Sustainable Cities and Society 22 (2016) 116–125

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Evaluation of net-zero energy residential buildings in the MENA region

Moncef Krarti[a,*], Pyeongchan Ihm[b]

[a] Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, CO 80309, USA
[b] Department of Architectural Engineering, Dong-A University, South Korea

ARTICLE INFO

Article history:
Received 5 October 2015
Received in revised form 5 January 2016
Accepted 7 February 2016
Available online 8 February 2016

Keywords:
Energy-efficient measures
Life cycle cost
Net-zero energy
Optimization
PV system
Residential buildings.

ABSTRACT

This paper outlines the approach and the cost-effectiveness potential for designing net-zero energy residential buildings in the Middle East and North Africa (MENA) region. Specifically, a sequential search technique is utilized to optimize the design of residential buildings in several locations within the MENA region in order to minimize life cycle energy costs using a wide range of energy efficiency measures. In the analysis, design features of air-conditioned single-family homes are considered including orientation, window location and size, glazing type, wall and roof insulation levels, lighting fixtures, appliances, and efficiencies of heating and cooling systems. First, optimal design features for net-zero energy single-family homes are determined for over 160 MENA locations. In particular, the potential energy use savings obtained for the optimal designs as well as the size of the photovoltaic panels required for net-zero energy residential building designs are estimated for the MENA sites. The impacts of both energy cost subsidies and cost variations for implementing energy efficiency measures are evaluated for selected MENA countries. In particular, it is found that optimal designs can cost-effectively reduce the annual energy use typically by 50% compared to the current design practices of homes through most countries in the MENA region. However, the cost-effectiveness of these optimal designs is found to be highly dependent on the level for energy prices and the implementation costs of energy efficiency measures. The sensitivity analysis results clearly show that the best policy to promote energy-efficient and net-zero energy buildings is to reduce and ultimately eliminate energy subsidies in the MENA region.

1. Introduction

In the last three decades, most of the Middle East and North Africa (MENA) countries have seen a significant increase in energy consumption. Specifically, MENA region's primary energy consumption has increased at annual rate of 8% in the last decade (RCREEE, 2015). In 2012, the primary energy consumption mix of the region was dominated by oil products (57%) and natural gas (42%), with coal (1%) playing a minor role, and hydroelectricity (less than 1%) being the only form of renewable energy to make a measurable impact. The consumption of electricity accounts for 21% of total primary energy consumption. Of the total use of electricity, the residential sector represents the largest share (45.6%), followed by tertiary (28.7%) and industry (23.2%). Thus, buildings consume over 74% of total electricity generated in the MENA region (RCREEE, 2015).

Moreover, energy costs are highly subsidized in the MENA region as depicted in Table 1 providing electricity rates for residential buildings. Table 1 summarizes for each MENA country the electricity rate set for residential customers as well as the available electricity generating capacity, the electricity consumption per capita, and carbon emissions per capita, and electricity subsidies per capita (IEA, 2012; IMF, 2015; MEW, 2014). The energy subsidies especially for the GCC countries are among the highest in the world and may explain the high electricity consumption and carbon emissions per person prevalent for several MENA countries as illustrated in Table 1.

The trend for high energy demand in the MENA region is expected to continue over the next decade especially in the building sector due to high population growth and significant urbanization. Indeed, the annual urban population growth rates in Arab countries range between 2% and 6% with an average for the region of 3.8% (UN-Habitat, 2013). Moreover, a total of $4.3 trillion is forecast to be spent on construction in the MENA region over the next decade, representing a cumulative growth of 80% (OEGC.P, 2011).

The development, implementation, and the enforcement of energy efficiency requirements for new buildings are the most

* Corresponding author. Tel.: +1 303 492 3389; fax: +1 303 492 7317.
E-mail address: krarti@colorado.edu (M. Krarti).

http://dx.doi.org/10.1016/j.scs.2016.02.007
2210-6707/

Nomenclature

Acronyms

CDD	cooling degree-days
CFL	compact fluorescent lamp
COP	coefficient of performance
EEM	energy efficiency measure
EER	electrical efficiency ratio
GCC	Gulf Cooperation Council
HDD	heating degree-days
HVAC	heating, ventilating, and air conditioning
LCC	life cycle cost
MENA	Middle East and North Africa
NZEB	net-zero energy building
PV	photovoltaic
WWR	window-to-wall ratio

Symbols

LCC	life cycle cost (expressed in $)
N	life period (defined in years)
r_d	annual discount rate (provided in %)
USPW	uniform series present worth factor [defined by Eq. (2) and expressed in years]

effective approach to reduce energy consumption in the building sector for countries with high construction activities as is the case in the Arab region. Indeed, buildings' lifespan can reach 40–50 years and even higher in some MENA countries. Therefore, the impact of energy savings associated with energy-efficient buildings can last for several years resulting in significant reduction in national energy consumption and greenhouse emissions. Some MENA countries have developed energy efficiency codes, standards, and label ratings for buildings and/or energy consuming equipment such as appliances (refrigerators in particular), cooling systems (air conditioners and chillers), and lighting fixtures (use of compact fluorescent lamps or CFLs instead of incandescent lamps). The level of implementation and enforcement of these codes and standards is, however, variable depending on the country (RCREEE, 2015).

A wide range of studies are reported to assess the impact of design and operating conditions on energy efficiency of residential buildings in the MENA region. Some of the studies focused on the impact of only few design features (Al-Mumin, Khattab, & Sridhar, 2003; Al-Ragom, 2003; Al-Sanea & Zedan, 2011; Al-Sanea, Zedan, & Al-Hussain, 2012; Riadhi, 2008) or use simplified analysis methodologies (Daouas, 2011; Znouda, Ghrab-Morcos, & Hadj-Alouane, 2007). While the concept of sustainable and net-zero energy buildings (NZEBs) has been developed, debated, and applied in several parts of the world (Griego, Krarti, & Hernandez-Geerrero, 2012; Hernandez & Kenny, 2010; Kapsalakia, Leala, & Santamouris, 2012; Sartori, Napolitano, & Voss, 2012; Torcellini, Pless, Deru, & Crawley, 2006), very limited investigations have focused on the cost-effectiveness of combining a wide-range of energy efficiency measures to design low-energy buildings in the MENA region (Alaidroos & Krarti, 2015; Alnaser, 2015; Ihm & Krarti, 2012). An integrated analysis approach is commonly considered to design NZEBs in order to evaluate a wide range of energy efficiency measures or EEMs using detailed simulation tools and optimization techniques (Bichiou & Krarti, 2011; Caldas & Norford, 2003; Jaber & Ajib, 2011; Petersen & Svendsen, 2012; Tuhus-Durow & Krarti, 2010; Wanga, Zmeureanu, & Rivard, 2005). Over the last decade, several MENA countries have made significant efforts to improve the energy efficiency of their building stock by developing new codes and introducing rating systems and labeling programs for sustainable buildings mostly by following European directives (EPBD, 2010; IEA, 2014) or existing rating systems such as LEED and BREAM (Asif, 2016; Sharifi & Murayama, 2013). Some attempts have been made to introduce region-specific rating systems such as QSAS and PEARL (Amin & Abu-Hijleh, 2012; GORD, 2010).

In this paper, cost-effective design options for NZEBs are investigated for the entire MENA region. In particular, the analysis is based on a sequential search optimization analysis to determine design and operating features that minimize the life cycle costs while maximizing energy efficiency and thermal comfort for a prototypical residential building in the MENA region. First, the general optimization analysis approach to determine the main features of NZEB for MENA prototypical single-family houses is described. Then, a set of recommendations is outlined in order to improve the design of single-family homes in various climatic regions in the MENA region.

2. Analysis methodology

To perform an optimization analysis to assess the cost-effectiveness of a wide range of energy efficiency measures and PV system sizes suitable for residential buildings throughout the MENA region, a simulation environment with various components

Table 1
Electricity prices, energy efficiency, and carbon emissions indicators for MENA countries.

Country	Cost of electricity ($/kWh)[a]	Electricity generation capacity (MW)[a]	Electricity consumption per capita (kWh/person)[b]	CO_2 emissions per capita (tons/person)[b]	Subsidies of electricity per capita ($/person)[c]
Algeria	0.051	10,464	1236	3.316	88.27
Bahrain	0.008	2917	17,395	17.947	1536.24
Egypt	0.033	27,000	1700	2.635	88.96
Iraq	0.009	14,527	1474	4.202	47.21
Jordan	0.092	2995	2357	3.601	207.64
Kuwait	0.007	12,060	15,722	28.103	1431.21
Kingdom of Saudi Arabia	0.013	53,864	8405	18.073	636.98
Lebanon	0.046	2744	3102	4.668	456.13
Libya	0.016	6520	4707	6.205	217.31
Morocco	0.123	5580	875	1.738	NA
Oman	0.026	6500	6095	20.204	275.63
Qatar	0.022	6000	16,183	44.019	1108.09
Syria	0.004	7703	1222	2.737	NA
Tunisia	0.127	3144	1411	2.402	127.37
UAE	0.080	16,798	10,463	20.433	630.88
Yemen	0.041	1358	170	0.920	21.47

[a] Average prices for residential buildings estimated based on 500 kWh of consumption (RCREEE, 2015).
[b] Data obtained from IEA (2012).
[c] Data are obtained from IMF (2015).