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Reducing Energy Demand in High-Rise Buildings: Integrating Passive Design and Solar Energy in Almoayyed Tower, Bahrain

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Abstract **—** This paper examines the potential for energy conservation in Bahrain's architectural landscape by focusing on the Almoayyed Tower, the Kingdom's first skyscraper. As electricity demand in Bahrain rises—driven largely by cooling and HVAC systems—there is an urgent need for high-efficiency building envelopes [1]. This study investigates the integration of passive design measures and renewable energy technologies, specifically Building-Integrated Photovoltaics (BIPV). Through simulation using DesignBuilder, the research evaluates how high-performance glazing and solar integration can reduce energy consumption. Findings indicate that a comprehensive envelope retrofit can reduce annual energy use by 20-30%, potentially generating 3 million kWh of solar electricity annually and reducing CO2 emissions by approximately 3,000 tons [2].

Keywords — Energy Conservation, Almoayyed Tower, Sustainable Architecture, Bahrain, Building Envelope.

I. Introduction

Global energy demand in the building sector has increased rapidly over the past decades. Buildings are responsible for nearly **one-third of global energy consumption and about 40% of resource use worldwide** [3] . As a result, improving building energy efficiency has become a key strategy for reducing greenhouse gas emissions and addressing climate change [4].

In the Gulf region, the hot climate creates extremely high cooling demand. Air-conditioning systems are therefore the main source of energy consumption in most buildings [5]. As cities continue to grow and more high-rise buildings are constructed, improving building efficiency has become an important priority. The design of high-rise buildings in the Gulf has changed over time through several architectural phases:

1) *Early architecture phase:*
Earlier towers were typically designed with solid façades and limited openings, reflecting traditional construction approaches and provided some protection from the harsh climate.

2) *Later phase – rapid economic growth:*
During periods of rapid economic growth, many buildings adopted fully glazed curtain wall systems. These façades created a modern architectural image and allowed more daylight and external views. However, large glass surfaces often increase solar heat gain, which leads to higher cooling loads and energy consumption in hot climates [6], [7].

3) *Contemporary phase – sustainability focus:*
Today, there is increasing attention toward environmentally responsive architecture that considers climate conditions and energy efficiency. In Bahrain, sustainability strategies are gradually being introduced to reduce energy consumption and environmental impact. Retrofitting existing buildings has therefore become an important approach to improving the energy performance of the built environment.

This study investigates the **potential for improving the energy efficiency of Almoayyed Tower,** one of the most recognizable high-rise buildings in Bahrain. The research explores how combining passive design strategies with renewable energy technologies can enhance the building's environmental performance. In particular, the study examines how façade improvements and solar energy integration can reduce energy demand while maintaining the building's architectural identity.

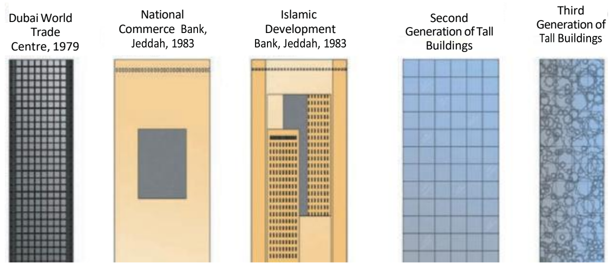

Fig. 1 Three Generations of tall buildings in the Gulf Region.

Fig. 1 show the more solid façade design in the first generation, while the second generation proposed full transparency. The third generation combines glazing and shading technologies in façade design.

II. PROJECT OVERVIEW

The Almoayyed Tower, completed in 2004, and is located in the Seef District in Manama, Bahrain, as showing in (**Fig. 2 and Fig. 3**). The tower rises to approximately **172 meters** and has a total built-up area of about **48,419 square meters**. The building mainly consists of office spaces and commercial facilities.

The tower's structural system includes a **reinforced concrete central core** combined with composite **steel beams**, which provide stability for the high-rise structure. The exterior façade is designed as a **curtain wall system** with reflective blue glass, which gives the tower its modern appearance.

Although the glass façade provides natural light and aesthetic value, it also allows significant solar radiation to enter the building. This increases indoor heat gain and leads to greater reliance on mechanical cooling systems. As a result, the building consumes a large amount of electricity for air-conditioning.

Because of these characteristics, Almoayyed Tower provides a suitable case study for examining how energy-efficient retrofitting strategies can improve the performance of existing skyscrapers.

Fig. 2 show site plan and 3D of AlMoayyed Tower with the surrounding, Source: Google earth

Fig. 3 show the building in bigger scale to show the entrance and materials used of Almoayyed Tower with the surrounding, Source: Google earth

Table 1 Energy and Buildings. Source: N.W. Alnaser et al.

Table 2
Monthly sums of incident solar radiation on surfaces at different tilt angle in Manama, Kingdom of Bahrain

Monthly sum of solar energy (kWh/m²)

Month	Surface slope (s)			
January	102.7	116.9	128.5	137.1
February	130.8	143.5	153.0	159.2
March	134.7	140.3	143.2	143.3
April	166.9	168.5	166.8	161.8
May	167.2	165.2	160.2	152.3
June	180.7	176.8	169.7	159.5
July	164.2	161.7	156.3	148.2
August	159.5	160.3	158.0	152.6
September	156.9	162.6	164.8	163.8
October	129.0	138.9	145.8	149.6
November	118.8	134.1	146.3	155.2
December	93.8	106.0	115.9	123.3
S	1705.2	1774.7	1808.4	1805.9

Table 3
Monthly sums of incident solar radiation on surfaces at specified tilt angle (16s, for summer setting), (26s, for fixed setting), and (36s for winter settings) facing south, in Manama, Kingdom of Bahrain

Monthly sums of the incident solar energy (kWh/m²)

Month	Surface slope (°)		
January	124.2	134.0	140.8
February	149.6	157.1	161.2
March	142.4	143.6	142.0
April	167.9	164.2	157.4
May	162.5	155.8	146.3
June	172.9	163.9	152.0
July	158.8	151.7	142.1
August	159.2	155.1	148.1
September	164.3	164.6	161.6
October	143.4	148.5	150.4
November	141.8	152.1	158.8
December	112.2	120.7	126.5
S	1799.2	1811.3	1787.1

Bahrain receives strong solar energy throughout the year, making photovoltaic (PV) panels very effective for buildings like Almoayyed Tower. The data shows that the best orientation for maximum electricity production is south-facing panels tilted at 26°—which matches Bahrain's latitude. South-facing PV at 26° tilt gives the highest annual output: 279.2 kWh/m² per year, as shown in (**Table 1**). The study also examined solar energy on vertical surfaces—useful for façade-integrated PV. Annual insolation (kWh/m²/year):

- West: 1158.4 → 175.3 kWh/m² electricity (highest among facades)
- South: 1124.8 → 163.9 kWh/m²
- East: 870.3 → 124.9 kWh/m²
- North: 622.4 → 89 kWh/m² (lowest; usually not recommended)

Total PV Potential for Almoayyed Tower Combining roof + facades:

- Total yearly solar electricity: ≈ 3,017,500 kWh
- Daily average: ≈ 8,219 kWh/day

Enough to power around 171 houses (based on 2 kW/home).

III. PASSIVE AND ACTIVE ENERGY STRATEGIES

Improving the energy efficiency of high-rise buildings often requires a combination of passive design solutions and renewable energy technologies. Passive strategies help reduce the need for mechanical cooling, while renewable energy systems provide clean electricity. To optimize the performance of the Almoayyed Tower, the following three strategies are proposed:

1) *High-Performance Envelopes:*
Utilizing well-insulated and airtight building envelopes is a fundamental step in reducing thermal gain. Implementing these measures can lower the overall cooling demand by 30-50% [6], as shown in (**Fig.4**).

2) *Smart Glazing:*
The application of advanced Electrochromic glass allows for the real-time control of sunlight and glare. By adjusting to external light levels, this technology can reduce cooling energy consumption by up to 20% and artificial lighting requirements by as much as 60% [1].

3) *BIPV Integration:*

Replacing standard glazing with ASI Glass modules allows the facade to generate electricity while providing essential shading for the interior [7].

By integrating these passive and active elements directly into the building, the tower can produce renewable energy without compromising its design aesthetic, as showing in (**Fig. 5, and Fig. 6**).

To evaluate these strategies, building performance simulations were conducted using **Design Builder software**. The results show that upgrading the building façade and integrating photovoltaic panels could significantly reduce energy consumption. The simulation results indicate that these improvements could reduce total energy use by around **20–30%.** In addition, the photovoltaic system could generate approximately **3 million kWh of electricity each year.** These measures could also reduce carbon dioxide emissions by nearly **3,000 tons annually,** supporting Bahrain's sustainability goals [8].

Overall, the results demonstrate that improving the building envelope and integrating renewable energy technologies can significantly enhance the environmental performance of existing high-rise buildings.

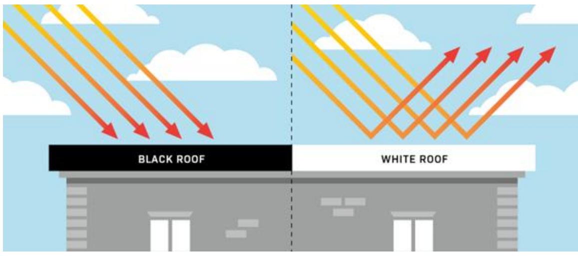

Fig. 4 Heat Reflective White Color Roofing. https://constrofacilitator.com/heat-reflective-materials-driving-energy-efficiency-in-buildings/.

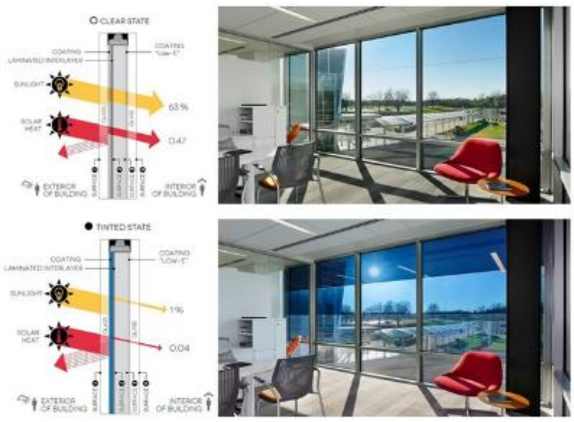

Figure 5The effect of EC glass in the indoor environment. Source: https://stavba.tzb-info.cz/zaskleni/23317-nove-technologie-bezpecnost-a-ekologicke-aspekty-v-oboru-stavebniho-skla.

Fig. 6 Electrochromic glass in indoor environment. Source: https://www.energy.gov/eere/buildings/articles/better-windows-better-outcomes-how-electrochromics-improve-health.

SUN EXPOSURE PERCENTAGE %

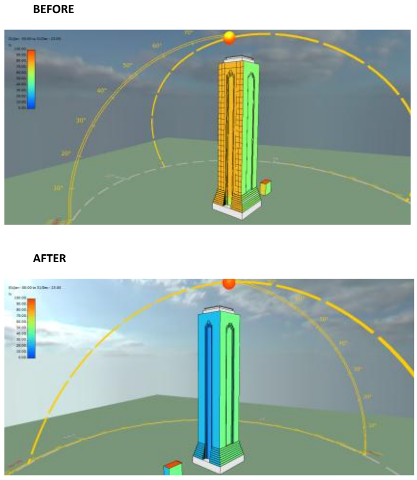

Fig. 7 SUN EXPOSURE PERCENTAGE %. Source: Raneem, 2025

The redesign significantly reduces the building's overall sun exposure percentage, shifting from high-intensity heat zones to lower-exposure, red color is the maximum intensity, and blue color is the lowest as shown in the (**Fig.7**).

ENERGY ANALYSIS (KWH/SQM)

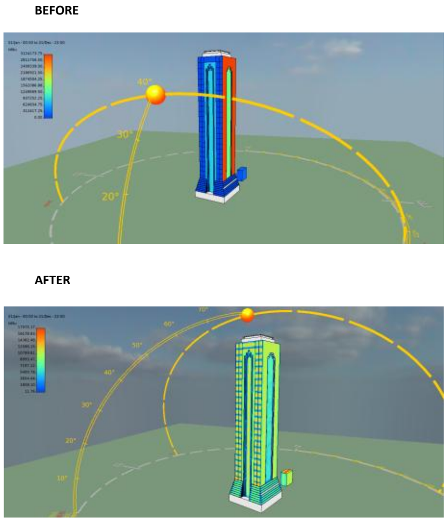

Fig. 8 ENERGY ANALYSIS (kwh/sqm). Source: Raneem, 2025

Intensity per square meters reduces the modification, to more efficient façade performance and enhanced human comfort, red color is the maximum intensity, and blue color is the lowest as shown in the (**Fig.8**).

CONCLUSION

After studied Almoayyed Tower is considered to be a high-energy consumption building since requires 48,000 kwh daily, which is approximately the electricity usage of 500 Bahraini households. This amount of electricity has impact on national electricity consumption. The application of passive strategies, such as building orientation optimum south orientation, proper façade material, and energy efficient glazing, in the active strategies like ASI and BIPV, could lead to substantial reductions in its electricity bills. A well-chosen material and considering the tiny details can make a difference in energy consumption starting from user experience, turn off the lighting after use can reduction electricity bills. 16,000 sqm of photovoltaic panels, thus saving ~506,880 BHD/year and reducing CO2 emissions by ~3,000 tons. These potential strategies would make Almoayyed Tower both energy-efficient and ecologically sustainable, the potential of combining passive and active design techniques in modern high-rise building.

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