CASE STUDY

Lockdown impact on energy consumption in university building

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Abstract
COVID-19 has had a significant impact on the global demand and consumption of energy. In particular, the effect of the lockdown measures due to the COVID-19 pandemic can be seen directly in the reduced energy consumption in educational buildings. Therefore, the objective of this study is to assess the impact of COVID-19 on the electricity use in university buildings. The Research Complex Building of the National University of Malaysia was selected as a case study. An energy audit analysis was conducted based on the data collection via walk-through field audits and data loggers during the normal year (2019) to establish a baseline of data. The comparison of the electricity pattern during the normal year with the lockdown period of 2020 shows that the Building Energy Index (BEI) during a pandemic decreased by approximately 11% from the BEI in the normal year. In this regard, the energy audit verified that the main factors of electricity consumption are occupant presence and energy use in buildings. Hence, on the basis of the energy audit results, three appropriate energy conservation measures (ECMs) were detected and subsequently proposed to minimise the waste of energy. Results show that the implementation of ECMs can improve the energy consumption of buildings and reduce energy consumption by 21.81% or approximately 19% from the normal year. Hence, efficient energy use in buildings in the post-pandemic period can be achieved by the implementation of all the ECMs proposed.

Keywords COVID-19 · Lockdown · Work from home · Energy audit · Building energy index (BEI) · Energy conservation measures (ECM)

Abbreviations
AHU Air handling units
BEI Building energy index
CMCO Conditional movement control order

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COVID-19  Coronavirus disease  
ECM  Energy conservation measures  
FCU  Fan coil units  
Fuel Cell  Institute of fuel cell  
HVAC  Heating, ventilation, and air-conditioning systems  
i-CRIM  Centre for research and management  
IEA  International energy agency  
IMEN  Institute of microengineering and nanoelectronics  
IPI  Institute of climate change  
MCO  Movement control order  
R&D  Research and development  
SERI  Solar Energy Research Institute  
SOP  Standard operating procedure  
UKM  National University of Malaysia  
VRV  Multi-split types  
WHO  World Health Organization  

1 Introduction

The World Health Organization (WHO) announced on March 11, 2020, that the coronavirus disease (COVID-19) had been characterised as a pandemic and had spread quickly worldwide (WHO, 2020). Consequently, several countries took certain measures, such as strict lockdowns, travel restrictions, quarantine measures, and social distancing protocols, to mitigate the global spread of the virus. Daily life also changed, as new norms had to be practised, e.g., wearing of masks, washing hands regularly and limiting physical interaction. These changes in lifestyle are direct reflections of the global economy. The pandemic has greatly affected numerous industries, including the manufacturing, education, sports, tourism and transportation sectors (Elavarasan et al., 2020; Nicola et al., 2020; Werth et al., 2021).

National lockdowns were among the measures that the majority of the countries implemented. Previous studies reported that the lockdowns affected energy demand and consumption in the energy sector (Bahmanyar et al., 2020; Geraldi et al., 2021; Ivanko et al., 2021; Vaka et al., 2020). In addition, the International Energy Agency (IEA) reported that countries in partial lockdowns have experienced an average decline of 18% while those in full lockdowns have experienced a decline of approximately 25% in the weekly energy demand (IEA, 2020). Consequently, the lockdown has significantly changed the higher educational sector. During lockdown, schools and universities were closed in most countries and moved to online learning. As a result, the energy use in buildings destined for education decreased.

In the analysis of electricity use trends during the pandemic in municipal buildings in Florianopolis, Brazil, it was found that during the lockdown, the energy use of administrative buildings, elementary schools and nursery schools was reduced by approximately 38.6%, 50.3% and 50.4%, respectively (Geraldi et al., 2021). However, at the University of Almeria, Spain, a study by Chihib et al. (2021) found that the library category was found to be the most influenced, and the research category was found to be the least influenced by the impact of closing the campus on energy use. This is because most of the research equipment remained operational while the library
was fully shut down, which drove down the electricity consumption during lockdown. Besides, a study by Ding et al. (2021) reported that the electricity demand in the kindergartens and schools was almost at the same level, while there were apparent changes in the apartment and townhouse buildings. Nevertheless, the climate conditions and the location of the lockdown are factors in which the magnitude of the energy usage will be increased. Gaspar et al. (2022) reported that the energy consumption in academic buildings was found to be clearly influenced by climatic conditions, particularly in winter. Meanwhile, a study by Gui et al. (2021) found that there is a high demand for cooling in the summer but little demand for heating in the winter in the energy consumption of academic buildings at Griffith University, Australia. Moreover, occupant presence in buildings may significantly reduce the overall energy consumption of buildings. This observation is supported by a report from Mokhtari and Jahangir (2021), which stated that an optimal population distribution in winter and summer can reduce energy consumption by 32%.

Hence, the main contribution of this study is the comprehensive analysis of the impact of lockdown measures during a pandemic on university buildings. The energy consumption of university buildings decreases during the lockdown due to the closed down or online-based learning environment. However, the study on energy-saving potential might have been useful to measure the energy consumption of vacant buildings and devise energy-saving options in the post-pandemic period. Thus, to fulfil the research purposes, an energy audit was performed to analyse the electricity consumption during the normal year to establish a baseline of data. The energy audits of higher educational or university buildings have specific characteristics that differ from those performed in other types of buildings. Buildings for higher education include numerous complexes, which are usually grouped and sometimes share the energy supply infrastructure. Moreover, higher education institutions usually have a considerable number of buildings, with high overall energy consumption and associated financial costs (Bernardo & Oliveira, 2018; Samira & Nurmammad, 2018). In Malaysian universities, numerous researchers have presented energy audit analyses for faculty or administrative buildings, showing a reduction in energy use without any negative effect on the comfort of the occupants and operations (Sadrzadehraie et al., 2012; Syed Yahya et al., 2015; Tahir et al., 2017; Zainal & Che Kar, 2018). Furthermore, Singh et al. (2012) found that energy audits can improve the efficiency of a building and reduce energy wastage.

Specifically, our case study focuses on a building at the National University of Malaysia (UKM). This study aims to explore how the electricity consumption of one building has responded to the pandemic situation. The monthly electricity consumption of the building during the pandemic is compared with the same period in previous or normal years. An energy audit was performed to analyse the electricity consumption during the normal year and establish a baseline of data. Then, the electricity consumption during lockdown was measured and analysed to determine the impact of COVID-19 on the building’s electricity consumption. Consequently, the relationship between energy use reduction and an electricity boundary for a typical year was investigated. Finally, the best energy conservation measures (ECMs) are proposed to reduce the electricity consumption in the UKM to achieve efficient energy use in buildings during the post-pandemic period. Additionally, this case study could be applied to other universities and inspire the energy managers of institutions to provide guidelines and assistance for undertaking energy-saving measures that can reduce the energy consumption of buildings.
2 Methodology

Figure 1 presents the outline of the main steps. Scenario 1 is the data collection of the energy audit process, which focuses on the preliminary audit stage. The energy audit area covered in this audit was the whole Research Complex Building, which involved all eight floors. All information about the building was obtained from architectural, mechanical, and electrical as-built drawings, and the latest historical energy bill data (year 2019) were collected from the Infrastructure Unit at UKM. The electricity consumption of each level was investigated and determined by walk-through field audits. The Fluke (1735) Data Logger (Fluke, 1735) was installed at the distribution boards to obtain the load profile pattern of electricity consumption in the building. The details, such as the type of electrical equipment, quantity and rated power, were recorded in the survey form. The result was set as the baseline data for this research. Scenario 2 is an analysis of the impact of lockdown that focuses on the pattern of electricity usage in the year 2020. The relationships between the reduction in energy consumption and the electricity boundary in a normal year were investigated. Finally, Scenario 3 is the ECMs. The ECMs are proposed to reduce UKM’s electricity costs based on the findings in Scenarios 1 and 2. In this research, the benchmarks used for this study were based on the Malaysia Standard MS1525:2014 and it is stated that in the Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-residential Buildings in Malaysia, the benchmarks are set at 136 kWh/m²/year (Malaysia, 2014; Moghimi et al., 2014).

2.1 Case study building

The study was conducted in the Research Complex Building at UKM in Bangi, Selangor. The criteria for selecting this building as the study case were based on its electricity consumption, which was among the highest electricity consumption of Research and Development (R&D) buildings at UKM. The study was conducted throughout the used and occupied levels from the ground floor to the seventh floor. This building accommodates a few research institutes, which are the Solar Energy Research Institute (SERI), Institute of

![Fig. 1 The workflow of the analysis of electricity use](https://example.com/fig1.png)
Microengineering and Nanoelectronics (IMEN), Institute of Climate Change (IPI), Institute of Fuel Cell (Fuel Cell) and Centre for Research and Management (i-CRIM). This building consists of approximately 192 people, including staff and students from five institutes. Most of the research activities in this building are for undergraduate and postgraduate levels. In addition, the building was built in 2012, and it provides basic facilities, which include offices, laboratories, research rooms, meeting rooms, lecturer rooms, a store, and a prayer room. Figure 2 provides details on the occupants of the building according to each floor of the building complex. Mostly, each floor is combined with one or two institutes. This building consists of five different institutes, thus explaining the huge amount of electrical equipment that is available on all floors. This electrical equipment can be categorised as two types of equipment, namely laboratory equipment and office appliances. The breakdown of the device categories in the building is shown in Fig. 3. Moreover, the lighting system in this building uses 36-W fluorescent lamps. Besides, this building has no heating and has various types of air-conditioning units, including multi-split types (VRV), air handling units (AHU), fan coil units (FCU) and split-unit air conditioners. Meanwhile, this building is equipped with three lift systems, and the maximum load for each lift is 1365 kg. Furthermore, this building operates for an average of nine hours daily, which is from 8 a.m. to 5 p.m., five days a week. For certain weeks, several laboratories are open during the weekend for research purposes, with operating times between four and six hours.

2.2 Energy measures calculation

The monthly electricity consumption according to the walk-through field data is estimated using Eq. 1:
where $E$ is the electricity usage, kWh; $P$ is the power rating, kW; $T$ is the time usage in a day, h; LD is the loading factor; $Q$ is the quantity of the equipment, unit; and Nd is the number of days in a month, day. Meanwhile, the annual electricity consumption is estimated using Eq. 2:

$$A = E \times t,$$

where $A$ is the annual electricity consumption, kWh/year; $E$ is the electricity usage, kWh; and $t$ is 12 months. In addition, the Building Energy Index (BEI) is calculated by taking the ratio of the annual energy consumption of a building to the net floor area of the building, as in Eq. 3:

$$BEI = A/AB,$$

where BEI is the building energy consumption, kWh/m²/year; $A$ is the annual electricity consumption, kWh/year; and $AB$ is the net floor area of the building, m². Meanwhile, a simple payback period for energy-saving strategies can be calculated using Eq. 4:

$$\text{Simple payback period (years)} = \frac{\text{Proposed investment cost}}{\text{cost saving}}.$$

Additionally, the CO₂ emission reduction is calculated using Eq. 5, where the emission factor is 0.69 kg/kWh (Mohamed et al., 2016)

$$\text{CO₂ emission reduction} = \text{Electricity saving} \times \text{emission factor}.$$
3 Results and discussion

3.1 Scenario 1: Baseline data of electricity consumption

Generally, Malaysia is a country that experiences high humidity and temperatures throughout the year. The buildings in Malaysia face the hot and humid climate and have little seasonal variation with a constant annual average. Based on the report by Mirrahimi et al. (2016), it shows that Malaysia’s climate is hot and humid all year around with a uniform temperature and high humidity. Hence, the data were taken as a baseline and the comparison with other years is acceptable as the climate is a constant annual average. The breakdown of monthly electricity consumption in the Research Complex Building is shown in Fig. 4. The data were acquired from the walk-through energy audit conducted. As shown in Fig. 4, air-conditioning consumed the highest amount of electrical usage (35%), followed by office appliances (32%), laboratory equipment (18%), lighting systems (14%) and lifts (1%). Air-conditioning was expected to have the highest electricity consumption due to the inherently energy-intensive working mechanisms of air-conditioning units, including their chillers, boilers, pumps and fans. Moreover, Malaysia is a developing country with a hot and humid climate where the air-conditioning systems are often the only means of ventilation (Damiati et al., 2016). In addition, air-conditioning is extensively used throughout the building, covering nearly all parts of the research complex, except the hallways and corridors. As mentioned in Fig. 3, the air-conditioning system in the building comprises centralised AHU, FCU and VRV types. Hence, this system cannot be turned off immediately when not in use. Although the centralised system of the VRV is energy efficient, the unavailability of control measurements has caused higher electricity consumption than the ideal volume (Ali et al., 2021).

The second highest consumers of electricity in the building are the office appliances. These appliances are mostly used in the main offices of each institute, which include computers, laptops, printers, photocopy machines, and pantry appliances (e.g., microwaves, kettles, and refrigerators). Most of these devices run for nine hours a day, in line with office hours. From the observations made during the walk-through energy audit, HP and Dell were the most commonly installed computer models in various levels of the building. Computers run for 24 h, as they are set to standby operation mode after office hours. This standby operation mode consumes 1.5–3 W of energy for the average computer and 0.5–5 W for the monitor (Bray, 2006).
The third highest consumer of electricity in the building is the laboratory equipment, which accounts for 18% of the total electricity consumption in the building. Given that the building serves as a research hub for multidisciplinary institutes, a huge amount of electrical equipment is available on all floors. Laboratory equipment is used mostly by research fellows and students. Most of the scientific instruments used in this building have high power specifications, and they are used for extended periods in laboratories. For example, some of the equipment in i-CRIM laboratories needs to run for 24 h to prepare and analyse samples. The equipment that consumes the most energy is the Nuclear Magnetic Resonance (NMR) 600, which uses 134 kWh of energy per day for 24 h. X-ray photoelectron spectroscopy (XPS) is another type of equipment found to consume the most energy, as it uses 75 kWh per day for 24 h.

Additionally, lighting is the equipment that consumes the least electricity, as it accounts for only approximately 14% of the total electricity consumption. Specifically, the total number of lights in the whole building is 2663 units. In addition, the lighting system uses 36-W fluorescent lamps. Ali et al. (2021) reported that the energy consumption of lighting systems is influenced by four factors, which are the type of light, quantity of lights, floor size area and suitable luminaires. From the analysis in Table 1, the area of the floor directly impacts the energy consumption of the floor. Lighting systems in common areas such as hallways, corridors, the surau and the main office operate during office hours. Meanwhile, lights in research laboratories and fellow offices operate for more than eight hours a day.

In addition, the energy consumption of lifts is the lowest compared with other devices in buildings. Other studies have reported that the R&D building at Universiti Malaya, which consists of 25 floors of operational floors and six units of lifts, consumes 7% of the total energy consumed in the building (Ali et al., 2021). As a comparison, the energy consumption of the lift in the building in the current study is the lowest when compared to other R&D buildings because this building only has three units of lift and eight operational floors.

Table 1 shows the electricity consumption of each floor from the ground floor to the seventh floor. The highest electricity consumption was recorded on the third floor, followed by the fourth floor, first floor, sixth floor, second floor, fifth floor, ground floor and seventh floor, respectively. This finding indicates that the designated room type influences its electricity consumption. Other studies have reported that energy use in laboratory buildings is four to five times higher than that in non-laboratory buildings (Federspiel et al., 2002;
In this case, the building levels that have a research laboratory, i.e., the third floor, fourth floor, first floor, sixth floor and second floor consume more energy than other typical levels. Students and fellows often use the research laboratory extensively, usually longer than the office hours. This extended period of use is due to the unpredictable nature of doing research, which requires long hours of experimentation most of the time. Moreover, the air-conditioning requirement is also high for laboratories, thus influencing the electricity consumption on the floor where the laboratory is located. Meanwhile, the fifth floor, ground floor and seventh floor use less energy, as these levels only have the main offices of institutes, small laboratories and a few rooms for fellows and students. According to the utility bill, the average monthly electricity consumption of this building is 98.93 MWh. Thus, the electricity consumption recorded in the walk-through energy audit is 5% higher than the average electricity consumption in the tariff charges on the utility bill. The result shows the lowest of the other studies by Ali et al. (2021), as the energy consumption through the walk-through energy audit is found to be 7.5% higher compared to the average consumption in the R&D building. Hence, the walk-through energy audit performed is within the acceptable range.

The Fluke (1735) Data Logger (Fluke, 1735) was installed at the distribution boards to obtain the load profile pattern of the electricity consumption of the building. The average weekly profile pattern of this consumption is shown in Fig. 5, covering weekdays and weekends. The graph pattern shows a nearly similar pattern for weekdays in which the highest energy consumption was recorded at approximately 230 kW from 12 p.m. to 2 p.m. The energy consumption during this period is attributed to the outdoor temperature. Malaysia has a hot and humid climate, with average temperatures exceeding 30 °C between 12 p.m. and 2 p.m. Therefore, this condition increases the building’s cooling load in heating, ventilation and air-conditioning (HVAC) systems, thus increasing the load energy consumption in the building (Cai et al., 2019; Sehar et al., 2016). Additionally, most of the buildings have centralised air-conditioning that runs from 8 a.m. to 5 p.m. The air-conditioning in this building is not directly related to the building’s occupancy. Hence, the air conditioners still run even though the rooms are not occupied by the maximum number of people. Furthermore, the graph clearly indicates that the energy consumption starts to increase gradually from 8 a.m. to 2 p.m. and then gradually decreases until 6 p.m. Most of the devices that use electricity operate during working hours, with high laboratory utilisation or class-work sessions during this period. However, the power consumption starts to decrease after 5 p.m. as some devices start shutting off or going into standby operation.
mode after working hours. Meanwhile, energy consumption is lower on weekends than on weekdays, with the highest demand at approximately 120 kW. Much of this energy usage can be attributed to the lighting in the corridors and the standby operation mode of office appliances and laboratory equipment.

3.2 Scenario 2: Impact of pandemic COVID-19

Figure 6 shows the data taken from 2019 and 2020 with the tariff charges by the Tenaga Nasional Berhad (TNB) (local utility company) at RM 0.36 (US $0.087) for every kWh of energy usage (commercial building rates). The total amounts of energy consumed in 2019 and 2020 were 1187.15 MWh/year and 1055.31 MWh/year, respectively. Meanwhile, the total costs in 2019 and 2020 were RM 427,375.08 (US $103,611.07) and RM 371,468.08 (US $90,162.18), respectively. This result reveals that during the pandemic (2020), electricity consumption decreased by approximately 11% compared with that of a normal year (2019). In addition, the graph shows some fluctuation in the energy consumption in certain months of 2020. A decrease in energy consumption was observed from March 2020 to June 2020 before it started rising again in July 2020. However, energy consumption started slowly decreasing again in November until the end of 2020. During these periods, Malaysia implemented the Movement Control Order (MCO) from March 2020 to June 2020 and continued with the Conditional Movement Control Order (CMCO) from mid-October 2020 to December 2020 as a preventive measure in response to the COVID-19 pandemic. The MCO was commonly referred to as a lockdown and the CMCO was referred to as a partial lockdown.

During the MCO, the government of Malaysia imposed a mandatory ‘stay in house’ order on everyone in the country. These circumstances had a direct impact on the decrease in commercial and industrial demand (Qarnain et al., 2021). The most significant impact of this order on the university was that all research that was unrelated to COVID-19 was placed on hold. In addition, the administrative office needed to close, and all the academic classes were moved to online classes. Thus, the occupancy scenario during the MCO directly influenced the total electricity consumption in the building. Figure 6 demonstrates that during the MCO, the building consumed approximately 66 MWh of energy in March and April, which was the lowest energy consumption in 2020. This energy consumption

Fig. 6 Energy consumption and cost in year 2019 and 2020 (charges by TNB)
can be attributed to some lighting in the corridors that remained on for safety reasons. Furthermore, office appliances and laboratory equipment were left in standby operation mode. Hence, during the standby operation mode, the equipment continued to consume energy due to some functions. This outcome was supported by Alajmi (2012) that lighting systems and plug-in equipment consumed energy as they were left on after work hours and during weekends. Additionally, during lockdown, other researchers also identified the standby loads and vital loads as the main contributors of energy usage in the building (Chihib et al., 2021; Gaspar et al., 2022; Geraldi et al., 2021).

However, from mid-October 2020 to December 2020, Malaysia experienced a second wave of COVID-19. Consequently, the government of Malaysia implemented the CMCO or a partial lockdown. During the CMCO, most economic sectors and activities were allowed to operate under a strict Standard Operating Procedure (SOP). In the university, administrative offices could operate with limited staff, and research activities can be carried out with strict SOP. Thus, Fig. 6 shows that the energy consumption in the building decreased slightly by approximately 90 MWh during the CMCO period. Nevertheless, most of the buildings have centralised air-conditioning that runs from 8 a.m. to 5 p.m. The air-conditioning in this building is still running even though the rooms are not occupied by the maximum number of people. During the MCO, the air-conditioning systems were fully shut down as part of the mandatory 'stay in house' order in Malaysia. However, during the CMCO, the partial operation with limited staff used air-conditioning even though the rooms were not fully occupied.

These results reveal that during the lockdown, the energy demand was closely related to people’s activities, especially those related to work. At the university level, classroom teaching has been replaced by distance teaching and online class learning. A university ordinance stated that administrative offices could operate with a ratio of 30:70, with 30% of staff needed to work in the office and 70% needed to work from home during the partial lockdown. In the case of research facilities, the social distancing implementation limited students to research activities with strict SOP. Thus, this new norm scenario largely affected and reduced the electricity consumption in the building. Hence, we must highlight that the electricity consumption of the building was largely influenced by the occupant presence and energy use in the building (Geraldi et al., 2021; Mokhtari & Jahangir, 2021). The energy audit also confirmed that the primary sources of energy consumption were vital and standby loads such as lighting, office appliances, and laboratory equipment. Moreover, this consumption is attributed to the purpose of the research building, which requires several types of high-equipment laboratories with heavy plug loads that remain in operation regardless of the occupancy rate.

3.3 Scenario 3: Economic impact analysis

To achieve efficient energy use in buildings in the post-pandemic period, the changes in energy use in buildings during the pandemic and normal years must be understood. According to Scenario 2 (lockdown impact), the electricity consumption of the building was largely influenced by the occupant presence and energy use in the building. Therefore, on the basis of the energy audit results (Scenario 1), we recommend ECMs that focus on the occupancy behaviour factor as the main contributor to the building’s electricity consumption. We recommend three ECMs: (1) a retrofit lighting system, (2) increasing the thermostat set point temperature of the air-conditioning, and (3) regular maintenance of the air-conditioning system. The benefits of the ECMs must be analysed in terms of
energy saving and CO₂ reduction. Furthermore, Malaysia is in Southeast Asia, which has a generally hot and humid (tropical) climate throughout the year, with an average rainfall of 250 cm a year and an average temperature of 27 °C. These typical subtropical climatic conditions of Malaysia greatly affect the indoor environmental comfort conditions in buildings and the energy consumption of air-conditioning systems. Hence, the air-conditioning system is one of the components that should be focused on, in addition to lighting systems (Hassan et al., 2014; Shaikh et al., 2017).

### 3.3.1 ECM 1: Retrofit lighting system

The lighting system contributes to 14% of the total electricity consumption and is the fourth largest electricity consumer after air-conditioning, office equipment and laboratory equipment. Savings can be achieved by a control method or several advanced lighting fixtures (Al-Mofleh et al., 2009). In this case, we propose an ECM to retrofit lighting systems by replacing all 36-W fluorescent lights with highly efficient 14-W LED lights. The advantages of LEDs can reduce energy use and maintenance costs, as they last longer than incandescent fluorescent fixtures (Dzobo et al., 2018; Lim et al., 2014; Thumann & Younger, 2008). The electricity and cost savings for the whole building were calculated by summing up all eight floors of the Research Complex Building, as presented in Table 2. The percentage reduction was calculated by dividing the total electricity savings with the total annual electricity consumption of the lighting, thus providing a significant energy and cost reduction of 61.11% through the retrofitting of the lighting system in the building. The total investment and payback period for the retrofitting of lighting systems for the whole building are RM 74,564 (US $18,098.06) and 1.87 years, respectively.

### 3.3.2 ECM 2: Raising thermostat set point temperature

The air-conditioning system in this building contributed to the highest overall electricity consumption per year. Malaysia is a tropical country that experiences hot and humid climates all year around, so people rely on HVACs for cooling and maintaining thermal comfort. Based on the energy audit, this building mostly used a centralised system and set

**Table 2** Electricity saving, cost saving and investment by retrofit lighting system

| Floor | Annual electricity consumption (MWh/year) (Baseline) | Electricity saving (MWh/year) | Cost saving (RM/year) | Lamp quantity | Investment (RM) |
|-------|--------------------------------------------------|--------------------------------|----------------------|---------------|-----------------|
| G     | 9.02                                            | 5.53                           | 1991.72              | 146           | 4088            |
| 1     | 17.41                                           | 10.64                          | 3830.48              | 321           | 8988            |
| 2     | 15.99                                           | 9.77                           | 3517.25              | 257           | 7196            |
| 3     | 65.32                                           | 39.92                          | 14,370.76            | 673           | 18,844          |
| 4     | 35.98                                           | 21.99                          | 7914.93              | 600           | 16,800          |
| 5     | 17.48                                           | 10.68                          | 3844.95              | 349           | 9772            |
| 6     | 17.50                                           | 10.69                          | 3849.65              | 217           | 6076            |
| 7     | 2.05                                            | 1.25                           | 450.12               | 100           | 2800            |
| Total | 180.77                                          | 110.47                         | 39,769.86 (US $9652.88) | 2663 | 74,564 (US $18,098.06) |
the air conditioners at 23 °C. All air-conditioning systems have at least one temperature control device, such as a thermostat, to control comfort cooling that can be adjusted locally or remotely. Therefore, improving the operating settings and control strategies of HVAC systems also has energy-saving potential (Roslizar et al., 2014). Damiati et al. (2016) have found that the thermal comfort in university buildings in Malaysia is higher than 24 °C to achieve thermal comfort. As a result, we examine the savings obtained by increasing the thermostat set point temperature to 25 °C. In the study by Kongkiatumpai (1999), it was found that the mean energy consumption reduction corresponding to a 1 °C increase in the set point (from 22 to 28 °C) is about 6.14%. This is also confirmed by the study of Atthajariyakul and Leephakpreeda (2004), which found approximately 6% savings for every 1 °C increase when the temperature set point changes from 25 to 28 °C. Furthermore, Yamtraipat et al., (2006), who carried out some work on indoor air-conditioning set point temperature and some experimental work on the influence of temperature on air-conditioning energy consumption in commercial buildings in Thailand, found that raising the thermostat set point from 22 to 26 °C can save 24% energy consumption. Hence, in this study, an energy-saving estimation has been made based on Yamtraipat et al. (2006) finding as the climatic conditions of Malaysia and Thailand are quite similar. The assumed 12.28% energy reduction by increasing 2 °C of set point temperature and the electricity and cost savings calculated for the whole building are given in Table 3. The total electricity and cost savings achieved after increasing the set point temperature to 25 °C are 53.38 MWh/year and RM 19,216.22 (US $4,675.48) per year, respectively. The third floor has the highest electricity saving per year compared with other floors, which is 12.14 MWh/year, because of the high electricity consumption of the air-conditioning system on the third floor.

### 3.3.3 ECM 3: Regular maintenance of air-conditioning system

A properly maintained and managed air-conditioning system provides occupants with a comfortable indoor environment. In addition, the optimum maintenance strategies are also one of the approaches to minimising the total cost (Darabnia & Demichela, 2013). Therefore, regular maintenance must be provided, including changing air filters, especially for the system that is used for the longest operating hours and with high frequency usage. By assuming that 15% of the electricity savings achieved by regular maintenance and total

| Floor | Annual electricity consumption (MWh/year) (Baseline) | Electricity saving (MWh/year) | Cost saving (RM/year) |
|-------|-------------------------------------------------------|-------------------------------|----------------------|
| G     | 32.21                                                 | 3.96                          | 1424.13              |
| 1     | 61.85                                                 | 7.60                          | 2734.32              |
| 2     | 54.60                                                 | 6.71                          | 2413.90              |
| 3     | 98.90                                                 | 12.14                         | 4372.07              |
| 4     | 50.69                                                 | 6.22                          | 2240.63              |
| 5     | 41.72                                                 | 5.12                          | 1844.24              |
| 6     | 94.71                                                 | 11.63                         | 4186.93              |
| Total | 434.68                                                | 53.38                         | 19,216.22 (US $4,675.48) |
investment is RM 5000 for each floor, the electricity and cost saving were estimated, as shown in Table 4. From Table 4, we estimated that the total electricity saved by the regular maintenance of the air-conditioning system was 65.20 MWh/year and the cost saving was RM 23,472.58 (US $5,697.23) per year. The payback period for the whole building was 1.49 years.

### 3.3.4 Electricity saving, cost saving and \( \text{CO}_2 \) emission reduction

The overall potential electricity and cost savings, reduction percentage and total \( \text{CO}_2 \) emission reduction through the implementation of the ECMs are calculated and shown in Table 5. The results reveal cost savings of up to 21.81%, with a total electricity savings of 229.05 MWh/year. Retrofitting the lighting systems will contribute the highest electricity savings among the ECMs. The lighting system in the building mainly used 36-W fluorescent lights. Hence, replacing the lights with high-efficiency LED lamps would result in a high electricity savings of 10.52% and a cost savings of RM 39,769.86. Moreover, lighting is one of the parameters for achieving good indoor environmental quality as it relates to the health and comfort of building occupants (Musa et al., 2012). The regular maintenance of air-conditioning units is the second highest contributor to the energy reduction percentage, that is, 6.21%, with a cost savings of RM 23,472.58. Meanwhile, raising the set point temperature of air-conditioning is the third highest contributor. On the basis of the ECM evaluation, the ECMs can be classified into no-cost and low-cost measures. Even though the raised set point temperature of air-conditioning is lower than those of others, this implementation does not involve any cost or disruption to building operations. Meanwhile, retrofitting lighting systems and the regular maintenance of air-conditioning systems are low-cost measures with payback periods of less than two years.

Alongside energy savings, the energy audit revealed that electricity consumption also comes from vital and standby loads. Hence, energy awareness measures can also affect the energy consumption of the building. The other energy awareness initiatives of occupants, including (1) unplugging office appliances after working hours, (2) switching off equipment when not in use and (3) understanding the energy saving of laboratory equipment, such as shutting the sash of the fume hood if not in use, will contribute to a high percentage of energy reduction.

### Table 4 Electricity saving and cost saving of regular maintenance the air-conditioning system

| Floor | Annual electricity consumption (MWh/year) (Baseline) | Electricity saving (MWh/year) | Cost saving (RM/year) | Investment (RM/year) |
|-------|------------------------------------------------------|-----------------------------|----------------------|----------------------|
| G     | 32.21                                                | 4.83                        | 1739.57              | 5000                 |
| 1     | 61.85                                                | 9.28                        | 3339.97              | 5000                 |
| 2     | 54.60                                                | 8.19                        | 2948.57              | 5000                 |
| 3     | 98.90                                                | 14.83                       | 5340.48              | 5000                 |
| 4     | 50.69                                                | 7.60                        | 2736.92              | 5000                 |
| 5     | 41.72                                                | 6.26                        | 2252.74              | 5000                 |
| 6     | 94.71                                                | 14.20                       | 5114.33              | 5000                 |
| Total | 434.68                                               | 65.20                       | 23,472.58 (US $5697.23) | 35,000 (US $8495.15) |
| ECM                               | Electricity saving (MWh/year) | Investment (RM) | Cost saving (RM/year) | Percent reduction (%) | Payback Period (years) | CO₂ emission reduction (kg CO₂/Year) |
|----------------------------------|-------------------------------|----------------|-----------------------|-----------------------|-----------------------|--------------------------------------|
| Retrofit lighting                | 110.47                        | 74,564.00      | 39,769.86             | 10.52                 | 1.87                  | 76,225.56                            |
| Raise thermostat set point       | 53.38                         | 0.00           | 19,216.22             | 5.08                  | –                     | 36,831.09                            |
| temperature of air-conditioning  |                               |                |                       |                       |                       |                                      |
| Regular maintenance of air       | 65.20                         | 35,000.00      | 23,472.58             | 6.21                  | 1.49                  | 44,989.12                            |
| conditioning                     |                               |                |                       |                       |                       |                                      |
| Total                            | 229.05                        | 109,564.00     | 82,458.66             | 21.81                 | –                     | 158,045.77                           |
| (US $26,593.21)                  | (US $20,062.94)               |                |                       |                       |                       |                                      |
Given that building energy use is related to CO₂ emissions, all ECMs proposed will not only improve energy-saving activities in the building but will also reduce CO₂ emissions by approximately 158,045.77 kg/year. Moreover, the Research Complex Building accounts for 2% of the total electricity consumption of the UKM buildings. Although this percentage is often underestimated, the implementation of ECMs in all buildings in the UKM can have a considerable impact on future energy use.

3.4 Building energy index (BEI)

The energy efficiency of a building is measured using the Malaysia Standard Guidelines of MS 1525:2014; according to these guidelines, a building’s BEI rate must be equal to or less than 136 kWh/m²/year (Malaysia, 2014; Tahir et al., 2017). Through this research, the energy consumption and the BEI were calculated. The BEIs in 2019 and 2020 were 194.14 and 172.58 kWh/m²/year, respectively (Table 6). This outcome indicates that the electricity consumption of the building remained inefficient because it exceeded the standard BEI rate of MS 1525:2014; the differences in the BEIs of 2019 and 2020 were 58.14 and 36.58 kWh/m²/year, respectively. On the basis of the literature in other universities in Malaysia, Tahir et al. (2017) found that the BEI value of the study building recorded at University Utara Malaysia was 202.02 kWh/m²/year, which was more than 60 kWh/m²/year compared with the required rate in MS 1525:2014. However, Zailan and Che Kar (2018) reported that the BEI value of the Faculty of Engineering Technology building at University Malaysia Pahang was 98.04 kWh/m²/year, which was lower than the MS 1525:2014 standards. These patterns indicate that the universities in Malaysia could meet the requirements of the MS 1525:2014 standard. During the pandemic year (2020), the BEI was reduced by 11% from the normal year. Therefore, based on the energy audit results, we posited that the BEI could be reduced if we applied the energy efficiency approach selected in this research. Based on an analysis of scenario 3, the implementation of ECM can reduce costs by approximately 19% based on baseline data (scenario 1). The results show that the implementation of ECM can reduce the energy consumption of the building by more than a percentage in a pandemic year. However, it also needs to be noted that COVID-19 started in March 2020, which means the first two months of 2020 were ‘non-COVID-19’ months, thus the reduction in electricity due to COVID should be greater than 11%. Hence, in the post-pandemic period, efficient energy use in buildings can be achieved by the implementation of all the ECM proposed. Furthermore, the proposed ECM consists solely of no-cost and low-cost measures with low investment value and minimal disruption and installation aspects to existing building systems.

| Year | 2019 (Scenario 1) | 2020 (Scenario 2) | Implement ECM (Scenario 3) |
|------|------------------|------------------|----------------------------|
| Electricity consumption (MWh) | 1187.15 | 1055.31 | 958.10 |
| BEI (kWh/m²/year) | 194.14 | 172.58 | 156.68 |
4 Conclusion

The scenario analysed in this research was explored based on the impact of the COVID-19 pandemic. The study focused on the lockdown measures for the electricity consumption of the Research Complex Building in the UKM. This research proves that the lockdown largely affected the electricity consumption of the building, as the electricity consumption was influenced by the occupants’ presence and energy use in the building. In this regard, the energy audit verified that the main factors of electricity consumption were vital and standby loads, such as lighting, office appliances, and laboratory equipment. Additionally, the result indicates that the BEI of the building in 2020 decreased by 11% from that in the normal year that preceded it (2019). The energy audit results indicate that the three ECMs proposed are based on the recognised energy-saving potential from the auditing process. This point is expected to reduce energy consumption by 21.81%, or approximately 19% from the normal year, which is more than a percentage in the year 2020, or pandemic year. Thus, these findings may have an impact on the building’s energy consumption in the post-pandemic period and have a significant impact on the energy consumption in the university.

This research provides the factors that act as controls to optimise the university building’s energy consumption from a global perspective. In general, the reduction in energy consumption during the lockdown is comparable to that of all universities in the region. However, the specific recommendation on ECMs and the benefits of energy saving can be prioritised based on the lockdown factor and outcomes. Furthermore, the research results will be used as a benchmark for the setup of new building standards corresponding to energy patterns and performance in the research building. Based on what this guideline proposes, energy efficiency testing can be conducted with more proper methods compared to the existing approach. Future studies on energy management programmes are strongly recommended to optimise the building’s energy performance in the university building.

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