

Article

Techno-Economic Analysis of Green Building Codes in United Arab Emirates Based on a Case Study Office Building

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Abstract: Green building regulations in the United Arab Emirates are required to obtain building permits so that future construction projects can create a sustainable living environment. Emirates such as Abu Dhabi, Dubai, and Sharjah have specific green building regulations, whereas other emirates follow Abu Dhabi's regulatory criteria. Previous work fails to present a techno-economic cross-code analysis for various green building regulations in the UAE by evaluating energy and water performance. A case study using an existing high-rise green office building was formulated using the Integrated Environmental Solution: Virtual Environment (IES-VE) platform and the U.S. Leadership in Energy and Environmental Design (U.S. LEED) water consumption evaluation tool to study its energy and water performance, respectively. The archived results were used to devise an economic study based on the discounted cash flow technique. The principal findings of this research allowed us to determine a cross-code analysis and propose cost-effective trade-offs. These will aid the consultants and contractors in choosing appropriate green building regulations in the UAE by highlighting the potential of each parameter within green building regulations in terms of energy, water, and economic performance.

Keywords: business appraisal; energy modeling; IES-VE; energy performance; water performance

1. Introduction

Energy efficiency measures in the built environment sector are considered the low-hanging fruit because prior research indicates that the building sector consumes 80% of overall energy demand in the United Arab Emirates (UAE) and 40% across the globe [1,2]. These energy efficiency standards are promulgated within green building regulations, but constructing green buildings requires higher investment capital than ordinary buildings. The UAE has set a high bar by requiring all new construction projects to comply with green building regulations specific to each emirate to obtain a building permit in that region. Meanwhile, prescriptive guidelines in the UAE are becoming more stringent for sustainable living. Evaluating the technical performance of green building regulations in compliance with economic viability explores a balanced option for introducing (or revising) the benchmarking criteria that may be adopted by various stakeholders [3]. In other terms, this work proposes cost-effective trade-offs by performing a cross-code analysis based on technical and economic performance.

To evaluate the technical performance of regulations, relevant studies on Gulf Cooperation Council (GCC) countries are reviewed in this work. Green buildings and energy conservative measures were first recognized in the UAE in 2003 upon the issuing of Degree 66 under the legal affairs department, restricting envelope measures and suggesting heating, ventilation, and air conditioning (HVAC) designs. Later in 2008, the Government of Dubai tailored and calibrated a set of prescriptive and

descriptive regulations confined to Dubai ports and the free-zone area based on the U.S. Green Building Council's Leadership in Energy and Environmental Design (USGBC LEED) evaluation system and liberalized to the UAE's environmental requirements known as Trakhees. These mainly focused on warehouses and factories, before Trakhees was revised to incorporate residential, commercial, recreational, industrial, and institutional development within the defined free-zone perimeter initiated in 2011.

After that, the Dubai municipality issued the prescriptive Dubai Municipality Green Building regulations (DMGB) [4,5] regulation endorsing sustainable living for all public sector buildings in 2012. These regulations govern the grantsmanship of green building permits based on design, construction, and operation compliance. Since March 2014, these codes have been revised to comply with the private building sector. Most importantly, these mandated regulations focus on constructional design specifications. Recently, the Dubai Municipality (DM) has started issuing Al'Safat regulations [6,7]. It is a rating system based on DMGB regulations, LEED, and ASHRAE to enforce a minimum of a bronze rating system for all new and existing building construction upon building permit application and renewal [8,9]. This enforcement technique is similar to Estidama, as all buildings within Dubai are required to meet green building standards as per Dubai's 2021 vision proclaimed in "Al'Safat".

On the other hand, in Abu Dhabi, Estidama was created in 2007 to help reach Abu Dhabi's 2030 sustainable living goal under the Urban Planning Council (UPC) [10]. Similar to Dubai's current (2016–2017) regulations, Abu Dhabi had issued prescriptive regulations since 2010 on Estidama's official website [11]. It requires that there be a minimum of a pearl 1 rating for all new communities, villas, and buildings within the private sector and a minimum of pearl 2 for all governmental projects for schools, mosques, and government buildings as of September 2010 [12]. Conversely, other rating systems cannot be transferred to the pearl rating system. Moreover, building permit renewal for existing buildings has to be re-indited to comply with Estidama guidelines [11,13]. Furthermore, all of these esteemed guidelines and regulatory standards comply with ASHRAE's HVAC requirements due to their renowned maturity within the sustainable environment field.

The parameters that impact the building energy intensity by targeting the cooling load demand were determined because space cooling is a major energy consumer in GCC countries classified under architectural, electrical, and mechanical design criteria [14–16]. Friess et al. [17] provided research-based contextual evidence that the variations in architectural design parameters corresponding to the thermal insulation structure of the building envelope yielded around 23.3% energy savings for skin-dominant buildings when the thermal transmittance value was changed from 2.4 to 0.6 W/m² K. The regulations may include the environmental impact based on the thickness of insulation as present in [18] for consultants to make an informed decision since a slight variation in thickness or R-Value for a high-rise building will be substantial [19]. Afshari et al. [20] and Radhi [21] identified 1–3% cooling load savings for non-skin-dominant buildings based on their simulation results. These results showed that energy-saving potential is dependent on the building's envelope feature, specifically, the window-to-wall aspect ratio. This conceptional idea was verified by Friess et al. [22] and Aboul-Naga et al. [23], who identified an energy-saving potential of 55% for high-rise non-skin-dominant commercial/office buildings, but electrical and mechanical measures were used in compliance with the architectural measures. Potential savings of 20–28% in cooling load were identified by modulating the thermal transmittance value of the fenestration from 2.4 to 1.47 W/m² K for high-rise buildings [17,21,24]. However, low-rise buildings with a similar wall-to-window ratio had energy savings of 12% [25] and a cooling load of 5% [20]. These identified potential margins indicate that the non-skin dominant high-rise buildings are sensitive to the slightest changes in glazing design parameters due to the reduction in solar gain through curtains with a large surface area [26,27]. Previous studies on the regulations in the UAE lack economical optimization techniques in terms of a cost-effective trade-off that considers energy efficiency.

Al-Absi et al. [28] reviewed various work on using phase change materials (PCMs) within the building walls to identify appropriate insulation materials. These PCMs predominately absorb energy,

and the heat transfer from these materials can be controlled to potentially reduce HVAC energy consumption by maintaining the indoor temperature for longer if they are placed in close proximity to the indoor area. Li et al. [29] investigated the performance of PCMs for buildings in the United States, where 30%, 55%, and 60% reductions in HVAC requirements were identified for three sets of occupancy density. Thus, the applicability of this technique must be investigated with the GCC region alongside the use of geopolymeric coating for passive cooling [30]. However, Katanbafnasab [31] assessed Electrochromic Glazing in office buildings in the UAE that had up to 33% savings with the integration of photovoltaics (BIPV). Rehman et al. [32,33] identified solar insulation materials and summarized the performance of dry insulations through an experiment in Ras Al Khaimah. Akbari et al. [34,35] identified that a reflective roof yields 700 kWh/year of energy savings for a house and around 1000 kWh/year for an office building in very hot climate conditions. Ezzilden et al. [36] and Taleb [37] present energy-saving potential for multi-mode passive ventilation for low-energy and residential villas. The proposed technique is not suitable for high-rise buildings, but their observations of improvements in ventilation during nighttime may suggest that this could be useful in green building codes for residential typology.

Studies on the energy performance of a design that minimizes the internal gains through modifications of the architectural design measures showed energy savings of 28–46% [15,38,39]. The highest energy saving potential was achieved when envelope, glazing, heating, ventilation, and air conditioning (HVAC) set points were used with lighting [40,41], and the lowest was achieved using thermal insulation parameters [22,42–44]. The impact of these complex relationships between the parameters has not been reported in GCC-based research articles; however, Johnson et al. [45] and Wang et al. [46,47] identified the influence of orientation, window area, and glazing properties, such as the U-value, shading coefficient, and visible transmittance, on energy intensity for the office buildings in the United States using parametric sensitivity analysis techniques. Bande et al. [48] carried out a sensitivity analysis for a retrofit building simulation model in Abu Dhabi, confirming changes in design parameters produce different energy requirements. Banihashemi et al. [49] used a similar approach to verify the fenestration properties and reported different energy performance values depending on the location, climatic conditions, and physical properties in office buildings in the cities of Rasht, Ardabil, Yazd, and Bandar-e-Abbas. Ragab et al. [50] and Maria et al. [51] identified the impact of green roofs, and Callejas et al. [52] and Al-Sallal et al. [53] studied the potential of green roofs for passive cooling in tropical climates. These techniques showed potential, but high-rise buildings do not have enough area on which to install green roofs [54–56]. However, green roofs may be employed for villas, as carried out in [17,23,57], which constitute the other 25% of building typologies [52,58] in the UAE, with a potential saving of 12–18% [39]. Brien et al. [59] investigated the improvement of occupant working environments in building codes and standards. They analyzed the behavior pattern to identify the load profile to configure the HVAC settings in the Building Management System (BMS) [60,61]. Auer et al. [62] identified the critical settings needed for a school environment to enhance occupant well-being. Similar studies [60,63] within the region show similar results. The collated control algorithms that define load profiles for various office environments from international codes may be included as a suggestive code in the UAE, as there is a lack of detailed descriptive parameters. The primary goal of this paper is to identify cost-effective trade-offs while preparing an appraisal based on the technical performance and economic viability of various green building codes practiced in the UAE since new construction projects are required to comply with green building regulations. This research project used an existing green building as a case study by acquiring relevant building and unit price cost data from a reputable construction firm based in the UAE. According to market research [58,64,65], 75% of newly completed buildings in Dubai in 2019 were high-rise buildings. These high-rise buildings tend to have similar floor plans and are either of office building or residential building typology [66,67]. The HVAC system design in high-rise buildings is relatively common [40,44], and the occupancy density for an office building per unit area is much higher than that for residential buildings [68,69]. Additionally, the load profiles indicate the peak energy demand is during office

hours. Thus, the selected case study building is a high-rise office building. The reference building was modeled using the building energy modeling (BEM) software (Integrated Environmental Solution: Virtual Environment (IES-VE) platform) to evaluate the building energy performance for each code [70]. The water consumption pattern was computed using the appropriate estimation tool provided by a renowned regulatory society (U.S. Green Building Council's Leadership in Energy and Environmental Design (U.S. LEED)) [71]. Then, a cash-flow plan for each regulatory standard was devised to determine its cost-effective benefits.

2. Methodology

Previous work has failed to present a cross-code analysis for evaluating the UAE's green building regulations in terms of technical and economic performance to determine a cost-effective trade-off. Figure 1 represents a five-phase framework methodology used in this research. Building energy modeling (BEM) under the IES-VE platform was used as the primary modeling tool to evaluate the building's energy performance.



Figure 1. Five-phase methodology block diagram implemented in this project.

The accuracy of the simulated results was determined through an uncertainty analysis. This analysis estimates the uncertainty of the simulation by quantifying possible error. The error margin is a relative percentage of the simulated value and measured value. The water consumption analysis was based on a computational approach prescribed within the U.S. LEED water consumption evaluation procedure, and the techno-economic evaluation was based on the discounted cash-flow financial evaluation technique. This technique provides a detailed financial analysis in terms of net present values and establishes a common base for comparing investment alternatives. The U.S. LEED water consumption evaluation uses flow rates, timing, occupant density, and frequency to estimate the water consumption precisely for various uses. This approach is superior to a water metering system, as it does not measure microscopic consumption patterns, such as the flow rates, to attain control over usage. These statistical results were combined with the simulated results to identify the potential of each green building standard.

2.1. Building Energy Performance Analysis

The energy demand associated with a building is broadly classified into the following categories:

- External Factors: yearly distributed climatic conditions such as the temperature, humidity, solar radiation, wind direction, and intensity.
- Prescriptive design parameters:
 - Geometrical conditions: the building orientation, shape, window-to-wall ratio, and exposed surface area created by shade from adjacent buildings.
 - Thermo-physical properties: the thermal transmittance of the external walls, roof, and external floors; thermal mass; and factor of solar heat gain through glazed surfaces.
- Hedonic parameters: set-point temperatures, the occupation density, the ventilation rate, and internal gains through lighting and equipment.

It must be noted that this research paper does not consider the use of renewable energy, as it is not required to attain green building status. However, this factor is required to attain net zero building status [72]. This research only focuses on evaluating the design parameter that contributes to energy demand, whereas renewable energy systems generate electricity to support the demand.

The quantitative design and hedonic parameters defined in Table 1 represent the synthesized fragment of each green building standard in the UAE, specifically, the Dubai Municipality Green Building regulations (DMGB); Trakhees; Al'Safat; the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE); and Estidama for office building typology. This research uses the high-rise office building with a high glazing ratio as its case study building. The use of this typology provides control over energy usage patterns from equipment and defined operational hours, whereas residential [73], hotel [42], or hospital [74] energy patterns are hedonic in nature due to varying occupancy and mentality. The variation in typology is predominately confined to the building usage that is controlled by equipment and lighting density within the regulations to an extent, as it is variable in terms of frequency of usage. Additionally, high-rise buildings with high glazing ratios are prominent in the UAE, where the market research indicates a 1.5-fold increase in the number of new buildings, with 90% of them being high-rise buildings, by 2020 [65,75,76]. Thus, the case study building includes the most critical envelope structure that cannot be controlled with communication systems, whereas the equipment and lighting power density may be controlled using smart communication systems for other typologies.

The parameters of the case study building are tabulated in the first column of Table 1 as a base reference for comparison. The three standards DMGB, Trakhees, and Al'Safat [77] were issued and are followed by the Emirate of Dubai, while Estidama is under the emirate of Abu Dhabi, and ASHRAE is an international standard used in the UAE. The quantitative design and hedonic parameters defined in Table 1 were predominately fed into the BEM software using the ModelIT package within the IES-VE platform. The hedonic parameter was defined within the existing case study building in terms of office use, which was then considered for the standards in this study. Figure 2 portrays a sample instance of solar shading analysis and an overview of the reference building's external structure. The building has four different floor plans to accommodate the ground podium, parking podium, office, mechanical floors, and terrace, with 15 defined zones for the entire building.

These variable categories govern the changes in energy intensity, while other categories were assumed to be constant. This is a significant limitation, and the numbers obtained may not be regarded as benchmarked numbers but simply a source for understanding the parametric behavior [78]. Equation (1) provides a computational formula for benchmarking the building energy performance commonly used by energy engineers in the building sector. This equation represents an index referred to as the energy utility index (EUI) for the ease of comparing building performance. It must be noted that this study normalizes electricity consumption per unit of conditioned floor area; this criterion is the most influential among other parameters, such as occupancy density, for the selected case study building typology.

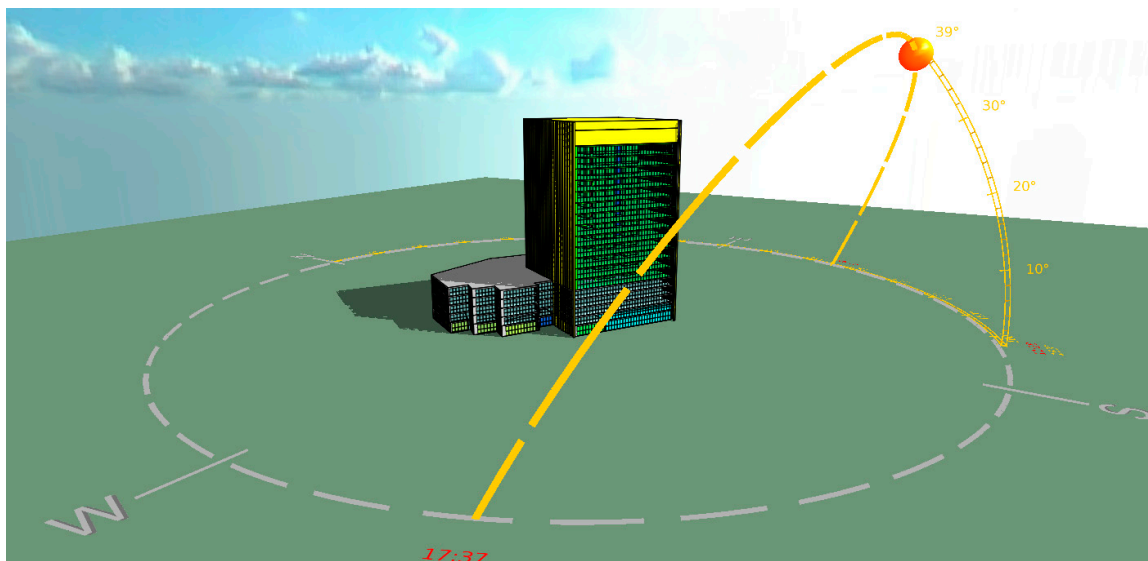
$$EUI = \frac{\text{Total Electricity Consumption (kWh)}}{\text{Total Conditioned Floor Area (m}^2\text{)}} \quad (1)$$

The simulation results were rationalized by incorporating the sensitivity analysis as represented by Equation (2) [79]. This sensitivity index is the percentage of output differences and is calculated by changing an input parameter from its minimum value ($E_{i,pi,min}$) to its maximum value ($E_{i,pi,max}$), normalized to the energy demand in the initial configuration of the building ($E_{d,i}$). The index indicates the parameter and model variability while confirming the true range of sensitivity of the independent input variable with respect to dependent output variable, i.e., the energy demand. A positive index confirms that the input has an independent nature and a lower probability contribution to the energy demand. However, a negative index indicates an indirect impact that increases the complexity of identifying the contributing factor affectivity and the certainty of the energy distribution profile. The strength of the dependency may be estimated using Pearson's correlation coefficient [80].

$$\text{Sensitivity Index (SI)} = \frac{E_{i, pi, max} - E_{i, pi, min}}{E_{d, i}} \quad (2)$$

Table 1. Summary of prescriptive regulatory specifications for analyzing energy performance.

Parameter	Reference Case Study Building	DMGB	Trakhees	Al' Safat	ASHRAE	Estidama
External Wall/Envelope (W/m ² K)	0.57	0.57	0.28	0.57	0.7	0.32
Roof (W/m ² K)	0.44	0.44	0.26	0.3	0.36	0.14
Wall and Roof (W/m ² K)	0.25	0.25	0.13	0.2	0.24	0.1
Glazing (W/m ² K)	3.18 (SC = 0.40)	3.28	2.1	1.9	6.9	2.2
Internal Light Power Density (W/m ²)	14	10	7.53	10	11.84	11.84
Equipment Power Density (W/m ²)	(200 W/desk + 10 W/m ²)	–	–	–	12	12
Occupancy (m ² /Person)	8.4	ASHRAE 62-2007	=	≥25 per 100 m ² ≈ 4	20	20
HVAC Type	Chillers	Air conditioning equipment placed in Table 502.1 and efficiency requirement as per ASHRAE 90.1	Air conditioning equipment placed in Table 502.1 and efficiency requirement as per ASHRAE 90.1	Chillers with 95% of the year free cooling	Efficiency requirement as per ASHRAE 90.1	Air and water-based chillers
Heating Design Temperature	22 °C (±1)	25.5–22.5 °C	–	As per DM regulations	20 °C	20 °C
Cooling Design Temperature	23 °C (±1)	24 °C	24 °C	24 °C	23.8 °C	23.8 °C
Ventilation Rate (m ³ /h/Person)	30.06	5% of the design volume	ASHRAE 62.2-2007, Ventilation	ASHRAE 62.2-2007, Ventilation	25.5	25.5
Infiltration Rate (ac/h) @ Normal Pressure	0.5	0.5	0.5	0.5	0.25	0.6552

**Figure 2.** Reference building design using ModelIT tool in Integrated Environmental Solution: Virtual Environment (IES-VE) platform.

2.2. Water Consumption Analysis

This analysis was performed by employing the computation methods prescribed in the U.S. LEED water consumption evaluation procedure and using an Excel spreadsheet with the parameters relevant to office buildings presented in Table 2. This technique is recognized by official authorities and widely used at corporate levels within energy saving companies across the UAE. It measures the flow rates, timing per use, occupant density, and frequency of usage to perceive the consumption pattern. Utilizing a metered system does not provide a breakdown of usage patterns for controlling and conserving water.

Table 2. Summary of prescriptive regulatory specifications for estimating water consumption patterns.

Fixture/Appliances	Units	Maximum Flow Rate					
		Reference Case Study Building	DMGB	Trakhees	Al'Safat	ASHRAE	Estdama
Kitchen Taps	l/min	6	7		7		6
Bathroom Washbasin Tap	l/min	1.9 per use	6		6		6
Toilet Dual Flush	l/flush	6 or 4.8	6 or 3	Not Given	6 or 3	Not Applicable	6 or 4
Bidet spray	l/min	6	–		–		6
Shower head	l/min	9.5	8		8		9.5
Ablution Fixtures	l/min	6	–		–		6
Dishwasher	L/place setting	–	–		–		1.3
Washing Machines	L/kg of dry load	–	–		–		8.5
Urinal	L/flush or waterless	0.5	1		1		–

ASHRAE and Trakhees do not have a prescribed set of parameters and were considered unknown in the analysis (Table 2). These unknown parameters were replaced with the reference building's defined parameters and behavior patterns, which were assumed constant because they influence the water usage per person. The number of working days and occupancy density were used to normalize the consumption patterns using the simulated occupancy results from the previous BEM analysis. The net annual water consumption (Equation (3)) was calculated using the wastewater amount and condensate water consumption, which is directly dependent on the chiller flow supply, specific humidity in the air, and specific volume of dry air. The quality of the storm water collection system depends on net water consumption, which in turn depends on the annual rainfall and volumetric run-off coefficient for impervious covers.

$$\text{Net Annual Consumption} = \text{Annual Consumption} - \text{Storm Water} + \text{Condensate water} \quad (3)$$

Moreover, the accuracy of water consumption measurements is highly dependent on occupancy density, as this parameter is unpredictable and variable in nature. Therefore, the value of the occupancy density and usage pattern was assumed to be constant. This value corresponds to the specified occupant density in the standards (Table 1) and the assumed usage pattern to match the water utility consumption of the case study building.

2.3. Techno-Economic Analysis

The analysis was performed as a feasibility study to understand the costs and benefits of complying with the green building standards, to investigate the cash flow pattern by integrating the net present value technique under the discounted cash flow of the financial analysis. To calculate the cash flow, the cost of the entire project was estimated by considering a list of requirements as presented in Appendix A. A summary is presented below:

- Pre-requisite expenditures (permit, consultation, Environmental Impact Assessment (EIA), and land acquisition);
- On-site infrastructure expenditure;
- Operational expenditure;
- Structural construction expenditure;
- Payroll;
- Internal structure (cabling and soundproofing);
- Internal services such as mechanical, electrical, and plumbing (MEP) expenditure.

The net income was estimated from the rental charges (AED 115/sq ft) [81], and energy and water savings were computed at the end of the second and third stages.

3. Building Energy Performance Analysis Results

The overall energy performance efficiency evaluated using the energy utility index (EUI) approach is depicted in Figure 3 using the simulation results obtained from the BEM within the IES-VE platform by accommodating all the influential design parameters for each standard (Table 1) for high-rise office buildings. The building characteristic details are presented in the appendices.

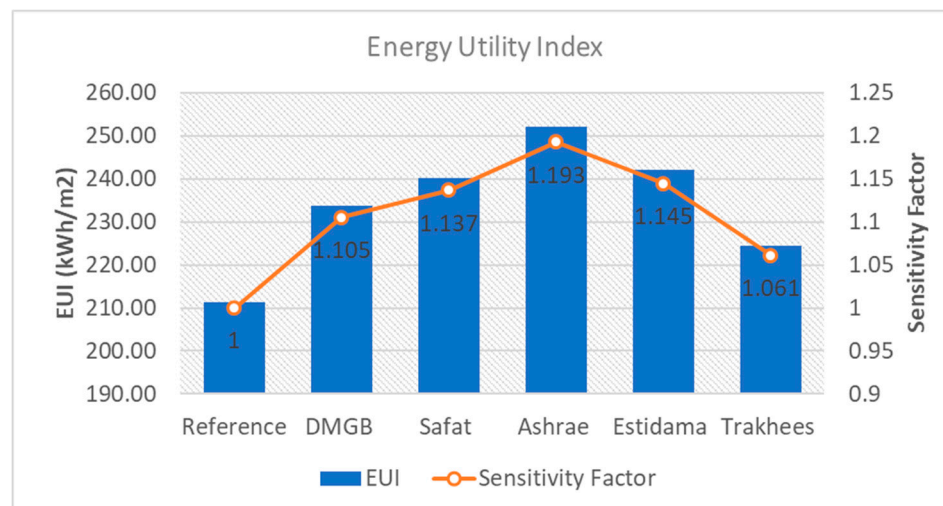


Figure 3. Cross-code analysis comparing green building standards in the UAE using the energy utility index approach, whose characteristic data were simulated using the IES-VE platform.

The cross-code analysis is illustrated in Figure 3 using the EUI approach and highlights the energy performance of each regulation, while the sensitivity factor is also the relativity factor, i.e., a ratio of actual and reference values [82]. Trakhees showed the best overall energy performance since its design parameters were developed to obtain a yield high performance. The intricate design conditions that enhanced the potential of each design criterion are related to its regulatory nature, confined to Dubai ports and free zones or being the first mandated regulation in the UAE in 2008 [83,84]. This finding is consistent with the findings of Jagannathan [85] while studying constructing low-carbon buildings using Trakhees' guidelines; however, the research of Jagannathan did not identify the potential of a few design criteria using all design conditions.

DMGB was regarded as a discrepancy in Figure 3, as Al'Safat and Estidama's design parameters had the potential to yield higher performance, indicating that the performance of each parameter was overshadowed by others. The effect of other variables on electric and chiller loads was computed using the sensitivity index (Equation (2)) [86] and is depicted in Figure 4. The EUI indicates the total electricity consumption pattern per unit of gross floor area. It does not specify the constituent distribution of the amount of energy lost through external or internal gains or the HVAC unit's energy requirements. Therefore, the simulation-based energy performance analysis does not necessarily paint a clear picture of the influence of each parametric design on the energy or cooling load outcome.

The simulated variables representing the total electricity and cooling load demand are not in agreement (Figure 4), implying that the variables that affect the electricity demand are different from those of the cooling load. Figure 4 shows that the chiller load is influenced by ventilation gain, internal gain (people, lighting, and equipment gain), and solar gain (convective and radiative heat gain through fenestration) [70]. This observation can be explained by the theory that these gains are responsible for the higher temperatures in a room. Thus, ventilation and glazing design parameters can control the chiller load.

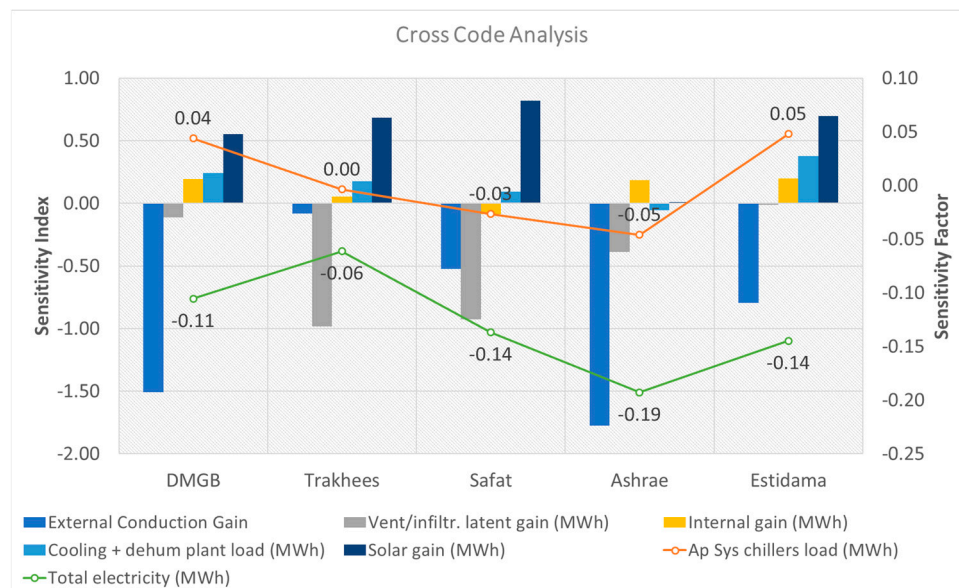


Figure 4. Impact on electric and chiller loads due to other variables in detailed cross-code analysis comparing green building standards in the UAE, where detailed cross-code analysis includes all other parameters to obtain the relationship pattern.

Electric load is directly dependent on lighting and equipment power density, but its direct dependence on conduction and convection gains indirectly indicates its reliance on the chiller load because internal gains contribute to the elevated heat in a room. The chiller load and electric load dependency affect the performance of DMGB in relation to Al'Safat because the Dubai municipal authority enhanced the individual design criteria for Al'Safat, which were based on DMGB's regulations. This was not an ideal modification because it did not balance the influence of other variables, and the slightest change in the design value greatly impacted the overall building performance. Moreover, the effect of the ventilation gain and envelope measure has the potential for reducing energy intensity to enhance building performance (Figure 4).

Uncertainty Analysis

The simulated results were used to perform energy, water, and economic analysis in the IES-VE platform. An uncertainty analysis was conducted for one variable, and it was assumed to have the same impact on other variables. The parameter chosen was the chiller load because this is an essential parameter in the Middle East, where the cooling load contribution to the energy distribution profile is around 60–70% in energy-efficient buildings [13,48]. The reference case study building is set up with four 1500 MW chiller plants with an estimated 5.47 MW load. The actual value was provided in the documentation collected during the data acquisition phase. The analysis presented a marginal error of 7.4% (Equation (4)).

$$Error_{Cooling\ load} = 1 - \frac{5873.46}{5469} = 7.4\% \quad (4)$$

The error margin of 7.4% is consistent with that in another study that determined the energy simulation accuracy of IES-VE, which varied by 0.4% from the reported range (6–7%) [87]. This variation was caused by the difference in the environmental conditions such as the external dry bulb temperature, wind intensity, or energy usage pattern defined by the user. Since the accuracy of the platform is in a reasonable range (under 10%), the simulated results were left unaltered throughout the project. The simulated results were not calibrated to project the real-time results, as this error margin confirms how close the simulation results are to real-life evaluation.

4. Water Consumption Analysis Results

The parameters listed in Table 2 for each regulatory standard were used to perform a water consumption analysis based on the U.S. LEED water estimation procedure. Since ASHRAE and Trakhees do not have a prescribed set of parameters, they were considered unknown. These unknown parameters were replaced with the reference building's defined parameters and behavior pattern, which were assumed to be constant, as they influenced the water usage per person. However, the number of office working days and occupancy density were used to normalize the consumption pattern using simulated occupancy results from a previous BEM analysis. The net annual water consumption (Figure 5) constitutes waste and condensate water consumption, which is directly dependent on the chiller flow supply, specific humidity in the air, and specific volume of dry air. It must be noted that the quality storm water collection is deducted from the net water consumption, which depends on the annual rain fall and volumetric run-off coefficient for impervious cover under coverage [88].

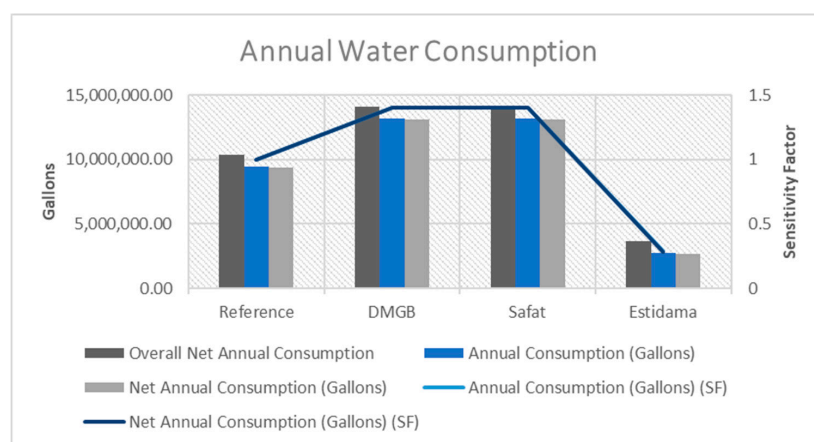


Figure 5. Cross-code annual water consumption pattern for green building standards in the UAE.

DMGB and Al'Safat have the same consumption scheme (about 140% of the reference buildings), whereas Estidama consumes only 29%, as shown in Figure 5. This competitive cross-code water consumption performance study showed that Estidama had the most effective regulative design parameters.

Figure 6 demonstrates the simulated variation in the supply air flow in cubic feet per minute to contemplate the end condensate water consumption, with a variation under 1.29% across each standard.

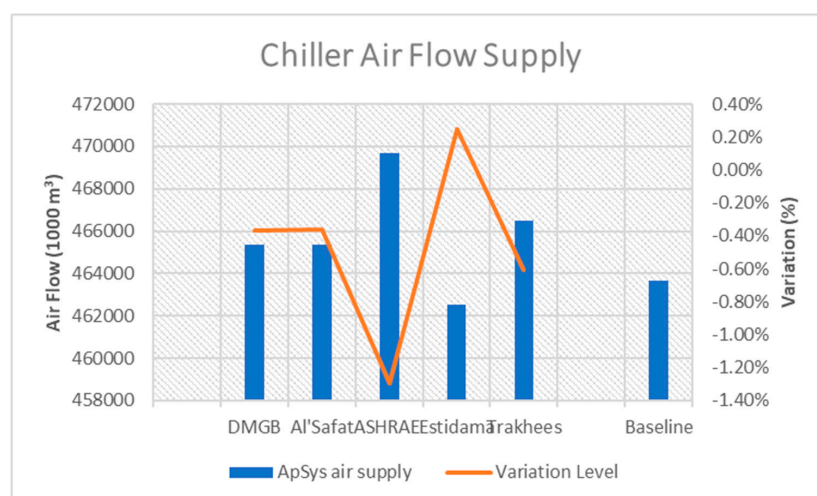


Figure 6. Chiller system's air flow supply for each green building standard obtained using simulation results on IES-VE platform.

Figure 7 demonstrates the cross-code analysis in the normalized form (index value), where the water consumption level of ASHRAE and Trakhees was estimated using the reference building's pattern. The number of occupants and its respective index values are presented numerically above the blue and orange bar graphs, respectively.

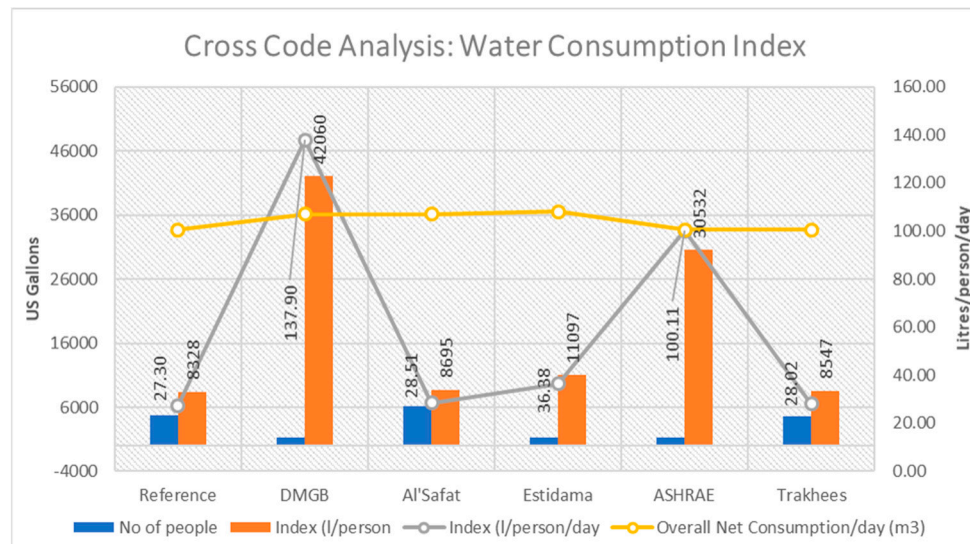


Figure 7. Cross-code analysis: water consumption index depicted considering all parameters using IES-VE platform.

Figure 7 contradicts Figure 5 because the water consumption per person index (gray line) shows that Al'Safat outperforms the other standards, followed by Trakhees and Estidama; ASHRAE and DMGB have the least significant standards in terms of water consumption patterns. Moreover, there are differences among the indices of ASHRAE, Trakhees, and the reference building owing to the variations in occupancy density, even though the total water consumption was assumed to be the same. The number of people in the building was incorporated in the simulation while performing the energy analysis modeling in the IES-VE platform using the occupant density accordingly.

Consequently, the parameter occupant density is identified as an opportunity for enhancing water consumption standards. For instance, the trade of Estidama's water consumption standard can be optimized by considering the value of the occupant density from Al'Safat. Therefore, it can be concluded that the water consumption analysis depends not only on allocated design parameters but also on occupancy density. The HVAC load has an influence on the variations in condensate water. In this regard, the design parameters influencing the chiller load will either increase or decrease the amount of condensate water required, affecting the water consumption pattern. ASHRAE and Trakhees were disregarded because their standards do not comply with the strategic water analysis structure. This is because ASHRAE complies with the requirements to reduce and maintain the heating and cooling load, and Trakhees follows the free-zone standard, which was typically prescribed for warehouse buildings during the early 2000 s. Since then, the UAE has become a commercial hub with rapid development in free zones. For instance, Jumeriah, Dubai, is a free zone and currently considered a suitable base for office buildings [77,83]. Trakhees requires revisions to incorporate the water consumption strategy because it was one of the first regulatory standards in the UAE [17]. Figure 7 shows that Estidama has a water consumption index closer to Al'Safat's and the best water consumption design standards. The water consumption analysis was performed by strictly defining the behavior pattern and is considered a major limiting factor that can significantly affect the outcome.

5. Techno-Economic Analysis Results

The building energy performance and water consumption were evaluated to compare the energy saving potential of each set of green building regulations and to verify whether they were economically feasible. It is necessary to ensure the feasibility and to understand the economic benefits of energy conservation by considering the investment details presented this section. The net cash flow using the discounted cash flow technique was computed by considering the following:

- The two-year construction period for which there is no income;
- The loan is taken at a 7% annual interest rate;
- The loan amount includes 7% annual interest for the first two years of construction.

The net cash flow for the first scenarios depicted in Figure 8 was determined using the income from rental charges and energy savings. These were the simulated energy results in terms of the EUI from Figure 3 that were used to compute the profit margin for energy savings as shown in Table 3. The net cash flow indicates the return-on-investment path, i.e., a percentile of income with respect to the initial investment. This cash flow pattern includes the interest rates applied at 7%, as per the assumptions stated earlier in this section.

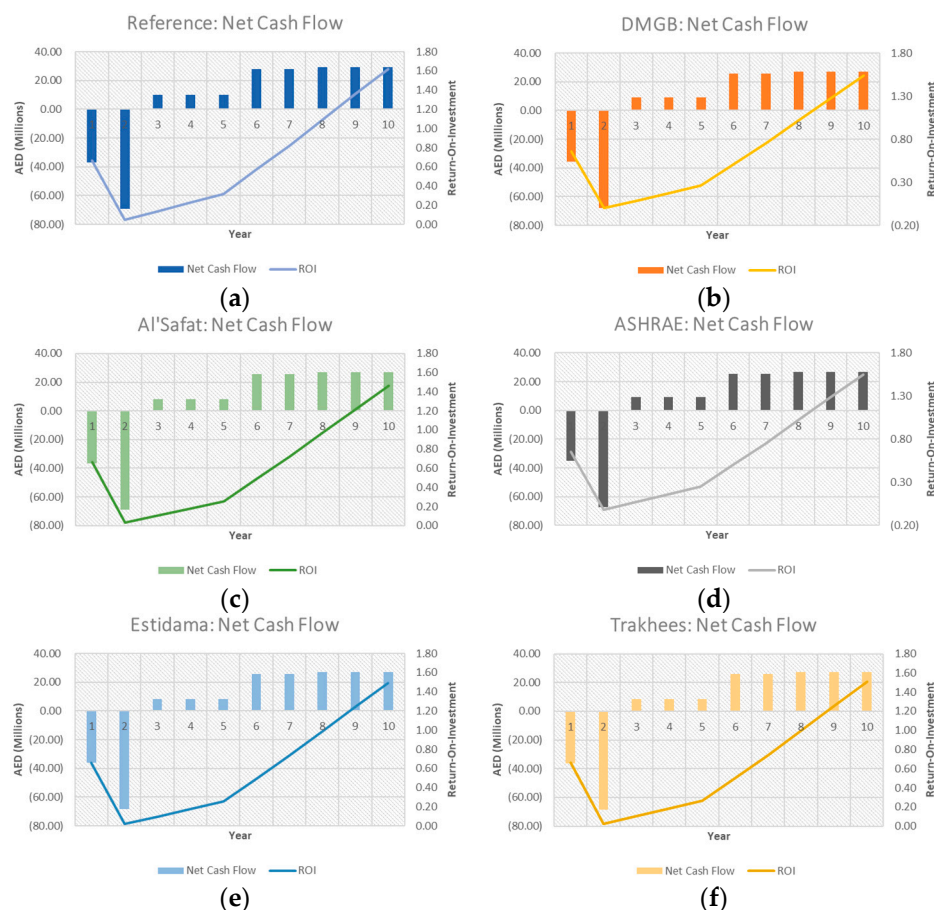


Figure 8. Net cash flow and return-on-investment (ROI) curve for each set of green building standards in the UAE for a 10-year period: (a) reference case study building; (b) DMGB; (c) Al'Safat; (d) ASHRAE; (e) Estidama; (f) Trakhees.

Table 3. Summary for techno-economic analysis with only electricity utility pay out.

	Investment (Millions)	Loan At 7% (Millions)	Payback Period (y)	ROI	IRR for 10 y Plan	Excess Money PBP (Millions)
DMGB	AED 70.19	AED 103.55	7	1.009	13.62%	AED 0.92
Al'Safat	AED 73.90	AED 109.03	8	1.261	12.68%	AED 28.41
Trakhees	AED 72.87	AED 107.51	8	1.293	13.20%	AED 31.48
Estidama	AED 72.20	AED 106.51	7	1.013	13.68%	AED 1.30
ASHRAE	AED 68.37	AED 100.86	8	1.284	13.02%	AED 30.25
Reference	AED 75.14	AED 110.84	8	1.273	12.95%	AED 30.28

Figure 8 represents the net cash flow diagrams for each green building regulation for the first scenario considering the income from energy-saving and rental charges, where each clustered column represents a one-year period. The primary vertical axis represents the annual net cash available in millions at the end of year, whereas the secondary vertical axis represents the return on investment (ROI). The payback period is determined when the line crosses “1.00”, where it indicates a 100% return on investment.

Figure 8 demonstrates that regulatory standards have a payback period of seven or eight years, but they do not necessarily provide the investment details along with the return-on-investment (ROI) factor at the end of the payback period and the internal rate of return (IRR) after a ten-year investment scheme. A detailed summary of the net cash flow is tabulated in Table 3.

The results show that ASHRAE has the smallest investment, and Trakhees outperforms the others in terms of the IRR value at the end of 10 years, as this code has a positive effect on the EUI index compared to the rest. The 10-year mark was utilized to verify the IRR and identify it as a good investment. The significance of using the IRR evaluation method rather than the whole life-cycle cost, which considers the resale of the building, is prevalent due to the real estate market in the UAE. Moreover, the life-cycle cost was not considered since the design selection for the parameters must have a minimum lifetime of 25 years or more to qualify as a green building as per UAE regulations.

Table 3 illustrates the effect of energy performance on the economic assessment; the results for each regulation were approximately the same due to the minute variations in the cost per service pricing obtained from a reputable developer in the building sector in the UAE. Trakhees was considered a better choice, even though ASHRAE had the lowest investment and Estidama had the highest return-on-investment rates for the scenario when considering the income from the office space rent and profits from energy savings. Trakhees has a lower impact on the environment in the long run, due to higher energy savings and potentially lower carbon emissions. It has an IRR value close to that of Estidama because it requires a lower building maintenance investment due to its high building energy performance. Note that the income for this case study was from the energy-saving profits and rental charges, but the rental charges were not consistent with those for green buildings, even though green buildings receive 5 to 10% higher rental income. This was primarily done to estimate the values for the worst-case scenario.

A detailed techno-economic analysis considering water utility savings, metering, lighting, and furnishing fixtures is presented in Table 4 and assumes that the desalination plant does not change the unit price (4.6 fills per imperial gallon) in Dubai for the next 10 years.

Table 4. Summary for detailed techno-economic analysis including water and electricity savings.

	Investment (Millions)	Loan At 7% (Millions)	Payback Period (y)	ROI	IRR for 10 y Plan	Excess Money PBP (Millions)
DMGB	AED 89.01	AED 131.31	8	1.061	9.22%	(AED 7.98)
Al'Safat	AED 92.72	AED 136.79	8	1.021	8.41%	(AED 2.81)
Trakhees	AED 91.69	AED 135.27	8	1.050	9.03%	(AED 6.74)
ASHRAE	AED 87.19	AED 128.62	8	1.069	9.37%	(AED 8.87)
Estidama	AED 91.01	AED 134.27	8	1.052	9.07%	(AED 7.04)
Reference	AED 94.80	AED 139.85	8	1.032	8.69%	(AED 4.53)

Water consumption utility charges and interior furnishing charges brought the payback period to eight years for all the green building standards. These characteristics showed that the investment plan does not depend on the regulatory standard. This analysis considered Estidama to be a better choice, even though ASHRAE had the lowest investment plan and the highest IRR value at the end of 10 years. The water index for ASHRAE and Trakhees was estimated while considering the reference building's consumption, as these regulations did not have a prescribed set of standards for water performance. This is the reason the two scenarios for economic analysis were formulated to provide equal opportunities for each regulation to showcase its conservation potential. Moreover, the water consumption analysis was performed by strictly defining the behavior pattern and is considered a major limiting factor that can significantly affect the outcome. However, Al'Safat was not considered the best option for economic analysis based on the water utility scenario because its internal rate of return dropped significantly. The excess money at the end of the seven-year period observed in the previous scenario was spent, and it increased the return-on-investment period to eight years. This indicates that the impact of water consumption utility charges is quite significant, leaving Al'Safat with the lowest return-on-investment rates. Considering both the energy and water consumption structure, Estidama will have the upper hand in energy and water performance in terms of economic viability and environmental protection.

6. Conclusions

This research investigated the technical and economic performance of existing green building regulations in the UAE to propose a technical and cost-effective trade-off. This work identified Trakhees as an energy-effective standard using the EUI benchmarking technique. To propose an energy-effective trade-off, a strategy to control energy performance was determined by evaluating a variable influence diagram. Previous studies showed that the standards in the UAE enhanced the individual performance of design parameters, but those studies did not perform a feasibility analysis. Previous studies also failed to identify the parametric pairing trade-off that produced similar overall energy performance when all influential design criteria were considered. This gap in the literature will be considered in a future study to quantify the influence of each parametric pairing to serve as a guideline for policymakers or consultants for devising a strategic energy and cost-effective building plan or revising an existing green building standard. This work showed that the chiller loads were mostly influenced by the ventilation rate, infiltration rate, and glazing thermal transmittance values, as they are responsible for heat gain. The electric load was directly dependent on power density and indirectly dependent on envelope design due to its dependence on the cooling load.

The water consumption analysis used a straightforward computational approach using the U.S. LEED's water consumption calculation principle. The results showed that in new green building regulations, Al'Safat outperformed Estidama by a margin due to its occupancy density design parameter. In the techno-economic analysis, employing the ASHRAE's prescriptive conditions was the cheapest considering energy utility, water utility, and internal furnishing expenditure. Complying with Estidama's

regulations was economical considering its energy and water performance, which ensures a sustainable living environment. Even though Al'Safat outperformed the others in terms of energy and water performance, the cost of implementing those measures yielded 2.5 times lower profits at the end of the eight-year period compared to Estidama.

A competitive standpoint was deduced based on office buildings with high window-to-wall ratios, where the reference case study building had an 18% wall-to-window ratio. The DMGB's glazing condition paired with the Trakhees' HVAC set point, ventilation, and infiltration rate would be a plausible cost-effective trade-off to improve the chiller load performance with minimal cost because envelope measures have a significant effect on the convective gain, which impacts chiller load performance. For instance, office buildings with wall-to-window ratios below 20% contribute to the convection and conduction gain through the wall (around 20%). Hence, a large investment to maximize the wall area is not an economical approach, but coating the exposed envelope area with reflective paint will block the heat gain through the external surface. The use of blinds or internal tinting of glass may be used to further maximize energy performance.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1 presents building characteristic details of the reference case study building.

Table A1. Summary of reference building's estimated surface area.

	Podium Parking Floor	Office Floor
No. of Floors	5-zone	13-zone
Floor Area/Floor (m ²)	7164.71	1874
Window Area/floor (m ²)	941.4	571.2
Wall–Window Area	18.40%	18.40%
Total Floor Area (m ²)	35,823.55	24,362
Total Wall Area (m ²)	1061.38	1674.4
Total Window Area (m ²)	4706.97	7425.6
Building Wall Area (m ²)		2735.78
Building Window Area (m ²)		12,132.57
Building Floor Area (m ²)		60,185.55

Table A2 presents the extracted data from the BEM simulation based on energy consumption.

Table A2. Simulated energy consumption results.

Variable Consumption (MWh)	DMGB	Al' Safat	ASHRAE	Estidama	Trakhees	Reference
Total Electricity	14,066	14,464	15,177	14,565	13,502	12,729
Total Energy	14,201	14,599	15,355	14,688	13,614	12,828
Total Lights Energy	3258	3258	3877	3815	2434	1682
Lights Electricity	3249	3249	3866	3805	2427	1668
Lights Misc. A	8.6	8.6	10.19	10.19	6.48	13.88
Total Equip. Energy	5191	5191	5175	5158	5182	5187
Equip. Electricity	5187	5187	5171	5154	5178	5182
Equip. Misc. H	4.62	4.62	4.62	4.62	4.62	4.62

The investment description to compute the techno-economic analysis is listed; however, the unit cost was obtained through market research and the help of various consultants in the field [61]. The maintenance cost is a part of internal service expenditure, where each of the pieces of equipment or services was allocated a certain percentage of degradation value along with inflation relative to its initial cost annually until a decommissioning cost was estimated at the end of 10 years. The degradation value included the maintenance expenditure for annual maintenance or quarterly, which lowered the asset value.

1. Pre-Requisite Expenditure Description:

- Land Acquisition Expenditure;
- Feasibility Study;
- Environmental Impact Analysis Study (EIA);
- Professional Consultation Fee;
- Land Acquisition and Commissioning Expenditure;
- Permits, Licenses, and Fees (Before Construction);
- Permits, Licenses, and Fees (After Construction);
- Other Miscellaneous Expenditure.

2. Site and Infrastructure Expenditure Description:

- Utilities (Electrical and Mechanical);
- Transportation;
- Waterway and Marine Construction;
- Other Miscellaneous Expenditure.

3. Construction Expenditure Description:

- Constructional Equipment Rent;
- Constructional Equipment Maintenance (Non-Rental);
- Other Miscellaneous Expenditure.

4. Payroll Description:

- Constructional Laborers (On-Site);
- Specialist and Technicians (Engineers, Supervisors, etc.) (On-Site);
- Specialist and Technicians (Engineers, Managers, etc.) (Off-Site);
- Consultants;

- Other Miscellaneous Expenditure.
5. Structural Construction Expenditure Description:
- External Wall (Concrete) (Light Weight) (Actual Building);
 - External Wall ($U = 0.7 \text{ W/m}^2 \text{ K}$);
 - External Wall ($U = 0.57 \text{ W/m}^2 \text{ K}$);
 - External Wall ($U = 0.28 \text{ W/m}^2 \text{ K}$);
 - External Wall ($U = 0.32 \text{ W/m}^2 \text{ K}$);
 - Masonry Wall (Ordinary);
 - Spandrel Panels ($U = 0.31 \text{ W/m}^2 \text{ K}$);
 - External Window (Glass) ($U = 1.5 \text{ W/m}^2 \text{ K}$) (Actual Bldg) (SC= 0.34);
 - External Window (Glass) ($U = 6 \text{ W/m}^2 \text{ K}$);
 - External Window (Glass) ($U = 3.3 \text{ W/m}^2 \text{ K}$);
 - External Window (Glass) ($U = 2.2 \text{ W/m}^2 \text{ K}$);
 - External Window (Glass) ($U = 2.1 \text{ W/m}^2 \text{ K}$);
 - External Window (Glass) ($U = 2.1 \text{ W/m}^2 \text{ K}$);
 - External Roof (Actual Building) ($U = 0.44 \text{ W/m}^2 \text{ K}$);
 - External Roof ($U = 0.44 \text{ W/m}^2 \text{ K}$);
 - External Roof ($U = 0.36 \text{ W/m}^2 \text{ K}$);
 - External Roof ($U = 0.3 \text{ W/m}^2 \text{ K}$);
 - External Roof ($U = 0.26 \text{ W/m}^2 \text{ K}$);
 - External Roof ($U = 0.14 \text{ W/m}^2 \text{ K}$);
 - Internal Partition Wall (Approx.) $U = ?$;
 - Internal Partition Door (Approx.) $U = ?$;
 - Ceramic Tile Flooring;
 - Other Miscellaneous Expenditure (Stairs and Other Rooms).
6. Internal Structure Expenditure:
- Painting (Cool Reflective Coating) (SHGC=) (External);
 - Painting (Cool Reflective Coating) (SHGC=) (Internal);
 - Thermal and Sound Insulation;
 - Moisture-Proofing Insulant;
 - Other Miscellaneous Expenditure (Electrical Wiring, Air Flow Duct, and Water Flow Pipes).
7. Internal Service Expenditure Description:
- Plumbing Service;
 - AHU (Equipment);
 - HVAC (Equipment);
 - Water Supply Pumps for Fire and Domestic Water;
 - Fire Protection Service;
 - Electrical (Transformer, Substation, etc.);
 - Furnishings and Fixed Equipment (Wash Room Taps and Desks for Offices);
 - Gray Water Filtration System and Pumps;
 - Solar Water Heater System;
 - Elevators (Lifts);
 - FAHU;
 - Extract Fan;

- Pressurization Fan;
- BMS System (Infrastructure Set-Up);
- BMS System (Equipment);
- Other Miscellaneous Building Specialties.

Additionally, Tables A3 and A4 present relevant data obtained from market research and simulations to compute the net income, respectively.

Table A3. Relevant data for computing net income.

Cost/sq ft	Plots (sq m)	Plot (sq ft)	Revenue
115	24,362	262,230.39	AED 30.16 Million
105	24,362	262,230.39	AED 27.53 Million
135	24,362	262,230.39	AED 35.40 Million

Table A4. Simulated savings data for computing net income.

	DMGB	Al'Safat	ASHRAE	Estidama	Trakhees	Reference Bldg.
EUI	233.71	240.32	252.17	242.00	224.34	211.49
Energy Saving EUI				211.49		
Energy Saving per sq m	−22.30	−28.90	−40.76	−30.58	−12.93	−0.08
Energy Saving kWh (Total Area)	−1,341,981.27	−1,739,379.67	−2,452,881.40	−1,840,686.82	−778,096.08	−4644.08
Cost Savings (Millions)	−0.43	−0.56	−0.78	−0.59	−0.25	0.00

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