Analysis Existing Mosque Buildings in the UAE

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According to the World Economic Forum, the building sector is responsible for 40% of global energy consumption and 33% of greenhouse gas (GHG) emissions, and this is expected to increase due to population growth and the subsequent impact on the environment, economy and health. To tackle the problem, countries have set new construction codes, policies and regulations for the construction of new buildings in an effort to make them greener. However, there is a need to enhance the status of the existing buildings, especially mosques, as they are the main contributors to energy usage and water consumption in the United Arab Emirates (UAE).

Keywords: energy ; mosques ; electricity ; consumption

1. Introduction

Over the last two decades, the consumption of energy around the world has increased by 49% and CO_2 emissions have increased by 43%, with an average yearly rise of 2% and 1.8%, respectively, due to the rapidly increasing global energy use that has sparked worries about supply issues, energy resource depletion and the severe environmental consequences. As a result, the worldwide contributions to energy consumption by buildings, both residential and commercial, has gradually grown and has surpassed the other main sectors: transportation and industry [1]. Moreover, population growth, a rising demand for building services and comfort levels and an increase in time spent within buildings, especially with the outbreak of COVID-19, all suggest that the increase in energy and water consumption will continue. As a result, energy efficiency in buildings is now a top priority for energy policy makers at the regional, national and international levels [2].

2. Improving the Energy Efficiency of Existing Buildings

Globally, 40% of energy is consumed by the building stock, and it releases one-third of the total GHG emissions [3]. Therefore, improving the energy efficiency of buildings is essential for tackling climate change and achieving net zero-energy. This has been the focus of several recent studies focusing on existing buildings that have tackled customer needs but increased their energy insufficiencies. Accordingly, all stakeholders need to collaborate to improve building performance. The basic actions to be considered to decrease energy usage in buildings include mechanical solutions, such as changing the heating, ventilation and air conditioning system (HVAC) and using natural ventilation for cooling, in addition to installing automated lighting systems or upgrading the building envelope. It is worth mentioning that each suggested solution for improvement comes with its own benefits and drawbacks, which create the need to evaluate such measures in real setups and not just rely on the proposed theoretical solutions.

All buildings, from the tiniest school to the highest skyscraper, rely on energy provided mostly by the combustion of fossil fuels. The combustion of fossil fuels emits GHG into the atmosphere, contributing to the problem of climate change. Worldwide, the building sector consumes electricity more than any other sector [4]. With rising urbanization, particularly in developing nations, the number and size of buildings in urban areas will grow, resulting in a greater need for electricity and the other kinds of energy widely utilized in buildings.

Studying the nature and structure of energy usage in buildings is critical for developing the appropriate future energy and climate change strategies. The literature reports how to improve buildings' energy operations, while assessing the advantages and disadvantages of energy efficiency improvement initiatives, such as energy conservation measures (ECMs). Such examples illustrate the possibility of implementing a framework to improve buildings' energy operations and to provide policy and decision makers with better solutions to tackle insufficient energy usage in the building sector. Whether these frameworks are applicable at the level of the United Arab Emirates (UAE) remains to be further addressed and evaluated. Nonetheless, the study and evaluation of implementing ECMs in warmer climates, such as the UAE, remains a gap in literature [5], as most of the existing studies are focused on improvements in the building envelopes in colder or mild climate regions. Therefore, the proposed study focuses on the existing mosques within the UAE and provides input to address the effectiveness of implementing ECMs in reducing energy consumption and the carbon footprint.

3. Energy (Electricity), Water Consumption and Buildings

According to the 2022 Global Status Reporting for Buildings and Construction issued by the United Nations Environment Program [6], the global energy demand reached around 135 Exajoule (EJ) in 2021, showing an increase of 4% compared to 2020 due to businesses resuming normal operations and buildings being operated more intensively than during the COVID-19 pandemic. Overall, the building energy demand, which included residential, non-residential and building construction industry, reached 34% of the total global energy demand in 2021. On the other hand, operational energy-related CO_2 emissions from buildings reached around 37% of the global CO_2 emissions in 2021, and showed an increase of around 5% compared to 2020, which indicates that the overall energy efficiency of existing buildings has not seen significant structural changes.

Within the context of the UAE, the State of Energy Report issued by the Ministry of Energy and Infrastructure in 2019 [7] shows that the UAE is moving toward a reduction in energy consumption to protect the environment by reducing the consumption of electricity, as the country relies on consuming natural gas to generate more than 90% of its power to meet the demand. The UAE is currently shifting towards employing other resources for electricity generation, such as renewable energy, but the current situation shows a high electricity demand, mainly due to a high consumer per capita rate and a population increase, coupled with economic growth.

Moreover, the latest available statistical report, issued in 2019 by the UAE's Ministry of Energy and Infrastructure [8], shows that the energy sector has experienced an upward trend in terms of increasing the energy generation. Abu Dhabi has produced the highest amount of energy amongst all the UAE emirates, as per the data obtained from the Department of Energy (DOE), followed by Dubai, as per the Dubai Electricity and Water Authority (DEWA). The next highest was Sharjah, according to the Sharjah Electricity, Water and Gas Authority (SEGWA), and lastly, the rest of the emirates, as per the Federal Electricity and Water Authority (FEWA). In terms of energy consumption, the report also shows the increase in the overall energy consumption in the UAE from 2016 until 2018, which is a reflection of the increase in energy generation.

In terms of carbon emissions, the report also highlights the contribution of several sectors, such as electricity and water production, along with the manufacturing industries and construction. Overall, the carbon emissions seem to have declined in the manufacturing and construction sectors, whereas they have increased over the period of 2015–2018 in the electricity and water sector, further confirming that the increase in energy consumption has led to an increase in electricity generation.

Regarding non-commercial buildings, such as mosques, it was reported through the Annual Statistics 2021 Report of DEWA [9] those non-commercial buildings consumed 7.44% of the total electricity consumed in 2020, equivalent to 3304 GWh, in addition to consuming 7.15% of the total water consumed in 2020, which is equivalent to 31.16 million cubic meters (m^3). As the vast majority of the UAE's population are Muslim, mosques, the holy place for worshipers in the Muslim community, are considered a major contributor to the UAE's water and electricity consumption. There are approximately 9083 mosques, as per the latest counts reported in 2020 [10].

4. Contributing Factors to the Inefficient Use of Energy in Existing Buildings in the UAE

The UAE has seen an increase in the number of buildings constructed, as reported by the latest statistical federal report released in 2022 by the UAE's Ministry of Energy and Infrastructure [11]. The total number of federal buildings constructed in 1971 was 37, which increased to 805 in 2000 and then began to decline, reaching 96 in 2019. The previous numbers indicate that the initial increase in federal buildings was necessary to drive the progress of the country, but after a period of time, the number of new buildings decreased upon satisfying the intended purpose of their construction. Moreover, when considering the local governments of the emirates, Dubai has seen an increase in the total number of constructed buildings, (i.e., residential, commercial, industrial, investment or private villas) from 121,584 in 2015 [12] to 160,128 in 2019 [13], which further shows that the growth of the construction sector is associated with a higher rate of energy consumption. Accordingly, the need to retrofit such buildings may arise after observing the energy consumption rates and realizing the potential for savings in terms of the cost and environmental impact.

Energy can be wasted in buildings due either to the buildings' designs [14][15] or the occupants' behaviors [1][16] within the building.

Previous studies have addressed the factors mentioned above. For instance, a simulation of the energy performance of a single-family two-story villa in Dubai [17] showed 23% energy savings upon applying insulation, while another study [18] revealed that AC cleanliness and chiller condition significantly impacted the energy use levels in mixed-used buildings in Abu Dhabi, UAE, further emphasizing the importance of tackling the parameters related to human behavior. Furthermore, a study on the electricity consumption per capita targeting 36 residential units and 15 villas in Abu Dhabi revealed the possibility of energy savings either by one or more of the following measures: adjusting the AC thermostat temperature to 24 °C; switching off the AC; switching off the domestic water heating system; retrofitting vials with roof insulation [19]. Overall, it seems that studies have focused on residential villas, but little is known regarding other types of buildings, such

as commercial or industrial buildings, and particularly mosques, within the UAE. There must be a focus on improving the operation of existing buildings through much more detailed studies with bigger scopes and realistic improvement measures, rather than suggestions or measures fitted for the design-stage of buildings.

5. Energy Efficiency and Conservation Actions in the UAE

In light of the UAE's Agenda for 2050 and the target of reducing the contribution of hydrocarbons, both in the overall energy sector and in electricity generation in particular, several initiatives have been taken to further diversify the energy sector and to tackle the reduction in energy consumption [20].

6. Sustainability and Energy-Efficiency Strategies

When it comes to policy and decisions makers [21], some general recommendations for setting up strategies could be formulated, as follows:

- Consider solar shading devices for windows and doors;
- Replace existing windows with high-performance windows appropriate for the climate and exposure;
- Reduce heating and cooling loads through alternatives such as natural ventilation and fresh air intake;
- Evaluate the optimum performance of energy and water systems by recommissioning to minimize consumption;
- Achieve the optimization of resources by reusing or recycling construction waste and demolition debris;
- Apply HVAC, daylight and lighting sensors in the appropriate places within projects upon an evaluation of the occupancy pattern;
- Install smart or submeters for electric, gas, water and other utilities for real-time consumption monitoring, demand control and increase accountability (cost control).

Overall, whether the previous strategies would be effectively implemented within the context of the UAE remains a subject for further evaluation, taking into consideration the climate, nature of buildings, residents' behaviors and other factors. Such an evaluation could be addressed through studies conducted on a large scale by including a significant number of buildings from different sectors (residential, industrial and commercial) and focusing, in particular, on existing buildings or recently established buildings that will have a long life cycle and be more eligible for maintenance or improvements compared to older buildings, which would reduce efforts and cost and improve the ultimate results.

7. Mosques in the UAE and Energy Consumption

The building sector in the UAE consists mainly of residential, commercial and industrial buildings. Among them, around 9123 mosque buildings currently exist in the different emirates [22], with 2305 mosques located in Abu Dhabi, 2154 mosques in Dubai, 2813 mosques in Sharjah and the remaining 1851 mosques distributed throughout the emirates. Such a huge number of mosque buildings must have a high consumption of energy, therefore resulting in high CO_2 emissions and a need for the implementation of proper energy conservation measures to improve their energy efficiency and lessen their negative impact on the environment.

Mosques are considered to be part of the non-commercial building sector. Moreover, mosques are known for their high consumption of energy, particularly due to two main factors: HVAC systems as the top factor, followed by lighting [23]. In addition, energy use in buildings is generally attributed to the characteristics determined through the construction and operation processes; therefore, it is crucial to evaluate the energy usage of any building throughout the different stages of its life, such as the design, construction and operation. For Mosques in particular, other social factors can contribute to the inefficient use of energy, such as the behavior of mosque visitors (similar to the behavior of school students, as mosques and schools are both considered educational places). Visitors might not be aware of how their actions affect the energy efficiency of the mosque, such as using the lights all the time when natural sunlight could be a substitute or turning on the AC during colder weather when natural ventilation could be an alternative.

8. Energy Performance Index (EPI), Energy Conservation Measures (ECMs) and Water Unit Intensity (WUI)

Energy conservation measures (ECMs) are known mainly as technological resources that can be implemented to improve the energy performance of a building [24], with the aim of reducing the consumption of energy caused by a process, a certain technology used or an installation. There are several types of ECMs, such as passive (reducing energy needed to heat or cool a building), active (replacement of HVAC energy supply components with better-performing options), renewable (employing renewable energy resources to reduce carbon foot print) and control (reprogramming start and end times for energy systems).

ECMs can also be categorized into the following groups [25]: building envelope, energy recovery ventilation, ground source heat pump systems, lighting, advanced controls, efficient refrigerant systems, radiant systems, fault detection and diagnostics and plug loads, with the most commonly used ECMs being high-performance building envelope (better insulation), HVAC control and lighting controls. These types of ECMs can be observed in buildings in general, such as residential or commercial buildings, and some are applicable in the case of mosques. As AC systems remain turned on most of the time while using mosques, switching to more efficient systems could reduce the energy demand of mosques while maintaining the occupants' comfort [26].

To further assess energy usage, certain indicators can be applied, such as the energy performance index (EPI) [27]. The EPI can be calculated by dividing the energy consumption of any building by a factor or a standardized reference of comparison, as this representation of energy usage determines the accuracy of the index. In addition, it is not sufficient to rely on the value of energy usage throughout the year as an indicator for energy performance. Therefore, the use of a single factor for normalization (for example, area of a building) can address the variations in type or location. Such an index can be measured to indicate the "specific consumption" by dividing the energy consumption over the area (kilowatt-hours per square meters or m^2) and may not yield values with normal distribution all the time. Nevertheless, it is still considered to be a good indicator for energy-efficient buildings.

Water usage can also be assessed in several ways, one of which is the water unit intensity (WUI) [28], which can be defined as the rate of water use in a specified area. The WUI reflects the amount of water that a building needs during its operation, eventually enabling the sustainable allocation of water resources and proper management over time, and it can be calculated by dividing the consumed water (in m^3) over the total area (in m^2) per year.

9. Mosques' Energy Consumption and Carbon Foot Print

Regarding the building sector and its contribution to carbon emissions, particularly CO_2, the Abu Dhabi State of Environment Report shows that the CO_2 emissions produced by electricity consumption were 0.42 kg of CO_2/kWh [29]. As the levels of CO_2 are increasing faster than the population, the values of CO_2 emissions remain the main indicator of the GHG emissions, fueling the need to properly assess its significance in the building sector. The main activity contributing to the increase in CO_2 emission is the production of public electricity, which is a major factor in operating buildings, including mosques.

Overall, the reviewed literature addressed the main aspects of energy consumption in the building sector and highlighted the importance of addressing energy efficiency in the building sector, with a particular focus on mosques, due to the lack of literature related to the matter. The literature review discussed the most important measures for assessing the energy performance in buildings, including the EPI, and its relation with the ECMs that can be implemented to improve the energy usage in buildings, as well as the resulting reduction in CO_2 emissions, which contributes to environmental sustainability. The literature review also discussed the importance of measuring the WUI to assess the water consumption status in mosques.

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