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Impact of COVID-19 Pandemic on Energy Consumption in Office Buildings: A Case Study of an Australian University Campus

Sara Tavakoli [1], Wipa Loengbudnark [1], Melissa Eklund [1], Alexey Voinov [2] and Kaveh Khalilpour [1,*]

[1] Faculty of Engineering & IT, University of Technology Sydney, Sydney, NSW 2007, Australia
[2] Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands
* Correspondence: kaveh.khalilpour@uts.edu.au

Abstract: Building energy management, in terms of both adopted technologies and occupant consumption behaviour, is becoming an essential element of sustainability and climate change mitigation programs. The global COVID-19 pandemic and the consequential lockdowns and remote working had a notable impact on office building operations and provided a unique opportunity for building energy consumption studies. This paper investigates the COVID-19 effects on energy consumption in office buildings, particularly in the education sector. We studied different buildings at the University of Technology Sydney (UTS) campus before and during the pandemic period. The results demonstrate that the changes in energy consumption due to COVID-19 in different UTS faculties are not as strongly correlated with occupant activity. The comparison shows that buildings with administrative offices or classrooms are easier to switch to a remote-working mode than those housing laboratories and special equipment. During weekends, public holidays, or conditions requiring working from home, the per capita energy consumption increases significantly translating into lower energy efficiency. Our findings highlight the essential need for some changes in office building energy management systems. We provide recommendations for office and commercial buildings in general to deal with similar crises and to reduce energy overconsumption in normal situations.

Keywords: COVID-19; lockdown; building energy management; building management system (BMS); commercial building; university building

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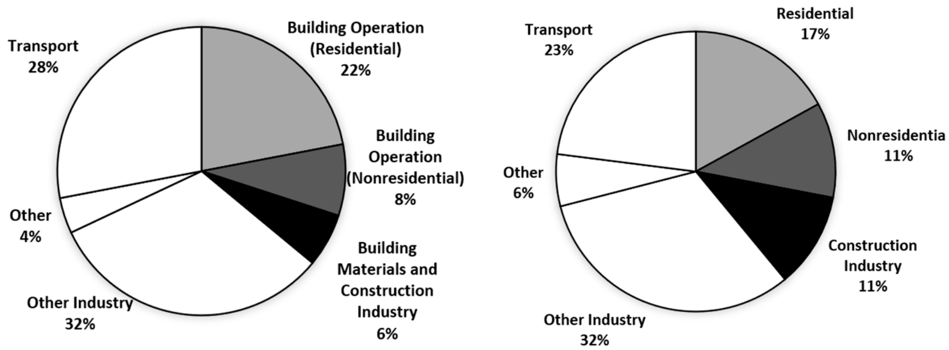
1. Introduction

Buildings are one of the major energy-consuming and CO_2-emitting sectors. According to the International Energy Agency (IEA), in 2018, the building and construction sector consumed more than one third of the global energy (36%) and accounted for 39% of global CO_2 emissions [1]. As shown in Figure 1B, most of these emissions (28%) come from building operations (residential and nonresidential), while the construction industry (embodied carbon in buildings materials, such as steel, cement, and glass) is accountable for 11%.

In this context, one legitimate enquiry is to investigate the impact of global pandemics and remote working on building energy efficiency and assess how the change in building occupancy impacts energy consumption and efficiency. This paper addresses these questions by reviewing the published reports and studying several educational buildings of the University of Technology Sydney (UTS) in the business district of Sydney, Australia. This study provides recommendations for improved energy management in both lockdown and normal situations. The main contributions of this study are identification of energy-saving potential in office buildings, providing recommendations for policymaking for remote learning and working from the energy consumption point of view, providing recommendations for energy management system changes in buildings, and providing energy-related lessons and emerging opportunities identified during quarantine. This investigation is mainly based on analyses of the Australian energy systems context, but the results and recommendations can be easily extrapolated for similar systems elsewhere.



(**A**) Global energy consumption (**B**) Global CO_2 emissions

Figure 1. Sectoral distribution of global energy and emissions (data from [2]).

1.1. Lockdowns and Energy Consumption

The first cases of COVID-19 were reported at the end of 2019 in China. Within a few months, cases were reported worldwide, and in March 2020, the World Health Organisation (WHO) declared a global pandemic [3]. Consequently, social distancing, targeted quarantines, and community lockdowns were considered effective ways to control the virus spreading. What at first seemed to be temporary lockdowns and mandatory holidays, turned into a permanent change in societies, referred to as the "new normal". In many parts of the world, industries and businesses were closed or worked under capacity. Except for the essential services, other activities, including education, became virtual with remote attendance. Along with the many reported negative impacts, the reduced business activities and communication virtualisation had some positive consequences, including reduced road traffic and reduced global greenhouse gas emissions. As such, the Earth Overshoot Day was delayed for over three weeks from 29 July 2019 to 22 August in 2020 [4].

Initially, some researchers believed that there would be an energy consumption reduction, and many studies showed this assumption was valid. Table 1 provides a list of studies that have reported the impacts of the COVID-19 pandemic on energy consumption across the world. Aruga et al. [5] reported a nearly 20–40% reduction in power demand in India between 25 March and May 2020. Their study included different regions of India and showed that even during the pandemic, as the lockdown regulation relaxed, energy consumption in wealthier regions recovered to the pre-COVID-19 level much more quickly. India energy demand was one of most affected ones in the world based on published reports and papers. According to the US Energy Information Administration (EIA) [6], energy consumption in the US reached its lowest value since 1989 in April 2020. Energy consumption in the US had an increasing rate since the 1980s with an exception in 2008–2010, but the COVID-19 impact was much worse than the 2008 financial crisis. Comparing similar times in 2019 (the prepandemic year) and 2020, the average daily load across peak hours showed a more than 30% reduction in some days in March and April 2020 in Italy, France, and the UK [7]. A study in Spain reported a 38% decrease in the nonresidential sector during full lockdown and 14% after that [8]. This study presents four different clusters of nonresidential consumers with different behaviour during and after severe lockdowns. While country-level data give policymakers insights, focused and clustered data give planners and middle policymakers valuable data for providing recommendations. In Kuwait, the electrical power demand was reduced by 17.6% compared with the expected demand [9]. Kuwait energy consumption per capita is the highest in the world, and the residential sector consumed 62% of the total energy consumption during the lockdowns. This reveals a serious need for detailed studies in the residential sector in Kuwait. Carvalho et al. [10] reported a 7% to 20% decrease in different Brazilian subsystems (7% in the subsystem with mainly residential load). Compared to many other countries that experienced increased consumption in the residential sector, Pakistan experienced an 11% decrease in energy consumption [11]. The authors investigated the effect of the pandemic on energy consumption on a country level and provided recommendations for country energy authorities. The New Zealand wholesale electricity demand decreased by 12% at level-4 restrictions (highest level, 26 April 2020–27 May 2020) leading to a 62.5% drop in electricity price [12]. Low electricity prices may hinder power system projects, especially in countries with free markets for electricity. Comparing the 2020 real demand with the estimated demand shows a decrease between 6% and 30% in Latin American countries [13]. Yet, in some countries, such as Sweden, with no lockdowns, energy consumption increased compared to the same period in 2019 [14]. The authors studied the daily patterns and found that while the weekday peak load declined, the evening peak load remained the same, and Thursday evening and weekend consumption increased. These results show that while energy systems were affected by COVID-19 in most countries, the effects are different, and there is a need for local studies.

Similar trends in the national-level energy consumption have been reported at the business level. For instance, 16% of the annual energy use of a university in southeast Queensland, Australia was saved due to shifting from on-campus teaching/learning to a virtual campus mode. Air conditioning shutdown led to a 57% decrease per week in some buildings [15]. The energy use at the University of Almeria (Spain) decreased by 2–42% in different buildings in 2020 versus 2019 [16]. While each building has its unique features, these results show the great potential of energy saving in academic buildings when they are sparsely occupied.

Table 1. Overview of studies on energy consumption during the COVID-19 pandemic in different locations.

Location	Change Value	Sector	References
India	−20% to −40%	Total electricity consumption	Aruga et al. [5]
The United States	−11%	The commercial sector electricity consumption	The U.S. Energy Information Administration [6]
	−9%	The industrial sector electricity consumption	
Italy, France, and the UK	−30% or more	Electricity consumption during peak hours	Bruegel [7]
Spain	−38%	The nonresidential sector electricity consumption	Garcia et al. [8]
Kuwait	+17.6%	Total electricity consumption	Alhajeri et al. [9]
Brazil	−7% to −20%	Total electricity consumption	Carvalho et al. [10]
Pakistan	−11%	Total energy consumption (electricity consumption and fossil fuel consumption)	Iqbal et al. [11]
Peru	−32%	The maximum deviation of real electricity consumption compared to estimated electricity consumption in 2020	Sanchez-Ubeda et al. [13]
Bolivia	−27.6%		
Dominica	−16.8%		
Costa Rica, Guatemala, Mexico, and Argentina	−10.9% to −14.3%		
Chile and Uruguay	−5.8% to −6.3%		

Table 1. *Cont.*

Location	Change Value	Sector	References
Queensland, Australia	−16%	Total electricity consumption of Griffith University	Gui et al. [15]
Spain	−2% to −42% in different buildings	Electricity consumption of the University of Almeria's buildings	Chihib et al. [16]
Sweden	+2.1%	Total electricity consumption	Bahmanyar et al. [14]
New York, US	Decreased	Total electricity consumption	Meinrenken et al. (The Columbia Climate School) [17]
	+7%	The electricity consumption of apartments on weekdays	
	+4%	The electricity consumption of apartments on weekends	
	+23%	The residential sector electricity consumption during working hours (9 a.m. to 5 p.m. weekdays)	
Melbourne, Australia	−7%	The commercial sector	Energy Networks Australia [18]
	−1%	The industrial sector electricity consumption	
	+14%	The residential sector electricity consumption	
Cross-country comparison	+29.3%	The projected energy intensity (GDP/Mtoe) of the USA	Jiang et al. [19]
	+7.8%	The projected energy intensity of Japan	
	+2.8%	The projected energy intensity of China	
	+1.03%	The projected energy intensity of the EU	

The pandemic had various effects on energy consumption in different sectors. Although electricity consumption in New York city decreased due to the closure of many office buildings and businesses, the electricity demand of apartments in New York City increased by 7% on weekdays and 4% on weekends. There was an even larger increase (23%) in residential electricity demand during working hours (9 a.m. to 5 p.m. weekdays) [17]. Comparing the data of two weeks, before and during the pandemic in northwestern Melbourne, shows a 7% decrease in the commercial sector and a 1% decrease in the industrial sector. There was also a 14% increase in the residential sector [18]. During lockdowns, most of the people worked or studied from home, keeping their numerous laptops or home computers on during working hours and class times. Additionally, household heating, ventilation, and air conditioning (HVAC) systems and other appliances were on during these hours instead of being fully or partially off (depending on the number of household members at work) at the same time before the pandemic.

In different countries, the energy consumption rate declined during the first few weeks of the pandemic, and recovery after that varied greatly. For instance, the USA showed a 29.3% increase in the forecast of energy intensity (GDP/Mtoe), followed by Japan with 7.8%, while the change was far less for China at 2.8% and the EU at 1.03% [19]. Even in a single country, the electricity consumption patterns may differ among regions. According to Aruga et al. [5], energy consumption has not been restored in the northern regions and northeastern regions of India as fast as in other regions. Yet, there is a need for studies focused on a more specific energy consumption pattern. A growing number of such studies and reports can be expected in the coming years.

1.2. Energy Consumption in Office Buildings

The commercial sector experienced the maximum drop during COVID-19 in many countries, including the United Kingdom, India, and Australia [20–22]. Educational buildings as a subcategory of office buildings are a type of commercial building with high energy consumption. A study in South Korea showed a drop of 14–23% in energy consumption of educational and research facilities [23]. Hafer [24] studied 220 buildings on the Stanford University campus and showed that 32% of the building energy consumption comes from plug loads. Among them, servers, lab freezers, incubators, water baths, lab refrigerators, and personal computers used the most energy [24]. Similarly, Gul and Patidar [25] showed that energy consumption is not strongly connected to the number of occupants in multi-purpose university buildings. They found that the largest share of electricity consumption is from the preset heating/cooling systems operated by a building management system (BMS) that did not consider activity or occupancy of the building [25]. Gaspar et al. [26] indicated that the energy consumption of the academic buildings of Universitat Politècnica de Catalunya-Barcelona Tech decreased by 19.3% or 4.3 GWh, which is within the range that Chihib et al. [16] provided for Spanish academic buildings. In total, during the lockdown, buildings consumed about 46.9% of their typical energy demand. This may not be a lot in a normal situation when the number of people visiting the campus is almost the same during the semester. However, this becomes a considerable waste of energy if we consider the number of people present, which would be extremely low in cases, such as under the COVID-19 restrictions or during semester breaks, weekends, and nights. Ding et al. [27] were among the few who, instead of comparing energy consumption before and during the COVID-19 lockdown, looked at normal weeknight and weekend electricity consumption of educational buildings to calculate the energy overconsumption during the COVID-19 lockdown.

During the pandemic, some university buildings were not fully closed. Some students and staff still had access to campus for essential purposes. According to Chibib et al. [16], some equipment, such as laboratory materials, fridges, and ultra-freezers; security systems, such as sensors and cameras; common appliances, such as vending machines; exterior lighting; and internet and telecommunications equipment remained working at the universities. The authors noticed a difference in the energy consumption change for various facilities. Laboratories with heavy electrical loads related to ongoing projects showed the minimum change in demand. In contrast, in libraries, the change was the greatest due to a reduction in lighting, air conditioning, and student plug-in appliances [16]. In addition, experimental instruments and facilities in the laboratories generally require a stable thermal environment, so heating/cooling equipment should work regardless of occupancy [28].

While data on total energy consumption patterns can be informative for policymakers, there is also much they can learn from analysing per capita consumption. Researchers from different fields, including medical emergency management, mental healthcare, economics, and power systems, can learn lessons from the COVID-19 pandemic to develop more efficient management strategies [21]. Many scholars believe that there was overconsumption in buildings during the COVID-19 pandemic, which can be verified by data from different case studies [29]. In our study, the energy consumption patterns of different buildings of the University of Technology Sydney (UTS) before and during the pandemic were studied. Various factors, such as the dynamics of the number of occupants and building facilities, were investigated. This aspect is usually neglected in studies considering changes in energy consumption patterns during the pandemic. Mokhtari and Jahangir [30] and Anand et al. [31] considered the impact of occupancy on energy consumption, but even they focused more on HVAC systems and air quality than on the improvement needed in COVID-19 or other similar situations.

1.3. Energy Consumption in University Buildings

Energy consumption in university buildings depends on the type of equipment used in the buildings and the number of occupants. Some buildings, such as the ones with laboratories, are approximately 1.5–2.5 times more energy-intensive (energy consumption per sq. meter) than buildings with offices and classrooms [32]. Studies show that university plug-in equipment may be placed into seven categories: audio/video, computers and monitors, gym and training equipment, kitchen and breakroom devices, lab equipment, office occupant comfort appliances, and printers and scanners [24]. However, electricity is consumed in university buildings not only by plug-in equipment. There are also cooling/heating equipment, lifts, and other mechanical equipment. Regardless of its purpose, each university building has some of this equipment. Some equipment consumes a fixed amount of electricity, while other pieces of equipment are turned on and off, so the load profile and the load change behaviour of each building are different. There are previous studies indicating that the appropriate management of occupancy could save energy. However, most of them used interviews [33] or simulations ([34–36]). The COVID-19 situation has provided a unique opportunity for a decent analysis of this issue using real and high-resolution data.

Social distancing and remote working reduce the frequency of student and staff visits to campus buildings. The change in energy consumption of buildings might have a different pattern based on their business function. We can expect that the highest impact on electricity savings in the university will be in buildings with a larger share of offices/classrooms and a lower number of laboratories. The former will show a larger decline in electricity consumption due to the reduced number of operating personal computers, printers and scanners, office occupant comfort equipment, and kitchen and breakroom equipment and reduced use of lifts. On the contrary, laboratory buildings, especially those with continuously operating fridges, freezers, water baths, and incubators, are expected to show a smaller change in energy use. Likewise, buildings with main facilities, such as central cooling/heating systems, servers, or uninterruptable power supplies (UPSs) are less affected. Another category of buildings is the administrative ones. While fewer students and faculty members visit the campus during lockdowns, some administrative roles are needed to maintain the security of the university infrastructure, both physical and cyber. Hence the electricity consumption of administration buildings may decline, but not as much as educational buildings.

The methodology in our case was a literature review, data collection, and processing. We reviewed previous studies on the impact of COVID-19 on energy consumption on the country level, sectoral level, and business level. On the business level, our focus was on commercial buildings, especially university buildings as a subcategory. Then, we picked the University of Technology Sydney (UTS) as our case study. We collected energy consumption and occupancy data and compared energy consumption in different buildings, and then we focused on one building to investigate the per capita energy consumption.

2. Materials and Methods

2.1. UTS Campus Buildings

The University of Technology Sydney (UTS) is located in the business district of Sydney, New South Wales, Australia. UTS is one of the largest universities in Australia, with a total enrolment of over 44,000 students. It offers courses across traditional and emerging disciplines, such as architecture, built environment, business, communication, design, education, engineering, information technology, international studies, law, midwifery, nursing, pharmacy, and science. Its campus has many buildings, but here we focus on five buildings. The basic information about these buildings is summarised in Table 2 with their aerial images shown in Figure 2. The UTS campus uses both electricity and gas. In this study, we focused only on electricity consumption. It is also noteworthy that opposite to the campus, is the Central Park Mall building, which has received several international awards as the world's most sustainable building. UTS receives some thermal energy from the cogeneration unit of the Central Park Mall.

Table 2. Basic information of the studied buildings.

Buildings	Number of Floors	Main Function	Details
Building 1	27	Administration/infrastructure	Most administrative centres are in this building.
Building 4	7	Laboratory	Faculty of Science building consists of various labs and teaching spaces, as well as informal study areas
Building 6	7	Academic/teaching	Faculty of Design, Architecture, and Building
Building 7	8	Laboratory	Faculty of Science
Building 11	13	Academic/teaching	Faculty of Engineering and IT

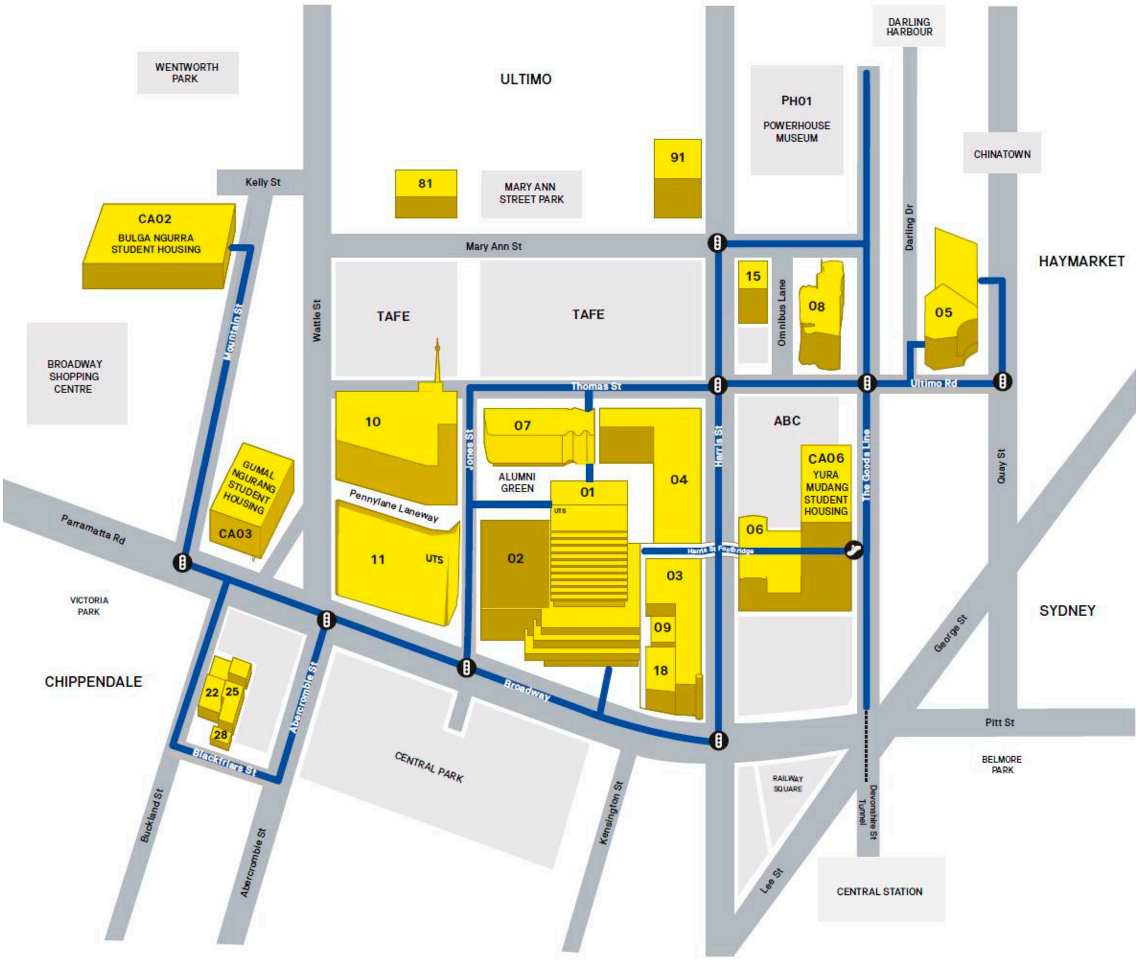


Figure 2. A schematic view of the UTS Campus at Sydney CBD [37] The buildings are close to each other and share the same ambient coonditions and sit on the same energy supply.

2.2. Lockdown Timeline

The UTS academic calendar consists of two main semesters, the Autumn session from March to June and the Spring session from August to November. The New South Wales government first introduced COVID-19 restrictions in mid-March 2020, at the beginning of the Autumn session, which was followed by a series of restrictions later to prevent the spread of the disease. The pandemic hit the state in April 2020. Lockdowns in New South Wales affected the power demand more than in other states [21]. A combination of the university academic calendar and the government restriction timeline is present in Figure 3.

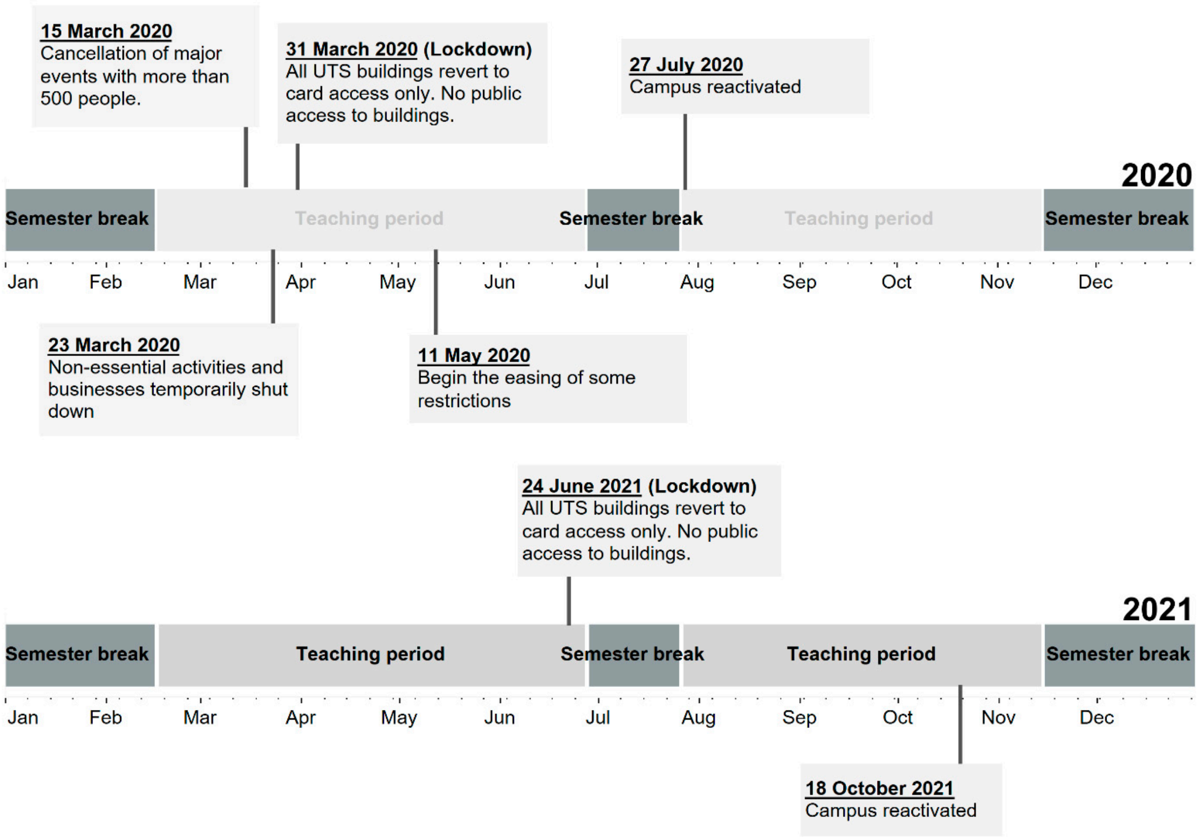


Figure 3. Restriction timeline of the university buildings during 2020–2021 global pandemic.

2.3. Data Collection

As mentioned in Section 2.1, five buildings of the UTS campus were the focus of this research. The hourly electricity consumption data for all five buildings were analysed to compare the effects of restrictions on university buildings with different purposes and equipment. Moreover, occupant data of Building 11 (Engineering and IT) were collected to study the relationship between electricity consumption and the number of occupants.

It should be noted that the chiller plant is located in Building 1 and supplies chilled and heating hot water for the HVAC system in all the buildings in this study. Thus, the electricity consumption data of Building 1 include energy consumed by the chiller plant. Meanwhile, HVAC-related electricity consumption data of all the other buildings, except Building 1, include only the electricity consumption for the air handling unit (AHU) fans. Cooling and heating are produced at Building 1 and then supplied to other buildings using water as the medium. In each building, there are fans to circulate cooling/heating air.

The electricity consumption data for all UTS buildings were monitored by smart meters and sent to the university energy management system that uses the Optergy platform [38]. We sampled the data for each building on an hourly basis from 1 January 2019 to 31 December 2021.

2.4. Methodology

From an energy consumption point of view, having more people in one place is an advantage, providing more efficient use of resources as is the case in any economies of scale.

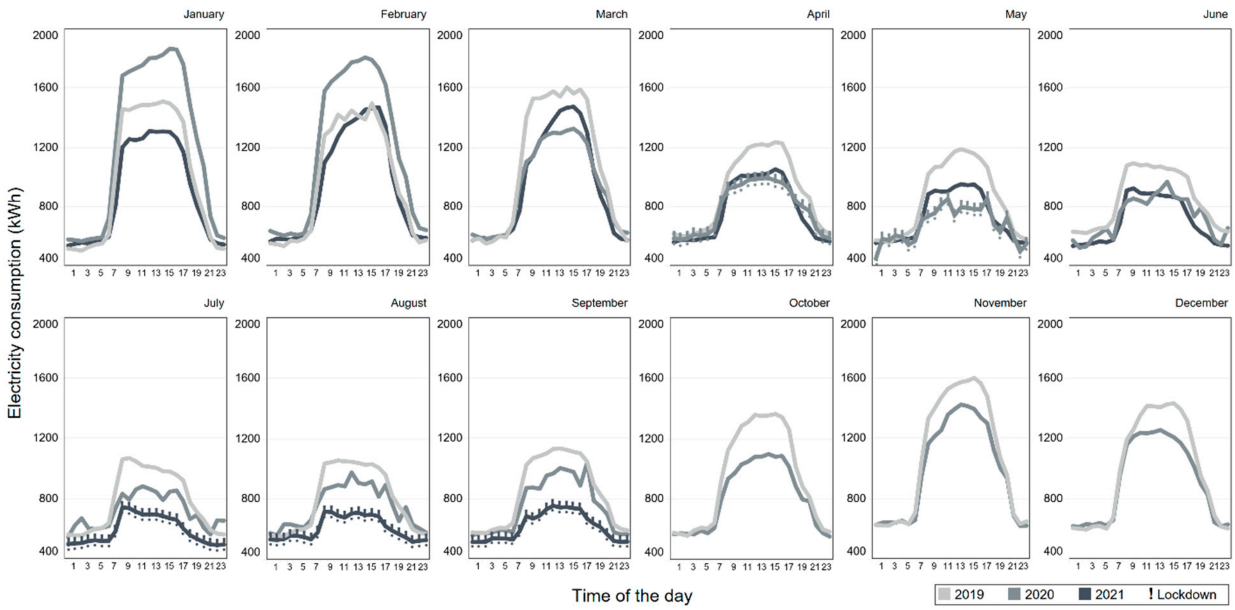
The HVAC systems can provide cooling/heating for more people with the same or slightly increased (or even decreased in the case of heating) energy demand. The same applies to lighting systems: energy consumption per person decreases in shared spaces. This means that the COVID-19 restrictions had the reverse effect. Fewer people were present in large commercial buildings designed to support the academic life of many people for long hours. The HVAC systems, cooling/heating water systems, security systems, and escalators worked normally, and halls and corridors were lit, while only a few people were present. Some energy waste may be unavoidable, but there are obvious changes and adjustments that can be implemented to avoid wasting energy, reduce CO_2 emissions, and save money.

In this regard, we first performed a literature review. We reviewed previous studies on the impact of COVID-19 on energy consumption on the country, sectoral, and business levels. On the business level, our focus was on commercial buildings, especially university buildings as a subcategory. Then, we picked UTS as our case study. We collected energy consumption and occupancy data with hourly sample times before and during the pandemic. The energy consumption data were averaged for the same hours on different days of each month and then compared. We looked for different patterns, such as the agility in different buildings. Then, we provided explanations for these different patterns based on the building's functions and facilities. Moreover, we focused on one building to investigate the per capita energy consumption. In addition to the energy consumption per capita in similar months and hours before and during the pandemic, the energy consumption on weekdays and weekends was compared.

3. Results

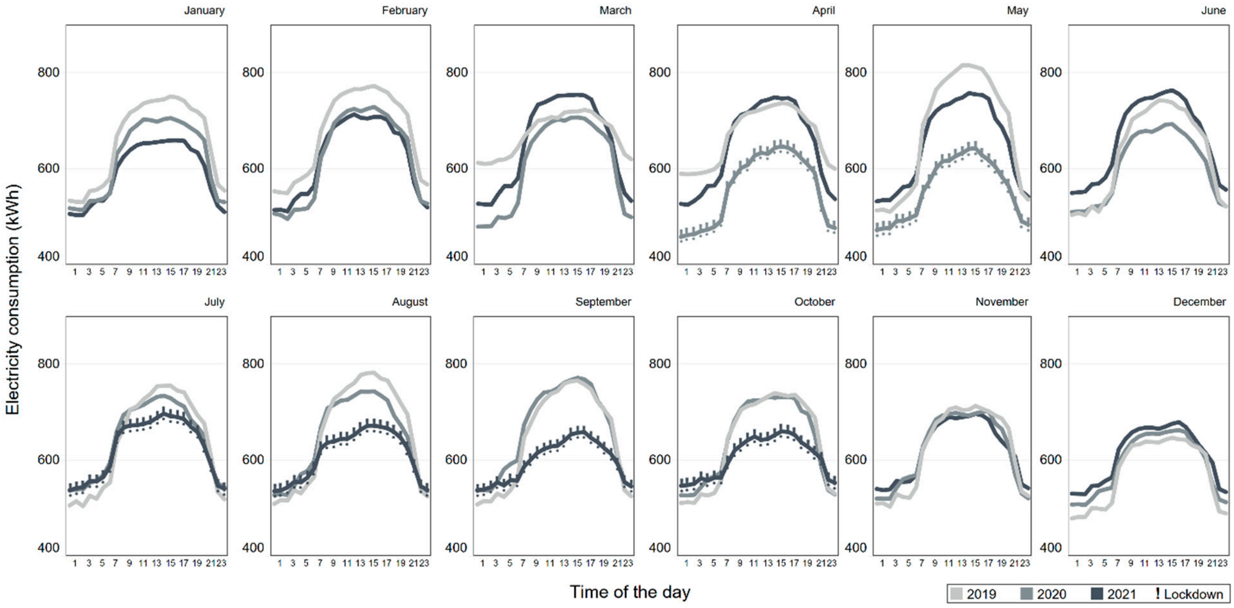
3.1. Electricity Consumption Results

The data were averaged for the same hours on different days of each month, and they were plotted in different colours for each year. This was performed for the comparison of each building's energy consumption pattern, which is represented in Figures 4 and 5. It should be noted that the data of Building 1 between October and December 2021 are missing, thus it is excluded from our comparison.

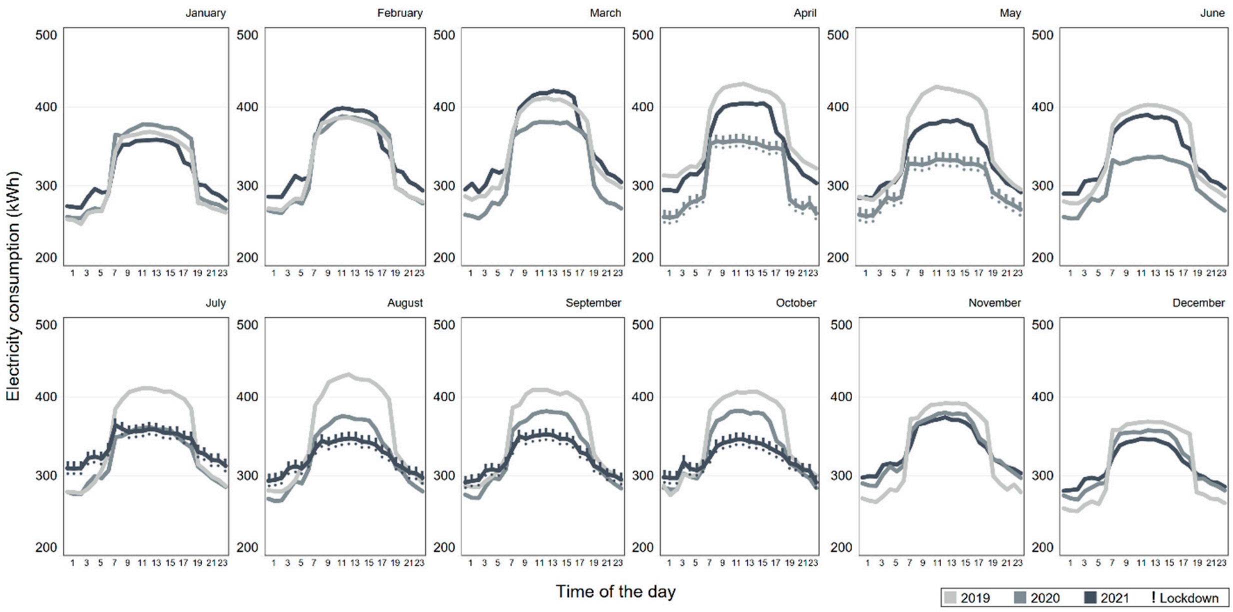


(**A**) Building 1 (Administration/chiller plant)

Figure 4. *Cont.*



(**B**) Building 4 (Faculty of Science/Laboratories)

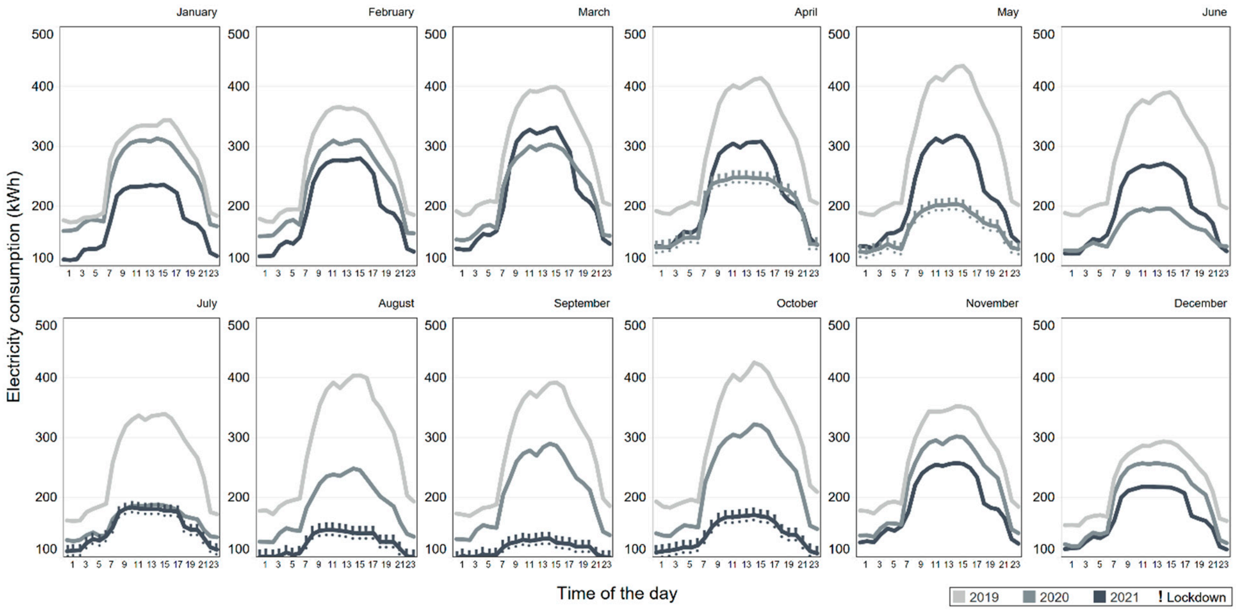


(**C**) Building 7 (Faculty of Science/Laboratories)

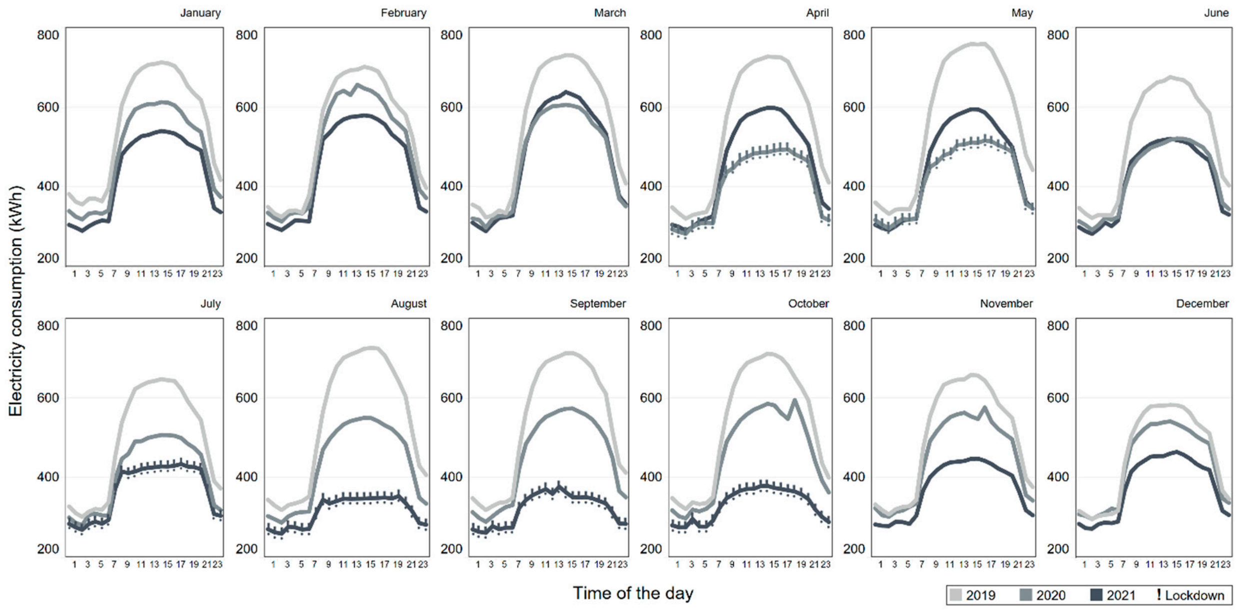
Figure 4. Electricity consumption of UTS buildings 1 (**A**), 4 (**B**), and 7 (**C**) during 2019–2021 (start of the global pandemic: March 2020).

The monthly energy consumption decreased up to 20%, 17%, and 16% in Buildings 1, 4, and 7, respectively, during the lockdown compared to 2019. Even if Buildings 1, 4, and 7 did provide different types of spaces and education disciplines, the electricity consumption did not change as much as could be expected due to the COVID-19 restrictions. Table 3 provides numerical data of the energy consumption change before and during COVID-19.

The data in Table 3 demonstrate that all three buildings experienced a decrease in energy consumption both during the 7 a.m. to 7 p.m. and 7 p.m. to 7 a.m. time periods. Building 1 saw the greatest decrease in electricity consumption at 33.9% in September 2021 after the lockdown was lifted. Buildings 4 and 7 had their largest decrease in energy consumption during the lockdown period in May 2020 at 21.5% and 20.9%, respectively. However, the data also show that the energy consumption of these buildings increased in the time periods after the lockdown. For example, there was an 8.1% increase in energy consumption in Building 7 during the 7 p.m. to 7 a.m. time period in July and an increase of 7.9% in Building 4 in October 2021. In contrast, the energy consumption of Building 1 continued to decrease after the lockdown period.



(**A**) Building 6 (Faculty of Design, Architecture, and Building)



(**B**) Building 11 (Faculty of Engineering and IT)

Figure 5. Electricity consumption of UTS Buildings 6 (**A**) and 11 (**B**) from 2019 to 2021 (start of the global pandemic: March 2020).

These findings are consistent with the overall pattern observed in all buildings, where the electricity consumption decreased to values lower than in 2019 in the first two months before the pandemic. What the buildings have in common is that the work activities in them (e.g., administration in Building 1, laboratory work in Building 4, or high volume of classrooms in Building 7) is not flexible by its nature and is hard to change. Building 7 is different from Buildings 1 and 4 because people from other educational disciplines come here to attend lectures and classes. Therefore, the occupants of Building 7 actually decreased their activities more between March and October 2020 until they returned to their normal work routine.

Table 3. Lockdown to normal operation (2019) change in electricity consumption of UTS Buildings 1, 4, and 7 in kWh and percentage.

	Hours	Apr 2020	May 2020	Jul 2021	Aug 2021	Sep 2021	Oct 2021
Building 1	7 a.m. to 7 p.m. (avg)	−187 (−16.6%)	−300 (−27.9%)	−304 (−31.2%)	−321 (−32.2%)	−357 (−33.9%)	
	7 p.m. to 7 a.m. (avg)	−40.2 (−5.9%)	−54.5 (−8.6%)	−89.1 (−14.9%)	−65.4 (−10.8%)	−97.8 (−15.5%)	
Building 4	7 a.m. to 7 p.m. (avg)	−97.8 (−13.6%)	−167.5 (−21.5%)	25.4 (−5.9%)	−42.6 (−12.4%)	−92.6 (−13.5%)	−98.2 (−10.5%)
	7 p.m. to 7 a.m. (avg)	−118.8 (−19.3%)	−68 (−11.9%)	12.8 (2.3%)	−0.8 (−0.1%)	1.2 (0.2%)	7.9 (1.4%)
Building 7	7 a.m. to 7 p.m. (avg)	−68.2 (−16.2%)	−87.2 (−20.9%)	−49.6 (−12.3%)	−77 (−18.4%)	−56.9 (−14.2%)	−60.5 (−15.1%)
	7 p.m. to 7 a.m. (avg)	−52.92 (−16.2%)	−25 (−8.3%)	23.95 (8.1%)	4.93 (1.6%)	0.71 (0.2%)	3.51 (1.2%)

Furthermore, the Figures and Table 3 show that the pandemic impacted the April and May load profiles, after which they returned to their normal course. This implies that

1. Due to ongoing lab experiments, administrative work, and use of classrooms by multiple educational disciplines, a quick change was not possible in March 2020.
2. People in these buildings resumed their activities as soon as possible because they needed the laboratories and spaces for their research and administrative purposes.

Building 6 for example, where the School of Architecture is located, does not house any laboratories or administrative offices. Their essential activities take place in design studios, which are like regular classrooms and do not require electricity in the same way as laboratories do when students and staff are away [39]. Much like Building 6, Building 11 occupants had the ability to quickly change their work from on-campus to off-campus. With a large number of offices in this building and just a few laboratories or administrative facilities, Building 11 experienced a more significant drop in electricity consumption than all other buildings [39]. Table 4 shows the numerical data of the energy consumption change before and during COVID-19.

Table 4. Lockdown to normal operation (2019) change in electricity consumption of UTS Buildings 6 and 11 in kWh and percentage.

	Hours	Apr 2020	May 2020	Jul 2021	Aug 2021	Sep 2021	Oct 2021
Building 6	7 a.m. to 19 p.m. avg	−136.6 (−36.2%)	−199.5 (−51.1%)	−144.4 (−45.2%)	−227.5 (−62.0%)	−228.2 (−64.6%)	−217.5 (−57.5%)
	19 p.m. to 7 a.m. avg	−69 (−30.6%)	−89.2 (−39.4%)	−69.8 (−35.7%)	−109 (−50.3%)	−103.2 (−49.6%)	−107.8 (−47.8%)
Building 11	7 a.m. to 19 p.m. avg	−204.1 (−30.3%)	−214.4 (−30.6%)	−185.7 (−30.7%)	−326.4 (−48.8%)	−305.9 (−46.3%)	−290.9 (−44.4%)
	19 p.m. to 7 a.m. avg	−80.2 (−19.1%)	−78.5 (−18.0%)	−63.9 (−16.8%)	−124.3 (−30.1%)	−125.8 (−30.4%)	−112.3 (−27.3%)

Table 4 illustrates that the magnitude of the decrease in energy consumption varied between months and time periods within each building, similar to Buildings 1, 4, and 7.

As seen in Table 4, both Buildings 6 and 11 experienced a decrease in monthly energy consumption of up to 51% and 31%, respectively, during the lockdown compared to 2019. The largest decrease in energy consumption occurred at the time the lockdown was lifted in August 2021 for Building 11 (48.8%) and shortly after in September 2021 for Building 6 (64.6%). After the lockdown period, the energy consumption decreased by around 36–64% in Building 6 and by around 19–44% for Building 11. Additionally, the data show that both buildings had a larger decrease in energy consumption during the 7 a.m. to 7 p.m. time period during and after the lockdown period. These decreases in consumption may be attributed to the adaptability and agility of the people from Buildings 6 and 11.

With relaxed restrictions, electricity consumption increased in April and May 2021 compared to the same months in 2020, but the Delta variant of COVID-19 led to new restrictions and public lockdowns from June 2021.

3.2. Occupancy Impact Results

Building 11, with many offices and few laboratories, was most affected by the COVD-19 restrictions. Occupancy data were collected by fixed dome network cameras located in the building's entrances. These cameras have the capability to count the number of people but do not have facial recognition capability. The data were collected on an hourly basis from 1 January 2019 to 31 December 2021. Figure 6 shows the electricity consumption per person during 2019–2021.

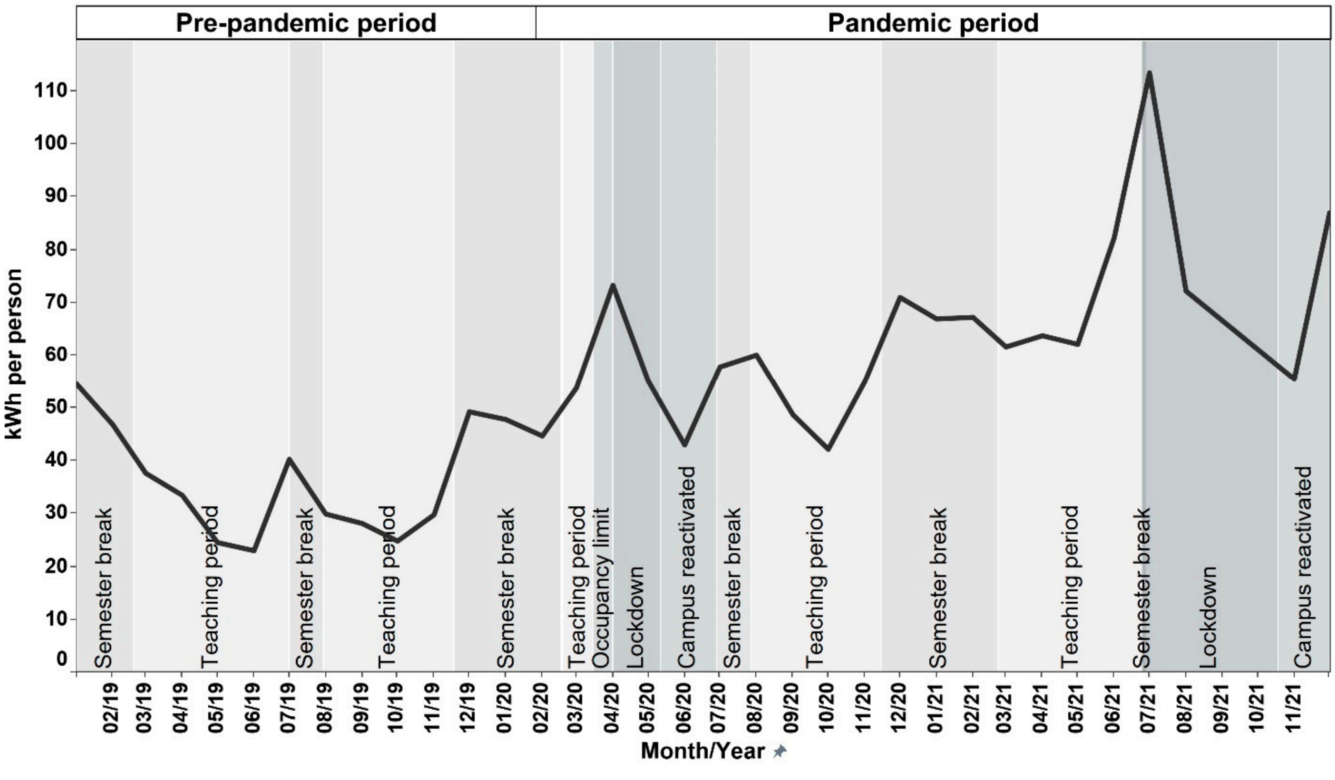


Figure 6. Electricity consumption per person for the UTS Engineering and IT Building from January 2019 to December 2021.

Before the pandemic (in 2019), electricity consumption was approximately 25–30 kWh per person during the teaching period, and it was twice that during the semester break (40–50 kWh per person). With COVID-19 spreading and government restrictions introduced, electricity consumption per person significantly increased. As Figure 6 shows, electricity consumption reached 70 kWh per person in April 2020 when access to the university buildings was restricted. Furthermore, it reached the peak again with more than 110 kWh per person in July 2021 due to the reintroduction of the restrictions.

Figure 7 shows the hourly electricity consumption for Building 11 compared to occupancy during weekdays and weekends in 2019–2021. The left-hand side plots in Figure 7 show the electricity consumption and occupancy for 2019, the year before the pandemic. According to the figure, there is constant ~300 kWh hourly energy consumption in the building regardless of occupancy. In 2019, the peak load decreased from 789 kWh on weekdays to 577 kWh on weekends, accounting for −27%, while the peak in occupancy dropped from 582 persons on weekdays to 135 persons on weekends, accounting for −77%. The same results were confirmed for 2020 and 2021.

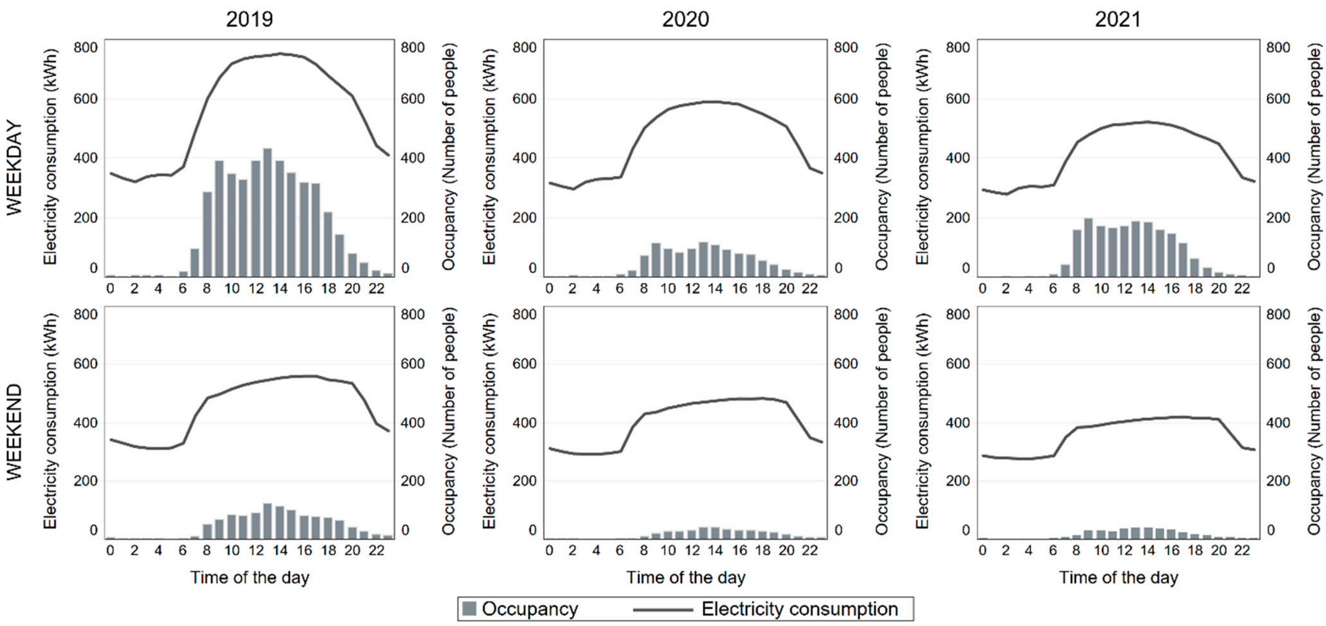


Figure 7. Comparison of average electricity consumption and occupancy for Building 11 in 2019, 2020, and 2021. Weekdays and weekends are plotted separately.

The comparisons of electricity consumption and occupancy in 2020 and 2021 with 2019 show that the COVID-19 lockdown effect is close to the weekend effect, but for a more extended period. A comparison between 2019 and 2020 showed that, on weekdays, occupancy decreased by 83% (from 582 to 97 persons), but there was only a 30% drop in energy consumption (from 789 to 556 kWh). Likewise, energy consumption decreased from 577 to 480 kWh on weekends. This was just a 17% energy consumption reduction for a 72% occupancy reduction from 135 to 38 persons. Similarly, a comparison between 2019 and 2021 showed that occupancy decreased from 582 to 240 persons on weekdays, a 59% decrease, but there was only a 20% drop in energy consumption from 789 to 634 kWh. Furthermore, there was just a 17% energy consumption reduction from 577 to 478 kWh, for a 64% occupancy reduction from 135 to 48 persons on weekends.

More than two thirds of the electricity consumption and half of the peak load of the building come from constant electricity-consuming loads. Gul and Patidar [25] studied electricity consumption and occupancy of an academic building. Their case study building has four floors, cellular office spaces for staff members, one lecture theatre, seminar rooms, three meeting rooms, one café, social space, and study space. It consumes about one third of its peak load at night. Most of the electrical consumption comes from the building's preset heating/cooling systems. The University Estates department operates the BMS that controls the heating/cooling systems. This study does not consider the room activity or occupancy status. So, there is an energy-saving potential for the Gul and Patidar case study building, but there is even more significant potential for energy saving in Building 11.

4. Discussion and Conclusions

The COVID-19 pandemic caused major social and economic disruptions, which provided a unique opportunity for researchers in many fields to study how systems behave in critical conditions. Many researchers reviewed routine emergency procedures in their fields of study and found them inefficient; power and energy systems were no exception. Several studies have been carried out to assess the changes in regional- or national-level energy consumption by investigating the aggregated and sectoral energy accounts. As discussed in Sections 1.1 and 1.2, the COVID-19 pandemic had different impacts on energy consumption in different countries because of their different policies, regulations, and life styles. Therefore, there is a need for local studies based on locally collected data. However, many of our conclusions are very much driven by common sense and usual consumption practices, which should make them relevant to other localities and countries, especially those with similar energy systems and policies. For example, it seems natural to try to reduce energy waste in buildings that are unoccupied and to use per capita energy use as an indicator of energy efficiency rather than the total energy consumption.

Based on the data provided in Table 1, we conclude that the pandemic impacted energy consumption in Australia and the United Sates in similar ways, but in some European countries, such as Spain, the decrease in energy use was much higher. Country-level studies can help policymakers in high-level planning or decision making. However, targeted smaller-scale studies, such as ours, are equally beneficial for self-assessment, for finding solutions and personal energy-saving behaviour changes, or for guiding management and policymaking on a local scale. We focused on office buildings as a type of commercial building to compare electricity consumption before and during the COVID-19-related restrictions. Looking at five different buildings on the UTS campus, we found that, in some cases, energy consumption of an office building can drop to less than half if it is near empty, which is what we found in Building 6 experiencing a 65% decrease in September 2021. However, this was not the case in other buildings. We see that specific procedures can be designed to avoid energy waste in office buildings when there are fewer visitors. These procedures are building-specific and can be planned. In summary, we conclude that

(a) a change in the load profile of a building due to a lockdown highly depends on the purpose of the building;

(b) buildings with more laboratories are less affected because they require a constant electricity supply for laboratory equipment that does not depend on the number of people in the building;

(c) buildings with more administrative offices and teaching spaces are most affected by the lockdowns. People are usually able to work from their homes instead of their offices on campus.

Normally, it is assumed that energy consumption should decrease if there are fewer people on campus, especially in buildings that are mainly dedicated to offices. However, the results from Building 11 on electricity consumption per person show that

- Even in a normal situation, there is much energy consumption at night when there are no people in the building. It is about half of the peak load, while similar buildings consume only one third of their peak load when they are not fully occupied.
- Because consuming electricity at night or on weekends and public holidays, when fewer people are on campus, means wasting energy, emitting more CO_2, and losing money, there is even more energy wasted in extreme conditions such as during the COVID-19 pandemic, when people do not come to their offices for a long time.

Birch et al. suggest that universities should have a shutdown procedure and a checklist to reduce energy consumption during lockdowns [40]. We believe that these procedures and checklists can be used both in critical and in normal situations with some modifications. Based on our studies and the above-mentioned findings, we suggest that office building administrations, including university administrations, may reduce building electricity consumption by taking the following steps:

1. Identify main electricity consumers in the building;
2. Categorise electricity consumers into (a) permanent consumers, such as some laboratory equipment that requires energy supply all the time; (b) fixed-variable consumers, such as HVAC systems; c) facilities or equipment that can be switched on and off, such as lights or computers; and d) building areas or locations that can be controlled separately and independently in terms of energy supply, such as hallways, classrooms, or floors;
3. Design incentives, defaults [41], and nudges that would encourage users in category (c) to be mindful of their energy consumption and turn off the equipment that they can control;
4. Control (b) and (d) user categories considering building occupancy. For example, provide cooling for only part of the building and for only part of the time or turn off escalators if the number of visitors is less than a preset threshold value. Frequent or automatic changes may be difficult for shorter periods, but over extended periods, such as during COVID-19 with lockdowns or during summer and winter breaks and weekends, this can be a simple and cheap way to save energy.

Moreover, as seen in Figure 7, if the academic buildings are left open even when there are just a few visitors, the energy consumption of the building remains high and, as seen in Figure 6, energy consumption per capita increases unreasonably, in this case by up to four times. So, there is also a lesson for smart city planners or policymakers. Many commercial buildings in cities are designed for many occupants and consume the full energy capacity even during periods with a reduced number of visitors. Because of this, there is a significant opportunity if commercial buildings can share spaces, resources, and capabilities. For example, encouraging people to use the facilities as much as possible during down times and providing access and functionality for study, work, or entertainment will decrease the energy consumption per capita. For this to be possible, it is important to create flexible spaces and a versatile environment. There are already some trends regarding opening up offices for clients and partners. Commercial building owners are already cutting down on the number of workspaces/desks and creating more spaces for meetings to increase the usability of buildings. This is not a new trend, but it has now intensified after the pandemic, which again demonstrated its potential [42]. In addition, remote work or telework gained popularity among white-collar employees during the COVID-19 first wave [43], and this may lead to future adoption of various remote-working options, including near-home shared spaces instead of traditional offices.

Another reason to encourage higher use of office buildings is that they are usually better built, better insulated, and are more energy-efficient than regular residential dwellings. While working from home may have its attraction in some cases, we should keep in mind that it is most likely to come with a higher energy consumption per capita, as well as the associated CO_2 and other environmental footprints. This is especially the case in places such as Australia, where a relatively mild climate and historically cheap energy have resulted in very poor insulation in residential buildings [44] and much HVAC energy wasted for nothing. Moreover, developing energy consumption standards with occupancy considerations for large commercial buildings can lead to a huge energy saving at state or national levels. Some researchers suggest installing sensors and thermal cameras or real-time assessment [45].

It is worth mentioning that most of our findings could have been already anticipated when looking at building performance during the week vs. weekend or when comparing regular office performance with what was happening during vacation time. However, previously, these low attendance periods were rather short and hardly attracted much attention. The pandemic and prolonged lockdown periods have created an opportunity to observe the significance of the wasted energy and how it could be saved with some minor improvements in the BMS.

For future studies, we can suggest going into more detail about energy consumption of individual units and parts of the building to develop more detailed plans for specific energy-saving strategies. Lastly, a broader study among multiple commercial buildings throughout different countries could help to further improve energy efficiency and the sustainability of building maintenance.

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