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Article

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Analyzing Energy Consumption in Universities: A Literature Review

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ABSTRACT

This study investigates energy consumption in general and in universities in particular. A literature review was used as the methodology of the study to show the energy consumption purposes, major findings, research gaps, limitations, and future research about how to analyze energy consumption levels. The number of references examined was 60, with 29 references about universities and some of them are concentrating on the buildings' consumption in the GCC area. Most of the references concentrated on investigating case studies in different countries. Analysis of the findings showed that tools such as big data analytics, machine learning, simulations, and predictive models were used. However, big data analytics was the most important one. It was found that AC systems are the most important component of energy consumption, especially in hot weather countries. The studies also showed that monitoring the consumption rates will reduce the total consumption of energy. In universities, the type of the building and the day index were found the most important factors affecting energy consumption. Factors such as number of smart devices, location, and floor space were found to have different positive and negative impacts on energy consumption from one study to another. Recommendations for future research were also presented.

Keywords: Big Data Analytics, Energy Consumption, Campus Buildings, Modeling
JEL Classifications: Q4, N7, O13, P48

1. INTRODUCTION

The prudent use of resources and the management of energy use have become critical in the pursuit of a sustainable future. Universities, as significant energy consumers, are critical in establishing energy consumption trends and putting improvements into effect (Yang et al., 2023). The difference between university buildings and normal buildings is that universities have some laboratories that consume more energy than other normal buildings (Wei et al., 2022). Another difference is that universities have a changing demand from time to time. For example, during the summer break, the energy consumption is lower than that during the normal semester. Moreover, the consumption during the day is much larger than the consumption during the night or the weekend (Akbar et al., 2020). In the GCC countries, the consumption is generally much more during the summer than during the winter because of the hot weather and the need for air conditioning. Furthermore, different buildings are built in different years with different designs and technologies, especially for new universities. The UAE has many new universities, and sustainability standards have been applied in recent years in the new buildings. The application of these standards needs to be investigated.

With a 32% average consumption/output ratio, GCC nations quadrupled primary energy production in three decades, resulting in substantial CO_2 emissions (Sakhrieh, 2016). The international energy agency (IEA) highlights energy efficiency as the "first fuel" and considers it more crucial than other energy-generating technologies (Kim, 2020). In countries with harsh weather conditions, such as the United Arab Emirates (UAE), buildings consume more than 70% of the power generated (Al Amoodi and Azar, 2018). Energy management and monitoring is one of the most essential components in preserving the building's efficiency in terms of energy usage.

Kim et al. (2020) showed that a major loss in efficiency is caused by a defect in the design of the Heating, Ventilation, and Air Conditioning systems (HVAC). AC control variables are critical indicators that may be used when the building is already inhabited and a gap remains in the performance of these HVAC systems due to mismanagement.

The analysis of energy consumption is widely known in the literature. However, not much was published about the energy consumption in the campus buildings, especially in hot weather countries. Despite research on energy usage in buildings and universities, the UAE region has yet to show undiscovered potential in this field. By reviewing the literature, this study explains the issues typically faced in energy consumption studies, especially in the GCC region. This investigation is useful in developing a fruitful work plan for analysis. The paper examines methodologies in different references and identifies gaps in past research about energy usage and fluctuations in energy usage.

2. METHODOLOGY AND DIRECTIONS OF RESEARCH

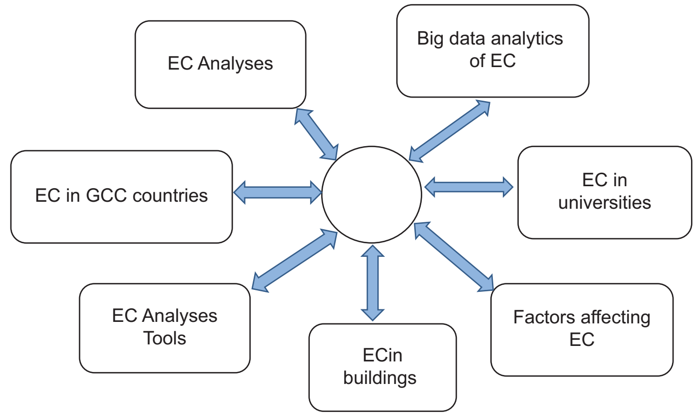
The methodology in this research depends on the literature review. Figure 1 shows the categories of references reviewed in this study and the relationship between them. In this figure, EC stands for energy consumption. The circle in the middle and the arrows coming in and out of it mean that it is possible to find a study that contains any two categories or more. For example, a study can be about big data analytics of EC in universities and a GCC country. For example, in the category, of EC Analyses, examinations of energy use in various facilities are established. This field of research offers insights into consumption patterns and variables that affect energy use and methodologies used. It is true that the focus of this study is to review the studies about EC in universities, but other categories can be found in the same reference.

Such as categorization is useful because we want to show the differences in results based on factors such as the region. For example, the results of a study in Europe can be different than the results of a study in the UAE because of the different climate conditions in the two regions. Another example is the effect of the analysis tool used and the results obtained. Sometimes big data analytics is used, but sometimes other tools are also used, or machine learning is used based on the available big data.

2.1. Energy Consumption in Buildings

Several studies investigated the energy consumption in buildings in general. For example, Meng et al. (2021) used an algorithm-centric method to analyze energy use in big buildings. They used a smart automated meter to collect data on consumption characteristics which included energy use, temperature, and lighting intensity. The data was processed using Apache Kafka and Spark Streaming modules. However, the concept was impractical for occupied buildings due to data transfer issues and obstructive infrastructure.

Figure 1: The categories of studies reviewed



Himeur et al. (2023) considered big data analytics using AI in buildings to consider several tasks such as energy anomaly detection in residential and office buildings and energy. A study by Sodenkamp et al. (2017) that focused on the use of smart meters showed that 9 out of 11 energy efficiency-related equipment in households could be identified with an accuracy of 70% and the aggregation of hourly reading gave high prediction quality.

Ahn et al. (2017) concluded from data analysis that building age and stricter energy codes such as following consumption policies and regulations such as peak time scheduling did not reduce overall consumption. In fact, there was no correlation between location, number of floors, number of lifts, and floor area, implying that there was no clear dependence between any of these factors, making them independent of one another. Nonetheless, Moreno et al. (2018) established a linear relationship between the number of occupants in a building and the amount of error generated by the data analysis done through Big Data where the increase of occupants caused an increase in the errors generated due to the unpredictable dynamic of occupant's behavior. Barakhnin and Danilov (2021) concluded that the number of smart devices in a building shapes the consumption of electricity being a factor with a linear relation (more smart devices = more consumption) as the machine learning models suggested in the analysis.

When using data analysis, it was found that ecological factors such as the climate and external temperatures affect the consumption rate of the buildings in a study by Angelopoulos and Pollalis (2021) while stressing that smart meters implementation can cause a reduction in consumption by 2-8%. In this same study building usage visualization helped in optimizing loads and surveys showed a 15% reduction in consumption.

In research involving the use of energy in diverse buildings, several techniques of data collection are observed throughout investigations. Research, for example, used energy audits and energy conservation analyses to discover that 14% of Malaysia's energy consumption is found in buildings, where HVAC systems contribute the most energy (Birkha Mohd Ali et al., 2021). In a study by Ferrari et al. (2020), using the empirical calculations method it was shown that in Italy the consumption in summer is double that in other seasons signifying the effect and influence of cooling systems on electricity usage.

2.2. Energy Consumption in the GCC Countries

Lin et al. (2018) deduced that 70% of consumption in the UAE is connected to buildings while the other 30% is found in areas like transportation, waste management, etc. by using mathematical methodologies to indicate the influence of AC cleaning. This conclusion was reached after conducting energy audits and subsequently analyzing the data to create an energy index for the buildings. Similarly, Al-Anazi and Almasri (2023) employed the RetScreen and Atlas software packages to collect data, which was then fed into energy efficiency models to analyze the impact of the GCC's unique environment on energy use. According to the study, HVAC is the largest energy user in buildings, and mitigations include renewables and building envelope enhancement. According to the findings of Rauf et al. (2022), the installation of solar solutions in the GCC is expected to boost consumption efficiency by 34-45%. However, Luo et al. (2022) discovered that even during the COVID pandemic the consumption of HVAC remained constant while lighting usage reduced by 50-80%, this data collection and analysis signifies the lack of proper HVAC management.

2.3. Big Data Analytics of Energy Consumption

Henning et al. (2021) investigated the benefits of analyzing energy consumption data in manufacturing such as reporting, optimization, fault detection, and predictive maintenance. Gupta et al. (2020) used a big data-based method, with the major goal being to develop cluster nodes, reports, and models for stakeholders using a distributed cluster architecture that evaluated data using open-source software. Zhao and Yan (2022) also employed a coherent big data technique incorporated into energy consumption analysis, which utilized a 5G network rather than a 4G network. The ZigBee method was used for analysis, which was then compared to predictions made using clusters and neural networks. This resulted in the discovery, among other things, that the thermal conductivity of the outer walls was excessive.

Zhang et al. (2018) and Pérez-Chacón et al. (2018) both used big data approaches, there were some notable differences: Whereas Zhang et al. (2018) implemented an energy management system (EMS) with an architecture framework that resulted in a 3% reduction in consumption. Pérez-Chacón et al. (2018) used an Apache Spark algorithm that feeds into four clustering validity indices producing prediction patterns alone, with optimization solutions to assist in the predictions produced by the algorithm. Pak et al. (2021) took a different approach, consisting of a four-stage process that included data understanding, meteorological data, data processing, and analytics done with R solutions code development. The study discovered that collecting additional data including energy consumption using different approaches would improve the "R solutions" analysis model that processed the relation between energy consumption of houses and the architectural elements of the building.

Both Islam and Hasan (2021) and Kassela et al. (2019) suggest a big data system that provides solutions and predictions respectively being the best approach for today's energy demand and control, stressing the positive effects on energy consumption reduction. Islam and Hsana (2021) hope to see their proposed system implemented on a large scale across the country in a way that facilitates data collection as it has not yet been implemented, but rather just studied theoretically. This will be accomplished by utilizing a unified big data platform from all different government facilities and buildings. Kassela et al. (2019) provide the BigOptiBase system for mobile network base stations such as the 5G base station that experiences high demand and thus high consumption, using radio networks to optimize consumptions using machine learning algorithm, and further extends into being able to function for a natural petrol station as well.

Zhou et al. (2016) presented a comprehensive smart energy management using big data. They considered the smart grid as the research background using a literature review. Zhang and Yang (2021) explain that qualitative data sets lack precise values, making them inappropriate for data processing in big data analysis. The use of both quantitative and qualitative data was suggested as an option. Han et al. (2015) relied on an upgraded data envelopment analysis cross-model to provide more effective decision-making.

2.4. Algorithms

Sarswatula et al. (2022) suggest that the best-performing machine learning algorithm is the Random Forest Regressor as results show high precision, recall, and accuracy. The comparison was done against Multiple Linear Regression, Decision Tree Regressor, and Extreme Gradient Boost Regressor, the best-fit model value noted as "R^2" for Random Forest Regressor was given as 0.869 which was the highest. This finding helped in identifying the best approach to achieving the most accurate data analysis for energy consumption. Another study predicts electrical energy consumption using data science, achieving 92.4% accuracy on train data and 77.4% on test data (Mtolo and Himunzowa, 2023). These findings were found using Microsoft Power BI for visualization. Another big data-driven study, this time by Liu et al. (2020), is based on data mining and emphasizes the importance of utilizing energy systems, specifically integrated energy systems that convert surplus energy into renewable energy.

More specifically, El-Houda Bezzar et al. (2022) findings state that using the XGBoost algorithm for data analysis and forecasting is the best methodology to acquire accurate predictions in the state of the art. When applying the "bottom-up" approach to data models, the system design process commences by addressing individual elements or components. These smaller units are then interconnected in a step-by-step manner, gradually forming larger, more complex functional components. This method offers a structured and modular way to build systems, as it emphasizes the gradual integration of discrete elements into a cohesive whole.

The bottom-up model proved to be the best for long-term predictions as per Gholami et al. (2021). This model helped in analyzing that double-glazed windows and energy-saving lights have no significant reduction in energy consumption.

2.5. Energy Consumption in Universities

Some studies were concerned with energy consumption on university campuses. Ding et al. (2018) used statistical approaches such as OLS, DT, DEA (ordinary least squares, decision tree, data envelopment analysis), and others to generate benchmarks for energy consumption metrics. This study's weakness was that it relied exclusively on basic building information meaning that operating factors were not taken into consideration. Furthermore, the monitoring scope was constrained since it depended on a small number of inputs such as energy and electricity consumption. The introduction of real-time sensors and a web interface yielded instant feedback of a 5-15% decrease in consumption rates in a study by Emeakaroha et al. (2012). Prediction models, which were used in Akbar et al. (2020) study, on the other hand, construct a dependency relationship between energy consumption and two factors. The factors are the weekday index and dry bulb temperature of the area, and using the ANN model analysis shows that the weekday index is the most important variable, followed by the dry bulb temperature. The effects of the weekday index are high on working days, while non-working days have the lowest consumption. On the other hand, an increase in the dry bulb temperature directly increases consumption. Two recent studies confirmed that HVAC was the primary energy user on university campuses (Torres-Navarro et al., 2022; Wei et al., 2022). Furthermore, both studies relied on a prediction model and were optimistic about the possibilities for energy efficiency on university campuses. While Wei et al. (2022) discovered that laboratories consumed 3 to 4 times more energy than conventional buildings, Torres-Navarro et al. (2022) determined that, while regular structures consumed more energy overall, buildings that facilitate research work and lab equipment had a higher energy intensity. Similarly, Hossain et al. (2020) discovered that after using data analysis and collecting several energy patterns, HVAC scheduling can help save energy, and aggressive temperature setbacks during unoccupied times can help reduce base load. Escobedo et al. (2014) got a different finding utilizing energy audits of area vs user behaviors, revealing that 28% of campus consumption was from lights, placing them at the top of the list in his case study. Two more research projects in this area used an analytic and statistical approach, employing surveys and energy audits. The results of the two- researches had different conclusions. Kim et al. (2012) discovered that gross floor space was an important determinant as they deduced a linear relation showing that the unit total area average electricity consumption was 71.34 kWh/m^2 year. On the other hand, Li et al. (2017) discovered that the concerned university's ability to reduce consumption was between 8% and 12% by enhancing the operational or maintenance efficiency of AC systems and that air conditioning equipment was responsible for 50% of the consumption on campus due to low operational efficiency. After examining the benchmark data obtained, Chung and Rhee (2014) concluded that the optimal mitigation lies in windows, insulation, and interior temperature regulation. A corresponding study by Zhao et al. (2021) used the bottom-up model to minimize mistakes in data collection and data analysis. The study showed a maximum error of 54% to within 15% using the mentioned model showing the importance of error control in such studies. In contrast to other studies that used minute intervals for their measurements, Popoola et al. (2018) conducted a study in which data was collected monthly using ICT-driven approaches. The collected data was then analyzed using one-way analysis of variance (ANOVA) to develop consumption trends like differences in means of the energy consumption values and propose potential research in the areas of energy efficiency, campus planning, etc. In comparison to the preceding categories, GCC-specific research is scarce on energy analysis. However, the few studies that exist agree that HVAC is the primary energy user, and have shown a link between outside temperature and energy usage. For example, Jomoah et al. (2013) discovered that HVAC and lighting were the most significant consumers on university campuses in the GCC. Computers in addition to HVAC and lighting, were a large consumer according to Alfaoyzan and Almasri (2023). However, Al Amoodi and Azar (2018) found that human actions like overuse of AC or neglecting proper light management cause ±25% variation in consumption, stating in the end that there is a lack of publicly available data in the UAE.

Kostepen et al. (2020) considered the concept of a smart campus in which the energy consumption is efficient. A road map for a smart campus was described in a university in Turkey. The smart campus was found to be efficient in reducing energy consumption. Another study that considers the smart campus for sustainable development is the one by Villegas-Ch et al. (2019a), where the energy consumption is monitored for any anomaly. This monitoring is important to reduce energy consumption in the smart campus. The framework presented integrates big data analytics. Villegas-Ch et al. (2019b) applied the smart city model to a traditional university campus using big data, where the data acquisition is performed using the Internet of Things. They considered a smart campus to be a good prototype to start implementing the smart cities concept. Wu et al. (2023) proposed an evaluation model to benchmark the campus building energy consumption. The random forest method was used to identify building features that have outstanding contributions to building energy consumption intensity. A study by Yang et al. (2023) used a three-stage strategy to examine the energy consumption patterns and characteristics of college dormitory buildings in China using an unsupervised data mining method. They found different occupants have different consumption rates of energy based on their tolerance for coldness. They found also that the gender of occupants and floor and orientation location of rooms affect the consumption rate. The effect of the pandemic on the electricity consumption of open universities in the Netherlands was investigated in a study by Xu et al. (2023). The strict restriction policy during COVID-19 reduced significantly many buildings' energy consumption. The effect of occupant distribution on energy consumption in a university building was examined in a study by Mokhtari and Jahangir (2021). The HVAC system's energy consumption depends on the number of occupants. A study by Im et al. (2022) developed a model for building energy prediction by using statistical analysis. It shows the influence of climate change on a university campus' energy consumption. They found categorizing buildings by building type is very important. The laboratory buildings are the most consuming buildings.

Kim et al. (2020) found that energy consumption in a university in the UAE is 85% higher than projected owing to multiple consumption gaps in terms of perceived, static, and dynamic gaps caused by the campus's poor control, operation, and scheduling. These conclusions were reached by an ASHRAE energy audit, a POE, and a dynamic simulation model to identify solutions such as using this simulation method to calibrate the active operational management of the AC system to close the gap. In a study by Kumar et al. (2020), an algorithmic technique based on neural network clouds, clustering, and MatLab analysis was developed to prepare pattern analysis on the electricity consumption and helped in classifying them for further studies. Some gaps were addressed by Azar and Al Ansari (2017), such as limited scope of work, lack of data on human actions, and simple and basic data collection methods that don't consider specific variables or relations to consumption.

Factors influencing energy consumption in university campuses based on the literature are multidimensional. Monitoring and real-time feedback mechanisms play a crucial role in achieving an instant 5-15% reduction in consumption rates. HVAC systems consistently emerge as the primary energy user, with studies emphasizing the importance of effective scheduling and temperature setbacks during unoccupied times. Prediction models include weekday indices and dry bulb temperatures are considered important factors. Research facilities and laboratories showed high energy consumption compare with traditional buildings. Adopting smart technologies, efficient energy equipment and monitoring systems could contribute to efficient energy consumption in universities. Behavioral actions, like leaving lights on, also contribute significantly to energy consumption.

2.6. Descriptive Statistics about References of Energy Consumption in Universities

From the 60 studies investigated in this research, 29 were found about campus buildings. Figure 2 shows the countries of studies. Three studies did not determine the place of the studies, and therefore, they are counted as "general." According to Figure 2, the topic of energy efficiency in universities is analyzed in several countries but the number of research articles on this subject is limited. Despite the varied levels of research activity in this field, analysis of references on energy consumption in universities over the specified years shows clearly that this topic gained more attention in the last 4 years as illustrated in Figure 3. Researchers used a diverse range of methodologies in analyzing energy consumption in universities as shown in Figure 4. Big data and data analysis are the most frequent used method. This can be attributed to the importance of statistical techniques and quantitative approaches to analyze and interpret energy consumption patterns in universities. A focus on forecasting future energy trends and behaviors within universities using predictive models is considered one of the most important methods in analyzing energy in universities. Other methods such as field survey, simulation and machine learning gained almost the same attention from researchers.

Figure 3 shows the dot plot representing the number of references over the years. Most of them are very recent.

Figure 4 shows the methodologies used in the 29 references about energy consumption in universities.

Table 1 shows the 29 references used in this study about energy consumption in universities. It is important for the studies to be from different countries on different continents with different weather conditions to provide general results that can be utilized everywhere.

Figure 2: Number of references about energy consumption analysis of universities

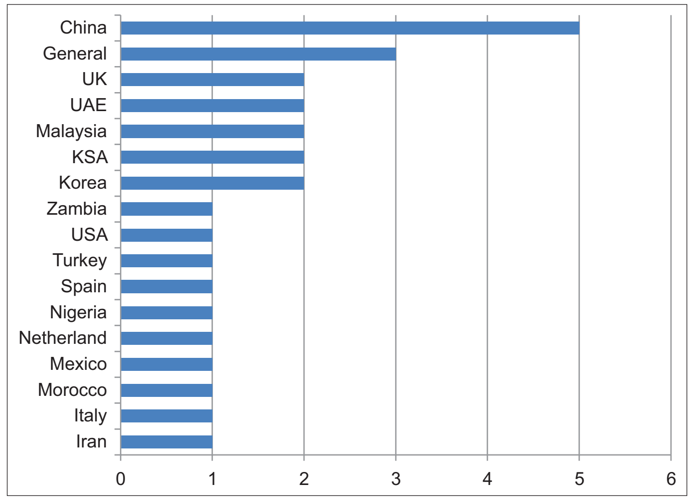


Figure 3: Number of references about energy consumption in universities per year

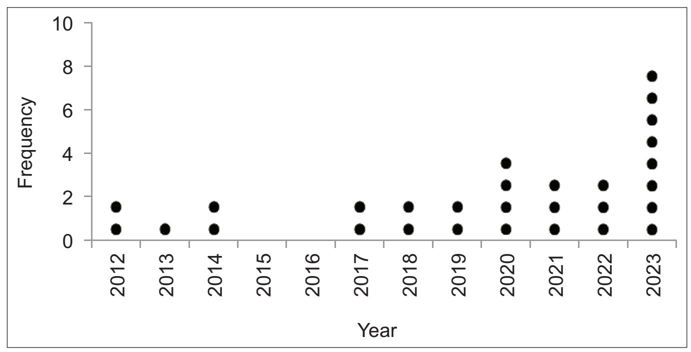
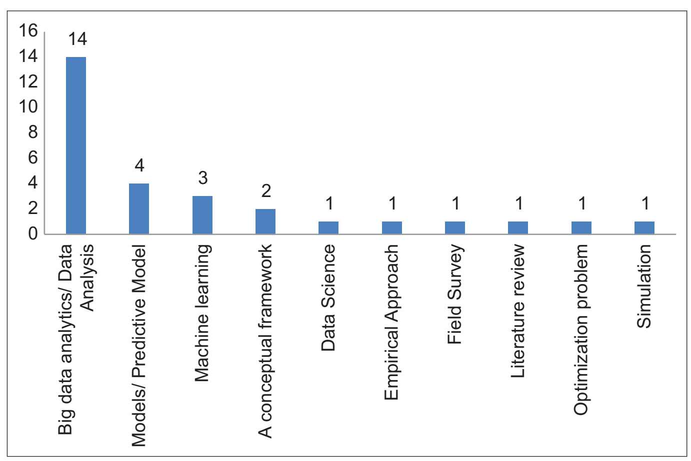


Figure 4: Different methodologies of the references about energy consumption of universities



3. ANALYSIS OF FINDINGS

Figure 5 shows the word cloud of the most important terms in the 29 references about energy consumption in universities. The

Table 1: Previous studies about energy consumption in universities

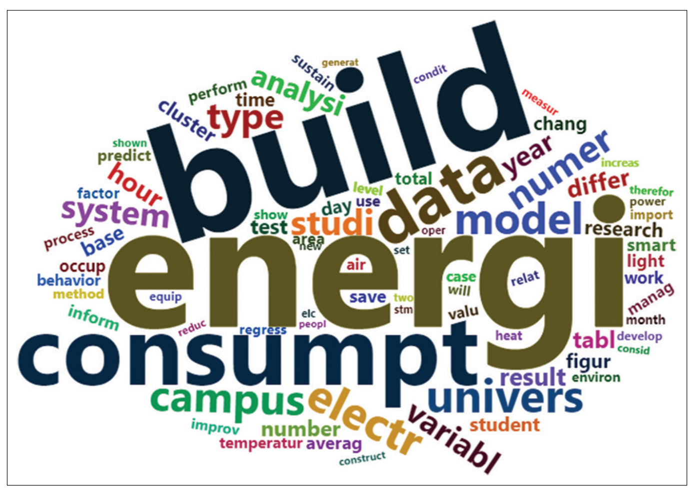
Study	Region/ country	Field of research	Used methodology
Akbar et al. (2020)	UK	Academic building electricity consumption	Predictive model
Alfaoyzan and Almasri (2023)	KSA	Energy consumption benchmarking for sustainability	Data analysis
Azar and Al Ansari (2017)	UAE	Building occupants' energy conservation motivations and actions.	Data Analysis, Survey
Birkha Mohd Ali et al. (2021)	Malaysia	Building's energy consumption and potential savings.	Models
Chung and Rhee (2014)	Korea	Potential opportunities for energy conservation	Field Survey
Ding et al. (2018)	China	Analyzing campus building electricity consumption benchmarks.	Data Analysis
Emeakaroha et al. (2012)	UK	Challenges in enhancing university campus energy efficiency using persuasive technology.	Data Analysis, Real-Time Data Interface
Escobedo et al. (2014)	Mexico	Energy consumption and GHG emissions scenarios.	Data Analysis
Ferrari et al. (2020)	Italy	Evaluating tertiary building electricity consumption.	Empirical Approach
Faiq et al. (2023)	Malaysia	Prediction of energy consumption	Data Analysis
Im et al. (2022)	USA	Energy prediction models	Statistical analysis
Jomoah et al. (2013)	KSA	Installation of an energy management system	Data Analysis
Kim et al. (2012)	Korea	Survey and Analysis of Energy Consumption	Data Analysis
Kim et al. (2020)	UAE	Analysis of energy performance gap.	Simulation
Kostepen et al. (2020)	Turkey	A road map for founding a smart and sustainable campus	A conceptual framework
Laasri et al. (2023)	Morocco	Energy optimization	Data analysis
Li et al. (2017)	China	Energy consumption data analysis.	Data analysis
Mokhtari and Jahangir (2021)	Iran	Optimum occupant distribution patterns	Optimization problem
Mtolo and Himunzowa (2023)	Zambia	Predicting Electrical Energy Consumption	Data science
Popoola et al. (2018)	Nigeria	Presenting data on energy consumption	Data analysis
Quevedo et al., (2023)	Brazil	Energy Benchmarking	Machine learning
Torres-Navarro et al. (2022)	Spain	State of the art about electricity consumption	Literature review
Villegas-Ch et al. (2019a)	General	Big data framework in a smart campus	Big data analytics
Villegas-Ch et al. (2019b)	General	Applying a smart city model to a traditional university campus	A conceptual framework
Wei et al. (2022)	China	Building load forecasting model.	Models
Wu et al. (2023)	General	Determine the features of buildings that affect energy consumption	Machine learning
Xu et al. (2023)	Netherland	Effect of COVID-19 on energy consumption in campus buildings	Statistical analysis
Yang et al. (2023)	China	Analyze the energy consumption patterns and influencing factors	Machine learning (Clustering)
Zhao et al. (2021)	China	Energy consumption prediction model.	Models

figure shows the importance of big data analytics, models, cluster analysis, and sustainability. By investigating the words which are associated with the word "reduce," the first word was "design." That means better designs will lead to energy reduction.

Figure 6 shows the cluster dendrogram of the terms of two words. It shows the concepts that are usually mentioned together in the same context. For example, the two concepts "air conditioning" and "energy efficiency" are associated with each other. This relationship shows the importance of managing air conditioning in a way to better enhances the efficiency of the energy consumption on campus.

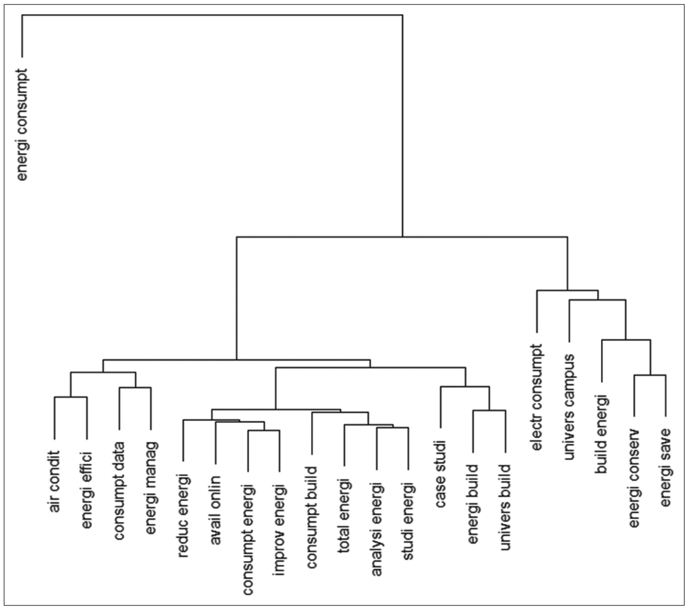
After reviewing the 60 studies it is understood that the field of energy consumption in buildings is a recent interest for all researchers and as it is trending as a hot topic in this community, many different methodologies are being tested to enhance the consumption. Although it is being approached in different manners, the fact that it has the potential in being able to prove capabilities of increasing efficiency and reducing consumption still shows regardless of the categorization of the building. Moreover, the studies demonstrated through the conducted research that the most suitable candidate for implementation of any such method, of reducing consumption is indeed the university campus buildings, due to their position as a learning and development institution. Figure 5 shows different methodologies used to analyze energy consumption in universities. The importance of big data analytics and machine learning is very clear. Nevertheless, the variation in

Figure 5: Word cloud of the literature about energy consumption in universities



methodologies used from models, algorithms, simulation, big data, and others only explains that there are no restrictions to the way of addressing this topic. In fact, this demonstrates the flexibility of the matter of consumption in terms of studies. On the other hand, the most recent findings did share common grounds specifically: The use of big data, the utmost need for data analysis, and the major effect of summer and occupants on consumption. Moreover, big data is a strong tool to use when tackling this topic of research, but the most important thing as shown in the study is, the availability of large data inputs in order to formulate solid results.

Figure 6: Cluster dendrogram of two-word concepts in the literature



Many of the results make sense but some of the results were unexpected when looking back at the studies, such as double-glazed windows and power-saving lights having a negligible effect on consumption (Gholami et al., 2021), more smart devices in a building resulting in higher consumption of electricity (Barakhnin and Danilov, 2021), old school buildings being less consuming than new ones due to the lack of smart devices being implemented in such buildings (Torres-Navarro et al., 2022), finding no correlation between location of the building, number of floors, number of lifts, floor area respectively with the energy consumption of the building (Ahn et al., 2017). While these findings are true in the circumstances of each of their respective study but rather unexpected.

To any expert or fresher that is aiming to engulf in this field we recommend exploring the possible methodologies and then finalizing on one that suits the particular study since there exists a number of approaches in this field and more are emerging with time. Additionally, keeping up with the state of the art is crucial because of the young age of this field much new information is developing quickly so it is highly recommended to do so.

To summarize, the following results were found generally in all types of buildings:

- Many studies focused on finding energy anomaly detection
- Many studies focused on finding high-prediction quality
- HVAC systems contribute the most energy, even during the pandemic
- 70% of consumption in the UAE is connected to buildings
- Big data analytics of energy consumption has many advantages in the industry
- The thermal conductivity of the outer walls affects energy consumption
- Machine learning and data mining are very helpful in big data analytics
- The bottom-up model is useful for long-term predictions.

Some results are particular to campuses such as:

- Methods such as OLS, DT, DEA, and ANN are very important for data analysis of energy consumption
- HVAC is the primary energy user on university campuses, and HVAC scheduling can help save energy
- The number of occupants determines how much energy HVAC systems consume
- GCC universities were energy-intensive in terms of HVAC and lighting
- Research buildings and lab equipment have a high energy intensity
- It was found that 28% of campus consumption was from lights, making them the most energy-intensive component.
- Enhancing the operational or maintenance efficiency of AC systems can reduce energy consumption by 8-12%
- There is a large variation in consumption due to human actions such as overusing AC or not managing light properly
- COVID-19's strict restriction policy reduced the energy consumption of many buildings significantly
- Energy consumption is reduced on smart campuses. Energy consumption monitoring is important to achieve that
- The smart campus is a good prototype to start implementing the smart cities concept
- The gender of occupants and floor and orientation location of rooms affect the consumption rate
- The restriction policy of COVID-19 reduced many buildings' energy consumption
- Classifying campus buildings by building type is very important
- Control, operation, and scheduling of the buildings can lead to energy consumption savings

Several limitations were mentioned in the previous research such as the following:

- Some studies considered factors affecting consumption, but they did not include operating factors or they depend on a small number of inputs
- In some studies, human actions were neglected.

The following factors were found to reduce the energy consumption:

- Climate and external temperatures
- Building usage visualization
- Energy management system
- Optimal mitigation considering windows, insulation, and interior temperature Regulation Weekends
- Gender (females consume less energy).

In some studies, the following factors did not affect the energy consumption:

- Building age
- Policies and regulations such as peak time scheduling
- Number of floors, number of lifts, and floor area.

The above factors open the door for future research because they can have different effects from one study to another. There are some factors that increase consumption in one case study but decrease it in another. For example, smart devices in a building can increase consumption (Barakhnin and Danilov, 2021), but the use of smart meters can decrease consumption because of the monitoring capability they offer (Angelopoulos and Pollalis, 2021). Gross floor space was found an important factor in a study (Kim et al., 2012), but it was not important in another one (Ahn et al., 2017). The location of the apartment was found important in a study (Yang et al., 2023) but not important in another one (Ahn et al., 2017). Such factors need more investigation in future research.

Following all the studies and their results, some gaps were still found that should be addressed in the future, such gaps were the lack of variables considered, lack of availability of data either in terms of building usage history or public data, no explanation or reasoning for some the findings and having no clear action plan based on the findings of some studies for instance, stating the need of building management and scheduling or recommending the implementation of renewables for devices such as HVAC or enhancing insulation work to control temperature and hence the consumption etc. In the future it would be better if such studies are immersed in the entirety of the case study, meaning that all data and variables be taken into consideration even the smallest inputs such as data on occupants and their activity schedule, history of modification work done on the building, location, and geometry of the building, overall, all data besides the consumption and hence a course of action to be specified on how to use these results to enhance the consumption. However, the major gap in this field lies in having a very small number of studies done on university campuses and even fewer in the region of GCC specifically. Future research in the UAE can utilize such research depending on case studies about university campuses to identify the factors that cause high energy consumption such as building material or insulation, occupants' behavior, HVAC capacity, and schedule, and address them, this should stand as an opportunity to explore this region and develop new findings. Finally, we suggest the implementation of various techniques such as modeling, simulation, visualization, Big Data analytics, algorithms, and extensive data analysis simultaneously to compare their respective results aiming to identify a common issue to be addressed by our study in more depth.

Regarding this field, policymakers and countries should implement some sort of mandatory regulation in all buildings to accommodate a system of energy consumption analysis that provides annual reports that assist the government in monitoring and applying guidelines for all buildings. More importantly, this will be handy for all research since buildings will already have large amounts of data previously, some sort of setup will also be ready and it will be a good way of raising awareness about this field.

4. CONCLUSION

In this study, we investigated the importance of tracking energy consumption in general and consumption in campuses in particular using a literature review. We classified the literature and concentrated on the studies held in the GCC area that has hot weather. Many results were obtained about the methodologies used for such an analysis such as big data analytics, classification using machine learning, and mathematical modeling. More results about the purposes and benefits of analyzing data on energy consumption. One important direction is to find the most important factors affecting energy consumption such as building design, data consumption visualizations, number of occupants, behavior of occupants, and others. The importance of HVAC was highlighted as the most important energy consumer, especially in the GCC countries. Lights were generally found important, but their importance was different from one study to another depending on the country in which the study was held. Moreover, the type of building in the universities was very important as a factor affecting the level of energy consumption.

Research and labs buildings were found to be the most important energy consumers and therefore they should be better designed and monitored closely. Different directions were found and sometimes contradicting results were obtained between different studies. This opens the door for future research. Limitations in some studies were also found such as operating factors and human actions. Decision makers should contribute to the concept of energy savings by making policies that save energy such as certain isolators in the buildings.

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