An Analysis of Changes in Electricity Consumption at the University of Edinburgh's Appleton Tower Due to the COVID-19 Pandemic

Adam Russo

25th March 2025

1 Overview

This report examines the impact of the COVID-19 pandemic on the consumption of electricity at the University of Edinburgh's Appleton Tower. Through the analysis of the average daily and the average hourly electricity consumption, this report will explore any changes that occurred during and after the COVID-19 pandemic. Two key visualisations were created to determine if any such changes had taken place: one comparing the average hourly electricity consumption throughout an average day and one comparing the average daily electricity usage across semester months. The statistical and practical significance of the change was assessed using a paired t-test on consumption data from pre-pandemic, during-pandemic and post-pandemic periods.

The analysis revealed a significant decrease in electricity consumption during and after the pandemic compared to pre-pandemic levels. The analysis revealed a remarkably similar diurnal daily electricity usage pattern between the pre-pandemic and post-pandemic periods. This pattern helps explain the drop in electricity consumption as a decrease in building occupancy, due to the adoption of hybrid working by students and staff following the pandemic. These findings support the notion that the COVID-19 pandemic has had a lasting impact on Electricity consumption at Appleton Tower.

2 Introduction

Context and motivation Appleton Tower is a centrepiece building at the University of Edinburgh's George Square Campus offering five lecture theatres, teaching studios, seminar spaces and a concourse area which includes a cafe. During term times, the building is mainly used by students and staff as a space for organised study and work[13].

The COVID-19 pandemic was caused by the outbreak of the novel SARS-CoV-2 virus. The first recorded outbreak was in Wuhan, China in December 2019. The virus quickly spread all over the world with Scotland recording its first case of the novel virus on the 1st March 2020. Mitigations taken by the Scottish Government to lower the spread of COVID-19 include a stay-at-home order ('lockdowns'), travel restrictions and the closure of higher education institutions at various times since the 23rd March 2020[8].

During the COVID-19 pandemic, there was a significant transition from traditional in-person employment to remote working. At the peak of the lockdown in June 2020, 49% of workers in Great Britain were working from home, compared to approximately 12% prior to the pandemic[6]. As restrictions eased, many organisations adopted a hybrid model where employees would split their time between in-person and remote work[10]. Hybrid working proved to be popular with 22% of the workforce working from home at least once a week as of September 2022[6]. Similarly, at the University of Edinburgh, hybrid working practices remain prevalent with the majority of students and 90% of staff indicating interest in continuing working in a hybrid style post-pandemic[7].

Previous work Filimonau et al. reported that Bournemouth University saw a significant decrease in electricity usage in its buildings during the spring 2020 lockdown. However, they did note the results to be less significant than expected and highlighted the significant amount of electricity needed to maintain university campuses even in the absence of staff and students[3]. Research conducted by Mantesi et al. concluded that post-pandemic offices who employ a hybrid working model could use 50% less energy compared to pre-COVID-19 levels[5].These findings provide context for examining whether similar trends in electricity consumption are observed at the University of Edinburgh's Appleton Tower.

Objectives The objectives of this report are to determine if there was a change in electricity consumption at Appleton Tower during and after the COVID-19 pandemic. If any change has occurred, this paper will examine if this change is due to the changing working patterns of Appleton Tower's users or if it likely due to other confounding factors. This report will examine the trends in the electricity consumption at Appleton tower over three periods: pre-pandemic, during the Pandemic and Post-Pandemic to determine if a shift in consumption patterns occurred due to the pandemic. This study will conduct both visual and statistical analyses.

3 Data

Data provenance The data set used for this report was kindly provided by the Energy Manager, Alan Hughes, at the Estates Department of the University of Edinburgh. The data set was provided under the Copyright University of Edinburgh license, a license that allows the data to be used in any way the user sees fit. The license requires that its full bibliographical details are provided with any re-used material[1]. This report has used the data according to these rules and therefore has not breached the data license.

Data description The data set was provided in an .xlsx spreadsheet which was then downloaded as a CSV file format. The data set constrained 6270 records in total that provided data on the electricity and heat utilities consumed by the Appleton Tower from the 1st January 2016 to the 31st July 2024. There were 59 columns in total with the following being used in the analysis. Utility (provided the distinction between electricity and heat data), READING DATE (provided the date the readings of the record were made on), UNITS (Unit of utility being recorded) 48 columns spanning from 00:30hrs to 23:30hrs made in half-hour intervals (providing the half-hourly usage of each utility), Daily Total (Daily Total of the consumption of the given utility per day), Data Source and Min Reading (Minimum recorded consumption of utility per day).

Data processing The original data set, provided as a CSV file, was loaded into a pandas Data Frame. Given that this analysis focuses solely on electricity consumption, records pertaining to heat consumption were excluded. To clean the data, the Data Frame was initially checked for duplicated entries, with none found. Subsequently, records containing zero or negative values were removed, as these represented invalid or missing data points. The 'READING DATE' column was then converted into a pandas datetime object. An additional column indicating the month of the year, 'month', was created to aid in later analysis. Furthermore, all electricity records predating the 11th December 2018 were removed due to their origin from the 'N' Data Source. These records accounted for approximately 33% of the dataset and exhibited significantly larger values compared to those from the 'O' Data Source which made up the remaining 66% of the dataset, thereby skewing the analysis. Finally, the cleaned Data Frame was segmented into three distinct time periods that align with the University of Edinburgh's semester dates [11]: Pre-Pandemic (11th December 2018 – 23rd March 2020), During Pandemic (24th March 2020 – 23rd May 2021), and Post-Pandemic (20th September 2021 – 27th May 2024)[8]. Data from June to August was omitted across all periods since the analysis focuses exclusively on semester times, excluding the irregular consumption patterns observed during the University of Edinburgh's summer break. Irregularities found in the summer break are caused by Edinburgh's Fringe festival, which sees a large spike in energy consumption due to Appleton Tower being used as 'Venue 2' of the Fringe[12]

4 Exploration and analysis

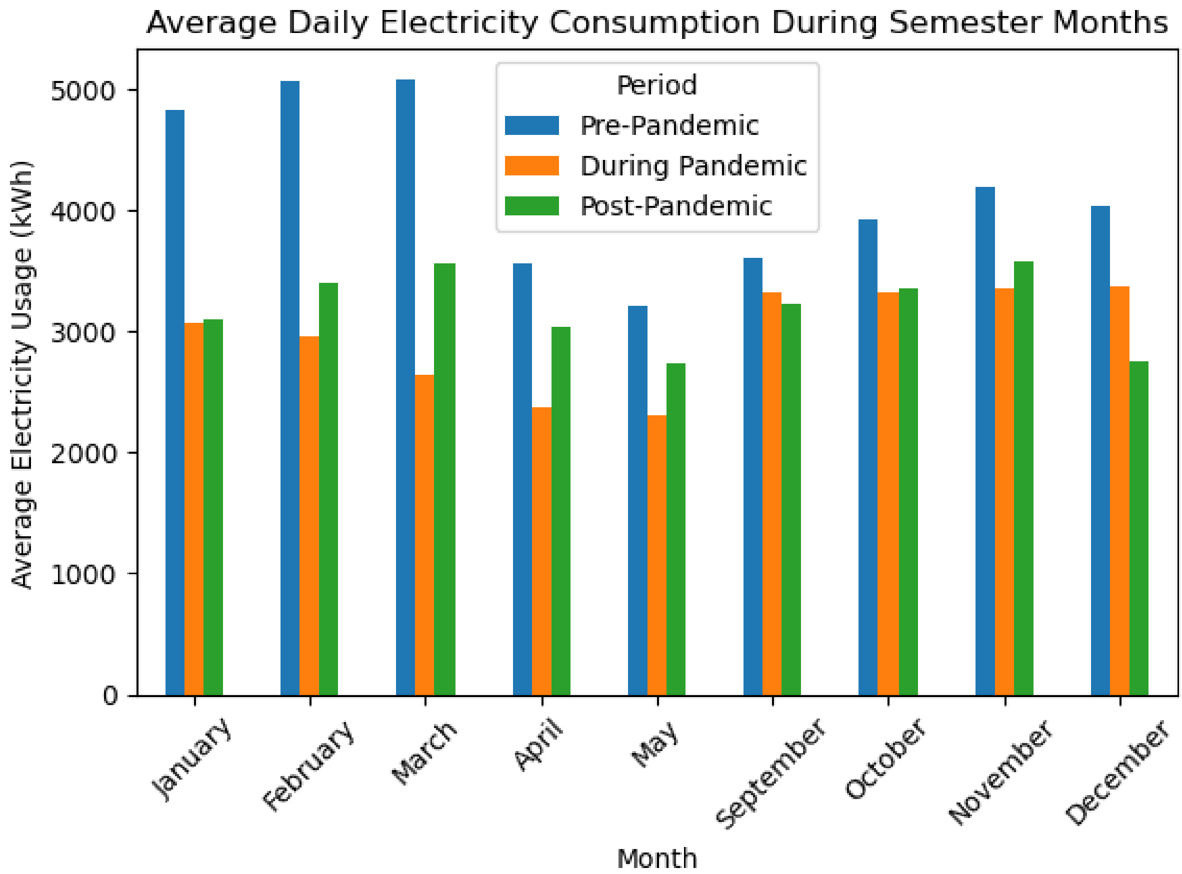

Figure 1: This bar chart compares the average daily electricity consumption (kWh) during semester months across three distinct time periods: Pre-Pandemic, during Pandemic, and Post-Pandemic.

Interpretation of the results Figure1 shows that the average daily electricity consumption was highest in the pre-pandemic period for every semester month observed. Consumption was shown to be significantly lower during the pandemic, with a noticeable drop in March, which contradicts the trend shown both before and after the pandemic. The drop in March can be contextualised by the lockdown's stay at home order[8], which will have significantly reduced Appleton Tower's occupancy. In contrast, the Post-Pandemic period shows a partial rebound in electricity consumption, though it remains below pre-pandemic levels across all months. It is of interest that in September and December, the average daily consumption of electricity in the post-pandemic period was lower than during the pandemic, despite no restrictions being in place. This suggests that other confounding variables, such as improved energy efficiency, may be contributing to these observed trends.

To assess the statistical significance of the differences in the mean average daily energy consumption across periods, paired t-tests were employed. Paired t-tests assume a natural pairing of observations and that the sampling distribution of the difference within each pair (e.g. post and pre-pandemic values) is approximately normal [2]. Since all the electricity consumption data is drawn from Appleton Tower, the observations across periods are naturally paired. Additionally, the large sample sizes justify the normality assumption through the Central Limit Theorem [2].

Table1 shows the three paired t-tests that were conducted to compare the daily electricity usage between the pre-pandemic, during pandemic, and post-pandemic periods. Each test was conducted at the 5% significance level with each test having 8 degrees of freedom.

Table 1: Paired T-Test Results for Electricity Consumption

Comparison	**Mean Diff.**	**t-statistic**	**p-value**	**Cohen's d**
Pre vs During	1200.93	4.8990	0.0012	1.6330
Pre vs Post	974.60	5.2416	0.0008	1.7472

For the paired t-test comparing pre-pandemic and during-pandemic electricity consumption, the null hypothesis (H_0) states that there is no difference in average daily consumption of electricity between the two periods, while the alternative hypothesis (H_1) suggests that there is a difference.As t(8) = 4.8990 and p = 0.0012, we have a statistically significant difference in electricity consumption; therefore, H_0 is rejected. Similarly, for the test comparing pre-pandemic and post-pandemic electricity consumption, H_0 states that there is no difference in average daily electricity consumption between the two periods, and H_1 indicates a difference. The results, t(8) = 5.2416 and p = 0.0008, leads to a rejection of H_0 due to the statistically significant difference.

Further insights into the change in average daily energy consumption between periods can be gathered by inspecting the mean difference and Cohen's d statistic. The mean difference in average daily electricity consumption dropped by 1200.93 kWh during the pandemic and by 974.60 kWh post-pandemic, relative to pre-pandemic levels.The cohen's d values, 1.6330 and 1.7472 respectively, are very high and therefore indicate a large effect size. This means that our results are not only statistically significant but also practically meaningful.

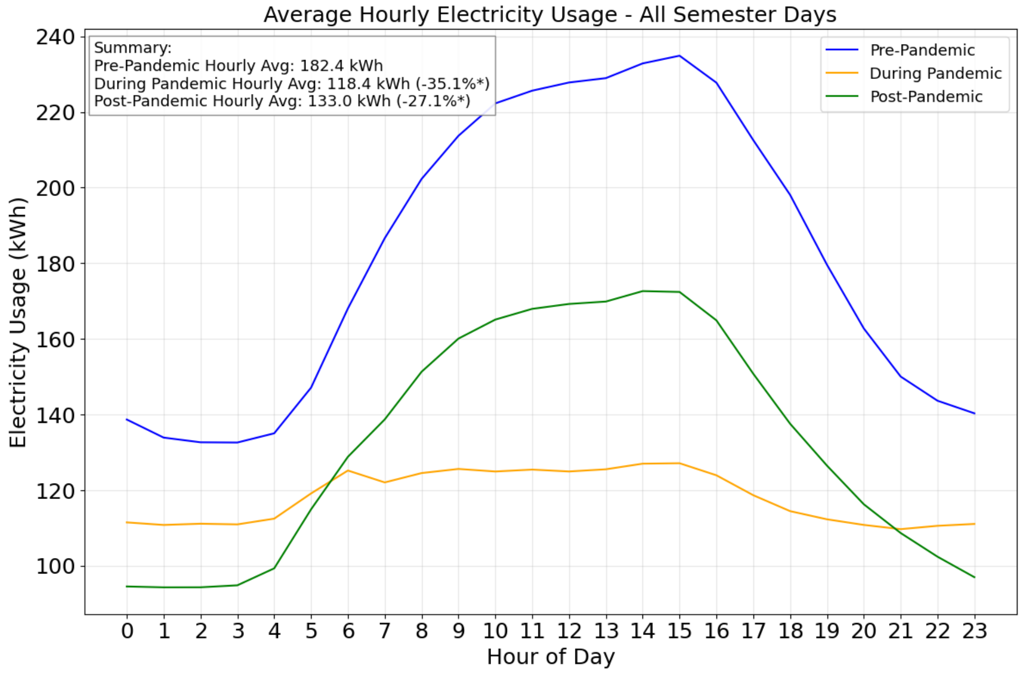

Figure 2: A graph comparing the average hourly energy consumption (kWh) for an average day across three distinct time periods: Pre-Pandemic, during Pandemic, and Post-Pandemic. * The average percentage difference of an hour when compared to same pre-pandemic hour.

Figure2 reveals various important insights regarding electricity usage patterns during an average day in each period at Appleton Tower. Pre-pandemic average hourly energy consumption is 35.1% greater than the average during the pandemic and 27.1% greater than the average post-pandemic. Despite these differences in magnitude, the pre-pandemic and post-pandemic average hourly electricity usage lines share a similar diurnal pattern. Lower consumption in the early morning and late evening, coupled with a pronounced midday peak from 9 a.m. to 5 p.m., corresponds to standard working hours in the UK[14]. This pattern suggests that electricity consumption in these intervals is largely driven by student and staff presence in the building. Notably, there is an extremely strong correlation ($\rho = 0.9922$) between the pre-pandemic and post-pandemic lines. Thus indicating that although the overall level of electricity consumption has changed, the underlying pattern in the daily electricity usage has largely returned to its pre-pandemic state. During the pandemic, average hourly electricity consumption also exhibits a diurnal pattern. The peak electricity consumption during the pandemic is both less intense and begins much earlier in the day. This suggests that, although daytime activity during the pandemic did increase electricity usage, the nature of that activity differed from pre- and post-pandemic conditions.

These findings support the notion that reduced occupancy, as seen with the adoption of hybrid working practices, is the primary factor driving the decrease in energy consumption. Other confounding factors cannot explain the large decrease in electricity consumption. For example, A study by the International Energy Agency, states that typical efficiency gains in commercial buildings yield reductions of around 10-20% in electricity consumption[4], much less than the observed decrease of 27.1% post-pandemic.

5 Discussion and conclusions

Summary of findings This report found there to be a significant decrease in electricity consumption at Appleton Tower both during and after the COVID-19 pandemic, when compared to the pre-pandemic period. Through the application of a paired t-test, the difference in average electricity consumption has been shown to be both statistically and practically significant. The analysis of the hourly energy usage patterns at Appleton Tower showed that despite a large drop in the magnitude of electricity consumption, the daily usage pattern of the building remained almost identical between the pre-pandemic and post-pandemic periods. This suggests that the decrease in electricity consumption is likely due to decreased occupancy which resulted due to a hybrid work model being adopted.

Evaluation of own work: strengths and limitations A Strength of this report was its clear and easy to interpret visualisations. Figure2 allowed the reader to analyse the hourly electricity consumption patterns and draw the conclusion that the pre-pandemic and post-pandemic usage patterns were similar without the use of complex statistical methods. Another strength was the paired t-test that supported figure1 as it provided significant results and helped to quantify the effects observed with the visualisation.

One weakness from this project was the way the data was cleaned. Removing all null and negative entries in the data set may not have been the best technique as it significantly reduced the number of available records and therefore hindered the accuracy of the analyses. In hindsight, imputation could have been used to replace missing and negative values. For example, if one day or time slot had null or negative data, then the corresponding value from the previous day could have been forward filled to replace it. This would have preserved data continuity and improved the robustness of the results.

Comparison with any other related work Filimonau et al. found a decrease in electricity consumption at Bournemouth University of 45% during the spring lockdown and noted that this decrease was largely due to decreased building occupancy[3].The findings do concur as this report found a decrease of 35.1% and concluded that the main cause of the decrease was reduced building occupancy caused by a hybrid work model. Filimonau et al. also investigated other factors and concluded that Bournemouth University had to significantly increase their electricity consumption for ventilation in order to meet the UK Government's COVID-19 advice. Unfortunately, this report failed to investigate the impact of ventilation and other confounding factors as this information was not available for Appleton tower.

Improvements and extensions A forecasting model, such as Meta's Facebook Prophet, could have been used to project what electricity consumption would have been in the post-pandemic period if pre-pandemic trends had continued. Facebook Prophet decomposes data into trend, seasonality and holiday effects[9]. By fitting Prophet, this report would have been able to quantify the specific impact of the reduced occupancy that resulted from the altered working patterns. This approach would have strengthened the analysis by isolating the effect of the pandemic from normal variations in electricity consumption.

Additionally, a comparison to other buildings at the University of Edinburgh could have been undertaken. Since Appleton Tower is mainly used for organised study it is possible that students opting to carry out the work independently could have instead been using other buildings such as the Main Library. With this data this report could have concluded if hybrid study had caused electricity consumption at the University to actually decreased or, if it had in fact just resulted in some buildings consumption decreasing while others increased, thus increasing the scope of this report.

References

[1] *Data and metadata policies*. Accessed: 19 March 2025. Aug. 2024. URL: `https://library.ed.ac.uk/research-support/research-data-service/after/data-repository/service-policies/data-metadata-policy`.

[2] Jay L. Devore and Kenneth N. Berk. *Modern Mathematical Statistics with Applications*. 2nd. Accessed 22/03/2025,(p. 509, P.298). Springer, 2018. DOI: 10.1007/978-1-4614-0391-3. URL: https://doi.org/10.1007/978-1-4614-0391-3.

[3] Viachaslau Filimonau et al. 'The carbon footprint of a UK University during the COVID-19 lockdown'. In: *Science of The Total Environment* 756 (2021), p. 143964. ISSN: 0048-9697. DOI: https://doi.org/10.1016/j.scitotenv.2020.143964. URL: https://www.sciencedirect.com/science/article/pii/S0048969720374957.

[4] International Energy Agency. *Energy Efficiency 2021*. https://www.iea.org/reports/energy-efficiency-2021. Accessed: 21 March 2025. 2021.

[5] Eirini Mantesi, Ksenia Chmutina and Chris Goodier. 'The office of the future: Operational energy consumption in the post-pandemic era'. In: *Energy Research Social Science* 87 (2022), p. 102472. ISSN: 2214-6296. DOI: https://doi.org/10.1016/j.erss.2021.102472. URL: https://www.sciencedirect.com/science/article/pii/S2214629621005594.

[6] N. Mutebi and A. Hobbs. *The Impact of Remote and Hybrid Working on Workers and Organisations*. POSTbrief 49. Accessed: 19 March 2025. UK Parliament, 2022. URL: https://post.parliament.uk/research-briefings/post-pb-0049/.

[7] A. O'Reilly. *The carbon impact of homeworking*. Accessed: 19 March 2025. Nov. 2021. URL: https://sustainability.ed.ac.uk/.

[8] Scottish Parliament Information Centre. *Timeline of Coronavirus (COVID-19) in Scotland*. https://spice-spotlight.scot/2021/03/19/timeline-of-coronavirus-covid-19-in-scotland/. Mar. 2021. (Visited on 19/03/2025).

[9] Sean J. Taylor and Ben Letham. *Prophet: Forecasting at Scale*. https://facebook.github.io/prophet/. Accessed: 23 March 2025. 2017.

[10] Thomson Reuters. *Practical Law – W-035-1935*. https://uk.practicallaw.thomsonreuters.com/w-035-1935?transitionType=Default&contextData=(sc.Default)&firstPage=true. Accessed: 21 March 2025. n.d.

[11] University of Edinburgh. *Semester Dates Archive*. https://semester-dates.ed.ac.uk/archive. Accessed: 21 March 2025. n.d.

[12] University of Edinburgh, School of Informatics. *History of Appleton Tower*. https://informatics.ed.ac.uk/about/explore-school-informatics/history-of-appleton-tower. Accessed: 21 March 2025. n.d.

[13] UOE Collection. *Appleton Tower*. https://www.uoecollection.com/conferences-events/venue-hubs/old-town-campus/appleton-tower/. Accessed: 21 March 2025. n.d.

[14] Use Multiplier. *Working Hours in the United Kingdom*. https://www.usemultiplier.com/united-kingdom/working-hours. Accessed: 21 March 2025. n.d.