodology for evaluating the historical energy consumption and renewable self-generation performance of university buildings for a later application as a case study to the University of Lleida, in Spain. The objective of the proposed method was to help universities to achieve Nearly Zero-Energy Buildings and included information such as the geometry of the building, hourly and quarter-hourly electricity consumption data, hourly gas consumption data, operational data and impact of climatic conditions. The assessed renewable energy research consisted of photovoltaic cells placed on the roofs of some of the buildings. Electricity consumption for two years was plotted, and they identified working and non-working periods taking into account the consumption patterns: peaks were presented in working days and, for non-working days, consumption dropped to the baseload. The magnitude of these peaks varied as a function of the external temperature. When no climatization equipment had to be used, their values were lower than when cooling or heating units were required. In general, electricity consumption on weekends represented between the 4% to 13% of total electricity consumption for the analysed buildings. These were high percentages for days in which there were no activities carried out and suggested the possibility of achieving great energy savings with an energy audit. The study also assessed the dependence of electricity consumption on climatic conditions, and it resulted to be smaller for lower temperatures than for higher ones, probably due to the higher efficiency of the equipment used for cooling purposes.

In Italy, Ferrari et al. [1] developed a methodology for the analysis of electricity consumption data, whose objective was to assess the electrical energy performance of existing tertiary buildings, giving priority to older ones. The proposed methodology involved using spreadsheet macros that the research team had developed for more than two years. The application of the methodology made them capable of defining different Electricity Consumption Indexes (ECIs), which can be used to compare the performance of different buildings. The data fed to the macros were real electricity consumption data measured in steps of 1 hour. When processing them, they were divided in three different time levels: medium and long-term, typical seasonal weeks and monthly. Medium and long-term graphs were used to analyse the increase in electricity consumption in the transition of seasons, the efficiency of heating/cooling systems, and to identify periods where the data collection system did not work properly. The purpose of typical seasonal weeks was to identify relations between electricity consumption sources of a building, and critical issues in equipment management. Lastly, monthly graphs were utilised to analyse the relation between electricity demand and occupation of the building, to identify the main loads that affected the electricity demand trend and to compute the ECIs. The authors analysed with their methodology two buildings of the Politecnico di Milano university with data acquired since the beginning of 2012 to Summer of 2015. As conclusions, they proposed some measures to improve their electricity usage efficiency [1].

Other authors, like Xinlei Zhou et al. [8], used the electricity consumption data to forecast building consumption and, thus, making easier the energy management on that building. According to the authors, most of the existing models presented performance degradation along the process. Their study integrated the prediction Long Short Term Memory (LSTM) model and Reinforcement Learning (RL) to predict electricity consumption and peak energy demand for the following day on a building. Their initial data comprised hourly electricity usage collected from university buildings and student accommodations, meteorological data, and schedule-related data. The raw data was filtered and then split into two groups. The first group was used for training the LSTM model (base model for prediction), whereas the second one was used for RL agent learning (dynamically tune LSTM according to the prediction error). The results showed that when the methodology was applied to buildings, where the monthly variations were negligible, the predictions did not differ too much from previous studies. However, when applied to student accommodations, which showed relatively large monthly variations in electricity consumption, their methodology improved the prediction accuracy by up to 23.5% with respect to previous research [8].

Following the approach of analysing electricity consumption data using machine learning, R. Pérez-Chacón et al. [6] carried out research on extracting consumption patterns with the objective of achieving energy and economical savings. The methodology was based on big data environments and clustering, being k-means the algorithm utilised. As a case study, they used electricity consumption data for the years 2011-2017 for 8 buildings of a public university. Firstly, a study was performed, and it revealed the optimal number of clusters. Next, considering the building type and characteristics such as the season of the year or day of the week, patterns were extracted. These patterns showed valuable information like that consumption behaviour depends mainly on the building characteristics (research centres, administration buildings, classrooms or leisure facilities) and the hours during the day in which they are used. Moreover, they found a strong relationship between temperature and consumption, and a high impact produced by the academic calendar [6].

Finally, Table 2 shows a comparison of the previous contributions that this paper has analysed. It comprises information such as if the building studied belongs to a university, if the building is studied in its entirety or just some parts of it, the time period during which the electricity consumption data have been measured, the sampling period and the objective with which the analysis was undertaken in the first place.

Table 2. Comparison of different contributions.

Reference	**University buildings**	**Entire Building**	**Data time length**	**Sampling Period**	**Objective**
[1]	Yes	Yes	3.5 years	1 hour	To assess the electrical energy performance of existing tertiary buildings.
[2]	Yes	Yes	2 year	-	To assess the impact that different academic calendars have on higher education buildings.
[3]	No	No	9 years	30 min	To evaluate the impact of occupants' behaviour in electricity consumption in Canadian school buildings.
[4]	No	Yes	6 years	-	To determine parameters in tenants' behaviour that can affect electricity consumption in households.
[5]	Yes	Yes	2 years	1 hour, 15 min	To help universities reaching Nearly Zero-Energy Buildings.
[6]	Yes	Yes	6 years	-	To propose a methodology to extract energy consumption patterns that can provide useful information for managers and governments.
[8]	Yes	Yes	-	1 hour	To forecast electricity consumption data to facilitate energy management.

4. Conclusions

This paper has summarized the state of the art of the problem we want to face: quantifying the impact of renewable energy (specifically solar PV) in the electricity consumption and billing of university campuses.

To the best of the authors knowledge, no previous studies have already analysed electricity consumption data of several campuses of a university, then renovate some of its buildings to include a renewable energy source for self-consumption and, finally, compared the new real data with the previous ones to assess the improvements that this operation may lead to.

Due to 1) the announcement of the Spain's Official Gazette [7], 2) the recording of previous electricity data and 3) the possibility of recording new data for the same buildings using renewable energies, UCLM is in a privileged position for quantifying the impact of solar PV in several types of buildings. These types of buildings are, amongst others, engineering schools, medicine schools, administrative buildings, research centres and libraries.

5. Future work

This paper establishes the base for future research, where the electricity consumption data of UCLM is going to be thoroughly analysed. During the timespan that these future investigations are conducted, solar PV installations are going to be constructed and started up. Buildings that will have them installed will get its electricity consumption measured and a comparison with the previous state will be able to be carried out. For future work, electric consumption data and invoices are available from 45 Universal Supply Point Code.

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