Life Cycle Costing for a Near Zero Energy Building in Jordan

Initial Study

Abstract

Green Building movement has grown in Jordan for the last 10 year for environmental and financial reasons directly related to energy consumption and cost. Despite the few success stories, green design and green buildings are not yet the norm in the building sector in the country. One main concern for design engineers as well as investors and building owners is the extra cost green building will bring compared to traditional one. This assumption is wrong since a building cost should be analyzed through its life cycle, which not only include design and construction but also operation and maintenance costs as well. Since issuing the Renewable Energy and Energy Efficiency Law No. 13 of 2012, Jordan opened a new era in the RE and EE, a changing point directly related to this law is the ability to sell electricity production to electricity companies and not only being consumers. The building sector is a direct winner if designers and engineers make right decisions. An ambitious but possible goal is to design and build Net Zero Buildings, which are buildings that produce energy as much as they consume. The aim of this paper is to provide real life cost-effective building strategies and design scenarios that will lead to a successful near Zero Energy Building in Jordan. The paper will use a representative residential apartment in the city of Amman (135- 150 m2) as the base case for the study. The design will be upgraded to include main green building strategies recommended for the climatic zone, provide loads for required systems, and test them all against performance and cost. Design scenarios will be tested and refined tell reach the best design formula that will be both functional and cost effective. The paper will provide a list of recommendations for best economically feasible design solutions and system selections that can lead to a near Zero Energy Building in Jordan for residential apartments.

Keywords: residential buildings, design strategies, construction cost, energy efficiency, renewable energy, cost benefit

1. Introduction

1.1. Introduce the Problem

Jordan has limited fossil energy sources. The country is considered as an emerging growing consumer of energy, in equivalence to South and East European countries (UNDP 2016). The use of fossil fuel in Jordan depends completely on imported gas and oil from neighboring countries. Rapid growth in population and urbanization is fueling high growth in energy consumption. Most parts of the world are witnessing a steady decline in the intensity of primary energy consumption since 1980, but Jordan is observing opposite trend and its primary energy consumption is growing faster than GDP (RECREEE 2016). Such high growth in energy intensity will have a significant impact on the country's economic competitiveness, by requiring more than 3 percent of GDP for energy infrastructure investment by 2030, versus 1 percent for the rest of the world (McNichol 2016). Residential buildings, in particular, are major consumers of energy in Jordan with an Energy usage patterns are somewhat different compared to many Western countries (Jaber, J. O., et al. 2004). In Jordan, up to 21 of final energy consumption and 42 percent of electrical energy demand is in the residential sector (Al-Salaymeh et al. 2016, Al-Sallami 2015).

On the other side, solar energy is one of the most promising renewable resources in Jordan. The average annual total irradiation is 2080 kWh/m2 per annum with approximately 300 sunny days (Etier et al 2010). Since issuing the Renewable Energy and Energy Efficiency Law No. 13 of 2012, Jordan opened a new era in the RE and EE, a changing point directly related to this law is the ability to sell electricity production to electricity companies with referenced pricing already set. A target of 10% renewable energy input into the energy mix by 2020 is set in the National Energy Strategy, mainly aiming for about 1000MW of Wind and 600MW Solar, currently, renewable energy projects in Jordan contribute 3-4 percent to the national electricity grid. Household energy consumption in Jordan depends on its particular climate and geographical location, construction technology, building characteristics and occupant behavior. The breakdown of domestic energy consumption has been estimated by several studies (Al-Sallami 2015) and is dominated mainly by heating, water heating, and air conditioning. Theoretically, all new buildings in Jordan must comply with the insulation requirements of the Jordanian

Thermal Insulation Code (JNBC 2009). In average the Jordanian authority issues annually 15000 construction permit equivalent to 10 Million square meters, in 2015 the number reached 13 Million with 83% as a residential area with 46% of the new construction located in Amman (Jordan Department of Statistics 2015). However, there is a discrepancy between the compliance drawings and the construction and there is hardly any number that documents the percentage of compliance, as built, and the construction quality. Nevertheless, energy efficiency programs hold great promise to reduce energy consumption in the region.

As a response to the previously mentioned contradicting facts, it is of the utmost urgency that the new building stock gets designed and constructed to meet national and international obligations to reduce the emission of CO2 and even achieve an annual zero or nearly energy performance (Biggs, 2005 and Green Peace 2013). New construction adding 4-5% to the building stock in Jordan each year, it should comply with local standards and apply bioclimatic design and energy efficiency measures to achieve zero or nearly zero energy balance depending on the climatic regions of Jordan (Johansson and Ouahrani, D. 2009) and (Attia 2016).

Similar to Northern Mediterranean countries and with the assistance of active solar systems the building stock can easily achieve the zero energy objectives due to a match between electric/thermal solar energy supply and cooling/ heating demand. Therefore, this study is significant to expand the architects and engineers bank of ideas, broaden the range of choices and allows assessing their sensitivity. Thus to put the near Zero Energy Building (nZEB) Concept in the regional context and better adapt it to the local traditional architectural practice.

The cost of the net zero energy objective depends on numerous factors including the current state of building design, local construction practices in the construction sector, availability of materials, and legal and regularity concerns. Therefore, the aim of this study is to examine the cost-effectiveness of near zero energy buildings in Jordan. The objective is to assess cost-effective building strategies and design scenarios that will lead to a successful near Zero Energy Buildings. By assessing the cost effectiveness of near Zero energy buildings we intend to mark up the economic benefits, identify and analyze the energy efficiency potential to inform the debate on environmental and governmental policy intervention on a national level.

1.2. NZEB

The zero energy buildings and zero carbon buildings goals seek maximum efficiency derive from the notion of neutralizing the resource consumption and define this as zero energy consumption (Marszal & Heiselberg, 2009). The design process involved an integrative approach looking to:

1) Avoid needs for energy by integrating passive heating and cooling and ventilation

2) Improve energy efficiency

3) Incorporate renewable energy and green power

The definitions of NZEBs were first discussed and proposed at the international level in 2008. The International Energy Agency (IEA) compiled and discussed the earliest definitions within Task 40: Towards Net Zero Energy Buildings comprising almost 20 countries (IEA 2013). The USA was discussing the definitions within the Energy Independence and Security Act of 2007 and the European Union was discussing the definitions within the recast of the Directive on Energy Performance of Buildings (EPBD) adopted in May 2010 (Crawley et al., 2009, EPBD 2002, 2010). The recast of the EPBD required the uptake of a definition of so-called ‘nearly zero energy’ buildings (nZEB) (EU 2009). All Member States had to engage in a more widespread deployment of such buildings by 2020. In addition, the Member States shall draw up national plans for increasing the number of nZEBs. These national plans can include differentiated targets according to the category of building.

Recently procedures were being developed in the energy administrations of the national regions to respond to the European requirements (Attia et al. 2015). This makes the EU a leader in terms of introducing regulatory changes to adapt buildings to nZEBs and NZEBs. For this paper, we are looking to distil the most important lessons learned from the European Southern Countries experience. Up till now, there is no cross-European understanding and agreement on the definition. But all EU countries must use the calculation procedures developed within EPBD (Visscher et al. 2009). However, the NZEB and nZEB definitions are subject to different market interpretations.

1.3. Minimum Energy Efficiency Threshold

For achieving building high efficiency an ambitious energy and carbon emissions reduction must be required for NZEBs using universal indicators (Sartori et al 2012 and Atanasiu et al. 2011). A low ambition for minimum building energy efficiency performance threshold would lead to insignificant savings. There is an agreement in Europe to use the primary energy use intensity indicator to reflect the depletion of fossil fuels and proportional

CO2 emissions. The EPBD recast introduced the concept of nZEB implying, for new buildings, very high energy performances and low energy needs that must be suppressed by renewable energy sources harvested on site, after the end of 2020 (2019 for buildings owned or occupied by public authorities) (European Parliament, 2009). This means that in five years, all new buildings will have to demonstrate very high energy performance and they're reduced or very low energy needs will be significantly covered by renewable energy sources. However, there is no agreement on the minimum building energy efficiency performance threshold for NZEBs. 'Zero energy' is generally interpreted as 'net zero energy': the i.e. balance between the consumed and produced energy on site. Due to the lack of policy definition for (very) low energy buildings, initially different definitions were introduced by business networks and mixed business/ policy networks in the recent years. As shown in Table 1, different thresholds are introduced for NZEB market creation in the EU (Annunziata et al. 2013).

Table 1: Different Minimum Performance Threshold for NZEB (ZEBRA 2016)

Category	EE Threshold		Country
	Heating	Cooling	
Energy efficiency	80 KWh/m2.a	80 KWh/m2.a	Belgium Flanders, Portugal, Greece, France, Spain
Low-energy	60 KWh/m2.a	60 KWh/m2.a	
Ultra low energy	30 KWh/m2.a	30 KWh/m2.a	Austria, Netherlands, Italy
Passive Standard	15 KWh/m2.a	15 KWh/m2.a	Belgium Wallonia

As shown in Table 1 there is a significant difference to define the minimum building energy efficiency performance threshold among the Southern European Member states mainly due to the climatic, social, technological and economic variation between the countries. Already several European countries opt to comply with the PassivHaus Standard to guarantee a minimum performance threshold of 15kWh/m2/a for heating demand. However, the Passive Standard is a high-tech building design and construction approaches and is not feasible across Europe. Therefore, the challenge to implement and comply with nZEB or NZEB performance requirements is high and setting minimum efficiency targets for CO2-emissions, primary and final energy demand should be done incrementally with intermediate targets for the building sector through policies. Therefore, the set values for minimum building energy efficiency performance threshold should be different depending on the countries regulations. For Jordan, no NZEB or nZEB threshold is set yet.

Although the research conducted on high-performance buildings in the last years, there is a large knowledge gap between present theoretical and technological ability and the adaptation of the NZEB concept to the local level in the South Europe and MENA region. The step forward in this paper is to model a multi-storey apartment block, located in the Mediterranean climate of Jordan. The aim is to provide suggestions about the best design options when trying to achieve a high-performance NZEB or nZEB.

2. Method

Several passive and active design strategies were applied to a representative case study in Amman, Jordan. The benefit of each strategy was assessed using a computer simulation program to compare energy consumption and comfort conditions before and after the implementation of the strategy. The cost of each strategy was obtained from local construction companies and compared with direct economic benefit from each measure. 2-3 sources of pricing were consulted and the average of the collected prices was used in the calculations.

2.1 Climate analysis of Amman

Jordan has several climatic zones that reaches up to nine climatic zones according to the Atlas of Jordan, (Ababsa, M. 2014) as shown in Figure 1. The climate is influenced by Jordan's location between the subtropical aridity of the Arabian Desert areas and the subtropical humidity of the eastern Mediterranean area. But according to Jordan Thermal Insulation Standard (NJBC 2009), the country can be divided into three vertically divided major climatic regions: (Zone 1) the Rift Valley in the west, (Zone 2) the eastern highlands and (Zone 3) the arid desert in the east. The agricultural Rift Valley runs along the entire western length of Jordan at an altitude of below 600 m it reaches all the way to Aqaba. It includes the Jordan Valley, the Dead Sea, Wadi Araba and Aqaba. The eastern highlands comprise of mountainous and hilly regions that run in the center and to the east, with varying altitudes of 600 to 1600 m. This is the most densely populated region, including the capital city Amman besides north colder zone including Ajloun as well as the southern parts including Al-Mujib, Karak, and Shoubak.

The climate of this region is characterized by warm summers and fairly cold winters. The semi-arid desert region in east comprises of a large area of Jordan. The climate varies dramatically between day and night as well as between the summer and winter seasons. Summers are hot, dry and windy where temperatures can exceed 40°C, while winter can be bitterly cold, humid and windy. This distinct variation in climate within Jordan advocates for different approaches for energy efficient building. In the highlands where Amman is located, the heating season is dominant whereas in the Rift Valley and the desert regions the cooling season is dominant.

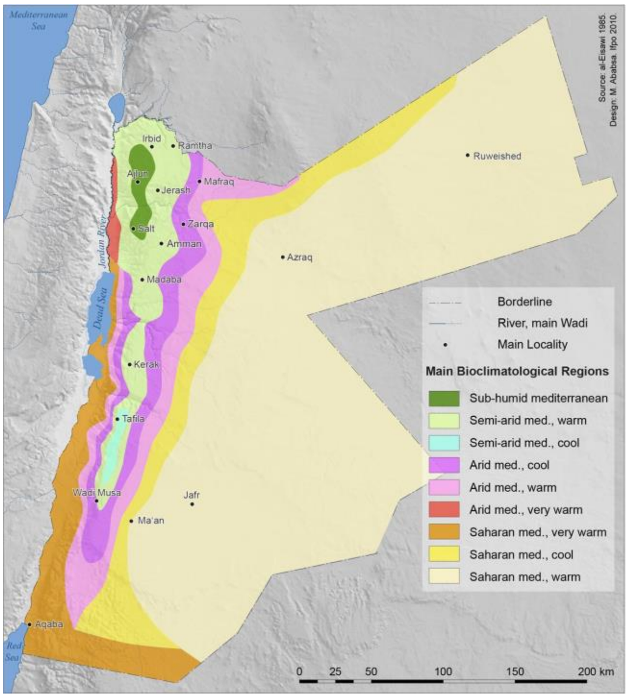

Figure 1: Climate Characteristics of Jordan based on Atlas of Jordan 2014

Amman city is the capital and the most populous city in Jordan where 42% of the population lives (Jordan Department of Statistics 2015). The average temperature in Amman (35.88E, 31.96N) ranges from 8.0°C in January to 25.3°C in July (JNBC 2010). We calculated the average heating (1471) degree days from Queen Alia Airport (35.99E,31.72N) Weather file for a base temperature of 18 during the last 5 years (Degree Days 2016). The temperature limit of 18°C is used as a reference in most of the known thermal codes in the world (e.g. USA, Egypt, Tunisia, and Lebanon) and the annual normal values noted as heating degree days are calculated. We calculated the average cooling (350) degree days from Queen Alia Airport (35.99E,31.72N) Weather file for a base temperature of 25 during the last 5 years (Degree Days 2016).

2.2 Base case Selection

As mentioned earlier, Amman is the city where 46% of the new construction in Jordan is taking place (Jordan Department of Statistics 2015), and where heating is dominated. The base case was selected as a typical upper-middle-class residential building, with apartment areas ranges between 135-150 m2 representing the average area of newly constructed apartments in Amman (Jordan Housing Development Association, 2016). The quality of the selected design is considered to be good with good compliance to Jordanian engineering design codes. Typical local design solutions are implemented ranging from wall section to MEP systems. The co-author was an architect at the A/E design firm who designed the selected building, which is a First Class, Rated “A” consulting company in Jordan with over 60 years of experience in the construction field.

The base case is shown in Figure 2, it is four floors building with 8 residential dwellings, with two apartments per floor. The base case represents a recently built building in a town called Al-Biniyat, South Amman (N31°53’22.50, E35°53’43.19). The apartment occupants represent upper-middle-class families. The apartments net areas vary from 135 to 150 square meter. The services for the apartments’ are grouped in the underground floor and on the roof. In the underground, there is a guard room and each apartment has a water tank, fuel tank, pump, and diesel boiler. Each apartment has a complementary water tank on the building top roof. Water mains come one day a week in Amman to fill in the underground tank before pumping the water and storing it in the roof tanks. The building construction is of concrete post and column structure with hollow block envelope and stone veneer as an external finish. The roof is flat and the average floor height is 3 meters.

Figure 2: Base case building characteristics

Table 1 lists the base case building characteristics. To select base case energy use characteristics, a compliant single-family semi-detached apartment was modeled in energy modeling software and a simulation was run in Amman climate zone. The construction type, HVAC and DHW system types were determined from the housing survey data by the Public Action Project and Jordan Green Building Council (JNBC 2009 & 2010). The Public Action Project (PAP), a public education and behavior change project funded by the US Agency for International Development to support its technical and policy investments in the Water, Energy and Environment sectors in Jordan (USAID/Jordan, 2013). The characteristics of the building envelope, the efficiency of the HVAC and DHW systems, and internal loads were chosen for PAP reports, and the usage profiles were adopted from Zawaydeh and Jaber (2013) and Al-Sallami (2015).

According to the 2015 Census, the national average family size is 4.82 people (Jordan Department of Statistics 2015). For our study, we opted for occupancy of 5 people per apartment, with an average density of 29 m2 on usable floor areas per person in the heated apartments. This represents an average middle-class family with three children, two working parents and average common income of 1500 Jordanian Dinar per month. According to the 2012 Population Census the national dominant age groups within apartments are people younger than 45 (50%) and people younger than 15 (21%). People between 15 and 45 would most likely be secondary school or university students or working adults while people younger than 15 were most likely school students. Most of the apartment occupants would be away from home between 08:00 and 15:00 on weekdays. Nearly all residents would stay at home after 23:00. Most residents would stay at home on Fridays because the weekend in Jordan is Friday and Saturday.

2.3 Building Performance Simulation

The simulations were performed using TMY2 weather data for Amman. The climate zones classified by the Jordanian Thermal Insulation Code (JNBC 2009) for Amman, AM is (moderate cold). TMY2 weather data were used for analyzing the building energy use and sizing the solar systems, respectively (Remund 2008). The simulation-based decision aid ZEBO was used in this study (Attia 2012a). ZEBO is a sensitivity-based simulation tool used for NZEB design during early design stages. The program embeds a residential benchmark coupling sensitivity analysis modeling with the energy simulation software EnergyPlus as a means of developing a decision-support tool to allow designers to rapidly and flexibly assess the thermal comfort and energy performance of early design alternatives (DOE 2016). ZEBO models a simple rectangular building created to mechanically represent mechanically heated and cooled apartment units within the Jordanian climatic and urban context.

Simulations were carried out in three steps. The first step was to create a base case model representing the selected design building and testing its performance. This step included the determination of an annual average of kWh usage, user's seasonal electric consumption patterns and spikes. The base case was calibrated and the monthly and annual energy profiles and Energy Use Intensity (EUI) were validated based on the study of (Al-Sallami 2015 and Attia et al. 2012b). Moreover, a specific inventory was made to identify the appliances and estimate the plug loads and potential occupant behavior. The second step was to introduce design strategies for code compliance as shown in Table 1. The major strategies were as follows:

1) Improving the envelope conductivity (U-value), the base case has code compliance thermal insulation in the solid parts of the exterior wall, but the required overall U-value of 1.6 W/m2.K was not achieved with single glass windows, so double glass windows were used in this case. To fulfill the code requirements for building envelope thermal insulation, we also added thermal insulation layer -EPS in this case- in roof and slabs open to air (lower level of building with parking garage underneath)

2) Avoiding thermal bridges by completely cover all parts of building envelope with continuous thermal insulation and a special attention to columns, slabs, and beams.

3) Controlling air infiltration by installing continuous air barriers and assuming all breaks to be sealed, although the code does not have a numerical value for acceptable air infiltration but it is required to be strictly controlled.

4) Controlling condensation by using vapor barrier according to the mandatory requirement of the 2009 Jordanian Thermal Insulation Code

5) Fulfilling the requirement for lighting intensity as per the requirement of the 2010 Jordanian Energy Saving Building Code which is 7.5 W/m2 for residential apartments.

Other strategies were installing solar thermal collectors for DHW as per Greater Amman Municipality requirements for apartments with an area of 150 m2 and more. The code compliant model was created and validated against similar studies. Finally, the third step was based on improving and introducing passive and active design strategies in order to achieve a near zero energy performance without compromising human comfort. The passive and active design strategies included:

1) Improving thermal insulation, by increasing the U-values of the building envelope components to exceed the requirement of the code by 70%.

2) Installing shading devices where needed, on southern elevations as overhangs and on eastern and western elevations as fins.

3) Installing energy-efficient lighting systems and appliances achieving lighting intensity of 6.5W/m2.

4) Installing high-efficient double glazing with a U-value of 0.8 W/m2.K and SHGC of 0.4.

5) Installing photovoltaic panels to produce electricity. With an available area of about 20 m2 per apartment, a system with a capacity of 2 KWP was installed per apartment.

Since this is an initial study, and it aims to evaluate the applicability of nZEB concept in Jordan, the strategies in each case were evaluated collectively, in future research each strategy will be considered independently and the resulted effect will be calculated and discussed intensively.

Table 1. Base case, code compliance, and nZEB characteristics

	Base Case					Code Compliant Case					nZEB Case				
	Sub Element	Thickness (mm)	Area (m2)	Performance	Cost (JD/m2)	Sub Element	Thickness (mm)	Area (m2)	Performance	Cost (JD/m2)	Sub Element	Thickness (mm)	Area (m2)	Performance	Cost (JD/m2)
	Envelope Airtightness (Air change rate (h^{-1}) at 50 Pa)			12					5					2	
Roof	Out														
	Ceramic Tile	8													
	Cement Mortar	10													
	Sand	70													
	Water Proofing Bitumen Roll 200gm.m2	4													
	No Thermal Insulation	-	314	U-Value 0.79	90	EPS Board/32kg.m3	50	314	U-Value Achieved=**0.45**, Required=0.55	5	EPS Board/32kg.m3	150	314	0.15	15
	Sloping Lightweight Concrete/450.m3 density	50-70													
	RC. Concrete	310													
	Plaster	25													
	Emulsion Paint	0.5													
	In														
Walls	Out														
	Stone Veneer	50													
	Concrete	150													
	EPS Board/ 32kg.m3 Non-bridged	50	921	U-Value 0.49	95	EPS Board/ 32kg.m3 Non-bridged		921	U-Value Achieved=**0.49**, Required=0.57	-	EPS Board/ 32kg.m3 bridged	120	921	0.15	15
	Concrete Hollow Block	100													
	Plaster	25													
	Emulsion Paint	0.5													
	In														
Ground-Open to air	Out														
	Emulsion Paint	0.5													
	Plaster	25													
	-		314	U-Value 1.47	63	EPS Board/ 32kg.m3	30	314	U-Value Ach.=**0.62**, Req.=0.80	5	EPS Board/ 32kg.m3	120	314	0.1	15
	RC. Slab	310													
	Sand	70													
	Cement Mortar	10													
	Ceramic Tile	8													
	In														
Windows	WWR (no overhangs or fins) 28%, 14%, 30%,21%					WWR (no overhangs or fins) 28%, 14%, 30%,21%					WWR (overhangs & fins) 28%, 14%, 30%,21%				
	U-Value, Single Pane- Clear, Aluminum Sliding Window White or Brown Coat		284	5.70	71	Double Pane – Clear 6-12-6 mm	24	284	2.80	90	High efficient Double Pane – Clear 6-16-6 mm	28	284	0.8	200
	SHGC			0.84					0.73					0.4	
	Vlt			0.89					0.79					0.7	
	External Roller Shutter on Window, Extruded Aluminum, White or Brown Coat			yes					yes					yes	
Lighting & Appliances	Microwave, Toaster, Iron, Xbox, Kettle, TV, Modem, Washing Machine, Clothes Dryer														
	Lamps (Light Intensity)			12.5 W/m²	15				7.5 W/m²	140				6 W/m²	390
	Gas Canister/monthly (Cooking)			1					1					1	
	External Lighting – Joint Services (Incandescent Bulbs)														
	Guard Room (Electric Heater)														
	Elevator														
HVAC	Diesel Boiler/per apt., Thermostat 80 C Annual Efficiency 90% Radiators, pipes, tank Heated Area: All Zones				4000					Same					Same
	Individual Gas Canister Heater per Apt. (running daily 5-6 hours in the winter)			Yes	100				No					No	
	2 Split Units per apartment COP 3, 1Ton (Living + Master Bedroom) Indoor Thermostat: 20-25 C				450					Same					Same
Ventilation	Natural: Operable Windows, (Closed during night in Winter, Semi Open during night in Summer) Windows and Doors are manually OPENED if cooling is needed									1000					1000
	Fan Forced Ventilation: WC, Kitchen														
	Mechanical ventilation 120 m³/h with heat exchanger (85%)			No					Yes					Yes	
	Standup Fans 2			Yes					Yes					Yes	
DHW	Electric Water Heater used mainly when boiler is not used for general heating (80 Liter capacity)				100 JD	8 Solar Hot Water Collectors (Evacuated Tubes) 2 m², 200 liter				900 JD	8 Solar Hot Water Collectors (Evacuated Tubes) 2 m², 200 liter				900 JD
	Diesel Boiler/per apartment			Yes					Yes					Yes	
PV				No					No		20 m² PV per apartment (14.5 efficiency)		160	0.05/kWh	1000 JD/kW

2.4 Life Cycle Analysis Cost (LCC)

The life cycle cost is the sum of all the expenses incurred during the whole study period, adjusted to the actual value as identified in BS EN 16627. LCC is calculated to identify effective alternatives that satisfy a certain level of technical performance and compare their cost. The most common application of LCC is to identify the best alternative from an economic viewpoint, considering their direct costs and benefits. To get the best use of this methodology we had to integrate it into our design process for the code complaint and nZEB scenario to define all details associated with every measure.

The base case (BC) was taken as a reference without any additional investment to determine the profitability of the two other scenarios. The study period was considered 60 years. The calculations were performed at constant currency, and correspondingly all rates were established in real terms for the year 2016. The calculations were performance using the software BLCC version 5 developed by NIST (2016). Cost elements that would differ between the compared alternatives were mainly calculated to decrease the amount of data and facilitate the interpretation and define the functional equivalency.

The economic data used for the LCC calculation included the introduction of each strategy, uniform recurrent costs, residual costs and energy cost, as detailed in the following:

- The cost of new design strategies. Local market values were considered to determine the costs of materials, labor, and equipment. 2-3 sources of pricing were consulted and the average of the collected prices was used in the calculations.
- Residual values of materials and building components.
- Energy costs including the current price and their tiers of electricity according to the National Electricity Company. The projections on the future cost of energy, explored by setting up different scenarios (see Table 2). A first historical scenario was estimated according to an average increase of the last 10 years (3%). A conservative scenario was also considered, in which there are no energy cost increases.
- Maintenance, repair, and replacement cost were included and assumptions were calculated according to the approach described in BS EN 16627 (see Table 3). The structure, in general, is made out of durable material, which requires minimum maintenance. For example, the exterior of the building will need façade cleaning and sealant every 7 years and the windows require maintenance every 5 years on average. But water insulation on top of roof required maintenance every 7 years on average and will require partial replacement. While the structure is very durable the water insulation has a limited service life and would require complete replacement as shown in table 3.

Table 2. Energy prices for residential sector in Jordan 2016

Electricity [a]		Diesel [b]	LPG
Tiers	Tariff	0.405 JD/Liter	Canister 12.5 kg
1-60 kWh/month	0.033 JD/kWh	Equiv. 0.0405 JD/kWh	7JD/Canister
161-300 kWh/month	0.072 JD/kWh		533.11JD/Ton
301-500 kWh/month	0.086 JD/kWh		
501-600 kWh/month	0.114 JD/kWh		
601-750 kWh/month	0.158 JD/kWh		
751-1000 kWh/month	0.188 JD/kWh		
1000 » kWh/month	0.265 JD/kWh		

a: www.nepco.com.jo/en/electricity_tariff_en.aspx   b: www.memr.gov.jo/Pages/viewpage.aspx?pageID=238

For the present values of costs and benefits, the calculations have been performed using a real discount annual rate of 0.3%, a typical rate for a low-risk profile private investor according to the Central Bank of Jordan. Once that all data were determined, the LCC analysis was done for the two different scenarios:

- Scenario 1 (SC1): Code compliant design
- Scenario 2 (SC2) : nZEB design

Table 3. Maintenance, repair and replacement cost were included as assumptions

Building Component		Service Life	Maintenance/Repair	Replacement
Facades	Structure	100	-	-
	Insulation	60	-	-
	Stone Veneer	100	7	-
	Windows	100	5	-
Internal Walls	Finishing	100	7	100%
Roof	Structure	100	-	-
	Insulation	60	-	-
	Finishing	30	15	25%
Installations	Diesel Boiler	25	3	-
	Split Unit	12	1	-
	Exhaust Fans	7	-	-
	Electric Heater	10	-	-
	Solar Hot Water Collectors	15	-	-
	PV System	20	-	-

3. Results

3.1 Energy Performance

Complying with the Jordanian Thermal Insulation Code Requirements (JNBC 2009) in Amman increased the consumption use up to 30% (equivalent to 25 kWh/m2.a) compared to the base case. This is mainly due to the improved comfort conditions, an extension of comfort hours and introduction of mechanical ventilation. The following performance target of nZEB decreased the consumption by approximately 50% compared to the code compliant case reaching equivalent to a consumption of 50 kWh/m2.a. On the energy production level, the simulation results indicated that the evacuated tube solar water heater will yield in average 3.0 to 3.8 kWh/m2.a as shown in Figure 3. This shows that the domestic hot water needs can be almost met through RES. However, the system had to be coupled to the diesel boiler for back up. Regarding the photovoltaic, PVSyst simulation results in consultation with several PV companies in Jordan confirmed that 20 m^2 of PV panels will yield approximately 3 MWh annually (equivalent to an average of 17 kWh/m2.a). This means that the 20 m^2 PV panels can almost meet half of the total nZEB energy production within the current geometric roof limitation.

The EUI for the base case was 85 kWh/m2.a with 30% thermal comfort achieved, while EUI for the Code compliance Case was 110 kWh/m2.a with 100% thermal Comfort, the nZEB had an EUI of 50 kWh/m2.a with 100% thermal Comfort all year round and a production of around 50% of its required energy (see Figure 3).

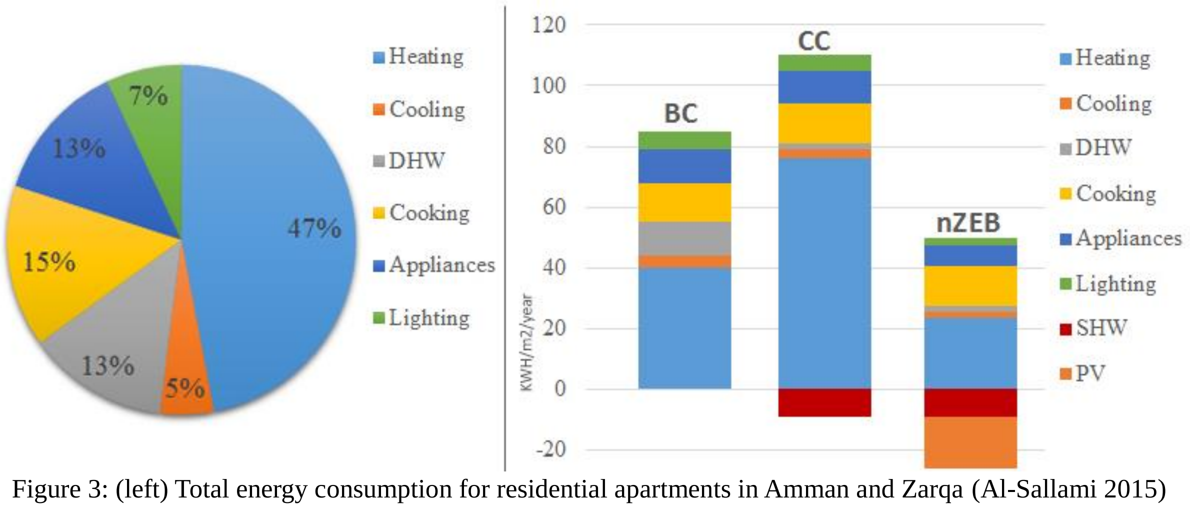

Figure 3: (left) Total energy consumption for residential apartments in Amman and Zarqa (Al-Sallami 2015) (right) Energy consumption comparison of the base case and the two design scenarios in Amman

3.2 LCC

Table 4. LCC results

	Base case in JD		Code Comp. in JD		nZEB in JD	
		Cost (20 years)		Cost (20 years)		Cost (20 years)
Envelope Airtightness & Vapor barrier	-	-	-	1000	-	1000
Roof	-	-	5x314	1570	15x314	4710
Walls	5x921	4605	same	4605	15x921	13815
Ground Open Air	-	-	5x314	1570	15x314	4710
Windows	70x284	19880	90x284	25560	200x284	56800
Lighting	15x40x8	4800	140x6x8	6720	390x1x8	3120
HVAC	5000x8	40000	same	40000	same	40000
Ventilation	-	-	1000x8	8000	1000x8	8000
DHW	100x8	800	900x8	7200	900x8	7200
PV	-	-	-	-	8x2000	16000
Passive, EE and RES Measures Cost		60 JD/m^2.a		80 JD/m^2.a		130 JD/m^2.a
Apartment Cost (including land)		665 JD/m^2		685 JD/m^2		735 JD/m^2
Operation Cost (20y) Electric Amman	1160x35x20 = 812000 kWh	0.087 70644 JD	1160x45x20 = 1044000 kWh	0.114 119016 JD	1160x5x20 = 116000 kWh	0.033 3828 JD
Operation Cost (20y) Thermal Amman	1160x50x20 = 1160000 kWh	0.0405 46980 JD	1160x55x20 = 1276000 kWh	0.0405 51678 JD	1160x20x20= 464000 kWh	0.0405 18792 JD
Annual Energy Cost		5.00 JD/m^2.a		7.35 JD/m^2.a		0.97 JD/m^2.a
Initial Cost		60 JD/m^2.a		+20 JD/m^2.a		+70 JD/m^2.a
Savings		0		-30%		+100%
Comfort Quality		+30%		+100%		+100%
LCC (Present Value) of Passive, EE, and RES Measures Cost annually		65 JD/m^2.a		87.35 JD/m^2.a		131 JD/m^2.a

4. Discussion and Conclusion

This paper aimed to provide real life cost-effective building strategies and design scenarios that lead to a successful near Zero Energy Building in Jordan’s residential multi-family apartment building stock. The study tested several design improvements to the base case building and explained how the additional initial cost of the selected strategies is eliminated by the reduction of energy cost and the increasing of comfort quality.

The selection of an existing residential typology created some limitations regarding the selected strategies, for example, it did not allow some bioclimatic measures such as urban setting, orientation, form and window to wall ratio to be tested but, it allows us to focus on improving important elements such as the building envelope’s thermal characteristics.

To introduce design strategies for code compliance case, we focused on the following major strategies: improving the envelope conductivity (U-value), controlling air infiltration, avoiding thermal bridges and controlling condensation according to the mandatory requirement of the 2009 Jordanian Thermal Insulation Code as well as fulfilling the illumination intensity as per the Efficient Building Code and installing solar thermal collectors for DHW as per Amman Municipality requirement. The test of the nZEB was based on improving the code compliance case and introducing passive and active design strategies in order to achieve a near zero energy performance without compromising human comfort. The passive and active design strategies include improving thermal insulation, installing shading devices where needed, energy-efficient lighting systems and appliances, high-efficient double glazing, and photovoltaic panels. All these strategies are applicable but require skilled implementation on a construction site. To achieve a nZEB, the quality of the design and the construction should be carefully controlled. In Jordan the residential construction market is dominated by inexperienced project developers and non-qualified workers, this shall be overcome by training construction workers and regulate work for trained ones only. In the design stage, the architect should provide sufficient envelope details and material specifications and the site engineer shall control the implementation of the proper details and provide testing to elements such as insulation and air infiltration.

The EUI for the base case was 85 kWh/m2.a with 30% thermal comfort achieved, while EUI for the Code compliance Case was 110 kWh/m2.a with 100% thermal Comfort, the nZEB had an EUI of 50 kWh/m2.a with 100% thermal Comfort all year round and a production of around 50% of its required energy. The initial LCC calculations indicate that on a 20-year time frame, the nZEB will be a better economical choice than the code compliance case. But, the study remains theoretical with certain limitations and uncertainty in LCC results. We explicitly focused on the energy and comfort potential of a nZEBs and started the cost implementations and calculations, an in-depth LCC will be the following future work for the authors to fully investigate the economical part of the study.

Despite the fact that we based our base case on the results of 375 surveys distributed mainly in Amman and Zarqa to estimate the EUI in residential buildings (Al-Sallami 2015) we could not find any indication of fuel poverty. We doubt the average EUI for heating/cooling of 50 kWh/m2.a reported by Al-Sallami (2015) because our results indicate a low night time set back temperature of 16°C and 19°C during the day for the base case. One of the significant results of the study is that in the base case occupants control the range and values of heating set point values to reduce the energy consumption during winter. This means that the EUI value of 50 kWh/m2.a, for heating/cooling in Amman and Zarqa, is underestimated. In Jordan, there is still no standard method to assign the comfort and heating set point for residential buildings. Another advantage of the improving the comfort in the code complaint case is avoiding the use of the individual gas canisters heater that is a source of indoor combustion gasses such as carbon monoxide and particles (Jaber, 2002).

Another point to raise is the scarcity of available area on shared roofs of residential buildings, limited areas are available to install TSH and PV for all apartment, solutions should be tested whether it be a canopy like PV structure that may provide shading as well or an integrated system within available elevation. The PV option is more beneficial in the case of individual residents (Villa type).

The initial LCC results indicate the following:

1. There is no cost saving for code compliance case because there is serious fuel poverty and adapted occupant behavior to curb consumption. Improving the heated living space comfort requirements in the code complying case consequently increased the heating energy consumption by more than 70% for heating-dominated climate zone as we extended the comfort period.
2. Based on the previous initial findings, the nZEB objective is achievable but requires an upfront investment, adding the energy cost for the BC over 20 year period to its initial EE cost will exceed the

sum of energy cost, EE, and RES for the nZEB case.

3. The compilation of the selected strategies for the nZEB case in addition to the strategies used in the Code Compliance case which included: Increasing thermal insulation and conductivity of building envelope, installing high-efficient double glazing windows, installing shading devices and using energy-efficient lighting systems and appliances as well as installing thermal solar water heater and 2KW PV system per apartment. The strategies were evaluated collectively and all calculations shown in the paper include all strategies. An in-depth study will be the following future work for the authors to fully investigate the economical part of the study as well evaluate the efficiency for each strategy and the limits and opportunities each strategy allows.
4. In the context of the previous initial findings, we can assess the nZEB objective potential in Jordan as achievable but a NZEB will be challenging due to limited available areas on the shared roof of residential buildings. The study results indicate that improving the envelope conductivity and airtightness and the use or RE can lead to huge heating load reduction and almost energy consumption neutrality. The climate of Jordan is relatively warm with abundant solar radiation so it is possible to reach almost zero heating demand. Therefore, it is coherent to improve the envelope performance. However, the cost of energy is relatively low compared to industrial countries that tax the fuel with environmental taxes.
5. The benefits of thermal or electric energy demand reduction and avoided air pollution were not expressed in monetary terms to internalize external costs and to provide an estimate of the overall environmental cost and benefit to society. Future research will include them in order to strengthen the case of nZEB.
6. We advise giving incentives to developers and building owners who target nZEB and to create a structured rating program focusing on Energy Efficiency in buildings.
7. We advise to revise the Jordanian energy standards and define a performance based minimum energy efficiency threshold and comfort conditions.

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References

Ababsa, M. 2014. ATLAS OF JORDAN: History, Territories, and Society. Press Ifpo, French Institute for the Near East.

Al-Salaymeh, A., AlZaben, H., Habash, N., 2016. Investigation of the Current Energy Sector in Jordan: Energy Strategy, Resources and Regulatory Framework, Int. J. of Thermal & Environmental Engineering Volume 12, No. 2 (2016) 89-93.

Al-Sallami, H., 2015, Analysis of Energy Use Intensity in Residential Buildings in Jordan, Master Thesis, German Jordanian University.

Annunziata, Eleonora, Marco Frey, and Francesco Rizzi. "Towards nearly zero-energy buildings: The state-of-art of national regulations in Europe. "Energy 57 (2013): 125-133.

Atanasiu, B., Boermans, T., Hermelink, A., & Schimschar, S. (2011). Principles for Nearly Zero-Energy Buildings-Paving the Way for Effective Implementation of Policy Requirements. Building Performances Institute Europe (BPIE), Brussels, November, 1.

Attia, S., Evrard,A., Gratia, E. (2012b) Development of Benchmark Models for the Egyptian Residential Buildings Sector , Applied Energy, Vol. 94, June 2012, Pages 270-284, ISSN 0306-2619, 10.1016/j.apenergy.2012.01.065

Attia, S., 2016, Zero Energy Building design in Hot Climates Workshop, available from http://www.shadyattia.net/academic/WorkshopZEB/index.html, Accessed: 01.07.2016

Attia, S., Hamdy, M., Carlucci, S., Pagliano, L., Bucking, S. and Hasan, A., 2015, Building performance optimization of net-zero-energy buildings, in Modeling, Design, and Optimization of Net-Zero Energy Buildings (eds A. Athienitis and W. O'Brien), Wilhelm Ernst & Sohn, Berlin, Germany. doi: 10.1002/9783433604625.ch05

Attia, S., Zawaydeh, S., 2014, Strategic Decision Making For Zero Energy Buildings in Jordan, ASHRAE Proceeding of Conference on Energy and Indoor Environment for Hot Climates, February 24-26, Doha, Qatar.

Biggs, C. 2005. Building What? The Challenge of Introducing Alternative Building Practices into the Aqaba Built Environment. Lund University, Int. Institute for Industrial Env. Economics - IIIEE, Sweden: Lund University.

BS EN 16627:2015, Sustainability of construction works. Assessment of the economic performance of buildings. Calculation methods, BSI, ISBN: 978 0 580 79340 0.

Crawley, D., Pless, S., Torcellini, P., 2009, Getting to net zero, ASHRAE Journal 51 (9) 18–25de Dear, R.J., Brager, G.S., 2002, Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55, Energy Buildings, 34 (6) 549-561.

Degree Days, 2016, Weather Data for Energy Professionals, Accessed 07.06.2016, available from www.degreedays.net/

DOE, 2016. EnergyPlus [online]. Available from: http://apps1.eere.energy.gov/buildings/energyplus/ [Accessed 1 January 2016].

EPBD, 2002. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0091:EN:NOT, consulted: 30/03/2009.

EPBD, 2010. Directive of the European Parliament and of the Council on the energy performance of buildings (recast), Interinstitutional File: 2008/0223 (COD), http://www.europarl.europa.eu/meetdocs/2009_2014/documents/cls/cons_cons(2010)05386(rev3)_/cons_cons(2010)05386(rev3)_en.pdf, consulted: 14th June 2016.

Etier, I., Al Tarabsheh, A., Ababne, M. 2010, Analysis of Solar Radiation in Jordan, Jordan Journal of Mechanical and Industrial Engineering JJMIE, 4(6)

European Parliament, 2009. European Parliament legislative resolution of 23 April 2009 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2008)0780 – C6-0413/2008 – 2008/0223(COD)), http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P6-TA-2009-0278; consulted: June 15, 2009; last update May 15, 2009.

IEA SHC Task 40, 2013. Towards Net Zero Energy Solar Buildings. http://www.iea-shc.org/task40

Jaber, J. O. (2002). Prospects of energy savings in residential space heating. Energy and Buildings, 34(4), 311-319.

Jaber, J. O., Badran, O., & Abu-Shikhah, N. 2004. Sustainable Energy and Environmental Impact: Role of Renewables as Clean and Secure Source of Energy for the 21st Century in Jordan. Clean Technologies and Environmental Policy.

Johansson, E., Ouahrani, D., 2009. Climate Conscious Architecture and Urban Design in Jordan, Printed in Sweden by Media-Tryck, Lund.

Jordan Department of Statistics, General Census of Population and Housing Report 2015.

Jordan Department of Statistics, Building Permit Report Nov. 2015

Jordan Housing Development Association, reports, 2016

JNBC, 2009. Thermal Insulation Code, Jordanian National Building Council, 2nd edition, Amman, Jordan.

JNBC, 2010. Energy Saving Buildings Code, Jordanian National Building Council, 1st edition, 2010, Amman, Jordan.

Marszal, A. J., Heiselberg, P., Bourrelle, J. S., Musall, E., Voss, K., Sartori, I., & Napolitano, A. (2011). Zero Energy Building–A review of definitions and calculation methodologies. Energy and buildings, 43(4), 971-979.

McNichol, E., 2016, It's Time for States to Invest in Infrastructure, POLICY FUTURES, February 23, 2016, Center on Budget and Policy Priorities, Washington, USA.

NIST, 2016, Building Life-Cycle Cost (BLCC) Version 4 Building and Fire Research Laboratory, National Institute of Standards and Technology. USA.

RECREEE, 2016, Energy Profile of Jordan, The Regional Center for Renewable Energy and Energy Efficiency (RCREEE), Nasr City, Cairo, Egypt

Sartori, I., Napolitano, A., & Voss, K. 2012. Net zero energy buildings: A consistent definition framework. Energy and buildings, 48, 220-232.

UNDP, 2016, UNDP in Jordan, Available from www.jo.undp.org/content/jordan/en/home/countryinfo.html, accessed 01.09.2016

USAID/Jordan, 2013. Public Action Project for Water, Energy and Environment project.

Visscher H. et al., 2009, The impact of energy performance regulations on systems of building control , RICS, COBRA Research Conference, University of Cape Town, 10-11, pp 1356-1367.

Zawaydeh, S., Jaber, H., 2013. PAP Modeling Information Sheets, Public Action Project USAID, at the Jordan GBC.

ZEBRA 2020 Data Tool, 2016, Energy efficiency trends in buildings. Available from: http://www.zebra-monitoring.enerdata.eu/overall-building-activities/nzeb-definitions-by-country.html, Accessed: 28.06.2016.