COVID-19 as an Energy Intervention: Lockdown Insights for HCI

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ABSTRACT

As the operation of buildings accounts for around 30% of global CO_2 emissions, reducing their energy consumption is considered crucial for climate change mitigation. Aware of this significance, the sustainable HCI (SHCI) community has conducted research on energy consumption for over 15 years. However, compared with domestic environments, commercial organisations are comprised of complex mixed-use buildings, and the socio-technical understanding of space and resulting energy use are relatively under-explored. In this late-breaking work, we present the initial findings of a longitudinal analysis that uses building energy data from a period covering the COVID-19 lockdown measures to help identify the energy associated with these buildings and their users. Viewing the pandemic as a unique, grand-scale 'energy intervention', the resulting consumption patterns are used to inform questions about leverage points for achieving change, stakeholder agency vs. infrastructure demand; and highlight the importance of putting energy data in context.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; • **Social and professional topics → Sustainability**.

KEYWORDS

Sustainable HCI, energy data, rebound effect, COVID-19 pandemic

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1 INTRODUCTION

Tackling the climate crisis remains one of the existential challenges of our time, becoming more urgent with each year that passes: compared to pre-industrial levels, our planet has already warmed by 1.1°C [21], and current country commitments and policies are estimated to lead to a total temperature increase of 2.6°C by 2100 [20]. Addressing buildings' energy demands plays an important role since their operation accounts for around 30% of global final energy consumption and 27% of total energy sector emissions. Critically, despite large shifts in working practice in many sectors following COVID-19 lockdown measures, both values have 'rebounded' to *above* 2019 levels in 2021 as these restrictions have eased [1]. Given the close link between energy consumption and CO_2 emissions, a key aim for researchers and industry stakeholders should we would argue be to reduce energy consumption in the built infrastructure.

For commercial organisations in particular, efficiency improvements, retrofitting and changes to working practices are required to help them meet carbon emission targets (for 2030 and beyond). In the UK, where our research takes place, large commercial organisations (250+ staff or £44 million turnover) are required to complete the Energy Savings Opportunity Scheme (ESOS)[1]. This is a mandatory scheme in which eligible companies audit their energy consumption. Specifically the ESOS compliant audit must: 1) be based on 12 months of verifiable data, 2) analyse the participant's energy consumption and energy efficiency, and 3) identify energy-saving opportunities. In this context, our research looks to understand the potential for energy-saving interventions that consider the relationship between buildings (including their infrastructure) and their end-users.

For our research, we consider the COVID-19 pandemic as an entirely unique, grand-scale energy intervention in which 'business as usual' was significantly disrupted and the people were largely removed from building premises. New working practices were installed both during and after lockdown measures were introduced. Our thesis being that this provides insights into a range of topics, such as maximum possible 'behaviour-related' energy savings; the building 'base load' relating to office-related technology and building systems that prevails when people are removed; and the agency across stakeholder groups in the aftermath of the pandemic measures, i.e., when 'business as usual' or what's considered as 'the new normal' for the buildings returns.

In this late-breaking work, we present the initial findings from a study that investigates the energy impacts of lockdown periods on a university campus in the UK. Aiming to support stakeholders in commercial organisations, our study includes a novel, longitudinal

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[1] https://www.gov.uk/guidance/energy-savings-opportunity-scheme-esos

analysis of how COVID-19 lockdown measures impacted energy consumption before, during and after these measures. The study reveals the magnitude of the change that resulted, and what happened as the lockdown measures relaxed. This uncovers potential challenges and opportunities for HCI to assist with energy transitions and decarbonisation of the built environment.

2 ENERGY RESEARCH IN HCI

HCI is well placed to develop insights involving buildings, energy, technology and its users. Since the field's emergence in 2007, energy consumption has been a major focus in SHCI [11]. The community's research covers domestic interventions (e.g., [15, 16, 22, 23]), design explorations (e.g., [9, 13]) and theoretical contributions/reflections (e.g., [5, 6, 25]), with a significant focus on domestic energy use and broadening SHCI's design space to consider energy in its social and economic context. The human-building interaction (HBI) community also focuses more broadly on the interactions that take place between people and the built environment, and their design implications (e.g., [2, 10, 19])—where we would argue that energy and climate change should be a clear focus.

Compared to domestic spaces, commercial organisations have less frequently provided the context for sustainability interventions in HCI. With a diversity of stakeholders and an increase in data complexity, a common approach in these organisations is to focus on automation and optimisation (e.g., low energy bulbs or automatic lighting). However, this approach relies on broad assumptions about the end-users working in these spaces (e.g., their work patterns and thermal comfort preferences) and can reduce their agency. In this context, people were found to prefer less automation (but not manual) when they care about comfort and more automation (but not full automation) when they care about energy savings [24]. And there are clear indicators that automating without involving the end-users can easily backfire: when participants in Bedwell et al.'s study of energy consumption and management in the workplace of a district council raised a lack of control, the authors noted numerous adjustments to circumvent systems and policies by participants to regain control over their environments [4]. Among the proposed approaches to better understand occupant needs in buildings are digital surveys [8] and participatory evaluations [17, 18].

It is not only occupants who struggle with a lack of agency. Energy managers and building managers, who play a key role in organisational energy management, often find themselves constrained by e.g., a shortage of resources, expectations from senior management and company policies [7, 12]. Reflecting on the use of a 'living laboratory' campus to promote more sustainable energy consumption, Bates and Friday [3] discuss many of the challenges that are relevant in the context of our study including complex energy management infrastructures, organisational practices, and heterogeneous, incomplete and sometimes inaccessible data.

3 STUDY CONTEXT

We have been running our study on the campus of a medium-sized campus university in England, UK, i.e., the university is situated on one site and contains student accommodation, teaching and research facilities, leisure and businesses all together on this site. Reflecting this diversity, some but not all of the buildings on campus are mixed-use (e.g., a single building may contain small businesses, offices and flats). Energy consumption on campus is recorded in several systems, including a building management system (BMS) and an energy management system (EMS). Data from building main meters and individual floor-level and room-level meters with typically half-hourly resolution can be used to calculate and visualise the energy consumption for different buildings and spaces on campus over time. Due to e.g., changes of the energy and metering systems and infrastructures over the decades, and periodic faults with meters, these data are complex and contain gaps and errors.

The official 'teaching term' times for students run from October until June, with short breaks in winter and spring. As there is no teaching during the summer break, a majority of the undergraduate students who usually live on campus leave, although postgraduate students and some international students may remain. During the COVID-19 pandemic, many campus buildings were closed. However, parts of the campus needed to be kept open as some of the students who lived on campus stayed in their accommodation during the pandemic (e.g., as they could not travel home). Some of these buildings could be accessed through a sign-up system.

3.1 COVID-19 timeline in the UK

In the UK, the first COVID-19 lockdown was announced on 23 March 2020 and came into force three days later [14]. The lockdown measures continued until 10 May 2020 when the restrictions started to get gradually lifted: on 15 June non-essential shops reopened, followed by indoor entertainment venues on 14 August. From an energy perspective, this 'easing out of lockdown' coincided with the beginning of summer, the season with typically the lowest energy consumption due to reduced heating. After new restrictions in September 2020, the second national lockdown in England came into force on 5 November; it ended on 2 December. After the Christmas period, England entered its third national lockdown on 6 January 2021. From 8 March 2021 onward, the restrictions got lifted again: on 12 April non-essential retail and public buildings reopened, and on 19 July most legal limits and social contacts were removed. Based on this timeline, we divide the pandemic into four phases that correspond to the last four years (2019: pre-pandemic, 2020: height of the pandemic, 2021: transitioning out of the pandemic, 2022: return to 'in person' operation).

4 STUDY DESIGN

We use 2019–2022 campus energy use data to calculate the changes in energy demand that occurred as a result of adjustments to the building infrastructures and working practices made during the pandemic. For our analysis, we look at 19 campus buildings for which we were able to obtain good-quality energy data from the EMS. We draw on our qualitative understanding of the campus from earlier pre-existing consultations with expert stakeholders to identify the context and use of each of these buildings. Due to the large number of sensors and data streams, which allow for a more fine-grained analysis, we chose to focus on electricity use for this analysis.

We needed to identify a suitable time window in our data where 1) we could cover the full lockdown in spring/summer 2020; 2) it was during teaching term time when students and staff are mostly

		Total kWh for 35 days in 2019	**2019 to 2020 change**			**2019 to 2021 change**		
#	**Building type**		**Total**	**Night time**	**Day time**	**Total**	**Night time**	**Day time**
1	Pre-school	4670	-70%	-32%	-93%	77%	190%	12%
2	Business space/meeting rooms	1458	0%	-1%	-16%	16%	8%	35%
3	Business space	751	-27%	0%	-44%	-7%	10%	45%
4	Offices/meeting rooms	12032	-4%	-10%	-1%	17%	6%	34%
5	Offices/meeting rooms	1520	-15%	-15%	9%	29%	24%	35%
6	Offices/meeting rooms	1536	5%	2%	81%	19%	4%	140%
7	Student residences	1433	-17%	-17%	-15%	7%	22%	-4%
8	Offices/meeting rooms	11670	-18%	37%	-58%	-8%	-13%	7%
9	Offices/meeting rooms	1025	-30%	-27%	-39%	-19%	-33%	-11%
10	Offices/hardware workshops	1256	-15%	-25%	-15%	-18%	-39%	-4%
11	Mix of offices and residential spaces	1774	-26%	-13%	-38%	-11%	-10%	-6%
12	Meeting rooms, event spaces	2162	-23%	-3%	-18%	-10%	-6%	1%
13	Offices, meeting rooms, event spaces	2116	-35%	-28%	-44%	-32%	-49%	-29%
14	Hotel building	4911	-68%	-31%	-86%	-60%	-32%	-74%
15	Sports facility	99786	-27%	16%	-31%	-65%	-57%	-67%
16	Offices/meeting rooms	8362	-45%	3%	-70%	-34%	-16%	-52%
17	Mix of offices and residential spaces	742	-7%	8%	-23%	-73%	-82%	-66%
18	Library	2162	-17%	-5%	11%	-11%	-8%	-3%
19	Student residences	1367	8%	20%	-6%	9%	8%	-1%

Table 1: Overview of selected buildings, their total energy consumption from April 29 to June 2 in 2019, and the savings observed during lockdown (change from 2019 to 2020 by percentage) as well as the rebound after COVID-19 (change from 2019 to 2021).

expected to be present on campus in regular non-pandemic campus operation; and 3) excluded public holidays, i.e., after the Easter break and formal campus closure days. This resulted in a five-week window for analysis starting on the last Monday in April and lasting for 35 days. For the 19 campus buildings in our sample, we have complete electricity data for 2019, 2020, and 2021 during those time frames (15 of these buildings also have complete electricity data for the corresponding time range in 2022).

An overview of the buildings and corresponding data can be found in Table 1. We include the total energy consumption for our selected five-week time window in 2019 to illustrate the approximate scale of the building (larger buildings typically have higher energy demand). To find the effect of the pandemic, when many staff and students were required to work or isolate at their family homes, we compare the energy consumption in 2019 to that in 2020 during the same time window; the table includes the consumption during night time (midnight to 6am) to estimate a base load, and the day time consumption during peak work hours (10am to 5pm) when buildings are typically occupied (weekends excluded). In practice, operating hours for each type of building vary (e.g., lecture theatres may be in use until 7pm).

We can regard the base load as the energy cost due to the equipment in the building and other 'always on' electrical appliances in kitchens, offices, server rooms and embedded into the building fabric itself. We chose the described time frames as they offered the most consistent data across all sample buildings. Due to the heterogeneous nature of usage and working practice, this varies greatly between minimum and maximum use but saw most overlap during those specific hours. The last three table columns illustrate the post-pandemic consumption change (from 2019 to 2021), using the same hours and weekend exclusions as for the during COVID-19 analysis.

5 INITIAL RESULTS

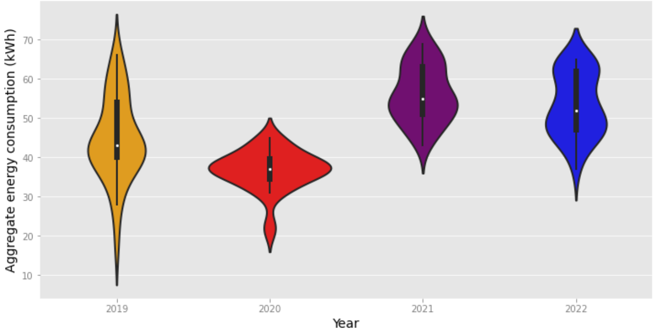
We would expect to find a substantial drop in energy demand during lockdown periods, and that the 'new normal' of home and hybrid working would keep the energy consumption below pre-pandemic levels. What our initial analysis of the 19 campus buildings actually showed was that the buildings can be clustered into four distinct categories based on their change in energy profile. These categories emerge from the combination of two dimensions: 1) whether there was a significant electricity *reduction* during the year 2020 (a decrease in energy consumption larger than 10% compared to 2019) and 2) whether there was an electricity demand *rebound* in 2021 (an increase of more than 10% compared to the pre-COVID-19 2019 level). To see the maximum impact of lockdown periods, we categorise day time energy use during working hours. The categories are as follows (also cf. Table 2):

(A) buildings showing significant electricity reduction for 2020 and an electricity increase in 2021 (three buildings)
(B) electricity demand increase in 2021 without a preceding reduction (three buildings)
(C) electricity reduction in 2020 without rebounding higher than 2019 levels of consumption (eleven buildings)
(D) neither energy savings in 2020 nor a rebound in 2021 (i.e., they stayed roughly equivalent) (two buildings)

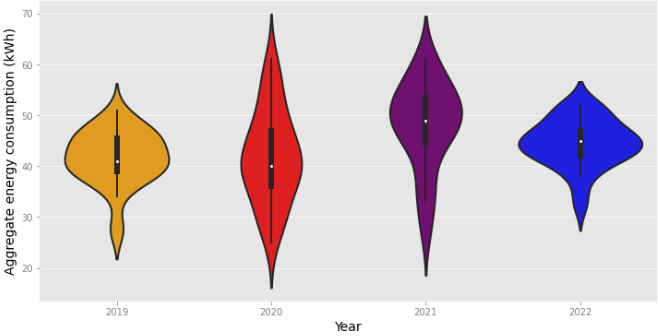
	Savings	No savings
Rebound	(A) 1, 2, 3 Pre-school, business	(B) 4, 5, 6 Offices
No rebound	(C) 7 - 17 Various buildings	(D) 18, 19 Library, residences

Table 2: Categorisation of buildings

Figure 1 plots the distribution of aggregate daily electricity use for representative buildings that saw a rebound in energy consumption after the COVID-19 lockdown, with a 16% saving during working hours during the lockdown for the first building (Figure 1a), a mixed-use space with offices and businesses. The second building (Figure 1b), comprising offices and meeting rooms, saw no savings during lockdown working hours (but a small increase of 9%). Both buildings saw a 35% increase in energy consumption in 2021 (and subsequently a decrease again in 2022).



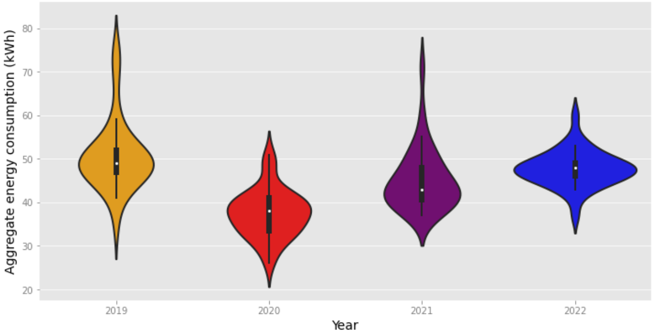
(a) Building 2, business space/meeting rooms



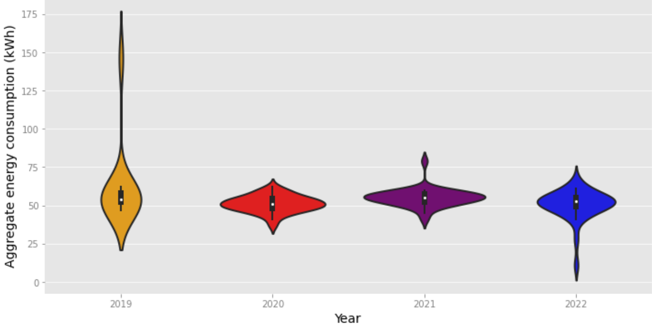
(b) Building 5, offices/meeting rooms

Figure 1: Figure 1a shows the electricity profile of a building from category A with a significant electricity reduction in 2020 and a subsequent increase in 2021 (compared to 2019). Figure 1b shows the electricity profile of a building from category B where the electricity demand also rebounded higher than in 2019, without significant savings in 2020.

Figure 2 shows two buildings for which we did not observe rebounds in energy consumption after lockdown, i.e., the values for 2021 did not exceed those of 2019. The library (Figure 2b) was one of only two buildings that did not see any savings (for weekday working hours) during lockdown, and also stayed relatively stable in the two years afterwards. It has to be noted that the total consumption did see a reduction of 17% during lockdown (cf. Table 1), which was offset by an increase during working hours. The only other building that saw no rebound and no savings was a student residence. The majority of buildings, however, fell into the third category, such as the one displayed in Figure 2a: a reduction of energy consumption during lockdown across the board, that continued post-COVID-19 or at least did not exceed pre-COVID-19 usage.



(a) Building 11, mix of offices and residential spaces

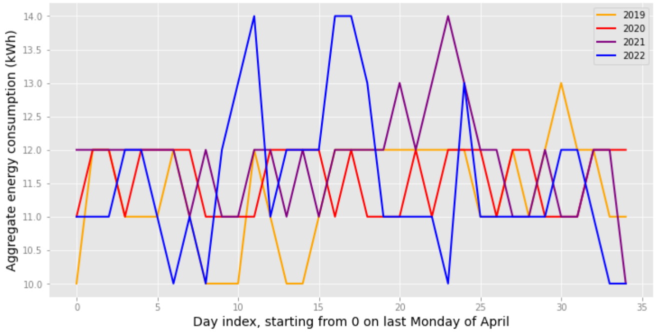


(b) Building 18, library

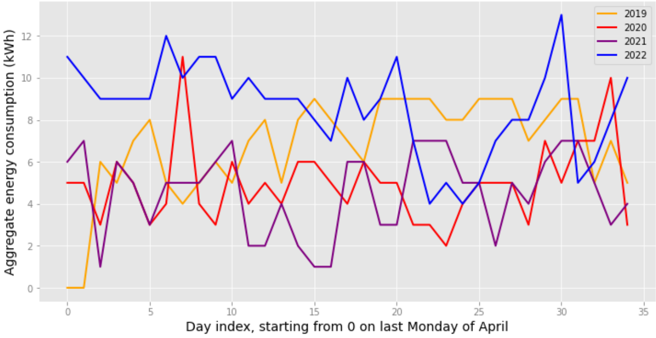
Figure 2: Figure 2a shows the electricity profile of a building from category C with a significant electricity reduction in 2020 and a return to 2019 consumption levels in 2021. Figure 2b shows the electricity profile of a building from category D where the electricity demand in 2021 was again similar to that of 2019, but without savings in 2020.

Compared to its day time consumption, the night time consumption of building 5 with offices and meeting rooms, did not only show a rebound in 2021 but also significant energy savings of 15% in 2020. This means that in a night time consumption analysis, building 5 would no longer be placed in category B but in category A. We ran this comparison for all 19 buildings and found that 8 buildings were assigned the same category for their day time and night time consumption, while 11 buildings were assigned a different category.

To begin to consider direct electricity consumption from end-use (e.g., building residents/workers using appliances) and secondary consumption that operates during core business hours (e.g., heating, cooling) we look at what we call the “nightly base load” between 00:00am and 06:00am. This base load will include ‘always on’ assets in buildings such as ICT infrastructure (e.g., routers, switches, Wi-fi hotspots) used by end-users and for essential campus-wide systems. Figure 3 shows the patterns of night time consumption over the 35-day period for each year. These consumption patterns vary considerably (e.g., spiky and aperiodic, vs. quite regular), warranting further investigation.



(a) Building 9, offices/meeting rooms, night time



(b) Building 6, offices/meeting rooms, night time

Figure 3: The night time consumption patterns for building 9 (Figure 3a) and building 6 (Figure 3b)

6 DISCUSSION

Our results tell a perhaps unsurprisingly complex story across different buildings, of different types and purposes in our four categories (see Table 2); the resulting questions will guide our future work. Even excluding people entirely from certain areas and buildings did not lead to as much reduction in energy demand as we expected, highlighting the significance of base load. Perhaps this suggests a gap in the infrastructure's sensing and control capabilities; poor visibility of what comprises this; or, poor systems and procedures for controlling it. Certainly, the current data and analysis are insufficient to fully explain this—yet, it is also clear that popular mental models supposing high energy use to relate to ‘poor user practice’ may be overestimating the energy attributable to buildings' end-users. A confirmation of this preliminary finding would support the broader shift in SHCI away from behaviour change research [5].

Thirteen of the buildings studied significantly reduced their day time electricity consumption during the 2019 lockdown, with three of these rebounding to *higher* consumption levels in 2021. Of the five buildings for which we did not observe such savings, three also had a consumption increase in 2021 compared to 2019. Why there is so much diversity remains an open question. The range of building types on campus likely plays a role, although this needs to be investigated in more detail. As Table 2 shows, there were *no rebounds* in any of the student residences—only in businesses, offices, and the pre-school. Our analysis also shows three office buildings with no electricity savings. It is clear that a relationship between building use and policy exists which needs further contextualisation with decision makers and energy experts.

An important consideration in assessing energy consumption and the savings potential is base load. As evidenced in Figure 3, the base load was not consistent throughout all days and years, but instead varied greatly, for almost all buildings in our sample. This raises further questions, such as: what causes this variance? Is it an unavoidable or intended effect (such as cost-efficient night time load shifting)? Can it be reduced by eliminating ‘unnecessary’ energy consumption during non-working hours? In the context of a university campus, there is potential for establishing policies and deploying interventions to reduce the base load, but this will have implications for campus users—bringing energy reduction into tension with those whose primary needs include learning and conducting research. We should be realistic also, as to the magnitude of savings these changes might likely engender without a better and more targeted understanding of how this demand is composed or is linked and shaped by the built infrastructure and its use.

One of the surprising findings was the *increased* energy consumption *after* the pandemic, to levels higher than pre-COVID-19 times. The reasons are unknown to us at this point and require further investigation. There is unlikely to be one general cause as the effects only occurred for some buildings, and differed by extent. Assumptions we can make based on informal knowledge of the campus, range from changes in end-use, building reconfiguration, infrastructure and policy changes. For example, a lasting policy to increase airflow to reduce the transmission of COVID-19 may well have knock-on effects to electricity consumption (e.g., air conditioning or heating units have to work harder due to lower room temperatures, building users bringing in their own space heaters). With regard to end-users' footprint and their agency to reduce energy consumption, it is unclear how many end-users have actually returned regularly to campus after lockdown and therefore it is difficult to attribute rebounds and savings in 2021 to end-use.

Regardless of the reasons for this effect, it is the opposite of what we were hoping and perhaps expected to see. If one considers COVID-19 lockdowns as an ‘extreme intervention’ that permanently changed working practice, a desirable outcome might be a lasting reduction of campus energy demand instead of a rebound to pre-intervention or even higher levels. Understanding this further, yields a promising avenue for future HCI research in this area as it suggests to investigate how energy interventions not only need to be evaluated by the effects during and immediately afterwards in the context of changing practice and infrastructure, but also be judged by their long-term effects. Once we have learned more about the reasons why and how those rebounds occurred, we might be able to mitigate or even prevent them.

6.1 Limitations

While COVID-19 provided us with a unique opportunity to study the campus with people taken 'out of the loop', it was neither intended as an energy intervention nor was it a perfect intervention. Air ventilation policies, for example, were introduced to reduce the virus load in indoor spaces, but may also have increased the energy consumption. Differences in energy usage across buildings and time periods might also partly be due to factors that are unrelated to COVID-19 measures (e.g., the type of equipment in a building, frequency of use patterns, and changes in the building's structure and/or its size over time). We aim to concretely identify relevant policies and factors in the upcoming stages of our research.

In addition, when we see an energy reduction on campus, the energy demand might to some extent have *shifted* to people's homes in which they worked during lockdown periods. Beyond our campus-specific findings, this would affect any conclusions drawn about the overall energy consumption impact of the pandemic. Another limitation is the complexity and incompleteness of the energy data we worked with. While this is representative of many real-world environments, it limited the choice of buildings for our analysis. For these data to have more value to organisations in understanding and addressing climate change, we would strongly advocate more emphasis in organisations on data quality and resources around energy, building management and recording contextual data.

7 CONCLUSION

Our work has highlighted the need to work closely with energy and commercial stakeholders to uncover context needed to make sense of energy data in a combined holistic approach. HCI is central to engaging with and supporting these stakeholders. From our analysis of COVID-19 as a proxy for a 'large scale energy intervention' we show the *relatively low importance* of energy mitigation measures limited to individuals' agency, versus the energy 'locked-in' to built infrastructure comprising the base load. Further data gathering and analysis is needed to better understand stakeholder agency and infrastructure demand, and how this relates to shifting policy and practice. It is clear that whilst time-series energy data is readily available, contextual data required to further situate the energy reductions and rebounds in the mixed-use and messiness of a university campus, is not.

We will continue to explore HCI's role in supporting sustainable energy reductions in complex commercial buildings and sites, particularly with regard to uncovering and applying this context. In future work, we plan to analyse water and gas consumption (more closely linked to heating and heat demand in UK). These kinds of analyses are likely highly informative for energy audits and carbon reduction plans enabling longer-term reductions.

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