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Evaluation of Nearly Zero Energy Residential Buildings Design Strategies in Three Climatic Zones in Jordan

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ABSTRACT

Designing zero or near zero-energy residential buildings will considerably help in reducing the general energy consumption. Geographically, Jordan retains three different altitude zones with unique climatic conditions for each which imperatively entails deploying different approaches to attain near zero-energy houses. This study aims to investigate the best economic feasible design strategies that possibly lead to near zero-energy residential buildings. Based on the most common detached house design-layout and materials on each zone, three case study houses were designed. The research methodology was based on three levels of efficiency. By using Design Builder, each efficiency level was examined by three design strategies: passive, active, and renewable energy design strategies in order to improve the energy performance of the buildings. The results showed that implementing the three levels concurrently would result in achieving the nearly zero-energy houses with efficient cost and less than 10 years payback period. In the high-land altitude zone, the annual consumption of power was reduced from 79.1 kwh/m^2 to –13.6 kwh/m^2. For the medium altitude zone, the annual consumption dropped down from 78.8 kwh/m^2 to –16.5 kwh/m^2. Finally, the annual consumption of electricity in the low-latitude zone decreased from 75.7 kwh/m^2 to –21.1 kwh/m^2.

Keywords: Near Zero Energy Buildings, Climate Zone, Residential Buildings, Simulation, Design Strategy
JEL Classifications: Q20, Q43, D61

1. INTRODUCTION

The construction boom in Jordan led to a gradual growth in energy consumption particularly in buildings' sector. Generally speaking, buildings worldwide consume 40% of the total energy use as referred to the annual energy review (EIA, 2014). In Jordan, buildings' share of energy consumption accounts for 36% of the total Kingdom energy consumption; the residential sector accounts for 23% of the total Kingdome energy consumption, and 40% of the electricity use (MEMR, 2016). With this tremendous share of energy consumption, designing sustainable and energy efficient houses became an urgency rather than a need. Consequently, the last decade in Jordan witnessed the development of green buildings' trend; for both economic and environmental purposes (Attia and Al-Khuraissat, 2016).

Zero energy building (ZEB) defines those buildings where the generated energy equals the consumed one over a period of time. A three categories belong to this building genre: the net zero energy buildings, the near zero energy buildings (NZEB) and the plus energy buildings. In the former, the total energy balance of the building equals zero. In the NZEB, the consumed energy may slightly surpass the generated one. Finally, in the plus energy building the generated energy is more than the consumed one, which is also called positive energy building (Voss et al., 2012).

The ZEB aims to achieve the maximum efficiency to neutralize the energy resource. The design methodology of these buildings is based on reducing the energy demand and improving their energy efficiency -by applying passive and active design strategies- and the use of renewable energy systems and green power for the remaining amount of consumption (Attia and Al-Khuraissat, 2016). Such buildings are important as they provide a way for a sustainable energy future. However, to achieve this type of buildings, the high initial cost and its cost efficiency are vital concerns for designers, investors, and clients. The inconsistency and the wide range of variables that should be taken into account make it hard to achieve a ZEB within an affordable economic framework. Therefore, the global economic crisis directed the lawmakers to scale down targets as they consider the fact that net zero energy buildings are costly and too expensive (Voss et al., 2012).

NZEB is considered as an alternative and more feasible economic solution. The NZEB are buildings with high efficiency energy performance that requires the minimal amount of energy and could be covered by renewable resources D'Agostino and Mazzarella, 2018). This study investigates and analyzes different design strategies that might lead to energy self-sufficient houses with the least possible cost. The aim of the study is to evaluate different cost-effective design strategies of residential buildings that will lead to a NZEB for different climatic zones in Jordan. Furthermore, this research aims to define the best fit energy efficient design strategies for each climate from environmental and economic dimensions. The study will provide recommendations for the decision makers to develop codes and standards of designing NZEB with the most efficient and economically practical systems.

1.1. Economic Sustainability

The goal of economic sustainability is to minimize costs of the projects during construction and through its life cycle (Fregonara, 2018) The economic pillar of sustainability is directly related to cost and economy, as it is important to evaluate it in all design phases (Eklová, 2020). This research focuses on the economic dimension which will help in applying the proposed strategies easily in the construction market. The importance of economic dimension lies in the constant raising in the prices of the primary resources. In this research economic sustainability aims to investigate cost-efficient design strategies that will lead to NZE houses. The final output of the study is economic feasible house design that meets with energy efficient and self-sufficient aspects.

1.2. Geography and Climate of Jordan

In compared to its small area, Jordan is diverse in terrain and landscape. This variety in topography creates different distinctive climatic zones. According to NMTJ (2018), Jordan's land area comprises five physiographic regions;

1. Semi-desert (the Badia): This region is located in the east of Jordan and represents 78.4% of the total country's area.
2. Plains: This region is located in the western side of the country and represents 11.2% of Jordan's total area.
3. Rift Valley: This area includes the farmland in western Jordan and represents 9.2% of the country's total area. This region includes the lowest point in the country "the Dead Sea", at level 416 meters below the sea.
4. Highlands: This region includes rain-fed agricultural land in western Jordan, and it represents 0.6% of Jordan's total area. The highest level, Um Dami Mountain, at level 1845 meters above the sea.
5. Territorial waters: it includes the Dead Sea and the Aqaba Gulf, and represents 2, 0.6% of Jordan's total land area.

Climate in Jordan is eastern Mediterranean with a relatively two long seasons; summer and winter (Ababsa, 2014). Summer is hot and dry, and winter is a rainy season. Spring and autumn seasons are short and dry. The average temperatures increase rapidly from the highland to the low ground level and decrease moderately from north to south, according to the increase of altitude (NMTJ 2018).

2. RESEARCH METHODOLOGY

This research aims to define the most adequate design strategy for different climatic zones in Jordan. To achieve this goal, various qualitative and quantitative methods will be applied. First, the climatic zones in Jordan will be studied and analyzed to define and select three distinctive climatic zones. Then, three base-case houses will be modeled, one for each climatic zone. The three base-case houses will be simulated, and the energy performance for each case will be used as a base-line reference before implementing any proposed strategies. The implementation of proposed strategies will be applied into three levels; passive design, active design, and renewable energy systems. For passive and active design, Design Builder will be used as a simulation software. For renewable energy systems; T-Sol software for solar systems simulation, and PV-Sol software for PV systems will be used. Each level of strategies will be economically analyzed by using a simple payback period method Figure 1.

2.1. Selection of Climate Zones

The country climate is Mediterranean, characterized by the division of the year into a hot dry summer and mild rainy winter (Ababsa, 2014). Jordan's climate is influenced by its location between the humid eastern Mediterranean and the subtropical arid Arabian Desert (Attia and Al-Khuraissat, 2016). For this study, the criteria of selection will predicate on the Jordan Thermal Insulation code which divided the country into three major climatic zones; Zone 1: The eastern highlands, Zone 2: The desert in the east, and Zone 3: The western rift valley. Table 1 illustrates the three zones and the main characteristics of each zone.

2.1.1. Energy consumption of the selected climate zones (real data)

The energy consumption in Jordanian houses is divided into five main types: HVAC (heating and cooling), lighting, cooking, electrical appliances, and domestic hot water (MEMR, 2013; Rahim, 2015). In reference to the survey data of each zone, the electricity and gas energy consumption is calculated separately referring to the local energy prices at the time of conducting the study. The energy price for electricity ranges from 0.033 JD/kwh to 0.265 JD/kwh based on the different classes identified by the National electric power company. On the other hand, the energy for Diesel is 0.055 JD/kwh, and for LPG is 0.048 JD/kwh The energy prices and annual energy consumption for each zone is screened in Table 2.

As Table 2 shows, the average energy consumption of Zone 1 is 92.25 kwh/m^2, Zone 2 is 91.05 kwh/m^2, and Zone 3 is 82.5 kwh/m^2. While the highest energy consumption in Zone 1 is for

Table 1: Selected climate zones characteristics (JNBC, 2012)

Zone number	Altitude	Weather data	Weather description
Zone 1 (highlands)	High altitude zone (≥+800)	Amman	Moderate cold (heating season)
Zone 2 (desert)	Medium high-altitude zone (≥+600≥+780)	Mafraq	Hot-dry (heating and cooling season)
Zone 3 (aghwar)	Low altitude zone (≤−300)	Ghour Al-Safi	Hot humid (cooling season)

Table 2: The Annual Energy Consumption for residential sector in Jordan*

Energy use	Zone 1		Zone 2		Zone 3	
	Consumption kwh/m^2	Price JD/ m^2	Consumption kwh/m^2	Price JD/ m^2	Consumption kwh/m^2	Price JD/ m^2
Cooling	12	1.45	19	2.25	30.75	3.5
Lighting	14	1.7	13.5	1.6	13.1	1.55
Domestic hot water	14	1.7	15	1.8	14	1.7
Electrical appliances	7.3	.85	6.45	.75	7.2	.85
Heating	33.35	3.35	25.5	2.55	6.15	.6
Cooking	11.6	1.15	11.6	1.15	11.3	1.13
Total	92.25	10.2	91.05	10.1	82.5	9.3

*Energy sources prices are not fixed. The prices in Table 2 are calculated based on the current used values.

Figure 1: Research methodology chart

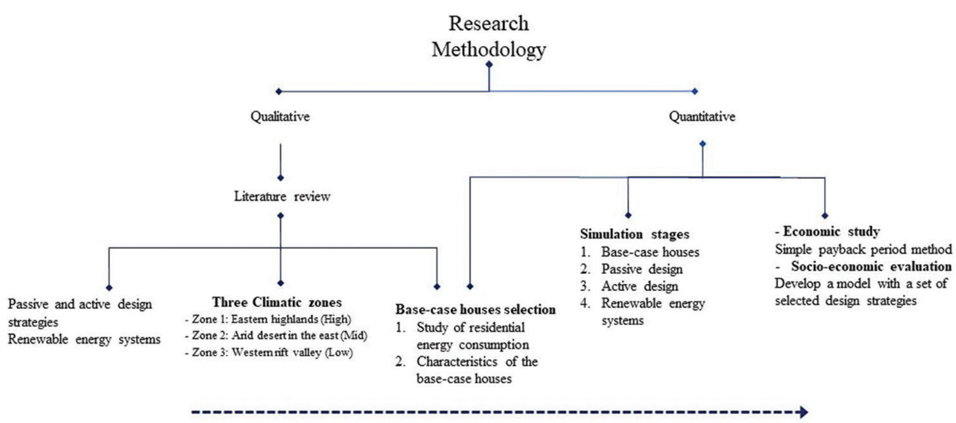
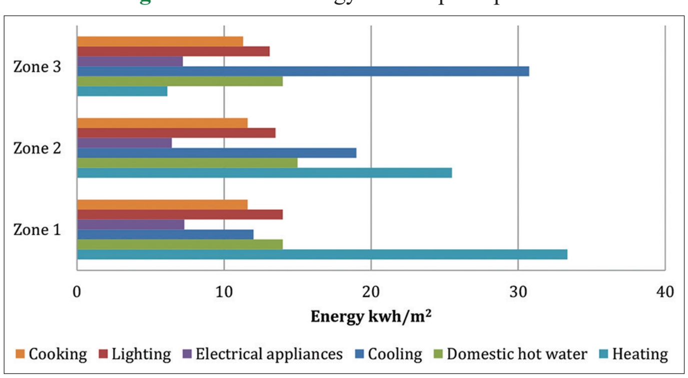


Figure 2: Annual energy consumption per area



heating purposes, in Zone 3 the major consumption is for cooling purposes, Figure 2.

2.2. Selection of Base-Case Houses

Three case study houses were selected, a typical house design for each location. The base-case of the research is a single detached house, which represents 54.1% of the total residences. The design of the case study represents the common house layout; that could help to generalize the case and recommended suitable design strategies for future houses. The design of the three case study houses relied on the collected data through archival reports and documents, field surveys and interviews with local architects. All building features were provided from the survey of the collected cases from the municipality of each zone.

a. Zone 1: Base-case house

The total area of the house is 165 m^2. The main construction material is stone cladding on a concrete skeleton. The average height of the building is 4.40 m, as the clear height from finish to finish is 2.90 m, Figure 3a.

b. Zone 2: Base-case house

The total area of the house is 155 m^2. The main construction material is concrete. The average height of the building is 4.00 m, as the clear height from finish to finish is 2.75 m, Figure 3b.

c. Zone 3: Base-case house

The total area of the house is 130 m^2. The main construction material is concrete. The average height of the building is 4.00 m, as the clear height from finish to finish is 2.75 m, Figure 3c.

All wall and roof systems in the base cases have no thermal insulation. The base-case houses area varies from zone to zone. The characteristics of the three base-case houses are summarized in Table 3.

2.3. Calculations and Analysis of the Base-case Simulation Results

The simulation results include the energy consumption of the base-case buildings. The results show that Zone 1 has the highest energy consumption as the heating loads constitutes more than 1/3 of the total consumption. On the other hand, Zone 2; has an almost equal cooling and heating loads. Zone 3 has the lowest total consumption as 1/2 of the energy consumption for the cooling loads. These results are close to the real data calculations of the three climates, see Table 4 and Figure 4.

3. CALCULATIONS AND ANALYSIS

Three layers of energy efficiency were examined; the passive, active design strategies and renewable energy systems. The proposed design strategies were analyzed in terms of energy saving and cost.

3.1. First Level: Passive Design Strategies

This level embraces orientation, walls and roof systems, openings' systems, shading devices, and window to wall ratio.

3.1.1. Building orientation

The study includes 8 alternatives: the four main directions in addition to the 45° angel directions in between (North-east, North-west, South-east and South-west). This direction refers to the main long elevation of the building. The simulation results

Figure 3: (a-c) Ground floor plan of the base-case houses

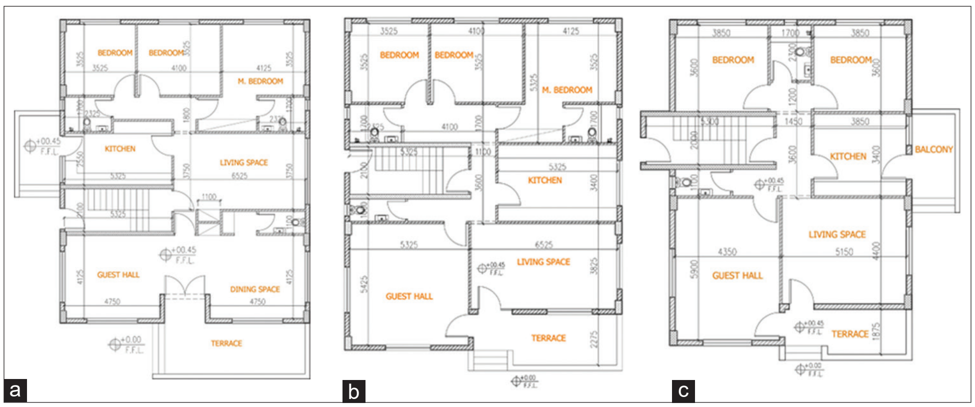


Table 3: Summary of the three zones location criteria and their base-case house characteristics.

Criteria	Zone 1	Zone 2	Zone 3
Climate characteristics			
Latitude	31.9	32.37	29.55
Longitude	35.9	36.25	35.00
Altitude	784m	683.0m	-300m
ASHRAE Zone	3C	3C	1B
Weather Description	Hot summers and fairly cold winters	Hot summers and cold winters	Very hot summers and moderate winters
Base-case house characteristics			
Built-up Area	170 m^2	155m^2	130m^2
Rooms	6 rooms/ guest hall, living space, 3 bedrooms and kitchen	6 rooms/ guest hall, living space, 3 bedrooms and kitchen	5 rooms/ guest room, living space, 2 bedrooms and kitchen
Occupancy	5 people	6 people	6 people
Shape and Dimensions	Rectangle 15m *12m	Rectangle 14.5m *12m	Rectangle 13.5m * 10m
Construction type	Concrete/ post and beams system	Concrete/ post and beams system	Concrete/ post and beams system
Exterior wall system	50mm Stone veneer, 100mm Concrete, 100mm hollow concrete block, 25mm Plaster and paint	25mm Plaster and paint, 200mm Solid concrete block, 25mm Plaster and paint	
Roof system	Water barrier, 50mm Concrete screed, 70mm Reinforced concrete, 180mm Cement ribs, 25mm Plaster and paint		
Windows System	Single glass/ aluminum framing		
WWR	25%	20%	20%
Shading Elements	-	-	-
HVAC Systems	Gas Heater AFUE 70%, and electrical split units COP 2.25		Gas Heater AFUE 70%, and ceiling fans
DHW System	80-litre electric water heater COP 75%		
Thermostat set-point	21°C for heating, 24°C for cooling		
Natural Ventilation	Manual opening of windows and doors		
Mechanical Ventilation	Only bathrooms mechanical fans	-	-
Lighting Features	Traditional Halogen lamps 77 watt		

Table 4: Simulation results of base-case buildings.

Zone No.	Consumption Type	Energy Consumption/ m² (kwh/m²)	Price/m² (JD/m²)
Zone 1	Heating	32.4	3.4
	Cooling	13.5	1.6
	Lighting	13.4	1.6
	Domestic hot water (DHW)	12.8	1.5
	Electrical Appliances	7.2	0.9
	Total	79.1	9.0
Zone 2	Heating	25.7	2.6
	Cooling	20.4	2.5
	Lighting	13.1	1.6
	Domestic hot water (DHW)	13.2	1.6
	Electrical Appliances	6.3	0.8
	Total	78.8	8.9
Zone 3	Heating	6.2	0.6
	Cooling	32.7	3.6
	Lighting	14.3	1.7
	Domestic hot water (DHW)	14.0	1.7
	Electrical Appliances	8.5	1.0
	Total	75.7	8.6

show that the lowest energy consumption (heating and cooling) for Zone 1 is 44.42 kwh/m² for the south dimension. For Zone 2; the results show that the lowest energy consumption (heating and cooling) is 42.09 for north orientation. For Zone 3; the lowest energy consumption (heating and cooling) is 31.1 for north orientation, Figure 5.

According to the above Figure 5, for Zone 1, it is highly recommended to direct the main long elevation of the house toward the south, to reduce the heating loads. In general, it is important to locate the living spaces and bedrooms to face south or west, and locate the less commonly used spaces like staircases, bathrooms toward the north dimensions. For Zone 2 and 3, it is highly recommended to face the main long elevation of the house toward North, to reduce the cooling loads.

3.1.2. Wall systems

The wall system alternatives are divided into two types: the stone type and the non-stone type. The stone types is related to Zone 1. The plaster and paint walls finishing are related to Zone 2 and Zone 3. In all study-cases the external walls are not thermally insulated. The proposed wall system alternatives are designed with different layering and insulation materials built in different thicknesses and configurations to achieve the maximum performance. The following wall systems were designed based on the available materials in the market, Tables 5 and 6.

All proposed alternatives of wall systems with different configurations and thicknesses were analyzed in terms of heating and cooling energy saving, see Figure 6.

Figure 6 shows that the best energy saving for Zone 1 is 24.55%, wall system 8, which is composed of a double layer of extruded polystyrene panels. For Zone 2; the best energy saving is 27.67%,

Figure 4: Annual energy consumption/ area

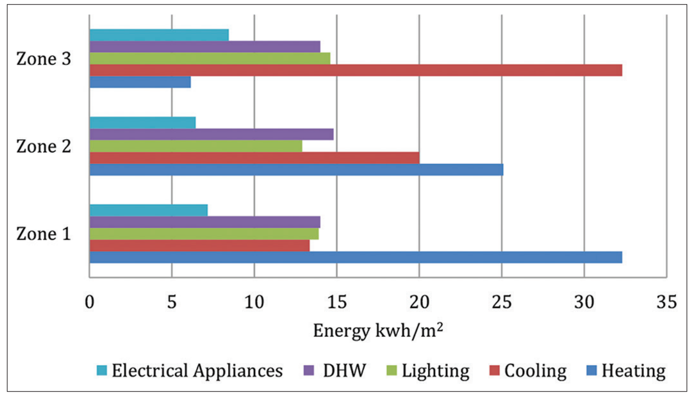
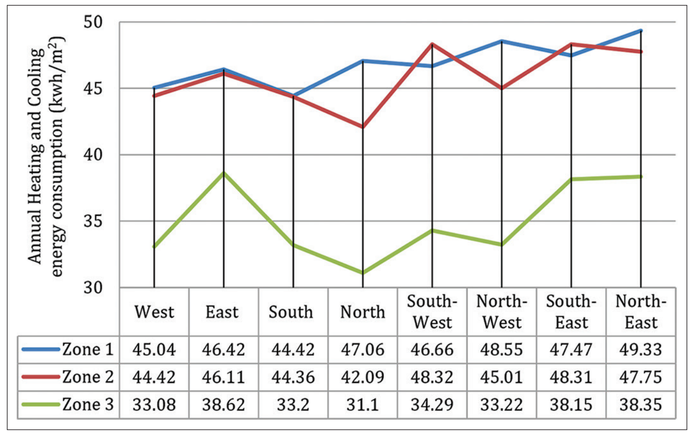


Figure 5: The effect of building orientation on Energy Consumption



wall system 5. The best wall systems are 5, 6 and 9 which are composed of 100 insulation materials with different configurations. For Zone 3; that the best energy saving is 26.46%, wall system 7. The best wall systems are 5, 6 and 7 which are also composed of 100 insulation materials.

3.1.2.1. Economic study

The economic study of the research is based on the simple payback period method (SPPA) which is directly related to the total initial cost and the annual energy saved cost. The equation of this method is to divide the total initial cost over the saved energy cost (the base-case energy cost - the energy cost of the proposed system).

PP = Total initial cost/Annual saved cost

The total initial cost is calculated over the whole walls area of the building. Table 7 shows the economic analysis for the proposed systems and concludes the payback period of each system.

The results of the economic analysis show that the best payback period for Zone 1 is 5.1 years, wall system 3 and 6. For Zone 2; the best payback period is 9.18 years, wall system 6. Wall systems 3 and 6 have a payback period less than 10 years. For Zone 3; the best payback period is 8.59 years, wall system 6. Wall systems 3, 6 and 7 have a payback period less than 10 years. According

Table 5: Proposed stone wall systems for zone 1

System number	Wall configuration	Total thickness (mm)	U (w/m² k)	Cost (JD/m²)
W1	OUT >50 mm stone veneer, 100 mm concrete, 100 mm hollow concrete block, 25 mm plaster and paint <IN	275	2.123	80
W2	OUT >50 mm stone, 100 mm concrete, 50 mm polyurethane, 100 mm hollow concrete block, 25 mm plaster and paint IN	325	0.443	90
W3	OUT <50 mm stone, 100 mm concrete, 50 mm EPS, 100 mm hollow concrete block, 25 mm Plaster and paint >IN	325	0.468	85
W4	OUT <50 mm stone, 100 mm concrete, 75 mm hollow concrete block, 50 mm air gap, 75 mm hollow concrete block, 25 mm plaster and paint >IN	375	1.472	87
W5	OUT <50 mm stone, 100 mm concrete, 100 mm polyurethane, 100 mm hollow concrete block, 25 mm plaster and paint >IN	375	0.25	95
W6	OUT <50 mm stone, 100 mm concrete, 100 mm EPS, 100 mm hollow concrete block, 25 mm plaster and paint >IN	375	0.263	88
W7	OUT <50 mm stone, 100 mm concrete, 75 mm hollow concrete block, 50 mm air gap, 75 mm hollow concrete block, 50 mm EPS, 25 mm painted gypsum board >IN	425	0.415	90
W8	OUY <50 mm stone, 100 mm concrete, 75 mm hollow concrete block, 50 mm EPS, 75 mm hollow concrete block, 50 mm extruded polystyrene, 25 mm painted gypsum board >IN	425	0.252	93
W9	Out <50 mm stone, 10 mm concrete, 50 mm polyurethane, 100 mm thermal concrete block, 25 mm plaster and paint >IN	325	0.368	96

EPS: Expanded polystyrene

Table 6: Proposed paint finish wall systems for zone 2 and 3

System number	Wall configuration	Total thickness (mm)	U (w/m² k)	Cost (JD/m²)
W1	OUT <25 mm plaster and paint, 200 mm solid concrete block, 25 mm plaster and paint > IN	250	2.296	38
W2	OUT <25 mm plaster and paint, 100 solid concrete block, 50 mm air gap, 100 mm hollow concrete block, 25 mm plaster and paint > IN	300	1.357	47
W3	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm EPS, 100 mm hollow concrete block, 25 mm plaster and paint > IN	300	0.462	51
W4	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm polyurethane, 100 mm hollow concrete block, 25 mm plaster and paint > IN	300	0.438	56
W5	OUT <25 mm plaster and paint, 100 mm solid concrete block, 100 mm polyurethane, 100 mm hollow concrete block, 25 mm plaster and paint > IN	350	0.246	58
W6	OUT <25 mm plaster and paint, 100 mm solid concrete block, 100 mm extruded polystyrene, 100 mm hollow concrete block, 25 mm plaster and paint > IN	350	0.261	52
W7	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm air gap, 75 mm hollow concrete block, 50 mm EPS, 75 mm hollow concrete block, 25 mm plaster and paint > IN	400	0.40	53
W8	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm air gap, 100 mm hollow concrete block, 50 mm EPS, 25 mm painted gypsum boar > IN	350	0.396	52
W9	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm EPS, 100 mm hollow concrete block, 50 mm extruded polystyrene, 25 mm painted gypsum board > IN	350	0.253	49
W10	OUT <25 mm plaster and paint, 100 mm solid concrete block, 50 mm EPS, 100 mm thermal concrete block, 25 mm plaster and paint > IN	300	0.382	59

EPS: Expanded polystyrene

to above wall system 6 is recommended as it has a short payback period in addition to high percentage of energy saving.

3.1.3. Roof systems

The roof system of all the base-cases is not thermally insulated in the existing situation. The JTIC set the roofs' minimum U-Value 0.55w/m²k. Table 8 shows the proposed roof systems.

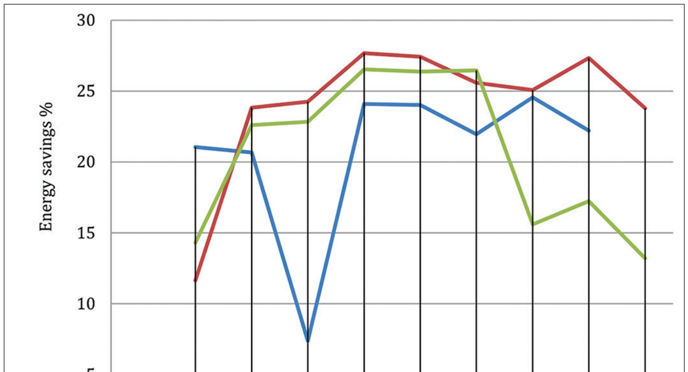
All proposed systems were analyzed to investigate the best alternative, Figure 7 shows the energy saving curve for each alternative.

As Figure 7 shows, the roof insulation has a greater effect on reducing heating and cooling energy consumption more than walls. For Zone 1; the highest total energy saving is 28.33%, R4. For Zone 2; the best roof systems are 4 and 10. The highest saving is 28.97%, also R4. For Zone 3; the best roof systems are 4, 6 and 10. The highest saving is 34.84%, R4.

3.1.3.1. Economic study

The total initial cost is calculated over the roof area of the building. Table 9 shows the economic analysis for the proposed roof systems and concludes the payback period of each system.

Figure 6: Energy saving of Wall systems alternatives



	W1/ Base-case	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10
Zone 1		21.04	20.67	7.38	24.09	24.02	21.96	24.55	22.2	
Zone 2		11.63	23.82	24.25	27.67	27.42	25.58	25.07	27.34	23.78
Zone 3		14.29	22.59	22.83	26.53	26.37	26.46	15.6	17.23	13.19

The results of the economic analysis show that the best payback period is 4.23 years, R3, as Roof system 3, 4 and 5 have payback periods less than 10 years, but R4 has greater energy saving with relatively short payback period. According to the above, roof system 4 is recommended for all zones as it offers a short payback period with a high percentage of total energy saving.

3.1.4. Window systems

Window systems of the Base-cases in the three selected locations are simply single clear glass panels with non-thermal break aluminum frames. The proposed window systems are designed as a combination of the glass and aluminum alternatives, Table 10.

All proposed window systems were analyzed; Figure 8 shows the energy saving curve.

For Zone 1; the best total energy saving is 5.20%, window system 6, which is composed of double low energy glass with UPVC framing. For Zone 2, the best total energy saving is 8.18%, window system 6, and the lowest total energy saving is 4.66%, window system 2. For Zone 3; the best total energy saving is 19.93%, window system 6. The lowest total energy saving is 6.50%, window system 3.

According to the result it has been concluded that the impact of walls and roofs savings is higher than windows, and the cooling savings is higher than heating savings. In general, it is clearly found that UPVC framing is better than the Aluminum with thermal break framing, and Low-e glass had a significant impact to reduce cooling loads than clear double glazing.

Table 7: Economic analysis of proposed wall systems

Zone No.	System number	Total Initial cost (JD)	Energy saved/m^2 (KWH/m^2)	Total energy saved cost (JD)	Payback period
Zone 1	1	12,976.00		Base-case	
	2	14,598.00	9.64	161.34	10.05
	3	13,787.00	9.47	158.62	5.11
	4	14,111.40	3.38	58.15	19.53
	5	15,409.00	11.04	184.55	13.18
	6	14,273.60	11.01	184.25	7.04
	7	14,598.00	10.07	168.88	9.60
	8	15,084.60	11.25	188.48	11.19
	9	15,571.20	10.18	169.35	15.32
Zone 2	1	5996.40		Base-case	
	2	7258.80	5.36	88.48	14.27
	3	7732.20	10.98	178.95	9.70
	4	8679.00	11.18	182.27	14.72
	5	8994.60	12.76	208.12	14.41
	6	7890.00	12.64	206.27	9.18
	7	8205.60	11.79	193.21	11.43
	8	7890.00	11.56	188.13	10.07
	9	8205.60	12.61	205.05	10.77
	10	9152.40	10.96	176.60	17.87
Zone 3	1	4180.00		Base-case	
	2	5060.00	5.43	83.48	10.54
	3	5390.00	8.59	131.59	9.20
	4	6050.00	8.68	132.98	14.06
	5	6270.00	10.09	154.63	13.52
	6	5500.00	10.03	153.72	8.59
	7	5720.00	10.06	154.46	9.97
	8	5500.00	5.93	90.36	14.61
	9	5720.00	6.55	99.79	15.43
	10	6380.00	5.02	76.18	28.88

Table 8: The proposed roof systems

System number	Floor configuration thickness (mm)	Total thickness (mm)	U (w/m² k)	Cost (JD/m²)
R1	OUT <- mm water barrier, 50 mm concrete screed, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	325	1.847	100
R2	OUT <30 mm tiles, 50 mm gravel, water barrier, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	365	1.215	98
R3	OUT <30 mm concrete screed, 100 mm foam concrete, 30 mm polyurethane, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	435	0.355	97
R4	OUT <30 mm concrete screed, 100 mm foam concrete, 100 mm polyurethane, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	505	0.188	108
R5	OUT <water barrier, 100 mm concrete screed, 50 mm polyurethane, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	375	0.399	109
R6	OUT <50 mm white natural gravel, geotextile sheets, 50 mm EPS, water barrier, 50 mm concrete screed, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	437	0.394	118
R7	OUT < - mm tiles, 20 mm cement mortar, 50 mm sand fill, 50 mm EPS, water barrier, 30 mm concrete screed, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	445	0.439	124
R8	OUT < - mm tiles, 20 mm cement mortar, 50 mm sand fill, 50 mm EPS, water barrier, 50 mm lightweight foam concrete, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	445	0.424	125
R9	OUT <50 mm white natural gravel, water barrier, 30 mm concrete screed, 100 mm foam concrete, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	465	1.074	115
R10	OUT <50 mm white natural gravel, water barrier, 30 mm concrete screed, 100 mm foam concrete, 50 mm EPS, 70 mm reinforced concrete, 180 mm cement ribs, 25 mm plaster and paint > IN	505	0.385	115

EPS: Expanded polystyrene

Table 9: Economic analysis of proposed roof systems

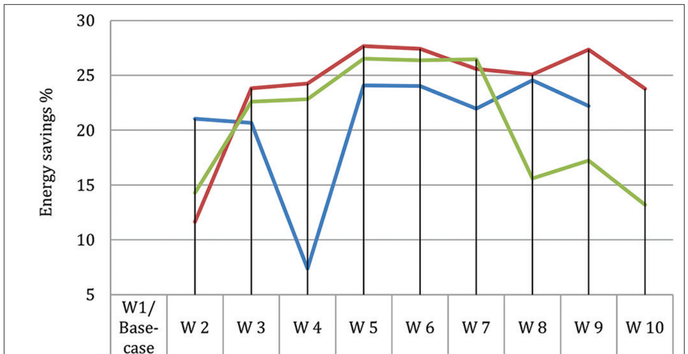
Zone No.	System number	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	16,400.00		Base-case	
	2	16,728.00	3.78	67.62	4.85
	3	17,220.00	11.15	193.91	4.23
	4	17,712.00	12.98	225.70	5.81
	5	17,876.00	11.28	194.15	7.60
	6	19,352.00	10.65	186.80	15.80
	7	20,336.00	10.57	184.12	21.38
	8	20,500.00	10.70	186.44	21.99
	9	18,860.00	4.26	78.73	31.24
	10	19,188.00	10.79	189.01	14.75
Zone 2	1	14,420.00		Base-case	
	2	14,708.40	4.38	77.05	3.74
	3	15,141.00	11.51	197.10	3.66
	4	15,573.60	13.36	228.54	5.05
	5	15,717.80	11.17	189.24	6.86
	6	17,015.60	11.48	198.31	13.09
	7	17,880.80	11.07	189.89	18.22
	8	18,025.00	11.19	192.05	18.77
	9	16,583.00	5.70	102.75	21.05
	10	16,871.40	11.56	199.46	12.29
Zone 3	1	11,000.00		Base-case	
	2	11,220.00	5.75	89.83	2.45
	3	11,550.00	11.35	176.88	3.11
	4	11,880.00	13.25	206.27	4.27
	5	11,990.00	10.27	159.03	6.23
	6	12,980.00	12.38	193.26	10.25
	7	13,640.00	11.49	178.71	14.77
	8	13,750.00	11.58	180.14	15.27
	9	12,650.00	8.65	136.00	12.13
	10	12,870.00	12.44	194.04	9.64

Table 10: Proposed window systems

System number	System description		Glass U-value (w/m² k)	Frame U-value (w/m² k)	Cost (JD/m²)
	Glass characteristics	Frame type			
Win1	Single glass 6 mm	Aluminum framing (no break)	5.778	5.881	40
Win2	DblClr 6 mm/13 mm air	Aluminum framing (with thermal break)	2.665	4.719	60
Win3	DblClr 6 mm/13 mm Arg	Aluminum framing (with thermal break)	2.511	4.719	100
Win4	DblLoE (e2=0.1) Clr 6 mm/13 mm air	Aluminum framing (with thermal break)	1.761	4.719	120
Win5	DblClr 6 mm/13 mm air	UPVC framing	2.665	3.476	85
Win6	DblLoE (e2=0.1) Clr 6 mm/13 mm air	UPVC framing	1.761	3.476	130

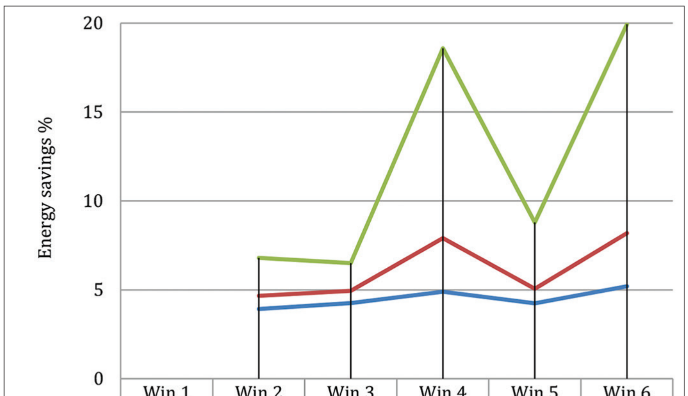
UPVC: Unplasticised Polyvinyl Chloride plastic material

Figure 7: Energy saving of Roof systems alternatives



	W1/ Base-case	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10
Zone 1		21.04	20.67	7.38	24.09	24.02	21.96	24.55	22.2	
Zone 2		11.63	23.82	24.25	27.67	27.42	25.58	25.07	27.34	23.78
Zone 3		14.29	22.59	22.83	26.53	26.37	26.46	15.6	17.23	13.19

Figure 8: Energy saving of Window systems alternatives



	Win 1	Win 2	Win 3	Win 4	Win 5	Win 6
Zone 1		3.92	4.25	4.89	4.24	5.2
Zone 2		4.66	4.94	7.91	5.06	8.18
Zone 3		6.79	6.5	18.58	8.79	19.93

3.1.4.1. Economic study

The total initial cost is calculated over the windows area of the building. Table 11 shows the economic analysis for the proposed systems and concludes the payback period of each system.

The results of the economic analysis show that the best payback period in Zone 1 and 3. All window systems have a long payback period of more than 10 years which are not recommended. The high initial cost of window systems obstructs the strategy. For Zone 2 the best payback period is 9.92 years, window system 2. The other window systems have greater payback periods which are not recommended.

3.1.5. Window to wall ratio (WWR)

The WWR of base-case (Zone 1) is 25%, as in Zone 2 and Zone 3 the WWR is 20%. The previous studies show that the less WWR the best for the cooling season areas. And the greater ratio fits with the heating season areas. The study includes 4 alternatives for the WWR: 15%, 20%, 25% and 30%. Figure 9 shows the energy consumption/m² for each alternative.

The figure shows that the best WWR for residential buildings is located in Zone 1 is 25%. As it records the highest heating energy saving. The higher WWR helps to acquire the best heat gain in winter, whereas reducing the heating energy consumption. For Zone 2 and 3; the best WWR is 15%, as the highest window to wall ratio increases the cooling loads.

3.1.6. Shading systems

The base case of the three locations has no shading devices on all of the elevations. Constructing fixed window overhangs during the construction phase is much more economical than adding it after finishing the construction. The heating season areas shading devices form a negative factor for the heating loads, for that applying movable overhangs and louvers is recommended. The proposed shading systems of the study are shown in the Table 12.

All proposed shading systems were analyzed; Figure 10 shows the cooling energy saving curve. Note that for Zone 1 and 2 movable systems were used, as in Zone 3 fixed shading systems were used.

The results show that the best cooling energy saving is using horizontal louvers with 0.3m depth. In Zone 1 it saved 21.52% of the cooling energy, in Zone 2 it saved 32.15%. for Zone 3 using the fixed louvers it saved 42.65% of cooling, and –16% of heating, which in total 35% of heating and cooling energy saving.

3.1.6.1. Economic study

The total initial cost is calculated over the total number of shading elements used. Table 13 shows the economic analysis for the proposed systems.

The results of the economic analysis show that the best payback period in Zone 1and 2 is shading system 2 and 3. Shading number 3 has a long payback period which is not recommended. For Zone 3; all proposed shading systems have short payback period, shading system 3 is highly recommended since it has a short payback period with a high percentage of energy saving.

3.2. Second Level: Active Design Strategies

The second level of the study is the active design; this level includes the study of the proposed strategies that are related to mechanical and

Table 11: Economic analysis of proposed window systems

Zone No	System number	Total initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	1120.00		Base-case	
	2	1540.00	1.80	31.80	13.21
	3	2800.00	1.95	34.21	49.11
	4	3640.00	2.24	41.66	60.50
	5	2380.00	1.94	34.23	36.81
	6	3920.00	2.38	43.99	63.65
Zone 2	1	996.00		Base-case	
	2	1369.50	2.15	37.63	9.92
	3	2490.00	2.28	39.67	37.66
	4	3237.00	3.65	66.51	33.69
	5	2116.50	2.33	40.79	27.47
	6	3486.00	3.77	68.56	36.32
Zone 3	1	1316.00		Base-case	
	2	1809.50	2.58	39.15	12.61
	3	3290.00	2.47	37.30	52.93
	4	4277.00	7.07	108.97	27.17
	5	2796.50	3.34	50.94	29.06
	6	4606.00	7.58	116.87	28.15

Table 12: The proposed shading devices for the three zones.

System No.	Zone No.	Shading System	Material	Cost (JD/m²)
1	1&2	Movable 0.5m overhang	Painted wood with fabric	30
2		Movable 1m overhang	Painted wood with fabric	30
3		Movable .3m horizontal louvers	Painted wooden louvers	50
1	3	0.5m overhang	0.1 cm thick. Painted concrete	20
2		1m overhang	0.1 cm thick. Painted concrete	20
3		.3m horizontal louvers	Painted wooden louvers	30

Table 13: Economic analysis of proposed shading systems

Zone No	System number	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	210.00	1.49	29.45	7.13
	2	360.00	2.13	42.12	8.55
	3	900.00	2.90	57.45	15.67
Zone 2	1	180.00	3.20	59.60	3.02
	2	330.00	4.96	92.34	3.57
	3	900.00	6.57	122.19	7.37
Zone 3	1	180.00	5.84	91.63	1.96
	2	360.00	9.71	152.38	2.36
	3	540.00	13.35	210.24	2.57

Figure 9: Energy saving of WWR alternatives

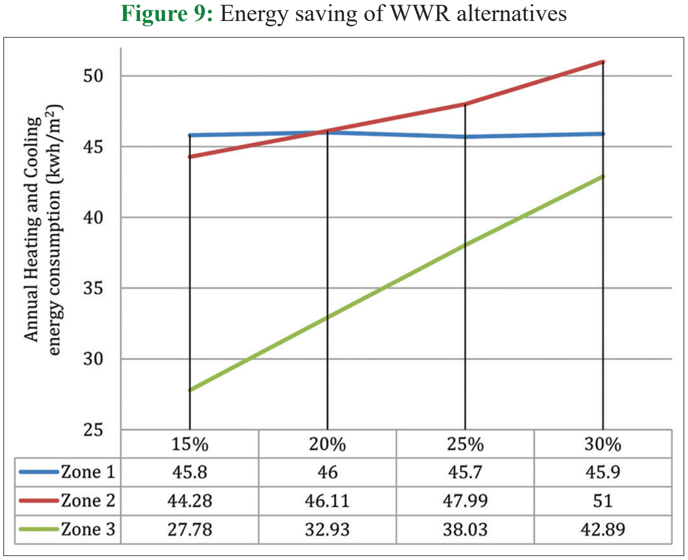
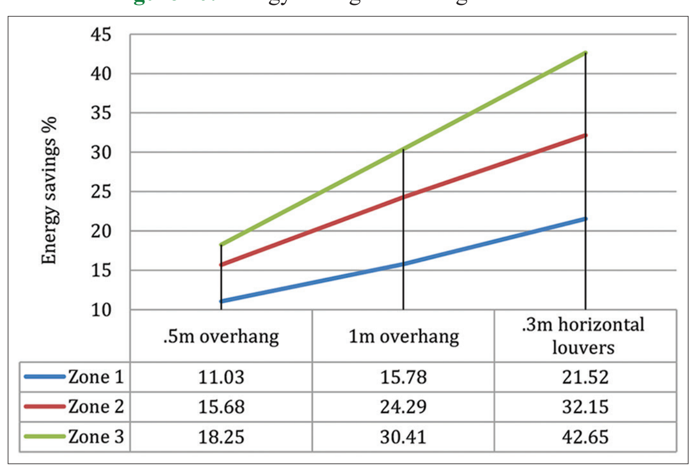


Figure 10: Energy saving of shading alternatives



electrical systems. Active design includes performance of heating and cooling appliances, water heating system, and lighting fixtures.

3.2.1. Lighting systems

The proposed lighting system is to replace the traditional halogen lamps with fluorescent lamps (23 watt) and LED lamps (12 watt). Table 14 shows the proposed lighting systems with the prices/lamp.

The test of lighting systems shows that fluorescent lamps saved 35% of lighting energy consumption, as LED saved 74% of lighting energy consumption.

3.2.1.1.Economic study

The total initial cost is calculated over the total number of lighting fixtures. The economic analysis for the proposed systems is shown in Table 15.

The economic study shows both lighting systems have short payback periods, which is recommended. The LED lamps is highly recommended since it has a short payback period with a high percentage of energy saving.

3.2.2. Cooling systems

The base-case air conditioning system for Zone 1 and 2 is the split units with coefficient of performance (COP) 2.25. This type of split units has only fixed speed with no inverter to control the compressor speed to arrange the average temperature continuously. The base-case cooling system is ceiling fans. The proposed air conditioning system is DC invertor split unit with 4 COP which contain the control inventor and DC motor. Table 16 show the proposed cooling system.

The test of cooling systems shows that split units with 4 COP saved 30% of cooling energy consumption.

Table 14: The lighting systems and their initial cost.

System No.	Description	Wattage (watt)	Rated Average Life (Hrs.)	Price (JD)
1/B.C.	Traditional halogen lamps	77	1000	1
2	Fluorescent lamps	23	10000	5
3	LED lamps	12	50000	9

3.2.2.1. Economic study

The total initial cost is calculated over total number of units. Table 17 shows economic analysis for the proposed systems

Table 17 shows that the proposed cooling system in Zones 1 and 2 has a fairly short payback period less than 10 years. The proposed cooling system is recommended as it has a short payback period in addition to the high percentage of energy saving. For Zone 3, payback period is greater than 10 years, which is not recommended. The proposed cooling system is not recommended for Zone 3 as it is not economically feasible.

3.2.3. Heating systems

The heating system of the base-case is individual Gas canister heater with Annual Fuel Utilization Efficiency (AFUE) ratio 70%. The proposed Gas heater achieves 85% AFUE, in addition to the split unit heating. Table 18 shows the proposed heating systems.

The use of the proposed Gas Canister can afford 10% of heating energy saving, as the split unit.

3.2.3.1. Economic study

The total initial cost is calculated over total number of units. Table 19 shows the economic analysis for the proposed systems.

The table shows that the proposed heating system in Zones 1 and 2 has a fairly short payback period less than 10 years. The proposed heating system is recommended as it has a short payback period in addition to the high percentage of energy saving. For Zone 3, payback period is greater than 10 years, which is not recommended. The proposed heating systems are not recommended for Zone 3 as it is not economically feasible.

3.2.4. Domestic hot water (DHW) systems

The Domestic hot water (DHW) system of the base-case is a local electrical water heater with 80 liters with 75% COP. The proposed electric heaters achieve more than 85% COP. Table 20 shows the proposed DHW system.

The test of the proposed heating system 2; electric water heater with 80% COP saved around 5% of energy, and the proposed

Table 15: The economic analysis of the proposed lighting systems.

Zone No.	System No.	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	35.00		Base-case	
	2	175.00	4.68	61.73	2.27
	3	315.00	9.89	130.52	2.41
Zone 2	1	25.00		Base-case	
	2	125.00	4.60	57.05	2.19
	3	225.00	9.73	120.63	1.87
Zone 3	1	20.00		Base-case	
	2	100.00	5.00	52.02	1.54
	3	180.00	10.58	109.99	1.45

Table 16: The proposed cooling systems.

System No.	Description	COP	Machine type	Price (JD)
1/B.C.	Split unit	2.25	Fixed speed	800
2	Split unit	4	DC invertor	1000

heating system 3; electric water heater with 85% COP saved around 10% of energy.

3.2.4.1. Economic study

The total initial cost is calculated over total number of units. Table 21 shows the economic analysis for the proposed systems.

The table shows that the proposed DHW system in Zones 1 and 2 has a fairly short payback period less than 10 years. The proposed heating system is recommended as it has a short payback period in addition to the high percentage of energy saving. For Zone 3, payback system 2 has a short payback period, as system 3 has a greater payback period than 10 years, which is not recommended.

Table 17: The proposed cooling systems analysis.

Zone No.	System No.	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	3200.00	Base-case		
	2	4000.00	4.38	86.75	9.22
Zone 2	1	3200.00	Base-case		
	2	4000.00	6.13	114.02	7.02
Zone 3	1	450.00	Base-case		
	2	3000.00	10.75	167.70	15.21

Table 18: The proposed heating systems analysis (omit)

System No.	Description	Efficiency	Price (JD)
1/B.C.	Individual Gas canister	AFUE: 70%	90
2	Individual Gas canister	AFUE: 85%	200
3	Split unit	COP: 4	1000/ cost of equipment calculated in the cooling initial cost

Table 19: The proposed heating systems analysis

Zone No.	System No.	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	450.00	Base-case		
	2	650.00	3.23	53.30	3.75
	3	0.00	-3.23	-63.96	7.04
Zone 2	1	450.00	Base-case		
	2	650.00	2.57	39.79	5.03
	3	0.00	-2.57	-47.75	9.42
Zone 3	1	360.00	Base-case		
	2	520.00	0.62	8.00	20.00
	3	0.00	-0.31	-4.80	75.00

Table 20: The proposed DHW systems analysis (omit).

System No.	Description	COP	Price (JD)
1/B.C.	Electric water-heater /local	75%	35
2	Electric water-heater/Saudi	80%	60
3	Electric water heater/ international	85%	110

Table 21: The proposed DHW systems analysis.

Zone No.	System No.	Total Initial cost (JD)	Energy saved/m² (KWH/m²)	Total energy saved cost (JD)	Payback period
Zone 1	1	90.00	Base-case		
	2	165.00	0.02	12.64	5.93
	3	330.00	0.06	37.92	6.33
Zone 2	1	90.00	Base-case		
	2	165.00	0.03	12.29	6.10
	3	330.00	0.08	36.88	6.51
Zone 3	1	90.00	Base-case		
	2	165.00	0.26	10.95	6.85
	3	330.00	0.78	32.84	10.05

Table 22: The proposed solar water heating systems analysis (omit).

System No.	Description	Number of collectors	Capacity (Liter)	Price (JD)
1	Open-loop solar water heating system, flat plate collectors 'HC100'	4	250	700
2	Closed-loop solar water heating system, Solar collector INISOL 'CH 250'	4	300	3500

3.3. Third Level: Renewable Energy Design Strategies

The third layer is the renewable energy systems which includes the PV solar and solar water heating systems.

3.3.1. Solar Water Heating systems

The base-case of the three zones has not the solar system. Only 20% of residences have the solar water heating system in Zone 1. The percentages become less than 10% in the other two zones. (MEMR 2016). There are two proposed solar systems each has its own capabilities and technology, Table 22. The prices in the total system with application are shown in Table 23.

The proposed system 1 saved around 70% of the DHW energy consumption, as system 2 saved around 80% of the energy consumption. System 1 has a very short payback period which is highly recommended, but system 2 has a long payback period due to the high initial cost.

3.3.2. Photovoltaic cells (PV)

Two photovoltaic cells systems proposed in the study. The type of cells used is Solar World AG 290 mono. The inverter type is sunny boy. The proposed system oriented toward the south (Azimuth=0), and the tilt angle is 25° to get the optimum generation. Table 24 shows the description of the proposed PV systems.

Table 23: The proposed solar water heating systems economic analysis.

Zone No.	System No.	Total Initial cost (JD)	Energy saved/m^2 (KWH/m^2)	Total energy saved cost (JD)	Payback period
Zone 1	1	880.00	8.93	176.90	4.41
	2	3000.00	10.21	202.18	14.84
Zone 2	1	880.00	10.41	193.70	4.03
	2	3000.00	11.90	221.38	13.55
Zone 3	1	880.00	9.82	153.26	5.55
	2	3000.00	11.23	175.15	17.13

Table 24: The proposed PV system analysis (omit).

System No.	Description	Number of panels	System sizing (kwP)	Panels type	Price (JD)
1	On-grid PV system	8* 1.7 m^2	2.4	290 Mono	2800
2	On-grid PV system	12* 1.7 m^2	3.6	290 Mono	3700

Table 25: The proposed PV system analysis.

Zone No.	Total Initial cost (JD)	Generated electrical energy (KWH)	Generated energy/ area (KWH/m^2)	Total energy saved cost (JD)	Payback period
Zone 1	3700.00	5921.00	35.88	592.10	6.25
Zone 2	3700.00	6100.00	39.35	610.00	6.07
Zone 3	3700.00	5689.00	34.76	568.90	6.50

Table 26: Recommendation for designing new houses in Jordan.

	Recommendations
Passive design strategies	1. Zone 1; Orient the long main elevation toward South. For zone 2 and 3; Orient the long main elevation toward North. 2. For walls: use the 100mm extruded polystyrene insulation. 3. For roofs: use 100mm polyurethane and 100mm of foam concrete. 4. For windows: the double glass systems are not recommended for zone 1 and 3 as they have a long payback period, using double glass with thermal break aluminum framing is recommended for Zone 2. 5. Using the low-e glass is not recommended as it increases the heating energy consumption for zone 1. Low-e glass is recommended for zone 3. 6. Use the higher WWR to reduce the heating energy consumption for zone 1, for zone 2 use medium WWR, and for 7. Zone 3 the minimum WWR is recommended. 8. 25% WWR is recommended for Zone 1. 9. 15% WWR is recommended for Zone 3. 10. Using the movable 100cm overhangs is recommended for Zones 1 and 2 as it reduces the cooling energy consumption in summer without affecting the heating consumption in winter. 11. Using the fixed shading devices is recommended for zone 3 as it reduces the cooling energy consumption.
Active design strategies	A. Use the LED lamps to reduce lighting energy consumption. B. Use the inverter DC split units with 4 COP to reduce the cooling energy consumption for Zone 1 and 2. For Zone C. 3 using the base-case cooling system (Ceiling fans) is much recommended. D. Use 85% individual gas canister heaters to reduce the heating energy consumption for Zone1 and 2. E. Using the electrical split units for heating is safer than gas heaters. F. Use the international electrical water heater with .85 COP to reduce the electrical energy used for water heating.
Renewable energy design strategies	A. Using the open-loop solar heating system is highly recommended to reduce the electrical energy needed for water heating purposes. B. Using the closed-loop solar heating system is not recommended as it has a long payback period. C. The solar system must be oriented toward the south with a 25° tilt angle to get the optimum energy saving. D. Using the PV system is highly recommended as it generates electricity that covers a high percentage of annual consumption. E. The PV must have oriented toward the south with a 25° tilt angle to get the optimum energy saving.

The proposed system generates high quantities of electricity which help to enhance the balance of energy consumption. Table 25 shows the economic study of the PV system.

The table shows that the PV system has a short payback period. The results of economic analysis show that the payback period is around 6 years. According to the above results PV system is recommended as it has a short payback period with high total energy saving.

4. CONCLUSIONS AND RECOMMENDATIONS

This research studies three different base-cases that present three climatic zones in Jordan. The study analyzes the current energy consumption of the three selected zones based on the actual use of energy concluded from the observed real data.

4.1. Evaluation of Design Strategies

The design strategies studied in this research is divided into three levels of efficiency: the passive design strategies, the active design strategies, and the renewable energy design strategies. The selected strategies were evaluated based on the economic dimension (simple payback period method) in reference to the energy efficiency dimension. The findings of the three levels can be summarized as follows:

4.1.1. Level one; passive design strategies

Combining the recommended passive design strategies has an important impact on reducing the heating and cooling energy consumption within a relatively short payback period. For Zone 1; it saved 77.31% of the total energy consumption, as it reduces the annual energy consumption from 79.1kwh/m^2 to 43.7kwh/m^2, with a payback period 5.17 years. For Zone 2; it saved 78.82% of the heating and cooling energy consumption, as it reduces the annual energy consumption from 78.8kwh/m^2 to 42.5kwh/m^2, and the payback period is 6.79 years. For Zone 3; the saving percentage is 84.92%, as it reduces the annual energy consumption from 75.7kwh/m^2 to 42.7kwh/m^2, and the payback period is 5.35 years. The combined passive design strategies are highly recommended once it achieves energy efficiency with economic feasibility.

4.1.2. Level two; Active design strategies

Combining the recommended active design strategies has an important impact on reducing the total energy consumption within a relatively short payback period. For Zone 1; it saved 24.57% of the total energy consumption, as it reduces the annual energy consumption from 79.1kwh/m^2 to 59.7 kwh/m^2, and the payback period is 4.12 years. For Zone 2; it saved 25.9% of the total energy consumption, as it reduces the annual energy consumption from 78.8kwh/m^2 to 58.4kwh/m^2, and the payback period is 3.85 years. For Zone 3; the saving percentage is 14.9%, as it reduces the annual energy consumption from 75.7kwh/m^2 to 64.4kwh/m^2, and the payback period is 1.39 years. The combined active design strategies are highly recommended once it achieves the energy efficiency with the economic feasibility.

4.1.3. Level three; Renewable energy design strategies

Combining the recommended renewable energy design strategies has an important impact on reducing the total energy consumption within a relatively short payback period. For Zone 1; it saved 56.63% of the total energy consumption, as it reduces the annual energy consumption from 79.1kwh/m^2 to 34.3 kwh/m^2, and the payback period is 5.28 years. For Zone 2; it saved 50.56% of the total energy consumption, as it reduces the annual energy consumption from 78.8 kwh/m^2 to 40.3 kwh/m^2, and the payback period is 6.32 years. For Zone 3; the saving percentage is 70.80%, as it reduces the annual energy consumption from 75.7 kwh/m^2 to 22.8 kwh/m^2, and the payback period is 6.32 years. The renewable energy design strategies are highly recommended, once it achieves energy efficiency with economic feasibility.

4.2. Recommendations

According to the analysis and results of the research, a number of recommendations are stated when designing new houses in Jordan as follows (Table 26).

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