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Energy Savings in the Jordanian Residential Sector

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Abstract

The aim of the present study is to evaluate the reduction in energy use in terms of consumption and cost in the Jordanian residential sector resulting from applying energy efficiency measures. A baseline model for houses in Jordan has been developed to represent the average dwelling unit in terms of construction and energy consumption using the outcome of governmental surveys. Three energy efficiency measures were introduced individually and simultaneously in five scenarios. The energy savings from each scenario were simulated using Hourly Analysis Program (HAP) software and then quantified by comparison with the energy consumption in the baseline. It was found that using enhanced building envelop material can save 24% in energy consumption and 22% in energy cost. Replacing conventional lighting fixtures with efficient fixtures can save 7% of consumption and 10% of cost while the savings from replacing electric water heaters with solar heaters can be 8% in consumption and 13% in cost. If all measures are applied simultaneously, the realized savings were estimated to be 39% in consumption and 41% in cost. Finally, applying the practically viable measures (efficient lighting and solar heaters) can achieve 15% savings in consumption and 22% in cost.

Keywords: Energy; Jordan; Residential Sector; Simulation..

1. Introduction

Jordan is considered one of the poorest countries in the primary energy sources not only in the region but also in the world, unlike its neighboring countries in the Arabic Gulf area. This makes the search for clean, sustainable, and cheap energy sources a serious need. Another objective of engineers and researchers is to find the optimum way of energy utilization in terms of production and efficiency.

One of the measures that indicate the bad energy situation in Jordan is the huge amount of imported energy sources which represents 97% of the country's needs. In 2013, the electrical consumption in the residential sector was 5666 GWh which represents 40% of the total electrical consumption for all sectors (industrial, street lighting, water pumping, commercial buildings) [1]. In 2014, this ratio increased to 43 % and can be increased to 51% if water pumping and street lighting are excluded. Residential sector energy consumption share in addition to electrical energy represents 23 % of all energy consumption with different sectors in Jordan [2].

Since the residential sector consumes more than third of the total electrical consumption of the country and quarter of all energy sources , the potential of energy saving in this sector sounds to be significant and promising. This fact fueled the enthusiasm of researchers to start seeking for energy saving in the residential buildings by means of buildings simulation and considering building envelope smart designs, and other engineering approaches which would allow for satisfying the utilities needs and maintaining the energy consumption at its least.

Jordanian researchers described the energy situation in Jordan in terms of available sources, renewable energy sources, consumption attitudes, and potential of saving, such as the study which was carried out in [3] where the researchers developed two empirical models based on multivariate linear regression analysis as well as the impact of adopting some of the energy efficiency measures (solar heating, efficient lighting) were analyzed. It was found in [4] that the energy and exergy efficiencies in Jordan are equal to 48.2 and 23.2%, respectively. In addition, the study provided an insight to energy analysts and decision makers in Jordan when considering the process of implementing energy policy measures, such as energy efficiency standards in Jordan.

Some of the research focused on specific type of energy source where it has been shown that on percentage basis, the cost to benefit ratio of wind heating system is 4.3% and 3.9% as obtained by fuzzy sets and by AHP method, respectively, compared to 28.5% and 18.6% for electric heating devices, under identical operating

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conditions [5]. The results of [6] showed that 18% of country total energy was consumed by residential sector, while urban residential sector consumes 84% of the total residential energy consumption. Also, 27% of urban houses were using solar water heaters. According to [7], space heating in Jordan accounts for 61% of the total residential energy consumption with Kerosene being the most popular fuel used and followed by Liquefied Petroleum Gas (LPG). At the time of published results, 5% of houses wall constructions have thermal insulation and it was found that space heating load can be reduced by about 50%, when using thermal insulation materials in the building envelope.

While using passive and climatic design (like building orientation, optimum size of windows and shading devices and optimum insulation thickness), studying a typical residential building in Jordan shows that the reduction in annual energy consumption of 27.59% using TRNYSIS software and life cycle cost is reduced by 11.94% [8]. A villa in Tunisia is studied and analyzed including the following feature: orientation, window location and size, glazing type, wall and roof construction, lighting fixtures, appliances and efficiencies of heating and cooling systems [9]. It was found out that implementing energy measures can cost-effectively reduce the annual energy use by 50% compared to the current design practices in Tunisia.

Solar energy systems have attracted a lot of attention in Jordan in recent years due to the promising energy savings both in residential and solar sectors. The decreasing solar systems prices are setting the grounds for increased usage of solar energy in Jordan where the solar intensity is high. An adaptive solar tracking system was designed in [10] where simulation results showed accurate system performance. The feasibility of a PV solar system in Jordan was studied in [11]. An experimental solar system including water heater collectors with the circulating pump operated by a PV module was studied towards achieving optimum efficiency of the system [12]. The results relied on the prediction of the system performance done in [13] using the system neural network model developed in [14]. A single-axis tracking parabolic collector for moderate temperature applications was designed and constructed in Jordan [15]. Adaptive neural networks were successfully applied to solar tracking [16]. Similar neural networks techniques have been previously applied to camless engines [17-18] where they showed excellent capabilities.

The aim of the present study is to evaluate the energy use reduction in terms of consumption and cost in the Jordanian residential sector resulting from applying energy efficiency measures. A baseline model for houses in Jordan has been developed to represent the average dwelling unit in terms of construction and energy consumption using the outcome of governmental surveys. Three energy efficiency measures were introduced individually and simultaneously in five scenarios. The energy savings from each scenario are simulated using Hourly Analysis Program (HAP) software and then quantified by comparison with the energy consumption in the baseline.

2. Residential Model

A comprehensive survey and study was carried out in 2013 by the Jordanian Ministry of Energy and Mineral Resources (JMEMR) to investigate energy consumption in residential sector in Jordan [1]. The results of the present study are utilized to construct a baseline model that represents the current construction and energy consumption of a typical dwelling unit in Jordan which is used to assess energy savings resulting from applying different energy efficiency measures on the residential sector.

The dwellings in Jordan are basically divided into three categories: villa, house and apartment. According to the study, the percentages of the categories for Jordan of twelve governorates are 40.5% apartments, 54.1% houses and 4.8% villas. Therefore, the model takes the form of the category with highest percentage which is the detached house [1].

In order to evaluate the performance of energy efficiency measures in the house model, the parameters of the dwelling that affect energy consumption are defined. These parameters are:

1. A. House characteristics.
2. B. Building envelope.
3. C. Cooling and heating systems.
4. D. Electric appliances.
5. E. Hot water consumption.
6. F. Weather data.
7. G. Electric bill
8. H. Lighting
9. I. Energy Prices

The house layout which represents the baseline model is shown in Figure 1 and is adopted to reflect the construction and energy consumption parameters of the house model. Table 1 provides area breakdown for the individual spaces. The parameters that are used in the calculations of the model under consideration are summarized in Table 2.

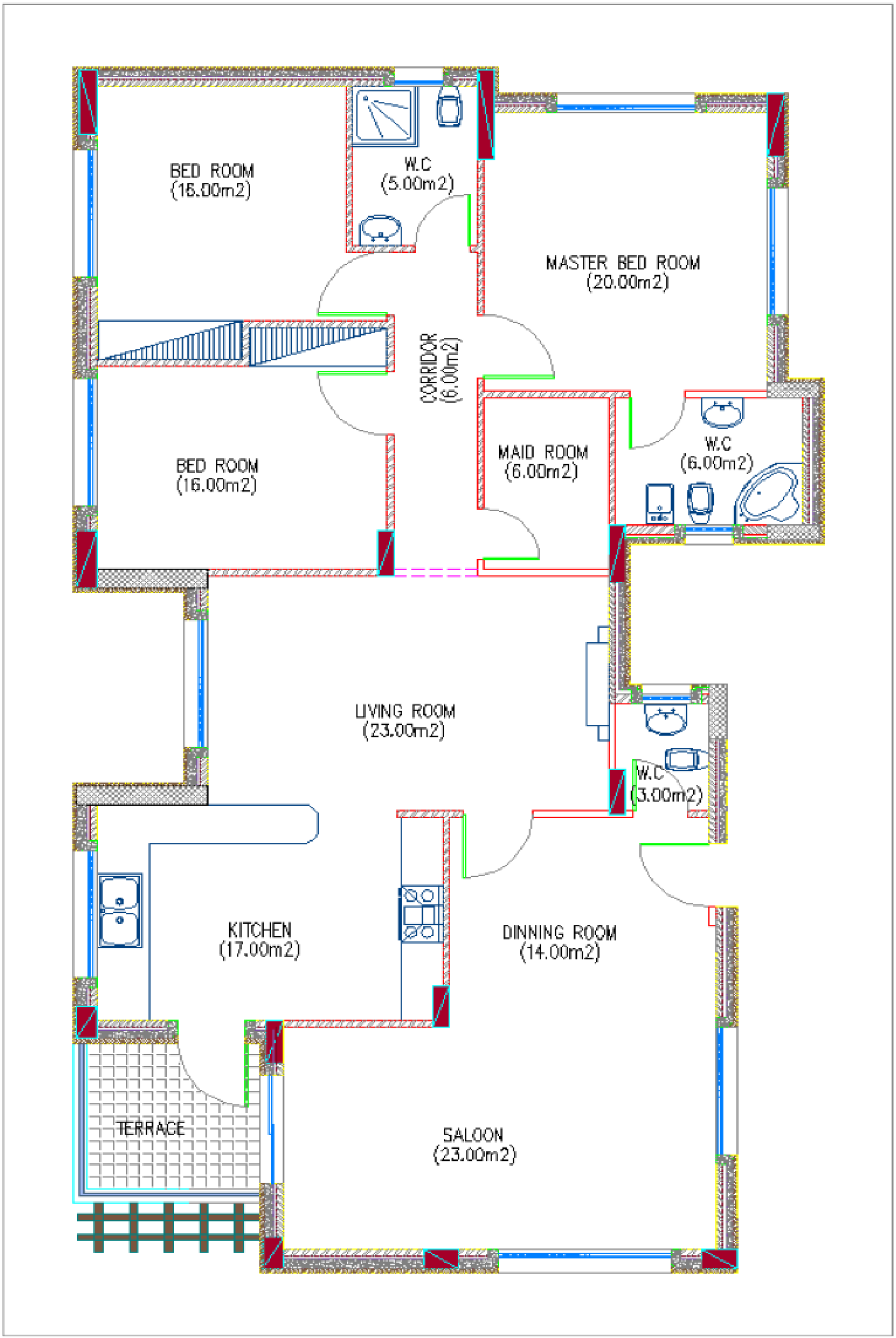

Figure 1. House layout (Baseline model)

Table 1. Area of spaces in the house model

Room	Gross Area (m^2)
Master Bedroom	20
Bedroom 1	16
Bedroom 2	16
Living Room	23
Kitchen	17
Dining Room	14
Living Room	23
Corridor	6
Maid Room	6
Master Bathroom	6
Child Bathroom	5
Guest Bathroom	3
Total	155

Table 2. Summary of all house model parameters and characteristics

House Characteristics	Type	House model
	Area (m^2)	155
	Size of family	6
Building Envelope	Wall	
	U-Value (Overall Heat Transfer Coefficient)	1.74 $W/m^2.K$
	Roof	
	U-Value	1.372 $W/m^2.K$
	Ratio %	46
	Floor	
	U-Value	1.055 $W/m^2.K$
	Ratio %	46
	Glass	
	U-Value	5.52 $W/m^2.K$
	SHGC (Solar Heat Gain Coefficient)	0.73
	Ratio %	30
	Infiltration	
	ACH (Air Change per Hour)	0.25
Cooling and Heating Systems	Systems	
	DX (Direct Expansion)	2 spaces
	LPG (Liquefied Petroleum Gas)	5 spaces
	Seasons	
	Heating	6 months
	Months	November-April
	Cooling	4 months
	Months	June-September
	Operating Time	
	Cooling	6 hours
	Heating	5 hours
	Set Temperature	
	Summer	23 ^oC
	Winter	19 ^oC
Hot Water	Type	Electric
	Coil Load	9.7 kWh
	Operating Time	5.87 h/day
Design Weather Data	Summer Temperature	37 ^oC
	Winter Temperature	0 ^oC
	Location	Amman - Jordan
Electric Bill	Summer Consumption	466 kWh
	Winter Consumption	504 kWh
	Annual Cost	433 JD
Lighting	Intensity	W/m^2
	Master Bedroom	4.61
	Bedroom 1	5.53
	Bedroom 2	5.72
	Living Room	3.86
	Kitchen	5.19
	Dining Room	6.69
	Guest Room	7.55
	Corridor	6.86
	Maid Room	8.4
	Master Bathroom	11.11
	Child Bathroom	13.33
	Guest Bathroom	26.09
	Operating Time	6 hours
Energy Prices	Electric	2015
	LPG	8.2 JD/cylinder

3. Methodology and Simulation

This section describes the methodology of evaluating the amount of energy saving that results from applying different energy efficiency measures on the house model given in the previous section which represents the average dwelling unit in Jordan in terms of construction and energy consumption. The house model is the baseline against which different scenarios are compared. In each scenario, pre-defined energy efficiency measures in residential buildings are applied to the house model. Hourly energy simulation is carried out for the baseline and five scenarios which results in certain energy consumption and cost amounts. The consumption and cost of each scenario is then compared with that of the baseline to have a quantified assessment for each scenario.

There are various methods for the estimating energy use in buildings which can be classified according to the purpose of the simulation [19] as follows:

1. Forward modeling: modeling for energy consuming systems design and design optimization.
2. Data-driven modeling: modeling energy use of existing buildings for establishing baselines and calculating retrofit savings.

Energy simulation, in the present study, uses the data-driven modeling to identify and complete the simulation input in order to match the simulation results with the energy use in the house model (baseline) described in section 2. On the other hand, the forward modeling is used to estimate the energy consumption for different scenarios explained in this section. This approach is called the calibrated simulation approach where simulation program is used to tune or calibrate the various inputs to the program so the actual energy consumption matches with the simulation results. The simulation program can be used then to predict savings from individual retrofits.

The Hourly Analysis Program (HAP) is used to carry out the energy simulation of the different scenarios. It is one of the simulation software recognized by the US Green Building Council (USGBC) for proving the achievements of green building energy credits for Leadership in Energy Environmental Design and it is widely used in the cooling and heating load calculations all over the world.

HAP estimates annual energy use and energy costs for HVAC and non-HVAC energy consuming systems in a building by simulating building operation for each of the 8,760 hours in a year. Results of the energy analysis are used to compare the energy use and energy costs of alternate HVAC system designs so that best design can be chosen. Specifically, HAP performs the following tasks during an energy analysis:

1. Simulates hour-by-hour operation of all heating and air conditioning systems in the building.
2. Simulates hour-by-hour operation of non-HVAC systems including lighting and appliances.
3. Uses results of the hour-by-hour simulations to calculate total annual energy use and energy costs. Costs are calculated using actual utility rate features, such as stepped, time-of-day and demand charges, if specified.
4. Generates tabular and graphical reports of hourly, daily, monthly and annual data.

Five energy efficiency scenarios recruiting three energy efficiency measures are simulated and compared with the baseline. The scenarios and the associated energy efficiency measures are summarized as follows:

1. Scenario 1: Enhanced building envelope characteristics.
2. Scenario 2: Efficient Lighting fixtures.
3. Scenario 3: Solar water heaters.
4. Scenario 4: Total measures.
5. Scenario 5: Solar water heaters and efficient lighting fixtures.

4. Results and Discussion

The results of the energy simulation for the house model (baseline scenario) and the enhanced scenarios are illustrated and discussed. Then a comparison in terms of annual energy consumption and annual cost for each scenario is conducted. For each scenario, the following results are illustrated:

1. The house components share in the annual energy consumption (kWh).
2. House model annual energy cost (JD).

After discussing each scenario results, comparisons between the different scenarios are conducted in terms of their annual energy consumption and the annual energy cost.

The house model components share in the annual energy consumption (kWh) and the annual energy costs for the baseline scenario are shown in Figures 2 and 3, respectively. The annual energy consumption for the house model (baseline) equals 7783 kWh, and the heating system represents maximum system energy consumption which is equal to 2245 kWh. Cooling equipment, lighting fixtures, and fans in the air conditioning equipment, are not considered major energy consumption systems since they consume 795, 690, and 184 kWh, respectively. The miscellaneous electrical equipment consumes approximately the same amount of energy which is consumed by the heating system and equals 2234 kWh. Amongst all systems, it is anticipated that the heating system will have the maximum potential for energy saving when considering the enhanced scenarios.

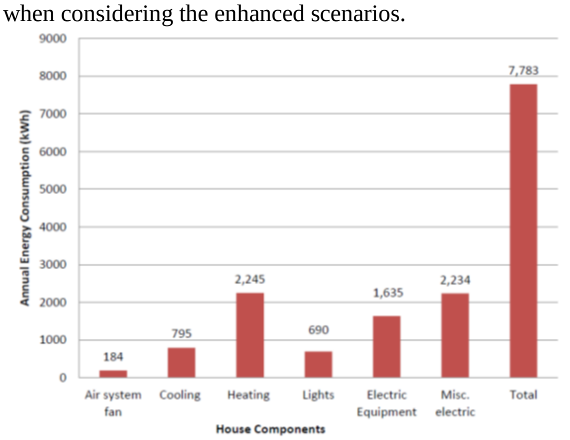

Figure 2. House model components share in annual energy consumption (kWh) for the baseline scenario.

As shown in Figure 3, the annual energy cost for the house model (baseline) equals 542 JD. The heating system represents the maximum energy consumption system which costs 120 JD. Since the cooling equipment, lighting fixtures, and fans in the air conditioning equipment are not considered major energy consumption systems, they cost 65, 52, and 14 JD, respectively. It is observed that, the heating system and the miscellaneous appliances have similar energy consumption in kWh, yet different energy cost which is justified by the fact that the heating system is operated by two sources of energy which are the electricity and the LPG. Hence, the use of LPG in operating the heating system lead to a reduced energy cost, which means that converting the heating energy source from electricity to LPG is considered one of the areas of enhancement. This should be considered by energy analysts and decision makers.

In the enhanced building envelope characteristics scenario 1, annual house energy consumption and cost are shown in Figures 4 and 5, respectively. The annual energy consumption equals 5,931 kWh, and the heating system consumes 623 kWh which was an anticipated result when the building envelope was enhanced in terms of its design parameters. It is obvious that none of the electrical appliances, electrical equipment, lighting fixtures, and fans, is affected by enhancing the building envelope, hence no energy savings were observed in any of these systems.

As shown in Figure 5, the annual energy cost for the model scenario 1 equals 423 JD and the heating system was the most governing factor in the cost reduction between scenario 1 and the house model. Since the cooling system is considered dependent on the building envelope, its annual cost was decreased from 65 JD to 44 JD when the building envelope was enhanced. The cost of the rest of energy consumption systems which were not affected by enhancing the building envelope was not reduced.

In the efficient lighting fixtures scenario 2, annual house energy consumption and cost are plotted in Figures 6 and 7, respectively. As shown in Figure 6, it is obvious that the annual energy consumption was decreased due to the enhancement in the lighting efficiency by 500 kWh, in addition to the decrease in the lighting energy consumption. Heating system energy consumption was not reduced as a result of enhancing the lighting efficiency because the simulation software does not incorporate the heat emitted by solar sun and by any electrical lighting or appliances in the heating load calculation.

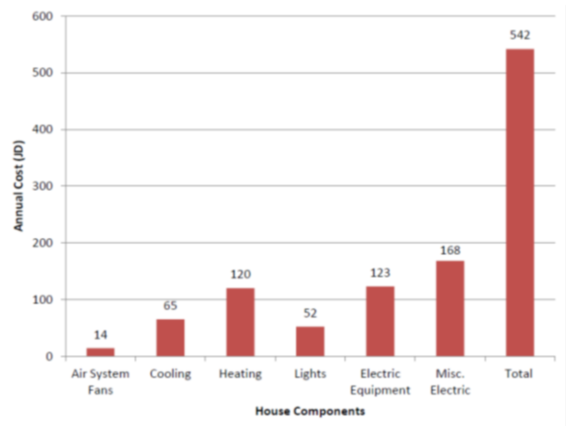

Figure 3. House model (baseline) annual energy cost

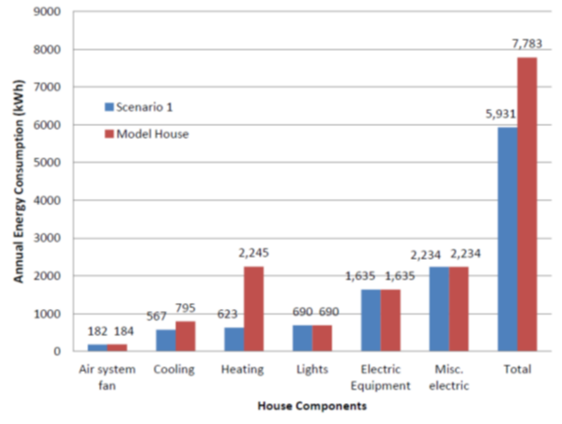

Figure 4. House model components share in annual energy consumption (kWh) for scenario 1

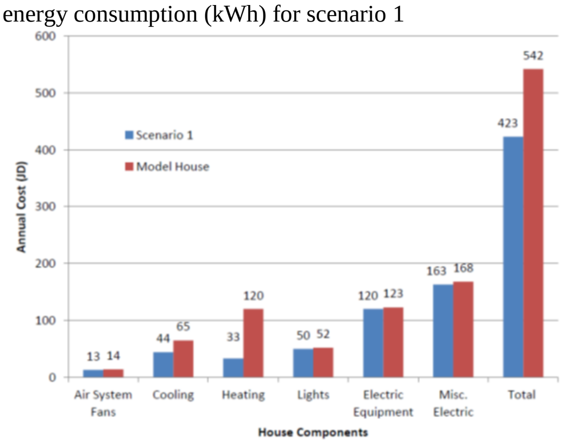

Figure 5. House model's annual energy cost for scenario 1

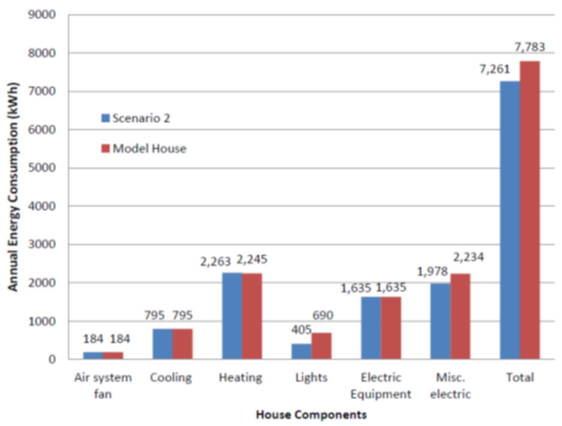

Figure 6. House model components share in annual energy consumption (kWh) for scenario 2

In Figure 7, the annual energy cost for scenario 2 and how it is distributed between the house energy consumption systems are shown. The annual energy cost for scenario 2 equals 486 JD, and since the heating system was not affected by enhancing the lighting efficiency, its annual cost remains 120 JD. The same result is observed for the rest of systems which were not affected in terms of their annual energy cost except the lighting which was reduced from 52 JD to 29 JD and this is considered a major energy cost saving.

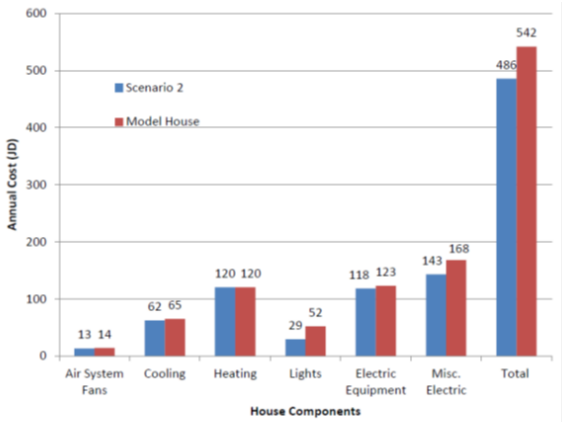

Figure 7. House model's annual energy cost for scenario 2

In the solar water heater scenario 3, annual house energy consumption and cost are represented in Figures 8 and 9, respectively. The annual energy consumption for scenario 3 equals 7151 kWh, and the effect of installing a solar water heater is obvious when observing the reduction in the annual energy consumption in the miscellaneous electrical items, which include the electrical water heater. Adding the solar water heater reduces the need for operating the electrical water heater Therefore none of the energy consumption systems such as air conditioning systems and lighting fixtures was affected by this enhancement .

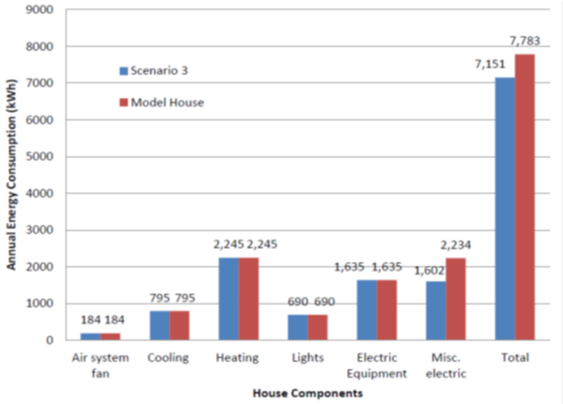

Figure 8. House model components share in annual energy consumption (kWh) for scenario 3

In Figure 9, the annual energy cost for scenario 3 and how it is distributed between the house energy consumption systems are shown. The annual energy cost for scenario 3 equals 472 JD, and since the energy saving was due to the adoption of a solar water heater, the saving in the annual energy cost was observed in the miscellaneous electrical appliances which include the solar water heater as the governing factor in the total cost saving. Minimal saving in the cost of operating the cooling system was observed to be 7 JD annually.

The annual house energy consumption and cost for the total measures scenario 4 are shown in Figures 10 and 11, respectively. Adopting scenario 4 (which implies combining all different scenarios in enhancing the house model) was anticipated to result in significant annual energy consumption reduction, and the results shown in Figure 10 are consistent with this anticipation. The total annual energy consumption was decreased from 7783 to 4778 kWh, as well as each individual system was decreased in terms of its energy consumption expect the air fans and the electrical equipment systems which were not enhanced in any of the scenarios.

As shown in Figure 11, the annual energy cost for scenario 4 equals 321 JD, and the cost saving represents 40%. This major saving was from combining all scenarios simultaneously. As mentioned earlier, air fans and electrical equipment were not taken into consideration while proposing systems enhancement. Therefore, none of them have participated in the total cost savings.

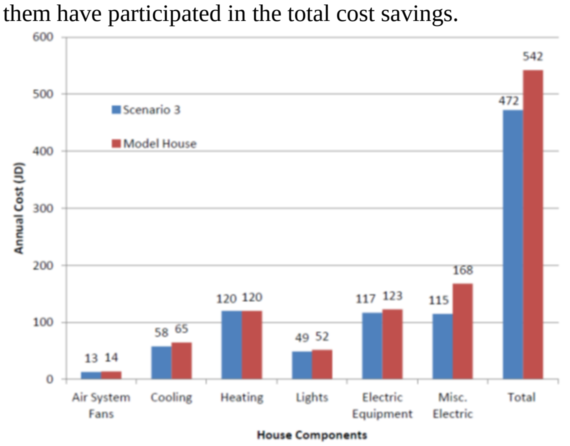

Figure 9. House model's annual energy cost for scenario 3

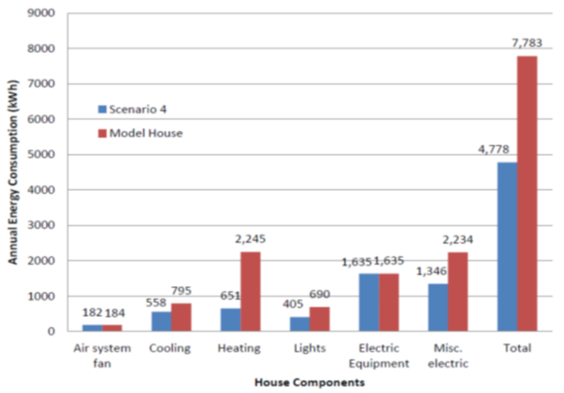

Figure 10. House model components share in annual energy consumption (kWh) for Scenario 4

In scenario 5, namely the solar water heaters and efficient lighting fixtures scenario, the corresponding annual house energy consumption and cost are shown in Figures 12 and 13, respectively. As shown in Figure 12, the annual energy consumption for scenario 5 equals 6629 kWh. As described in section 3, this scenario was proposed for the existing buildings since it is applicable in both new constructed and existing buildings. Combining the lighting efficiency enhancement measure in addition to adopting solar water heaters resulted in a significant energy saving which represents 15% of the annual energy consumption. The non-enhanced systems such as the electrical equipment and the heating system (which are not affected by the lighting and the solar water heater) were not affected here as well.

As shown in Figure 13, the annual energy cost was decreased from 542 JD to 425 JD which represents 22% reduction. Lighting energy cost decreased from 52 JD to 28 JD, and the electrical appliances energy cost decreased from 168 JD to 98 JD which represent 46% and 41%, respectively. Other systems did not participate in the annual energy cost since none of them was enhanced in this scenario.

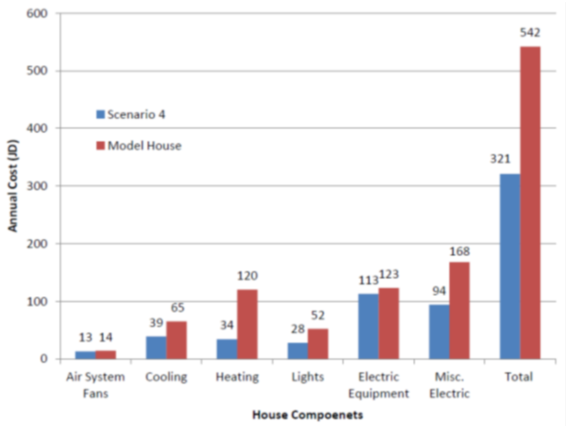

Figure 11. House model's annual energy cost for scenario 4

The illustrated results above are summarized to enable a comparison between different scenarios as well as to assess each scenario share as an energy saving approach. Annual house energy consumption comparison for all scenarios is shown in Figure 14. The highest energy consumption is for the baseline model and equals 7,783 kWh. The scenario with lowest energy consumption is scenario 4 and its consumption is equal to 4,778 kWh. Scenario 2 has the highest consumption of 7,261 kWh. For reduction ratios from baseline model, best scenario is 4 with 38.6% reduction followed by scenario 1 with 23.8% reduction, whereas scenario 5 scored 14.8% reduction and the remaining two scenarios, namely scenarios 2 and 3 with reductions of 6.7% and 8.1%, respectively.

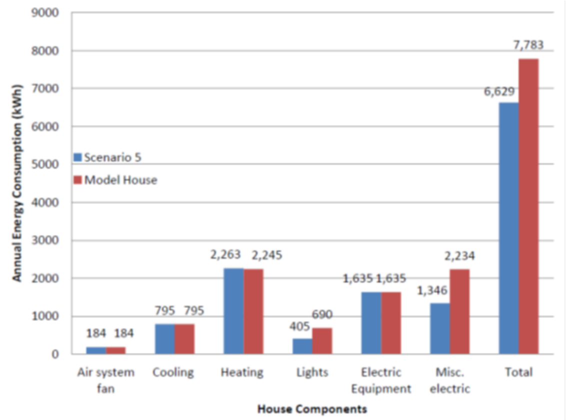

Figure 12. House model components share in annual energy consumption (kWh) for scenario 5.

The results for annual cost comparison of all scenarios are shown in Figure 15. The scenario with highest annual cost is scenario 2 with 486 JD annual cost and corresponding reduction of 10.3%. Scenario 3 annual cost and reduction are 472 JD and 13%, respectively. The scenario with the least annual cost is scenario 4 with 321 JD annual cost and an associated reduction percentage of around 41%. Scenario 5 has annual cost of 425 JD and savings on annual cost from baseline model of 21.6%. Similarly, scenario 1 annual cost and reduction are 423 JD and 22%, respectively. Thus, using solar water heaters and efficient lighting give similar results as using enhanced building envelope.

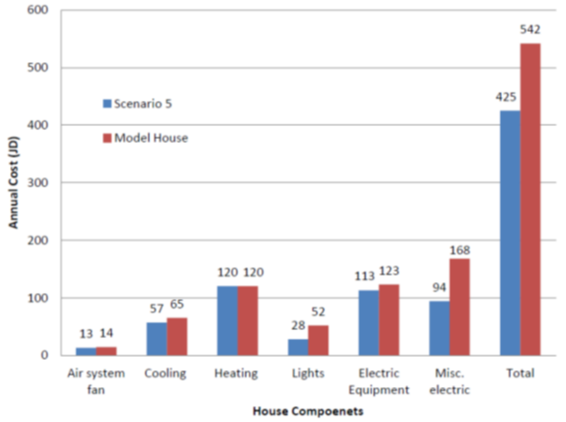

Figure 13. House model's annual energy cost for scenario 5

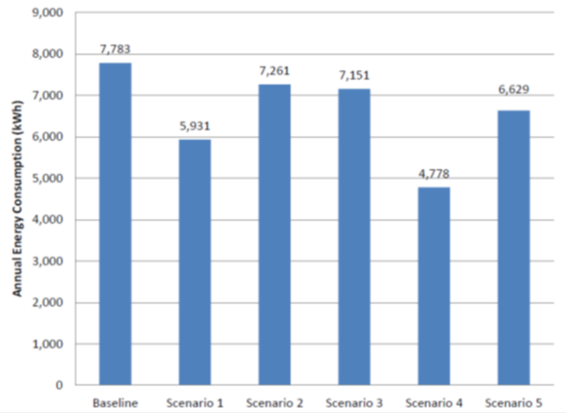

Figure 14. Annual house energy consumption comparison

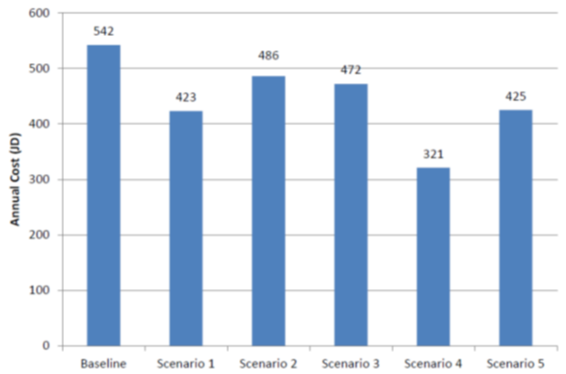

Figure 15. Annual cost comparison for all scenarios

5. Conclusions

A baseline model was defined using statistics, calculations and assumptions to represent the current energy use of the residential sector in Jordan. Three energy saving measures were introduced in five scenarios to assess their individual and collective impact on energy consumption. Hourly energy simulation was performed for the baseline and the five scenarios using HAP software. The savings were introduced and discussed for each scenario and a thorough comparison with the baseline was conducted. The best scenario for new houses before construction is the total measures scenario with 39% reduction in energy consumption and 41% reduction in annual energy cost. On the other hand the best scenario for existing houses is the solar water heaters and efficient lighting fixtures scenario with reduction percentages of

15% and 22 % for energy consumption and annual energy cost, respectively.

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