# SUSTAINABILITY THROUGH ENERGY CONSERVATION BUILDING CODES: COMPARATIVE ANALYSIS OF GREEN BUILDING REGULATIONS IN THE MIDDLE EAST

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ABSTRACT
In the UAE, buildings consume more than 80% of the total electrical generation, where the cooling systems are responsible for approximately 70% of the buildings' peak electrical load. The government of Dubai initiated several efforts to improve building efficiency and move towards a more sustainable city. This paper benchmarks the different building codes in the UAE and the GCC, focusing on building envelopes, HVAC efficiency, and the application of renewable energy. Additionally, we compare requirements with the UAE early adopters of the Zero Energy Building concept. Despite having similar climate conditions and construction systems across the UAE, the green building regulations of Dubai, Abu Dhabi, and Ras Al Khaimah have different threshold requirements. For example, the maximum thermal transmittance (u-value) of the exterior walls in Dubai is 0.57, 0.32 in Abu Dhabi, and 0.48 W/m$^2$K in Ras al Khaimah. Constructed Nearly Zero Energy buildings have U-values that are substantially lower than the Dubai regulations, between 0.06 to 0.32 W/m$^2$K. We also found differences in other envelope requirements, the share of renewables, and COP values for air conditioning systems. The differences between the codes and between the early adopters nZEB help us to identify opportunities for improvement and standardization of these regulations and define a path toward wider nZEB adoption in the Emirates.
*Keywords: sustainable cities, green buildings, zero energy buildings, energy consumption, building envelope, cooling systems, building code.*

## 1 INTRODUCTION

Worldwide energy consumption and greenhouse gas emissions are rising due to urbanization, population growth, and economic development. Therefore, national and international organizations are implementing efforts to improve energy demand management, reduce energy waste, and transform the buildings into producers of clean energy. The 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) and the 2015 Paris Agreement on climate change emphasizes the urgency to reduce the $CO_2$ emissions of the building sector [1]. Building regulations are one of the most efficacious and cost-effective policies to reduce greenhouse gas emissions from both new and existing buildings [2]. The transition to Nearly Zero Energy Buildings (nZEB) and Zero Energy Buildings (ZEB) is a necessary action to achieve climate-neutrality in the built environment. Near Zero Energy Buildings (nZEB) increase energy efficiency by an average of 74%, provide reliable performance and high owner satisfaction [3].

Building energy use intensity (EUI) decreased between 2000 to 2015 in the US, the European Union, China, and India. However, during this period, the building EUI in Arab countries experienced significant growth. In the Gulf Cooperation Council (GCC) countries, commercial buildings' average EUI doubled in this period, from 311 to 598 kWh/m$^2$, and the average EUI of the residential sector increased from 198 kWh/m$^2$ to 306 kWh/m$^2$ (Analysis of Optimal). Among the GCC countries, Kuwait was the first to introduce a building

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efficiency code and implementing its first Energy Conservation Code of Practice in 1983 that is regularly revised [4], [5]. The Kingdom of Saudi Arabia (KSA) started implementing an energy efficiency program in buildings in 2010. In 2018, the Saudi Building Code National Committee launched the Saudi energy conservation codes, SBC-601 and SBC 602, for residential and non-residential buildings [6]. Additionally, the Ministry of Housing of the KSA developed the Mostadam Rating System, aiming to contribute to the sustainability of residential units [7]. In 2018, the Kingdom of Bahrain launched its first energy conservation code, focusing on governmental entities and, in 2020, the Unified Guidebook of Building Permit Regulations, a building code with mandatory requirements for all the buildings in the kingdom. Qatar developed the Global Sustainability Assessment System (GSAS) in 2019. This was the first performance-based system in the Middle East and North Africa region and was developed for rating both green buildings and infrastructures [5], [7].

In the UAE, there is not a federal building energy code. However, three emirates have developed their green buildings regulations and their respective building rating systems. In 2008, Abu Dhabi established the Estidama Green Building Code and created the Pearl Building Rating [8]. In 2008, the Dubai government announced an energy conservation code for buildings as part of the Dubai Demand Side Management (DSM). The Dubai Electricity and Water Authority (DEWA) and the Dubai Municipality introduced the first version of the Green Building Regulations and Specifications in 2011. In the beginning, they were mandatory only for government buildings. In 2014, they became compulsory for all the Dubai buildings [9], [10]. Two years later, Dubai Municipality launched the Al Sa'fat Rating System to contribute even more to the sustainable built environment. Similarly, Ras Al Khaimah Municipality launched Barjeel, Ras Al Khaimah's Green Building Regulations, in 2018, to reduce 30% of the energy consumption of the buildings in this emirate [11].

Dubai is committed to the goal of becoming one of the most energy-efficient cities in the world. To reach this goal, the Dubai Supreme Council of Energy developed the Dubai Demand Side Management (DSM), with the support of several governmental [12]. Most DSM programs are related to the buildings sector, recognizing that buildings in Dubai consume more than 80% of total electricity output [13]. The DSM strategy includes continuous updates of buildings policies and regulations, building retrofitting, district cooling, equipment energy certification, and other initiatives aimed at increasing the efficiency of the buildings and lay the foundation for the transition to the nZEB. DEWA established the Distributed Renewable Resources Generation program that enables the development of nZEB in Dubai, and, in 2014, launched the Shams Dubai, a pioneering initiative in the GCC, designed to accelerate and facilitate the installation of photovoltaic in buildings. These frameworks have stimulated the development of several commercial and pilot projects inspired by nZEB concepts that demonstrate its benefits and viability [14], [15].

Our study supports the efforts of Dubai, other Emirates, and the GCC governments to increase the level of sustainability of their cities by identifying areas of potential improvement in building codes, benchmarking them against each other, and with actual building performance of nZEB early adopters.

## 2 METHODOLOGY

To assess building energy codes in context, we first quantify the current demand trend in the electrical energy consumption of buildings in Dubai. Then, we summarize the vision and main objectives of the Dubai GBR&S and compare it with the relevant regulations in other jurisdictions shown in Table 1. Using publicly available information, we compare GBR&S requirements with the corresponding building regulations and building rating systems in other GCC countries (the Kingdom of Saudi Arabia, the Kingdom of Bahrain, Qatar, and

Kuwait). Then, we compare GBR&S with the regulations of other Emirates (Abu Dhabi and Ras Al Khaimah) and with the early adopters of ZEB concepts. We focus our analysis on the elements that most affect the energy consumption in GCC buildings, their envelope, and cooling systems, in addition to the share of renewables, an essential requirement for the nZEB. As early adopters of nZEB Buildings in the UAE, we selected three residential projects: The Sustainable City (TSC) in Dubai, the Masdar Eco-villa in Abu Dhabi, and the Mohammad Bin Rashid Space Center (MBRSC) Autonomous House in Dubai. These three cases exceed the current UAE regulations, have energy use intensity (EUI) significantly lower than the typical UAE buildings, and show different levels of energy balance. We finalized our study identifying the potential areas of improvement of the current Dubai GBR&S.

Table 1: GCC building regulations that are part of this study.

| Country/city | Regulation | Rating system | Most recent edition | Ref. |
|---|---|---|---|---|
| Dubai | Al Sa'fat | Sa'fa | 2017 | [16] |
| Abu Dhabi | Estidama | Pearl Rating System | 2016 | [8] |
| Ras Al Khaimah | Barjeel Green Building Regulation | - | 2018 | [17] |
| Kuwait | Energy Conservation Code of Practice | - | 2014 | [5] |
| Kingdom of Saudi Arabia | Saudi Green Building Code | Mostadam Rating System | 2018 | [7] |
| Kingdom of Bahrain | Unified Guidebook of Building Permit Regulations | - | 2019 | [18] |
| Qatar | Global Sustainability Assessment System | - | 2019 | [19] |

## 3 BUILDINGS IN DUBAI AND GOVERNMENT RESPONSE

### 3.1 Buildings in Dubai: energy consumption and $CO_2$ emissions

Dubai is a cosmopolitan city undergoing massive urban growth and industrialization; therefore, electricity consumption within the Emirate has become a rising concern. Fig. 1 shows electricity demand by sectors in 2019. Buildings are responsible for 86.1% of all the city electricity consumption. Commercial buildings demanded 49.0% of electricity, the residential sector 29.0%, and the government buildings (mosques, police stations, offices, public hospitals, schools, etc.) 8.2%. Furthermore, Fig. 2 shows the electricity demand per number of commercial and residential customers. Over the past six years. There is no clear indication that commercial buildings' efficiency has increased. However, the average consumption per residential customer started to decrease from 2015 slightly [13], [20]–[24].

### 3.2 Dubai Demand Side Management (DSM)

Dubai is committed to the goal of becoming one of the most energy-efficient cities in the world. To reach this goal, in 2013, the Dubai Supreme Council of Energy developed the Dubai DSM as part of the Dubai Integrated Energy Strategy (DIES) 2030. DSM focuses on the design and management of programs and measures that have as objective to incentive and guide the end-users towards more efficient use of the energy. The DSM strategy 2030s objective is to reduce electricity and water consumption by 30%. Green building regulations, voluntary standards and labels, building retrofits, and tariffs are policy options available to

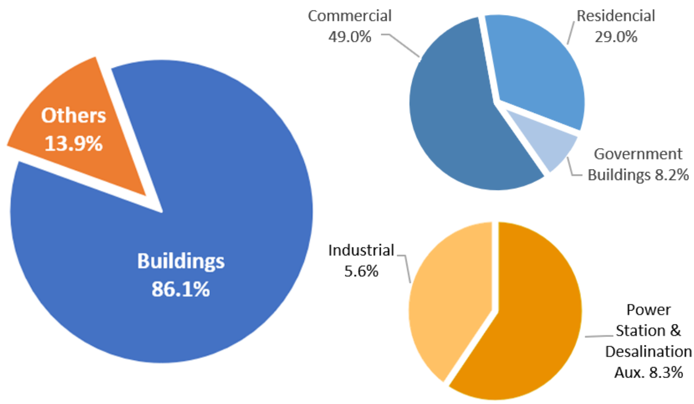


Figure 1: Dubai electricity demand by sectors, 2019. *(Source: Authors, using data from Dubai Electricity and Water Authority [13].)*

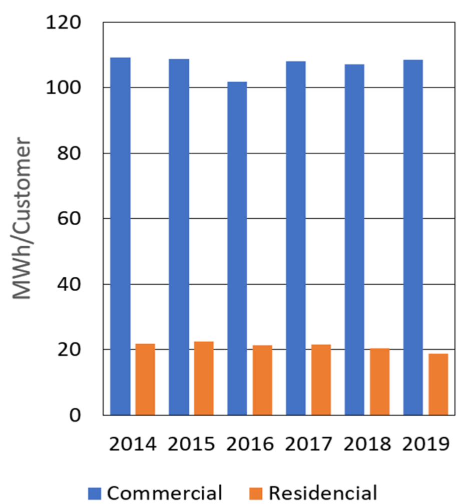


Figure 2: Dubai annual average electricity demanded by customers. *(Source: Authors, using data from [13], [20]–[24].)*

achieve these goals [12]. In 2013, DEWA established Etihad ESCO to develop a viable performance contracting market for energy service companies, centered on building retrofits, installation of PV in buildings, and increasing the penetration of district cooling.

The constant evolution of the Dubai buildings regulation is Dubai Municipality's contribution to the DSM strategy. As planned, the DSM is in the phase of scaling-up its impact and developing new initiatives, including the transition to nZEB [9], [12].

In Dubai, electricity rates follow a slab tariff approach that increases the rate with consumption (Table 2). While simple, this system is not fully exploiting the options provided by a more adaptive tariff system. Hence, the Dubai Supreme Council of Energy has included

Table 2: Dubai Electricity and Water Authority (DEWA) residential/commercial tariffs. *(Source: www.dewa.gov.ae/en/consumer/billing/slab-tariff.)*

| Code | Consumption (kWh)/ month | Slab tariff (fils/kWh) | Slab tariff US cents/kWh | Remarks |
|---|---|---|---|---|
| G | 0-2000 | 23 | 6.3 | - Electricity fuel surcharge 6.5 fils/kWh (1.8 US cents/kWh) September 2020.<br>- Currency conversion: 3.67 Dirhams = USD $1. |
| Y | 2001-4000 | 28 | 7.6 | |
| O | 4001-6000 | 32 | 8.7 | |
| R | 6001 and above | 38 | 10 | |

the program "Change of tariffs rates" as part of its DSM programs, which may signal the start of a positive transformation.

### 3.3 Dubai Green Building Regulations and building ratings

In 2010, Dubai Green Building Regulations and Specifications (GBR&S) was only mandatory for new government buildings, and in 2014 was enforced to all the buildings [9]. The GBR&S aim is to support Dubai's Strategic Plan, create a more sustainable urban environment, and extend the ability of this emirate's infrastructure to meet the needs of its future development. Dubai Municipality relaunched the buildings' regulations in 2017 as Al Sa'fat, Dubai Green Building Evaluation System. Al Sa'fat has 33 mandatory general requirements, many optional provisions whose compliance determinates the building ranting. Al Sa'fat rating system has five main categories; one of them is the "Resource Effectiveness – Energy". This category includes all the requirements for high energy-efficient buildings in Dubai, including requirements about the envelope, air conditioning, ventilation, and renewables in buildings Nearly ZEB [16], [25].

## 4 DUBAI AND THE GCC BUILDING REGULATIONS

### 4.1 GCC climate

The climate in GCC countries is very similar, with long and very hot summers, as shown in Fig. 3. They correspond to the Bwh (Hot Desert Climate) in the Köppen-Geiger climate classification and 1B (Very Hot-Dry Climate) in the International Energy Conservation Code (IECC), developed by the International Code Council (ICC) [26]. According to this code, all areas that surpass 5000 degree-days of the annual CDD10ºC belong to Zone 1 (see Fig. 4). And, the B correspond to Dry areas, locations meet the following criteria (annual precipitation in cm < 2.0 × (annual mean temperature in °C + 7). As a reference, we include the Cooling Degree Hours (CDH 26.7°C) in Fig. 5. As previously mentioned, cooling loads that utilize HVAC systems take the larger share of the electricity consumption within the GCC countries, all due to the challenging climatic conditions of the region. Therefore, it is essential to apply passive design strategies, use highly efficient equipment, and adequately operate the buildings to reduce the energy demand related to the cooling needs.

### 4.2 Building regulations in the GCC

GCC countries have instituted building codes and regulations to manage their electricity consumption and foster a more energy-efficient built environment. Kuwait took the lead in introducing a building efficiency code, publishing the first version of its Energy Conservation

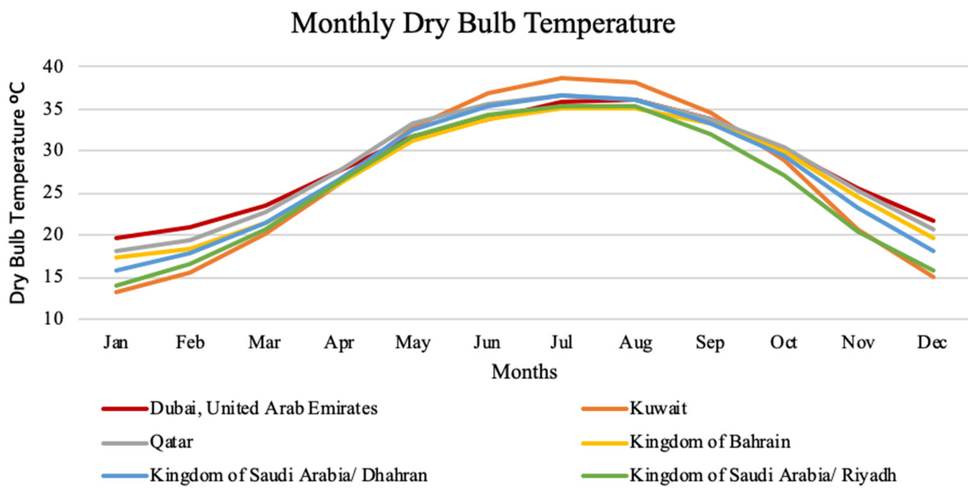


Figure 3: GCC countries' typical ambient temperature. *(Source: Authors.)*

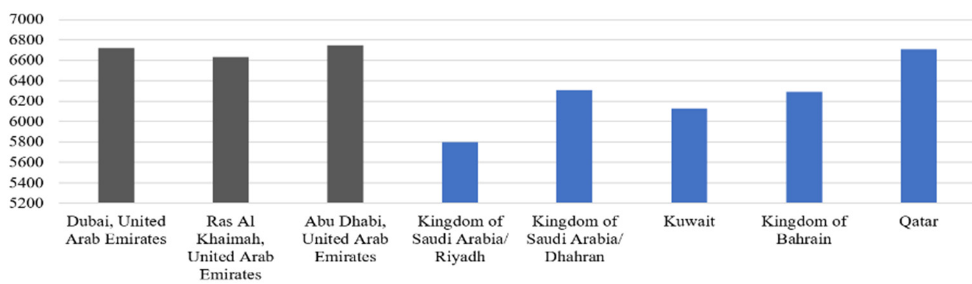


Figure 4: Climate of the GCC countries – Annual Cooling Degree Days (CDD) 10°C. *(Source: Authors.)*

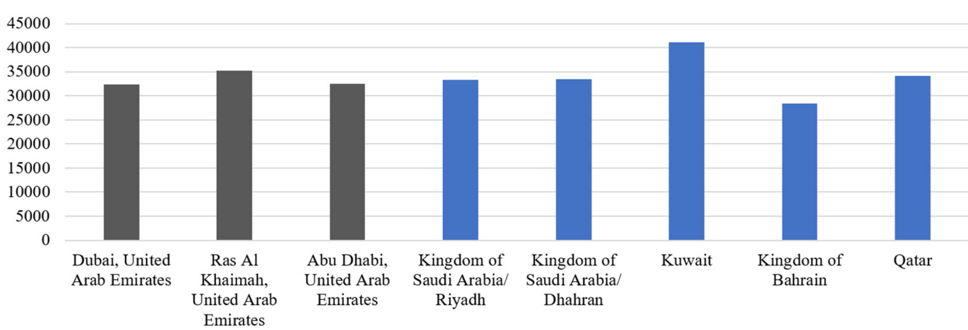


Figure 5: Climate of the GCC countries – Annual Cooling Degree Hours (CDH) 26.7°C. *(Source: Authors.)*

Code of Practice in 1983. The code has since been revised in 2010, and more recently, in 2014. A study performed on a residential model in Kuwait found that buildings built according to the 1983 code can achieve up to 23% in energy savings when retrofitted according to the 2010 revision [27].

In 2010, the Kingdom of Saudi Arabia (KSA) launched an energy efficiency program called the Saudi Energy Efficiency Center through the Council of Ministers' resolution [28]. What followed was the enactment of the Saudi Building Code (SBC) 601 and 602 in 2017 aimed to regulate the energy performance of residential low-rise buildings and commercial high-rise buildings [29]. These codes had yearly released publications, with the latest edition released in 2019 [6]. This paper will draw comparison values from the 2019 SBC 602. Additionally, KSA devised the Sustainable Building Regulation in 2019 in line with its Vision 2030 of creating a pathway for future economic and developmental action. The building code created was coupled with the Mostadam Rating System, aimed to contribute to the sustainability of residential units [7]. A study carried out before the launch of the Saudi Green Building Code shows that it is possible to reach an energy savings of 45%, improving the thermal characteristics of the buildings' envelope [30].

Similarly, the Kingdom of Bahrain published its Unified Guidebook of Building Permit Regulations in 2019 through its building permit portal, Benayat [18]. It is of note that the focus of this regulation is not sustainability or energy efficiency. Its main objective is to implement in the kingdom the latest international construction standards and best practices. However, as later comparisons will show, Bahrain's guidelines are not very different from the energy efficiency-oriented codes set by other GCC countries, and the Bahrain Sustainable Energy Authority is working on the Green Building Code, and Labelling Program is under development [31].

Finally, Qatar has released the Global Sustainability Assessment System (GSAS) in 2007 through the Gulf Organization for Research and Development. The system has since had four editions released, with its latest version published in 2019. The GSAS is unique in the sense that it is the first performance-based system in the GCC and broader MENA region. Unlike the other regulations and codes in the GCC, GSAS does not rely on benchmark values for passive parameters within the building envelope. GSAS assesses the sustainability and efficiency of a building through a specific method of performance analysis, with the help of a custom devised simulation [19]. In that sense, the GSAS assures that the end goal of the building, energy efficiency, and sustainability, is indeed achieved as measured by its actual performance.

### 4.3 Comparison between Dubai and other GCC regulations

Table 3 compares the thermal transmittance (U-values) required by the regulations of the GCC countries. Since the climate of these countries is similar, the U-values should equal or very close. However, we found significant differences between the requirements of their building codes. In Dubai and Bahrain, there is one U-value for walls and another for the roofs. However, in Kuwait, the U-value depends on the type of construction. The thermal transmittance requirements different between light and heavy construction and between walls with exterior light or dark colors. The KSA has three climatic zones (main area, north, and mountain), and rightly, each of them has theirs on requirements. We utilized the requirements of the main area for the comparisons. Bahrain's regulation is the least restrictive, which can be explained by the fact that its regulation is not focused on energy efficiency. In general, Dubai's values fall in the mid-range of the countries that we compared. Finally, as mentioned, Qatar's regulations are based on performance and not on the properties for building elements.

Table 3: Comparison of opaque buildings' envelope requirements in the GCC.

| Country | Regulation | Year | Average U-value ($W/m^2K$) | | | | Ref. |
|---|---|---|---|---|---|---|---|
| | | | External walls | Roof | Floor | Basement walls | |
| Dubai | Al Sa'fat[a] | 2014 | 0.57 | 0.30 | - | [b] | [16] |
| Kuwait | Energy Conservation Code of Practice | 2014 | 0.227–0.568[c] | 0.155–0.397[c] | [d] | - | [5] |
| Kingdom of Saudi Arabia | Saudi Green Building Code | 2019 | 0.34–0.45[e] | 0.2–0.27[e] | - | - | [6] |
| Kingdom of Bahrain | Unified Guidebook of Building Permit Regulations | 2019 | 0.75 | 0.6 | - | - | [18] |

[a]Individual Private Villas are exempt if 200 mm thermal blocks with a U-value of maximum 0.5 $W/m^2K$ are used.
[b]The floors are in contact with the ground, the insulation should only be applied to 1 m in from the perimeter of the building.
[c]U-value of the external wall varies depending on the construction (very light to heavy construction) and wall color (light to dark exterior color).
[d]floors exposed to ambient conditions shall be treated as roofs, and partitions exposed to non-air-conditioned areas shall be treated as walls for U-values requirement.
[e]Dependent on the different zone classifications within the country.

Table 4: Comparison of the translucent envelope requirements in the GCC.

| Emirate | Regulation | Year of mandate | Average U-value ($W/m^2K$) | | | SHGC | Ref. |
|---|---|---|---|---|---|---|---|
| | | | Glazed walls and windows | | Skylights | | |
| Dubai | Al Sa'fat | 2014 | ≤ 40%<br>40%–60%<br>≥ 60% | 2.1<br>1.9<br>1.9 | 1.9 | ~ 0.35[c]<br>~ 0.28<br>~ 0.22 | [16] |
| Kuwait | Energy Conservation Code of Practice | 2014[d] | ≤ 15%<br>15%–50%<br>≥ 50% | 3.61<br>3.33<br>2.0 | - | 0.4<br>0.25<br>0.23 | [5] |
| Kingdom of Saudi Arabia | Sustainable Building | 2018 | 25% | 2.67 | 4.26 | 0.35 | [6] |
| Kingdom of Bahrain | Unified Guidebook of Building Permit Regulations | 2019[d] | ≤ 40%<br>≥ 40% | 2.1<br>1.9 | - | - | [18] |

[a]The average U-value and the SHGC of the glazed walls and windows depends on the percentage of the total area of the external walls that let in light.
[b]SHGC will differ for walls and roofs depending on the average percentage of the area that allows light to pass. conditioned floor area.
[c]The SHGC was calculated by multiplying the Shading Coefficient with 0.87 [32].
[d]Year of the latest edition.

Table 4 compares the U-values of the Glazed walls, windows, and skylights as well as the Solar Heat Gain Coefficient (SHGC) of Dubai and the building codes of the GCC countries. The U-values for Dubai and Bahrain are almost equivalents, alternating between 2.1 and 1.9 $W/m^2K$ for glaze walls and windows. And, in that case, Kuwait has a more relaxed threshold in place, allowing a U-value up to 3.61 W/m$^2$K for some cases. However, Kuwait requires the lowest SHGC value 0.25 for the most common sizes, 15% to 50% of glazing. And Dubai requires the lowest SHGC value for ample glazings, 0.22 for 60% glazed areas or larger.

## 5 DUBAI AND OTHER EMIRATES BUILDING REGULATIONS

### 5.1 Other building regulations in the UAE

The Abu Dhabi Urban Planning Council launched the Estidama – Green Buildings Regulations in 2008, and two years later, the Estidama Pearl Rating System [8]. This sustainable building rating system has four pillars environmental, economic, social, and cultural. The rating system has five levels. Buildings that comply with all the mandatory requirements get the level 1 Pear. Starting in September 2010, all new applicable buildings must meet the 1-Pearl, and all government-funded buildings must achieve a minimum 2-Pearl rating.

The Estidama includes documents for four rating options: Pearl Villa Rating System, Building Rating System, Pearl Community Rating System, and the Public Realm Rating System. And, similarly to the Al Sa'fat regulation, one of the seven Pearl Rating System is "Resourceful Energy". This category deal with the buildings' energy conservation, energy efficiency, and renewables, as well as with the improvement of social awareness, monitoring, and reporting [8].

The Ras Al Khaimah government launched the Barjeel – Green Building Regulations in 2018, under the RAK Energy Efficiency and Renewable Energy Strategy 2040, as part of its energy and water savings initiatives [11]. Barjeel regulates all new buildings in the Emirate of RAK, including the economic and free zones. Barjeel sets minimum requirements for different building types. The regulations target five main areas, two of which are related to energy use and harvesting: energy efficiency and renewable energy. During its first year, its compliance was voluntary. However, from January 2020, its requirements are mandatory for all new construction [11].

### 5.2 Comparison between Dubai and other emirates regulations

Table 5 shows the maximum thermal transmittance (U-value) for opaque envelopes of the different emirates' green building codes. The weather of the three emirates is very similar. However, their stringency levels vary. The newer regulations included new requirements and are generally more stringent. Barjeel's requirements for the roof are the same as the Al Sa'fat, but when it comes to the wall, it is more exigent. The current version of Estidama came approximately two years after Al Sa'fat and introduced more restricted requirements than Barjeel and Al Sa'fat. The cooling demand of the buildings that follow the current version of Estidama will be lower than the ones following other UAE regulations.

In Table 6, we compare the U-values and Solar Heat Gain Coefficients (SHGC) of the different emirates green building codes. Al Sa'fat requirements for glazed walls and window is more restrictive than both Estidama and Barjeel. However, there is no significant difference between them. Al Sa'fat mandates the U-values to be between 1.9 and 2.1 W/m$^2$K, and the other Emirates regulations require 2.2 W/m$^2$K. For skylights, Al Sa'fat and Barjeel establish a threshold of 1.9 and 1.8 W/m$^2$K, respectively, and Estidama is less restrictive as it requires 2.2 W/m$^2$K. Al Sa'fat relates the U-value of the glazed wall and windows to the window-to-

Table 5: Comparison of the opaque envelope requirements in the UAE.

| Emirate | Regulation | Year of mandate | Average U-value (W/m²K) | | | | Ref. |
|---|---|---|---|---|---|---|---|
| | | | External walls | Roof | Floor | Basement. walls | |
| Dubai | Al Sa'fat[a] | 2014 | 0.57 | 0.30 | - | [b] | [16] |
| Abu Dhabi | Estidama[c] | 2016 | 0.32 | 0.14 | 0.15 | 0.28 | [8] |
| Ras Al Khaimah | Barjeel | 2020 | 0.48 | 0.30 | - | - | [11] |

[a]Individual Private Villas are exempt if 200 mm thermal blocks with a U-value of maximum 0.5 W/m²K are used.
[b]The floors are in contact with the ground, the insulation should only be applied to 1 m in from the perimeter of the building.
[c]Glazed-elements with back insulated panels must be treated as walls (and therefore must meet the performance requirement for walls.

Table 6: Comparison of the translucent envelope requirements in the UAE.

| Emirate | Regulation | Year of mandate | Average U-value (W/m²K) | | | SHGC | Ref. |
|---|---|---|---|---|---|---|---|
| | | | Glazed walls and windows | | Skylights | | |
| Dubai | Al Sa'fat | 2014 | ≤ 40% | 2.1 | 1.9 | ~ 0.35 [c] | [16] |
| | | | 40–60% | 1.9 | | ~ 0.28 | |
| | | | ≥ 60% | 1.9 | | ~ 0.22 | |
| Abu Dhabi | Estidama [d] | 2016 | | 2.2 | 2.2 | 0.30 | [10] |
| Ras Al Khaimah | Barjeel | 2020 | | 2.2 | 1.8 | 0.30 | [11] |

[a]The average U-value and the SHGC of the glazed walls and windows depends on the percentage of the total area of the external walls that let in light.
[b]SHGC will differ for walls and roofs depending on the average percentage of the area that allows light to pass conditioned floor area.
[c]The SHGC was calculated by multiplying the Shading Coefficient with 0.87 [32].
[d]Glazing area must be less than 15% of the conditioned floor area.

wall ratio, while Estidama establishes that the glazing area must be less than 15% of the conditioned floor area.

Al Sa'fat establishes the minimum energy efficiency requirements of HVAC and other requirements as zones subdivisions and controls. As shown in Table 6, Estidama in Abu Dhabi, the air conditioning system must have a minimum coefficient of performance (COP) of 3.4. Al Sa'fat stipulates that the ventilation energy recovery systems must be provided in all new buildings where the need for treated outdoor air exceeds 1,000 l per second. In this case, these systems must handle at least 50% of the total exhausted air and should have at least 70% sensible load recovery efficiency (DGBC). Table 7 also shows the significant differences in terms of minimum COP for air-cooled air conditioners. Abu Dhabi's Estidama seems to be the most updated with the progress of AC system efficiency.

## 6 COMPARISON WITH UAE EARLY ADOPTERS OF THE NZEB CONCEPT

As early adopters of Nearly and Zero Energy Buildings in the UEA, we selected three residential projects: The Sustainable City in Dubai (a real estate success), the Masdar City Eco-villa in Abu Dhabi (demonstrate economic feasibility and availability of the necessary materials and equipment in the local market), and the Mohammad Bin Rashed Space Center Autonomous House in Dubai (prototype of the passive house concept and positive energy buildings).

Table 7: Air conditioning and energy recovery ventilation requirements in the UAE.

| Emirate | Regulation | Year of mandate | Air conditioning | Ventilation | Ref. |
|---|---|---|---|---|---|
| | | | Minimum COP | Sensible load recovery efficiency | |
| Dubai | Al Sa'fat | 2014 | 2.8[a] | 70% | [16] |
| Abu Dhabi | Estidama | 2016 | 3.4 | – | [8] |
| Ras Al Khaimah | Barjeel | 2020 | 2.37 | 70% | [11] |

[a]COP requirement varies depending on the type of equipment.

### 6.1 Early adopters of the Nearly and Zero Energy Buildings in the UAE

The Sustainable City in Dubai serves as a comprehensive sustainable community comprised of 500 villas, 89 apartments, a mixed-use development, an urban farm, an equestrian club, and a school. TSC considers social, economic, and environmental sustainability. The villas' design utilizes both passive strategies and highly efficient systems, resulting in 65% lower Electricity Use Intensities (EUI) than similar villas in Dubai [9], [33]. The four-bedroom villas consuming about a 100 kWh/$m^2$ year and have a PV system able to generate 40% of their total energy demand.

Masdar City's Eco-Villa puts forward a residency equipped to the needs and expectations of the typical Emirati family in a highly energy-efficient structure. They constructed its walls using Insulated Concrete Forms (ICF), resulting in low thermal transmission opaque envelope. Having the goal to maintain the consumption below to 97 kWh/$m^2$ year, this house also includes high-efficiency equipment and energy management systems. Additionally, it has a PV system able to generates 102% of the house energy demand. On the other hand, 90% of the materials used within the construction of the project were locally sourced. That points out that the UAE market is ready to supply the necessary materials to the nZEB buildings [34].

MBRSC Autonomous House is an ambitious early adopter of ZEB, showcasing the strides that can be achieved within the path of energy efficiency. Standing at a two-floor office structure, passive elements such as the geometry alongside the orientation of the building helps reduce the primary energy consumption. A highly efficient air-cooled electric chiller efficiently delivers cooling loads to the building. Moreover, a PV field producing 40 kW in addition to a 48 kWh battery storage generates enough power to fulfill the demands of the building, enabling the building to produce more energy than it consumes, and granting it the title of a positive energy building [35].

As seen in Table 8, the early adopters prove to be highly efficient and cover all or a significant portion of its annual energy with renewable energy produced on-site.

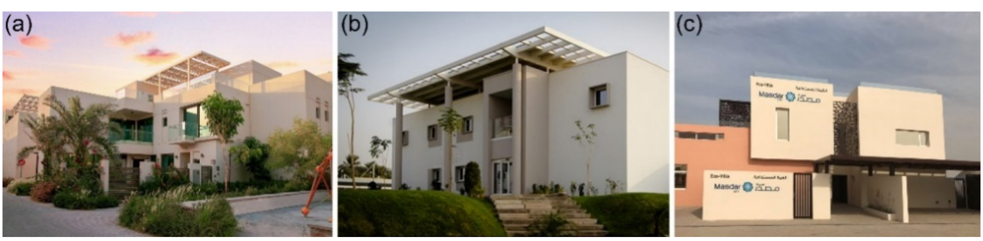


Figure 6: Early adopters of the nZEB and ZEB in the UAE. (a) The Sustainable City – four-bedroom villa; (b) Masdar – Eco Villa; and (c) MBRSC Autonomous House. *(Source: Diamond Developers, MBR Space Center, and Masdar City.)*

Table 8: Minimum air conditioning and energy recovery ventilation requirements.

| Early adopter | City | Area ($m^2$) | Consumption ($kWh/m^2year$) | PV installed (kWp) | Share of renewables (%) | Ref. |
|---|---|---|---|---|---|---|
| The Sustainable City | Dubai | 433[a] | 100[a] | 9.8[a] | 40[a] | [9], [33] |
| Masdar City – Eco Villa | Abu Dhabi | 405 | 97 | NIA[b] | 102 | [34] |
| MBRSC Autonomous House | Dubai | 550 | 42[c] | 40.0 | 187 | [35] |

[a]Information based on 2018 data of 4-bedroom villas, using a sample size of 53% (120 units).
[b]As per Masdar City documents, the villa has 89 PV panels with an output of 40,000 kWh year.
[c]Used as an office, without the typical use of the kitchen, laundry, and bathroom a house.

Table 9: Comparison between Dubai and ZEB early adopters' envelope regulations.

| Emirate | Regulation/case study | Year of mandate | Average U-value ($W/m^2K$) | | | | Ref. |
|---|---|---|---|---|---|---|---|
| | | | External walls | Roof | Floor | Basement. walls | |
| Dubai | Al Sa'fat[a] | 2014 | 0.57 | 0.30 | - | [b] | [16] |
| Dubai | The Sustainable City | 2015[c] | 0.32 | 0.20 | 1.3 | - | [9], [33] |
| Dubai | Autonomous House (MBRSC) | 2016[c] | 0.063 | 0.061 | 0.7 | - | [35] |
| Abu Dhabi | Eco-Villa (Masdar city) | 2017[c] | 0.16 | - | - | - | [34] |

[a]Individual Private Villas are exempt if 200 mm thermal blocks with a U-value of maximum 0.5 W/m²K are used.
[b]The floors are in contact with the ground; the insulation should only be applied to one meter in from the perimeter of the building.
[c]Year of construction.

### 6.2 Comparison between Dubai regulations and the early adopters of the ZEB in the UAE

The U-values of the wall and roof, seen in Table 9, of the Sustainable City villas, exceed Al Sa'fat requirements, and are close to complying with the Estidama regulations. However, they were designed more than a year before. Having a successful real estate project developed with U-values lower than Al Sa'fat indicates that the market can accept more restricted requirements for the buildings' opaque envelope. The Autonomous House, on the other hand, has a U-value significantly lowers than the other early adopters and the regulations in the UAE. This fact shows that voluntary certifications for the buildings in the UAE can suggest values that drastically exceed the current energy conservation codes.

Similarly, as Table 10 shows that windows in The Sustainable City villas have a U-value that is much lower than that of Al Sa'fat. This fact also indicates that there is a margin to revise the current Dubai green buildings regulations. As anticipated, the Autonomous House proves to have the lowest U-value glazing of 0.7 $W/m^2K$. But reach these values are only possible using triple glazing, cavities filled with inert gasses, Low-E coatings, and very efficient frames.

Table 10: Comparison between the U-value of translucent building envelopes.

| Emirate | Regulation/case study | Year | Average U-value (W/m$^2$K) | | | SHGC | Ref. |
|---|---|---|---|---|---|---|---|
| | | | Glazed walls and windows | | Skylights | | |
| Dubai | Al Sa'fat | 2014 | ≤ 40% | 2.1 | 1.9 | ~ 0.35[c] | [16] |
| | | | 40–60% | 1.9 | | ~ 0.28 | |
| | | | ≥ 60% | 1.9 | | ~ 0.22 | |
| Dubai | The Sustainable City | 2015[d] | | 1.3 | - | - | [9], [33] |
| Dubai | Autonomous house (MBRSC) | 2016[d] | | 0.7 | - | 0.29 | [35] |

[a]The average U-value and the SHGC of the glazed walls and windows depends on the percentage of the total area of the external walls that let in light.
[b]SHGC will differ for walls and roofs depending on the average percentage of the area that allows light to pass conditioned floor area.
[c]The SHGC was calculated by multiplying the Shading Coefficient with 0.87 [32].
[d]Year of construction.

Table 11: Recap of best values found in the GCC building regulations and the early adopter of the nZEB in the UAE. For the units of the values, refer to the previous tables. *(Source: Authors, from [5], [8], [9], [11], [25], [31], [33]–[35].)*

| | Dubai's regulation | | Best regulation in the GCC | | | Nearly zero energy early adopter | | | Zero energy prototype (MBRSC) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Value | % | Value | % | Country/City | Value | % | Adopter | Value | % |
| Wall U-value | 0.57 | 100 | 0.426[a] | 134 | Kuwait | 0.16 | 356 | Eco Villa | 0.063 | 905 |
| Roof U-value | 0.3 | 100 | 0.199 | 151 | Kuwait | 0.2 | 150 | TSC | 0.061 | 492 |
| Glazed walls and windows U-value | 1.9[b] | 100 | 1.9 | 100 | Dubai and Bahrai28n | 1.3 | 146 | TSC | 0.7 | 271 |
| SHGC | 0.28[c] | 100 | 0.25[d] | 100 | Kuwait | - | - | - | 0.29[e] | 121 |
| HVAC COP | 2.8[f] | 100 | 3.4 | 121 | Abu Dhabi | 3.9[g] | 163 | Eco Villa | - | - |
| Sensible load recovery efficiency | 70% | 100 | 70% | 100 | Dubai/RAK | - | - | - | - | - |

[a]This value was selected based on the average U-value, specifically for medium construction, dark external color.
[b]Based on the U-value taken at the glass area percentage between 40% and 60%.
[c]Based on the SHGC taken at glass area percentage between 40% and 60%.
[d]Based on the SHGC taken at glass area percentage between 15% and 50%.
[e]The window glass area percentage is very low on the MBRSC prototype. Thus, it is compared to the Dubai Regulation's SHGC value of 0.35.
[f]COP requirement varies depending on the type of equipment.
[g]Two variable refrigerant flow cooling systems for this villa were studied [36].

# 7 OPPORTUNITIES FOR THE NEXT UPDATE OF THE DUBAI REGULATIONS

Table 11 shows the regulations set within Dubai and compares them to the most restrictive regulations found in the GCC as well as the early adopters present in the UAE. The values for the Al Sa'fat regulations in Dubai are listed, then the strictest regulation value and its subsequent percentage increase from the Al Sa'fat code as well as its belonging county. For the nZEB early adopters, the better performer between the Masdar Eco Villa and The Sustainable City was chosen based on their specific performance in each category.

Additionally, the MBRSC Autonomous House was selected to represent the Zero Energy Prototype, as shown in Table 11. The U-values of the wall and roof were both prevailed by the Kuwaiti regulations code, which had the lowest average for minimum U-value in their regulations. It is important to note that in other categories of construction, the Kuwaiti code could call for either a lesser or higher U-value benchmark for the building model; however, the average values were selected for the comparison in this table. As for the nZEB early adopters, the Eco Villa and TSC both prevailed in different compartments within the compared properties, showing their strides in energy efficiency. Finally, the comparison between the Dubai building code and the MBRSC Zero Energy Prototype sheds light on the extent of the performance of the prototype, with the U-value of the wall exceeding nine times the fraction of the upper threshold set by Al Sa'fat.

## 8 CONCLUSIONS

In the middle East, several governments are implementing policies to promote a more sustainable built environment. In the GCC countries, these efforts have become more intense over the last decade, with the launch of new or updated building codes and with the creation of Demand Side Management strategies. Essential actions for the transition to the zero net emissions and carbon neutrality.

In our study, we provided an overview of the GCC countries' regulations comparing them to each other and the actual building performance of early adopters of nZEB. The differences found between them are a valuable source of information for the revision of the current regulations and the progressive changes toward the nZEB buildings. In the case of Dubai, we found that the government has implemented a very complete Demand Side Management program that has the buildings, responsible for the 86% of the electricity consumption, as its focus. Some of the implemented actions to accelerate the transition to the city decarbonization are the revision of the electricity and water tariff, the building retrofits program (Etihad ESCO), the impulse of the district cooling, the distributed generation, the creation of the Shams Dubai program, and the development of the Dubai Green Buildings Regulations and Specifications. Regarding the regulations and the reduction of cooling energy demand, we have found the following opportunities:

- Thermal insulation requirements of the building opaque envelope. The required U-values can be more restrictive, in a conservative way, moving from the current 0.57 and 0.30 $W/m^2K$ for walls and roofs to 0.42 and 0.20 $W/m^2K$ as in the Kuwait regulation. Or being more demanding and establish a limit for the walls equal or close to 0.16, as in the Masdar City Eco Villa. The value for roof and walls of the MBRSC Autonomous House (0.06 $W/m^2K$) can be used for voluntary requirements and to provide recognition to outstanding buildings.
- The glazing thermal transmittance requirements. Similarly, the U-values of the glazing systems might conservatively change form 1.9 $W/m^2K$ to 1.5 $W/m^2K$, surpassing the other GCC codes, or be lowered to 1.3 $W/m^2K$ as in the villas of The Sustainable City. Values below 1.1 $W/m^2K$, as in the MBRSC house (0.7 $W/m^2K$), requires highly efficient triple glazing. Adequately designed buildings, in most cases, will not need these outstanding solutions to get adequate performance.
- The glazing solar heat gain coefficient (SHGC). Due to the high temperatures and solar radiation that characterizes the region, the SHGC value is also very relevant facto. The current Dubai regulation already has a low value (0.28) for 40–60% glazed area, surpassed only by Kuwait, with 0.25 for 15% to 50%.

- Coefficient of Performance (COP) of the air conditioning. The efficiency of the HVAC systems has noticeably increased in the last years, which offers an excellent opportunity to reduce the buildings' energy efficiency. The current COP requirement of the water chiller package varies depending on the type of equipment, starting from 2.8. However, the air conditioning system must have a minimum coefficient of performance (COP) of 3.4, as the Estidama Pearl system.

Our future works will include the energy-saving and the economic analysis of the potential regulations' changes, inferred by this comparative study. There are two other relevant aspects of the evolution of the current codes that require further research. One is the transition from prescriptive to mix regulations (prescriptive/performance), as have been already done by Qatar. And the other is to evaluate the benefits of different codes for non-residential and residential (including low rise buildings), as per the ASHRAE model. The Kingdom of Saudi Arabia used this model.

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