Contribution Sustainability in Electricity Consumption: A Case Study of Nine University Buildings

Khalid AlSuwaidi[1], Shaikha Aldoukhi[1], Nour Kashwani[1], Mohamed Al Marzooqi[1], Salwa Beheiry[2]

[1] American University of Sharjah, Sharjah, UAE
[2] Cleveland State University, Cleveland, USA
g00077179@aus.edu

Abstract
The escalating concerns over sustainability and energy efficiency have prompted educational institutions globally to adopt proactive measures to understand and mitigate energy consumption. This study investigates electricity consumption trends and patterns in nine academic buildings in the United Arab Emirates (UAE) from 2020 to 2023. The aim is to identify critical factors influencing electricity usage and propose strategies to enhance energy efficiency. The research objectives include reviewing global and local energy consumption trends in the construction industry, analyzing historical electricity consumption, examining seasonal variations, and exploring potential factors such as weather conditions, building age, and building orientation. The methodology encompassed comprehensive data collection from utility bills, followed by trends and patterns analysis to identify consumption trends and influential factors. Findings reveal significant seasonal variations, with peak consumption in summer months despite reduced campus activity. Older buildings exhibited higher energy consumption, highlighting the need for refurbishment. Additionally, building orientation and exposure to sunlight were critical factors impacting energy use. Recommendations included extensive refurbishment of older buildings, optimizing building orientation, and implementing vegetation barriers to reduce heat exposure. Furthermore, adjusting academic schedules to avoid peak summer months, consolidating class locations during off-peak times, and optimizing HVAC and lighting systems through Building Management Systems (BMS) are suggested to reduce energy consumption. Continuous monitoring and stakeholder engagement are essential for effectively implementing and evaluating these strategies. This study underscores the importance of targeted energy conservation measures in enhancing the sustainability of academic buildings and educational campuses, ultimately contributing to the socio-economic and environmental well-being of the university community.

Keywords
Sustainability, Electricity consumption, Academic buildings, Energy conservation, Analysis.

1. Introduction

The increased concerns over sustainability and energy efficiency in general, and in academic institutions worldwide in particular, urged taking proactive measures to understand and address the energy consumption patterns to prioritize strategies and measures that will lead to sustainable, energy-efficient educational campuses. According to (Ahmed et al., 2020)Academic buildings are the main contributors to the country's success, as they educate people and societies and enable nations to progress and grow. Moreover, those academic buildings must set a leading example for societies. Sustainable practices are one of the practices that educational institutions should activate, leading to better socio-economic and health of the people within the university campus (Ahmed et al., 2021b). Study in (Darby et al., 2016) indicates that 9.245 million tons of CO2 per year is the amount of emissions emitted from educational buildings in the UK, contributing to 1.32% of the UK's total emissions. Of those emissions, 26% of the total CO2 comes from electricity consumption, whereas 14% are indirect emissions, mainly from commuting to and from educational buildings. Likewise, academic institutions in the USA are also massive sources of emissions. As an example, Sam Wyly Hall University produces up to 67,500 tons of CO2 emissions per year (Muthu, 2021). This indicates the impact of energy consumption globally.

In the UAE, the urge to discuss this topic was captured by establishing an office of sustainability in 2009 to address energy consumption issues. According to (Samara et al., 2022)The total CO2 emissions for those academic buildings in 2018–2019 were 94,553.30 tCO2e per year, of which 60.91% came from electricity consumption. This shows that to create a sustainable environment, trends and pattern analysis of electricity consumption in such academic buildings must be carried out to identify critical factors influencing electricity usage and potential strategies for improving energy efficiency. Hence, this study aims to analyze the trends and patterns of electricity consumption in nine academic buildings in the UAE from 2020 to 2023 and identify the key factors influencing electricity usage to provide potential strategies for improving energy efficiency. The objectives of this research that are mapped to the aim of the study will be as follows:

1- Identify the local and global trends and impacts of energy consumption in the construction industry and the strategies adopted.
2- Review the historical electricity consumption trends in nine academic buildings from 2020 to 2023.
3- Analyze seasonal variations and peak consumption periods within the academic year for different academic buildings.
4- Investigate potential external factors contributing to changes in electricity consumption over time, such as weather conditions, building age, and building orientation.
5- Propose recommendations for energy conservation and efficiency measures opportunities based on analyzing electricity consumption data.

2. Literature Review

2.1 Energy Consumption Practices in UAE

The United Arab Emirates (UAE) is a country where the population is growing every year and where the percentage growth in the total number of people has averaged around 1% every year since 2010 (World Bank Open Data, 2024). Also, the country is going through an industrial boom where the industrial sector contributed approximately 200 billion AED in 2023 to UAE’s Gross Domestic Product (GDP), and this was almost 9% higher than the figures in 2022 (Arab News, 2024). Moreover, the manufacturing sector has gained lots of attention since the announcement of UAE’s “Operation 300bn” even though the industry was already considered one of the main contributors to UAE’s GDP (Walters, 2023). This “Operation 300bn” aims to enhance the industrial sector in the UAE further and develop it to increase its contribution to the country’s GDP to around 300 billion AED by the year 2031 (UAE Government, 2023)These growths and expansions are going hand in hand with an increasing energy demand, as statistics show an increase in the forecasted energy demand in the Emirate of Abu Dhabi and Dubai. (Salma, 2022) (John, 2023). Also, the demand for water in the UAE is expected to increase to reach almost double by the year 2030, compared to its level back in 2022 (Hilal, 2022). The current energy and water consumption and the increase in the forecasted future demands raise a concern; statistics show that in 2021, 39% of UAE’s CO_2 emissions resulted from the production of electricity and heat, and another 39% resulted from the different industries (International Energy Agency). Furthermore, although there have been considerable investments to cover electricity and water demands focusing on renewable and clean energy, as per (International Energy Agency), the UAE was ranked fifth in 2021 globally when it comes to CO_2 emissions per capita. This emphasizes the importance of studying the energy consumption of existing buildings in the UAE to align with the country's agenda and strategic vision. Moreover, in the UAE, it is anticipated that the building and construction industry emissions will surpass global figures significantly, primarily because of the substantial cooling needs and the inefficiency of energy usage in current building structures. Consequently, prioritizing initiatives such as green building practices and efficient energy enhancements have emerged as crucial strategies in combating climate change within the UAE. (Hajjar & Fayyad, 2020). In 2019, the United Arab Emirates (UAE) was among the pioneering national governments to declare its dedication to the 'Zero Carbon Buildings for All' campaign, a collaborative global effort spearheaded by the World Resources Institute (WRI) and backed by the United Nations Secretary-General. Demonstrating its resolve, the UAE government pledged to devise a comprehensive strategy aimed at attaining carbon-neutral buildings by 2050 (Hajjar & Fayyad, 2020).

Therefore, different regulations and codes have been issued in the UAE to achieve net zero carbon. The UAE Ministry of Energy and Infrastructure has issued the “National Green Building Regulation,” which sets the minimum requirements for new buildings regarding energy and water (Ministry of Energy and Infrastructure, 2021).

Table 1. STRATEGIES AND REGULATIONS IN ENERGY CONSERVATION IN THE UAE [33].

Entity	Strategy / Regulation	Purpose
The UAE Cabinet	Green Buildings Specifications and Standards	Save AED 10 billion and 30% reduction in carbon emissions by 2030.

2.

Ministry of Energy and Infrastructure	Sustainability Guidelines for Buildings and Roads	Enhance the construction industry to align with the 2030 sustainability targets
Ministry of Energy and Infrastructure	National Hydrogen Strategy	To support low carbon industry and achieve climate neutrality by 2031
Ministry of Energy and Infrastructure	'Save to sustain' campaign	Raise public awareness of energy consumption
Department of Municipalities and Transport in Abu Dhabi	Pearl Rating System	Encourage the advancement of eco-friendly constructions in terms of reduction in energy, water, and waste.
Dubai Municipality	Al Sa'afat Rating System	Assess carbon footprint, reduce and eliminate emissions, and assess green buildings.
Sharjah Electricity, Water and Gas Authority (SEWGA)	Established Conservation Department	Supports the conservation of electricity, water, and gas.
Ras AlKhaimah Municipality	Ras Al Khaimah Energy Efficiency and Renewable Strategy 2040.	30% savings in electricity consumption, 20% savings in water consumption, and 20% contribution from renewable energy.

The government of Abu Dhabi has issued through its Department of Municipalities and Transport the "Pearl Building Rating System" to encourage the advancement of eco-friendly constructions and enhance the standard of living; where this rating system has set explicit requirements to promote the reduction in energy, water, and waste (Department of Municipalities and Transport, 2024). On the other hand, the Government of Dubai, represented by Dubai Municipality, has issued "Green Building Regulations and Specifications" along with a practice guide that aims to enhance the efficiency of buildings in the Emirate of Dubai by reducing the consumption of energy and water effectively (Government of Dubai, 2020). In 2016, Al Sa'fat was approved as a rating system for green building by the ruler of Dubai, H.H. Sheikh Mohammed Bin Rashed Al Maktoum, leading to the revision of Dubai's green building code. The rating system was later updated to the "Dubai Green Building System," replacing the previous regulations and specifications. Al Sa'fat aims to promote sustainability and minimize energy consumption (Dubai Municipality, 2024). Table 1 summarizes the strategies and regulations launched by the UAE to encourage energy conservation and reduce energy consumption in the building sector.

The effectiveness of such strategies in the UAE context remains an important subject for further assessment, considering factors such as climate, building characteristics, occupants' behavior, and other pertinent variables to ensure the alignment with the countries' obligations to national and international commitments in terms of building sustainability in general and reduction of energy consumption in buildings in specific.

2.2 Factors Affecting the Use of Energy in Existing Buildings

The building sector in the UAE plays a vital role in the country's development. One of the most crucial types of buildings is higher educational buildings, such as universities, which account for nearly 80 institutions across the country (Commission for Academic Accreditation, 2020). Academic buildings and educational campuses contribute highly to total global energy consumption. A study conducted by researchers in the United States found that academic buildings contribute to 13% of the overall building energy consumption, positioning them as the fourth-largest contributor, following retail buildings, office buildings, hotels, and restaurants (Pérez-Lombard et al., 2008). In addition, according to research conducted in the Kingdom of Saudi Arabia, specifically in educational buildings in the province of Dammam, the energy use intensity, that is, the amount of energy consumed per area unit of the building, has been approximately 217 kWh/m2 Year (Hamida et al., 2020). This shows educational institutions' high contribution to the construction sector's energy consumption.

In addition, some studies have categorized the factors affecting energy consumption into five main categories, namely, climate, building characteristics such as type of purpose of the building, total floor area, and literature have identified different factors that affect the electricity consumption levels in buildings. According to the study conducted by (Silva & Sandanayake, 2012) the factors were categorized into size, hours of function, orientation, and geographic location. In addition, the third category is the characteristics of the occupants, including their behavior, awareness, and occupancy rate. Also, the building service system, including the operation and socio-economic pillar, are considered the last two categories of the factors affecting energy consumption in buildings. In all cases, and despite the way the factors are being categorized, it has been proven that those factors may or may not affect the energy consumption in buildings depending upon the data captured in every case.

For instance, building age is a crucial factor contributing to different energy consumption levels in buildings. The results found through the literature review indicated that building age is among the building characteristics that are strongly linked to lower consumption of electricity (Chen et al., 2018). A study conducted on some Canadian schools found that among the different factors analyzed for their impact on electricity consumption, the age of buildings was the only factor showing a statistically significant effect (Ouf & Issa, 2017). This study found an

increasing trend in electricity consumption within the studied schools, where newer-built schools consumed more electricity than older schools. In another study aimed to assess the correlation between United Kingdom (UK) schools building age and their energy performance, it was noted that modern schools are considered an intensive consumer of electricity, despite the different initiatives taken to design schools that are low energy consumers, where this was justified as a result of the increasing dependencies on Information Technology (IT) equipment and virtual teaching environments (Mohamed et al., 2021). However, in a study conducted in the Kingdom of Saudi Arabia (ALshibani, 2020), it was noted that there had been a weak correlation between building age and AC capacity systems in different schools, although the building's ages considered ranged between 11 years and 51 years. This shows that, depending on the data analyzed in the study, various factors may impact energy consumption as opposed to others.
In general, research has primarily concentrated on residential villas and offices. In contrast, few studies have focused on academic buildings, leaving a gap in understanding other building types, like academic buildings, especially in the UAE. International studies have been conducted on educational buildings, such as the study conducted by (Khoshbakht et al., 2018) eighty academic buildings were investigated to estimate the energy consumption and intensity to define energy benchmarks per building. On the other hand, (Song et al., 2017) have conducted an "energy-efficiency based course timetabling algorithm" for academic entities where it has been found that optimal scheduling in terms of energy consumption has resulted in 4% energy saving in cooling and heating seasons compared to the existing schedule in terms of room allocation. Hence, due to the lack of studies concerning energy consumption reduction in educational buildings in the UAE, there's a necessity to prioritize enhancing the operation of current buildings through comprehensive studies with broader scopes and practical improvement strategies rather than relying solely on suggestions or measures suitable only for the design phase of construction. The research objectives were designed to provide an answer to the three research questions. Those questions are: What are the trends and patterns of electricity consumption, including seasonal variations or peak consumption periods in academic buildings from 2012 to 2023? What factors contributed to changes in electricity consumption trends over the study period? What opportunities exist for implementing energy conservation and efficiency measures based on analyzing electricity consumption data?

3. Methodology

This study investigates electricity usage in nine academic buildings by comparing the electricity consumption. Monitoring the electricity efficiency of different educational buildings is crucial as it encourages users to enhance their performance and quality of life. The research method will involve data mining on existing data related to energy consumption spanning from 2020-2023 for nine academic buildings. To attain the study's objectives and answer the aforementioned research questions, the methodology used in this research will start with obtaining existing data for nine academic buildings, followed by data analysis, comparative analysis, and stakeholder consultation for validation of factors causing the trends and ending with potential opportunities and recommendations for energy consumption optimization in academic buildings. The factors contributing to energy consumption trends will be obtained from the literature, whereby a backward manner will be followed to check the literature for relevant factors causing the results of patterns. Therefore, data obtained will include detailed records of electricity usage, broken down by building, month, and year, received from utility bills. The collected data will be analyzed to identify trends, seasonal variations, and peak consumption periods. Later, a comparative analysis of electricity consumption patterns across different academic buildings will be carried out, and outliers or areas with significant deviations from the overall trend will be identified. This step will be followed by a validation process through Stakeholder consultation by Consulting with relevant stakeholders, including facility managers and energy experts. Findings will be validated, and potential energy-saving opportunities will be explored.

Table 2. BUILDINGS' DISCIPLINES

Building Number	Discipline
Building 1	Associated with business administration courses
Building 2	Library
Building 3	Associated with courses related to arts and mathematics and contains several computer labs for mathematical and mass communication courses..etc.
Building 4	Associated with Engineering related courses.
Building 5	Associated with Engineering-related courses (new).
Building 6	Main building.

2.

Building 7	Associated with science labs and science-related courses
Building 8	Associated with arts and first-year courses such as physics.
Building 9	Associated with language courses.

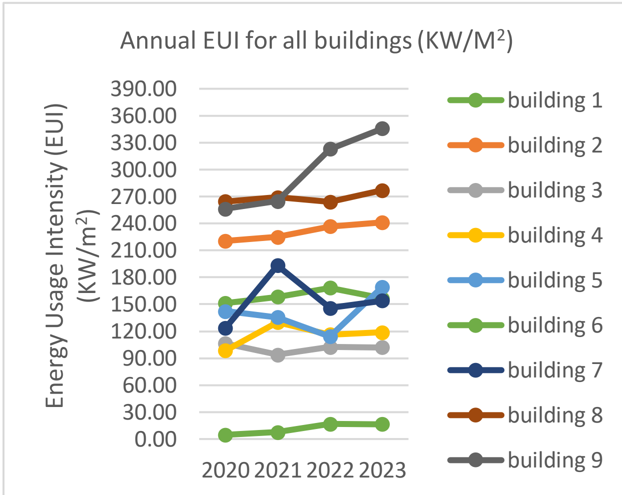

Fig. 1. Annual EUI for all buildings (KW/M2)

4. Data Analysis

Data were obtained for nine academic buildings to study energy consumption in educational buildings. The data included the monthly electricity consumption per educational building from December 2019 to December 2023. Energy Usage Intensity (EUI) will be calculated to normalize the data. EUI (KW/m2) is the monthly energy consumption of the educational building in (KW) to the area of the academic building in (M2) (Ahmed et al., 2021a). Normalization will allow for a better understanding and interpretation of the energy consumption of each building. Also, it will help conduct a fair comparison of the energy consumption of the educational buildings every month.

$$\mathrm{EUI}_{\mathrm{imy}}\left(\frac{\mathrm{KW}}{\mathrm{M2}}\right) = \frac{Consumption\ building\ i\ in\ m\ in\ specific\ y\ (KW)}{Area\ of\ \ building\ i\ \ (M^2)} \qquad (1)$$

Where,
i= Building's Number from 1 to 9
m= Calendar Months JAN to DEC
y=years from 2020-2023
Hence, to analyze the annual trends of the energy consumption of each of the nine educational buildings, a summation of the yearly EUI was calculated.

$$\mathrm{EUI}_{\mathrm{iy}}\left(\frac{\mathrm{KW}}{\mathrm{M2}}\right) = \sum \mathrm{EUI}_{\mathrm{imy}}(for\ all\ months\ m\ in\ year\ y) \quad (2)$$

Where i= Building's Number from 1 to 9
m= Calendar Months JAN to DEC
y=years from 2020-2023

4.1 Annual Trends

The annual energy consumption trends for each educational building can be observed using the annual EUI. Table 2 shows the disciplines taught in each of the buildings for reference.
Building 1 is experiencing a significant annual increase in energy consumption between 2020-2022 and then decrease in 2023. Between 2020 and 2021, the yearly EUI increased by almost 4.7% from 151.3 KM/M2 in 2020 to 158.39 KW/M2 in 2021. The annual EUI continued to grow in 2022, reaching 168.1 KW/M2, which indicated an almost 6.2% increase from 2021 and 11.2% from 2020. In 2023, the annual EUI Dropped by 6.8% compared to 2022, with an energy use intensity of 156.7 KW/M2, as shown in Figure 1.
For building 2, there is a gradual increase in annual EUI from 2020-2023, hence an increase in energy consumption. In 2020, the yearly EUI was 220.57 KW/M2, which increased by 2% in 2021 to reach 225 KW/M2. The increase

2.

continued in 2022 with annual EUI readings of 236.8 KW/M2, 5.27% more than in 2021. Again, in 2023, there is an increase in the Annual EUI, which reached 241.2 KW/M2, with a 1.8% increase from the previous year, as shown in Figure 1.

The highest annual EUI for Building 3 was in 2020. 106.3 KW/M2 was the annual energy usage intensity for that year. The EUI dropped significantly by 11.6% in 2021, reaching 93.99 KW/M2. In 2022, the Annual EUI increased considerably by 9.05% with a usage intensity of 102.5 KW/M2. A minor drop in annual EUI was noticed in 2023, reaching 101.88 KW/M2, 0.6% less than in 2022, as demonstrated in Figure 1.

In 2020, the annual EUI of building 4 was 98.33 KW/M2, which experienced a considerable increase in 2021. With a 32.1% increase, the yearly EUI of building 4 reached 129.98 KW/M2. The annual energy usage intensity decreased by 10.44% in 2022, reaching KW/M2. The EUI increased in 2023, reaching 118.86 KW/M2, 2.1% more than the previous year, as per Figure 1. Building 5 annual EUI experienced a decrease between 2020-2022, with a massive increment in 2023. Annual EUI was 142.27, 135.37and 114.13 KW/M2 during 2020,2021 and 2022, respectively. This showed a decrease of 15.69% between 2020 and 2022. A 48.4% sudden increment in energy usage was observed in 2023. The Annual EUI touched 169.37 KW/M2, as shown in Figure 1.

As an annual trend observation, the Annual EUI increase from 4.68 KW/M2 to 7.6 KW/M2 between 2020 and 2021 is almost 62.26%. The annual EUI continued to increase in 2022, reaching 16.86 KW/M2, an intensity of 121.88% higher than in 2021. In 2023, a slight drop, 1.6% compared to 2022, in the Annual EUI was observed. The annual EUI in 2023 was 16.58KW/M2. During the data-obtaining process, it was revealed that building 6 went into substantial renovation in 2021. The data showed that EUI doubled afterward. It is worth noting that the values/readings in this building are significantly lower than other buildings, indicating the possibility of being an outlier. This might be due to human error while manually entering the data. Also, this could be caused by instrumental error where electricity meters do not reflect the actual consumption, as demonstrated in Figure 1.

A 123.46 KW/M2 was the annual EUI of building 7 in 2020. This value increased to 193.14 KW/M2 in 2021, an increment of 56.4%. In 2022, building 7 had a lower Annual EUI than in 2021; the Annual EUI dropped by 24% to 145.93 KW/M2. A 5.6% increase was perceived in 2023, where the Annual EUI reached 154.11 KW/M2, as per Figure 1. Building 8's annual EUI slightly increased to 269.15 KW/M2 in 2021 from 264.55 KW/M2 in 2020. This is approximately a 1.73% increase in annual EUI. In 2022, the yearly EUI dropped almost by the same percentage,1.8%, reaching 264.08 KW/M2. The annual EUI reached its maximum in 2023, with an increase of 4.89% compared to 2022(277.02 KW/M2), as per Figure 1. Building 9 has continuously increased throughout the study period (2020-2023). It started with 256.45 KW/M2 in 2020, then increased by almost 3.3% in 2021, reaching 264.9 KW/M2. The annual EUI continued growing in 2022 and 2023 with an Annual EUI of 322.94 KW/M2 and 345.61 KW/M2, respectively. This is a 21.9% increase between 2021 and 2022 and a 7% increase between 2022 and 2023, as shown in Figure 1.

4.2 Annual EUI for all Educational Buildings

In 2020, the UAE government imposed several measures to contain the COVID-19 spread. One of the measures was to shift educational institutions from on-campus classes to remote learning and online courses. This shift was effective from March 2020 to September 2021. Only a few people were allowed to enter the educational buildings during this period. Logically, the energy consumption should drop significantly during this period. According to Figure 1 below, all buildings had 2020 as the lowest energy consumption year except buildings 3 and 5, with the lowest energy consumption in 2021 and 2022, respectively.

Buildings 2, 8, and 9 had the highest energy consumption, which urges a detailed investigation of those specific buildings. Moreover, buildings 2 and 9 have a continuous upward trend across the studied years. Those buildings were found to be located at the very end of the campus on both sides. Building orientation, positioning, and location can be the reasons for the high EUI due to sun exposure. Furthermore, those three buildings are among the oldest on campus and haven't undergone significant refurbishment since being built. Also, from a building function standpoint, buildings 2 and 9 are used by almost all students within the campus across all majors and schools. On the other hand, building 6 was found to be, by far, the most minor energy-consuming building. However, as indicated in the annual individual building analysis, building 6 data has enormous potential to be an outlier. Looking into the monthly EUI can reveal extra information on the pattern and trends of energy consumption for each of the examined educational buildings.

4.3 Monthly Analysis

To obtain more details on the energy consumption of the nine educational buildings under study and evaluation, each building will be analyzed monthly within each year. The monthly consumption has been compared with the previous monthly consumption of the same building to analyze the change in consumption throughout the year. Moreover, the

2.

monthly consumption of year X is compared with the same monthly consumption in year Y to ensure whether the increment is a trend.

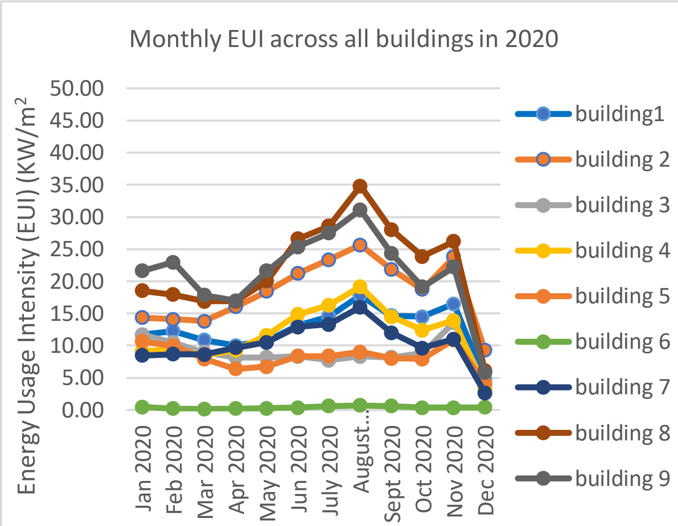

Fig 2. Monthly EUI across all buildings in 2020

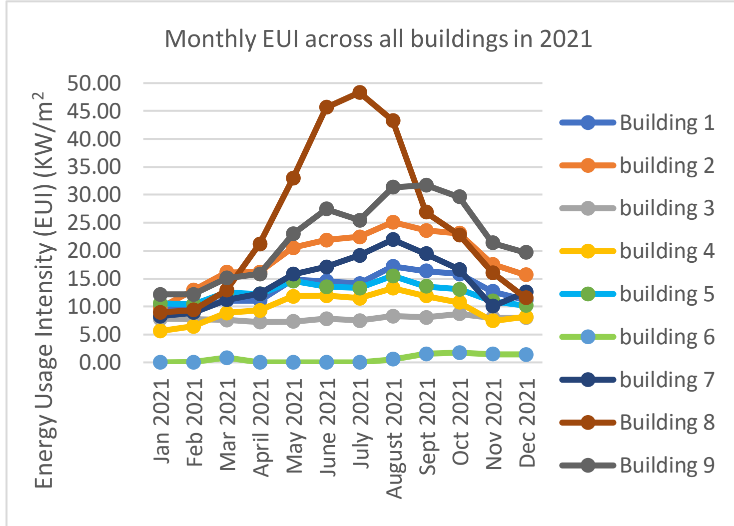

Fig 3. Monthly EUI across all buildings in 2021

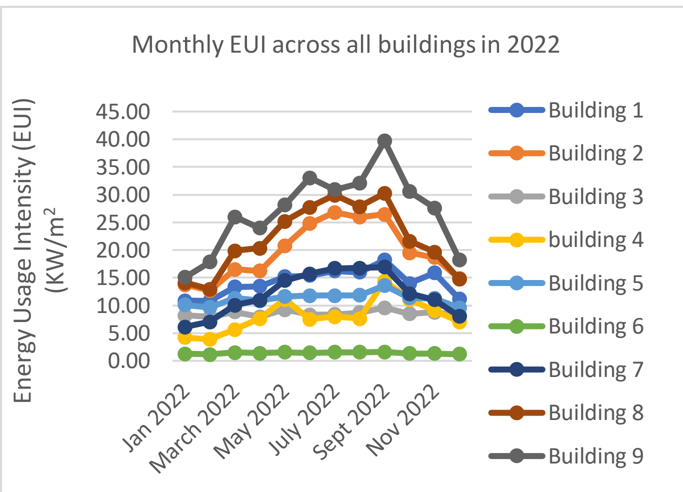

Fig 4. Monthly EUI across all buildings in 2022

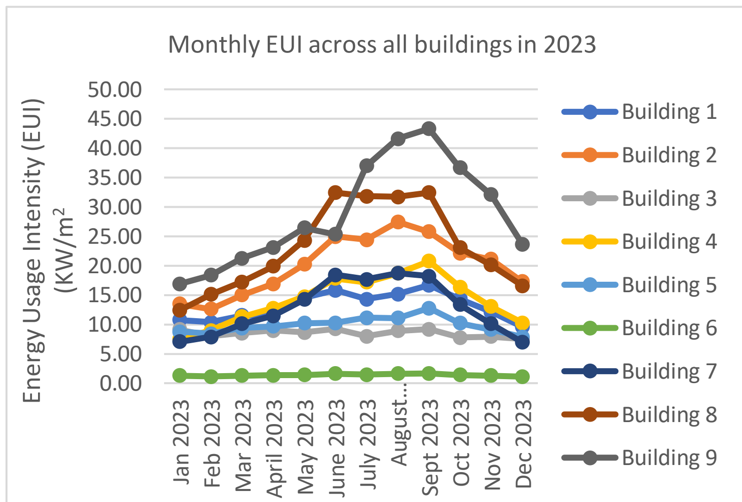

Fig 5. Monthly EUI across all buildings in 2023

It can be easily interpreted that there is a seasonal pattern in the EUI of building 1. There is an upward trend between April and August, followed by a downward trend from September to December, with a significant decrease in December. In other words, summer months were found to have the highest EUI throughout the years. This is mainly because of the necessity of extra cooling due to the harsh hot climate. On the other hand, December is considered the lowest energy consumption month across all studied years due to winter holidays and cool temperatures.
The above-demonstrated graphs show an upward pattern across all studied years between March and August. A downward trend repeatedly occurs between September and December. For similar reasons to building 1, building 2 is experiencing high consumption within the summer months, where consumption is almost double the other months of the year. Building 3, considered for mathematical and other arts and science general disciplines, had no noticeable trend that can be spotted. There is minimal fluctuation in EUI within the different months and the four years considered in this study.

In Fig 4, the effects of climate and high temperature can be seen. Summer months have more EUI than other months of the 4 studied years except during 2022. Due to limited information, one can't figure out why summer months in 2022 had way lower EUI than other years. This urge for monthly monitoring of the electricity consumption can help

2.

reduce EUI and, hence, the electricity consumption in the academic buildings. Energy consumption almost doubled in the summer compared to December and January. Building 5 recorded the least EUI during the remote learning period compared to the monthly EUI of other years. For the rest of the years, an upward trend is noticed between February and August/September and a downward pattern for the remaining months. A climate effect on electricity consumption can also be seen in this building.

As investigated in the annual analysis, building 6 can be easily identified as an outlier. The monthly EUI is significantly lower than all other buildings. This might be due to human error while manually entering the data. Also, this could be caused by an instrumental error in which electricity meters do not reflect actual consumption. Another observation on building 6 is that the energy consumption almost tripled starting August 2021. During the data-obtaining process, it was revealed that Building 6 underwent substantial renovation between January 2021 and August 2021, which explains why most of the readings within that period are zero. A further investigation should be done to justify the massive increase in EUI and, hence, the energy consumption after the renovation period.

The upward trend for building 7 starts from February to August and then has a downward effect from September to December. Seasonal patterns can be noticed clearly in the graph above.

Year 2021 shows a peak in consumption between February and July, followed by a sharp reduction in EUI between August and December. Further investigation should be carried out to list the reasons for this substantial extra consumption during this period; the data obtained doesn't justify the increase. For the rest of the years, seasonal patterns can also be observed from the data collected. Winter months consume significantly less than summer months.

Building 9's upward trend starts from March to September and then has a downward effect from October to December. Seasonal patterns are visible in the Graph above.

5. Discussion of results

As per the results obtained in the study demonstrated in section 4, and since the research focuses on data mining techniques to analyze the results, further mining into the literature to prove the findings has been done. Hence, one of the most crucial factors found in the literature was building orientation and layout, that is the positioning of the building to the sun. Research has shown that building orientation and layout are vital in minimizing energy consumption in buildings, regardless of other factors. Nine buildings are studied. Optimizing the orientation and design of buildings, such as direct sunlight exposure and the building's shape, (Tibermacine & Zemmouri, 2017) indicated that optimizing building orientation can significantly reduce energy consumption by up to 40%. This underscores the crucial role of thoughtful building layout and orientation in achieving energy efficiency goals. Moreover, Friess and Rakhshan, in (Friess & Rakhshan, 2017) explored the impact of daylight on energy consumption, particularly in the UAE context, where direct sunlight can adversely affect buildings. The influx of the sun often generates heat, prompting increased usage of air conditioning systems, thereby exacerbating energy consumption levels. Mokri et al. in (Mokri et al., 2013) verify those discoveries regarding exceptionally intense irradiance. However, in countries with moderate climates, the effect of daylight is often preferred, as it helps conserve lighting costs and promotes energy efficiency. This is because daylight can effectively illuminate indoor spaces, reducing the need for artificial lighting and subsequently contributing to lower energy consumption (Aboulnaga, 2006). The findings corroborate those of (Friess & Rakhshan, 2017) and (Mokri et al., 2013), which identified buildings 8 and 9 as having the highest energy consumption due to the influence of daylight direction. Furthermore, the analysis revealed that buildings 3 and 6 exhibited the lowest energy consumption levels. Notably, these buildings are positioned to minimize direct exposure to daylight, contributing to their reduced energy usage compared to other structures in the study. Therefore, it can be concluded that considering factors such as the direction of the daylight and building shape is crucial in both building design and energy management strategies.

Another critical factor that can be reflected in the results obtained in the study is the weather conditions in the UAE. According to (Li et al., 2024) in a recent study conducted in 2024 in an office building in humid-hot regions of similar weather conditions in the UAE resulted in an increase of 4.6% in energy consumption due to climate change. In addition, as per (Alam & Devjani, 2021) a study on educational buildings was conducted using clustering analysis, resulting in energy consumption rates depending on climate change during the week. Similarly, in a survey conducted in schools in Turkey, the research revealed that in hot climates, it is anticipated that energy consumption shall be doubled according to the prediction model formed (Ashrafian, 2023). Ironically, in a study conducted in Finland (Sekki et al., 2015) despite the cold weather in Finland, there is high electricity consumption in educational buildings constructed in the 2000s. This shows the significant impact of weather conditions on energy consumption in buildings. Therefore, as per the study performed in 9 educational buildings, it has been noticed that for most buildings, the results found in the literature are proven in the current research as well, where the clear seasonal pattern has been seen in

2.

buildings 1, 2, 4, 5, 7, 8 and 9 where there is an upward trend in March/April until August and a downward trend from September onwards. In addition, the building age is considered one of the main factors that affect energy consumption. Through data analysis, buildings 2, 8, and 9 were the most energy-consuming and among the oldest buildings within the campus that haven't gone through extensive refurbishment. Building 2 was built 18 years ago, while buildings 8 and 9 were built 27 years ago and haven't gone through significant refurbishment. All other studied buildings were constructed or renovated within the last 10 years. Unlike (Chen et al., 2018) (Ouf & Issa, 2017) (Mohamed et al., 2021), where newer academic buildings consumed more energy than the older ones, this study ultimately shows the opposite. The newer academic buildings performed much better than the old buildings regarding energy consumption. This might be because newer technology that regulates energy consumption was implemented in the newer buildings, such as motion sensing for lighting within the building and building management systems (BMS) that promptly regulate primary sources of energy consumption (lights, HVAC, and computer devices). Moreover, (Chen et al., 2018)(Ouf & Issa, 2017)(Mohamed et al., 2021) studied buildings age over a more significant period, which could be the source of discrepancy as the more substantial the time gap between buildings, the more technology and methods of teaching are introduced, which primarily affects the energy consumption.

References

Aboulnaga, M. M. (2006). Towards green buildings: Glass as a building element—the use and misuse in the gulf region. Renewable Energy, 31(5), 631–653. 10.1016/j.renene.2005.08.017

Ahmed, V., Abu Alnaaj, K., & Saboor, S. (2020). An Investigation into Stakeholders' Perception of Smart Campus Criteria: The American University of Sharjah as a Case Study. Sustainability, 12(12)10.3390/su12125187

Ahmed, V., Saboor, S., Ahmed Almarzooqi, F., Ahmed Alshamsi, H., Abdalla Alketbi, M., & Ahmed Al Marei, F. (2021a). A Comparative Study of Energy Performance in Educational Buildings in the UAE. University of Technology, Sydney (UTS). 10.5130/ajceb.v21i3.7681

Ahmed, V., Saboor, S., Almarzooqi, F. A., Alshamsi, H. A., Alketbi, M. A., & marei, F. A. A. (2021b). A Comparative Study of Energy Performance in Educational Buildings in the UAE. Construction Economics and Building, https://api.semanticscholar.org/CorpusID:240573217

Alam, M., & Devjani, M. R. (2021). Analyzing energy consumption patterns of an educational building through data mining. Journal of Building Engineering, 44, 103385. 10.1016/j.jobe.2021.103385

ALshibani, A. (2020). Prediction of the Energy Consumption of School Buildings. Applied Sciences, 10(17)https://doi.org/10.3390/app10175885

Arab News. (2024, Jan 18). UAE industrial sector adds $54bn to economy in 2023, up 9%. https://arab.news/g2nx9

Ashrafian, T. (2023). Enhancing school buildings energy efficiency under climate change: A comprehensive analysis of energy, cost, and comfort factors. Journal of Building Engineering, 80, 107969. 10.1016/j.jobe.2023.107969

Chen, Y. -., Matsuoka, R. H., & Liang, T. -. (2018). Urban form, building characteristics, and residential electricity consumption: A case study in Tainan City. . Environment and Planning B: Urban Analytics and City Science, 45(5), 933–952. https://doi.org/10.1177/2399808317690150

Commission for Academic Accreditation. (2020, Nov 26). Higher Education Institutions. https://www.caa.ae/Pages/Institutes/All.aspx. Retrieved 1 Mar 2024, from https://www.caa.ae/Pages/Institutes/All.aspx

Darby, H., Elmualim, A., Clements-Croome, D., Yearley, T., & Box, W. (2016). Influence of occupants' behaviour on energy and carbon emission reduction in a higher education building in the UK. Intelligent Buildings International, 8, 1–19. 10.1080/17508975.2016.1139535

Department of Municipalities and Transport. (2024, Feb 9). Pearl Building Rating System. https://pages.dmt.gov.ae/en/Urban-Planning/Pearl-Building-Rating-System. Retrieved 17 Feb 2024, from https://pages.dmt.gov.ae/en/Urban-Planning/Pearl-Building-Rating-System

Dubai Municipality. (2024, Feb 16). Al Sa'fat – Dubai Green Building System. https://www.dm.gov.ae/municipality-business/al-safat-dubai-green-building-system/. Retrieved 17 Feb 2024, from https://www.dm.gov.ae/municipality-business/al-safat-dubai-green-building-system/

Friess, W. A., & Rakhshan, K. (2017). A review of passive envelope measures for improved building energy efficiency in the UAE. Renewable and Sustainable Energy Reviews, 72, 485–496. 10.1016/j.rser.2017.01.026

Government of Dubai. (2020). Green Building Regulations and Specifications Practice Guide. UAE: Government of Dubai. https://www.dm.gov.ae/wp-content/uploads/2020/11/Green-Buildings-1.pdf

2.

Hajjar, J., & Fayyad, M. (2020). UNITED ARAB EMIRATES: 2020 GREEN BUILDING MARKET BRIEF. Emirates GBC. https://emiratesgbc.org/wp-content/uploads/2020/09/UAE-Brief_NewTemplate_electronic_final.pdf

Hamida, M. B., Ahmed, W., Asif, M., & Almaziad, F. A. (2020). Techno-Economic Assessment of Energy Retrofitting Educational Buildings: A Case Study in Saudi Arabia. MDPI AG. 10.3390/su13010179

Hilal, N. (2022, Mae 22). World Water Day: A chance for the UAE to re-think our use of resources. The National https://www.thenationalnews.com/opinion/comment/2022/03/22/world-water-day-a-chance-for-the-uae-to-re-think-our-use-of-resources/#:~:text=If%20current%20patterns%20and%20rates

International Energy Agency. United Arab Emirates - Countries & Regions. Retrieved 16 Feb 2024, from https://www.iea.org/countries/united-arab-emirates/emissions

John, B. (2023, Feb 01). Dubai's energy demand rose by 5.5% in 2022. The National News https://www.thenationalnews.com/business/energy/2023/02/01/dubais-energy-demand-rose-by-55-in-2022/

Khoshbakht, M., Gou, Z., & Dupre, K. (2018). Energy use characteristics and benchmarking for higher education buildings. Energy and Buildings, 164, 61–76. 10.1016/j.enbuild.2018.01.001

Li, J., Zhai, Z., Li, H., Ding, Y., & Chen, S. (2024). Climate change's effects on the amount of energy used for cooling in hot, humid office buildings and the solutions. Journal of Cleaner Production, 442, 140967. 10.1016/j.jclepro.2024.140967

Ministry of Energy and Infrastructure. (2021). National Green Building Regulation. UAE: Ministry of Energy of Infrastructure.

Mohamed, S., Smith, R., Rodrigues, L., Omer, S., & Calautit, J. (2021). The correlation of energy performance and building age in UK schools. Journal of Building Engineering, 43, 103141. 10.1016/j.jobe.2021.103141

Mokri, A., Aal Ali, M., & Emziane, M. (2013). Solar energy in the United Arab Emirates: A review. Renewable and Sustainable Energy Reviews, 28, 340–375. 10.1016/j.rser.2013.07.038

Muthu, S. (2021). LCA Based Carbon Footprint Assessment10.1007/978-981-33-4373-3

Ouf, M. M., & Issa, M. H. (2017). Energy consumption analysis of school buildings in Manitoba, Canada. Elsevier BV. 10.1016/j.ijsbe.2017.05.003

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398. 10.1016/j.enbuild.2007.03.007

Salma, S. (2022, Feb 14). Peak electricity demand in the emirate of Abu Dhabi in the United Arab Emirates from 2000 to 2030. https://www.statista.com/statistics/1141928/uae-abu-dhabi-peak-electricity-demand/. Retrieved 16 Feb 2024, from https://www.statista.com/statistics/1141928/uae-abu-dhabi-peak-electricity-demand/

Samara, F., Ibrahim, S., Yousuf, M. E., & Armour, R. (2022). Carbon Footprint at a United Arab Emirates University: GHG Protocol. Sustainability, 14(5)10.3390/su14052522

Sekki, T., Airaksinen, M., & Saari, A. (2015). Measured energy consumption of educational buildings in a Finnish city. Energy and Buildings, 87, 105–115. 10.1016/j.enbuild.2014.11.032

Silva, M. D., & Sandanayake, Y. G. (2012). Building energy consumption factors: a literature review and future research agenda. https://api.semanticscholar.org/CorpusID:157696653

Song, K., Kim, S., Park, M., & Lee, H. (2017). Energy efficiency-based course timetabling for university buildings. Energy, 139, 394–405. 10.1016/j.energy.2017.07.176

Tibermacine, I., & Zemmouri, N. (2017). Effects of building typology on energy consumption in hot and arid regions. Energy Procedia, 139, 664–669. 10.1016/j.egypro.2017.11.269

UAE Government. (2023, Feb 13). Operation 300bn, the UAE's industrial strategy. https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/industry-science-and-technology/the-uae-industrial-strategy. Retrieved 16 Feb 2024, from https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/strategies-plans-and-visions/industry-science-and-technology/the-uae-industrial-strategy

Walters, J. (2023, Oct 17). UAE: Manufacturing sector overview. Emirates NBD https://www.emiratesnbdresearch.com/en/articles/overview-of-the-uae-manufacturing-sector#:~:text=Real%20UAE%20GDP%20growth%20in

World Bank Open Data. (2024). Population Growth (% annual). https://data.worldbank.org/. Retrieved 16 Feb 2024, from https://data.worldbank.org/indicator/SP.POP.GROW?end=2022&locations=AE&start=1961&view=chart