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Energy Audit of Faculty of Engineering Buildings in the Islamic University of Madinah - Saudi Arabia

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Abstract: This paper presents an energy audit conducted on the Faculty of Engineering building at the Islamic University of Madinah in Saudi Arabia. The study focuses on assessing and analyzing the electrical energy consumption patterns within the building, with particular emphasis on air conditioning systems as the main energy consumer in the building. The aim of the energy audit is to identify the energy use intensity (EUI) and energy-saving opportunities, especially in arid climate regions like Saudi Arabia. An investigation was carried out to accomplish this, including data collection, analysis, and benchmarking against industry standards and best practices. The findings reveal the status of EUI in the university and the faculty of engineering buildings are significantly different. The EUI of the university in general is lower value if benchmarked to the building sectors in the Gulf region. Meanwhile, the EUI of the faculty of engineering buildings is of higher value compared to the university in general and also to the building sector in the Gulf region. The air conditioning systems that were found to be the major contributors to electricity consumption, can be aimed for a substantial portion of energy-saving opportunities. Based on the audit results, the operation of air conditioning systems through temperature and humidity control can produce energy-saving opportunities of approximately 15 MWh/month. The outcomes of this energy audit can provide valuable insights and serve as a foundation for future sustainability initiatives within the university campus and similar academic institutions.

Keywords: Energy Audit; Academic Building; Arid climate; Energy Efficiency

1. Introduction

As a country in an arid climate, Saudi Arabia presents a unique energy consumption pattern characterized by high electricity demand, primarily driven by building cooling requirements[1)]. In recent years, the Kingdom has embarked on an ambitious energy efficiency program as part of its Vision 2030 initiative[2)]. This program aims to enhance sustainability, reduce energy consumption, and diversify the economy[3)]. Within this context, improving energy efficiency in buildings holds immense importance due to their significant contribution to the country's overall energy consumption.

Energy efficiency in buildings has become a global priority as it offers multiple benefits, including reduced energy costs, lowered carbon emissions, and improved indoor comfort[4–10)]. With its rising energy demand and aspirations for a sustainable future, enhancing energy efficiency has emerged as a crucial strategy in Saudi Arabia. Implementing energy-efficient measures in buildings not only aligns with the national sustainability goals but also contributes to the overall economic development and resource conservation[11,12)].

An essential component of any energy efficiency program in buildings is conducting energy audits. Energy audits play a vital role in assessing the energy performance of a building, identifying areas of inefficiency, and proposing recommendations for improvement[4,13,14)]. Through a systematic evaluation of energy consumption patterns, equipment, and systems, an energy audit provides valuable insights into potential energy-saving opportunities[15–17)]. However, despite the importance of energy audits in advancing energy efficiency, there is a lack of research specifically addressing the implementation of energy audits in educational facilities in Saudi Arabia[18)]. This gap signifies the need for further investigation to address specific challenges and opportunities related to implementing effective and sustainable energy audit initiatives within educational institutions across the country.

The primary objective of this manuscript is to contribute to Saudi Arabia's energy efficiency program by conducting an in-depth energy audit in an educational building. The findings and recommendations derived from this case study will serve as a valuable reference for future energy efficiency initiatives in educational buildings across the country. By improving energy performance and optimizing electrical energy consumption, this study seeks to support the Vision 2030 goals, enhance sustainability, and achieve cost savings in educational facilities in Saudi Arabia[2,19,20)]

Educational buildings, such as the Faculty of Engineering building at the Islamic University of Madinah, represent a significant segment of the built environment. By performing a case study of the energy audit in the Faculty of Engineering building, this manuscript aims to contribute to the existing knowledge on energy efficiency in educational buildings in Saudi Arabia. The study will analyze electrical energy consumption, with a particular focus on air conditioning systems. The findings will highlight areas of energy inefficiency and propose effective strategies and recommendations for energy conservation and cost savings. Ultimately, this manuscript seeks to facilitate the implementation of energy-efficient measures and contribute to the overall energy efficiency program in Saudi Arabia.

2. Methodology

Collecting existing data is an essential step in conducting an energy audit of an educational building. During this initial phase, it is important to gather all the necessary information, including the building's as-built details like architectural plans and specifications, as well as data on equipment and utilities. In addition, data on past energy consumption is gathered to establish a reference point for tracking energy usage trends over a period of time. This data is essential for the audit, as it offers valuable insights into the building's energy performance and helps identify areas that could be improved. Through careful examination and evaluation of the available data, the audit team is able to accurately gauge the energy efficiency of the building and develop specific strategies to enhance energy usage and lower overall costs.

2.1 Building Analysis

The Islamic University of Madinah is a public university in the city of Madinah, Saudi Arabia. The university was established in 1961 and currently hosts more than 16,000 students from about 170 countries to study Islamic religion, Science, Computer Science, and Engineering. Overall, the main campus has a total number of buildings of 125 built in the area of 1,697,961.52 m^2 with a net building area of 1,004,594 m^2.

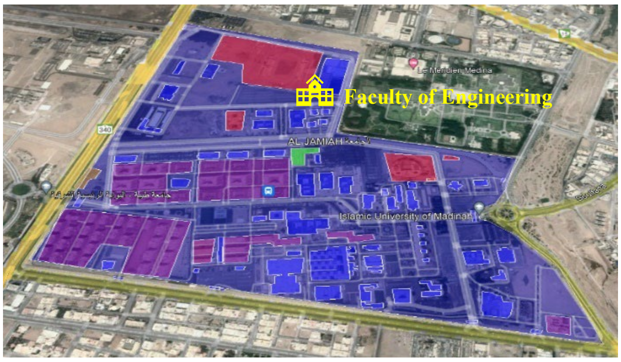

Fig. 1: Site plan of the Islamic University of Madinah (IUM)

The Faculty of Engineering buildings were selected as a case study for educational buildings undergoing energy audits at the Islamic University of Madinah, Saudi Arabia. The engineering buildings comprised two buildings built in 2014, the E1 building and the E2 building which were almost identical and had a total floor area of 4,310 m^2, including the roof area. The building has 4 floors, and all floors are air-conditioned. The Faculty of Engineering buildings are generally open from 7:00 a.m. to 5:00 p.m. every Sunday to Thursday.

Fig. 2: The Faculty of Engineering Building of IUM

Various data points were collected as part of the case study, including detailed building profiles, which are shown in Table 1. These profiles include important information on the building's function, location, occupancy details, floor area, height, space types, and envelope characteristics. Such data lays the groundwork for a full examination of energy usage trends and potential efficiency improvements, directing targeted measures to improve sustainability in educational infrastructure.

Table 1. Building Profile of the Faculty of Engineering

Parameter	Value
Asset information	
Main Information	
Building Name	Educational building Engineering College
Location	Medina,Western Province,KSA
Year Built	2016
Tariff Category	Governmental
Total Area of all Floors (m^2)	3,448
Total Conditioned Area (m^2)	3,448
Roof Area (m^2)	862
Number of Floors (Above Ground/Below Ground)	4/0
Air-Conditioned Floors (Above Ground/Below Ground)	4/0
Operating Hours Per Day	9
Operating Days Per Week	5
Operating Weeks Per Year	52
Regular/Average Number of Building Occupants	300
SEC Account/s # of Meter/s Connected to This Building	
Usage (Offices, classes, etc…)	Offices, Classes, Meeting Rooms
Total Surveyed Area (m^2)	4310
Exterior Wall	
Exterior Walls cladding	Plasters and paints
Exterior Walls Insulation Type	Polystyrene sheets
Insulation Thickness	5 cm
Fenestration	
Type of Glazing (Single/Double)	Double
Type of Windows (Fixed/Operable)	operable
Window to Wall Ratio (%)	5%
Tinted Glass (Yes/No)	Yes

2.2 Air Conditioning System

Two categories of units comprise the cooling system of the building: package and split. A sum of 5 package units and 1 split unit is present, each possessing a cooling capacity of 2 tons or 90 tons, respectively. The operating components of the cooling system are manufactured by York and General under the model designations DMS 1080 COOA221DHNVXI and ASSA18UMTA, respectively. The overall operational refrigeration capacity is 450 tons, while the combined power consumption for package units is 331.3 kW, and for the split unit it is 2 kW. Both varieties of units are 7.2 years old.

Three varieties of units comprise the exhaust and supply fan system of the building: supply, exhaust, and other. Cook is the manufacturer of each unit, and the model number for each exhaust and supply unit is 270 OMX 2700MX. All six exhaust units and one supply unit are operational; their combined age is 7.2 years. An assortment of units does not contain an installed Variable Frequency Drive (VFD).

Additionally, the structure is equipped with a heating system comprising a total of eight operational units. The heater system is manufactured by Al Jawdah and is designated with the model number AOTC-GEWH: V50. The heater system operates at a total power consumption of 9.6 kW, with a motor capacity of 1.20 kW. 7.2 years have passed since the heater system was initially installed.

Table 2. Cooling system in Faculty of Engineering

Cooling System		
Type	Package	Split
Make/ Brand	York	General
Model Number	DMS 1080 COOA221DHNVXI	ASSA18UMTA
Year Installed	2016	2016
Total Units Quantity	5	1
Units In Operation	5	1
Cooling Capacity/unit	90 Tons	2 Tons
Air or Water Cooled	Air	Air

Unit Location (Rooftop/Ground, etc)	Rooftop	WALLMOUNTED
Motor Power (KW)	66.26	2
Voltage/Phases/Hz	380/3/60	220/1/60
Total Cooling Capacity	450 TR	1.5 TR
Total Electrical Power	331.3 kW	2 kW
Age	7.4	7.4

Table 3. Specification of Exhaust and Supply Fan

Exhaust & Supply Fan			
Type	Exhaust	Exhaust	Exhaust
Make/ Brand	Cook	Cook	Cook
Model Number	270 OMX 2700MX	270 OMX 2700MX	210 CPS 210 CPS CL1
Year Installed	2016	2016	2016
Total Units	6	1	4
Units In Operation	6	1	4
(VFD) (yes/no)	No	No	No
Motor Power (KW)	14.92	7.46	3.73
Total Power	89.52	7.46	14.92
Age	7.4	7.4	7.4

2.3 Illumination

The illumination systems in the faculty of engineering buildings have undergone major improvement since 2019. Gradually all the lighting systems have been replaced with LED luminaires with motion sensors to automate the on/off operation. Currently, all the lighting systems have been replaced with LEDs with a total installed power of about 39 kW. The operating hours of the lighting systems are estimated at 9 hours per day and the energy consumption of the lighting system is about 10.6 MWh/month or equivalent with around 127.7 MWh/year.

2.4 Historical Energy Consumption

The university's facility department provided the historical data set for energy consumption used in this research, as shown in Table 4, which shows the monthly energy usage for the entire university from 2018 to 2022. These electrical energy loads are often split up across lighting, equipment and device loads, and HVAC systems. Table 4 clearly illustrates the overall trend of a substantial rise in energy consumption due to high cooling requirements in early and late summer (June-July and September-October). Since most students leave campus for their homes during the holidays, the midsummer does not witness the high energy consumption. The general trend indicates that the strong demand for cooling is the cause of the rising energy use since the HVAC system accounts for the majority of electrical demands.

Table 4. University's monthly energy consumption (MWh)

Month	2018	2019	2020	2021	2022
Jan	2,569	10,616	6,165	5,099	4,762
Feb	2,335	3,814	5,708	5,145	4,561
Mar	3,380	5,772	5,449	1,539	4,488
Apr	3,422	6,611	5,688	7,569	5,547
May	4,032	6,353	6,046	6,619	7,579
June	45,601	6,056	7,214	6,484	9,576
July	15,082	11,057	10,666	8,234	10,598
Aug	13,111	8,931	10,491	9,288	7,551
Sept	11,089	8,614	9,676	7,915	9,458
Oct	17,067	13,944	10,085	10,013	11,277
Nov	9,487	10,361	8,531	9,027	7,539
Dec	7,742	7,879	6,356	6,029	6,585
Total	134,917	100,007	92,078	82,963	90,475

3. Auditing Results

As per the findings of the survey, energy meters are not universally installed in buildings for the purpose of monitoring their individual energy consumption. Therefore, it is not possible to provide a comprehensive breakdown of the historical energy consumption patterns of each building at the university. Due to the fact that electricity bills are consolidated for the entire university and no individual building bills are maintained, it is not possible to discern a pattern of energy consumption from historical electricity bills.

To address this issue, a power quality tester is installed in the E1 and E2 buildings' electrical panels during the survey to sample the power consumption pattern. Figures 3 and 4 depict the overall energy consumption for the E1 and E2 buildings based on the readings. According to the numbers, the electricity power consumption for the E1 is generally higher than the E2, with the peak power consumption of the E1 being around 670 kW at around 2 p.m., whereas the peak power consumption of the E2 is only around 375 kW, which is reached on a few occasions between 7 a.m. and 3 p.m. According to the data, the faculty of engineering's operational hours are officially from 7 a.m. to 5 p.m., but the E1 and E2 buildings were found to operate for more than 12 hours per day, as evidenced by the power consumption pattern, which significantly decreased only after 7 p.m.

As a sampling result, the data also can be used as an estimator for monthly energy consumption for the faculty engineering building as a fraction of energy consumption in the whole university. As a note, the energy audit was conducted in May 2023 at the beginning of the summer season and the energy consumption will be reflected in the June 2023 bills. From the results that were taken during the working days of the buildings, it can be estimated that the energy consumptions are about 7,500 kWh/day and 4,100 kWh/day for E1 and E2 buildings. Given that there are 22 working days/month it can be estimated that the monthly energy consumption for June 2023 bills are somewhere between 261.7 MWh (if energy consumption on the weekend is considered equal to the average minimum in the weekdays) to 348 MWh (if energy consumption in the weekend is considered equal with energy consumption in the weekdays). These fractions are equivalent to around 2.7 % to 3.6 % of the total energy consumption in the university.

In addition to the main panel, there are also distribution panels that are specifically designed to supply power to the HVAC system, utility system, and other systems within the building. A power quality analyzer was also installed in these panels to sample the consumption pattern in these systems. Based on the sampling results, it was discovered that the HVAC system is responsible for the majority of electricity consumption in both the E1 and E2 buildings, accounting for 94% and 92% respectively, as depicted in Fig. 5 and 6. Figures 7 and 8 display the results of the sampling measurements in the HVAC systems of buildings E1 and E2, respectively. Based on the sampling results, it is evident that the power consumption pattern of the HVAC system closely mirrors the power consumption pattern of the entire building. This is primarily due to the HVAC system's dominant consumption compared to other systems.

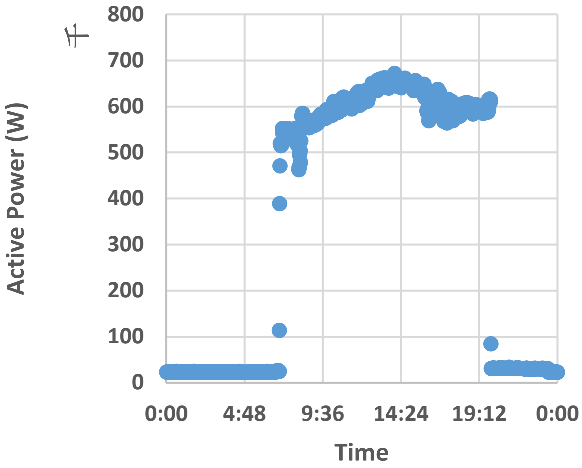

Fig. 3: Typical daily power consumption pattern in E1 Building

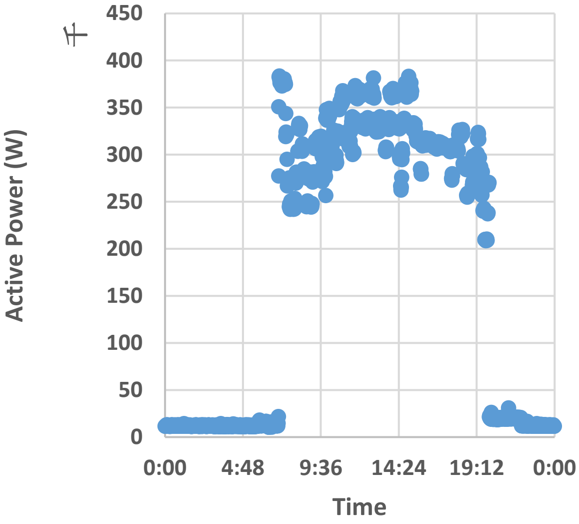

Fig. 4: Typical daily power consumption pattern in E2 Building

The HVAC system is mostly centralized. The cooling system consists of five Package systems for each building. Most package systems have the same cooling capacity, which is 63 tons. Although, the E1 Building has a few package units with a higher cooling capacity, which is 90 tons. The HVAC package system is also equipped with 30 fan motors, which are either floor-mounted or wall-mounted split units.

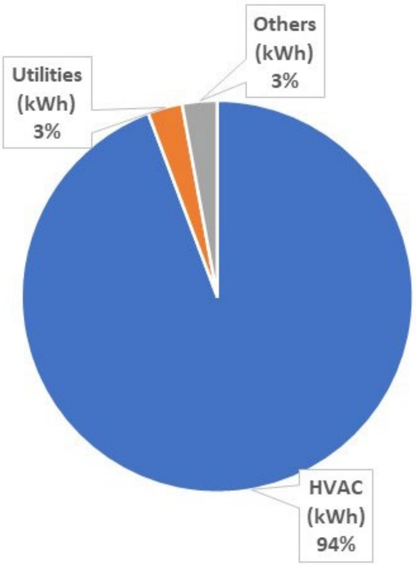

Fig. 5: Breakdown of electricity usage in E1 Building

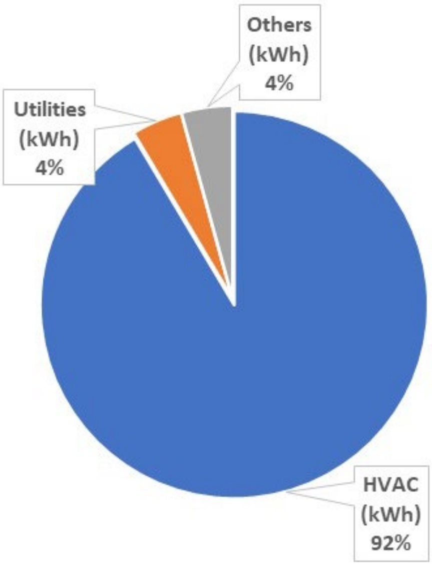

Fig. 6: Breakdown of electricity usage in E2 Building

Table 5 shows measurement results related to the assessment of the thermal comfort conducted in the E1 and E2 for each floor (G floor, 1st floor ,2nd floor, and 3rd floor). The assessments were conducted between 11 a.m. to 3 p.m. when the cooling load was generally at the peak. The measurements were taken at several points on each floor and averaged. The results show that generally, the HVAC system has successfully made the indoor temperature colder with a temperature difference of about -20 °C than the outside air temperature. It was also observed that the air temperature in all investigated areas was cooler than the recommended standards set by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) in their ASHRAE 55-2013 guidelines for Thermal Environmental Conditions for Human Occupancy. The recommended values for achieving thermal comfort conditions based on the standard is between 23-26 °C21).

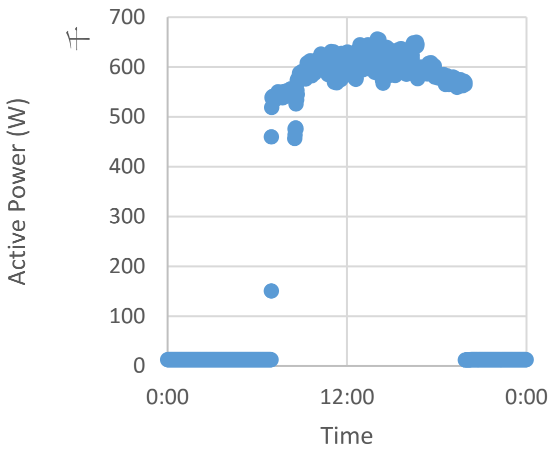

Fig. 7: Typical Power Consumption for HVAC in E1 Building

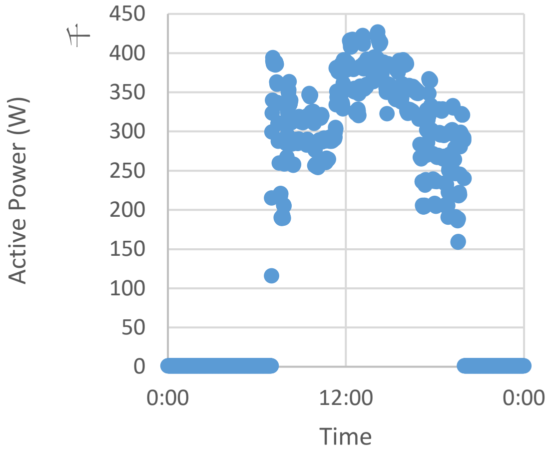

Fig. 8: Typical Power Consumption for HVAC in E2 Building

The relative humidity levels were also recorded in accordance with the guidelines specified in ASHRAE 55-2013, which suggests a comfortable range of relative humidity between 40% to 60%21,22). It was found that the relative humidity in all the measured areas also did not comply with the ASHRAE standards. The recorded values were generally below the recommended comfortable ranges indicated in Table 5.

Furthermore, because of the absence of control over humidity settings, the relative humidity percentages fluctuated within the same type of spaces in a manner comparable to the temperature data. In conclusion, these air temperature and relative humidity readings point to inefficiencies in the HVAC system's performance, which lead to unnecessary energy use and occupant discomfort23). These findings suggest the potential for energy optimization in these spaces.

Table 5. Thermal survey in E1 and E2 buildings

Area in E1 and E2	**Temperatures (°C)**		**Relative Humidity (%)**	
	Measured		**Measured**	
	E1	**E2**	**E1**	**E2**
G Floor	**20.9**	**19.4**	**21.3**	**19.4**
1st Floor	**20.7**	**19.9**	**21.5**	**19.9**
2nd Floor	**21.0**	**20.9**	**22.9**	**20.9**
3rd Floor	**20.5**	**20.7**	**25.3**	**20.7**
Outside temperature	**40.2**		**7.8**	

4. Analysis

Figure 9 shows the Energy Use Intensity (EUI) in kilowatt-hours per square meter per year (kWh/m^2/year) for the years 2018 to 2022. The data shows a decreasing trend in the annual electricity consumption over the years, from 134.92 kWh/m2 in 2018 to 90.48 kWh/m^2 in 2022. This decrease may be due to the combination of the implementation of energy-saving measures or the use of more energy-efficient lighting systems as well as the excess impact of pandemic COVID19 during 2020-2022 where most of the activities were shifted to online mode.

The EUI also shows a decreasing trend over the years, indicating that the entity is becoming more energy-efficient. A lower EUI indicates that the entity is using less energy per unit of floor space[24]. Overall, although the data suggests that the entity has been successful in reducing its energy consumption over the years, the actual progress of energy conservation should be proven with the trend of energy consumption in 2023 where the whole activity has returned to normal. It is also important to note that the data only provides information on electricity consumption and does not account for other energy sources such as natural gas or renewable energy. If the EUI is benchmarked with the EUI of similar buildings in the Gulf countries region in 2015, around 300 kWh/m2/year, the university generally consumes less energy than most buildings in similar climates.[13,14,25]

However, if the same measures of EUI are estimated for the E1 and E2 buildings, where the monthly energy consumption is estimated at around 169.4 MWh and 92.3 MWh for E1 and E2 buildings respectively and the total area of 3,448 m^2 for each building, the calculated EUIs are 589 kWh/m^2/year for E1 building and 321 kWh/m^2/year for E2 building. These EUIs are significantly higher than the EUI of the whole university and higher than most buildings in the Gulf region.

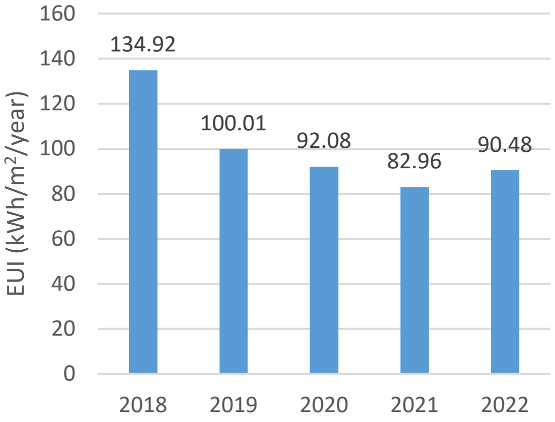

Fig. 9: Energy Use Intensity (Electricity) in kWh/m^2/year from 2018-2022

With respect to the E1 and E2 buildings, where more than 90 % of their power consumption is consumed by the HVAC systems, the effort to reduce the EUI of the building should be focused on the reduction of power consumption by the HVAC system. Generally, the effort to reduce the power consumption of the HVAC system can be done with two methods. The first method ensures that the HVAC system is operated at its optimal efficiency level indicated by the Coefficient of Performance (CoP). The second method is by observing the HVAC system's outcome, which is the thermal comfort level produced by the HVAC system[26].

In this study, the first method is not possible to be conducted yet, since the survey did not measure the performance of the HVAC system in specific. However, the second method can be conducted through the thermal survey results. The thermal survey results have revealed that all conditioned areas in the building generally have temperatures less than 22 °C with a temperature difference of about -20 °C from the outside temperature. Meanwhile, many studies have suggested that the comfort level is from 23-26 °C[27-30]. It indicates that the achieved temperature is too low. A temperature that is too low will have two disadvantages, firstly it will not produce comfort level as some occupants might feel too cold, and secondly, it will consume more energy than what is needed. According to certain studies[30-32], increasing the temperature settings to 1 °C could result in energy savings ranging from 3% to 10% depending on the kind of HVAC equipment and climate. If the worst-case scenario of savings of 3% is considered and the temperature setting is adjusted by 2 °C to achieve a closed thermal condition of 23 °C, the HVAC system's energy usage can be decreased to approximately 6%. As the HVAC system accounts for approximately 92% and 98% of electricity usage in the E1 and E2 buildings respectively, these savings will amount to approximately 9.35 MWh/month for the E1 building and 5.43 MWh/month for the E2 building. Another more specific energy-saving possibly comes from limiting loss through fenestrations[33-35]. However, more detailed data and analysis are needed to determine the potential savings from this area.

5. Conclusions

The energy audit results found that the university's Energy Use Intensity (EUI) exhibits a decreasing trend in the annual electricity consumption over the years, with a reduction from 134.92 kWh/m^2 in 2018 to 90.48 kWh/m^2 in 2022. This decline may be attributed to the implementation of energy-saving measures, the use of more energy-efficient lighting systems, and the impact of the COVID-19 pandemic during 2020-2022, where most activities were shifted to online mode. Benchmarking the EUI with similar buildings in the Gulf countries region in 2015, which averaged around 300 kWh/m^2/year, highlights that the university generally consumes less energy than most buildings in a similar climate. However, when estimating the EUI for the E1 and E2 buildings, with monthly energy consumption estimated at 169.4 MWh and 92.3 MWh, respectively, and a total area of 3,448 m^2 for each building, the EUI is estimated to be around 589 $kWh/m^2/year$ for E1 and 321 $kWh/m^2/year$ for E2. These values are significantly higher than the EUI of the entire university and exceed those of most buildings in the Gulf region. Considering that over 90% of the power consumption in the E1 and E2 buildings is attributed to HVAC systems, efforts to reduce their EUI should focus on minimizing power consumption by optimizing the HVAC system's efficiency.

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