Evaluation of a Green Building Design Using LCC and AHP Techniques

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Abstract: This project evaluates the implementation of green technology on a current building design and provides applicable alternatives using life cycle cost (LCC) and analytic hierarchy process (AHP) techniques. The two main aspects of green technology are considered: energy and water. For energy alternatives: photovoltaic system and solar water heater system, while for water: greywater system. Using LCC analysis, the costs of photovoltaic (PV) cells versus solar water heating system (SWHS) and traditional sewage and greywater system are calculated using annual present value method. The AHP was then used to evaluate the alternatives taking into consideration the relative weights of cost, environmental impact, market availability, reliability, ease of installation and maintenance. From LCC analysis, it is found that: (a) For energy alternatives, it was found that the SWHS more feasible and cost effective to install and (b) For water alternatives, a greywater system is more cost effective to install than to keep the traditional sewage system. Considering the criteria including: environmental aspects, market availability, reliability, ease of installation and maintenance, the AHP analysis reveals that: (i) For energy alternatives, the PV system and the SWHS had a relative weight of 0.637 and 0.430 respectively, and (ii) For water alternatives, the traditional sewage system and the greywater sewage system had a relative weight of 0.300 and 0.799 respectively. In conclusion, this research provides a detailed methodology to engineers in assessing the LCC of green building and guidelines for identifying the applicable alternatives.
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1. Introduction

The world's population has grown exponentially. There are large amount of materials used and energy consumed during the construction and operation of an average building. One of the growing areas of interest is the implementation of green technologies when constructing new facilities in order to produce buildings that are more energy efficient and have less impact on the natural environment. These environment-friendly buildings are also known as "green" buildings. A green building may cost more upfront but, in the long run, will save money through lower operating costs over the life of the building. Green building offers a host of environmental, economic, health and community benefits.

The green building approach applies a project life cycle cost (LCC) analysis for determining the appropriate up-front expenditure (Fabrycky and Blanchard, 1991; Norman, 1990; Flanagan *et al.*, 1987). This analytical method calculates costs over the useful life of the asset. LCC is a tool for assessing the total cost performance of an asset over time, including the acquisition, operating, maintenance, and disposal costs. Its primary use is in evaluating different options for achieving the client's objectives, where those alternatives differ not only in their initial costs, but also in their subsequent operational costs. LCC techniques are central to the current international drive to achieve better value for money from the buildings and a constructed asset that has been procured and used. Instead, the focus has shifted to the evaluation of all the costs and impacts of operating constructed assets over their life cycle, and to minimizing both the LCCs and the environmental impact. LCC has many common ranges of applications in supporting decisions (Pascale *et al.*, 2011; Kim *et al.*, 2010; Glucha and Baumann, 2004; Sterner, 2000; Larsson and Clark, 2000; Cole and Sterner, 2000).

In practice, several measures can be used to assess alternative including reliability, availability, environmental, installation and maintenance, in addition to cost. Among efficient techniques for evaluating decisions with multiple criteria is the analytic hierarchy process (AHP). The analytic hierarchy process (AHP) method, firstly developed by Saaty (1980), is a powerful tool that help analysts to select the best decision among multi decisions by structuring the decision problem in a hierarchically structure at different levels, each level contains finite number of decision elements, where the upper level of the hierarchy represents the overall goal, while the lower level represents all possible alternatives and the intermediate levels shape the decision criteria and sub-criteria (Saaty, 2008; Kahraman *et al.*, 2007; Ertay *et al.*, 2006; Kulak and Kahraman, 2005; Kurttila *et al.*, 2000).

The AHP allows the assessment of factors, which considered as criteria and the alternative strategies by giving them relative weight. Therefore, a pairwise comparison is carried out for all factors by assigning weights between one to nine for factors from equally to extremely importance, whereas, a reciprocal values are assigned to the inverse comparison. Then, based on each factor, again, a pairwise comparison is carried out for all strategies by a scale between one and nine for equally good to absolutely better. Finally, the integration between relative weight of factors and strategies are used to find out the overall weight of each strategy.

Unlike other countries of the Middle East, Jordan is a non-oil producing country. Its domestic recoverable energy resources are limited and do not satisfy the demands of an increasing population and the country's economic growth. Thus, the country at present relies – and will continue to do so in the near future – almost solely on the combustion of imported fossil fuels in order to satisfy its national energy demand. This research, therefore, aims at implementing green building concepts combined with LCC and AHP in construction. The remaining of this paper including the introduction is organized as follows. Section two evaluates the current building design. Section three evaluates the green building alternative. Section four compares between the current and green building designs. Finally, conclusions are summarized in section five.

2. Current Building Design

A first-floor building shown in Fig. 1 with a total area of 2800 m^2 will be studied. Each floor contains two apartments, making a total of 10 apartments, and a parking lot located in Amman with all facilities; such as, heating, cooling, modern-style finishing, the skeleton of the building based on reinforced concert, and external walls of stone cladding according to Jordanian codes for Class (B) buildings. Estimating the future cash flows for feasible alternatives is a critical step in engineering economics. Estimating costs, revenues, salvage values and other pertinent data can be the most difficult, expensive and time consuming part of the study. The purpose of estimating is to develop cash-flow projections and not to produce exact data about the future, which is virtually impossible. Studying the cost helps to make important decisions concerning the future. The initial costs are listed in Table 1. The maintenance and operation costs are displayed in Table 2. The LCC of the building can be represented and simplified in a cash flow diagram in order to help reading and understanding the given information. Fig. 2 shows the cash flow diagram of the building at the existing design.

The following calculations represent the net present value of the whole costs in the building, which contains total salvage value (TSV), administration, energy, water and maintenance costs, and taxes. These costs are calculated as follows (Figures 1, 2):

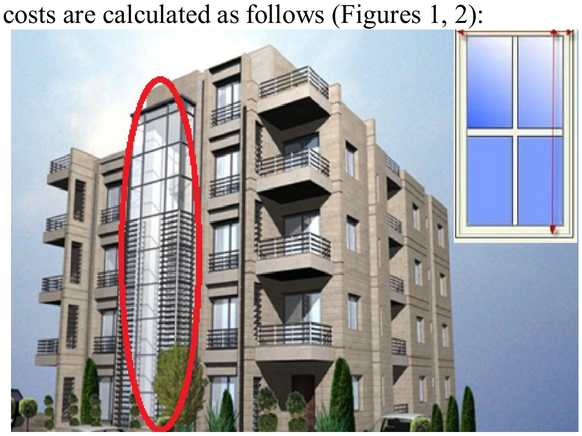

Fig. 1. The current building.

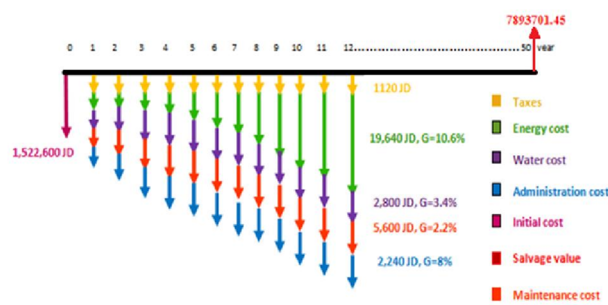

Fig. 2. Cash-flow diagram.

(1) TSV is calculated using Eq. (1), where salvage value of the building ($SV_{building}$) is added to the salvage value of the land (SV_{land}).

$$TSV=SV_{building}+SV_{land} \quad (1)$$

The SV_{land} is calculated using present worth method at an interest rate, *i*.

Table 1. Initial building cost data.

Details	Cost calculations
Investment cost data	Six floor(467m^2) building and car park floor for total area 2,800m^2
Building costs	280 JD/m^2 of building area 2,800m^2 ; 2,800 *280=784,000 JD
Site costs	600 JD/m^2 of land (1,140m^2); 1140*600= 684,000 JD
Design cost	7.5 JD /m^2; 7.5*2,800=21,000 JD
Salvage value	7,893,701.45
Other (license, gov. fees etc.)	12 JD / m^2; 12*2,800=33,600 JD
Total building cost	1,522,600 JD

Table 2. Operation and maintenance data.

Details	Cost calculations
Administration cost	0.8 JD /2,800m^2 per year; 0.8*2,800=2,240 JD/ year
Energy cost	47 JD*12month*10 apartment=5,640 JD/ year Electricity 5 JD/m^{2}per year *2,800=14,000 JD /year Diesel oil Total = 19,640 JD/year
Water cost	1 JD /m^2 per year *2,800=2,800 JD /year
Maintenance cost	2 JD /m^2 per year * 2,800=5,600 JD
Taxes	0.4JD/m^2 year *2,800=1,120
Total operation and maintenance cost	31,400 JD/year

Given that the present value, *P*, of land is 684, 000 JD and the interest rate, *i*, for the land is 5 per cent per year for 50 years (*n* = 50), the future cost, *F*, is calculated as shown in Eq. (2):

$= 684{,}000\times(1+0.05)^{50} = 7{,}843{,}701.45$ JD (2)

The $SV_{building}$ after 50 years equals 50,000 JD. The TSV is calculated as:

$$F = P(1+i)^n$$

TSV= 7,843,701.45+ 50,000= 7,893,701.45 JD

Then, present worth value for SV then estimated as calculated in Eq.(3).

$$P = F/(1+i)^n =$$

$7893701.45/(1+0.062)^{50}$ =389,991.25 JD (3)

(2) Administration cost is calculated using Eq. (4), where the inflation rate which is also called gradient (G) is equal 8 per cent and the interest rate during 50 years is equal to 6.2 per cent. Then, the present value is calculated as:

P=A[1-(P/F,*i*,N)(F/P,G,N)]/(*i*-G)=163,917.17JD (4)

(3) Energy cost is calculated using Eq. (4) where, G, is equal 10.6 per cent and, i, is equal to 6.2 per cent then the present value is calculated and found equals to 2,951,604.62 JD

(4) Water cost is calculated using Eq. (4) where, G, is equal 3.4 per cent and ,*i*, is equal to 6.2 per cent then the present value is calculated 73,709.36 JD

(5) Maintenance cost is calculated using Eq. (4) where, G, is equal 2.2 per cent and, *i*, is equal to 6.2 per cent then the present value is calculated 119467.26 JD.

(6) Taxes is calculated using Eq. (5), where,*i*, is equal to 6.2 per cent and the annual cost=1120 JD

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] =$$

$$1120\left[\frac{(1+0.062)^{50} - 1}{0.062(1+0.062)^{50}}\right]$$ =17172.03 JD (5)

(7) Net present value (= 4,458,479.19 JD) is calculated by adding the initial, administration, energy, water, taxes and maintenance costs, and subtracting the total salvage value.

Finally, the percentage of each cost is shown in Fig.3.

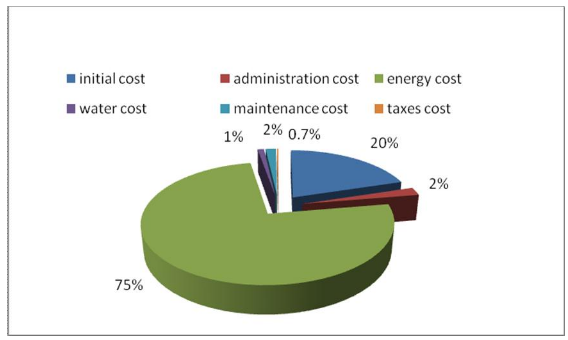

Fig.3. Pie chart represents the total cost percentage.

From Fig.3, it is noticed that energy cost comprises the largest percentage. Thus, an alternative system that has a renewable resource and is environment friendly should be developed.

3. Green Building Alternatives

Nearly all generated electricity in Jordan is produced from power plants that use fossil fuels. The most popular fuels are heavy fuel oil and diesel fuels. However, this option is not very attractive since Jordan's spending on petroleum is more than 50 per cent of its export earnings. Jordan lies between Latitude (28°4'-33°30' N) and Longitude (35°-39° E). The total area of Jordan is about 89,206 Square Km. It is important to state that Jordan, with global radiation of 2080 KWh/ m² and more than 300 sunny days a year, (with projection angle of 32°), has excellent potential for solar energy generation.

3.1 Photovoltaic System

Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity (Hang *et al*., 2012; Stolte, 1992; Whisnant *et al*., 1986). PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect. A typical home will use about 10 to 20 solar panels to power the home. The panels are mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight. Hours of sunshine are an important factor in PV calculations. Jordan has more than 300 sunny days a year, providing a sunshine duration of about 3125 hr/year. The average value of sunshine duration in Amman during summer is about 12 hours and the minimum value in winter is more than five hours. Consequently, a building in Abdoun (Amman city) has been chosen as a case study to conduct calculations of energy consumption. The power of electrical devices in the building includes: the power of bulbs (60 W for each, florescent light 40 W and decorative wall light 60 W). The power for the lights and the number of operating hours has been selected to be realistic and similar to data obtained from monthly electricity bills. The distribution of light units in the apartment and its power output is indicated in Table 3.The calculations of monthly electricity consumption of the apartment are displayed in Table 4.There are four different categories of electricity prices in Jordan according to the amount of monthly consumption. The electricity price increases rapidly with consumption. The lowest tariff category is 0.032 JD (0.045 $US) per kWh for a monthly electricity consumption less than 160kWh. The second category of electricity tariff is JD 0.071 ($0.10) per kWh for a monthly electricity consumption in the 161–300 kWh range. The cost of 1 kWh electricity in the third tariff category is JD 0.085 ($0.12) per monthly power consumption in the 301–500 kWh range. The highest tariff category is 0.113 JD ($0.16) per kWh electricity for a monthly consumption more than 500kWh. The monthly cost of electricity, X, in Jordan is calculated according to the prices of the Jordanian Electricity Company is as:

Electricity cost =160 (KWh)×0.032 (JD/KWh) + (300-160) (KWh) ×0.071(JD/KW h) + (500-300) (KWh) × 0.085 (JD/KW h) + (X-500) (KWh) × 0.113 (JD/KWh) (6)

The monthly consumption of electricity of the case study apartment is 502kWh, while the electricity cost is calculated using Eq. (6) as:

Electricity Cost
=160×0.032+140×0.071+200×0.085+2.0×0.113=32.29 JD

The monthly net electricity bill includes the electricity consumption costs, taxes and an overhead cost (elevator and lighting) is calculated as:
= 32.29+4.776(taxes) +10× (overhead costs) = 47 JD.

The application of photovoltaic solar cells requires replacement of standard light bulbs to low energy lights, and a DC solar compressor to use for the refrigerator. The power required for low-energy lights is 15W each and the power for the solar compressor is 70W DC. The required daily power for lighting shown in Table 2 is recalculated as shown in Table 5.

The monthly lighting load is calculated assuming that 1/3 of the lighting load runs in parallel for eight hours daily:

- The monthly lighting loads=1120× 8 × (1/3) × 30=89.6 KWh/month
- The power load for the refrigerator=70 × 24× 30=50.4 KWh/month (DC)
- Total monthly load = 89.6+50.4+36+30+8.0+72=286 KW/month

3.2 PV System Design

The PV system is designed according to the calculated electricity load required for the case study apartment in Amman. The PV system design includes the selection of PV components such as the photovoltaic array sizing; battery size, the controller and the inverter. This section reviews procedures to select PV system components for the case study apartment.

(a) Calculation of the Average Daily Load Energy Requirements

The results show that using energy saving lights and a DC compressor for the refrigerator reduce monthly electricity load to 286.0KWh. Daily electricity is calculated using

Load=Monthly load / 30 days = 9.53 KWh (7)

Table 3. Calculation of electrical power for the apartment lighting.

Room	Number of light units	Power (W)
Saloon Living room	3 Chandelier (8 lamps 60 W each) 1 Chandelier (6 lamps 60 W each)	1,440 360
Kitchen	2 Ceiling light 2 florescent lamp	160
Store	1 Light bulb	60
3 Bathrooms	3 Light bulbs	180
3 Bedrooms	2 Bulbs each	360
Corridor	2 Bulbs lamps	120
Terrace	1 Bulb	60
Main stairs	1 Bulb	60
Five spot light units		300
Total		3,100
Assume one third of lights are used at the time		1,033.33

Table 4. Total electrical energy consumption per month.

Application	Power (W)	Duration time of operation (hour)	Power consumption (kWh/month)
Lighting	1,033.33	8 hr/day	248
Computer	300	4 hr/day	36.0
Refrigerator	150	24 hr/day	108.0
Iron	1,500	5 hr/week	30.0
Washing machine	400	5 hr/week	8.0
Others	2,000	9 hr/week	72
Total			502.0

(b) Photovoltaic Array Sizing

In a stand-alone system solar energy yield is matched to energy demand. Solar energy yield often does not correspond in time with energy demand from connected loads, thus, a storage system (batteries) is required. The stand-alone system requires batteries to store the generated electricity. The battery charge/discharge causes power losses, thus a 20 per cent factor is added to compensate for power losses. The daily electricity load

Table 5. Daily power load for lighting.

Room	Number of light units	Power (W)
Saloon Living room	3 Chandelier (8 lamps 15 W each) 1 Chandelier (6 lamps 15 W each)	360 90
Kitchen	2 Ceiling light 2 florescent lamp	160
Store	1 Light bulb	15
3 Bathrooms	3 Light bulbs	45
3 Bedrooms	2 Bulbs each	90
Corridor	2 Bulbs lamps	30
Terrace	1 Bulb	15
Main stairs	1 Bulb	15
Five spot light units		300
Total		1,120
Assume one-third of lights are used at the time		373.33

needed is indicated in Eq. (8) is recalculated as:

Daily consumption=Daily needed × (1.2) = 9.53×1.2=11.44 KWh (8)

Batteries used are generally of 12 V, the total amp-hour (TA.hr) is calculated as:

TA.hr=PL/V=11.44x1000/ 12 = 954.33A.hr/ day (9)

Standard PV cells are usually effective for an average value of sunshine duration of 5 hours. The power produced by PV cells per hour of sunlight can be calculated as a ratio between the required daily load and the effective sunshine duration as estimated:

Power produced by PV cells/hr=modified daily load / effective sunlight period power produced by PV cells/ hr =11.44/5 = 2.29 KW/h (10)

Eq. (10) indicates that the required PV arrays should produce electrical power equivalent to 2290 WP per hour. To compensate power loss in the inverter, 10 per cent of power is added to the value in Eq. (10) to calculate the required peak power per hour as:

Hourly peak power needed =
Power produced by PV cells / hr×(1.1) = 2.29×1000×(1.1) = 2519 WP (11)

In order to calculate the number of PV cells needed, a standard PV cell produces an average power of 160 WP [12]. The total number of PV cells required for the case study is calculated in Eq. (12):

Number of PV cells required = hourly peak power needed/power of each PV cell (12)

Number of PV cells required (2519/160) = 16 cells

The PV cells must be connected in combined connection, i.e. six panels in parallel and two in series in order to give an output voltage of 48V. In the present investigation, the PV panel's type chosen for this experiment is CQ 160 from the GO Solar Company. The single PV panel cost is 646.61 JD (USD 912.0), the total cost of the 16 panels is 10,345.76JD (USD14,592).

(c) Battery Size Calculation:

Energy generated by PV cells is accumulated and stored in batteries to use as needed. Battery capacity for storing energy is rated in amp/hr. Battery capacity is listed in amp/hr at a given voltage. The following calculations can be performed to select the suitable size of batteries.

The required output voltage is 48 V, then the required amp per hr for the daily power is calculated as:

Battery's amp-hour capacity=Daily power needed/ voltage (13)

Battery's amp-hour capacity =5(2519)/48 = 262.39 amp/hr

If a 20 per cent safety factor is added, the capacity of batteries in amp-hour as shown:

Modified battery amp/hr capacity= 262.39A/hr×1.2=314.87A/hr (14)

If battery cycle is used deeply on a regular basis, it will have a shorter life. The required total current (A.hr) as:

I total (A.hr) = 314.87/ 0.6 = 524.78A.hr (15)

The battery system required for each apartment needs to produce about 524.78 amp.hr, eight batteries of

12V each are required, each four batteries are connect in series. This battery system will produce 48V. Batteries selected according to above calculations are Sun Extender batteries PVX2120L. The cost of each battery selected is US$344.47 (244.23 JD). Total cost of the eight batteries in their life cycle which is about 10 years is:

244.23 JD × 8= 1,953.83 JD. The annual inflation rate (*g*) in batteries prices is considered to be 5 per cent and the market discount rate is 6.2 per cent (*i*).

Initial cost of the first group of batteries = 1953.83 JD

Initial cost of the second group of batteries = 1953.83 (F/P, 5 per cent, 10) = 3182.58 JD

Initial cost of the third group of batteries = 1953.83 (F/P, 5%, 20) = 5184.09 JD

Fig. 4 represents the cost for the three groups of batteries, to find the present worth for them:

PW = 1953.83 + 3182.58 (P/F, 6.2 per cent, 10) + 5184.09(P/F, 6.2 per cent, 20) = 5,254.4 JD

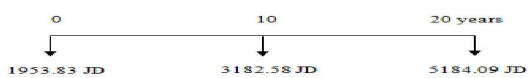

Fig. 4. Cash flow diagram of the cost for the three groups of batteries.

d) Selection of Controller

According to the above calculations, six PV panels are required, each panel producing 24 V and160 Wp (= 6.67 A). PV panels are connected in parallel to give 40 amps. A controller is needed tohold at least 40 amps. A controller that carries a current of 45A, 48 V DC is been chosen. The cost of this a controller is US$150(=106.35 JD).

(e) Selection of Inverter

Inverters change direct current (DC) to alternating current (AC). Stand-alone inverters are used to convert DC current from a battery to AC to run electronic equipment. For the suggested PV system, the needed inverter should give 220–240 V AC, 50 Hz. The chosen inverter is the outback inverter FX2348ET, 2300 W 48 V 230V AC/50 Hz. The cost of this inverter is about$US1489 (=1055.7 JD). The peak efficiency considered in the design of the PV system suggested is 93 per cent.

3.3 Economic Estimation of the PV System

The LCC of the PV system is estimated by considering the lifecycle of the PV system components for 30 years except for the batteries, which are considered for a lifetime of 10 years. The payback period is calculated for the two types of the PV systems as shown in Eq. (16) which is the grind connected and the stand -alone system. The cost of the stand-alone system for the case study apartment in Amman of a 30-year life cycle includes the cost of PV panels, batteries, controller and inverter.

Total cost of PV = cost of PV panels + cost of batteries + cost of controller + cost of inverter (16)

Total cost of PV = 10,345.76 + 5,254.4 + 106.35 + 1055.7= 16,762.21 JD

Total cost of PV system for entire building=16.762.21×10 = 167,620.21JD

The estimated cost for the first PV systemis167,620.21 JD. The estimated cost for the second PV system is calculated as follows:

Cost estimated for the second PV system = 167,620.21 (F/P, 11.2 per cent, 30) =4,050,139.65 JD, where interest rate is 11.2 per cent.

Total PV system cost= 167620.21+ 4050139.65(P/F, 6.2 per cent, 30) = 83,4019.45 JD

(a) Total initial cost is calculated by adding the installing cost for the two PV systems to the initial cost of the building as:

TIC =1,522,600 + 167,620.21 + 4,050,139.65 (P/F, 6.2 per cent, 30)

TIC =2,356,619.45 JD

(b) Energy cost is the diesel/oil cost, while the electricity cost equal to zero, depending on the assumption of stand-alone system, then the present value is calculated as Eq. (17). Inflation equals 10.6 per cent and interest rate is 6.2 per cent.

P=A [1-(P/F, *i* per cent, N) (F/P, G per cent, N)]/ (*i*-G) = 2,103,995.15 (17)

(c) Net present value (NPV)is calculated by adding the initial investment, administration, energy, water, taxes and maintenance costs, and subtracting the total salvage value.

NPV = 2,356,619.45-389,991.25+163,917.17+2,103,995.15+73,709.36+119,467.26+17,172.03= 4,444,889.17 JD

The expected payback period of the suggested PV system is more than 50 years. The results shown in Fig. 5, where obtained by assuming that the PV system features and electricity prices have an inflation rate of 10.6 per cent. However, if the annual increase in grid electricity prices is 1 per cent more than the interest rate, then the payback period for the stand-alone PV system will decrease to 36 years from 50 years. The payback period will decrease dramatically if the annual increase in the grid electricity prices is 2-3 per cent higher than the interest rate, and then the expected payback period for the stand-alone PV system will decrease to 29 years and to 25 years. Taxes and fees paid with the monthly electricity bill were taken into account. Table 7 compares the cost categories for the traditional building with the PV system building. Comparing between traditional and PV systems, it is noticed that the PV system results in decrease of energy cost from 75 % to 40 %. This resulted in increase of initial cost from 20 % to 45 %.

3.4 Solar Water Heating System (SWHS)

Solar water heating system (SWHS) is usually called domestic hot water system. This system uses the sun to heat either water or a heat transfer fluid. Domestic SWHS are widely used in Jordan. About 12 per cent of dwellings in Jordan use solar systems for water heating (Etier *et al*., 2010; AlShamaileh, 2010; Al-Soud and Hrayshat, 2009). The SWHS in Jordan have a high share among the renewable energy sources in the total mix of the energy consumed. In general, taking the concept of time value of money in consideration, then the annual cost (AC) of a system can be expressed as:

$AC=IC\times CRF+AFC+AMC-SV\times SFF$ (18)

where: IC: initial cost of the system; CRF: capital recovery factor; AFC: annual fuel cost; AMC: annual maintenance cost; SFF: sinking fund factor; SV: salvage value at the end of the assumed operation life of the system.

(a)The Capital Recovery Factor (CRF) and the Sinking Fund Factor (SFF)

CRF and SFF can be expressed as Eq. (19) and Eq. (20) respectively.

$CRF = i \times (i + 1)^{N} / [(i+1)^{N} -1]$ (19)

$CRF = 0.062 \times (0.062 + 1)^{25} / [(0.062 + 1)^{25} -1] = 0.079719$ $SFF = i / [(i +1)^{N} -1]$ (20)

$SFF = 0.062 / [(0.062 + 1)^{25} -1] = 0.017720$

Where:

N: operation time of the system in consideration [year].

i: annual discount rate .

The cost of one unit of useful energy (C) delivered by a system can be computed as shown in Eq. (21):

$C = AC/ADUE$ (21)

where ADUE denotes annual delivered useful energy, [kJ/year].

The annual delivered useful energy for the SWHS can be considered as the energy needed to provide for the annual hot water needs of an average Jordanian family.

(b) Annual Maintenance Cost of a System

To simplify analysis, it will be assumed that the annual maintenance cost of a system is directly proportional to its operation time, in other words, it can be calculated as shown in Eq. (22):

$AMC = \alpha \times N$ (22)

$AMC = 0.25 \times 25 = 6.25$

Where, α is proportionality constant, JD/year. Based on some research on the market, α is 0.25 for the SWHS. This system is under guarantee in the first three years and little maintenance is incurred in the introduction stage.

(c) Salvage Value of a System

The salvage value of the system is dynamic with its assumed lifetime (N). Having researched the market, the average price of a single panel of the SWHS is about 300 JD and it has a maximum lifetime of 20-30 years. Hence, assuming linear depreciation of the system with time, then the salvage value at time N could be expressed as:

$SV (N) = IC - D\times N$ (23)

$D = IC / N_{max}$ (24)

$D = (300\times4) / 25 = 48$

$SV (N) = 1200 - 48\times25 = 0$

Where:

N_{max}: time after which the system is entirely discarded [year].

D: depreciation rate [JD/year].

(d). Annual Fuel Cost Determination (AFC)

Annual fuel cost for the SWHS is only the cost of electrical energy used to heat water during cold days. The energy needed to secure for the daily hot water needs (EDHN) of an average family is approximated according to:

$EDHN = AFS \times ADHP \times C_P\times\Delta T$ (25)

$EDHN = 5\times 25 \times 1.16307\text{x}10^{-3} \times40$

$EDHN = 5.82$

Where:

AFS: average family size

ADHP: average daily hot water needs of a person, [liter/person/day]

Cp: specific heat of water, [kJ/kg.K]

ΔT: temperature difference, [K].

AFS is estimated to five people per family, ADHP is estimated to 25 liter/person/day, and since the average heat water ranges from 15 to 55 C, then **Δ**T is also estimated to 40 K. Hence, EDHN is evaluated to 8.82kWh/day. The solar collector area (A) needed to deliver this amount of energy can be approximated according to the following Eq. (26):

$A=EDHN/(ADSR\times\mu_{SWHS})$ (26)

where:

ADSR: average daily sun radiation, [kWh/m^2/day]

μ_{SWHS}: efficiency of the SWHS.

The efficiency of the Jordanian SWHS can be assumed as 35 per cent and hence the average collector area needed is about 4 m^2. The average price of such a SWHS is 300 JD per panel.

Thus, AFC for the SWHS can be determined as:

$AFC= NOD \times EDHN \times P_{el} / \mu_{el}$ (27)

$AFC = 65\times5.82\times0.05/0.25 = 75.66JD$

Where NOD, number of days electricity is used to provide for the full daily hot water needs of a family,[day].

μ_{el}: efficiency of the electric coil
P_{el}: price of electricity [JD/kWh].

Table 7. Comparison between traditional and photovoltaic buildings.

Compared value	Traditional building	PV
Initial investment cost	1,522,600	2,356,619.45
Salvage value	389,991.25	389,991.25
Administration cost	163,917.17	163,917.17
Energy cost	2,951,604.62	2,103,995.15
Water cost	73,709.36	73,709.36
Maintenance cost	119,467.26	119,467.26
Taxes	17,172.03	17,172.03
Net present value	4,458,479.19	4,444,889.17

Table 8. Summary of estimated cost parameters.

IC	300×4=1200 JD
N_{max}	25
A	0.25 JD=year
P_{el}	0.05 JD=kWh
μ_{el}	90 per cent
EDHN	5.82 kWh/day
I	6.2 per cent

AC = IC × CRF + AFC + AMC –SV ×SFF
AC = 1200× 0.079719 +75.66+ 6.25 – 0
AC = 177.57JD
Annual cost for the whole building = 10 ×177.57 = 1775.7 JD
Present worth for the whole building = AC × (P/A, 6.2 per cent, 25) = 22,274.35 JD
Assuming the cost for the first SWHS is 22,274.35JD; with interest rate equal to 11.2 per cent then the estimated cost for the second SWHS will be calculated as follows:
Cost estimated for the second SWHS = 22,274.35 (F/P, 11.2 per cent, 30) =538,206.15 JD
Then the total SWHS cost will be calculated as follows:

Total SWHS cost= 22,274.35 + 538,206.15 (P/F, 6.2 per cent, 30) = 110,829.36 JD

(1) Total initial cost (TIC) is estimated by summing the initial cost of the building and the installing cost for the two SWHS:
TIC=1,522,600 + 110,829.36
TIC=1,633,429.36 JD
(2) Energy Cost estimated as 14000 JD/year for diesel / oil, as79 per cent for space heating and 21 per cent for water heating then it costs 2940 JD,11060 JD for water and space heating, respectively. Energy cost is the summation for the diesel/oil costs and the electricity costs so it is calculated as follows:
Energy cost = 11,060 + 5,640=16,700 JD per year

The present worth is calculated as shown in Eq. (28) with inflation rate equals 10.6 per cent and interest rate equals 6.2 per cent.
P=A [1-(P/F, *i* per cent, N) (F/P, G per cent, N)]/ (*i*-G) = 2,509,765.64 JD (28)
(3) Net present value (NPV) is calculated by adding the initial investment, administration, energy, water, taxes and maintenance costs, and subtracting the total salvage value.
NPV=1,633,429.36+389,991.25+163,917.17+2,509,765.64+ 73,709.36+119,467.26+17,172.03=4,127,469.57 JD

Table 9 compares the cost categories for the traditional building with the SWHS building.

Table 9. Comparison between traditional and SWHS.

Compared value	Traditional building	SWHS building
Initial investment cost	**1,522,600**	**1,633,429.36**
Salvage value	389,991.25	389,991.25
Administration cost	163,917.17	163,917.17
Energy cost	**2,951,604.62**	**2,509,765.64**
Water cost	73,709.36	73,709.36
Maintenance cost	119,467.26	119,467.26
Taxes	17,172.03	17,172.03
Net present value	4,458,479.19	4,127,469.57

The payback period is calculated between 7 and 8 years. It is noticed that the SWHS results in increasing the initial investment cost from 1522,600 to 1633,429.36 JD, whereas it results in reducing the energy cost from 2,951,604,62 to 2,509,765.64 JD.

3.5 Greywater system

Jordan is one of the countries that suffer serious water shortage in which providing sufficient water for different sectors is a challenging issue. Almost all quantities of wastewater collected are being reused for agricultural purposes (Mourad *et al*., 2011; Al-Hamaiedeh and Bino, 2010; Godfrey *et al*., 2009; Halalsheh *et al*., 2008; Goddard, 2006; Gross *et al*., 2005; Nolde, 2005; Friedler, 2004; Friedler *et al*., 2005). Using treated greywater for toilet flushing would save about 35 per cent of the drinking water. Two treatment methods were analyzed: artificial wetlands (AW) and a commercial bio- filter (CBF), each of which has its own characteristics and conditions to be applied. Since the greywater system is new in Jordan, the cost of a whole system is estimated from prices in the United States and it is about $US10,000 (7,000JD).
(a) The total initial cost is calculated by adding the installing cost for the GW system to the initial cost of the building.

TIC=1,522,600 + 7,000=1,529,600 JD

(b) Water cost is calculated by taking into account that using of treated greywater for toilet flushing would save about 35 per cent of the drinking water. Water bill will change from 2800 JD/year for the whole building to 1820 JD. Then the present value will be calculated using inflation rate equal to 3.4 per cent and interest rate equal to 6.2%.

P= A [1-(P/F, *i* per cent, N) (F/P, G per cent, N)]/ (*i*-*G)* = 47,911.086 JD

The expected payback period of the suggested GW system is three years. The sewage system installation for the whole building is 6,000 JD. The whole system costs 79709.36. Then,

Present worth of the system = 7,000+47,911.086=54,911.086 JD

(b) Net present value NPV is calculated by adding initial investment, administration, energy, water, taxes and maintenance costs and subtracting the salvage value.

NPV=1,529,60-389,991.25+163,917.17+ 2,951,604.62+47,911.086+ 119,467.26+17,172.03 = 4,439,680.92 JD.

Table 10 compares the costs between the traditional and GW buildings. In Table 10, it is noted that the initial investment cost using the greywater increases from 1,522,600 to 1,529,600 JD. Whereas, water cost decreases from 73, 709.36 to 47,911.086 JD.

Table 10. Comparison of costs between traditional and GW.

Compared value	Traditional building	Greywater
Initial investment cost	1,522,600	1,529,600
Salvage value	389,991.25	389,991.25
dministration cost	163,917.17	163,917.17
Energy cost	2,951,604.62	2,951,604.62
Water cost	73,709.36	47,911.086
Maintenance cost	119,467.26	119,467.26
Taxes	17,172.03	17,172.03
Net present value	4,458,479.19	4,439,680.92

4. Applying Analytic Hierarchy Process (AHP)

In this part, the four systems (PV, SWHS) and (traditional sewage, greywater system) will be assessed relative to multiple criteria. First, the relative weights between each pair of measures are determined for each criterion. The cost of each system, how much it reduces the negative impact on the environment, its market availability, reliability, the ease of installation and its maintenance where taken into consideration.

4.1 Cost comparison between PV system and the SWHS.

Table11 displays the cost comparison between PV system and the SWHS.

Table11. Cost comparison between PV system and the SWHS.

(a) Cost

Cost	PV system	SWHS	Relative weights
PV system	1	1\2	0.33
SWHS	2	1	0.67
Total	3	1.5	1.0

(b) Environmental aspect

Environmental aspect	PV system	SWHS	Relative weights
PV system	1	1\3	0.25
SWHS	3	1	0.75
Total	4	1.33	1.0

(c) Market availability

Availability	PV system	SWHS	Relative weights
PV system	1	5	0.833
SWHS	1\5	1	0.167
Total	1.2	6	1.0

(d) Reliability

Reliability	PV system	SWHS	Relative weights
PV system	1	3	0.75
SWHS	1\3	1	0.25
Total	1.33	4	1.0

(e) Installation

Installation	PV system	SWHS	Relative weights
PV system	1	2	0.67
SWHS	½	1	0.33
Total	1.5	3	1.0

(f) Maintenance

Maintenance	PV system	SWHS	Relative weights
PV system	1	3	0.75
SWHS	1/3	1	0.25
Total	1.33	4	1.0

4.2 Comparison between traditional sewage and Greywater system sewage.

The cost comparison between traditional sewage and Greywater system sewage is conducted then the results are shown in Table 12.

Table 12. Cost comparison between sewage and greywater.

(a) Cost:

Cost	Traditional building	Greywater	Relative weights
Traditional sewage	1	1\2	0.33
Greywater system sewage	2	1	0.67
Total	3	1.5	1

(b) Environmental aspect:

Environmental aspect	Traditional building	Greywater	Relative weights
Traditional building	1	1\3	0.25
Greywater system	3	1	0.75
Total	3	1.33	1

(c) Market availability

Market availability	Traditional building	Greywater	Relative weights
Traditional building	1	1\9	0.1
Greywater system	9	1	0.9
Total	10	1.11	1

(d) Reliability aspect

Reliability	Traditional building	Greywater	Relative weights
Traditional building	1	1\2	0.33
Greywater system	2	1	0.67
Total	3	1.5	1

(e) Installation

Installation	Traditional building	Greywater	Relative weights
Traditional building	1	1\9	0.1
Greywater system	9	1	0.9
Total	10	1.11	1

(f) Maintenance

maintenance	Traditional sewage	Greywater	Relative weights
Traditional sewage	1	1	0.5
Greywater system	1	1	0.5
Total	2	2	1

After calculating each weight for the previous criteria an overall relative weight for optimum benefits are conducted and then listed in Table 13. From Table 13, comparing the overall weights for the four alternatives, it is concluded that the PV system (= 0.637) is more applicable then SWHS (=0.43). Moreover, the greywater system (0.799) is more applicable than the sewage (0.300).

5. Conclusions and Recommendations

This research utilized the LCC and AHP to evaluate three alternatives of the current building design. The LCC of the current design is calculated 4,458,479.19JD. Two alternatives were proposed using PV and SWHS systems. Using LCC analysis, the costs of PV versus SWHS and traditional sewage and greywater system are calculated using annual present value method. To make a better decision, several criteria should be used including cost, its impact on the environment, reliability and market availability. The AHP was then used to evaluate the

Alternatives taking into consideration the relative weights of cost, environmental impact, market availability, reliability, ease of installation and maintenance. From LCC analysis, it is found that: (a) For energy alternatives, a PV system and a SWHS, it was found that the PV system costs 834019.45 JD and the SWHS costs 110829.36 JD, which makes the SWHS more feasible and cost effective to install and (b) For water alternatives, a greywater system costs 54911.086 JD, which makes it more cost effective to install than to keep the traditional sewage system. Considering the criteria including: environmental aspects, market availability, reliability, ease of installation and maintenance, the AHP analysis reveals that: (i) For energy alternatives, the PV system and the SWHS had a relative weight of 0.637 and 0.430 respectively, and (ii) For water alternatives, the traditional sewage system and the greywater sewage system had a relative weight of 0.300 and 0.799 respectively. In conclusion, this research provides a detailed methodology to engineers in assessing the LCC of green building and guidelines for identifying the applicable alternatives.

Table 13. Relational scoring and relative weights for optimum benefits.

	Cost	Environmental aspect	Availability	Reliability	Installation	maintenance	Relative weights
PV system	(0.33× 0.048)+	(0.25 × 0.148) +	(0.833×0.076)+	(0.75 ×0.172)+	(0.67×0.32)+	(0.75×0.236)=	0.637
SWHS	(0.67×0.148) +	(0.75 × 0.148) +	(0.167×0.076)+	(0.25×0.172)+	(0.33×0.32)+	(0.25×0.236)=	0.430
sewage	(0.33×0.148) +	(0.25× 0.148) +	(0.1× 0.076) +	(0.33×0.172)+	(0.1×0.32)+	(0.5×0.236)=	0.300
Greywater	(0.67×0.148) +	(0.75× 0.148) +	(0.9× 0.076) +	(0.67×0.172)+	(0.9×0.32)+	(0.5×0.236)=	0.799

	Cost	Environmental aspect	Availability	Reliability	Installation	Maintenance	Relative weights
Cost	1	1\5	1\2	1\3	1/5	1\2	0.048
Environmental aspect	5	1	3	2	1\7	1\7	0.148
Availability	2	1\3	1	1\2	1\2	1\3	0.076
Reliability	3	1\2	2	1	2	1\3	0.172
Installation	5	7	2	2	1	3	0.320
maintenance	2	7	3	3	1\3	1	0.236
Total	18	16.03	11.5	8.83	4.17	5.30	1

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