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Evaluating Design Strategies for Nearly Zero Energy Buildings in the Middle East and North Africa Regions

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Abstract: There is international pressure for countries to reduce greenhouse gas emissions, which are blamed as the main cause of climate change. The countries in the Middle East and North Africa (MENA) region heavily rely on fossil fuel as the main energy source for buildings. The concept of nearly zero energy buildings (nZEB) has been defined and standardized for some developed countries. While most of the developing countries located in the MENA region with hot and tropical climate lack building energy efficiency standards. With pressure to improve energy and environmental performance of buildings, nZEB buildings are expected to grow over the coming years and employing these buildings in the MENA region can reduce building energy consumption and CO_2 emissions. Therefore, the paper focuses on: (a) reviewing the current established nZEB standards and definitions for countries in the hot and warm climate of Europe, (b) investigate the primary energy consumption for current existing buildings in the MENA region, and (c) establishing a standard for nZEB and positive energy buildings in kWh/m^2/year for the MENA region using a building simulation platform represented using Autodesk Insight 360. The result of the simulation reveals high energy use intensity for existing buildings in the MENA region. By improving building fabric and applying solar photovoltaics (PV) in the base model, significant reductions in primary energy consumption was achieved. Further design improvements, such as increasing the airtightness and using high efficiency solar PV, also contributed to positive energy buildings that produce more energy than they consume.

Keywords: nZEB; energy positive buildings; energy performance simulation; renewable energy; passive design

1. Introduction

A substantial proportion of energy is consumed within the building sector, and is larger than the industrial and transportation sectors in many developed countries [1]. Energy is consumed within the built environment to provide and maintain indoor environmental quality and other processes within buildings. World Energy Outlook [2] argues that "the world's energy system is at a crossroads, current global trends in energy supply and consumption are patently unsustainable—environmentally, economically and socially" with buildings being large energy consumers, and part of the strategy for addressing the balance of energy consumption and supply is to reduce energy consumptions in the built environment.

This paper investigates the potential of achieving a nearly zero energy buildings (nZEB) standard in the Middle Eastern and North African (MENA) region. The MENA region has significantly increased their energy consumption for the last couple of decades. The current energy mix for the Middle East relies heavily on fossil fuels with 63% gas, 29% for oil, 5% for hydropower, 2% for coal, and 1% for solar [3]. However, the percentage share of renewables technologies is expected to increase by around 13% and 2% for solar and wind utilization, respectively [3].

The cost of energy is heavily subsidized in the MENA region, especially the Gulf countries where energy prices are amongst the cheapest in the world due to the high government subsidy. These subsidies led to inefficient consumption of energy which is evidenced by the high electricity consumption and CO_2 emissions per capita [4]. Energy demand is expected to increase in the Middle East due to the high population growth and urbanization [5].

The developed countries of the world have responded to the challenge of building energy consumption with strengthening of the building regulations and standards with respect to building energy efficiency. While there is structured and robust building regulations in many developed countries, in developing countries on the other hand there is either poorly developed regulations or no regulation at all [6]. The development of energy codes and standards are the most effective strategy to reduce the energy consumption in the MENA region, especially for countries with high energy consumption and CO_2 emissions. The whole building lifecycle is assumed to be around 40–60 years. Therefore, implementing energy codes can have a lasting impact for years to come, resulting in controlling the level of greenhouse gas emissions and reduce the impact of climate change.

A number of studies [7,8] discussed the improvement of current building standards in Middle East countries to achieve low-energy buildings. Aldossary et al. [9] investigated improving the current building standards in Saudi Arabia through use of building modelling and simulation packages such as IES-VE. Their findings showed that it is possible to achieve low-energy residential buildings with primary energy consumption ranging between 77 and 90 $kWh/m^2/year$. Alrashed and Asif [10] studied the potential of achieving zero energy homes for Saudi Arabia by simulation of residential building performance and using comparative analysis with buildings located in hot climate regions, such as USA and Australia, which have a similar climate to Saudi Arabia. They concluded that in order to achieve nZEB in Saudi Arabia, solar energy needed to be utilized to offset high-energy demand for cooling in the region.

Krarti and Ihm [8] simulated multiple case study buildings in the MENA region to investigate the potential of achieving nZEB with a cost-optimal consideration.

Zacà et al. [11] applied a methodology to analyze the cost-optimal levels for nZEB residential buildings located in a warm Mediterranean climate. The cost-optimal solutions have been identified through the assessment of technical features and energy performance. An analysis of standard and high efficiency buildings has been carried out with a focus on achieving reduction in primary energy and CO_2 emissions using cost-optimal configurations. Congedo et al. [12] presented data showing the application of a "comparative methodological framework and gives the cost-optimal solutions for non-residential buildings located in Southern Italy". The paper also presents an "assessment of optimal energy solutions in terms of primary energy consumptions and global costs for non-residential buildings". The study defined strategies to achieve nZEB buildings for a Mediterranean climate in accordance with the national regulations. The performance of the proposed strategies in terms of reductions in CO_2 gas emissions, primary energy consumptions, and costs have been obtained for several solutions compared to the reference building. Within the same context, various studies in a warm climate region, particularly in Italy, show that nZEB residential and non-residential buildings can save high costs and energy with a small amount of CO_2 emissions compared to traditional buildings [13,14].

Krarti and Ihm [8] investigated various design solutions without specifying codes for the studied countries as the main aim of the study was to evaluate the nZEB solutions based on their potential cost savings. Therefore, this study is focused on developing a unified standard and code for nZEB and positive energy buildings in the MENA region through evaluating the current building design standards and how these can be optimized to achieve higher energy and cost savings.

2. Materials and Methods

2.1. Current Building Definitions and Standards for nZEB

There are many definitions of zero energy buildings (ZEB) in different regions and countries around the world taking into consideration the climatic conditions and existing building standards. However, at the core, Torcellini and Deru [15] defined ZEB as "a building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied by renewable technologies". Therefore, at the core, ZEB can meet nearly all the energy requirements of the building "from low-cost, locally available, non-polluting, renewable sources". they [15] also argued that there appears to be a lack of common definitions of "zero energy". It is important, therefore, to study the concept of ZEB as applicable in different areas of the world to broaden the understanding and definitions of ZEB. The paper also went on to argue that the concept of ZEB is better achieved through building energy efficiency first and meet the rest of the energy demand either using on-site and off-site renewable energy production; this approach will be more effective in managing the operational cost of the building and the often-high capital costs associated with renewable energy technologies. The performance results achieved from a ZEB building depends on the definition of ZEB used to develop the design goals and strategy and they also summarized these into four broad categories of definitions based on site, energy source, energy cost, and net emissions:

1. Net Zero Site Energy: A ZEB site produces at least as much energy as it uses in a year, when accounted for at the site.
2. Net Zero Source Energy: A ZEB source produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.
3. Net Zero Energy Costs: In a ZEB cost, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
4. Net Zero Energy Emissions: A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

Crawley et al. [16] argued that the broad definition of nZEB also leaves room for different interpretations that could be misleading to some stakeholders, such as clients, designers, and contractors; therefore, having a common definition is essential to having consistent design definitions and strategies. This is often difficult to achieve due to different climates, building standards, and construction practices in different countries and regions of the world. Crawley et al. [16] also highlights the human aspect of managing perception and expectation of what an nZEB building will achieve and what definition of nZEB has been used to design and construct the building and ensure that all stakeholders including designers, clients, and users all understand the definition of nZEB in the context of the current buildings. Furthermore, the researchers highlighted the need to be realistic in the expectation of what nZEB could deliver; nZEB might not achieve the same performance every year due to changes in weather condition, abnormal use of the building, and some changes in the operation characteristics of the building. There is also the problem of a performance gap that is prevalent within the construction industry due to poor workmanship and performance prediction.

Another concept of nZEB definition has been proposed by Hernandez and Kenny [17] as a life-cycle zero-energy building (LC-ZEB); this concept considers both operational and embodied energy. An LC-ZEB is a a building "where the primary energy used in the building in operation plus the energy embodied within its constituent materials and systems, including energy generating systems, over the life of the building is equal to or less than the energy produced by its renewable energy systems within the building". They [17] proposed a methodology for evaluating the operational and embodied energy of the buildings. This concept has the potential to improve general environmental performance of nZEB building as well as refocusing the design of nZEB to the building fabric efficiency and environmental performance instead of a heavy reliance of renewable energy systems that often have a high capital cost.

Sesana and Salvalai [18] presented life cycle methodologies and analyses to help understand how to optimize the construction costs in the design and construction of sustainable and nearly zero energy buildings by estimating the ecological costs against intended development value. The paper presented the concept of nearly zero energy buildings in the "ecological/economical" dimensions and presents a critical overview of the current life-cycle methodologies currently known.

Most developed countries established a standard for energy performance in existing and new buildings. For example, the European Union set a target for all new buildings to be nearly zero by 2020 [19]. The climate is the most significant variable that impact the buildings overall energy and environmental performance [20]. Therefore, buildings should be adaptable to these changes through improving its building fabric features, design, and use of renewable technologies. The introduction of nZEB standards for buildings, especially in Europe, allow for mitigating the causes of climate change through improving the energy and environmental performance of buildings. Current standards for nZEB in Europe are developed by each country to suite its climatic condition, cost, and applicability of building design, materials, and technologies to achieve nZEB standards.

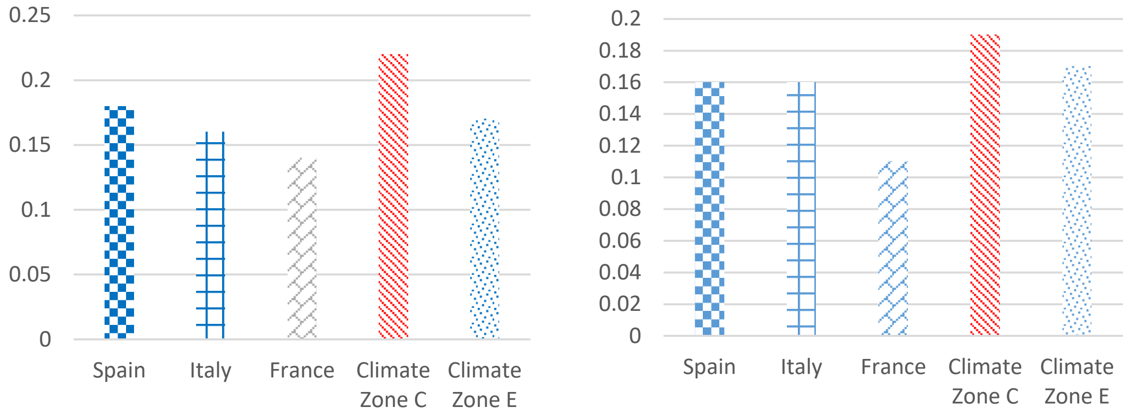
nZEB provides a fantastic opportunity to reduce energy consumption for buildings while maintaining high level of thermal comfort and less environmental impact. The nearly zero concept involves highly efficient buildings that consume very little energy and rely on a significant fraction of their energy demand to be produced by renewables on-site or off-site [21]. In USA, voluntary codes, such as architecture 2030, was developed to encourage architects and planners to adopt nZEB standards during the design of new buildings. The average estimated reductions in the region of 60%, equivalent to 57 kWh/m^2/year, is achieved by implementing the voluntary codes [22]. To identify the most applicable standards for nZEB in the MENA region, the database for current residential nZEB buildings in Europe were selected as a guide. The countries selected for the analysis have typical hot or warm summers similar to the climate in the MENA region as shown in Table 1.

Table 1. Shows nearly zero energy buildings (nZEB) definitions and average primary energy consumption for existing nZEB projects in Europe.

Countries	nZEB Definitions [a]	Average kWh/m^2/year [b]	Average kWh/m^2/year [c]
Croatia	33.40 kWh/m^2/year	62.79	15.9
Cyprus	Not defined	100	Not defined
France	50 kWh/m^2/year	50	67.2
Italy	Not defined	20.40	15.9
Malta	40 kWh/m^2/year	40	Not defined
Spain	Not defined	Not defined	87.3

[a] Data based on Reference [19], [b] data based on Reference [23], [c] data based on Reference [24].

It is observed that the nZEB standard energy use intensity varies between 15.9 to 100 kWh/m^2/year. Regarding the building fabric characteristics, the average U-value for walls is 0.17 W/m^2/year and 0.11 W/m^2/year for roofs as shown in Figure 1.



(**a**) (**b**)

Figure 1. (**a**) Developed by the authors represents the average nZEB U-value for the wall with W/m^2·K based on [23] and (**b**) Developed by the authors represents the average nZEB for U-value of the roof in W/m^2·K based on [23].

The reviewed nZEB standards gives the foundation for the development of a new standard for the MENA region since there is no nZEB standard that considers the climatic and building design factors for the region.

2.2. Methodology

Mwasha et al. [25] argued that a whole-system approach was required in the assessment of the energy performance of a building envelope and calls into question the ability of the current sustainability assessment frameworks/models to measure the whole performance of a building envelope system mainly because these models considered the tripe bottom line of economic, social, and environmental sustainability without including the energy and resource sustainability of the material and systems. The authors went on to develop an approach for determining the most appropriate sustainable energy performance indicators for a residential building envelope using quantitative survey data.

There are different approaches to energy performance modelling, and Mwasha et al. [25] grouped these methods into engineering, statistical, and artificial intelligence methods. Building energy performance prediction is very complex and often difficult to predict the exact energy consumption of the building during its operational life [26]. Some of these problems have been termed as a building performance gap, which is the difference between the actual and predicted performance of buildings. Zero Carbon Hub [27] found that “there is now clear evidence of a gap between the designed and as-built energy performance of new homes” and one of the reasons for this gap is the poor assumptions during performance predictions.

There are several building performance modelling and simulation tools, most of which currently have some level of inter-operability with other software platform. A 3-D modelling platform, such as REVIT and ArchiCAD, now have built-in energy performance simulation capability such as REVIT cooling and heating load analysis, Autodesk Insight 360, and Green Building Studio (GBS). Hernandez and Kenny [17] found that by using readily available tools, it is possible to add value, both during the design process, as well as part of the design outcomes in the context of energy performance. One of the main challenges of using building information modelling (BIM) models for building simulations is the lack of data interoperability between different design tools, which makes the process of energy analysis challenging; therefore, doing energy analysis linked to a common modelling environment will support the reuse of information and reduce duplication of data processing by transferring information into multiple discipline modelling environments [28].

Following the review of the current standards, a base model of a single family residential house was developed to represent the typical residential buildings in the Middle East, and its building features were developed based on a physical building survey conducted to formulate energy codes for Arab countries [6]. The model has been developed within the REVIT modelling software (2018, Autodesk, San Rafael, CA, USA). Figure 2 shows the energy analytic model rendered using the Autodesk Revit energy analysis tool. The model was linked to the cloud-based Insight 360, which is a Revit plugin that enables architects and designers to evaluate the performance of the buildings and allows early stage design changes to improve the performance by enhancing buildings features. The building materials and geometrical characteristics used to evaluate the nZEB potential are described in Table 2.

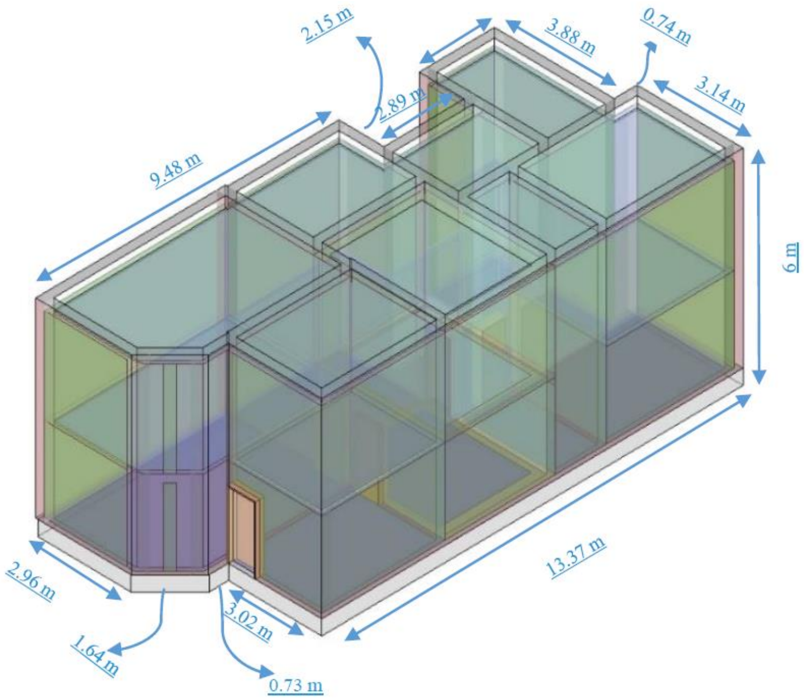


Figure 2. Typical residential building for the base model in Revit.

Table 2. Simulation assumptions for the base model.

Building Characteristic	**Description**
HVAC System	Residential 17 SEER split unit
Roof	12-inch heavyweight concrete (U = 3.12 W/m^2·K)
Wall	6-inch heavyweight concrete (U = 0.6819 W/m^2·K)
Window	$\frac{1}{4}$ inch single glass pane in heavy frame (U = 3.195 W/m^2·K)
Air Infiltration	2 ACH
Lighting	10 W/m^2·K
Building Orientation	0° (North)
Window Wall Ratio For Southern Wall and Eastern Wall	20%
Window Wall Ratio for Northern Wall	40%
Glazing Type	Single glazing for all windows
Shading Type	No shading applied for all windows

Definitions: HVAC—heating, ventilation, and air-conditioning; ACH—air changes per hour.

Table 3 shows the 14 countries selected for the study with their corresponding cooling degree days (CDD) and heating degree days (HDD). Cooling and heating degree days are a measure of the severity of the external temperature conditions relative to the energy required for heating and cooling in buildings. Heating and cooling degrees days are therefore simply a measure of how much and for how long, the external air temperature is below or above a certain level, referred to as the "base temperature". The data has been obtained from [8], where HDD was defined based on a base temperature of 18 °C and HDD was obtained based on a base temperature of 22 °C. It is obvious from the table that the highest CDD was in Gulf countries, such as Saudi Arabia, Kuwait, Qatar, Bahrain UAE, and Oman, due to high humidity and extreme hot days in summer. Therefore, the Gulf countries consume high energy for cooling to maintain thermal comfort. Higher HDD was observed for countries located in the coastal region such as Algeria, Morocco, and Tunisia compared with other Arab countries located in the desert region. Therefore, these countries require high energy for heating compared with its counterpart countries located in desert region.

Table 3. Heating and Cooling degree days for countries among the Middle East and North Africa (MENA) region.

Countries	HDD	CDD
Iraq	800	2400
Syria	1200	1600
Jordan	1000	1200
Kuwait	400	3200
Saudi Arabia	400	3200
Qatar	200	3600
Bahrain	200	3600
UAE	200	3600
Oman	100	3600
Egypt	400	1600
Libya	400	2000
Tunisia	600	1000
Algeria	1400	1600
Morocco	1000	1600

Definitions: CDD—cooling degree days; HDD—heating degree days.

2.3. Potential Solutions to Achieve nZEB

In this study a variety of solutions have been considered to improve building performance as implemented in the base model for countries located in MENA region. The solutions considered includes lighting, building envelope, appliances, and heating, ventilation, and air-conditioning (HVAC) systems. A full description of the solutions are as follows:

- Building envelope: Wall construction solutions that were available for the simulation are: uninsulated, R13 metal, 14-inch insulated concrete form.
- Windows to wall ratios (WWR): The percentage of the openings area are defined based on location of walls on the western, eastern, southern, and northern facade of the building. The percentage of the openings varies from 0% with no openings to 95% of openings.
- Windows glass type: Multiple options considered for glazing types and these are single-pane glazing, double-pane glazing, and triple-pane glazing.
- Photovoltaics efficiency, coverage area, and payback period: the options considered under this group are: 16%, 18.6%, and 20.4% efficiencies. The PV coverage areas considered are 60% moderate range to 90% high range. Payback periods range from 10 to 30 years.
- HVAC system: the options that are available within this group includes Association of Heating, Ventilation, and Refrigeration engineers (ASHRAE) Heat Pump, Split Air conditioning, and High Package Terminal AC.
- Appliances efficiency: the options within this category varies from 27.9 W/m^2 for inefficient appliances to 6.46 W/m^2 for high-efficiency appliances.
- Lighting efficiency: the lighting ranges from 20.45 W/m^2 for inefficient lighting to 3.2 W/m^2 for very efficient lighting.
- Air Infiltration: the options ranges between 0.17–2 air changes per hour (ACH) air leakage.

- Operation schedule and daylighting, and occupancy control: the hours that represent the time of running appliances, HVAC, and lighting. These vary from 24/7 to 12/5 hours/days per week.
- Roof Construction: options ranges from uninsulated roof to insulated roof with 10.25-inch SIP insulation system.

3. Results of the Simulation

Table 4 shows the simulation results in 14 cities. The primary energy was calculated and compared with the ASHRAE 90.1 code for efficient energy requirements under different climatic regions.

Table 4. Variation in primary energy consumption in the MENA region.

Country	Result with No Improvement kWh/m^2/year	ASHRAE 90.1 kWh/m^2/year
Iraq	229	119
Syria	236	156
Jordan	229	131
Kuwait	276	100
Saudi Arabia	274	100
Qatar	283	93
Bahrain	281	87
United Arab Emirates	285	87
Oman	278	82
Egypt	262	107
Libya	259	108
Tunisia	252	107
Algeria	274	108
Morocco	261	230

The results reveal that existing buildings do not meet low energy standards and primary energy consumption ranged from 229 kWh/m^2/year for Iraq and Jordan to 285 kWh/m^2/year for UAE. It is also observed that the countries in the coastal areas of the MENA region have a slightly higher energy consumption compared to countries located in the desert due to the high energy needed for heating in winter as well as high cooling energy demand in the summer. To improve the building energy performance, a couple of solutions are evaluated in the next section to evaluate their applicability to the chosen countries in MENA region.

3.1. Improving the Current Building Standards

To achieve nZEB in the case study region, it is imperative to develop multiple scenarios to comply with its standards and also to evaluate the possibilities of going beyond these standards to achieve positive energy buildings, which are defined as the buildings that produce more energy than they consume. The first scenario suggested for buildings was to improve the design of the building without using renewables. Insights 360 allows designers to assess the positive and the negative impact of proposed design solutions based on their energy reductions as shown in Figure 3.

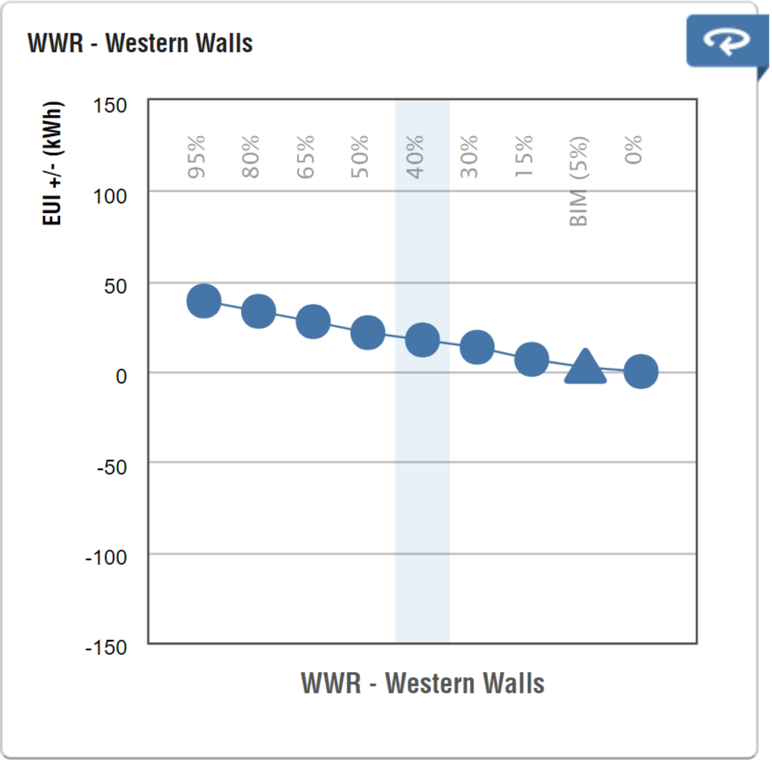


Figure 3. Insight 360 snapshot showing the impact of different wall orientations on energy consumption. The circles in the figure represents the suggested solutions by the software whereas the triangle indicates the current solution adopted by the 3D model.

After assessing the energy reductions strategies, a couple of design improvements were applied to reduce the energy consumption of the base model. The suggested solutions implied improving the building fabric by replacing the walls with high efficiency options such as the 14-inch insulated concrete formwork alongside roof construction of 10.25 inch structural insulated panels (SIP). Air infiltration was reduced to 1.2 ACH, and orientation did not have much impact on the building, therefore, it was kept as it was with no change. Half of the window heights were added as a shading strategy to the southeastern and western façade to eliminate overheating that occurs in the summer leading to high cooling energy demand and energy consumption for HVAC. The type of windows selected for the study were double low-e glazing for southern and northern windows, whereas appliance efficiency was reduced to 6.46 W/m^2. Implementing the following design options led to significant energy reductions relative to the base model as shown in Figure 4. The results show an energy use intensity value of between 52–98 kWh/m^2/year, a reduction of more than 70% for existing building performance and about 50% lower than ASHRAE 90.1.

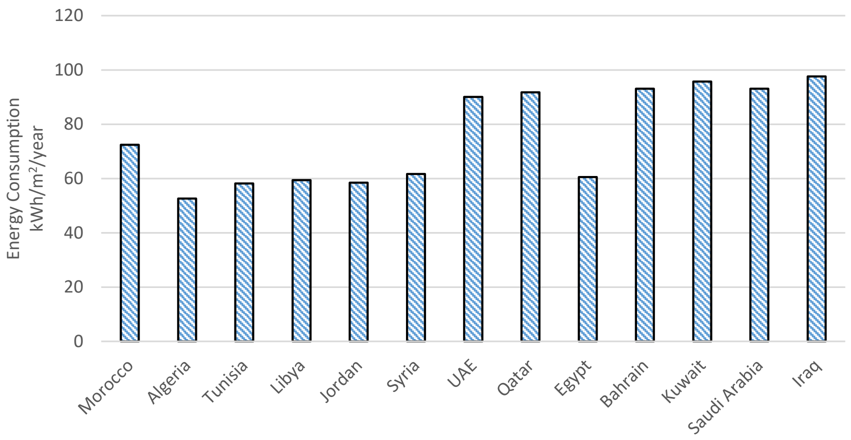


Figure 4. nZEB standards through improving the building fabric of the base model with no solar photovoltaics (PVs) on the roof.

3.2. Further Improvements to Achieve Positive Energy Buildings

Further design improvements were suggested to the base model to see if the model could achieve nZEB standards lower than 50 kWh/m^2/year, and the potential for producing more energy than the building energy requirement leading to the achievement of energy-positive building standards. The suggested improvements implemented include increasing the efficiency of the HVAC system to a highly-efficient heat pump alongside with utilizing 16% solar PV conversion efficiency covering 16% of the roof area, and a payback period of 10–20 years. The results showed significant improvement in the building energy performance as shown in Figure 5.

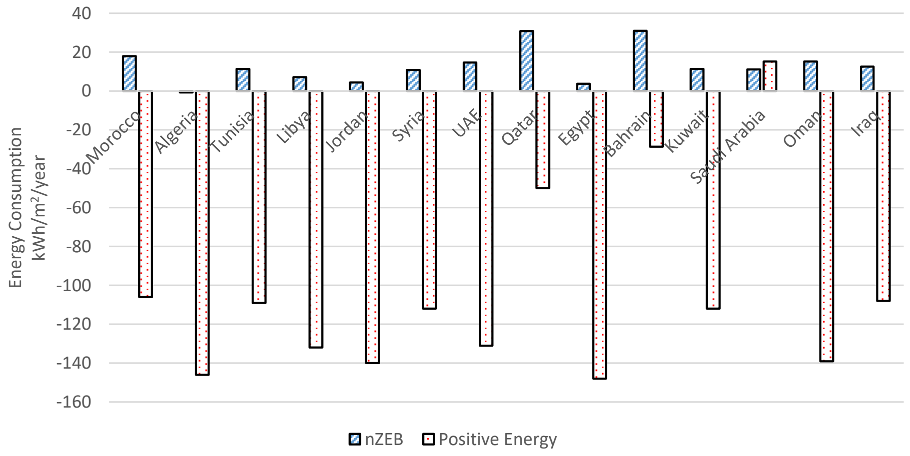


Figure 5. Achieving nZEB standards and positive energy standards for the base model after improving the building fabric and using PVs on the roof.

It is observed from the simulation results that countries with moderate HDD and high solar insolation, such as Egypt and Algeria, have the highest energy production as positive energy buildings with 148 and −146 kWh/m^2/year, respectively. Meanwhile, countries such as Bahrain and Qatar, have the lowest energy produced on site due to their high CDD, which contributes to high energy consumption for cooling compared with their counterpart countries in the region.

4. Conclusions

The current study evaluates the potential performance of existing buildings in the MENA region towards achieving nZEB or energy-positive buildings. The paper reviewed the current standards and definitions of nZEB in hot and warm climate countries to establish a reference for nZEB in the MENA region. The primary energy consumption for residential buildings in the MENA region is very high and falls within the range of 229 to 285 kWh/m^2/year. Several design scenarios have been simulated using AUTODESK Insight 360 to evaluate the primary energy consumptions. The suggested solution for nZEB standards achieved from the simulation are increasing the airtightness to 1.2 ACH, an HVAC with a highly-efficient heat pump, 14-inch insulated concrete formwork (ICF) walls with a U-value of 0.17, a U-value of 0.11 for the roof, a lighting efficiency of 2.32 W/m^2, an appliance efficiencies of 6.46 W/m^2, PV efficiency of 16% with a coverage of 60% of the roof area with a payback period of 10–20 years. However, to further improve the performance of the buildings to achieve a positive energy building standard, the airtightness was improved further to 0.4 ACH, while increasing the efficiency of the PV to 18.6% and coverage area to 75%, and finally the payback period was stretched to 20 years.

The developed building standards and levels of nZEB should be adopted and enforced by the countries in the MENA region due to the economic, social, and environmental benefits that are associated with such buildings. Subsidies should be reduced to encourage the adaptation and use of nZEB by designers and architects similar to Western countries in Europe and the world.

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Abbreviations

MENA	Middle East and North Africa
ZEB	Zero Energy Buildings
nZEB	Nearly Zero Energy Buildings
PV	Solar Photovoltaic
BIM	Building Information Modelling
GBS	Green Building Studio
HDD	Heating Degree Days
CDD	Cooling Degree days
HVAC	Heating, Ventilation, and Air-conditioning
SIP	Structural Insulated Panel
ACH	Air Changes Per Hour
IES-VE	Integrated Environmental Solution–Virtual Environment
ASHRAE	Association of Heating, Ventilation, and Refrigeration Engineers
WWR	Windows to Wall Ratio
ICF	Insulated Concrete Formwork
U-value	Thermal Transmittance

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