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# Challenges of retrofitting affordable housing to net-zero carbon in the United Arab Emirates

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**Abstract.** Following the Paris Agreement, several governmental bodies in the United Arab Emirates (UAE) started working on further initiatives to improve the energy efficiency of buildings. Some of these hope to target net-zero carbon for new and existing buildings. As in most countries, the stock of existing buildings represents the bigger challenge for this target. In particular, existing affordable housing is the most challenging segment of the building stock. The limited access to expertise and financial resources makes it more difficult for owners of these buildings to retrofit them. Therefore, there need to be appropriate guidelines on how to achieve net-zero carbon in such building typology. This paper identifies both the technical and the financial challenges when trying to develop such guidelines within the context of the UAE. It also discusses the possible solutions that can be used to overcome some of these challenges. The technical challenges include the variation in construction systems, and the quality of construction for these buildings. It also includes energy modelling challenges such as selecting relevant weather data, and defining the patterns of using electricity for the different functions. The financial challenges include the subsidized price for electricity, the cost estimation for various energy conservation methods, and the payback for installing local renewable energy sources. Finally, the paper suggests a path for research activities to address these challenges and to develop the guidelines.

## 1. Introduction

The United Arab Emirates (UAE) is committed to reducing its per capita carbon footprint. This is reflected in its signing of the Paris Agreement on Climate Change and in various short and medium term strategies published by the country and many of its emirates. One of these strategies is reducing the demand-side of energy. As the building sector is the largest consumer of energy in the country, many regulations and rating systems that support lowering the energy consumption of newly constructed buildings were developed and are being enforced by the different emirates. An example is the *Estidama* rating system in Abu Dhabi [1], *Al Sa'fat* rating system in Dubai [2], and *Barjeel* regulations in Ras Al Khaimah [3]. The retrofitting of existing buildings is also an important aspect of the strategy. For example, Dubai is targeting the retrofitting of more than 30,000 existing buildings and developing a market for Energy Service Companies (ESCO) to achieve its target.

Housing represents an important section of the stock of existing buildings in the UAE. In Dubai, for example, statistics show that individual villas represent about 77% of the number of buildings [4]. Residential consumption is about 32% of the energy consumed in that Emirate [5]. Affordable housing is a segment of these residential buildings. The term “affordable” housing is a relative term and depends on where it is used. For the purpose of this work, an affordable house is a house that is owned



by a UAE citizen through government support. This support can be through providing land and/or finances. Tens of thousands of such houses were built and are being built through some government programs [6], [7]. An affordable house for a UAE citizen is typically a detached or semi-detached villa of one or two floors occupying roughly 30% to 45% of its plot. The area of a villa is roughly between 250 to 500 m<sup>2</sup>. The cost is roughly in the range of US\$ 300K to 600K. Figure 1 shows a sample of a group of these villas forming a small community. Electricity is also subsidized for the occupants of these houses in most emirates. The subsidized charge is about US\$ 0.02 to 0.03 per kWh. In addition, regulations regarding energy efficiency were non-existing for a long period of time resulting in high consumption of electricity in these villas. A study by Al Awadhi et al. for five villas in the UAE, each representing the most common types of villas in each decade starting from the 1970s until the 2010s shows energy use intensity (EUI) from 602 to 371 kWh/m<sup>2</sup>/year [8]. The same study showed a potential saving that can reach 30% if these villas were built with a reasonable level required by the green building codes available at the time of the study.



**Figure 1** A Google Map for a sample of a residential community in the UAE.  
(Image © 2019 DigitalGlobe, Map data © 2019 Google)

The potential for energy saving by retrofitting these buildings is high. However, there are many challenges in trying to realize this potential. This paper discusses these challenges and the possible solutions to overcome some of them. The paper starts with examining the feasibility of achieving different low energy targets for a house in the UAE. It then discusses the technical and financial challenges to achieving a target. Finally, it recommends a line of studies that support developing guidelines to define and achieve the target.

## **2. Feasibility of Zero Net**

It is important to define the terms that are used as targets before studying the feasibility of achieving such target. In this paper, the following terms are defined as:

A Zero Energy (or a Zero Net-Energy) (ZNE) building is an "*ultra-low energy building that consumes only as much power as is generated onsite through renewable energy resources over the course of a year*" [9].

A Zero-Net Carbon (ZNC) is "*a highly energy efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually*" [10].

A Nearly Zero Energy Building (nZEB) is defined by the Emirates Green Building Council for the case of the UAE as "*a highly energy efficient building with a site EUI less than 90 kWh/m<sup>2</sup>/year and covers a significant portion of its annual energy use by renewable energy sources produced on-site or off-site*" [11].

The difference between a ZNE and a ZNC building is that the latter can procure renewable energy from off-site sources while the first cannot. The difference between a ZNC and an nZEB building is that the latter can use energy generated from non-renewable sources while the first cannot. All these buildings are connected to an electric grid and the calculations of net-energy are done on an annual basis. The author starts by examining the feasibility of having a ZNE house in the UAE. This is followed by examining the possibility of having a ZNC house. Finally, it discussed the possibility of having an nZEB.

### 2.1. Zero Net-Energy

To examine the feasibility of having a ZNE house in the UAE's harsh climate and high standards of living, one needs to find a reasonable number to represent the EUI for an affordable house in the country. Unfortunately, very little information is available on this. However, some studies were done on existing residential villas that can give some guidelines on a possible EUI in the UAE.

Friess et al. studied a villa that was constructed in 2009 from a project that had one thousand villas with the same model [12]. It is a two floor, semi-detached villa with an envelope that followed the municipality requirements at the time. They considered this villa to be representative of villas built in Dubai at the time. They found out that the EUI is 194 kWh/m<sup>2</sup>/year from the utility bill. They were able - through simulation - to reduce this EUI by about 23% by just insulating the reinforced concrete elements that represented thermal bridges in the envelope (e.g. R.C. columns). Adding 160mm of external insulation reduced that further to almost 30%.

The author studied the energy bills for 132 attached villas of various sizes. They are all with two floors and located in Sharjah, UAE. They were built in a span of 10 years starting from 1997. The results show that the older villas use an average of 185 kWh/m<sup>2</sup>/year while the newest ones that used a bit more insulation use an average of 140 kWh/m<sup>2</sup>/year.

The Emirates Green Buildings Council conducted a study using estimated energy consumptions from five villas that were to start being built in 2017 [11]. The range of EUI varied from 44 to 119 with a median of 98.8 kWh/m<sup>2</sup>/year. The study also included a survey of professionals about the feasible level of EUI in the UAE. They concluded that 90 kWh/m<sup>2</sup>/year is achievable for residential and office buildings.

Another study for the feasibility of achieving ZNE buildings in the UAE climate category concluded that it is feasible to reach 95 kWh/m<sup>2</sup>/year for an apartment building (not a villa) [13]. The study used 30 energy efficient measures to minimize energy use without considering their cost implications.

From the mentioned values for EUI in different studies, it seems reasonable to consider the value mentioned by EGBC (90 kWh/m<sup>2</sup>/year) as a feasible EUI value for a low-energy villa in the UAE.

From the other side, one needs to estimate the possible energy that can be generated/captured on a site in the UAE. Villas are typically able to do that through solar energy only. This can be in the form of photovoltaic (PV) panels or thermal solar collectors. For simplicity, we will assume the use of PV panels only.

The study by the EGBC mentioned that the five newly built villas in the UAE that voluntarily reported their data showed electricity generations of about 0, 55, 80, 95, 115 kWh/m<sup>2</sup>/year. It is not clear how the volunteers calculated these values for their villas. With such large differences, it is expected that this is the electricity each generated divided by the total floor area of the villa. We are interested here in calculating the potential of generating electricity on one square area of a horizontal building roof. To do this, the author uses the PVWatts Calculator tool developed by the National Renewable Energy Laboratory [14]. The weather data of Abu Dhabi (the capital of the UAE) airport is used and horizontally installed fixed standard PV panels are assumed. Default data for system losses

and efficiency are used. The result shows that producing about 210 kWh/m<sup>2</sup>/year of alternative electric current is expected from the PV panels. This estimation for electricity generation can be used in relation to the considered EUI value of 90 kWh/m<sup>2</sup>/year (of total floor area). By dividing 210 by 90, one can conclude that it is possible in the UAE climate for roof-installed PV panels to provide the electricity needs for a villa with two floors. Hence, it is feasible - at least in theory - to operate such a villa as a ZNE villa.

It is worth mentioning that a villa named the “Passive Autonomous House of Mohammed Bin Rashid Space Center” is in operation in Dubai [15]. It is a two-floor villa and fully operational off-grid using the PV panels installed on its roof. It was built for demonstrating the possibility of such operations and the cost did not seem to be an issue.

## 2.2. Zero-Net Carbon

In their study of existing - and relatively old - affordable villas in the UAE, Al Awadhi et al. reported an EUI of 371 to 602 kWh/m<sup>2</sup>/year [8]. These are very different EUI's than the 90 kWh/m<sup>2</sup>/year mentioned by the EGBC for newly constructed villas. This is why there is a large potential for energy saving through retrofitting these types of buildings in the UAE. Yet, it may prove to be cost prohibitive for many of the existing buildings to reach the EUI value of 90 kWh/m<sup>2</sup>/year and install PV panels to become ZNE buildings.

Therefore, it is expected that many of the retrofitted villas will require procuring renewable energy from outside the building site and hence become ZNC buildings. In the UAE, procuring renewable energy can be done in a variety of ways:

1. Using roads solar panels to generate energy at the community level. This seems to be promising considering that neighborhoods in the UAE tend to have no or very little trees that cast shadows on the street (see Figure 1). This can provide about 50% additional solar energy to those provided by PV panels installed on the roof for a typical arrangement.
2. Using solar panels installed on buildings in the community that have large roofs and seasonal use such as local schools.
3. Using solar panels installed on parking areas of buildings with cyclical use such as local mosques and recreational centers.
4. Making use of a program in Dubai that provides renewable energy credits. The program allows building owners to buy these credits and cover the energy that they cannot generate on their building site [16]. This program should be viewed in relation to the operation and continued construction of a 5000 MW solar park in Dubai. The park will provide many of these credits.

Because of the abundance of solar energy in the UAE, it seems feasible to retrofit many of the existing residential buildings to ZNC. The cost implication certainly needs to be studied.

## 2.3. Nearly Zero Energy Building

An nZEB can use non-renewable energy to cover its needs. However, according to the definition by the EGBG, such a building in the UAE should not be using more than 90 kWh/m<sup>2</sup>/year. It may prove cost prohibitive to retrofit old villas to that level of EUI.

From the above discussions of ZNE, ZNC, and nZEB, the author believes that having ZNC as a target would be the most feasible for retrofitting affordable housing in the UAE. Yet, this needs to be further studied to reach a definite conclusion.

## 3. The challenges of retrofitting

Many of the affordable houses in the UAE were built at times when energy conservation was not an issue of consideration. Building regulations that aim to conserve energy hardly existed in the UAE before the year 2000 and it took about 10 years after that to reach adequate standards. These regulations are getting better with time. Now with government commitments to reduce countries' carbon footprint and adhere to the Paris Agreement goals, retrofitting of these houses needs to be addressed.

The author suggests an approach where the current stock of affordable housing is classified into categories. Each category includes houses that were built using certain construction materials and building technology. It is common that during a period of time, a limited number of materials and technologies dominate the affordable housing market because of a variety of reasons including the cost. For each of the identified categories, a cost-optimal level should be defined following the example of the European Union [17]. This is combined with a retrofitting strategy that defines a set of energy conservation measures suitable for the category.

The author is investigating the possibility of using this approach for a group of 48 identical villas. These are attached two-floor villas in 8 separate clusters and with four different orientations. They were constructed between the years 1998 and 2000. Energy modeling is used to simulate the energy behavior of a representative villa (reference building). Several energy conservation measures are identified and tested. While this research is still ongoing, there are clear challenges that appear in the process. These challenges will face any efforts to address the retrofitting of housing projects in the UAE. The challenges can be categorized into technical ones and financial ones even though some of these challenges cross both categories.

### *3.1. The technical challenges*

The availability of the technical data is an important challenge. The villas were constructed from very simple drawings with hardly any details or written specifications. The trades' rules-of-thumb were used. Through the author's interviews with contractors working in the country at the time, information on walls and roof layers were collected to a reasonable quality. Properties of glass and window frames are estimated through visual investigation. Air leakage values were roughly estimated through visual appreciation of building components such as gaps in the window frames. Certainly, with more resources, these technical data can be identified more accurately using various technologies. Then, a reference building can be constructed digitally from this data. It would be reasonable to assume that this reference building represents most villas built at the same time. The impact of factors such as building orientation, size, and external shading elements should be studied and some correction factors may be used for a specific villa under study.

The more challenging aspect is estimating occupants' behavior in terms of plug loads, schedules of use, and control of systems (e.g. thermostat setting). Within the 48 villas studied, there are significant differences in electricity bills even with buildings having an identical orientation and similar external shading elements. The difference can be attributed mainly to variations in occupants' behavior. The UAE does not have relevant surveys similar to the "Household Electricity Survey" of the UK [18] or the "Residential Energy Consumption Survey" of the USA [19]. There is also no existing research work to estimate occupants' behavior like that done for Egypt [20]. Collecting this data seems to be a pressing issue for the UAE to support an appropriate retrofitting strategy. The author suggests that this is done first by categorizing affordable housing into groups based on aspects such as the number of occupants, building size, and household income. Then, sub-meters and other measurement tools are used to monitor energy related to users' activities in sample buildings within each category. The data is analyzed and patterns of occupants' behavior are defined for each category.

Sub-meters are also useful to measure the electric consumption of different systems, sub-systems, and specific equipment in sample buildings. This detailed data are very useful in performing the very challenging task of calibrating an energy model. Software are available now to make use of the detailed measurements to adjust various data in the energy model to be as close as possible to the modeled building. A well-calibrated model is necessary to estimate the energy saving impact of any combination of energy conservation measures. The estimated saving is key in determining the cost-optimal level and the retrofitting strategy for each category of housing.

The availability of the hourly weather data - needed for energy model calibrations - is less of a challenge now for the UAE as all major cities has commercially available historical hourly data. However, files with future expected typical weather that reflects the impact of climate change are limited.

### 3.2. *The financial challenges*

The major hurdle in retrofitting affordable housing is the heavily subsidized price of electricity. With the exception of Dubai, which has electricity prices comparable to the average price in the USA, all the emirates charge only 20-30% of that price to citizens. The author's initial investigation with different energy conservation measures found that almost no measure would make economic sense with the subsidized prices.

The author suggests that the actual cost of electricity – borne by the government – should be used to investigate the cost-optimal level and hence the retrofitting strategy for each identified category of affordable housing. Following this, the government should initiate programs that gradually shift its subsidy for consumed electric energy to a subsidy for energy conservation measures. The suggestions in the following paragraphs illustrate this approach.

To reduce the consumption of artificial lighting, the government can develop a program to replace existing light bulbs with LED. It can make it a condition to continue the electricity subsidy, remove other light bulb types used in houses from the market, and imbed the replacement cost in the electricity bill for a few years. The number of years should be calculated so the owners of the houses do not see a difference in their bills. The program may also include installing occupancy and daylight sensors for light control.

A similar program can be used for replacing old appliances with high efficiency ones. As an added incentive, the government can buy back old appliances. It can recycle/upgrade them to recover some of the cost.

It also takes a very long time to recover the cost of installing PV panels on villas. To overcome this problem, installing PV panels should also be a condition for continuous electric subsidies. However, the government should allow buying back the electricity generated from them. For a few years, it can pay a price per kWh that is similar to its actual cost to generate electricity. The number of years is calculated to allow the user to recover the cost of the PV installation.

Certainly removing the subsidies on consumed energy will be very beneficial for any retrofitting program. Yet, it does not seem to be happening soon. However, it may be possible to subsidize each housing unit up to a particular EUI. This keeps the government's commitment to its citizens but also encourages them to consume energy more consciously. Spending part of the money allocated to the subsidies on school educational programs and awareness campaigns to encourage energy conservation may also prove to be cost effective.

## 4. Conclusion and Recommendations

It will be difficult for the UAE to retrofit its existing stock of affordable housing for the purpose of minimizing its energy consumption. This is due to various challenges. Perhaps the biggest challenge is the subsidized energy cost which makes improving any aspect of the energy performance of a house makes no sense for the owner. Yet, it is the quickest challenge to overcome if the government decides to change its pricing strategy. The author would argue that it is better for the government to provide its citizens with current subsidies in the form of cash payments and to raise the electricity price to actual cost. This would generate an incentive to reduce consumption and to invest in retrofitting.

Yet, even with overcoming this challenge, owners need to know where best to invest their retrofitting investments. Individual owners lack the expertise and soliciting such expertise would be too costly. Therefore, the author suggests the following studies to be done for the UAE housing stock:

1. Categorize affordable housing units based on criteria identified through the analysis of the housing stock.
2. For each category, collect the technical data needed to create a quality reference building model. This would be through studying several representative villas and should include:
  - a. Identifying the material properties through invasive and/or non-invasive technologies.
  - b. Using standard techniques to identify a representative value for air leakage.
  - c. Installing sub-meters and other measuring equipment to understand the patterns of users' behavior and the efficiency of the available systems.

- d. Identifying energy conservation measures and the cost of each measure. This should take into account the impact of having a new and large retrofitting market on lowering some prices and increasing others.
  - e. Building a reference model, applying the different energy conservation measures, identifying a cost-optimal EUI, and defining a retrofitting strategy.
3. Test the retrofitting strategy on sample buildings for each category and make any necessary corrections.

From the above studies, guidelines can be developed for each category of housing. These guidelines certainly need to reflect the government's intended strategy to price electricity.

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