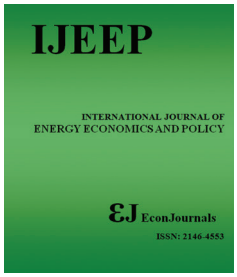


International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2020, 10(6), 325-336.

Evaluation of Near-net-zero-energy Building Strategies: A Case Study on Residential Buildings in Jordan

Hikmat H. Ali[1]*, Fahmi A. Abu Al-Rub[2], Bashar Shboul[3], Hind Al Moumani[1]

[1]Department of Architecture, College of Architecture and Design, Jordan University of Science and Technology, Irbid-Jordan, [2]Department of Chemical Engineering, College of Engineering, Jordan University of Science and Technology, Irbid-Jordan, [3]Department of Mechanical Engineering, College of Engineering, Jordan University of Science and Technology, Irbid-Jordan. *Email: Hikmat@just.edu.jo

Received: 17 June 2020 **Accepted:** 08 September 2020 **DOI:** https://doi.org/10.32479/ijeep.10107

ABSTRACT

Residential buildings contribute a significant share of energy consumption in Jordan, consuming 23% of total energy demand. It is the highest electrical energy consuming sector in Jordan, where it accounted for approximately 43% of the total electricity consumption in the year 2016. Therefore, improving the energy performance of existing residential buildings in Jordan is likely to reduce energy usage (approach net zero energy) and would be a means to minimizing national electrical consumption. A typical house model located in Irbid is selected as a case study for the near zero energy design and saving energy objective. The study investigates the economic and computational potential of various integrated passive and active design systems for the Jordanian residential building sector, by focusing on several parameters including orientation, layout, type of insulation, type of windows, shading system, type of ventilation system which used a comprehensive and detailed model of the natural convection air-cooled condenser integrated to stack (NCACC) as new efficient ventilation method, and using of two renewable energy technologies; PV and flat plate solar thermal collector during the design of the buildings. This study uses three-strategies of building energy analysis in order to achieve near Net Zero Energy Building (nNZEB) in Irbid, Jordan. Two approaches (computational and analytical) could be utilized for the identification of energy building performance analysis. A dynamic building energy modeling and simulation software with different climatic conditions was utilized to identify the best building energy model. A suitable economic evaluation criterion was used to estimate the payback period of all systems applied.

Keywords: Near-net-zero-energy Building, Residential Buildings, Energy Usage, Design Strategies
JEL Classification: Q2

1. INTRODUCTION

A Nearly Net Zero Energy Building (nNZEB) is a building that has optimum energy performance (Rezaie et al., 2013) (D'Agostino and Mazzarella, 2019) and should meet its energy requirements largely amount from renewable sources produced on-site or nearby (Department of the Environment, 2012). The purpose of nNZEB is carried out by using a set of different design strategies which apply efficient technologies that diminish energy demands of building and subsequently use renewable energy systems. More specifically, net zero energy strategies include; minimizing household electricity consumption by using energy efficient devices; minimizing energy demand via efficient demands; minimizing space cooling and heating load through an energy efficient building envelope; and selecting adequate site-based renewable energy technologies to generate electricity and heat.

The concept of a net zero energy building (NZEB) that was introduced by Torcellini et al. (2006) compared two types of renewable energy sources: On-site energy supply versus off-site renewable energy supply. The study encompassed five renewable energy technologies, two on-site options: PV and micro combined

This Journal is licensed under a Creative Commons Attribution 4.0 International License

heat and power, and three off-site options: off-site windmill, the share of a windmill farm and purchase of green energy from a 100% renewable utility grid. (Marszal et al., 2011). A net-zero energy building for dwellings could mainly produce energy via photovoltaic modules, wind turbines, or biogas generators. The net-zero energy residential building studied in this research utilizes PV modules to offset the electricity cost purchased from the grid (Www.Jordinvest.Com.Jo. (Accessed 19 March 2015)., n.d.). Wittchen et al. (2010) utilized two on-site renewable technologies: PV and flat solar thermal panels in order to generate energy needed to meet the nNZEB. The study found that this technology is the most appropriate and commonly used in Denmark (Wittchen et al., 2010).

The appropriate use of energy requires three effective energy management strategies by; reducing the demand, employing energy efficiency, and using renewable energy systems. Most of the energy loss comes because the breadth of the windows or canals and old appliances or ineffective heating and cooling systems. Interestingly, energy savings of up to 25% in buildings can be achieved through the following long-term strategies: Lighting lamps, air leakage testing, insulation, heating and cooling, checking the surfaces, landscapes, heating the air, windows, electrical appliances, and electronics (Panão et al., 2013) (Asadi et al., 2012).

This study investigated the economic and computational of various integrated passive and active design strategies for Jordanian residential building sector by focusing on building physical attributes such as orientation, layout, type of insulations, type of windows, shading system, type of ventilation system and use of renewable energy; PV and solar water heating system during the design of the buildings. A typical single house model located in Irbid was selected as a case study for near zero energy design and energy saving objectives. The main purpose of the study was to minimize energy consumption (approach net zero energy) and improve resident's quality life (minimize environmental effect) in Irbid City by introducing the concept of three-strategy building energy analysis to develop near net zero energy buildings in hot climate regions using passive and active advanced strategies for implementing nNZEB.

The aim of this study was to evaluate a cost-optimal nNZEB of two options by using life cycle cost analysis and explore different designing strategies of a nearly net zero energy for residential buildings in Jordan, to compare and collect existing standards and their criteria in order to find differences and similarities with a focus on both passive design (building layout, orientation, envelope configurations, window design and ratio to wall, ventilation and infiltration), and active design (flat plate solar collectors and PV systems). This can be achieved by proposing an applicable solution for reducing energy consumption in new residential buildings in Jordan, by introducing the concept of three-strategies building energy analysis. The findings can be beneficial by providing decision-makers, engineers and manufacturers with policies, tools, and strategies to develop new building codes using the energy efficient technologies and renewable energy systems for nearly net zero energy building in Jordan. The results indicate that off-site renewable supply options are more cost effective than on-site renewable supply options to invest in renewable energy technologies.

2. LITERATURE REVIEW

2.1. The Concept of Net Zero Energy Building (NZEB)

This study conducted implementation strategies in terms of passive strategies and active strategies based on the basic concept of NZEB. To illustrate, building that reduces the initial load through passive strategies and then saves the remaining residual load through active strategies, so that the sum of the amount of energy consumption and energy generation is zero).

A variety of studies have been carried out in relation to the reduction of building energy demand to reach NZEB. Marszal et al. (2011) presented a definition for a net-zero energy of single house building. The net-zero energy residential building studied in this research utilized photovoltaic modules (PV) to offset the electricity cost purchased from the grid (Marszal et al., 2011). It indicates that a net zero energy building for dwellings could produce energy via photovoltaic modules, a wind turbine, or a biogas generator. Torcellini et al. (2006) introduced the concept of a net zero energy building (NZEB) through comparing two types of renewable energy sources: on-site or off-site renewable energy supply. This study encompassed five renewable energy technologies comprising two on-site options: Photovoltaic and micro combined heat and power and three off-site options. The main purpose of the study was to evaluate a cost-optimal NZEB of two options by using life cycle cost analysis. The results indicate that the off-site renewable supply options are more cost effective than on-site renewable supply options to invest in renewable energy technologies (Marszal et al., 2011).

To study and investigate renewable technologies, Wittchen et al. (2010) utilized two on-site renewable technologies: PV and flat solar thermal panels in order to generate the energy needed to meet the NZEB. This technology is the most commonly used in Denmark (Wittchen et al., 2010). Venturi et al. (1997) discussed the technology options for the energy aspects which seem to not to be sufficient to ensure the diffusion of a nNZEB model in achieving a nNZEB objective; a significant role be played by designers and architects (Venturi et al., 1977). On the other hand, Meral Ozel (2012) used an implicit finite difference method under steady periodic conditions to estimate the optimum insulation thickness with different wall orientation related to the cooling and heating demands of buildings in Antalya, Turkey during the summer season (Ozel, 2013).

Fayez Aldawi et al. (2013) studied energy savings and thermal performance for new three alternative single house wall designs using AccuRate software as well as a conventional single house wall system (Aldawi et al., 2013). Shady Attia et al. (2013) used an energy building simulation tool (energy plus) to study the performance of buildings in the hot humid climate region and took an apartment in Cairo, Egypt as a case study. The purpose of the study was to improve new tools that help the decision making in designing NZEBs, net zero energy building. It was found that the early conceptual design stages of NZEBs enhance the design of NZEBs (Attia, 2012).

Alaidroos and Krarti (2014) studied the residential building envelope systems for five climate zones in Saudi Arabia as a case study: Riyadh, Jeddah, Dhahran, Tabuk and Abha. This study aimed to improve the energy performance of residential buildings in Saudi Arabia to select the optimal design by optimizing the building envelope components based on life cycle cost and energy savings analysis. These components include wall and roof insulation, window glazing and shading system, and thermal mass associated with exterior walls. The optimization and sensitivity analysis results presented that the government of Saudi Arabia could save up to 36% in annual energy cost subsidies by supporting the investments and energy efficiency projects of the residential building sector (Alaidroos and Krarti, 2015).

2.2. Energy Efficiency of Residential Buildings in Jordan

The energy demand in Jordan has increased progressively at a higher rate up to about 5.1% overall and about 4.6% annually in electricity consumption. Rising oil prices have recently impacted the budget, causing a high financial burden which reached 1.9 billion Jordanian dinars (JOD) in 2016, approximately 7% of GDP. Total energy consumption in the household sector in 2017 around (1342.5) toe, accounting for 23% of the total energy consumption in Jordan. Household Consumption of Electricity is 46% (The Ministry of Energy and Mineral Resources, 2017).

According to the Jordanian Urban and Housing Development Corporation and Department of Statistics, the number of housing units in Jordan is over 2.35 million as of 2015. Residential dwellings of the single-family house type accounts for 55.1% of housing units (The Ministry of Energy and Mineral Resources, 2017). Numerous studies have been conducted about the energy efficiency of residential buildings in Jordan. One study tried to optimize residential energy usage through adopting several design strategies in different climatic regions in Jordan. The tasks performed for this study included selection of five climatic locations, simulation of the baseline building, analysis of the on-site availability of renewable energy, minimization of building energy use with passive design and energy efficiency measures, and the sizing of systems for the collection and storage of renewable energy to meet the reduced building needs (Attia and Zawaydeh, 2014).

The percentage of homes that have knowledge of the means of energy savings is about (96.5%). The percentage of homes that use thermal insulation to insulate the walls is about (21%) and in Irbid is (15%). Polystyrene is considered the most popular material used in thermal insulation, where accounting for approximately (10%) of homes in Jordan and (16%) in Irbid. The percentage of homes with surface insulation is around (18%) in Jordan and (14%) in Irbid. Slope pouring is considered the most common method used to insulate the roofs of single houses, where the percentage of homes using this method in Jordan and Irbid is (11%) and (14%) respectively (The Ministry of Energy and Mineral Resources, 2017).

The most popular method used in the reduction of electricity consumption in residential dwellings is to switch off lights during natural light (94%), as well as switching off lights in unoccupied rooms. One less popular method used to reduce of electricity consumption in homes is the periodic maintenance of electrical appliances (47%). The percentage of houses using energy saving lamps in Jordan is 80% (Ministry of Public Works and Housing, 2013). Hammad et al. (2014) investigated the feasibility of implementing "Green Building" technology systems in Jordan, studying the latest trends in this technology worldwide and developing a customized version with respect to the local context of Jordan for retrofitting an older building toward green building conditions (Hammad et al., 2014).

Kiwan used two types of renewable energy systems, PV and wind, in addition to thermal insulation, which was implemented to achieve the maximum energy requirement for a house building. It was found that insulation of external walls only accounts for reduceing 30% of the heating load without any change in cooling load (Kiwan et al., 2020). Furthermore, adding insulation on roof could minimize heating and cooling loads to 70% and 20%, respectively (Attia and Al-Khuraissat, 2016; Hammad et al., 2014). On the other hand, Al-Salaymeh et al. (2009) studied the feasibility of installing two types of PV technology, stand-alone and grid-connected, in a commercial building in Amman, Jordan. The results indicated that utilizing a grid-connected PV-system is more economical than stand-alone PV in a single house building. The estimated payback period for stand-alone and grid-connected PV system was 50 and 30 years respectively (Al-Salaymeh et al., 2010).

AlZyood et al. (2010) studied the thermal and economic impact of employing passive and active solar systems in a typical Jordan residence, in which it was noted that the single houses were oriented towards south as the first step in zero heating houses (AlZyood et al., 2010). Another study evaluated the thermal performance of different test rooms with different covering constructions. It indicated that the thermal transmittance (U-Value) has a major role in choosing building materials and the results also investigated the importance of using the ground as a cooling source through the active concrete system. A comparative study was conducted between existing residential buildings with high and low energy consumption and three different hybrid systems and three different renewable energy resources were designed for a certain size. It observed that, without taking into account the economic factors, hybrid systems are dominant (Rezaie et al., 2013).

3. METHODOLOGY

The methodology implemented in this paper included multi design and energy efficiency strategies to achieve the target of near-net-zero energy building (nNZEB). First, a survey was conducted in the city of Irbid to study and evaluate the current situation of residential buildings. Second, a base case representative to the entire housing units was selected to study and analyze the attributes of building configurations. Third, different energy efficiency strategies to achieve nNZEB were applied.

In phase one combinations and permutations fundamentals used in the energy analysis to identify all possibilities of the design alternatives end with understanding the characteristics of

buildings taken from a survey. This phase analyzed the building parameters and made iterations to print out all design alternatives, to end with the optimum design single house from the existing residential building. In this phase, all parameters that presented form the survey are used with some adjustments through using building envelope sequence with insulation and new U-value, infiltration, lighting energy and cooling system taken from Jordanian building code. The second phase is the Efficiency system which divided into two parts: First part is passive design approach to end with base case building. The second part apply active design which creates a comprehensive and detailed model of the (NCACC). The results of the mathematical model consist of a set of linear and nonlinear mathematical equations. In phase three, two systems of renewable energy be adapted: first applying photovoltaic cells in electricity generation, and flat plate collector for domestic hot water (DHW). PVsyst software has been utilized to find the optimal system configuration which it is more economical.

Strategies in the study used in order to achieve near net zero energy building (nNZEB) in Irbid, Jordan by select the optimum design of three strategies. The computational study was based on energy simulation as a tools for design decision making, optimizing energy efficiency, reducing operating costs, life cycle cost analysis, and defining/validating performance targets. Building simulation used to answer architectural questions during the early design phase in order to provide a higher level of energy efficiency from the outset and save time during the design process. Design used for modeling and simulation that performs detailed analysis to predict how a building performs relative to; energy use, energy cost, and system sizing and performance. The engineering equation solver (EES) was used to solve the system equations of (NCACC).

The study took place in the city of Irbid which is located about 80 kilometers north of the capital, Amman. Irbid governorate is characterized by its outstanding location and economic, archaeological and historical importance, and is the second largest governorate after the capital, Amman, in terms of population. Irbid governorate is located in the far north, among fertile plains and valleys.

Jordan is also classified into three climatic regions: Region 1, the Jordan River Valley, Region 2, the Eastern highlands and region 3, the desert. Amman, the capital city of Jordan, is the most densely populated city and Irbid, Zarqa, Ma'an, Karak, and Ajloun are also more population spread cities after Amman (Hammad et al., 2014). Irbid governorate constitutes a major source for the needs of Jordan's plant and animal production as well as livestock and contains many of the industries that make up a large part of Jordan's exports (Http://Www.Essaymania.Com. (Accessed 09 January 2015)., n.d.). Jordan is well-situated to utilize renewable energy sources, especially Photovoltaic Cells and Solar Thermal Systems, because it has about 310 sunny days a year, providing a sunshine duration of about 3125 h/year (Www.Jordinvest.Com.Jo. (Accessed 19 March 2015)., n.d.), and the average daily solar radiation on a horizontal surface about 5.64 kWh/m^2 per days. (Ministry of Public Works & Housing, 2013). The climate data for Irbid city used in this study taken by the Jordanian Green Building Guide. This data presents the maximum number of sunshine hours (11.9 h) occurred in June and July, while the minimum number of sunshine hours (5.4 h) occurred in January and December (Hammad et al., 2014) (Kaynakli, 2012). There is potential for bioclimatic design in all climatic regions of Jordan.

The climate of Irbid Governorate is Mediterranean. The weather description for climate zones in this region is characterized by cold and rainy in winters and hot, dry summers, with rainfall in the Irbid ranging between (290-550) mm and average relative humidity between (70-80%) in winter, which drops to (40-50%) in summer. The average annual minimum temperatures range between (2-4) °C and the average annual maximum temperature rise to (36-38) degrees Celsius.

3.1. Archival Data and Field Survey

A multi-stage cluster sampling method was used in this survey by selecting seven regions of Irbid City: Nuzha, Manarah, Barha, Hashemiyah, Naser, Rowdah, and Al-Rabia. The sample of 726 single house units had been taken through site visiting of the municipality of each region. The survey studied various aspects of building attribute, including construction material, windows system, orientation, average living space, and layout. One-zone and typical one-story single-family residential building were studied in the survey.

It was found that most residential building layouts are of rectangular shape and represent about 61% of the total samples, whereas 3.6% of buildings have a U-shape layout, which is the least popular, as shown on Table 1. It is assumed that each of these layouts have their own energy performance attributes. The areas of these buildings ranged between 80 m^2 and 310 m^2. Around 38.1% of buildings in this sample had an area of 120 m^2.

Construction materials used varied between concrete bricks, which were used for around 48.5% of buildings, and around 31.1% used stones, while 20.4% used a mixture of concrete and stone. Some of these buildings used insulation materials as shown in Table 2. The percentage of units using insulation material for walls in Irbid is around (18.5%). Polystyrene is the most popular insulation material which represents around 9.5%, and air represent 7.3% while Rockwool represent around 2.8% of the total surveyed units. On the other hand, the use of insulation in roof comprises 35.6% of the total units. The most used material for slab is pouring which represent around 11%, while flagstone represents around 4.5% and asphalt represents around 1.9%. Opening was operable single sliding pane with single glazed and double glazed, Aluminum framed without any exterior shading equipment. Almost of windows (51%) in the four facades of buildings covers 20%-30% of the total wall area (WWR).

3.2. The Proposed Building Characteristics

The selected single house represents a typical housing unit in the Irbid region. The area of the building is 120 m^2. It consists of five rooms: two bedrooms, guest room, living room, kitchen and two bathrooms. The entrance is oriented south and the building

Table 1: The geometrical layout of the prototypical houses in Jordan and their percentage

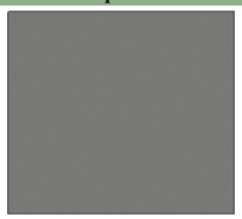
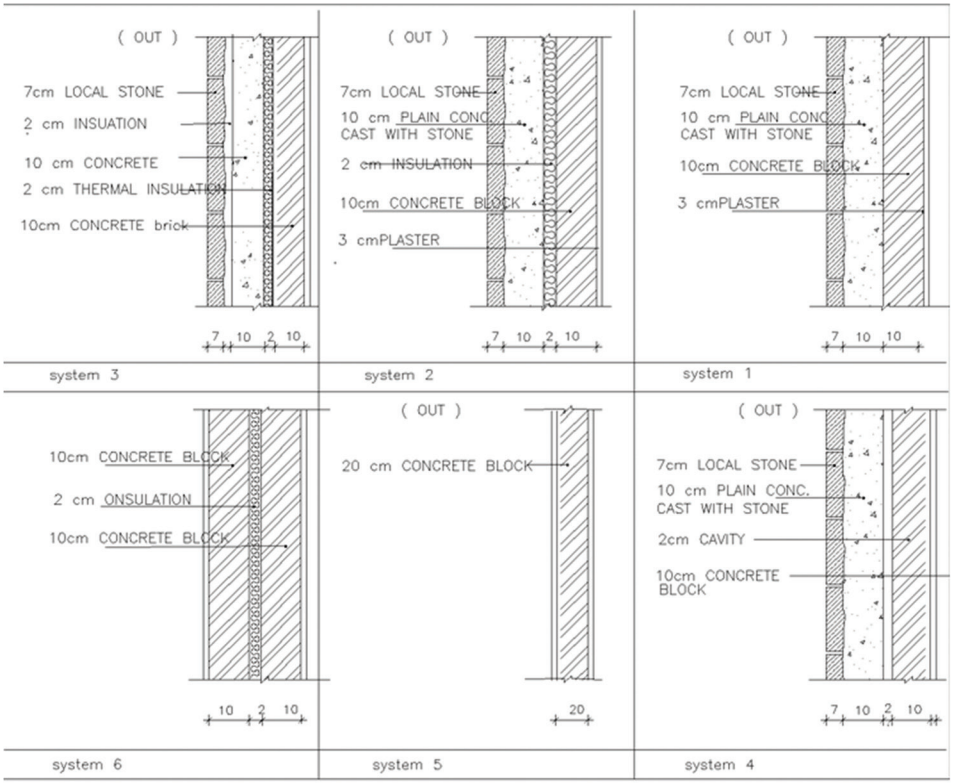
Floor layout	Rectangle	Square	L-shape	U-shape
Shape				
Percentage	61.0%	27.2%	8.2%	3.6%

Table 2: Wall and floor system configurations and properties for the prototypical house design

Wall construction sections			
			
	Construction element	**Thermal conductivity (W/m.k)**	**Density (Kg/m3)**	**Specific heat capacity (J/kg.k)**
	Wall construction			
1.	Stone	1.7	2200	1000
2.	Polystyrene	0.03	35	1400
3.	Concrete	1.75	2300	840
4.	Bricks	1.0	1900	840
5.	Plaster	1.2	1850	840
	Roof construction			
1.	Tile	0.55	1900	837
2.	Polystyrene	0.03	35	1400
3.	Mortar	1.4	2100	650
4.	Sand	1.83	2200	712
5.	Concrete	1.75	2300	840
6.	Ribs	0.95	1900	837
7.	Screed	1.83	2200	712

height is 3 m. The number of family members is 5 occupants. As shown in Figure 1.

The wall is composed of 3 cm plaster, 20 cm concrete block and 3 cm plaster for inner layer (system 5). The roof is composed of

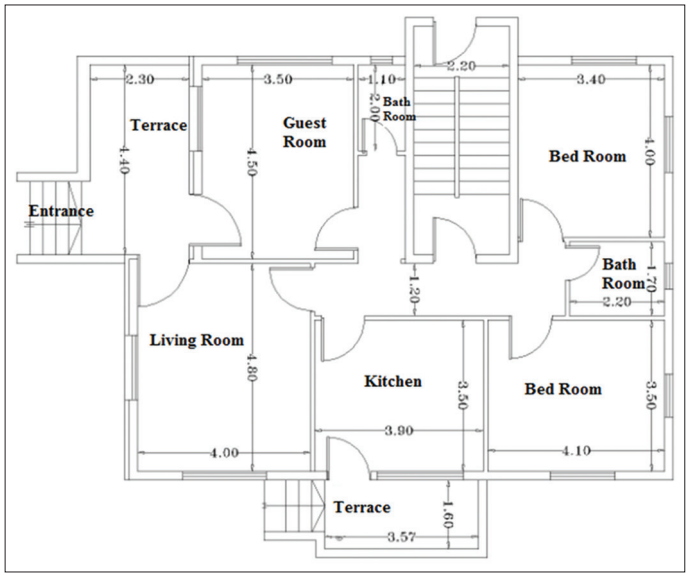
5cm screed, 7 cm concrete, 18 cm ribs, and 3 cm plaster. A flat roof has an inclination angle of 0° Table 3. Summarize all envelope configurations.

4. RESULTS AND COMPUTATIONAL ENERGY DEMAND

Heat transfer is the transient flow of thermal energy from one system to another due to temperature difference between the two systems. Based on theoretical one-dimensional heat transfer equations of three modes (conduction, convection, and radiation) as mentioned below by using Warner and Arpaci equations. These equations are used to estimate the heat loss or gain through the existing single house wall system monthly and annually. Warner and Arpaci equations were used to estimate the heat gain or loss through wall and roof by using one dimensional steady conduction, natural convection and radiation for vertical wall and horizontal roof composite materials determined [2]. The main purpose of these equations is to validate the results from simulation. Equation (1) below was to find heat gain or loss by conduction & convection.

$$Q_{\frac{loss}{gain}} = \frac{h_{in} A\left(T_{air,in} - T_{air,out}\right)}{\left(1 + \frac{h_{out} A}{h_{in} A} + \frac{h_{out} A}{k_{total} A}\right)} \quad (1)$$

Figure 1: Floor plan of the selected houses



For radiant heat loss or gain through the air inside house to inside wall, equation (2) is used.

$$Q_{\frac{loss}{gain}} = \varepsilon\sigma A\left(T_{air,in}^{\ 4} - T_{wall,in}^{\ 4}\right) \quad (2)$$

4.1. Stage One

The first stage Uses DesignBuilder energy building modeling software. The building parameters of existing residential units are listed in Table 4 below. The table below summarizes the characteristics of three strategies which are used to evaluate the energy performance.

The simulation results estimate the annual electrical energy consumption to be 3670.1 kWh and district heating consumption to be 2472.2 kWh, composed of 1333.2 and 1139.024 kWh of heating requirements and water system respectively. Total energy end use is 6142.3 kWh (51.2 kWh/m^2). According to the Irbid Electricity Company Annual Report, 2017, the average household

Table 3: Base case building properties and envelope specifications

Climate characteristics		
1.	Location of study	Irbid city
2.	Latitude, longitude	32, 35
4.	Altitude	616
General building characteristics		
7.	Building code (classification)	C: front, side, rear setback (4,3,4) m and 48% building area ratio
8.	Average area	120 m^2
9.	No. of room	Five rooms; three bedrooms, guest, living room, kitchen and 2 bathrooms
10.	Orientation	South facade
11.	Layout	Rectangle
12.	Building type	One story single family
13.	Construction material	Cement Bricks. (Block)
14.	Insulation type	No insulation material used
15.	Wall system configuration	3 cm, plaster board, 20 cm bricks, 3 cm plaster (system 5)
16.	Roof system configuration	Screed 5 cm, concrete 7 cm, ribs 18 cm, plaster 3 cm
17.	Windows type	Clear single pane
18.	WWR	20%
19.	Overhang and louvers	None
20.	Doors	Made of solid wood/one outer door
21.	Average water consumption	3.333 l/m^2-day
23.	Thermostat set point	20°C for heating, 25°C for cooling
24.	Lighting energy	4.5 W/m^2-100 Lux, surface mount
25.	Infiltration	0.7 ACH
26.	Electrical ventilation	No fan used
27.	Natural ventilation	Manual opening of windows and doors when internal thermal comfort is reduced
28.	Mechanical ventilation	Not used

Table 4: Characteristics of adopted strategies used to improve energy performance of buildings

Parameters	Strategy 1		Strategy 2 (active)	Strategy 3 (renwable)
	Phase 1(Base)	Phase 2 (passive)		
Wall U-value	2.381 W/m^2.k	0.57 W/m^2.k	0.2 W/m^2.k	0.2 W/m^2.k
Wall insulation thickness	0.0 cm	4.08 cm	4.0 cm	4.0 cm
Roof U-value	2.371 W/m^2. k	0.55 W/m^2. k	0.1 W/m^2. k	0.1 W/m^2. k
Roof insulation thickness	0.0 cm	3.71 cm	4.19 cm	4.19 cm
Window U-value	5.8 W/m^2.k	3.1 W/m^2.k	0.5 W/m^2.k	0.5 W/m^2.k
Window shading	None	None	Venetian blinds	Venetian blinds
Overhang and louvers	None	None.	0.5 m overhang	0.5 m overhang
Lighting Energy	4.5 W/m^2-100 Lux, surface mount	3.4 W/m^2-100 Lux, surface mount	3.3 W/m^2-100 Lux, surface mount	3.3 W/m^2-100 Lux, surface mount
Lighting control	None	None.	Used.	Used
Domestic water consumption	3.333 l/m^2-day	3.333 l/m^2-day	3.333 l/m^2-day	3.333 l/m^2-day
Infiltration	0.7 ACH	0.5 ACH	0.35 ACH	0.35 ACH
Electrical ventilation	None	None	The fan used for comfort cooling	The fan used for comfort cooling
Natural ventilation	Manual opening of windows and doors when internal thermal comfort is reduced	Manual opening of windows and doors when internal thermal comfort is reduced	Manual opening of windows and doors when internal thermal comfort is reduced	Manual opening of windows and doors when internal thermal comfort is reduced
Mechanical ventilation	None	None	NCACC	NCACC
Thermostat set point	20°C for heating, 25°C for cooling.	20°C for heating, 25°C for cooling	20°C for heating, 25°C for cooling	20°C for heating, 25°C for cooling
Cooling system	None	Split unit, COP 2.25	Split unit: heat pump COP 4.5	Split unit: heat pump COP 4.5
Heating system	Gas furnace: COP 75%	Gas furnace: COP 75%	Gas furnace: COP 90%	Gas furnace: COP 90%
DHW system	Instantaneous hot water only, COP 85%	Instantaneous hot water only, COP 85%	Stand-alone water heater, COP 85%	Flat Plate Solar Collector.
PV system	None	None	None	9 m^2 monocrystalline modules, PV field nominal power (Pnom) 1.3 KWp, 2.5 MWh/year

sector electricity consumer bill is 3247 kWh (27.06 kWh/m^2). This value validates the simulation result of electricity consumption, which is found 3670.1 kWh (30.6 kWh/m^2).

Irbid's comfort temperature range was calculated according to ASHRAE's adaptive thermal comfort equation below:

$$T_{op.com}\ 18.9 + 0.255\ T_{out} \quad (3)$$

Where $T_{op.com}$ is the operative comfort temperature, T_{out} is the mean monthly outdoor air temperature.

Maximum and minimum ambient air temperature and climatic parameters of Irbid city are used for monthly analytical calculations as illustrated in the Table 5 to find the total gross heat gain or loss. The analytical results show that the total heat loss or gain through the house wall system of strategy one-phase one (basecase) is about (−184.1) kWh/m^2/year, while, the total heat loss or gain through the house wall system of strategy two (new efficient) is approximately - 156.8 kWh/m^2/year.

The simulation results show that the energy saving of the second phase compared to existing residential buildings is 20.44% with total energy consumption equivalent to 40.7 kWh/m^2, in the square shape. Meanwhile the energy saving in the U shape was 12.9%. 384 iterations took place in order to predict the optimum building models and it is noticed that the square layout which is the best floor layout used and the U-shape is the worst one. A south facing orientation is the best and east is the worst one. Wall system 2 and roof system 2 work best when used in combination with each other. The Windows to Wall Ratio (WWR) that gives minimum consumption is 15%.

Different values of energy consumption could be printed out with different layouts, construction details, orientations, and WWR. It is observed that square layout is the best one while the U – shape is the layout achieved the minimum energy savings. The energy consumption increased with an increase in WWR. Table 6 represents the relationship between energy consumption and layout, orientation, wall and roof details, and windows ratio (WWR). These results compare the best energy consumptions and the worst one.

4.2. Stage Two

After selecting the best design alternative of base case strategy, six efficient parameters of passive design were added in order to achieve (nNZEB). These parameters are; Wall U-value, Roof U-value, Windows U-value, Infiltration, Overhang and louvers, and Shading. Second part is applying active design: This part of study creates a

Table 5: Analytically determined data for the existing single house wall system comparing with second phase in Irbid

Month	Human comfort Temp. Inside °C	Max. Air Temp. Outside °C	Min air Temp. Outside °C	The existing single house wall system(base case)			The second phase single house wall system		
				Q loss/gain with Max. Temp. (Cond. – Conv. –Rad.) kWh/m²/month	Q loss/gain with Min. Temp. (Cond. – Conv. –Rad.) kWh/m²/month	Total Q loss/ gain (Cond. – Conv. –Rad.) kWh/m²/month	Q loss/gain with Max. Temp. (Cond. – Conv. –Rad.) kWh/m²/month	Q loss/gain with Min. Temp. (Cond. – Conv. –Rad.) kWh/m²/month	Total Q loss/ gain (Cond. –Conv. – Rad.) kWh/m²/month
Jan	21.2	13	5.9	−11.43	−19.84	−31.26	−4.07	−14.38	−18.45
Feb	21.4	14.1	5.4	−10.39	−24.15	−34.54	−3.06	−14.93	−17.99
Mar	22.0	17	7.4	−7.00	−19.53	−26.53	−1.54	−13.72	−15.25
Apr	23.1	22.1	10.7	−1.38	−18.54	−19.92	−0.02	−11.58	−11.60
May	24.2	27	14.2	3.97	−13.85	−9.87	−0.70	−9.45	−10.15
Jun	24.9	30	17.5	7.27	−9.45	−2.18	−3.30	−7.01	−10.31
Jul	25.3	31.1	19.3	8.13	−8.86	−0.73	−5.30	−5.79	−11.09
Aug	24.4	31.4	19.7	9.84	−5.48	4.37	−9.87	−4.27	−14.14
Sep	25.0	29.8	18.2	6.86	−9.20	−2.34	−3.19	−6.40	−9.59
Oct	24.3	26.7	15.2	3.35	−13.45	−10.10	−0.56	−8.53	−9.10
Nov	22.9	20.7	10.1	−3.05	−18.73	−21.78	−0.29	−11.88	−12.18
Dec	21.6	15	6.4	−9.46	−19.79	−29.25	−2.63	−14.33	−16.96
Total gross heat loss/gain (kWh/m²/year)					**−184.1**			**−156.80**	

comprehensive and detailed model of the (NCACC). This model takes from book "DESIGN OF THERMAL SYSTEMS" (Stocker, 1989). The main purpose is designing minimum cost of a natural draft air-cooled condenser (ACC) that rejects 140 KW of heat. The results of the mathematical model consist of a set of linear and nonlinear mathematical equations. The engineering equation solver (EES) used to solve the system equations. Indeed, Lighting control, ventilation, cooling and heating system efficiencies and mechanical ventilation used in this strategy.

The simulation result shows the annual energy consumption reduced to 4073.6 kWh (33.9 kWh/m2), achieving 33.7% in total energy savings. The Table 7 shows the detailed energy consumption of electricity and district heating and cooling.

The NCACC system is solved using EES. This system is preferred to use in summer and spring, over 6 months. The annual total energy produced is 56.1 kWh/year (0.47 kWh/m²/year). The total energy saving of cooling consumption is 6.2%, therefore the annual energy consumption is reduced to 3820.2 kWh (31.8 kWh/m²), achieving 37.8% in total energy savings.

4.3. Stage Three

The PV solar technology type used in this study is monocrystalline modules. This module needed to cater the total electrical power consumption of 2415.8 kWh/year could be achieved in standard test conditions (STC) when the solar radiation is 1000 W/m² and the cell temperature is 25 degrees centigrade. After running the data through photovoltaic system software (PVsys), the optimal results data for installation of the PV system in residential buildings in Irbid is shown in Table 8.

The results of the PV system which include mean solar radiation and system output indicate that the system has minimum electricity production in December (153 kWh) and maximum productivity in August (232 kWh) with total output reach along the year to 2400 kWh. The total energy saving after applied all energy saving techniques from strategy 1 to strategy 3 is 82.4% for final total consumption 1080.2 kWh/year.

Table 9 shows the comparison between strategy 1, strategy 2 and strategy 3 according to total annual energy consumption of electricity and district heating and highlights the total energy savings. Figure 2 shows the variation of energy consumption of each strategy.

4.4. Economic Energy Saving Analysis

Economical energy savings analyses for the residential sector depend on construction materials, weather characteristic and occupant energy behavior. The table below shows the average cost of building materials. The average construction cost of the conventional house wall system is about 25.6 JOD/m² and of the new, efficient wall system is about 66.5 JOD/m². The cost of ceiling changes from 90.9 JOD/m² to 61.5 JOD/m². The cost of gas and electricity are taken into consideration in the estimation of energy costs. The average cost of electricity is about 0.086 JOD/KWh for strategy one and 0.072 JOD/KWh, whereas the cost of gas is 0.063 JOD/KWh for residential targets according

Table 6: Maximum/minimum energy efficiency parameters of the selected house

Layout	Square	U shape
Energy consumption (kWh/m²)/layout	40.724	44.563
Energy saving (%)/layout	20.44	12.94
Wall system	SYSTEM 2 Stone 7 cm, insulation 2 cm, concrete 10 cm, insulation 2.08 cm, bricks 10 cm, plaster 3 cm	SYSTEM 6 Plaster 3 cm, bricks 10 cm, insulation 4 cm, bricks 10 cm, plaster 3 cm
Roof System	SYSTEM 2 Tile 3 cm, mortar 2 cm, Sand 10 cm, mortar 5 cm, insulation 3.71 cm, concrete 12 cm, ribs 18 cm, plaster 3 cm	SYSTEM 1 Screed 5 cm, insulation 4.19 cm, concrete 7 cm, ribs 18 cm, plaster 3 cm
WWR	15%	30%
Energy Consumption (kWh/m²)/WWR	40.724	41.834
Energy Saving (%)/WWR	20.44	18.27
Layout	South	East
Energy consumption (kWh/m²)/orientation	40.724	42.740
Energy saving (%)/orientation	20.44	16.50

Table 7: The annual energy consumption of the second strategy used to improve building performance

Consumption	Electricity	District heating		District cooling
		Heating	Water System	
Annual energy consumption (kWh)	2415.8	209.2	1139.0	309.7
Annual energy consumption per meter square (kWh/m²)	20.1	1.7	9.5	2.6

Table 8: PV System adopted as major part of the third strategy used to improve performance

On-grid PV system sizing		
1. Geographical site		
1.	Location	Irbid city
2.	Country	Jordan
3.	Latitude	32.0 °N
4.	Longitude	35.0 °E
5.	Altitude	616.0 m
6.	Orientation of Collector plane	Tilt 30°
2. Main features of PV-field installation		
1.	Module type	Standard
2.	Technology	monocrystalline
3.	Mounting method	Flat roof
4.	Back ventilation properties	Free standing
3. System characteristics and pre-sizing evaluation		
1.	PV field nominal power (P_{nom})	1.3 KWp
2.	Collector Area (A_{coll})	9 m²
3.	Annual Energy Yield	2.5 MWh/year
4.	Economic gross evaluation (E_{year})	4274 JD
5.	Energy price	0.2 JD/kWh

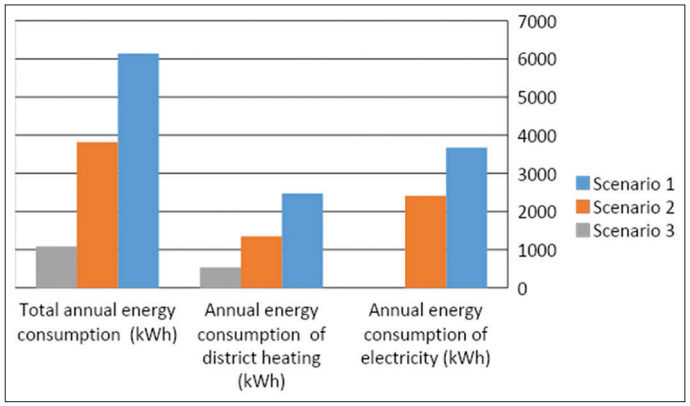
to Jordan Petroleum Refinery and Jordanian Electric Power companies.

According to the total energy required, the total cost of gas reduced from 3.2 JOD/KWh in strategy 1 (step 1) to reach 0.75 JOD/KWh after reaching step 3. Meanwhile the total cost of electricity decreases from 4.4 JOD/KWh to 0.72 JOD/KWh. The payback period estimated for the new efficient house wall system

Table 9: Comparison of energy consumption and saving from the first strategy to the third strategy

Consumption	Strategy 1	Strategy 2	Strategy 3	Saving (%)
Annual energy consumption of electricity (kWh)	3670.0	2415.8	0	100
Annual energy consumption of district heating (kWh)	2472.2	1348.2	533.4	78.4%
Total annual energy consumption (kWh)	6142.3	3820.2	1080.2	82.4
Total annual energy consumption (kWh/m²)	51.2	31.8	9.0	82.4

Figure 2: The variation of energy consumption of each strategy used to minimize energy consumption



(strategy 3) is 8.3 years when gas is the main source and 7.5 years when electricity is the main source, as represented in Table 10. Estimating the payback period by using the following relationship:

$$Payback\ period = \frac{Total\ construction\ cost}{Saving}\ or\ \frac{Total\ investmentt}{total\ yearly\ cost}$$

Estimating the saving by using the following:

- Total cost of gas power (strategy 2) - Total cost of gas power (strategy 1)

Table 10: Cost estimation of implementing different strategies to be used for reaching (nNZEB)

Parameter	Strategy 1				Saving 1	Strategy 2	Saving 2	Strategy 3	Saving 3
	Phase 1		Phase 2						
The total energy required of each strategy (KWh/m^2.Year)	51.2		40.7			31.8		9.0	
Construction cost (JD/m^2)	116.1		128		128-116.1=11.9	128	128-116.1=11.9	128	128-116.1=11.9
	Existing system (JD/m^2)		New wall system (JD/m^2)						
Wall	Render	5.4	Stone	11.5					
	Bricks	16.2	Bricks	7.0					
	Plaster	4.0	Polystyrene	3.0					
			R. Concrete	41.5					
			Plaster	4.0					
Total cost/wall	25.6 JD/m^2		66.5 JD/m^2						
Roof	screed	40.0	Tile	3.0					
	concrete	41.0	Polystyrene	3.0					
	ribs	5.0	R. Concrete	30.0					
	plaster	4.5	Plaster	4.0					
			Ribs	3.5					
			Sand	10.5					
			Mortar	7.5					
Total cost/roof	90.5 JD/m^2		61.5 JD/m^2						
Gas power cost (JD/kWh)	0.058		0.058			0.058		0.058	
Total cost with gas (JD/kWh)	LPG; Bulk Central Distribution 0.063 JD/kWh				3.2-2.6=0.6	2.00	2.6-2.00=0.6	0.57	2.00-0.57=1.4
	51.2 * 0.063=3.2		2.6						
Payback period when gas is main source (year)	-		18.3			20.8		8.3	
Electricity power cost (JD/kWh)	0.086 JD/kWh (Lay. 1).& 0.072 JD/kWh (Lay. 2)/ residential sector					0.072		0.08	
	0.086		0.086						
Total cost with electricity (JD/kWh)	51.2*0.086=4.4		3.5		4.40-3.50=0.90	2.3	3.5-2.3=1.2	0.72	2.3-0.7=1.6
Payback period when electricity is main source (year)	-		13.2			9.2		7.5	

- Total cost of electricity power (strategy 2) - Total cost of electricity power (strategy 1).

5. CONCLUSIONS

The aim of these passive and active strategies is to reduce building energy demands along the life cycle of buildings. In this study improving the energy efficiency of residential building sectors in Jordan, Irbid has been analyzed through analytical and computational methods to identify the energy performance of buildings. Three-strategies building energy analysis is utilized to achieve near net zero energy building (nNZEB) in Irbid, Jordan through economic and computational of various integrated passive and active design systems for the Jordanian residential building sector. Set of parameters have been considered in order to achieve maximum efficiency of nNZEB: layout, orientation, and window to wall ratio (WWR).

The simulation results showed an estimate of annual electrical energy consumption as 3670.09 kWh and district heating consumption as 2472.236 kWh, composed of 1333.212 and 1139.024 kWh of heating requirements and water system respectively. Total energy end use of the existing single house building (strategy 1) is 6142.327 kWh (51.186 kWh/m^2). For (strategy 1/phase 2) the energy saving compared to existing residential building is 20.44% with total energy consumption at 40.724 kWh/m^2. Also, for strategy two the annual energy consumption reduced to 3820.181 kWh (31.835 kWh/m^2) that achieved 37.81% total energy savings. Photovoltaic system was proposed to generate the electricity needed by the building. It was found that the PV system generates 2415.79 kWh/year. Flat-Plate Collectors Type "HC100" is generally used for Open-Loop Solar Water Heating Systems. Total number of collectors needed to meet the annual water heating demand (1139.024 kW) is four collectors. The payback period estimated for the new efficient single house wall system (strategy 3) is 8.3 years when gas is the main source and 7.5 years when electricity is the main source Finally the total saving in energy for the whole single house is found to be 82.41%, which approaches a near zero energy building.

Green building practices aim to reduce energy consumption and the environmental impact of buildings. In this work, a building in Irbid is redesigned moving towards low energy building, and based on the result obtained from this study it can be concluded that applying passive strategies to buildings is efficient. Applying thermal insulation (polystyrene) and double glazing windows (Aluminum frames) reduce the energy required by the building. After Applying thermal insulation according to Jordanian building code on existing house building, it can be achieved 18.2% total energy saving.

The optimum passive design strategy can be applied on Jordanian residential building when taken Jordanian building code into consideration: square layout, entrance of building oriented to south and WWR is 15%. This strategy can save about 20.44% from energy. On other hand the worst passive design strategy which the maximum energy saving cannot exceed 6% can be applied on Jordanian residential buildings when U-shape layout, entrance of building oriented to east and WWR is 30% used. Total energy saving can be obtained after applied all energy efficient active and passive strategies on conventional building is 37.8%.

Natural convection air-cooled condenser integrated to stack technology reduce the district cooling load required by the house building to achieve 6.2% and 4.1% energy saving in cooling load and total building code respectively. The total cost is 5329 JD with payback period 9.5 years. Using of photovoltaic system help to generate the electricity for the building during the year and for this case photovoltaic system generate 2415.8 KWh/yr. that happen by investment cost equal to 4274 JD with payback period 8.3 years. Flat-Plate Collectors Type "HC100" is generally used for Open-Loop Solar Water Heating Systems, the technical specification of Flat-Plate Collectors Type "HC100" from Hanania Company which is used in this study. Total number of collectors needed to meet the annual water heating demand (1139.0 kWh) is four collectors. Annual actual useful gain of heat is 324.2 kWh which achieved 71.5% saving of the annual water heating demand. Investment cost equal to 875 JD with payback period 6.7 years.

The payback period estimated for the new efficient single house wall system when renewable energy systems installed is 8.3 years when gas is the main source and 7.5 years when electricity is the main source. The total saving in energy in the whole single house was found to be 82.4% which is considered as a near zero energy building.

6. RECOMMENDATIONS

In light of the results and conclusions obtained through this study, some recommendations can be proposed. It is recommended to use renewable energy system as single system to generate the energy required by the building. Energy conservation methods (thermal insulation, double glazing windows, WWR, shading, and PV system) are recommended to be applied in Jordan. It is strongly recommended to use building monitoring system to manage the energy using inside the building. Finally it is strongly recommended to rewrite and redesign Jordanian building code to cover the new technology. It's expected that this study can be used as a base or guideline for energy researchers, architects, policymakers to understand the current situation for residential buildings and to establish future directions toward nNZEB.

REFERENCES

Alaidroos, A., Krarti, M. (2015), Optimal design of residential building envelope systems in the Kingdom of Saudi Arabia. Energy and Buildings, 86, 104-117.

Aldawi, F., Date, A., Alam, F., Khan, I., Alghamdi, M. (2013), Energy efficient residential house wall system. Applied Thermal Engineering, 58(1-2), 400-410.

Al-Salaymeh, A., Al-Hamamre, Z., Sharaf, F., Abdelkader, M.R. (2010), Technical and economical assessment of the utilization of photovoltaic systems in residential buildings: The case of Jordan. Energy Conversion and Management, 51(8), 1719-1726.

AlZyood, M., Harahsheh, H., Hammad, M. (2010), Thermal Economical Analysis of Renewable Energy Buildings, Towards Low Energy House in Jordan. Tunisia: International Renewable Energy Congress.

Asadi, S., Hassan, M., Beheshti, A. (2012), Development and validation of a simple estimating tool to predict heating and cooling energy demand for attics of residential buildings. Energy and Buildings, 54, 12-21.

Attia, S. (2012), A tool for Design Decision Making: Zero Energy

Residential Buildings in Hot Humid Climates. Belgium: Presses Universitaires de Louvain.

Attia, S., Al-Khuraissat, M. (2016), Life Cycle Costing for a Near Zero Energy Building in Jordan: Initial Study. The 5th Architectural Jordanian International Conference.

Attia, S., Zawaydeh, S. (2014), Strategic Decision Making for Zero Energy Buildings in Jordan.

Available from: http://www.essaymania.com. [Last accessed on 2015 Jan 09].

Available from: http://www.jordinvest.com.jo. [Last accessed on 2015 Mar 19].

D'Agostino, D., Mazzarella, L. (2019), What is a nearly zero energy building? Overview, implementation and comparison of definitions. Journal of Building Engineering, 21, 200-212.

Department of the Environment, Community and Local Government. (2012), Towards Nearly Zero Energy Buildings in Ireland, Planning for 2020 and Beyond.

Hammad, M., Ebaid, M.S.Y., Al-Hyari, L. (2014), Green building design solution for a kindergarten in Amman. Energy and Buildings, 76, 524-537.

Kaynakli, O. (2012), A review of the economical and optimum thermal insulation thickness for building applications. Renewable and Sustainable Energy Reviews, 16(1), 415-425.

Kiwan, S., Kandah, M., Kandah, G. (2020), Zero Energy Building in Jordan. 1st International Conference on Mechanical, Aeronautical, and Industrial Engineering Technologies (MechaniTek 2020), 1(1), 49-60.

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.

Ministry of Public Works and Housing. (2013), Housing and Urban Development Jordanian Housing Sector, Accomplishments and Performance Evaluation for the Period 2005-2013.

Ozel, M. (2013), Determination of optimum insulation thickness based on cooling transmission load for building walls in a hot climate. Energy Conversion and Management, 66, 106-114.

Panão, M.J.N., Rebelo, M.P., Camelo, S.M.L. (2013), How low should be the energy required by a nearly zero-energy building? The load/generation energy balance of Mediterranean housing. Energy and Buildings, 61, 161-171.

Rezaie, B., Dincer, I., Esmailzadeh, E. (2013), Energy options for residential buildings assessment. Energy Conversion and Management, 65, 637-646.

The Ministry of Energy and Mineral Resources. (2017), Energy Consumption in the Domestic Sector 2017.

Torcellini, P., Pless, S., Deru, M., Crawley, D. (2006), Zero energy Buildings: A Critical Look at the Definition. United States: National Renewable Energy Laboratory, Golden, CO.

Venturi, R., Robert, I.V., Brown, D.S., Izenour, S., Steven, R.V.D. (1977), Learning from Las Vegas: The Forgotten Symbolism of Architectural form. Cambridge: MIT Press.

Wittchen, K.B., Jensen, S.Ø., Kamper, S., Kvist, L. (2010), BOLIG+-an Energy Neutral Multifamily Building. Toronto: Proceedings of Euro Sun.