



Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB)



Enas Alkhateeb^{*}, Bassam Abu-Hijleh

Sustainable Design of the Built Environment Program, Faculty of Engineering & IT, The British University in Dubai, United Arab Emirates

ARTICLE INFO

Keywords:

Energy engineering
Net zero electricity building (nZEB)
Grid-connected PV
United Arab Emirates
Retrofitting existing buildings
Passive and active measures
Energy simulation

ABSTRACT

Demand Side Management of the building sector has attracted great attention in the United Arab Emirates (UAE). However, the challenge lies in the existing buildings that form the majority of the built environment. Therefore, retrofitting the existing stock has become a priority and many initiatives have emerged to speed up the pace within the retrofit market. This paper aims to assess the potential of retrofitting an existing federal office building to a net zero electricity building through a holistic retrofit approach. Several passive and active measures are implemented in order to achieve this goal including the integration of different grid-connected photovoltaic (PV) systems.

The commercially available Integrated Energy Solution – Virtual Reality (IES-VE) building energy simulation software is used to evaluate the impact of all the implemented strategies on reducing electricity consumption in order to highlight the optimal scenario prior to introducing the PV systems. In this particular study, the implementation of active measures has proven to be more effective in reducing energy demand than passive measures. The passive strategies reduced electricity demand by 14.7%, whilst active measures reduced electricity demand by 63.2%.

A PV system was able to cover the reduced energy demand resulting in a net Zero Electricity Building (nZEB).

1. Introduction

The UAE is moving at a steady pace towards sustainable development. Many policies, regulations, and initiatives have been implemented in order to regulate the newly constructed buildings. This effort and determination was a natural response to cope with the fast pace of the building construction sector especially after the country was labeled with the highest ecological footprint in 2007 [1]. According to a survey conducted by McGraw Hill Construction on some selected countries around the world, it was found that the impact of building legislative requirements on the green building trend placed the UAE in third place regarding newly constructed buildings [2]. However, the challenges lie within the existing stock, which forms the majority of the built environment in the UAE. According to a recent survey, it was found that the existing buildings which were built prior to 2001, had no or minimal consideration of thermal resistance properties [3]. Despite this fact, retrofitting the existing building sector has shown a slow pace towards energy efficiency [2]. Lately, a new project under the title "Energy Conservation of Federal Governmental Buildings" has been established within the UAE 2021 vision and the UAE Green Growth Strategy, which

both focus on retrofitting federal and governmental building [4, 5]. It is evident that around 30–80% of energy could be reduced as a result of using green strategies in both new and existing buildings [6]. Moreover, a reduction in CO₂ level could be achieved especially if a holistic retrofit approach is considered [7].

2. Materials and methods

2.1. Energy consumption profile in the UAE

According to the latest statistics, it was found that electricity consumption in 2013 was 105.4TWh with an increment by 35.3% compared to the consumption in 2008 [8]. According to IRENA REmap UAE report [8], the total energy used for the building sector was 0.2 EJ, with the majority coming from electricity usage; it is expected to reach 0.5 EJ by 2020 and 0.7 EJ by 2030. Furthermore, a big percentage of the electricity demand in 2030 will be by commercial and residential buildings Fig. 1 shows the UAE electricity consumption in 2013 [9]. Based on the population growth rate, it is expected that the UAE population will reach 12.5 million by 2030 which is a 50% increase from 2010. A recent study

^{*} Corresponding author.

E-mail address: bassam.abuhijleh@buid.ac.ae (E. Alkhateeb).

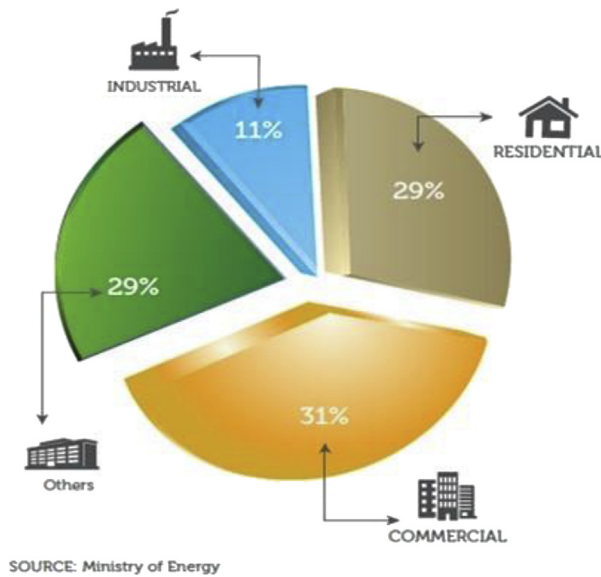


Fig. 1. Electricity consumption in the UAE by sector in 2013 [10].

published in Gulf News Energy Magazine sent a serious warning by analysts regarding the significant growth of electricity consumption. It is expected that by 2020, the UAE's gross domestic electricity consumption will reach 141 Terawatt-hours, which is equivalent to a 27% increase in consumption compared to 2014 [10].

2.2. Energy efficiency retrofit measures

Energy Efficiency is the management of energy usage in order to achieve the intended task without affecting the occupants' thermal comfort. There is a vast range of retrofit measures that can be used. These measures can be classified into three categories; passive, active, and behavioral measures. In this paper, the focus will be on the impact of the implementation of a range of passive and active measures.

Passive strategies have shown great influence on reducing the energy demand for heating and cooling purposes [11, 12, 13]. Shading elements, upgrading glazing thermal properties, and thermal insulation of the building envelope are considered among the most effective and viable passive measures. Taleb [14] has reported that implementing these passive measures in the UAE region is capable of reducing the cooling load by 23.6%. Moreover, in such a hot region, insulating the walls and roof has more impact on reducing energy demand comparing to external shading strategy [15, 16]. However, minimizing solar heat gain through providing shading elements in hot summer regions is considered a priority, and could offer energy savings that may reach up to 20% [14, 17]. Moreover, upgrading the building envelope elements' thermal insulation could reduce energy by 30% [18, 19]. However, it worth mentioning that retrofitting windows in hot climate regions recall for a lower solar heat

gain coefficient over multi-layered glazing [20]. Furthermore, solar window films have proven to be a very effective and viable measure on mitigating solar gain through windows in such hot regions [21, 22]. On the other hand, active measures have proven to be very effective strategies in reducing energy consumption. In fact, some active measures with zero initial cost such as widening the cooling or heating set point range could offer tangible savings that may exceed some physical improvements [23, 24, 25]. Moreover, the HVAC system's coefficient of performance (COP) plays a vital role in energy consumption. The higher the COP the more energy efficient the system is [26, 27].

In order to mitigate the Generation of Green House Gases (GHG), diversification in energy supply by considering Renewable Energy (RE) is among the main targeted activities in the UAE. Many policies have been implemented in order to increase the share of the RE up to 7% in Abu Dhabi by 2020 and up to 5% in Dubai by 2030 [28]. By 2030, the RE could contribute up to 10% of the final energy consumption of the UAE if some policies regarding fossil fuels are adapted [29, 30].

The UAE's geographical location has shown that solar energy is viewed as the most attractive and reliable source of RE. As a result, the Shams Dubai Rooftop Solar Photovoltaic power project was launched in Dubai in 2014. This project aims to allow Dubai's residents to install PV grid - connected system on their homes [31]. On 7 April 2019, DEWA announced that around 1,276 buildings in Dubai (residential & commercial) have installed PV systems with a total capacity of 81.3 MW [50].

Although the UAE local region had witnessed several studies that evaluated the impact of these measures in addition to their feasibility, there are no studies on the impact of a holistic retrofit approach that minimizes the energy demand to the lowest level that could be eventually supplied by onsite renewable energy. Retrofitting existing buildings in the UAE to nearly zero energy buildings (n-ZEBs) is doable especially with the available technology and the government support. This paper assesses the potential of upgrading the energy performance of an existing UAE's office federal building. The impact of an integrated passive and active retrofit measures on reducing the electricity demand is studied. Furthermore, onsite PV electricity production is introduced to minimize the reliance on grid electricity. Eventually, the annual net balance of electricity consumption is evaluated.

Life Cycle Costing (LCC) can be used to assess the economic feasibility of any proposed upgrade [52]. Proper LCC analysis is very detailed and requires extensive costing data including but not limited to: costs of the upgrade equipment, installation costs, loss of revenue during the upgrade process, changes in maintenance costs, impact on productivity, and impact on the useful life of the building. LCC was not included as part of the current research but could be considered as part of future research into the viability of different upgrading strategies.

2.3. The case study

The Ministry of Infrastructure Development (MOID) in Ras Al Khaimah (RAK) has been chosen as a case study for multiple reasons. Firstly, its modest building size suits the research time-frame. Secondly, the

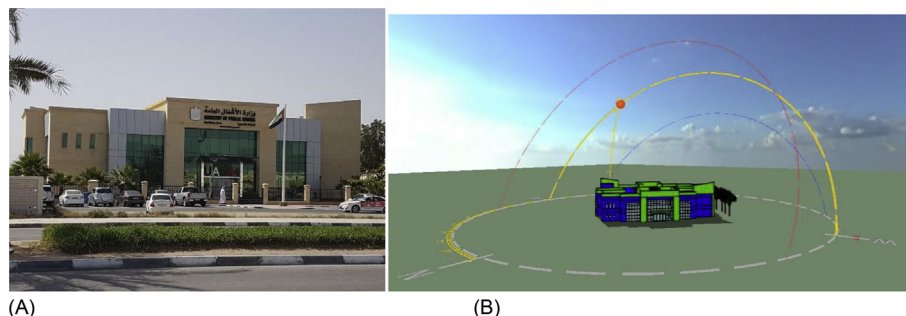


Fig. 2. The Ministry of Infrastructure Development MOID – RAK building. Actual view (A) and the IES model (B).

Table 1
Simulated energy consumption of the MOID-RAK (BAU).

Date	Total Energy (MWh)	Total Electricity (MWh)	HVAC Electricity Load (MWh)	Equipment Electricity Load (MWh)	Lighting Electricity Load (MWh)
Jan 01–31	12.325	12.161	2.682	5.413	4.229
Feb 01–28	13.888	13.740	4.736	5.124	4.028
Mar 01–31	29.575	29.411	19.075	5.868	4.632
Apr 01–30	35.823	35.664	26.201	5.393	4.229
May 01–31	51.322	51.159	41.679	5.413	4.229
Jun 01–30	64.361	64.202	54.309	5.619	4.431
Jul 01–31	75.767	75.603	66.981	4.958	3.827
Aug 01–31	77.522	77.358	67.021	5.867	4.632
Sep 01–30	70.673	70.515	61.907	4.938	3.827
Oct 01–31	49.813	49.649	40.169	5.413	4.229
Nov 01–30	35.911	35.753	25.860	5.619	4.431
Dec 01–31	14.245	14.081	4.602	5.413	4.229
Total	531.224	529.296	415.223	65.040	50.960

MOID-RAK building has been evaluated for another previous research that aimed to tackle the impact of retrofitting only the lighting system [32]. This gives an advantage of considering the result to form a complete overview for a holistic retrofit project which is needed before any installation of a RE system [33, 34]. Lastly, by choosing a federal building for a holistic retrofit study, a broader message of the country's vision towards sustainability will be delivered across the country which may increase the awareness of the private sectors, as well as individuals, towards the benefits of building retrofit. Fig. 2 (A) shows a front view for the MOID-RAK, while Fig. 2 (B) shows the IES Virtual Environment (VE) modeling and annual sun-path. IES VE will be explained in detail in the methodology section. IES has built-in weather files for many locations including the current location. These weather files include all relevant data such as temperature & humidity, wind speed & direction, solar irradiance, and rainfall.

The MOID building was built in 2010 according to the Green Buildings Guidelines (GBG) 2009. This GBG were provided to regulate the Ministry of Public Works new projects (new buildings) in the Emirates [35]. The building is located on an 80 m × 77 m plot with a total area of 2251m². It consists of G+1 levels, where the ground level occupies around 1200 m² whilst the first level area is 1083 m². The building consists of the following features:

- The external walls' area is 1308m²;
- The glazing forms around 37% of the external walls.
- The building consists of 2 receptions, 13 offices, 2 meeting rooms, a multipurpose room, a library, a nursery, and 4 storage rooms.
- The building has a central atrium that is covered with a 117 m² skylight.

The actual electricity consumption for 2015 was 568.4 MWh. This translates to an Energy Intensity (IE) of 252.5 kWh/m²/yr. This is a relatively high value compared to an EI of 110–170 kWh/m²/yr for the best practice buildings in the UAE [36].

In order to pinpoint the main source behind this high electricity demand, the base case building energy performance was simulated considering the input parameters based on the building's document. It is found that the total annual energy consumption is 547.4 MWh, around 75% of this energy is dedicated for cooling purposes. This is a higher contribution than the 57% what was reported in 2014 by Friedrich et al. [51] for non-industrial buildings in the city of Abu Dhabi-UAE. In their study, Friedrich et al. considered three types of non-industrial buildings, each with a different contribution to the total electrical load: Residential (45%), Offices (27.5%) and Retail (27.5%). Government buildings have a much different operational profile than the buildings studied by Friedrich et al. Government buildings have shorter operating hours compared to most building types; government buildings operate for 9 hrs/working day (7 AM–4 PM) and 5 working days/week excluding public holidays. Thus, internal loads such as lighting and connected loads work for about 30% of the year. On the other hand, and due to the harsh climatic

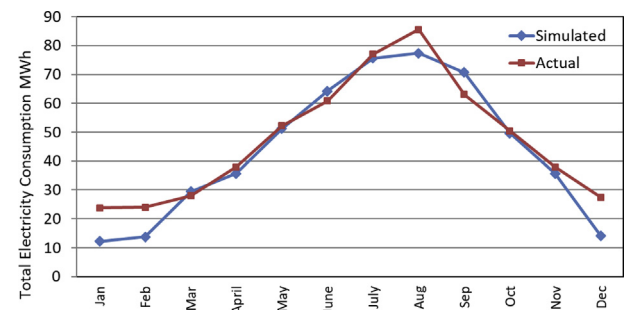


Fig. 3. IES software validation; the actual building monthly electricity consumption is compared to the IES simulation results (by the author).

conditions in the UAE, the current practice is to operate the HVAC system 24/7 year round. This would explain the high-energy consumption of the HVAC system when compared to other types of buildings.

The maximum electricity demand reaches its peak in the months of July and August as can be seen in Table 1 which shows the monthly energy consumption for the business as usual case (BAU). Although this is expected in a region with such harsh weather, the percentage is higher than average electricity consumption [32]. The high electricity demand could be justified due to the HVAC system's continuous operation profile in 2015 where it worked for 24 hours year-round. Managing the HVAC system performance from different angles is very important when it comes to energy efficiency. By doing so, great savings in energy and money is expected.

2.4. Methodology

Energy modeling simulation method is used in this study for its accuracy, reliability, and capability of predicting results [37]. According to Attia [38, 39], IES VE has shown high rating in accuracy and usability compared to the other nine tools studied. This software and by being used in over 80 countries worldwide, is considered one of the most popular among the simulation programs [40].

However, an accurate validation of simulated models is required to ensure providing credible results, thus a software validation was conducted at the start of this research. For that, the building was simulated for the business as usual (BAU) and the obtained results were compared to the 2015 actual electricity bills. The IES built-in climatic data files were used during the energy modeling exercise. A constant profile of 100% ON during working hours and totally OFF outside working hours was used for both the lighting and plugin loads during the simulation. The results of the IES model was compared to the actual electricity consumption during 2015, as shown in Fig. 3. A deviation of 6.8% was recorded. This difference is acceptable and could be justified due to the typology of the building with the great chance of unpredictable

Table 2
Building codes thermal performance values.

Design Component	MIOD Base case	1 Pearl Target Value	2 Pearls Target Value	PH Limiting Values
Walls (U-values)	0.47 W/(m ² ·k)	0.320 W/(m ² ·k)	0.290 W/(m ² ·k)	≤0.15 W/(m ² ·k)
Floor (U-values)	1.38 W/(m ² ·k)	0.150 W/(m ² ·k)	0.140 W/(m ² ·k)	≤0.15 W/(m ² ·k)
Roof (U-values)	0.21 W/(m ² ·k)	0.140 W/(m ² ·k)	0.120 W/(m ² ·k)	≤0.15 W/(m ² ·k)
Glazing (U-values)	2.1 W/(m ² ·k)	2.200 W/(m ² ·k)	1.900 W/(m ² ·k)	≤0.8 W/(m ² ·k)
Infiltration	0.35 ach	0.350 ach	0.200 ach	≤0.042 ach
Glazing SHGC	0.35	0.40	0.30	0.50

infiltration that may reach 18.288 m³/hr/m² (1.0 cfm/sf) through the building's entrances [41]. Moreover, the biggest difference was found during wintertime, when employees and visitors tend to leave the entrances' doors open to enjoy the outside breeze which leads to more infiltration, hence more cooling load. The electricity consumption of the simulated BAU will be used as the baseline for assessing the effectiveness of the different comparison of the different retrofit scenarios to be tested in this paper. The scenarios cover a range of Passive measures, Active measures and the addition of different onsite PV energy generation systems.

The Passive measures considered are 1) Solar Shading and 2) the Thermal Properties of the Building Envelop. Whilst the Active measures are: 1) Reducing the Internal Cooling Load and 2) Enhancing the efficiency of the HVAC system. The PVs category is focused on different PV panel technologies and areas. Details of each category will be included in the upcoming Results & Discussion section.

Different retrofit configurations were devised in order to assess the impact of some selected retrofit measures and their impact on reducing energy demand or producing energy supply. These configurations were grouped into three categories: baseline, passive measures, and active measures. The first category consists of the baseline scenario, which represents the existing building (BAU case). This scenario will be the reference to which all other scenarios will be compared. The passive measures category has three sets of simulations with multiple scenarios under each set. The first set offers different approaches to mitigating heat gain from solar radiation. It consists of two scenarios to assess the optimal shading: egg crate shading and PV self-shading. The impact of window films on reducing energy is also included in this set.

The second set in the passive category consists of five scenarios. The first one is to upgrade the existing building code to 1 Pearl rating standards for opaque materials, glazing, and air tightness. The second scenario is to apply 2 Pearls standards. The pearl rating is a green building rating system that is part of Estidama program which was introduced 2010 in Abu Dhabi as a sustainable building assessment system [42]. Due to the absence of a Federal green building assessment system, Estidama was used to guide the passive design improvements in the current study. The third scenario introduces the Passivhaus (PH) standards, which is a low energy standard with EU_i ≤ 15 kW/m²/year [43].

Table 2 presents the minimum U-values for 1 Pearl, 2 Pearls and Passivhaus standards. The fourth scenario of this set is to use Passivhaus standards with a lower shading coefficient (SHGC) of 0.20 for the triple glazing. The last scenario is about applying Passivhaus standards for the opaque elements and double glazing with SHGC 0.20.

The last scenario in the second set assesses the optimal passive measures configuration. The input parameters for this scenario are based on the results of previous scenarios in terms of the biggest reduction in energy while taking, into consideration the availability of materials and their cost.

Regarding the active category, there are three sets of simulations. The first set focuses on varying the cooling set-point with multiple alternatives. The second set is about upgrading the cooling system COP from the current 2.88 to 5.3; which represents the average of the most recent efficient systems and they offer around 30% savings in energy over the U.S. federal minimum COP value which is 3.8 [44]. The third set of simulations offers an optimal active scenario that combines the best

Table 3
The Baseline walls and glazing areas and orientation (IES VE, ModelIT).

Orientation	Above-grade wall area (m ²)	Vertical glazing area (m ²)	Vertical glazing area (%)
North	376.5	110.7	29.4
East	277.9	60.7	21.8
South	376.5	132.4	35.2
West	277.9	66.2	23.8
Horizontal	1196.4	106.5	8.9

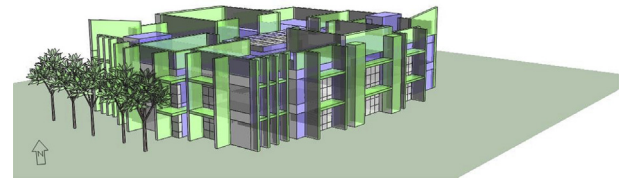


Fig. 4. Egg-crate shading elements (IES VE ModelIT).

results of varying set point and COP. The final optimal retrofit model will consist of both optimal active and optimal passive in one scenario. The obtained result will be analyzed and the electrical energy will be offset through PV electricity production.

The last simulation set presents multiple scenarios that assess the energy supply alternatives. Different PV installment approaches are considered (absolute & optimal), as well as the different PV technologies (mono-crystalline & poly-crystalline) with the highest recorded efficiency. Finally, the potential of increasing the PV's area to reach a net zero electricity building (nZEB) is studied as well.

3. Results and discussion

3.1. Passive measures

Passive measures are intended to reduce the external cooling load caused by the direct solar gain and heat conduction through the building envelope. The direct solar gain can be managed by the building orientation as well as the use of shading devices. By analyzing the building's orientation, and since the building is oriented at an angle of 45° from the north, the southeast and southwest elevations are exposed to the sunlight. Table 3 shows the percentage of glazing of the wall area and their orientation.

Since the building lacks any type of protection from the sun, solar heat gain is more likely to occur. The overhang shading is the most recommended configuration to provide shade for south orientation, whilst vertical fins are a better choice for east and west orientation. However, according to Giovani [45] using a frame that consists of horizontal overhang with vertical fins is the right shape to offer a perfect shading configuration for east and west elevations. For that, Egg-crate shading style that consists of 2m overhang and 2m vertical fins will be implemented on all southeast and southwest glazing as it shows in Fig. 4.

It is found that this shading configuration reduced the system's energy demand from 415.2 MWh (baseline) to 407.3 MWh, which is equivalent to 1.6%. Moreover, by considering the PV self-shading, the saving in the system's energy demand increased up to around 2%. In terms of PV

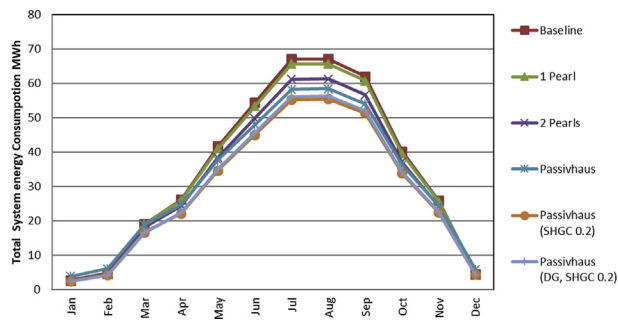


Fig. 5. The impact of different buildings codes on reducing total system energy.

shading impact on the total HVAC system energy reduction, it is noticed that the impact was limited and does not exceed 0.6%. It is worth mentioning that PV modules occupy around 514.2 m², which is around 50% of the roof's total area. Moreover, the baseline roof's U-value is 0.21 W/(m²·k), which is considered a green value since Dubai's Green Regulation roof's U-value is 0.3 W/(m²·k). All of these factors minimized the effect of the PV self-shading impact on the total system energy.

Window solar films is another effective way of reducing heat gain in a hot climate region, the closer the Solar Heat Gain Coefficient (SHGC) is to zero, better protection from solar heat gain could be achieved [46]. However, a balance between blocking solar gain and providing the needed daylight is a very important aspect. For this study, window films are applied to the southeast and southwest glazing. The films are installed on 70% of the glazing area, keeping the upper part as its baseline value SHGC = 0.35 in order to allow daylight to penetrate deep inside the building.

It is found that applying window films with SHGC = 0.20 on 70% of the glazing provides 3% reduction in total HVAC load. On the other hand, window films with SHGC = 0.15 on 70% of the glazing could increase the energy reduction up to 4.1% saving in total HVAC load. However, in the UAE local market, the most common type of window films are the ones with SHGC = 0.2., although SHGC = 0.15 offers more saving, the SHGC = 0.2 is more popular for providing a better view which clients prefer.

Regarding upgrading the building code, it is noted that by applying 1 Pearl values, the total cooling system energy was dropped by 1.4%. However, 2 Pearl values offer more saving where the HVAC load was reduced with 7.8% saving. Regarding Passivhaus standards, it is noted that in the winter months (December, January, and February) the system consumed more energy than 1 Pearl and 2 Pearls. This happened because of the type of glazing used in this Passivhaus standard (triple glazing with SHGC = 0.5). In winter, when the sun is low, more solar radiation is penetrated and trapped, which eventually adds up to the internal heat gain. However, aside from the winter months, the Passivhaus standard has shown more reduction in the HVAC load. The annual consumption dropped by 9.4%.

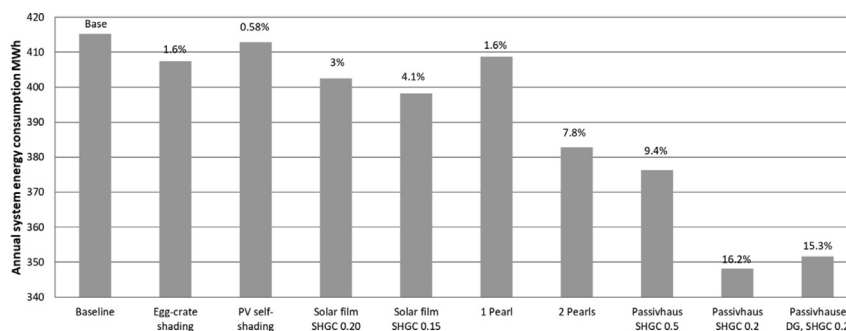


Fig. 6. The building's HVAC energy consumption and % reduction for all passive strategies.

Using Passivhaus standards are expected to provide more reduction in energy with smaller glazing SHGC. Therefore, in order to reduce solar radiation, Passivhaus values are used again with a glazing SHGC = 0.2. It was found that this change was very effective due to the building's glazing area which is around 485 m² of the total external walls (1300 m²); 35% of this glazing is facing south. As a result, the reduction in the system's energy reached 16.2%.

It is important to mention that multi-layered glazing does not provide the same energy efficiency in all climates [20]. Since Passivhaus standards, with its triple glazing, is more appropriate for cold climates, the last scenario will examine using Passivhaus values for opaque building elements. However, the glazing will be replaced with double glazing (DG) windows with SHGC = 0.2. The obtained result was impressive. It was found that DG with a low SHGC could provide better solar protection than triple glazing with a high SHGC. Also, such glazing combined with the opaque Passivhaus standard was able to reduce the HVAC load by 15.3%. Fig. 5 shows the impact of each scenario of building codes on reducing the HVAC energy demand.

Regarding the optimal passive scenario, it is essential not to consider the reduction in energy only, but also the availability and cost of the materials. For that, it is evident that considering optimal shading and applying Passivhaus standard for opaque elements with double glazing SHGC = 0.20 will offer the optimal passive approach. Regarding SHGC, although 0.15 offers more saving than 0.20, the optimal scenario will consider SHGC 0.2 since it is more preferred and available in the local UAE market. Fig. 6 compares the impact of each measure in reducing the system's energy demand.

Table 4 summarizes the HVAC load consumption with all passive strategies. Moreover, by combining the highlighted strategies in Table 4 into a singular combined optimal passive scenario this results in an 18.7% reduction in the system's energy and 14.7% in electricity consumption.

3.2. Active measures

Increasing the cooling set-point is the easiest retrofit measure with no cost and without compromising thermal comfort. Although the working hours for MOID-RAK are from 7 AM - 4 PM, the cooling system is usually left on continuously. In addition, after interviewing some people in charge, it was found that employees have easy access to the cooling set-point thermostat.

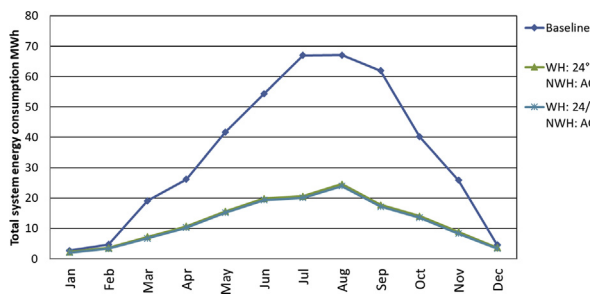
For this study, and as an active measure, the cooling system's profile is designed to work according to occupancy profile where the set point is kept 24 °C during working hours (WH) all year. The AC is kept off during non-working hours (NWH). As a result of this simple strategy, the system's energy dropped dramatically by 64%.

Moreover, It was found that increasing the set-point from 24 °C to 25 °C in all MOID building's zones could offer an extra 5.3% saving in the system's energy; however, in order to not compromise the occupants' thermal comfort, 25 °C as a cooling set point will be assigned only to

Table 4

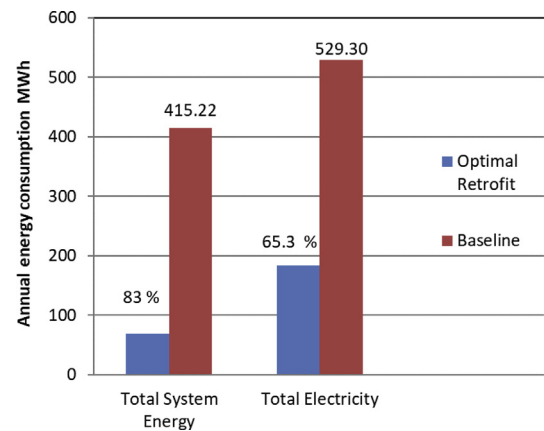
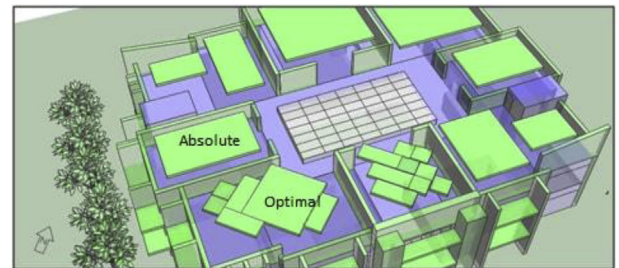
HVAC load consumption (MWh) with passive retrofit measures.

HVAC LOAD MWh	BAU	Egg-Crate Shading	PV Self-Shading	Window film SHGC 0.2	Window film SHGC 0.15	1 Pearl	2 Pearls	PH SHGC 0.5	PH SHGC 0.2	PH SHGC 0.2 D.G	Optimal Passive
Jan 01–31	2.681	2.377	2.676	2.276	2.124	2.726	2.692	3.848	2.577	2.429	2.152
Feb 01–28	4.736	4.216	4.673	4.028	3.7744	4.879	4.703	6.109	4.353	4.18	3.600
Mar 01–31	19.075	18.357	18.876	18.039	17.691	19.071	18.033	18.894	16.618	16.576	15.659
Apr 01–30	26.201	25.460	25.968	25.006	24.608	25.975	24.427	24.7340	22.163	22.350	21.144
May 01–31	41.679	41.003	41.422	40.288	39.820	41.025	38.388	37.681	34.635	35.090	33.589
Jun 01–30	54.309	53.742	54.056	52.97	52.524	53.280	49.773	47.985	45.006	45.610	44.102
Jul 01–31	66.981	66.361	66.71	65.647	65.200	65.592	61.148	58.229	55.282	56.059	54.465
Aug 01–31	67.021	66.271	66.753	65.679	65.228	65.608	61.226	58.335	55.447	56.253	54.558
Sep 01–30	61.908	61.073	61.651	60.660	60.242	60.66	56.577	53.974	51.363	52.022	50.426
Oct 01–31	40.169	39.281	39.911	38.993	38.602	39.532	37.032	36.237	33.840	34.235	32.774
Nov 01–30	25.862	25.071	25.631	24.909	24.598	25.635	24.164	24.315	22.406	22.511	21.408
Dec 01–31	4.602	4.117	4.531	4.019	3.811	4.713	4.588	5.887	4.440	4.268	3.757
Total	415.22	407.330	412.858	402.514	398.22	408.69	382.75	376.232	348.134	351.582	337.63

**Fig. 7.** HVAC load reduction with widening cooling set-point.

specific zones. Analyzing the building's orientation shows that the office zones are mainly facing northeast and northwest, which means less solar heat gain compared to other zones that are facing southeast and southwest. Also, some zones that are used for short periods of time (transit zones), regardless of their orientation, can handle higher cooling set points such as washrooms and service rooms. Another simulation will run where 24 °C will be set only for zones that are expected to be exposed to more solar gain including the central atrium. On the other hand, the other zones will be set to 1 °C higher for the cooling set-point to reach 25 °C, in addition to NWH; the AC will be shut off. This approach offers up to 65.5% reduction in the system's energy as shown in Fig. 7.

Having such a big saving in this particular strategy calls for more investigation to define the reasons behind the baseline's actual air conditioning (AC) profile. After interviewing some employees, it was found that there were three main causes of this huge wasted energy. First, the employees' easy access to controlling thermostats. Second, according to a mechanical engineer employee, the thermostats' location in relation to

**Fig. 8.** Annual energy consumption and % reduction as a result of implementing the optimal combination of passive and active retrofit measures.**Fig. 9.** Different approaches for installing PV panels.**Table 5**

Monthly optimal retrofit electricity demand & PV electricity production MWh with different technologies.

Date	Retrofitted Building Electricity Demand	514 m ² of PVs Panels		214 m ² of BIPV
		Mono Crystalline 21% Efficiency	Poly Crystalline 17% Efficiency	Thin Film 13% Efficiency
Jan 01–31	9.37	12.55	8.75	1.43
Feb 01–28	9.4	13.53	9.33	1.63
Mar 01–31	12.4	14.28	9.53	1.89
Apr 01–30	13.22	15.02	10.21	2.1
May 01–31	15.51	16.78	10.98	2.5
Jun 01–30	17.97	16.08	10.92	2.44
Jul 01–31	17.27	16.01	11.03	2.39
Aug 01–31	20.68	16.13	11.32	2.32
Sep 01–30	15.93	15.4	10.71	2.09
Oct 01–31	14.85	15.01	9.51	1.88
Nov 01–30	12.89	12.76	9.26	1.46
Dec 01–31	10.1	11.88	8.32	1.31
Total	169.59	175.43	119.87	23.44

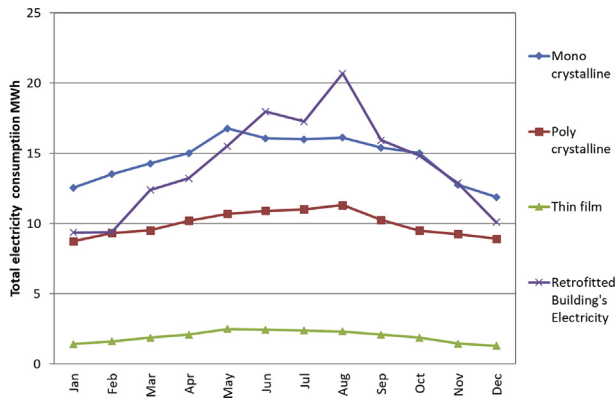


Fig. 10. Different PV technologies' electricity supply and the retrofitted building's electricity demand.

the air handling unit (AHU) shows some defects, whereas the furthest areas from the thermostat's location always suffer from reaching the assigned set-point which causes employees to lower the cooling set-point themselves. Finally, since the building's cooling system is controlled manually, individuals in charge forget to turn off the AC or raise the cooling set-point after working hours.

HVAC systems typically consume around 70% of the building's total energy consumption, whereas the chillers are responsible for consuming 25–35% of this energy. For MOID-RAK case study, the system's COP is 2.88. The US federal minimum COP is 3.8; however, in this study, the system's COP value has been chosen based on the average of the most

recent efficient systems that equal COP 5.3. The simulation result showed significant savings in system energy up to 45.5%.

The optimal active scenario consists of combining the strategy of varying cooling set-point 24°C/25 °C for working hours while shutting the AC off during non-working hours with upgrading COP to 5.3 in one simulation. The obtained result shows that the total system energy plummeted from 415.22 MWh to 81 MWh with 80.4% reduction. The total energy consumption reduced by 62.9% and the total electricity went down by 63.2 %.

3.3. Optimal retrofit proposal

This scenario aims to combine the optimal passive scenario, and the optimal active scenario, in a single simulation. This simulation is the optimal retrofit proposal that suits the UAE's local region. The obtained results have shown a major reduction in the total energy system from 415.22 MWh to 69.23 MWh, which is equivalent to 83%, and as a result, the total electricity reduction reached 65.3% as shown in Fig. 8.

The scope of this research focuses on retrofitting two areas: the building's envelope and the HVAC system. However, the optimal refurbishment in any project should consider retrofitting the lighting system as well, prior to introducing any RE as an energy supply. An earlier study was conducted on the same building MOID-RAK which focused on upgrading the lighting system [32]. The results have shown that lighting electricity could be reduced by 25% if daylight sensors and dimming systems were provided. Al Awadhi's results will be used in this project, and the savings from retrofitting the lighting will be deducted from the total lighting electricity. Thus, the total electricity after all retrofit action is equal to 169.6 MWh.

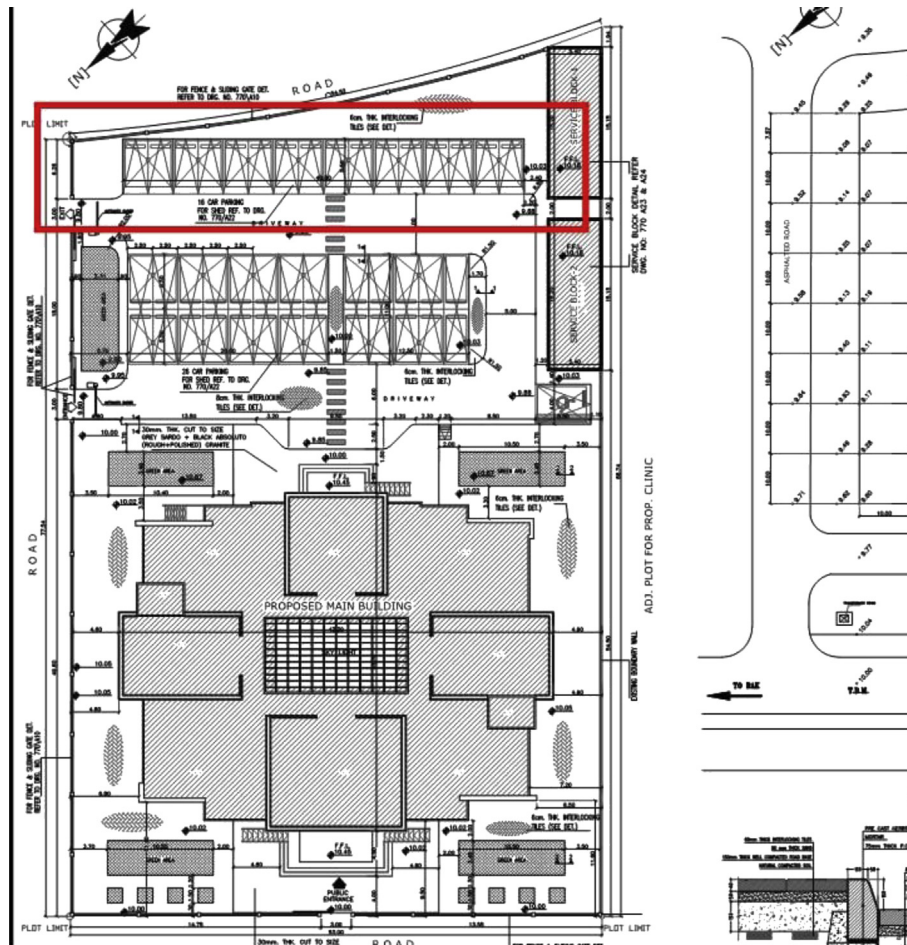


Fig. 11. Suggested location for extra PVs panels.

3.4. Photovoltaic energy supply

PV modules will be introduced in two types: as PV panels on the available area of the roof, and as BIPV on the central atrium skylight. However, the building is oriented at an angle of 45° from the north. For that, there are two approaches to install PV panels: the absolute orientation which could provide around 514 m^2 of PV panels, and the optimal orientation (facing south) which could offer around 230 m^2 of PV panels as it shows in Fig. 9. Two simulations will be run to define the most productive approach.

By comparing the two different approaches (absolute and optimal), it is found that following the absolute PV approach would allow the utilization of the maximum area of the roof. This could produce more solar energy regardless of the lack of the south optimal orientation. The absolute PV installment approach allows for an extra 50% area of PV's panels that compared to the absolute approach. This provided 53.5% of electricity. Also, according to Dubai Electricity and Water Authority (DEWA), only a maximum 5% energy loss could occur as a result of varying the azimuth of PV modules from -60° to $+60^\circ$ if the tilt angle is kept at 24° .

By considering the absolute installment approach with a total area of 514 m^2 , two PV's panel configuration will be assessed, the first one is mono-crystalline panels and the other one is poly-crystalline panels. For commercial panel applications, a U.S. manufacturer has recently released the X-series of monocrystalline PVs at a record-breaking efficiency of 21.5% for commercial use [47], this efficiency will be considered for the simulation input parameters. However, the efficiency of poly-crystalline technology will follow the latest best value which 17% and was recorded by Phono Solar manufacturer. Moreover, thin film technology will be used to produce solar energy through the central atrium skylight BIPV with a total area of 116.96 m^2 . According to the latest data, thin film technology efficiencies have reached between 7–13% [48], for this technology, 13% will be used. Table 5 summarizes the solar production for the different PVs configurations.

In addition to being able to simulate the energy requirements of buildings, the IES software is also able to model the electricity production from non-tracking PV panels. The needed solar irradiance site-specific data is included in the IES weather files and is used to predict the electricity production from the PV panels. The monthly electricity production from the PVs is summarized in Table 5.

According to the obtained results, it is clear that mono crystalline PV panels offer the highest solar electricity production with 175.43 MWh, which will exceed the retrofitted building electricity demand of 169.6 MWh and is capable of transforming the building to a net zero electricity building as shown in Fig. 10.

Polycrystalline PV panels and the BIPV on atrium's skylight combined could produce 143.31 MWh of solar energy. By considering this result, the building could be labeled as a nearly zero cost energy building. However, in order to classify it as a zero-cost electricity building, meeting the building's electricity demand is required. For that, in case of using polycrystalline technology, more PV area is needed; to add more PV panels, a thorough analysis was conducted to the building's site to define a suitable efficient area for installing PV panels. It was found that the parking lot is located behind the building with southeast orientation as shown in Fig. 11.

The furthest parking row from the building that is designated for 16 cars could offer 220 m^2 for monocrystalline PVs' panels. This could produce 50.9 MWh of solar energy, and eventually, the total production will reach 194 MWh and exceed the buildings' electricity demand.

Having the building's PV system connected to the utility grid provides great benefits for eliminating the need for storing batteries; whereas any excess energy could be sent to the grid and saved as credit so it could be used during peak times.

4. Conclusions

Both passive and active measures play an important role in reducing

electricity consumption. However, in a relatively new constructed federal buildings in the UAE with high internal gain, active measures proved to be more effective in reducing electricity consumption than passive strategies. The optimal passive scenario reduced electricity by 14.7%, whilst the optimal active scenario reduced electricity consumption up to 63.2%. However, with such a hot climate region, protecting the glazing from solar radiation is considered a priority as well, especially in a building with large windows like the base case. A holistic retrofit approach is recommended when considering renewable energy as an energy supply [49]. In this research, since the building is a small sized office building (G+1), PVs solar energy has proved to be a very efficient energy supply and can transform the building to a zero-cost electricity building. Implementing monocrystalline panels on the available roof area of 514 m^2 could transform the building to surplus one with an extra 6 MWh, however, using other PV technologies such as polycrystalline and BIPV, more area of PVs is required to reach the net zero electricity building (nZEB) goal.

In the case of multi-story governmental or federal buildings with high internal gain, understanding the building's form potentials is important to increase the PV area for more energy production. For example, utilizing the façades with the proper orientation to integrate PVs is one approach. Shading elements for the east, west, and south oriented windows could be another approach, as well as parking pergolas. In fact, any shading in public areas nearby could be used to integrate PV systems to meet the high demand. Moreover, mono-crystalline PV technology could be the best choice for its effectiveness with the lowest required area.

Declarations

Author contribution statement

Enas Alkhateeb: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bassam Abu-Hijleh: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

- [1] WWF, Living Planet Report 2006, WWF-World Wide Fund For Nature, Gland, Switzerland, 2006. URL: www.panda.org/livingplanet.
- [2] McGraw Hill Construction, World Green Buildings Trends, Business Benefits Driving New and Retrofit Market Opportunities in over 60 Countries, SmartMarket Report, McGraw Hill Construction & United Technologies, 2013. URL: www.construction.com.
- [3] A. Alnaqbi, W. AlAwadi, A. Manneh, A. Kazim, B. Abu-Hijleh, Survey of the existing residential buildings stock in the UAE, *Int. J. Environ. Sustain. Dev.* 3 (5) (2012) 491–496.
- [4] F. Rashid, Demand Side Management Strategy 2030: Building Retrofits Program, The Dubai Supreme Council of Energy, 2015. RETROFITTECH conference, Dubai.
- [5] B. Abu-Hijleh, A. Manneh, A. AlNaqbi, W. AlAwadhi, A. Kazim, Refurbishment of public housing villas in the United Arab Emirates (UAE): energy and economic impact, *Energy Eff.* 10 (2017) 249–264.
- [6] UNEP, Why Buildings?, United Nation Environment Programme and Sustainable Building and Climate Initiative, 2015. URL: www.unep.org/sbci/AboutSBci/Background.asp.

- [7] THE ROCKEFELLER FOUNDATION, United States Building Energy Efficiency Retrofits. Market Sizing and Financing Models, 2012. URL: rockefellerfoundation.org.
- [8] IRENA, REmap 2030: A Renewable Energy Roadmap, IRENA, Abu Dhabi, 2015. URL: www.irena.org.
- [9] M. Saches, STATE OF ENERGY REPORT UAE 2015, MOE, Ministry of Energy, UAE, 2016. URL: www.moenr.gov.ae.
- [10] C. Maceda, UAE Electricity Consumption to Grow More Rapidly, GULF NEWS ENERGY, 2015 [online], URL: <http://gulfnews.com/business/sectors/energy/uae-electricity-consumption-to-grow-more-rapidly-1.1569200>.
- [11] X. Gong, Y. Akashi, D. Sumiyoshi, Optimization of passive design measures for residential buildings in different Chinese areas, *Build. Environ.* 58 (2012) 46–57.
- [12] F. Hammad, B. Abu-Hijleh, The energy savings potential of using dynamic external louvers in an office building, *Energy Build.* 42 (2010) 1888–1895.
- [13] N. Al-Masri, B. Abu-Hijleh, Courtyard housing in midrise buildings - an environmental assessment in hot-arid climate, *Renew. Sustain. Energy Rev.* 16 (2012) 1892–1898.
- [14] H.M. Taleb, Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. Buildings, *Front. Architect. Res.* 3 (2) (2014) 154–165.
- [15] H.M. Taleb, S. Sharples, Developing sustainable residential buildings in Saudi Arabia: a case study', *Appl. Energy* 88 (1) (2011) 383–391.
- [16] A. Aguiar, B. Abu-Hijleh, Energy performance of public housing buildings in sao paulo-Brazil. An evaluation of the current design practices, in: Presented at the Sustainable Buildings 2010 Brazil Conference (SB10Brazil), Sao Paulo-Brazil, November 8–9, 2010.
- [17] L. Bellia, F. De Falco, F. Minichiello, Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates, *Appl. Therm. Eng.* 54 (1) (2013) 190–201.
- [18] O.F. Awadh, The Impact of External Shadings and Windows' Glazing and Frame on thermal Performance of Residential House in Abu-Dhabi, M.Sc. Dissertation, British University in Dubai, 2013.
- [19] W.A. Friess, K. Rakhshan, T.A. Hendawi, S. Tajerzadeh, Wall insulation measures for residential villas in Dubai: a case study in energy efficiency, *Energy Build.* 44 (2012) 26–32.
- [20] N. Mingotti, T. Chenvidyakarn, A.W. Woods, Combined impacts of climate and wall insulation on the energy benefit on an extra layer of glazing in the facade, *Energy Build.* 58 (2013) 237–249.
- [21] W.W. Chan, L.M. Mak, Y.M. Chen, Y.H. Wang, H.R. Xie, G.Q. Hou, D. Li, Energy saving and tourism sustainability: solar control window film in hotel rooms, *J. Sustain. Tour.* 16 (5) (2008) 563.
- [22] M. Katanbafnasab, B. Abu-Hijleh, Assessment of the energy impact of using building integrated photovoltaic and electrochromic glazing in office building in UAE, *Engineering* 5 (2013) 56–61.
- [23] C.-C. Teng, J.-S. Horng, M.-L. Hu, L.-H. Chien, Y.-C. Shen, Developing energy conservation and carbon reduction indicators for the hotel industry in Taiwan, *Int. J. Hosp. Manag.* 31 (1) (2012) 199–208.
- [24] T. Itani, N. Ghaddar, K. Ghali, Strategies for reducing energy consumption in existing office buildings, *Int. J. Sustain. Energy* 32 (4) (2013) 259–275.
- [25] F. AlFaris, B. Abu-Hijleh, A. Abdul-Ameer, Using integrated control methodology to optimize energy performance for the guest rooms in UAE hospitality sector, *J. Appl. Ther. Eng.* 100 (2016) 1085–1094.
- [26] M. Shekarchian, M. Moghavvemi, F. Motasemi, T.M.I. Mahlia, Energy savings and cost benefit analysis of using compression and absorption chillers for air conditioners in Iran, *Renew. Sustain. Energy Rev.* 15 (2011) 1950–1960.
- [27] N. Al-Badri, B. Abu-Hijleh, Grid electricity demand reduction through applying active strategies in Baghdad-Iraq, in: Proceedings of the World SB14 Conference, Barcelona-SPAIN, Oct 28–30, 2014.
- [28] IRENA, RENEWABLE ENERGY PROSPECTS: UNITED ARAB EMIRATES, REmap 2030 Analysis, Masdar Institute & IRENA, Abu Dhabi, URL, 2015. www.irena.org.
- [29] S. Sgouridis, A. Abdullah, S. Griffiths, D. Saygin, N. Wagner, D. Gielen, H. Reinisch, D. McQueen, RE-mapping the UAE's energy transition: an economy-wide assessment of renewable energy options and their policy implications, *Renew. Sustain. Energy Rev.* 55 (2016) 1166–1180.
- [30] J. Al-Amir, B. Abu-Hijleh, Strategies and policies from promoting the use of renewable energy resource in the UAE, *Renew. Sustain. Energy Rev.* 26 (2013) 660–667.
- [31] STATE OF GREEN ECONOMY, Your Roof. Our Power Plant, World Green Economic Summit, 2015.
- [32] W. Al Awadhi, Reducing the Energy Consumption in the Federal Buildings in UAE Using Lighting and Control System, M.Sc. Thesis, British University in Dubai, 2014.
- [33] M. Morelli, L. Ronby, S.E. Mikkelsen, M.G. Minzari, T. Kildemoes, H.M. Tommerup, 'Energy retrofitting of a typical old Danish multi-family building to a "nearly zero" energy building based on experiences from a test apartment', *Energy Build.* 54 (2012) 395–406.
- [34] N. Al-Badri, B. Abu-Hijleh, Grid electricity demand reduction through applying passive strategies for a House in Baghdad – Iraq, in: Proceedings of the SB13 Dubai Conference, Dubai-UAE, December 8–10, 2013.
- [35] TEC & MoPW, Green Buildings Guidelines, UAE, TEC and MoPW, 2009. MoPWs-01-290109-01, URL: <http://www.moid.gov.ae/EPublications/GBGUIDELINESENGLISH.pdf>.
- [36] K. Clarke, 80% Energy Consumed by Buildings, *Khaleej Times*, 2016 [online], URL: <http://www.khaleejtimes.com/nation/abu-dhabi/80-energy-consumed-by-buildings>.
- [37] J. Fong, Z. Alwan, Modelling to predict future energy performance of solar thermal cooling systems for building applications in the north east of England, *Appl. Therm. Eng.* 57 (1–2) (2013) 81–89.
- [38] S.G.M. Attia, A. De Herde, Early design simulation tools for net zero energy buildings: a comparison of ten tools, *IBPSA 1* (1) (2011).
- [39] S. Attia, L. Beltran, A. De Herde, J. Hensen, Architect Friendly": a comparison of ten different building performance simulation tools, in: Proc. Of Eleventh International IBPSA Conference, July 27–30, 2009, Glasgow, Scotland, 2009.
- [40] Y. Schwartz, R. Raslan, Variations in results of building energy simulation tools, and their impact on BREEAM and LEED rating: a case study, *Energy Build.* 62 (2013) 350–359.
- [41] K. Gowri, D. Winiarski, R. Jarnagin, Infiltration Modeling Guidelines for Commercial Building Energy Analysis, Pacific Northwest National Laboratory, U.S. Department of Energy., USA, 2009.
- [42] Abu Dhabi Urban Planning Council, Estidamah, 2010. URL, www.estidama.upc.gov.ae/pearl-rating-system-v10.aspx.
- [43] Building Research Establishment, PASSIVHAUS, Outline Specifications, Accessed on 4, Jun2, 2016, 2011. URL: <http://www.passivhaus.org.uk/standard.jsp?id=18>.
- [44] S.T.A.R. ENERGY, ENERGY STAR Most Efficient 2016- Central Air Conditioners and Air Source Heat Pumps, 2016 [online], URL: www.energystar.gov/index.cfm?c=most_efficient.me_cac_ashp.
- [45] B. Givoni, Passive Low Energy Cooling of Buildings (Architecture), John Wiley & Sons, United States, 1994.
- [46] R. Yin, P. Xu, P. Shen, Case study: energy savings from solar window film in two commercial buildings in Shanghai, *Energy Build.* 45 (2012) 132–140.
- [47] The ecoexperts, Which Solar Panels Are More Efficient?, 2016. URL: <http://www.theecoexperts.co.uk/which-solar-panels-are-most-efficient>.
- [48] M.A. Maehlum, Which solar panel type is best? Mono- vs. Polycrystalline vs. Thin film, *Energy Info.* (29 June 2016) retrieved on, <http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/>. URL:.
- [49] Z. Ma, P. Cooper, D. Daly, L. Ledo, Existing building retrofits: methodology and state-of-the-art, *Energy Build.* 55 (2012) 889–902.
- [50] DEWA Website, 2019. <https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2019/04/the-50-year-charter-a-plan-for-the-happiness-and-prosperity-of-dubai-s-citizens>. (Accessed 17 April 2019).
- [51] L. Friedrich, P. Armstrong, A. Afshari, Mid-term forecasting of urban electricity load to isolate air-conditioning impact, *Energy Build.* 80 (2014) 72–80.
- [52] L. Liu, P. Rohdin, B. Moshfegh, Investigating cost-optimal refurbishment strategies for the medieval district of Visby in Sweden, *Energy Build.* 158 (2018) 750–760.