2020 IEEE PES/IAS PowerAfrica

Electrical consumption in the Higher Education sector, during the COVID-19 shutdown

Christina Birch, Rodger Edwards, Sarah Mander
Department of MACE
The University of Manchester
Manchester, UK
christina.birch@manchester.ac.uk

Andy Sheppard
Ove Arup & Partner
Sheffield, UK

Excessive electrical consumption within buildings is a common issue across all sectors. Each sector responds to this differently, and the Higher Education (HE) sector is no exception, where energy-intensive laboratories are prevalent in most universities. The COVID-19 crisis has meant that these laboratories have either closed or reduced their opening hours; hereby, this offers an excellent opportunity to assess how shutdown periods impact on electrical consumption.

This research assesses unregulated electrical consumption within a single laboratory building, which functions as a research engineering building. An Energy-Management System (EMS) was used to collect the room-level data, primarily electrical consumption.

This study found that unregulated electricity consumption typically reduced rapidly during the shutdown period with a percentage reduction of 46.61% between the week before lockdown and the week during the lockdown.

***Index Terms*—Consumption; Higher Education; Unregulated Energy.**

I. Introduction

The analysis of electrical consumption patterns within buildings is an interesting topic and in certain sectors, such as the HE sector, remains somewhat overlooked. The HE sector is an incredibly varied and heterogenous environment; universities are diverse and the buildings can vary from research laboratories to aquatic sports centres [1]. The HE sector includes both colleges and universities, with the latter category of particular interest here. University buildings' expected baseload consumption differ accordingly, and lecture halls and teaching buildings are assumed to consume much less than laboratories [2]. Additionally, the consumption within these spaces is not always particularly well-understood, in part due to 'unregulated energy'. Ease of Use

A. Defining unregulated energy

The term "unregulated energy" refers to energy consumption where building regulatory standards do not impose a specific performance standard [3]. This consumption category includes equipment, servers, catering facilities, emergency and external lighting, supplementary heating, and lifts and escalators [4]. In comparison to this, regulated energy refers to Heating, Ventilation and Air-conditioning (HVAC), internal lighting and hot water [5]; these types of energy users are measured as a requirement of building regulatory standards. Based on the findings of this ongoing research, it has been noted that relevant papers that do assess this type of energy are all relatively modern and hence suggest a modern interest within this topic [4,6,7]. The issue here is that if unregulated energy is not accurately predicted during the design stage, it will affect the actual consumption within a building. Typically, it has been found that actual energy and predicted energy differ for a variety of reasons, including oversights at the design, construction and operational stages, and due to unexpected differences in occupants' behaviours [6-7].

Research focused on assessing unregulated energy within laboratories is particularly scarce in the literature. Several researchers focus on small-power loads [8-9], and others attest to the fact that unregulated energy can represent up to 50% of a building's total electrical consumption [10-11]. This percentage will naturally differ depending on the type of building and its use.

The total contributions of different types of unregulated energy vary, yet there remains a strong focus on equipment consumption. Small power loads can represent 20% of a building's total electrical consumption [12]. Naturally, understanding energy consumption in buildings is an ongoing challenge and one that is compounded by external events; this paper focuses on one example of such an event, namely the 2020 COVID-19 crisis.

EPSRC, and OVE Arup & Partners

B. The COVID-19 crisis

On the 17th March 2020, the case-study university officially closed its' campus buildings for students and staff at 17:00. Other universities have followed a similar course of action in light of the UK's governmental advice. On the 21st March, the UK government officially closed service industries, such as restaurants, leisure facilities and fitness studios [13]. Due to this event, the baseload consumption within universities will have been affected massively, as most are currently operating with only essential staff on campus.

The focus of this research, therefore, is to assess how unregulated energy consumption changed following the closure, within an engineering building selected from a case-study university. This case-study university was assessed as part of an ongoing PhD project. The university in question is characterised as being a "large" Russell group university, which has a combined staff and student population of over 50,000.

II. Methodology

A. Colelcting electrical data

For this study, electrical consumption data was collected for an engineering building, using an EMS to identify which sub-meters were classified as unregulated. Approximately 52 unregulated energy sub-meters were assessed during this process. In this instance, regulated sub-meters were defined as anything related to HVAC, internal lighting and hot water. As the focus for this work is unregulated energy only, the regulated sub-meters were discarded. Any sub-meters which were linked to lifts, equipment, emergency or external lighting, servers, catering facilities or specific room sub-meters were assessed as part of this work. The room sub-meters were included in this analysis as they provided further understanding of how different room-types respond to reduced occupancy levels.

B. The case-study university

The engineering building used for this study was selected due to its' high levels of granular sub-metering, which allowed the researchers to separate regulated and unregulated energy. The building was constructed in 2015, has a Net Internal Area of 4410m2, and had a total 2019 electrical consumption of 4,236,780kWh. It is a modern, research engineering building that is only used by staff and postgraduate students.

For the room-specific sub-meters, the selected sub-meters measured only equipment consumption and the results are thereby considered to be just unregulated energy.

The sample-set of data was essentially taken over three years. 2020 data was taken from 10/03/2020 – 30/03/2020; this represented exactly one week before the university closure, the week during the initial closure, and exactly one week after the closure. These three weeks of data were compared to both 2018 and 2019 datasets, using similar dates (13/03/2018 – 02/04/2018, and 12/03/2019 – 01/04/2019 respectively). As the first shutdown day was officially on a Tuesday, the exact dates used for the two prior years corresponded to this specific timeline. Easter weekend occurred on the 30/03/2028 – 02/04/2018, so it was expected that the end of the 2018 dataset offers lower consumption particularly across this specific weekend period.

The data was obtained was then broken down into annual, monthly, average daily consumption, and was compared to previous shutdown periods. Three-years' worth of data was assessed to help provide context for the different rooms (and different pieces of equipment) that were studied during this period. Of primary focus was the 2020 data, however, it was discerned that assessing data from previous years would act as a useful comparison.

Electrical consumption kWh measurements were used, instead of kWhm-2 measurements, as it was found that the sub-metering did not align with the floorplan designs of the buildings. In future work, the researchers will visually assess the building to help align the floorplan designs and the sub-metering information making kWhm-2 measurements available for future work.

In this building, 52 unregulated energy and room sub-meters were assessed, and their results were tallied. For all of the identified unregulated energy sub-meters, 2018, 2019 and 2020 data were compared. An overall percentage reduction was also calculated for the 2020 shutdown period. This conference paper presents results from five sub-meters, and in some lesser detail discusses the additional 47 sub-meters within the Results section.

III. Results

The results presented here focus on five sub-meters, which offered either interesting consumption patterns or indicated a large change in total unregulated electrical consumption. For these findings, only a few specific rooms have been assessed within the building; further findings will be published in future works.

Table 1 presents the total three-week period consumption for the five sub-meters, across the 2018, 2019 and 2020 timeframes, as were highlighted in the Methodology.

Table 2 focuses purely on the 2020 data and breaks down the three weeks' total consumption.

Table 3 compares the shutdown period data to the Christmas 2019 shutdown period. For the sake of fairness and clarity, approximately 11 days were assessed across the Christmas shutdown and the COVID-19 shutdown. The dates for this analysis are indicated in Table 3. 11 days were assessed here, to fully explore the entire Christmas 2019 shutdown period. In relation to this, 11 days of the COVID-19 shutdown were also assessed, to act as a comparison for this period.

Figure 1, Figure 2 and Figure 3 focus on three specific sub-meters which offered interesting patterns across the consumption data.

TABLE I. COMPARISON OF THREE-WEEKS' WORTH OF DATA DURING MARCH, TAKEN FROM 2018, 201 AND 2020, FOR FIVE SUB-METERS.

Building - submeters	**2018 – 2020 kWh comparison**		
	2018	***2019***	***2020***
S-24: Research lab 1	1019	1062	673
S-25: Research lab 2	1102	500	168
S-14: Open plan research lab (1)	4464	1675	1853
S-15: Open plan research lab (2)	1060	1263	757
S-107: Passenger lift	328	323	206

TABLE II. THE BUILDING'S 2020 COMPARISON, FOR THE SELECTED SHUTDOWN PERIOD.

Building – submeters	**2020 kWh weekly comparisons**		
	Week 1	***Week 2***	***Week 3***
S-24: Research lab 1	364	167	143
S-25: Research lab 2	156	12	0
S-14: Open plan research lab (1)	1518	230	105
S-15: Open plan research lab (2)	421	185	151
S-107: Passenger lift	93	64	49

TABLE III. COMPARISON OF THE COVID-19 SHUTDOWN PERIOD DATA (22/03/2020 – 01/04/2020) TO THE CHRISTMAS SHUTDOWN PERIOD (22/12/2019 – 01/01/2020).

Building - submeters	**COVID-19 shutdown kWh consumption vs Christmas consumption**		
	Christmas 2019	***COVID-19***	***% difference***
S-24: Research lab 1	532	224	58%
S-25: Research lab 2	150	0	100%
S-14: Open plan research lab (1)	2263	165	93%
S-15: Open plan research lab (2)	479	235	51%
S-107: Passenger lift	95	76	20%

It is noted here that S-14 and S-15 measure the same room and measure different pieces of equipment. Figure 1 assesses S-14 (Open plan research lab (1)) and focuses on daily consumption across Week 2, 2020. Figure 2 illustrates the total 2020 consumption for S-25 (Research lab 2) – this data collection period stopped on the 15th May, which was the last day of research for this paper. Finally, Figure 3 illustrates the average daily consumption for S-107 (Passenger lift) using data from the three weeks and comparing the data across 2018, 2019 and 2020.

The results obtained within this study are further explored below.

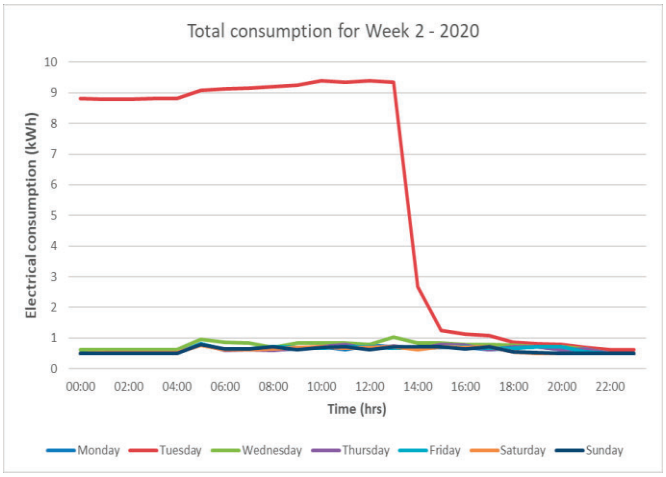

Figure 1. S-14's total daily consumption across Week 2 in 2020, calculated for each weekday.

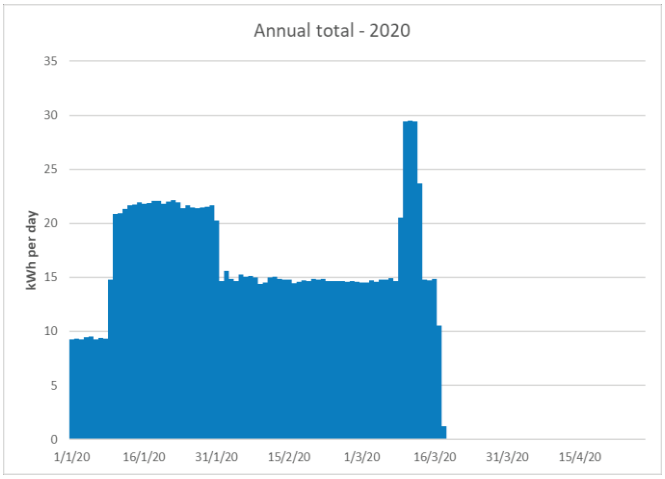

Figure 2. S-25's total annual consumption, in 2020.

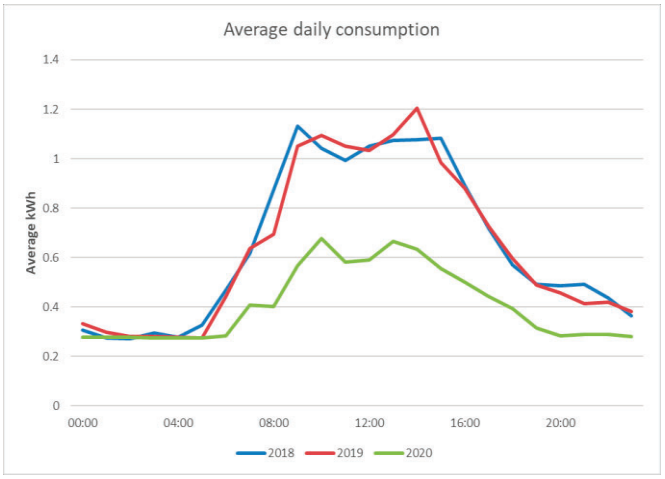

Figure 3. S-107's average daily consumption comparison across the three-week dataset, using 2018, 2019 and 2020 data.

IV. Discussion

The data from the building indicates very variable patterns in room-level electrical consumption. Within the engineering building, it was found that different types of rooms varied substantially from one another. The consumption patterns, when comparing the 2020 shutdown period to the comparative 2018 and 2019 periods, were also immensely diverse. Such a finding is not surprising, as it was expected that the 2020 consumption period would be much lower.

A. Five sub-meter comparisons

In the engineering building, S-14 (Open plan research lab (1)) indicated a particularly large decrease in consumption during the COVID-19 shutdown. For each of the sub-meters, there were noticeable decreases during Week 2 and Week 3.

Table 1 indicates the total effects of electrical consumption across three years, and the data covers exactly three weeks. Interestingly, S-14 indicated an increase in consumption values, when comparing 2019 and 2020 data. The 2019 Easter period did not coincide with the 2019 dataset, hence the reason for the lower 2019 data is uncertain. For the 2020 data, there was a large noticeable reduction in electrical consumption particularly on Tuesday in Week 2. This matches the findings in Figure 1, which demonstrates for S-14 that the most noticeable data point is Tuesday 17th March. In this case-study university, staff members were officially notified on 16th March that the university was considering closure in alignment with COVID-19 guidelines. Then, staff members were informed at noon on 17th March that the building needed to be emptied by 17:00 of the same day. The Tuesday data line, in Figure 1, corresponds to this announcement.

For the five sub-meters in this study, there was a very clear decrease on the 17th March that occurred more-or-less throughout the day. This response matches up to what would be expected for the sub-meters, as the staff were aware the buildings needed to be emptied by 17:00. This does offer an interesting view, however, of how quickly the effects of reducing occupancy have on also reducing unregulated energy consumption.

Table 2, on the other hand, compares the 2020 data for the selected five sub-meters. Again, S-14 represents the most noticeable differences, where a massive reduction in consumption is easily noticeable between Week 1 and Week 2. S-15 (Open plan research lab (2)) acts an interesting comparison here, where the consumption greatly differs to S-14, even though these sub-meters measure the same room (but different pieces of equipment).

Table 3 assesses the Christmas shutdown period, for all five sub-meters, and compares to the current COVID-19 shutdown period. For the sake of fairness, and to match the Christmas shutdown timeline, 11 days after the initial shutdown period was totalled here. These findings indicate that during the current shutdown period, consumption is much lower than during the previous Christmas shutdown period. Were HVAC values included within these sub-meter readings, it would be expected that electrical consumption during winter would be higher than in spring. However, these sub-meters only provide equipment consumption readings. It is suggested therefore that this shutdown period is more effective than previous Christmas shutdown periods. The COVID-19 shutdown data suggests that its' scale of reduction may be possible at other times of the year, such as through future Christmas shutdowns. When the COVID-19 period is compared to Easter, the reduction in consumption is also much higher, though this is mainly due to the building remaining open-access across the Easter Weekend.

Figure 2 displays the annual 2020 data for S-25 (Research Lab 1), which is a relatively standard research laboratory. It was noted that the electrical consumption of this room decreased substantially, to the point there were no electrical readings in Week 3. The sub-meter has been checked and appears to be functioning properly, thereby this massive reduction in consumption values may simply be an indication of minimal consumption within the room. The actual room itself is low-consuming, so such a finding is not impossible, though it is surprising that no kWh figures were detected at all. This indicates that the occupancy of this room must have been minimal throughout this period, and continues to indicate no readings up until the middle of May.

Figure 3 focuses on S-107 (Passenger lift) and compares the average daily consumption for 2018, 2019 and 2020, during the selected data timeframe. As expected, the 2018 and 2019 periods perform similarly, and a steady increase in consumption is noticed across an average day. kWh consumption also decreases to a minimal baseload during out-of-office hours. The 2020 data, on the other hand, suggests a different consumption baseload. Whilst the daily consumption pattern performs similarly to 2018 and 2019, the maximum consumption across the day is much smaller. For future work, the researchers will assess the 2020 Week 1 – Week 3 average daily consumption patterns for the selected sub-meters.

For the five specific sub-meters, the reduction in consumption between Week 1 and Week 2 ranged from 31% - 92%. The reduction in consumption between Week 2 and Week 3 ranged from 14% - 100%. Hence the massive differences in occupancy and equipment usage, even on a room-by-room level, are immediately noticeable.

B. The additional unregulated energy sub-meters

Finally, whilst not considered in-depth for this paper, an additional 47 unregulated energy sub-meters were also considered using the same approach as above. Out of a total of 52 unregulated energy sub-meters and using 2020 data, it was found that between Week 1 and Week 2, nine sub-meters indicated a higher consumption pattern in Week 2 than Week 1. The percentage differences in these periods were relatively minor, however, and ranged between 0.04% - 8.61%. The latter range referred generally to "1st Floor small power", hence the consumption values were very low during this period, and an increase in consumption was still considered to only be a minor increase. For the sub-meters where Week 1 and Week 2 perform similarly, or for the sub-meters that consumed more energy, these sub-meters were all related to communication rooms, life safety power, cleanrooms, small power loads for entire floors and an EBL beam.

For all the identified 52 unregulated energy sub-meters, there was an overall percentage decrease of 46.61%, when comparing Week 1 and Week 2, and a 10.59% decrease when comparing Week 2 and Week 3.

V. Conclusions

In this study, an engineering building was assessed using an EMS. Data were selected from the COVID-19 shutdown period and compared to previous years' data from the same timeframe. The unregulated sub-metering overall indicated that electrical consumption levels generally decreased during the selected timeframe. Only nine of the assessed 52 unregulated energy sub-meters indicated higher or similar levels of consumption, before the shutdown period.

For the sub-meters selected within this study, it was noted that Christmas shutdown periods could not be easily compared to the COVID-19 shutdown period. The current electrical consumption during this COVID-19 shutdown period is also much lower than for the typical Easter weekend.

Out of 52 unregulated energy sub-meters, it was noticed that the majority of the rooms indicated a massive decrease in electrical consumption, which primarily occurred on the 17th March, and occurred between 12:00 – 17:00. This coincided with the university's official notice to close. Consumption after this timeframe is noticeably much lower, which is naturally to be expected for this shutdown period. What was not expected was the total percentage decrease in overall consumption on a building-scale, and a room-level scale. As indicated in the Discussion, the five sub-meters indicated a large percentage difference between Week 1, Week 2 and Week 3.

For certain unregulated energy devices, such as S-107 (Passenger lift), the data indicated a general high baseload in consumption, even when the building was officially unoccupied (except for essential staff). This helps to further indicate the total effect specific types of unregulated energy can have, even on an individual object level. Hence, future interest will focus on how the continuing COVID-19 shutdown period will continue to affect unregulated energy devices such as S-107.

Finally, there is a clear correlation between unregulated energy and occupancy levels. Staff typically have immediate control of their environment, and hence this helps to confirm that unregulated energy can be defined as user-related. Rooms that sustained high levels of energy consumption were primarily comms rooms, or server rooms, and have little relationship to occupancy levels. Instead, they were required to remain operational, to sustain the university's campuses.

A. Recommendations

Based on the analysis conducted for this study, it is recommended to the university that sufficient shut-down procedures are implemented across all buildings. This would include a list of all types of equipment that require turning off and a list of equipment that requires being left on. A checklist and series of timings of the equipment being turned off are also suggested here. This paper acknowledges that such a topic is new, and requires much further research. One suggested method for improving this study is to correspond further with building managers to understand how the building is typically used. This will also help further understanding of what actions were taken during the COVID-19 shutdown period. A list of shutdown actions completed during Week 2 and Week 3 would also greatly benefit this work. Finally, assessing further building types will help to determine how different buildings respond to minimal occupancy.

Acknowledgment

The authors thank and gratefully acknowledge the support of our departmental colleagues.

References

[1] L. P. Amaral, N. Martins, and J. B. Gouveia. (2015, Feb.). "Quest for a sustainable university: a review", International Journal of Sustainability in Higher Education, vol. 16, pp. 155-172.

[2] HECFE. (1996, May.). "Energy management study in the higher education sector: management review guide", Reference M16/96, Bristol.

[3] BREEAM. (2016, Aug.). "Ene 01 Reduction of emissions" [Online]. Available: http://www.breeam.com/BREEAM2011SchemeDocument/content/06_energy/ene01_general.htm.

[4] CIBSE. (2012, Sep.). "GVF2012 Guide F: Energy Efficiency in Buildings (3rd ed.)". London: CIBSE, pp. 1 – 288.

[5] Ministry of Housing, Communities & Local Government. (2016). "Approved Document L2B: Conservation of fuel and power in existing buildings other than dwellings, 2010 edition (incorporating 2010, 2011, 2013 and 2016 amendments)" [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/540329/BR_PDF_AD_L2B_2013_with_2016_amendments.pdf.

[6] C. Demanuele, T. Tweddell, and M. Davies. (2010, Sep.). "Bridging the gap between predicted and actual energy performance in schools". World Renewable Energy Congress XI, [Online]. Available: https://www.maxfordham.com/assets/media/images/publications/Bridging%20the%20gap/WREC_paper_bridging_the_gap.pdf.

[7] A. C. Menezes, A. Cripps, D. Bouchlaghem, and R. A. Buswell. (2012, Sep.). "Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap", Applied Energy, vol. 97, pp. 355-364.

[8] M. Mulville, K. Jones, and G. Huebner. (2014). "The potential for energy reduction in UK commercial offices through effective management and behaviour change", Journal of Architectural Engineering and Design Management, vol. 10, pp. 79-90.

[9] C. Van Dronkelaar, M. Dowson, C. Spataru, and D. Mumovic. (2016, Jan.). "A Review of the Energy Performance Gap and Its Underlying Causes in Non-Domestic Buildings", Frontiers in Mechanical Engineering, vol. 1, pp. 1-17.

[10] K. Dougherty. (2018, May.). "Unregulated energy – why we should care" [Online]. Available: https://www.cibsejournal.com/opinion/unregulated-energy-why-we-should-care/.

[11] Designing Buildings Wiki (2020, Jan.). "Regulated and unregulated energy consumption" [Online]. Available: https://www.designingbuildings.co.uk/wiki/Regulated_and_unregulated_energy_consumption#Unregulated_energy.

[12] A.C. Menezes, A. Cripps, R. A. Buswell. And D. Bouchlaghem. (2013, Feb.). "Benchmarking small power energy consumption in office buildings in the United Kingdom: A review of data published in CIBSE Guide F", Building Services Engineering Research & Technology, vol. 34(1), pp. 73-86.

[13] Department of Health and Social Care. (2020, Mar.). "New regulations created by Secretary of State for business closure (COVID-19)" [Online]. Available: https://www.gov.uk/government/news/new-regulations-created-by-secretary-of-state-for-business-closure-covid-19.