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ENERGY CONSERVATION OPPERTUNITIES AND SOLAR ENERGY INTEGRATION PROSPECTS IN THE RESIDENTIAL SECTOR OF KSA

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Abstract

This study aims to explore various energy conservation opportunities in the residential sector of Saudi Arabia when available standards are employed as compared to the typical local design practices. Based on the information collected from literature, the local design practices including physical, thermal, and operational characteristics are defined and simulated as a base case scenario for a typical single family residential building in Dhahran. A proposed case study is performed according to the benchmark design considerations of International Energy Conservation Code (IECC) 2012 and the simulation results are compared with the base case scenario in order to evaluate the energy saving potential. The proposed building is integrated with solar energy to meet the part load of the building. The credibility of solar energy integrated building is justified in terms of its economic as well as eco-environmental benefits.

Keywords: *Residential buildings; Energy conservation; Solar energy integration; GHG emissions*

1. Introduction

The buildings consume about 80% of the total electricity generated in KSA, a figure well above the average electricity consumption for the buildings in all over the world. A breakdown advocates that the residential sector accounts for the major part of the consumed electricity in buildings with a very high value of 51.2 %, followed by the commercial and government buildings that stand for 13.6 % and 13.4 % consumption, respectively (Asif, 2016). Therefore, energy conservation measures in the residential buildings is an important study that needs to be examined carefully to strengthen the energy security situation in KSA. The use of computer simulations to evaluate the performance of a building is a common practice now-a-days. Several comprehensive simulation tools are available to assist designers to implement innovative ideas and evaluate the energy savings potential in their proposed designs (Hong, Chou, & Bong, 2000). In most of the published literature related to energy performance of the residential buildings in KSA, the main focus of the researches is on the design optimization of the buildings to reduce the energy consumption (Alaidroos & Krarti, 2015; Almutairi et al., 2015; Budaiwi & Abdou, 2013; Taleb & Sharples, 2011). Although generous guidelines are available to reduce the energy consumption in a typical residential building in KSA but few studies have been conducted that implemented energy conservation measures and then integrated the renewable energy sources to meet the energy requirements of these buildings. Some studies specified the prospects of integrating the renewable energy sources in residential buildings to motivate the zero energy buildings concepts in the residential sector of KSA (Alrashed & Asif, 2012; Atieh & Shariff, 2015; Banani, Vahdati, Shahrestani, & Clements-Croome, 2016; Charfi, Atieh, & Chaabene, 2015). In zero energy buildings, the complete load of a building is shifted from conventional energy sources to renewable energy sources that is currently not practical in KSA due to technical, financial, and social barriers. However, the shift of the minor load (water heating load, lighting load, etc.) of a residential building to the renewable energy sources is possible and also helpful in providing the stability during summer peak load in KSA.

This study specified the energy conservation measures and solar energy integration to meet part of the energy requirements

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of a residential building in KSA. A single family residential building was selected in Dhahran. A literature review was conducted on energy conservation studies related to the residential buildings in Dhahran. The architectural features were defined for a typical residential building based on the local design practices that includes physical, thermal, and operational characteristics. The building was modeled using Visual DOE 4.0 software and considered as the base case scenario. Parametric analysis was carried out for different envelope design considerations to improve the thermal performance of the building. A proposed case study was examined according to the benchmark design considerations of International Energy Conservation Code (IECC), 2012 and the simulation results were compared to the base case scenario in order to evaluate the energy saving potential. The proposed building is integrated with grid connected solar PV system to meet the lighting load. The credibility of solar energy integrated building is justified in terms of its economic as well as eco-environmental benefits.

2. Base Case for Residential Building

Significant research has been carried out to evaluate the design parameters adopted in different climates of KSA. (Al-Haddad, 1988) conducted a field survey on more than 300 houses in major cities of KSA to develop a typical villa for energy simulation studies. (A. Ahmad, 2004) stated the features of a typical residential building for single family in Dhahran. He collected the data from surveys, building plan reviews that are filled by municipal authorities, and interviews conducted with building owners. (Al-saadi & Budaiwi, 2007) also conducted a survey to summarize the characteristics of a typical residential building for a single family in Riyadh and Dhahran. Based on the data obtained from literature, the base case scenario is simulated using RETScreen software that imports authentic climatic data from its database recorded by the National Aeronautics and Space Administration (NASA). The initial base case is modelled based on the input data summarized in Table1.

The simulations were performed first for a typical residential building of Dhahran as a base case scenario. The annual energy consumption for the base case scenario is presented in Fig. 1. Fig. 1 shows that the space cooling load is the highest among all the loads and responsible for 71 % of the overall annual energy consumed in a typical residential building of Dhahran. Lighting load is the second major contributor in total annual energy consumption followed by space heating load, equipment's load, and water heating load.

Table 1. Typical architectural features of a single family residential building in Dhahran (A. Ahmad, 2004; Al-saadi & Budaiwi, 2007).

Location	Dhahran
Direction	Front elevation facing East
Shape	Rectangular
Number of floors	2
Height between floors	3.5 m
Dimensions of floor	15 x 20 m
The area of floor	300 m^2
The area of walls	490 m^2
The area of windows	20% of the total area of walls
Type of glass	Single glazed (6 mm)
The volume of house	2100 m^3
Infiltration	0.5 ACH (Airtight)
Walls construction	15 mm outside plaster (Stucco) + 200 mm CMU Hollow + 15 mm inside plaster (Stucco)
Roof construction	15 mm Cement plaster + 200 mm CMU Hourdi Slab + 100 mm Foam + 4 mm water proof membrane + 25 mm Sand Fill + 50 mm Mortar + Terrazzo
Floor construction	100 mm slab on grade
Number of occupant	6
Occupancy rate	50 % during weekdays and 75 % on weekends

Type of lights	30 % Incandescent lamps and 70 % fluorescent lamps
Lighting load	10 W/m^2 for 1st floor and 8 W/m^2 for 2nd floor
Equipment load	12 W/m^2 for 1st floor and 5 W/m^2 for 2st floor
Air conditioning system	Constant volume residential system with electric heating
Thermostat	Two position thermostat with 25ºC cooling set point and 21ºC heating set point
Coefficient of performance	2.87

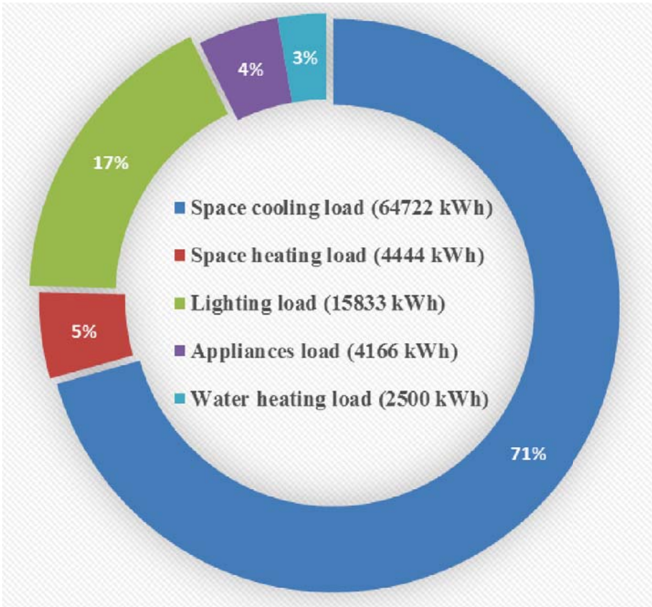

Fig.1. Annual energy consumption in a typical residential building of Dhahran (base case scenario).

2.1 Parametric analysis

Parametric analysis was performed to understand the effect of different design parameters on the energy consumption. Three different construction combinations were analyzed by varying the wall construction while keeping the roof construction same. These three combinations along with their properties are summarized in Table. 2.

Simulation results of different wall constructions were compared to the base case construction and presented in Fig. 2. Fig. 2 shows the decrease in energy consumption with the increase in thermal resistance of the walls. Construction 1 and 2 consist of a wall with higher thermal resistance and indicates a substantial decrease in the energy consumption for space cooling and heating when compared to the base construction. Although the wall in construction 3 has the highest thermal resistance, the decrease in energy consumption for Construction 3 is less as compared to construction 2.

Table 2. Different construction combinations by varying the wall construction while keeping the roof construction same.

Roof Construction	**R-value ($m^2.°C/W$)**	**Heat capacity ($KJ/m^2.°C$)**
15 mm Cement plaster + 200 mm CMU Hourdi Slab + 100 mm Foam Conc. + 4mm water proof membrane + 25 mm Sand Fill + 50mm Mortar +Terrazzo	1.69	629.8
Wall Construction	**R-value ($m^2.°C/W$)**	**Heat capacity ($KJ/m^2.°C$)**

Wall 1	15 mm cement plaster + 50 mm Precast Concrete Panel + 50 mm Polyurethane + 50 mm Precast Concrete Panel + 15 mm cement plaster	2.4	237.8
Wall 2	15 mm cement plaster + Hollow CMU Block + 50 mm Air Space + 100 mm Polyurethane + 15 mm Cement plaster	5	442.1
Wall 3	15 mm Cement plaster + 75 mm Polyurethane + 50 mm Precast Concrete + 75 mm Polyurethane + 15 mm Cement plaster	6.67	148.5

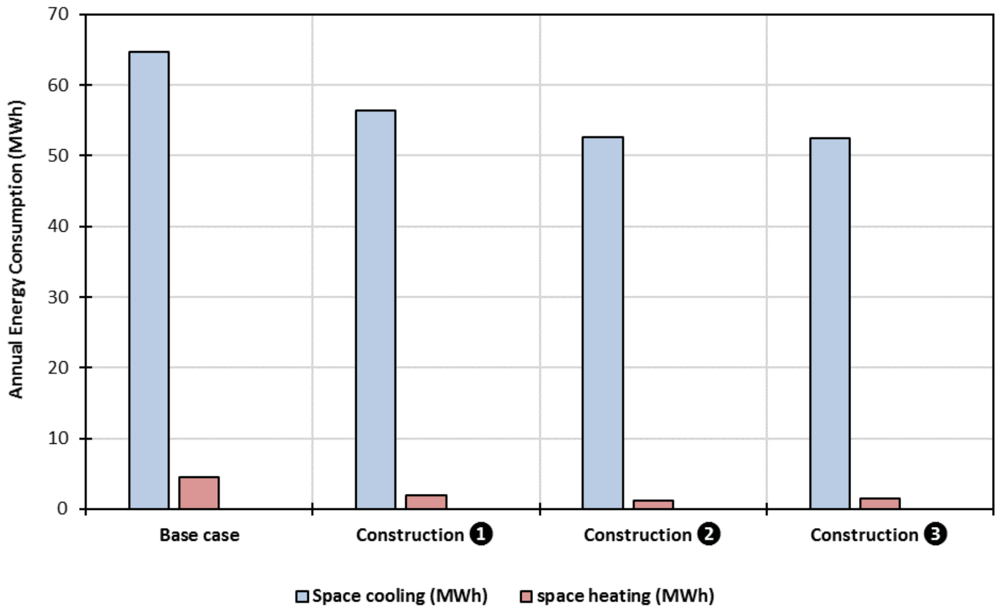

Fig.2. Annual energy consumption under different wall combinations.

The energy consumption of a typical residential building in Dhahran was also analyzed under different roof combinations. Three different construction combinations are analyzed by varying the roof construction while keeping the wall construction same. These three combinations along with their properties are given in Table. 3.

Simulation results of different roof constructions are compared to the base case and presented in Fig. 3. Fig. 3 shows the decrease in the energy consumption with the increase in thermal resistance of the roof. The impact of different roof combinations on energy consumption is not as much significant as in the case of different wall combinations. The reason of lower reduction in the energy consumption with different roof combinations is due to lower floor area as compared to gross wall area and two floors of the building. As only the second roof is directly exposed to solar radiations, the impact of different roof combinations majorly influenced the second floor energy consumption. Therefore, the impact of different roof combinations on energy reduction is not as much significant as in the case of different wall combinations.

Fig. 3 also indicates that the energy consumption for space heating is higher for construction 1 and construction 2 as compared to base case construction. These results can be justified from the heat capacity values and the location of thermal mass. For construction 1, the thermal insulation is placed on the interior side that does not allow the indoor generated heat to be stored in the construction material. In construction 2, the heat capacity value of the roof is very low as compared to the base case construction, therefore the potential to store indoor generated heat is reduced.

Table 3. Different construction combinations by varying the roof construction while keeping the wall construction same.

Wall Construction		R-value ($m^2.°C/W$)	Heat capacity ($KJ/m^2.°C$)
Single 200 mm Hollow CMU Wall + 15 mm Stucco finishes on both sides (without insulation)		0.34	380
Roof Construction		**R-value ($m^2.°C/W$)**	**Heat capacity ($KJ/m^2.°C$)**
Roof 1	15 mm Cement plaster + 50 mm Ext Polystyrene + 200 mm Clay Brick Hourdi + 100 mm Plain Concrete + 4 mm water proof membrane + 25 mm Sand + 50 mm Mortar + Tiles	2.56	567.1
Roof 2	15 mm Cement plaster + 200 mm Siporex Hourdi + 100 mm Foam Concrete + 50 mm Exp Polystyrene + 4 mm water proof membrane + 25mm Sand + 50 mm Mortar + Tiles	4.35	337
Roof 3	15 mm Cement plaster + 200 mm CMU Hourdi Slab + 100 mm Foam Concrete + 100 mm Polyurethane + 4 mm water proof membrane + 25 mm Sand + 50 mm Mortar + Tiles	5.88	638

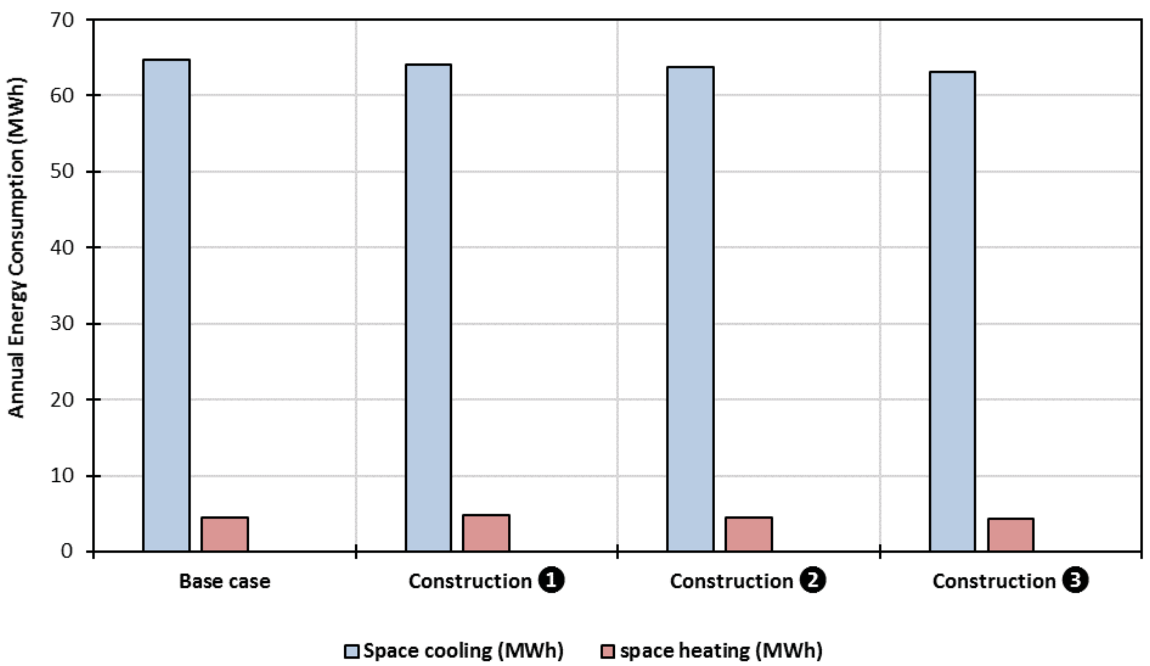

Fig.3. Annual energy Performance of Residential Building under different roof combinations.

The influence of different glazing on the energy performance of the building was also analyzed by using different glazing. Simulations were performed for double glazed, argon gas filled double glazed with low emissivity (low-e), and argon gas filled triple glazed with low-e. The characteristics of these glazing's are summarized in Table 4.

Simulation results of different glazing were compared to the base case and presented in Fig. 4 which clearly shows that the selection of glazing type plays a vital role in in the reduction of cooling and heating load. Fig. 4 shows that the energy consumption for space cooling is higher and energy consumption for space heating is lower for argon filled triple glazing when compared to argon filled double glazing. These results can be justified by the higher solar heat gain coefficient of argon filled triple glazing that allows more solar radiations to the space. Therefore, argon filled triple glazing performs better in winter for heating purpose but it increase the cooling energy requirements in summer. The appropriate selection of the glazing U-factor (1/R-value) and the SHGC are required to balance the heating and cooling energy requirements.

Table 4. The characteristics of different types of glazing

Description	U-factor (1/R value) ($W/m^2.K$)	Solar heat gain coefficient (SHGC)
Double glazed	2.788	0.613
Double glazed, low-e, gas filled	1.317	0.278
Triple glazed,low-e, gas filled	0.772	0.471

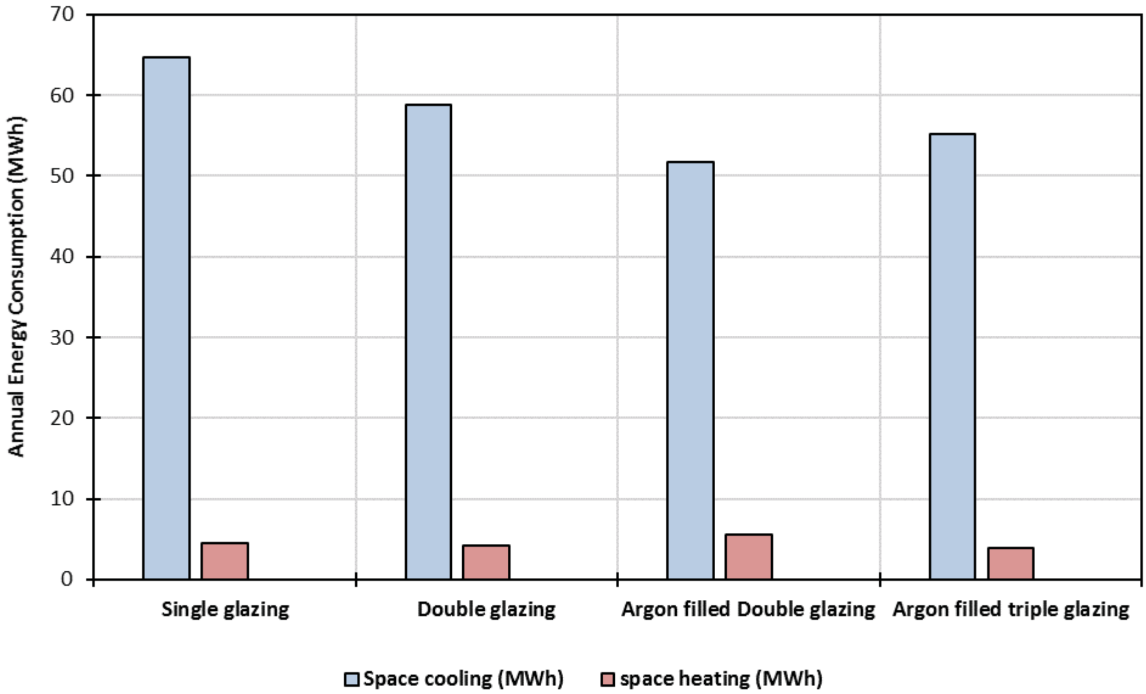

Fig.4. Annual energy Performance of Residential Building under different glazing types.

3. Proposed Case for Residential Building

A proposed case study was performed according to the benchmark design considerations of International Energy Conservation Code (IECC, 2012). IECC is intended to deliver state-of-the-art energy conservation practices for energy efficient building through model code regulations. The physical characteristics of the proposed case residential building are the same as in the base case. The minimum IECC requirements for envelope design in hot climates for residential buildings with less than or equal to 20 % windows area is as follow:

- The wall thermal resistance should be more than R-3/4.
- The roof thermal resistance (R-value) should be more than 5.28 m^2. ºC/W (R-30).
- The floor thermal resistance (R-value) should be more than 2.28 m^2. ºC/W (R-13).
- The U-value of glazing should be less than 2.27 $W/m^2.K$ with SHGC < 0.25.
- At least 75 % of the permanently installed lighting fixtures should be high efficacy lamps.
- All the appliances should be Energy Star certified.

Simulations were performed for the proposed case scenario according to the IECC standards and the results were compared to the base case scenario to check the energy saving potential in the residential building, as shown in Table 5. It shows that there is 56 %, 37 %, 46 %, and 27 % less energy consumption for space cooling, space heating, lighting, and appliances, respectively.

Table 5. Comparison of annual energy consumption in base case and proposed case.

Type of load	Space cooling	Space heating	Lighting	Appliances
Annual energy consumption (kWh) - Base case	64722	4439	15833	4163
Annual energy consumption (kWh) - Proposed case	28611	2772	8550	3055
Annual energy savings (kWh)	36111	1667	7283	1108
Annual energy savings - %	56 %	37 %	46 %	27 %
Annual fuel consumption (GJ) - Base case	233	16	57	15
Annual fuel consumption (GJ) - Proposed case	103	10	31	11
Annual fuel savings (GJ)	130	6	26	4

4. Solar energy integration in Residential Buildings

The Kingdom of Saudi Arabia (KSA) is blessed with abundant solar radiations throughout the year. The vast open land of KSA receives high intensities of solar radiation for long periods that makes it an ideal region for solar energy conversion and its applications (Abd-Ur-Rehman & Al-Sulaiman, 2014). Irrespective of the enormous prospective of solar energy, KSA utilizes only a small portion of it and nearly all its energy requirements are met by fossil fuels. In this study an effort is being made to meet the part load of a residential building by using solar energy. Although, meeting the space cooling load by solar energy is not practical due to very high initial investment but lighting load can easily be met by using solar water heater.

Lighting load is the 2nd highest among all the loads and responsible for 17 % of the overall annual energy consumption in a typical residential building of Dhahran (as shown in figure 1). This load is satisfied by using conventional grid electric power that is generated by burning fossil fuels. The shifting of lighting load dependence from the conventional grid electric power to solar PV system could be a milestone towards improving energy savings and security in future concerns. For this purpose, grid connected PV system is simulated to fulfill the lighting load demand of a typical single family residential building in Dhahran. There are different technologies like mono-Si, poly-Si, a-Si, CIS, CdTe, and spherical-Si, that can be used for a grid connected PV system. Selection of certain PV technology type is directly related to the ambient temperature, optimum efficiency, nominal output temperature, and solar collector area (Natural Resources Canada, 1997). For the current study, year round working grid connected PV system was simulated using poly-Si technology. The implication of grid connected PV system is beneficial in two perspective: one is replacement of fossil fuels with renewable energy and second is the supply of surplus electric power to the grid system. The features of the designed grid connected poly-Si PV model are listed in Table 6.

Table 6. Characteristic features of modelled grid connected PV system (Abd-ur-Rehman & Al-Sulaiman, 2016; Natural Resources Canada, 1997).

Property/ Factor	Value
PV technology type	Poly-Si
Efficiency	16.4%
Nominal operating temperature	45 °C
Frame area / PV module	1.94 m^2
Control method	Clamped
Collector slope	Latitude of location
Solar tracking mode	Fixed
PV panel cost	2.7 $/watt
Electricity export rate	2.5 cents/KWh
Fuel cost escalation rate	4.0%
Inflation rate	2.5%
Discount rate	2.0%

Modelled grid connected PV system was analyzed in terms of its technical and main economic determinants (i.e. NPV, IRR, payback period and benefit-cost ratio). GHG emissions analysis was also carried out to visualize the environmental effects of energy transition. The economic determinants of the modelled grid connected PV system are summarized in

Table 7. The electricity export rate is assumed to be 2.5 cents/KWh that is equal to the electricity cost in the residential sector. Assuming the life time of the modelled grid connected PV system to be 25 years, the payback period is 13.3 years that is more than the half of PV system projected life. The long payback period is due to the highly subsidized cost of electricity in KSA. The high initial cost and absence of government incentive are the major restrictive factors in establishing the solar PV system. To encourage the practice of installing solar PV systems, the government should start incentive programs and should provide subsidy to substantiate the initial cost of establishing solar PV system.

Fig. 5 illustrates the effect of subsidy on the economic determinants of the modelled grid connected PV system. Results shows that the economic viability of the modelled grid connected PV system is directly influenced by the percentage of subsidy provided by the government. The incentive program that provides 50 % subsidy on the establishment of proposed grid connected PV system, the payback period could be reduced from 13.3 years to 6.6 years. Therefore, government should develop such incentives program that favors the establishment of clean energy projects to strengthen the energy security condition of KSA.

Table 7. Economic determinants of modelled grid connected PV system.

Factor	Value
Annual Electricity exported to grid	3.247 MWh
Net Present Value (NPV)	10,175 $
Internal Rate of Return (IRR)	9.8 %
Simple payback period	13.3 years
Benefit to cost ratio	2.45

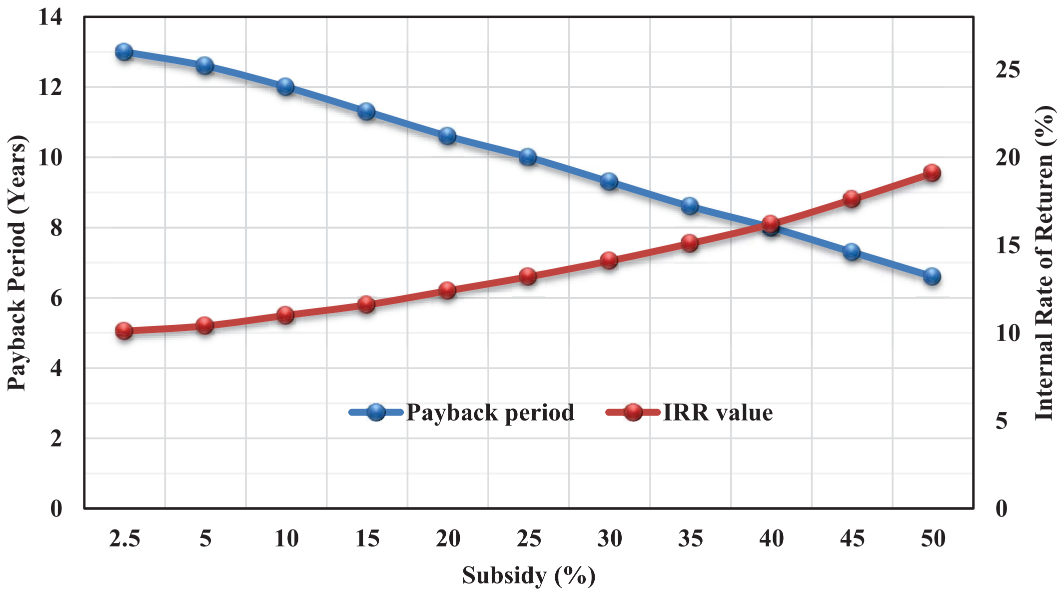

Figure 1. Effect of Subsidy on economic determinants of modelled grid connected solar PV system.

5. Conclusions

Residential buildings consume major part of the primary energy production and there is a huge energy saving potential in these buildings. Energy conservation measures in residential buildings is an important study and needs to be examined carefully to improve the energy security situation in KSA. The prevailing local design and construction practices in the residential buildings of KSA are energy inefficient. The buildings are poorly insulated, use inefficient appliances and lighting systems, and without the implementation of available standards. The implementation of IECC standards signpost the significant energy saving potential in the residential sector of KSA when compared to the typical local design practices. The simulation results for IECC standardized buildings shows 56 %, 37 %, 46 %, and 27 % less energy consumption for space cooling, space heating, lighting, and appliances, respectively.

Solar energy integration to meet the partial energy requirements in the residential buildings of KSA is technically and financially more viable as compared to zero energy building concept. The use of solar energy to meet the partial energy requirements of a residential building also provides the summer peak load energy stability in KSA. The implication of using grid connected PV system to meet the lighting load is economically justified in terms of subsidy provided by the government. Results indicate that the 50 % subsidy on the establishment of proposed grid connected PV system favors all economic determinants and results in reducing the payback period from 13.3 years to 6.6 years. Therefore, the government should start incentive programs and should provide subsidy to encourage the use of solar PV systems in residential buildings.

6. Acknowledgements

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7. Abbreviations

ACH	Air change per hour
a-Si	Amorphous-silicon solar cell
CIS	copper indium gallium selenide solar cell
CdTe	Cadmium telluride solar cell
CMU	Concrete masonry unit
GHG IRR	Greenhouse gas Internal rate of return (%)
KSA	Kingdom of Saudi Arabia
KWh	Kilowatt hour
IECC	International energy conservation code
MWh	Megawatt hour
Poly-Si	Poly-silicon solar cell
NPV	Net present value
PV	Photovoltaic
Poly-Si	Poly-silicon solar cell
Spherical-Si	Spherical-silicon solar cell
R-value SHGC	Thermal resistance Solar heat gain coefficient
SWH	Solar water heating
U-factor	Rate of heat loss
tCO_2	Ton of carbon dioxide

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