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Research Article

Building energy consumption assessment during and after lockdown: Case study of Malaysian housing

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Abstract

The COVID-19 pandemic caused devastation to society in 2020, forcing people all across the world to alter their lifestyles. During the pandemic, people spent more time at home, and this shift in occupancy can directly influence building energy usage. COVID-19 lockdowns hastened the transition to telework, which many predict will continue. Changes in energy usage during lockdown are thus a significant source for forecasting future energy consumption in buildings. This study aims to measure the effects of the COVID-19 lockout on home energy usage. The energy usage of a seven residential building complex in Johor Bahru, Malaysia before, during, and after the first lockdown phase was compared and analyzed. It was discovered that the initial two months in the lockdown period are the most severe energy consumption due to the tight lockdown measures implemented as reflected in energy consumption patterns. Overall energy consumption for all candidate appliances increased during and after lockdown. Still, the more significant change was that consumption occurred during the daytime rather than focused in the evening as before the lockdown. The findings provide insight into the effect of a lockdown on customer energy costs and how energy utilities may be approached during such an event.

Introduction

Coronavirus disease-19 (COVID-19) was designated a world pandemic by the World Health Organization in March 2020. Governments all across the globe implemented lockdown measures to limit the spread of the virus, which are still in force in most cases over a year [1]. Lockdowns have been a wide range of negative effects on the economy, jobs, and individuals' daily lives. According to a report by Google's COVID-19, retail and leisure center occupancy in Malaysia fell by 63% during the first month of the pandemic, while residential building occupancy rose by 21% [2,3]. As a result of adjusting to being at home more frequently, inhabitants in residential buildings changed their routines and behaviors. Changes in occupancy schedules directly affect building energy consumption [4]. Therefore, lockdowns' differences in pattern and behavior may impact building energy consumption patterns.

Research literature related to the COVID-19 pandemic and its impact is a new phenomenon in building energy consumption [2,3]. However, the impact of COVID-19 restrictions related to energy consumption, generation, load, and transmission has been explored in sixteen European countries [2]. During this period, most European countries experienced a remarkable drop in energy generation. The current practice for energy generation in most European countries is from gas, nuclear, and coal, with only a few that significantly shifted to sources energy from renewables. Similar behavior is also observed in Malaysia. At the pandemic's start, a reduction of carbon emission in the air increased, thereby allowing the sun to shine and reach directly to photovoltaic panels, which boost the solar

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energy generation [3,4]. Residential buildings energy research estimates that the proportion of total building electricity demand in Malaysia increased from 42% before the pandemic to 50% during the total lockdown period. In a study performed in New York, a participant stated that under the COVID-19 lockdown, their power use starts later in the morning and is pretty steady compared to the rest of the day [2,3]. A high percentage of the participant said they used more electricity before the pandemic, while only a handful said they used less [4].

Changes in tenant behavior in residential structures have also been observed outside of the realm of energy [5] report that the current pandemic has interrupted way of driving buildings toward higher waste diversion levels in term s of waste management [6]. A similar study in Brazilian shows a rise of 10% in energy consumption and water usage, with significant declines in commercial buildings such as institutions and industries [5]. Another research examined 143 people's physical activity levels before and after the COVID-19 lockdown [7]. During the pandemic, normal physical activity dropped from 8.701.7 to 3.134.7 MET-min/week, indicating a substantial drop in physical activity among those who were confined at home. Despite having greater occupancy hours, tenants in a London building depended more on the HVAC system during the lockdown, and the time of open windows was considerably less [8]. COVID-19 lockdowns had an evident impact on people's behavior in buildings, according to all of this research. Since then, the practicality of programmable thermostats has tended to be in question as tenants do not always use them to their full potential. As a result, the influence of the HVAC system in terms of energy consumption shows that when inhabitants telework, energy usage in homes may rise by an average of 20%, depending on the occupants' number in the building [9]. However, the majority of the literature on building energy usage does not use precise metering to assess energy consumption during lockdown days [10].

This research identifies the lack of information on building energy consumption patterns in residential structures in terms of individuals spending more time in the building than usual. The majority of scientific information on this subject is based on educated guesses and statistical analysis rather than precise measurements. Because individuals are projected to spend more time at home in the future [11], it's crucial to understand how this increase in occupancy will affect residential building energy usage. The majority of publications on the influence of the COVID-19 shutdown on building energy usage concentrated on one element of energy utilization. Some, for example, focus solely on power use. Although the data is useful, a comprehensive assessment of energy usage would be better because buildings contain many energy sectors (space heating, electricity, cooling, etc.). Most research on COVID-19's impact focuses on energy usage, perhaps because it is the most readily available data. When assessing the impact of the COVID-19 lockout, the "stochastic" behavior of occupancy in the building must be taken into account. Because tenant activity changes day today, many of the temporal and geographical variations in energy consumption behavior in residential structures. Differences in consumption seen during the lockdown might be attributable to 'natural' variance rather than the lockdown itself. For a full study of energy usage trends during the lockdown, statistical tests are required. We hope to overcome these flaws in this study by conducting a comprehensive analysis of energy usage in a residential building during a lockdown. This study considers 7 residential building structures in Johor, Malaysia. Since the occupation began in 2015, it has been closely watched [12]. The energy consumption analysis before and during the lockdown has been analyzed concerning the HVAC system.

The influence of the COVID-19 shutdown is separated from the inherent fluctuation of energy usage trends in buildings using statistical testing. The study aimed to answer whether COVID-19 lockout affects overall building energy consumption as well as changes in energy consumption behavior such as utilization period. Even though the COVID-19 phenomenon is relatively new, we have yet to come across any such comparison in the literature, particularly for this type of statistical analysis. The study and procedure used for the assessment of the energy consumption before and after COVID-19 are described in further detail in the next section. The findings for energy consumption and space heating are then shown in Section 3. The lockdown's timing and effect on building energy usage are also shown. Section 4 represents the discussion, and the last section represents the conclusion.

Research material and method

On March 13th, 2020, the Malaysian government declared many states with a public health concern as an emergency as a result of the COVID-19 pandemic. Unfortunately, a computer malfunction stopped data gathering from beginning a few days before that date, and the computer was only restarted in March 2020, owing to COVID-19 limitations. As a result, the majority of the non-essential services become suspended indefinitely following the public announcement. As a result, we designated March 2020 as the beginning of the pandemic for this research intending to assess and compare building energy usage before during the lockdown period. Before March, all non-essential enterprises, including institutions, retail centers, recreational, pubs and eatery, and all economic sectors companies, were already shuttered. We have opted to utilize data up until July 25th, giving us a four-month study period. This period encompasses the proposed plan to reopen the non-essential sectors in Johor Bahru, as seen in Table 1.

A limited movement is required to see if the COVID-19 lockout resulted in variation in energy usage. The year between

Table 1: Planned for reopening of economic sectors.

Phase	Activities	Resumption date
1	Construction, Landscaping and Mining industries	27th, April
2	Enteprises with outdoor service and access	19th, May
3	Educational sectors and research institude (50% sta)	18th, July
4	Individual fitness outdoor activities	7th, August
5	places of woship (20% attendant)	15th, August
6	Shopping malls, Saloon and Cosmetic	11th, October
7	Eatery, events and wedding related activities	24th, October

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March 2019 and February 2020 was chosen as the control period. A dataset from the various buildings about weather conditions is gathered during the lockdown, which might impact thermal behaviors like HVAC systems and windows state [1,2]. There is an attempt to curtail the period to finish during the began, so it can be observed whether there is a quick shift in energy use; thus, the control period shall be yearlong. The analysis covered months before, during, and after the first lockdown for the sake of brevity. According to the building's operating agents, residential energy consumption changes occurred during the control year. Therefore climate variable was not considered in the analysis. A plausible explanation can be that the lockout increased energy consumption while reducing peak demands by raising the number of time occupants spent in the building. These peaks generally occur in the early morning and late evening, before occupants leave for work and after they return to the building. By keeping individuals at the building during the noon hours, residents have greater freedom in terms of when they engage in energy-intensive activities. Indicators for data analysis and evaluation of energy consumption-related patterns before, during, and after the lockdown are needed to address these issues. The daily energy usage was chosen as the indication to address the first question: The quantity of energy utilized during hour e. The Root Means Squared Error (RMSE) is used to determine whether there have been variations in the time of day when energy is consumed.

$$e1 = \sum_{i=1}^{24} Ei \tag{1}$$

$$RMSE = \sqrt{\sum_{i=1}^{24} \frac{\left(Ei - E1,\ control\right)^2}{24}} \tag{2}$$

The control period data were used to calculate the average daily profile of energy use. The energy consumption pattern of each lockdown day is therefore evaluated with the average energy consumption pattern by using Eq (2). On an hourly basis, this comparison is made. A high RMSE value indicates that the examined day's profile differs significantly from the average energy consumption profile. This large disparity, however, does not essentially imply that usage occurred at various periods throughout the day. It might simply be due to differences in energy usage patterns, which are already recorded by the first analysis. To remove this parameter, all daily usage patterns are divided by overall energy usage to normalize them.

$$e2 = 100 * \sqrt{\sum_{i=1}^{24} \left(\frac{Ei}{\sum_{i=1}^{24} Ei} - \frac{Eicontrol}{\sum_{i=1}^{24} Eicontrol} \right) \frac{ei}{24}} \tag{3}$$

In a nutshell, we computed the percentage of daily consumption patterns for each hour. This indicates a lot of changes in terms of occupant patterns, which leads to a great deal of variation in average daily energy usage patterns. This indicates that energy usage in a single home might vary significantly from day to day. These differences can also be noticed between months of the year. As a result, the discrepancies among movement control order periods may be attributable to "natural" variations in consumption patterns rather than the COVID-19 lockdown itself. As a result, we'll need a statistical test to analyze the effects of the lockout properly.

$$Zmonth = \frac{\bar{x}\ control - \bar{x}\ month}{\sqrt{\frac{\partial^2\ control - \partial^2\ month}{\tau control - \tau month}}} \tag{4}$$

Where is the average value, s is the standard deviation, and n is the number of days in the group (here are 365 days with the 1-year control period). We calculated the two indicators e1 and e2 for each day of the control and lockdown periods. Then, for each month, we divided all days into monthly groups. This enables the computation of standard deviation values for the considered parameters. We computed the Z-score for each month using Eq (4). by comparing these values to those for the whole control period. These Z-scores were then converted to watt. Based on the assumption that both control and month are equally considered with the same priority, these watt values reflect the likelihood of generating Z-scores at least as severe as those reported. To immediately convert Z-scores to watt values, we utilized Matlab's normcdf function. Similarly, the scores and watt scores were computed for each month. With the noteworthy exception of changing the adaptation of smart lighting concerning the seasons, usage of electrical equipment used is mainly non-adaptive behaviors, meaning that environmental circumstances have little impact on these behaviors [13]. We can immediately apply the two specified metrics to these energy expenditures to answer our queries. On the other hand, outdoor circumstances have a significant influence on room heating. It would be inaccurate to compare building comfort before the lockdown and after the movement control order. When computing the first indication, during the period of control the value of the score is calculated by dividing the energy consumed during heating per hour to total heating of the day:

$$e1, Heating = \frac{\sum_{i=1}^{24} E1}{HDHday} \tag{5}$$

Where the day's heating degree-hours are computed using an 18°C base temperature. In the case of the second indication, heating per hour was unnecessary because the hourly value is standardized with entire day usage.

Energy consumption

Before the luck down period from 2015 to 2019, the average power consumption per resident is around 80kWh (Figure 1). However, during the movement control period, the energy consumption increased by an average of 25%, resulting in 110kWh equating to a monthly average. The average daily power use per residence during the lockout grew up by an average of 20% throughout the lockdown. Given that tenant behavior in buildings might vary from month to month. However, variations may be noticed when the lockdown duration is broken down

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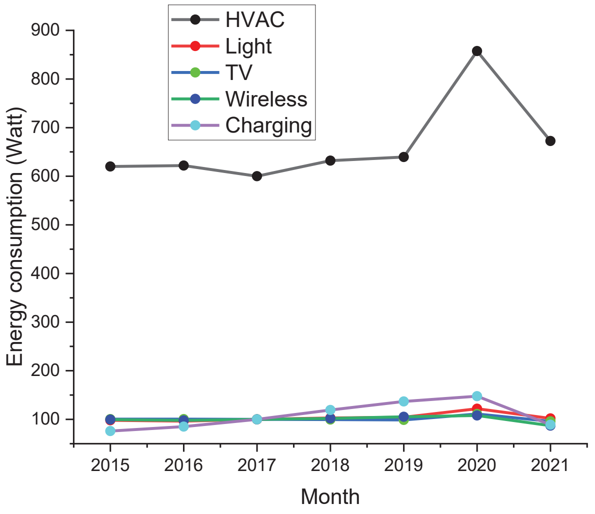

Figure 1: Building energy consumption from 2015-2021.

by months. In the first month of the lockdown, the average daily power consumption reached a value of 122kWh, 120.5kWh for the first month and 100.8kWh in the second month, and 100.8kWh in the rest of the months.

In the control period, the month with the highest energy consumption is 2020 with 145.4kWh per residence, while the month with the lowest consumption rate is September 2021 with 109.8kWh. Thus, the monthly demand of 120.2kWh per resident from March 2020 reflects a consumption level that has not been witnessed throughout the movement control period. The lockdown appears to have resulted in a direct rise in power usage in the period, which was marked by the most severe control measures (Figure 2).

Lighting and HVAC system are the major energy consumer in the building during the lockdown period. Figure 2 shows the building's average daily power usage profile throughout the motion control and in the period of movement control measures months. This graph shows the changes in terms of energy consumption before, during, and after the lockdown. In March 2020, energy usage was evenly consumed in contrast to the normal energy usage behavior during the lockdown, when use gradually increases in the day and reaches a peak in the evening.

The drop in lighting is noticeable in August and September, while the increase for the use of HVC system on same months when consumers used more power in the day than in the lockdown but cut back dramatically in the evening. As the two curves approach extremely close in June, the consumption behavior goes back to the predicted usage pattern. Because of the summer during the last months of the lockdown, the energy usage at nighttime tends to be lower than in day time.

The parameters I1 and I2 that are used as an indicator in seven homes whose electricity usage was analyzed are shown in Figure 3 and. We can observe from these data that residents responded to movement control in different ways. In April 2020, for example, the 7th residence had a significant rise in power usage, but the 6th home observed a drop during the month. The score of the RMSE for the first residence was 2.28% in the lockdown period and 3.98% in March 2020, indicating that residents' electricity consumption patterns altered during the lockdown. In April 2020, the RMSE for the fourth residence dropped from 5.43% to 2.98%. This means that the average usage pattern daily recorded during April was quite similar to the overall average energy consumption pattern. These variations in energy usage recorded during the lockdown varied between houses, which might be attributed to socioeconomic characteristics (occupant age, work level, etc.). Figure 3 indicates that the average score value of RMSE calculated for the entire building in April 2020 was 1.72%, 1.69% in May, 1.39% in June, and 1.42% in July. During the first two months of the lockdown despite the occupancy in the building have different energy usage patterns on various occasions.

There were months during the control period with total day consumption therefore the fact that the amount of consumption varies from month to month is not the result of COVID-19 lockout. However, during the lockdown, the concentration for higher HVAC system energy consumption is periodized. There

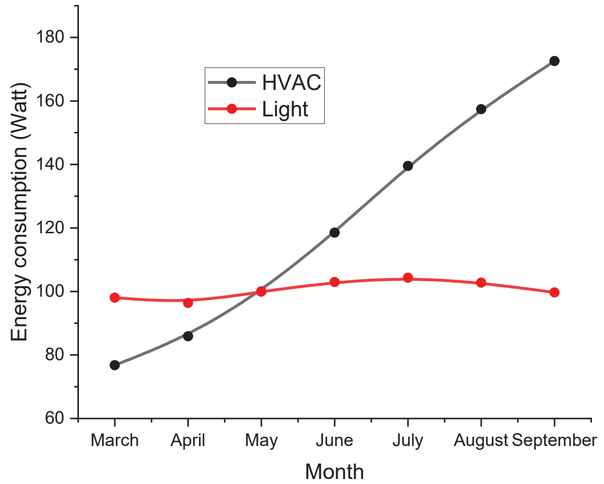

Figure 2: Appliance with the higher energy consumption during lockdown.

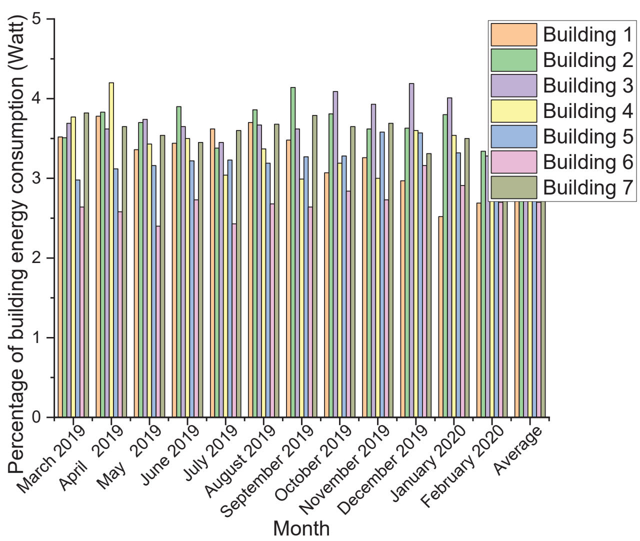

Figure 3: Case study buildings energy consumption before and during lockdown.

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were 34 occurrences in the event of the lockdown that reflect the changes in the energy usage, which statistically shows a cut-off significance level value of 0.078 out of the 92 analyzed values. This shows 27.2% towards the end of the lockdown was statistically different from the start of the lockdown energy usage rate. 49.4% of the months during the shutdown were statistically other. Six of the eight households changed their energy usage pattern from January to February 2020. Looking at the RMSE score data, it indicates the variations in during day time of consumed energy, the discrepancies among the control months are increasingly becoming clearer. There were fewer yellow instances during the lockdown, as indicated in Figure 3, compared to the daily energy usage. Similarly, Figure 3 indicates that many of the months during the lockdown had reached the peak energy usage that was not experienced before the lockdown that differed significantly from the whole control period. Few months after lockdown have shown an average of 20% drop in energy consumption. This is a result of hybrid control implementation that allows partial resumption of the workplace with limited staff capacity allowed in the building at particular hours in the day. This statistically shows the pandemic has brought the surge in building energy consumption with a large consideration of the HVAC system and lighting appliances even in July 2020 when the majority of the restrictions were eased.

When looking at overall power usage in the control year, we found that 35.4% of the months at the dwelling scale statistically deviate from the average of the whole control period. We can calculate the chance of seeing at least as many 'different' months as we did during the lockdown if we assume this ratio represents the real rate of 'different' months in a regular year. In April 2020, for example, six of the eight homes had distinct overall power usage patterns.

When looking at the RMSE data, which indicate if there were variations in the time of day when power was consumed, the discrepancies between the control and lockdown periods became increasingly clearer. There were fewer yellow instances during the control period for the RMSE figure than for total daily usage. The bright blue bar on the right side of the graph indicates that there was no month during the control period at the building size that differed significantly from the whole control period. Twelve control months out of 96% were different on the housing scale.

There were 11 statistically different months during the lockdown. The study limited analysis lockdown moths from April 2020 to July 2020, as shown in Figure 4. The study observed a ratio of 24.3%, increased during the lockdown period. According to the statistic, July was considered a month with average energy consumption due to the ease of the lockdown measures. In reality, with a large concentration of blue instances, the behavior looked back to the normal activities patterns in July 2020.

When looking at overall power usage in the control year, we found that 25.3% of the energy consumed at the beginning of the lockdown has deviated statistically from the average of the entire period. The variation of energy consumption during

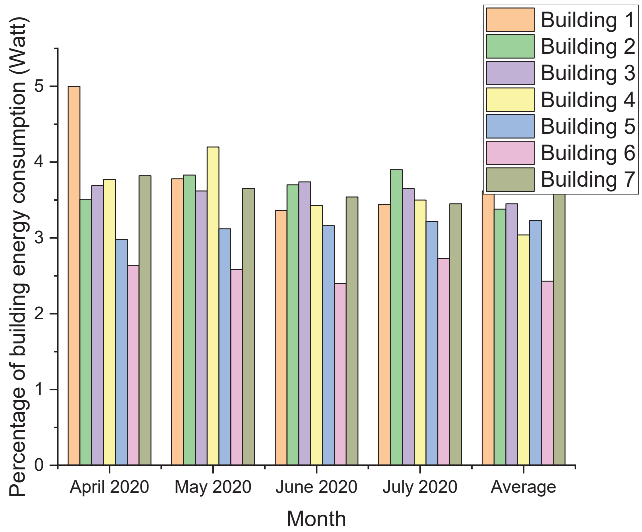

Figure 4: Case study building energy consumption during lockdown.

and after the lockdown was calculated to represent the ratio of the real rate in regular energy usage in a year. In April 2020, for example, six of the eight homes had distinct overall power usage patterns. If the fraction of different months is 23.6%, there is a 2.51% chance of this happening.

Figure 4 shows the analysis of the results of consumed energy in seven buildings for the lockdown period. The pattern for building energy consumption with distinct patterns in terms of analyzed RMSE score is notably unusual during the initial lockdown period, with the likelihood of 6 buildings out of 7 is 2%. As a result, the chances of the lockout influencing periods when inhabitants utilized electricity throughout that month are nearly zero.

Space heating consumption

In the initial phase of lockdown, a raised in space heating suddenly increased by an average of 50%, as indicated in Figure 5, with the average daily hour increased per day. The room heating use is generally consistent throughout the day during the control year. During the noon hours, usage drops somewhat, possibly owing to sun radiation partially heating the structure. There is a smaller drop in the evening than tally with times when more heat is created inside building electrical appliances. It is reflected in four months that the space heating use looks to be only moderately impacted by its occupancy schedules. The lockdown should have a minor impact on space heating usage. According to the four dashed in Figure 5, this appears to be the case. There is no significant deviation from the control period when the data in Figure 5 was analyzed. Because the outside circumstances for all of the shown curves are different, we chose to illustrate the fraction of the daily heating requirement in Figure 5 rather than displaying the average heat consumption.

Figure 5 presents three space heating energy consumption (Building 1, Building 2, and Building 3) before, and during the lockdown. The energy consumption during the lockdown tends to be higher than energy equally consumed before and

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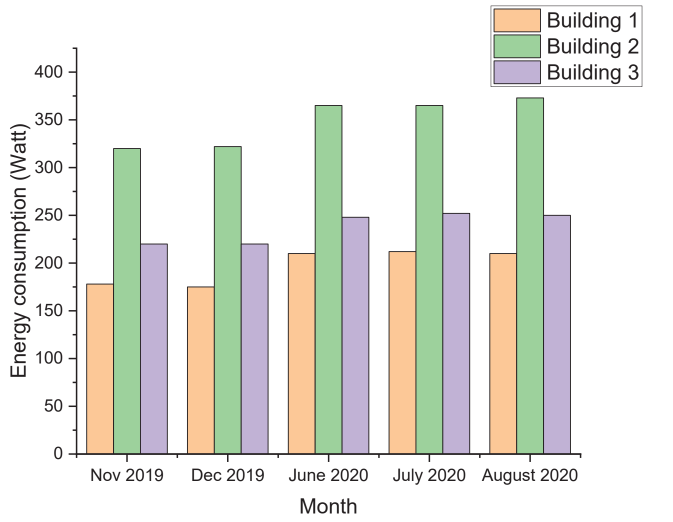

Figure 5: Heating energy consumption before, during, and after lockdown.

after the lockdown as finding reported indicate that space heating use has less month-to-month fluctuation. 2.5% of the energy consumed in 8 months was distinct in terms of energy consumed by heating. This ratio of 2.4% was analyzed for the lockdown period and an 11.9% drop when the majority of the restriction ware eased. This indicates there is a significant drop in energy consumed during and after the lockdown.

By controlling the thermostat, occupants can influence the space heating requirement. We examined the smart thermostat temperatures inside the building before and during the lockdown and found no significant differences. Before the lockdown, the average interior temperature was 23.57°C, with a standard variation of 0.42°C. These temperatures were 23.48 and 0.39°C during the lockdown, respectively. In other words, during the lockdown, the thermostat control did not appear to have altered. We did not include data from times when the outside temperature was over 12°C since we were seeking data from when the heating system was on. It should be noted that the building lacks a programmable thermostat.

Because window control is another approach for inhabitants to affect their home's heating demand, we examined the window opening behavior during the control and lockdown periods. We limited the control period for this section of the analysis from Nov 2019 to Dec 2019 before lockdown and June 2020 to August 2020, which corresponds to the months of the lockdown year. As a result, the control period excludes the winter months, when windows are more frequently closed. During the control period, a window was opened on average 403.2 minutes each day. Windows were opened 422.4 minutes per day during the lockdown period, an increase of 4.8%.

The difference between the two years is observed in terms of the windows status changes during the stay-at-home period. It is also observed that the window state has changed seven times per day compared to nine times before the stay-at-home period. As regard, the status of the window remains unchanged for an average of 30 minutes during the stay at home. Occupancy in the building remains constant when the window status is open for a short period.

Impact of lockdown on the time evolution

Building energy consumption impact on COVID-19 pandemic have been analyzed in the previous subsections. The variation among the phase six months of lockdown as a result of changes in official instructions about the stay at home. The impacts of stay at home on energy usage were often visible in the initial phase of the stay at home, which runs from April to August 2020. After July 2020, power usage tends to revert to the control period's usual pattern. The estimate of seven days averages of energy indicators for the building energy usage for the entire stay at the home period to examine the longitudinal impacts of the lockout.

The maximum score value of averages observed in the entire control year is discussed. The indicators recorded at the start of the stay-at-home period are all above these maximum value lines in all graphs, indicating that the six-day average power usage that time had all come to a level not observed during the stay-at-home period. In terms of overall energy usage, the six-day average energy consumption for heating and cooling indicate above the maximum score value from the control period until June. The effects of the lockdown appear to linger longer, until mid-May, based on the RMSE readings.

Primary schools, retail companies, construction sites, the manufacturing sector, and individual outdoor sports facilities were all reopened by mid-May, the period when the lockdown seems to stop having an influence on energy usage in the case study building. High schools and universities, retail malls, pubs, and restaurants were among the economic activity that was closed during the time.

Discussion

The findings reveal that during the most intense period of the lockdown, there was a substantial change in heating and cooling during the day. If the daytime is defined as 9a.m. to 5p.m., the usage of power during this period increased by 46% in April. In our literature study, we highlight findings that energy usage climbed by around 23% in Malaysia and 30% in the United Kingdom during the middle of the day. The rise in power usage in this research's case study building is more than what has previously been reported in comparable buildings.

For example, the childcare facilities and primary schools building may have a greater impact on their home lifestyle than in other buildings. Variances in general lifestyle between nations and differences in lockdown measures are further reasons why the shift is bigger in the case study building. We could not find another research to match the 103 percent increase in hot water consumption throughout the day, so we could not compare the data. Nonetheless, our research indicates that the increase in hot water use is far bigger than the shift in power consumption. The above paragraph implies that the basic trends identified during the COVID-19 lockdowns can be found elsewhere, albeit on a smaller scale. These identified trends are likely to be seen in similar structures in nations with a general lifestyle similar to Malaysia's. However, variances may exist in other nations. Given the existing knowledge gap,

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there is an obvious need to distribute additional energy usage analysis linked to the pandemic situation in many parts of the globe and settings.

The research is an initial step toward expanding our understanding of the influence of stay at home on building energy usage patterns and that it will aid in the development of a comprehensive global comparison.

It is unclear whether the above-mentioned trends in heating and cooling usage are a foreshadowing in upcoming future structures. On the other hand, the pandemic may last for many years, and additional could emerge.

Many people expect teleworking to tend to be common, thus the way of living witnessed during the stay at home may persist even if the lockdown is lifted. The move at the case study building, on the other hand, lasted around two months, during which time lockdown measures were strictly enforced. When the lockdown restrictions were relaxed, the shift vanished. Many nations are facing a second wave of COVID-19 and partially "re-lockdown" at the time of writing this study; we must continue to monitor the effects of such pandemic on building energy usage in the buildings to determine if the findings are replicated between the months.

The variation in the future building energy usage will influence planning, operation, and utilization of energy cost as well as governments utilities because daily energy consumption maxima might occur at varieties of times in a day. Residential building design and operation may need to adjust to this transition to achieve optimal energy efficiency and indoor comfort. When stay at home occurs in the summer, overheating concerns may likely emerge if the occupants stay at home, raisings the internal heat. It may require buildings like the one analyzed in this research to adopt heating in winter and air conditioners rather than rely on window ventilation to maintain the building comfort in the summer. The energy breakdown of the structure would be considerably altered as a result of this. Energy consumption would generally rise as residents used more heating and air conditioning. The current construction sector approach [14-17] would have to account for such a shift.

Conclusion

The building energy usage trends noted in a considered Malaysian residential building structure during and after a pandemic stay at home were compared to those measured before the lockdown in this article. The data collected confirmed a peak in energy consumption for both heating and air conditioning in the initial months of the stay-at-home period compared to previous months before implementing the stay-at-home policy, which covered the entire year. The result comparison was done on a monthly basis for heating, cooling, and lighting energy usage for the entire building as well as individual residences.

The result comparison was made based on the statistical analysis to identify variation on building energy consumption on the temporal scale that tally with tenant patterns. During the first month of the lockdown, there was a considerable rise in energy and hot water use, which was not witnessed during the control year. This rise, however, only lasted during the first month of the lockdown and did not continue for the remainder of it. In addition, a significant percentage of daily energy usage was shifted from the nighttime to the middle of the day.

For the first two months of the lockdown, this shift in energy usage remained. We did not notice any modifications in space heating usage. During the stay-at-home period, natural ventilation was also considered, which is not account for this study which might affect variation in energy usage. Some homes witnessed major modifications during the quarantine, while others saw no change at all.

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