Energy Consumption in Commercial Buildings in a Post-COVID-19 World

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***Abstract*—The ripple effects of the pandemic have resulted in an unprecedented shift in sectoral energy consumption as the workforce predominantly stays and works from home. Quantifying the impact of these restrictions on energy consumption offers a new direction towards intelligent energy services in a post coronavirus (post-COVID-19) world, especially for commercial buildings. Thus, utilising actual power consumption data, the study evaluates how energy usage in commercial buildings can change in a post-COVID-19 world, whilst examining the impact of digitalisation to identifying potential new opportunities. The paper analyses the changes in energy demand with occupancy rate based on data from 126 commercial businesses with varied classes across Manchester, United Kingdom. The results show that the reduction in energy demand is not proportionate to the occupancy level, resulting in high energy costs. For instance, an average footfall for February 2021 is 10% of 2020, while the costs of electricity only fall to 80% of 2020. Although most of the energy demand is from appliances, the absence of energy efficiency increases energy consumption, highlighting the urgent need for optimised energy efficiency measures to include the time of use and scheduled use of energy across people and processes.**

***Index Terms*—COVID-19, pandemic, hybrid deep learning, energy consumption prediction, energy transitions, energy efficiency.**

I. Introduction

The outbreak of the coronavirus disease (COVID-19), which originated in China in December 2019, has caused significant disruptions in business activities worldwide. As the cases of infections grew globally, the world health organisation (WHO) declared it a pandemic in March 2020 [1]. To contain the human-human spread of the several acute respiratory syndrome coronavirus-2 (SARS-CoV-2) that causes COVID-19, several countries imposed public health safety measures, including wearing a facial mask, social distancing, quarantine, and in some cases, a national lockdown. In the United Kingdom (UK), the government enforced a nationwide lockdown on March 23, 2020, while nearly a third of the world population went on lockdown by March 25, 2020 [2]. The enforcement of these safety measures to contain the spread of the virus had an unprecedented impact on both the UK and global economic activities and people's behaviour, where everyone except designated groups of essential workers stayed and worked from home.

The behavioural changes caused by the COVID-19 pandemic result in significant challenges to the different sectors of the UK economy, including agriculture, manufacturing, finance, education, healthcare, sports, tourism, and food [3]. In the Power and Energy sector, the greater reliance on remote working and virtual education tends to impact a sectoral change in energy demands from commercial buildings. The department of the UK Business, Energy and Industrial Strategy (BEIS) reported a 10% decrease and a 4% increase in commercial and household energy use respectively in 2020 compared to 2019 [4]. Although it is simple and clear to understand why the global energy demand in 2020 is estimated to decline by 6% compared to 2019 [5], the repercussions are very complicated in different regions' energy types and consumption patterns [6]. For example, people working from home implies minimal commuting, which directly affects oil and gas demand. However, there is little reason to expect that the same trend will happen in the rest of the world.

Discussions on the effect of the ongoing COVID-19 pandemic on the energy sector across different fora is currently underway by the sector experts [6], [7]. Preliminary results of the discussion highlight long-term uncertainty. This development can cause tension between short-term financial stresses and the long-term need for investment and adaptation while offering new opportunities in the energy sector. Authors in [7] argue that the COVID-19 crisis has brought forward new solutions and behavioural changes to accelerate the energy transition. While, in [8]–[11], the authors stated that the pandemic is not only a driver for energy transition but causes a significant disruption with potential longer-term implications on domestic energy consumption behaviour and environmental sustainability. An outlook of the global development of renewable and sustainable energy assessed in [12] suggested reducing the pace of transition to a sustainable energy world during the COVID-19 pandemic. Thus, increasing the challenges of achieving a net-zero carbon economy through several continued initiatives, including smart cities projects and energy trading [13], [14], in a post-COVID-19 world. An overview of the impact and challenges of COVID-19 pandemics on energy demand and consumption, highlighting energy-related lessons and emerging opportunities is presented in [6]. A recent study [15] highlights several other COVID-19 impacts in the energy sector, including domestic energy consumption, transportation use, cooking and entertainment, and heating or cooling and lighting.

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While several studies investigate the impacts of COVID-19 on energy use relating to residential properties, research evaluating energy implications on commercial buildings attracts little or no attention. This article is one of the few studies that analyse the impacts of the ongoing COVID-19 pandemic. Specifically, we undertake a comparative evaluation of the effects of the pandemic on commercial buildings covering the periods before COVID-19 (pre-COVID-19) and during COVID-19 in the UK. We stratify the pandemic period covered by this study into two categories, 'during COVID-19' and 'post-COVID-19,' representing the period characterized by community lockdown and gradual return to normalcy, respectively. The study provides insight into energy usage in commercial buildings during and the post-COVID-19 and recommends using intelligent solutions to combat unforeseen imbalance and shifting electricity demand. The key contributions of this study include the following:

- We grouped energy consumption data of 126 businesses across Greater Manchester into building levels to analyse energy usage in commercial buildings covering pre-COVID-19, COVID-19, and emerging post-COVID-19 cases.
- Utilising a hybrid deep learning model, we forecast energy demands in these commercial buildings in a post-COVID-19 world to assess the relevance of smart solutions in combating unforeseen imbalance and shifting of electricity demand.
- We provided recommendations for risk management in the energy sector, highlighting the opportunities brought about by digitalisation and energy transition lessons.

The rest of the paper is organised as follows: Section II presents the literature review on the impact of COVID-19 on energy consumption. Section III evaluates the effects of COVID-19 on commercial energy usage with a case study of 126 businesses across Greater Manchester, UK. With the easing down of lockdown, Section IV discusses the new energy usage pattern in commercial buildings while giving a forecast of energy demand post-COVID-19. This section also discusses recommendations on risk management and the emerging opportunities brought about by digitalisation. Section V concludes with a summary of the main findings from the study.

II. Literature Review

COVID-19 pandemic has led to a slow down of the economies of different countries all over the world. This in turn has affected different sectors, from the supply chains [16] to the power network [17]. In the power and energy sector, COVID-19 had an unprecedented effect on energy demand across buildings causing instability and pressure on system operators [17]. Although the energy intensity in 2020 presented apparent spatial–temporal differences, both energy demand and gross domestic product (GDP) decreased [6]. Four main energy ambiguities remain, these are, demand fluctuations and uncertainties, structure and pattern changes, associated environmental impacts, and the challenge to recover energy demand [6]. As the energy industry experts review these ambiguities to identify short and long-term emerging opportunities, the perspective of COVID-19 impacts on energy consumption is emerging in the literature. For instance, in terms of short or long-term uncertainties, [6] highlights that the structural changes in energy demand and consumption will have either short or long-term expectations. While [15] suggests that the impact of COVID-19 on domestic electricity usage could be either long-term or temporary.

Concerning the associated environmental impacts, the global energy-related carbon dioxide (CO_2) emissions have implied the real emergency in the power and energy sector. For energy-related emissions, CO_2 emissions were decreased by an average of 26% for individual countries during the extensive lockdown period [18]. For some countries, for instance, Pakistan, study [19] reported a reduction in nitrogen dioxide (NO_2) emissions by 40% from coal-based power plants and a 30% reduction in major urban areas compared to the same period in 2019. For the case of metropolitan cities in Asia-Pacific, a 50% reduction in NO_2 was recorded in Wuhan, China [20].

In contrast to analysing the immediate impact of COVID-19 in the power and energy sector, recent studies are analysing the lessons learned to support decision making and long-term planning. Notable ones are, [2] that quantified shorter-term effects and identified longer-term impacts of the pandemic waves on the power system. Study [21] reported for the Russian electric power industry in a post-COVID-19 world. These studies discussed the development trajectories and implications for other sectors of the economy. Study [22] suggested measures to combat the unforeseen reduction in energy demand, shifting of electricity demand, and recommendations for risk management in the power and energy sector. Similarly, for future planning-based predictive models, authors in [23] concluded that the deviation of the overall electricity consumption depends on the severity of the pandemic and the degree of lockdown policies. In [24], the main challenges introduced by the pandemic were highlighted by presenting patterns of electricity generation and demand, frequency deviations, and load forecasting. They showed that during lockdown there was a significant increase in frequency deviations and load forecasting errors. They also showed that the pandemic caused a decrease in consumption, which raised the relative share of renewable sources in the energy mix and provided a glance into a renewable-rich future. The authors recommended directions for future research such as machine learning-based algorithms that may assist system operators during crises.

Though a decrease in overall energy consumption during the pandemic resulting from the lockdown policy has been well documented, its impacts on domestic have increased energy consumption so far from the perspectives of electricity use, domestic energy choice, and home energy management [9], [25]–[27]. However, the effect does not only impact energy consumption in domestic, this stability is most felt in the commercial energy usage pattern during the ongoing pandemic. Considering the uncertainty of the recent COVID-19 pandemic, work from the home policy could be adopted by many businesses in long-term. For adequate planning towards the future, this paper studies the impact of COVID-

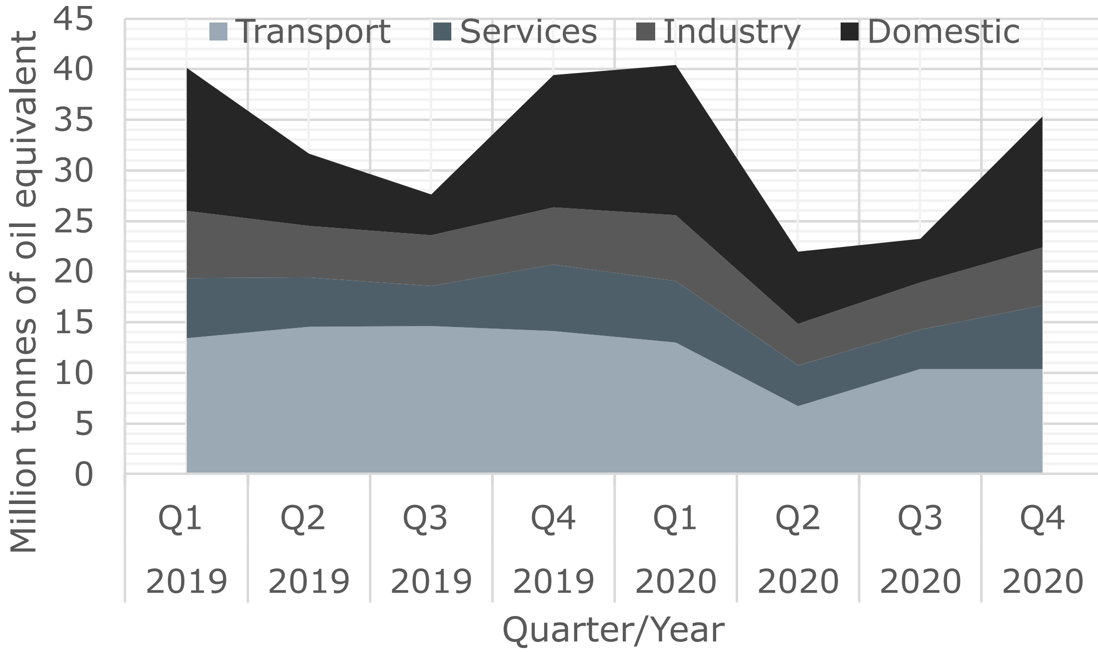

Fig. 1: UK final energy consumption for 2019 and 2020 [4]

19 pandemic on commercial buildings' energy consumption, and analyse the pre-COVID-19, COVID-19, post-COVID-19 consumption in the UK. It also suggests smart solutions to combat unforeseen reduction and shifting of electricity demand.

III. COVID-19 impact on energy usage in commercial buildings

COVID-19 has significantly changed how and when occupants use commercial buildings, and therefore the energy consumption and associated flexible demand profiles at these buildings have changed. Fig. 1 shows the final energy consumed by different sectors in the UK in each quarter of 2019 and 2020 [4]. In 2019, 40.8% of the total consumption is by the Transport sector, 16.1%, 15.4% and 27.7% are by the Industry, Services and Domestic respectively, while an equivalent of 33.5%, 17.4%, 16.7% and 32.5% for each sector in 2020, respectively. There is an increase in domestic energy usage in 2020 compared to 2019.

Comparing the last quarter of 2020 to 2019, BEIS reported a rise of 2.1% in domestic energy usage, while the service sector usage was down by 8%. However, comparing the years 2020 to 2019, the service sector was down by 10.4%, while the domestic rose to 4%. These statistics clearly illustrate the sectoral shift in demand from the services sector which includes the commercial buildings to the domestic sector resulting from the various lockdown measures. A case study of this impact is presented in the following using 126 businesses across the Greater Manchester area.

A. *Case study: Impact on demand*

In commercial buildings, the direct impact of COVID-19 can be measured through electricity demand variation in terms of power profile, energy consumption, occupancy rate/behaviour and energy efficiency measures in place. The direct impact of the pandemic lockdown measures on electricity systems is visible in the rate of electricity demand. This impact is evaluated based on the variation of power profiles to corresponding past periods before the pandemics. Reporting the energy demand variation D_v as a percentage to the baseline consumption, the following is derived.

$$D_v = \frac{D_N - D_{N-1}}{D_{N_i}} \times 100 \qquad (1)$$

where D_N and D_{N-1} represent the total demand of the examined period in the present year and the previous year, respectively.

Thus, in this work, we evaluate this variation utilising 126 commercial businesses across Manchester in the UK by comparing their energy profiles over 3 years to capture pre-COVID-19, during COVID-19 and emerging ease of lockdown period, whilst considering the different trajectories that energy demand may take moving forward the new normal. In the following, to capture the COVID-19 lockdown measures, the demand period started from March to February for the years under consideration.

The 126 businesses are grouped into building levels to capture their collective impact. Fig. 2 shows the monthly energy consumption of 5 of such buildings over 3 years from April 2018 to April 2021. The five buildings have a similar trajectory and as would be expected, the pre-COVID-19 energy consumption increased for 2019 compared to 2018 and before April 2020. A sharp fall in demand can be noticed in April 2020 at the peak of lockdown amidst COVID-19 uncertainty.

Similarly, Fig. 3 presents another set of 5 commercial buildings but with lower energy demand levels compared to Fig. 2.

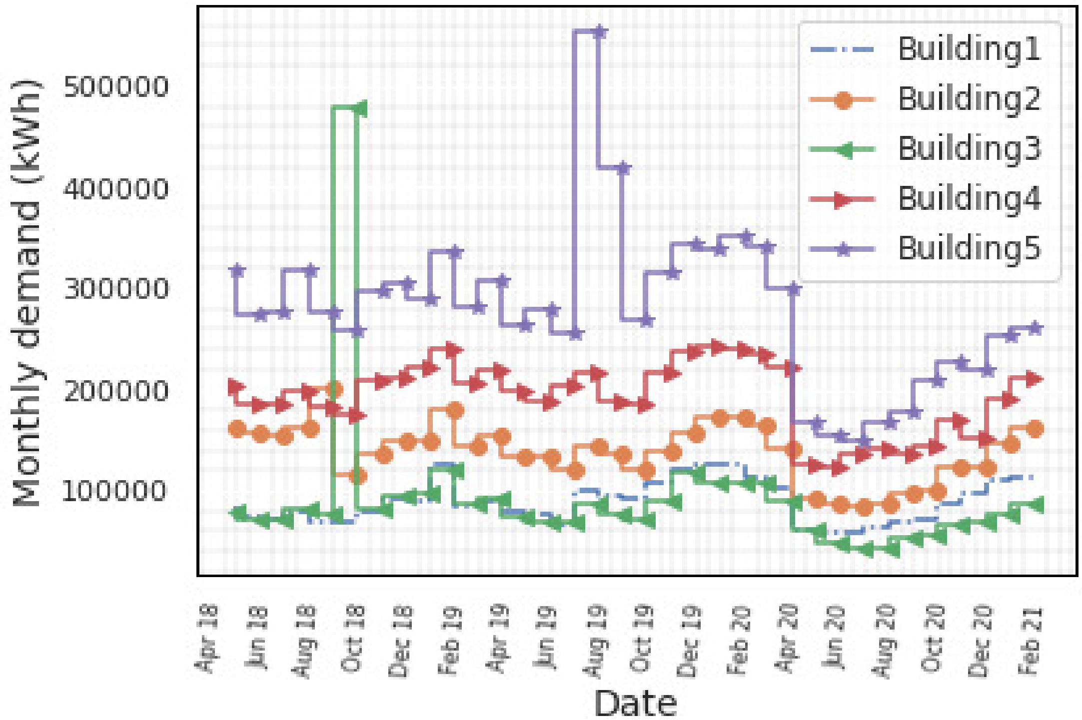

Fig. 2: Energy consumption for 5 high-demand commercial buildings.

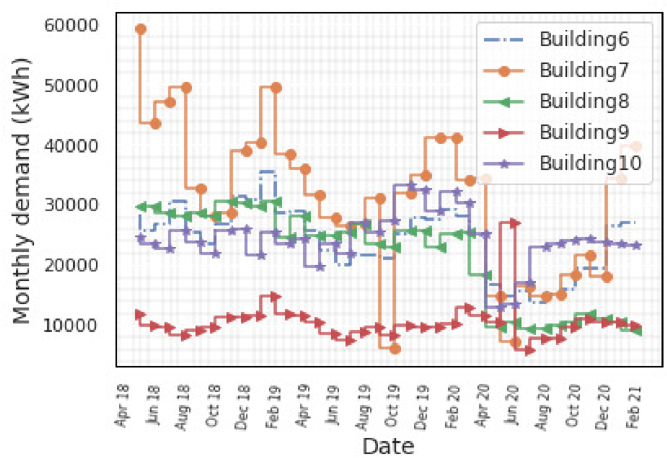

Fig. 3: Energy consumption for 5 low-demand commercial buildings.

B. *Case study: Impact on occupancy rate*

The effect of stay and work at home is highest with commercial buildings. For the buildings under consideration presented in Fig. 2, Fig. 4 shows the footfall of February data for 2020 and 2021. Utilising an average of 70% of the usual footfall before the pandemic for the year 2020, Fig. 4 shows an average of 10% occupancy rate in 2021 compared to the 2020 levels. The reduction in occupancy rate in the buildings resulted in reduced energy demand as shown in Fig. 5 compared to previous years of the same period.

However, these demand reductions are not proportionate to the average footfall in those buildings. It is evident that while the footfall reduces the demand, some of the appliances and equipment; cooling and heating, at the buildings will continue to function thus increasing the demand in the commercial buildings.

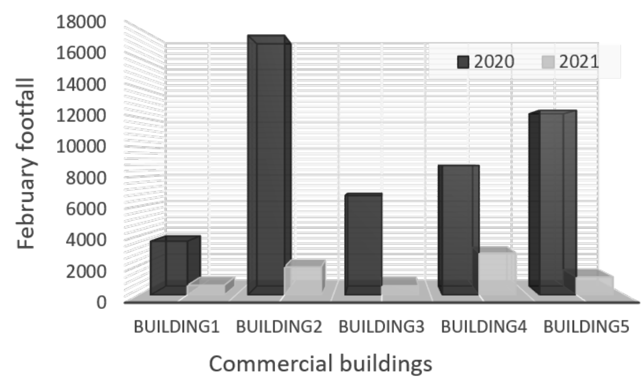

Fig. 4: February footfall for 5 commercial buildings for 2020 and 2021.

C. *Case study: Impact on energy bills*

It is expected that a decrease in demand in these buildings will result in a decrease in energy costs [22]. In the present case study, there is a decrease in the cost of electricity in February of 2021 compared to 2020. However, the disproportionate levels of footfall and demands resulted in disproportionate levels in the costs of electricity for that period. For instance, the February costs for the 5 buildings under

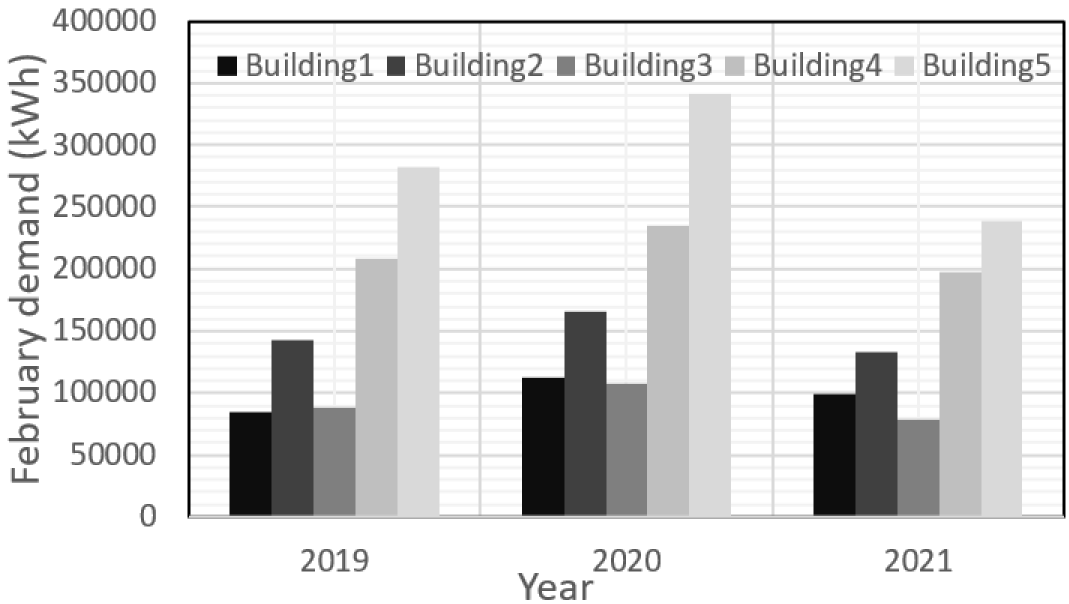

Fig. 5: February energy consumption for 5 commercial buildings.

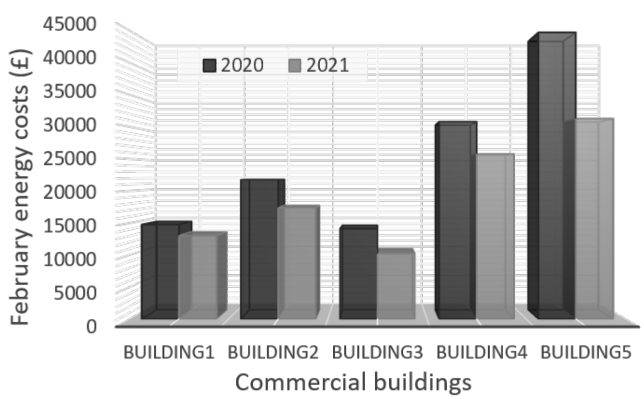

Fig. 6: February costs for 5 commercial buildings for 2020 and 2021.

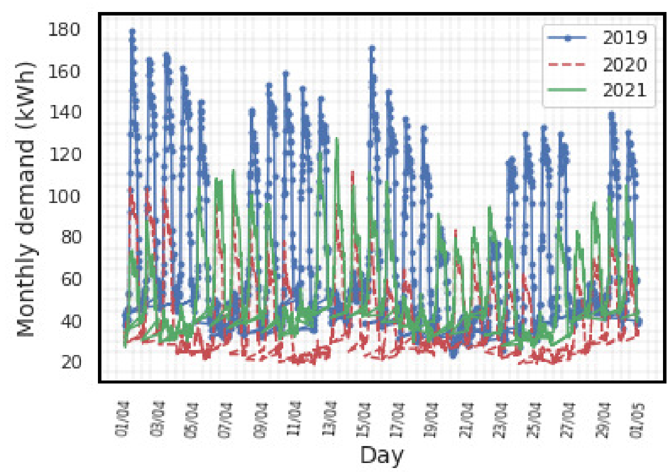

Fig. 7: April 2021 energy consumption for Commercial Building 1.

consideration remain at an average of 80% of 2020 costs despite the footfall being at 10% of 2020 levels shown in Fig. 6.

This shows while these buildings are not occupied, the thermal heating and cooling in place consume energy, thereby increasing the electricity bills. While COVID-19 posed various challenges, the insight from this study highlights the urgent need for optimised energy efficiency measures in commercial buildings to include the time of use and scheduled use of energy across people and processes.

IV. Post-COVID-19 energy demand in commercial buildings

As the UK transitions to the "new normal" post-COVID-19, this section explores the changes in the time of use of energy and presents a forecast of the commercial building energy usage. It also identifies opportunities for smart energy services.

A. Case study: Changes in time of energy use

The phase easing of lockdown in the UK started in March allowing schools' resumption. Non-essential retail, outdoor restaurants started operation on April 12, 2021, which saw other commercial services back to work. This is also reflected in the commercial buildings under consideration. Fig. 7 reflects the energy consumption for one of the buildings in April for 2019, 2020 and 2021.

From the figure, an increase in demand can be observed for 2021 after 12th April. Although this increase is not consistent, maybe due to not being fully in operation as would be expected, it reflects the urge to transition to normalcy.

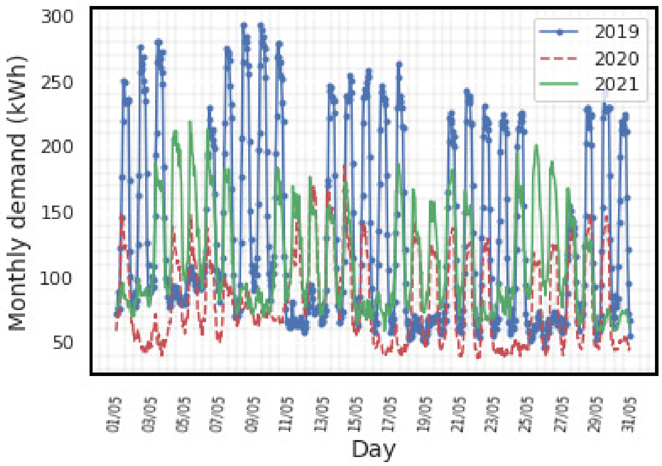

Fig. 8: May 2021 energy consumption for Commercial Building 1.

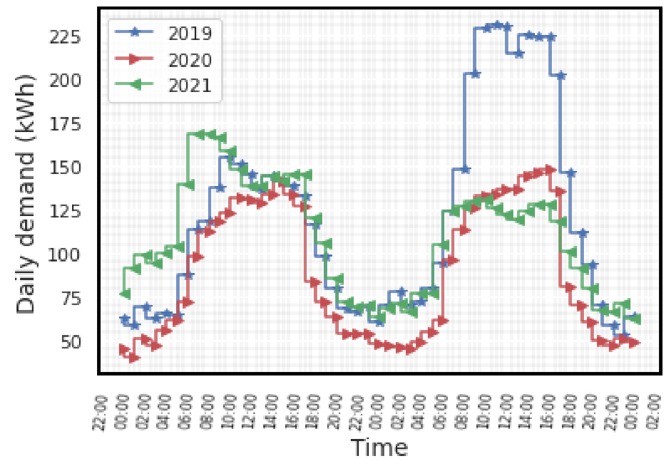

Fig. 9: Energy consumption for May 27 and 28, 2021 for Commercial Building 1.

Similarly, Fig. 8 shows the demand for May, 2019, 2020 and 2021. As would be expected the energy demand has started to rise compared to April. The increase observed in 2021 is less than the pre-COVID-19 levels of 2019, but it is more than the COVID-19 level of 2020.

To capture the effect of time of use of energy for efficiency measures, Fig. 9 shows two typical workdays in May (day 27, 28) for 2019, 2020, and 2021. A shift in time of energy usage is observed. For 2021, for day 1, it seems the tenants/customers using the buildings started work early at 6 am, which peaks between 8 and 10 am before a final descend at 8 pm. For day 2, the daily demand for 2021 is lower than 2019 but higher than 2020. The demand started to rise at 6 am, peaked at 7:30 am, before starting to descend at 5 pm till around 10 pm. Comparing the years against 2021, shows that tenants/customers are starting work at early hours and are staying till late before leaving the buildings. This observation suggests that peak demands in commercial buildings in a post-COVID-19 world might change to a new level and a new time of use. A new rethinking of energy efficiency measures is required to curb these rising demands, especially in commercial buildings.

B. Case study: Energy demand prediction

The previous discussion illustrates the effect of COVID-19 on electric power consumption for commercial buildings resulting from the impact of staying and working at home during those periods. This sudden change in demand resulted in energy supply and demand imbalance. Thus, to prevent this instability for appropriate energy efficiency measures and provisions, we forecast energy demand post-COVID-19. This is to provide an insight into future energy usage to inform smart energy services and policies.

Meanwhile, a predictive framework was developed as part of the Energy-IQ project[1]. The architecture of the predictive framework is presented in Fig. 10. The predictive architecture is a hybrid deep learning framework to accurately predict the energy demand consumption of different building types both commercial and domestic, spanning different countries, including Canada and the UK. The framework briefly comprises multiple architectures of two convolutional neural network (CNN) layers and an autoencoder (AE) layer made up of a bidirectional long short-term memory (BLSTM) as the encoder and a single long shot-term memory (LSTM) as the decoder [28]–[30]. The full description of the developed predictive framework is presented in [28] for interested readers.

To show the accuracy of the predictive framework, Fig. 11 illustrates an example of its training and validation loss with a mean square error of 0.01 and a root mean square error of 0.09 as presented in [28]. Utilising the predictive framework, we predict energy demand for the commercial buildings under consideration for four months into the future. In particular, for July, August, September and October, 2021. Fig. 12 shows the predicted levels of demand for one of the buildings for July, August, September and October. As would be expected, an increase in demand over the COVID-19 levels is predicted with an average of a 19.2% rise in demand over the coming months. This prediction would inform the provision of smart energy services and policies for commercial buildings.

C. Recommendations on risk management in the energy sector

The study conducted in [15] on the impact of COVID-19 on domestic energy consumption suggested an average of 67% increase in domestic electricity bills in February 2020 to 2019, 95%, 35% and 22% in March, April and May respectively. This evident report has seen a sectoral shift in electricity consumption from commercial buildings to domestic buildings. Despite the shift in electricity consumption, the impact on commercial buildings' energy bills is not equivalently shifting between the two sectors. This is impacted by user behaviour to consumption and the present energy efficiency measures in place. Evidence provided in this study further reinforced the need for smart energy services in both commercial and domestic to curb the increasing demand in both sectors. The

[1] Energy-IQ is a UK-Canada Power Forward Smart Grid Demonstrator project funded by BEIS to reduce energy usage, carbon and cost in domestic and SMEs buildings using AI and flexibility offerings

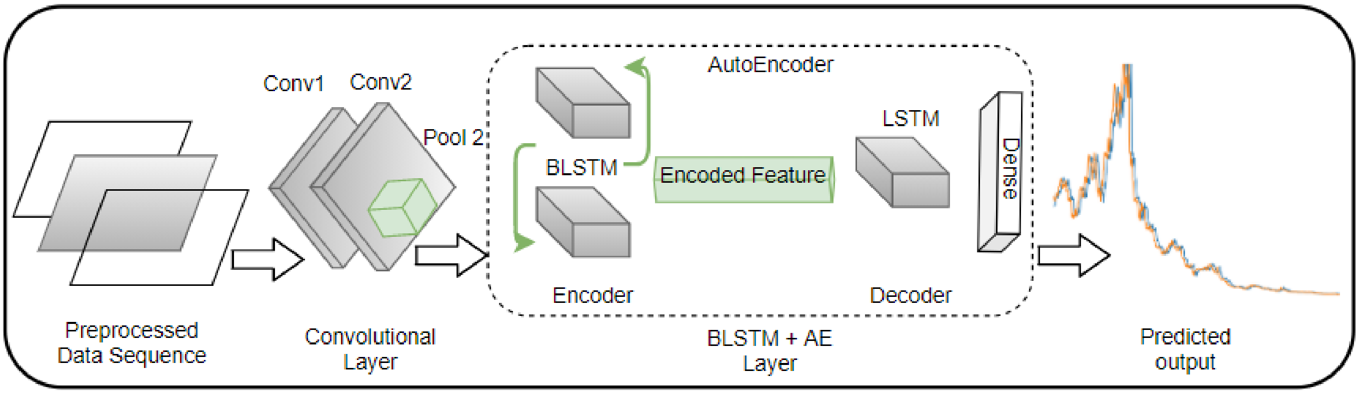

Fig. 10: A developed framework for energy prediction [28]

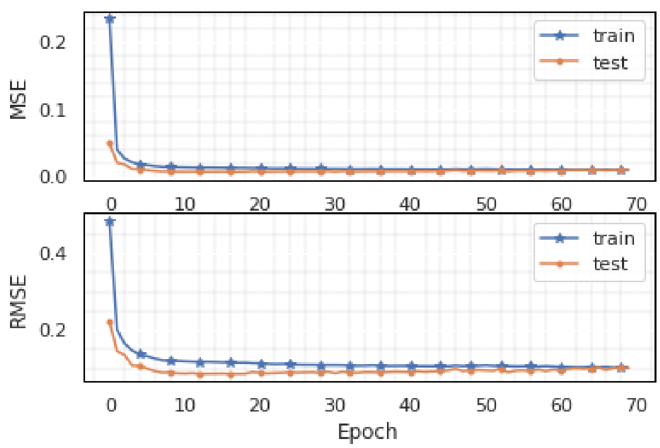

Fig. 11: Training and validation loss of the predictive model during training [28]

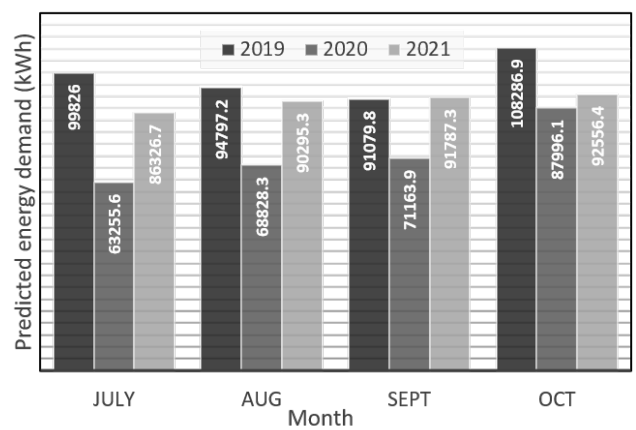

Fig. 12: Four months energy demand prediction for Commercial Building 1.

following recommendations are highlighted for the electricity costs, demand and carbon reduction in a post-COVID-19 world.

1) Energy efficiency measures: As people stayed and worked from home during the pandemic, energy consumption at the workplace reduced. But the rate of consumption is not proportionate to the footfall in the commercial buildings. Appropriate energy efficiency measures can further reduce energy consumption to an appropriate level. Energy efficiency measures can be deployed in several ways. Such as scheduling time of use of appliances, demand-side management programs, and encouraging green buildings including, installing energy-efficient cooling and heating equipment, renewable energy installation, etc., on new build and existing buildings. Efficient use of energy has its unprecedented benefits in achieving a clean and green economy.

2) Power system resilience: Vulnerabilities of the power system were exposed during the pandemic. For instance, the unpredictable event increased volatility of electricity supply and demand, which combined with distributed energy resources (DER) put a significant challenge to keep the grid balanced and stable. For instance, a 24% measured difference between the highest and lowest weekend energy demand in Britain [31] in the early weeks of the COVID-19 outbreak. Responding to these variances require resilience approaches in the power and energy sector. Such as anticipating and preparing for unpredictable events to quickly recover thereby minimising any disruptions. To achieve this, adequate planning and accurate forecasting are needed. Diversification of the energy generation mix and integration of distributed generation and improved storage systems would support resilience building and off-grid solutions.

3) Demand-side load management: is a scheme to balance peak load demand by scheduling power generation and transmission, allowing the grid operators to balance intermittent renewable energy sources. Thus resulting in a stable supply for customers and quantifiable benefit to the operators.

4) Policy and regulations: The main policy implications are on energy efficiency measures such as where consumers become prosumers. The Government policies and regulations on these ideas can enable greater power system controllability or can deepen the challenges in achieving a net-zero carbon economy in a post-COVID-19 world. Policy on the investigation and innovation of sustainable technologies are vital to abate costs. Furthermore, policymakers should prioritise strategic actions to sustainable energy transitions in the commercial sector

D. Emerging opportunities of Digitalisation and IoT

The impacts of COVID-19 on the power sector created several challenges as well as new opportunities and improvements [32]. Digitalisation is one of the opportunities of COVID-19. Digitalisation is vital in the energy transition initiative, fostering decentralisation of the energy systems, and value for the consumers. The main drivers of digitalisation are data from the internet of things (IoT) devices, advanced analytic and connectivity between systems and subsystems. Implementation of advanced analytic for predictive maintenance, planning and operation will result in the development of smart appliances for decarbonising buildings and transport. The potential impact of digitalisation is unparalleled in improving grid management and operation while reducing operation and maintenance costs. The use of data analytic brought about by digitalisation informs decision making, improves efficiency, improves system planning, reduces unplanned outages, extends asset lifetimes, improves system stability, reduces investment needs, reduces costs and ultimately, reduces carbon emissions. As the COVID-19 pandemic hastens application opportunities for technologies in the domestic sector [33], commercial buildings also present an opportunity for digitalisation for smart technologies. Such as the deployment of smart building controls, enabling demand-side response and offering a variety of new business models that could further reduce energy demand and use in the post-COVID-19 world. Resulting in low carbon technologies in the commercial sector and potential for more active consumer participation in the power sector, supporting aggregators and energy communities.

E. COVID-19 and energy transition lessons

Energy transition and COVID-19 are similar in terms of their impact on lives (emissions or contagions), the importance of scientific evidence and adverse consequences of unpreparedness. COVID-19 exposed the vulnerability of the economy to environmental changes including climate changes. An effective response energy transition and COVID-19 requires a collective effort across a variety of stakeholders to reduce its impact. This will involve behavioural changes and social practices. On behavioural changes, through COVID-19, people are now more receptive to warnings on sustainability and resilient development. COVID-19 highlighted the costs of unpreparedness and the importance of taking preventive actions than corrective responses. In contrast, COVID-19 showed the adaptability of human nature in responding to unanticipated events or implementing massive changes quickly and efficiently. Meaning if need be and if convinced of its impact, we can adapt and collectively fight climate change. To sum, while COVID-19 slowed energy transitions, it, however, increases the awareness of the need to tackle carbon emissions to prevent any unforeseen catastrophe event. Lessons learned from COVID-19 can reform energy transitions towards a greener, cleaner living.

V. Conclusion

As the world transition to a new normal, it is evident that the pandemic period shifted the sectoral demands of energy from commercial buildings to domestics through the work from home restrictions. While this initiative reduces the footfall at these commercial buildings, their energy bills were not significantly affected. This highlighted the urgent need for smart energy services in these commercial buildings for energy efficiency, costs and carbon reduction.

Secondly, the predicted energy demands over the coming months highlighted an average increase of 19.2% to the 2020 demands. This predicted increase in demand would increase costs and emissions. Similarly, the daily analysis of the change in working time/pattern, reflects tenants/customers starting work early and leaving work late. This forecasted increase in demand, as well as changes in the working pattern, would require energy efficiency measures throughout the day and not just at peak periods.

Finally, it is believed that while some working individuals and organisations are still working from home, energy demands have started to rise in commercial buildings. A mega rise in energy demands in both domestic and commercial buildings is inevitable in the coming months and maybe years if appropriate energy efficiency measures are not in place to curb the demand and costs towards a collective net-zero carbon community. An increase in efficiency measures will result in a decrease in costs, demand and carbon for a net-zero economy.

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