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Implementation of a Zero-energy Building Scheme for a Hot and Dry Climate Region in Iran (a Case Study, Yazd)

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Abstract
In this research work, a plan to implement a zero-energy building (ZEB) scheme for a hot and dry climate region in Iran, i.e. Yazd, is introduced and a comparison with a typical house of that climate is performed. Based on the climate conditions, several active or passive methods are available in order to create a balance between the energy supply and the demand, namely improving wall insulations, by using efficient heating/cooling devices, using solar energy, utilizing energy storage devices, etc. Here, the SketchUp software is employed to present the plot of the selected building. In addition, one of the interfaces of the Energy plus software called "BEOpt" is used for performing the energy and economic analyses on the fast-constructed and pre-fabricated schemes. Considering the equipment's world price, the results obtained demonstrate that the ZEB scheme in selected climate conditions is applicable, and the payback period is estimated to be about 5.5 years. In addition, replacing the typical buildings with a ZEB will decrease carbon dioxide emissions by about 27.4 metric tons/yr.

Keywords: *Zero Energy Building, Green building, Iran climate, Energy optimization, Reducing energy consumption, clean Energy.*

1. Introduction

Nowadays, the building sector confronts several considerable issues including energy consumption, energy shortage challenges, and climate change [1–4]. Furthermore, renewable energy markets have been emerged due to augmenting energy prices, as the result of which, the costs of renewable energy technologies such as ground source heat pumps [5] and solar absorption cooling [6] have been reduced significantly [7, 8]. Thus the boundaries of new developments have been pushed to achieve a sustainable environment. Such improvements are required to design more sustainable residential and commercial buildings [9–11]. A building that preserves the integrity of the structure regarding safety issues, users' convenient, and health as well as considering environmental impacts can be named as a sustainable building [12–15]. In other words, it can be defined as the maximum energy gains and efficiency simultaneously to the minimum possible loss [16–18]. There are many examples of both the commercial and residential buildings with zero energy status around the world. As an illustration, some investigations of energy-efficient buildings have been carried out in Australia [19, 20], China (including Hong Kong) [21–26], United Arab Emirates [27], United States [28], United Kingdom and Europe [29–33], and Burkina Faso in Africa [34]. Additionally, various case studies around the world have focused on exposing the potential of zero-energy buildings (ZEBs) for alleviating the shortage of energy resources and the degradation effects on the environment [35, 36].

Furthermore, increasing energy demand, limitation of fossil-based energy sources that result in increasing the prices, unsafety, and instability of energy markets in the last decade as well as global warming and pollution problems are effective factors that show the necessity of developing a new approach in the energy subject [37, 38]. Two basic solutions have been noted in the new approach:

1. Optimization in energy consumption and production;
2. Employing renewable energy.

Noticing the optimization of energy consumption and production is an important issue. Considering these issues cause to preserve the fossil energy sources and also prepare good conditions for using renewable energy. In fact, prior to the widespread utilization of renewable energy, energy usage should be decreased as much as possible [39]. Basically, decreasing energy usage is obtainable in two ways:

a. Decline in demand: to change in standards and quality of life;
b. Decline in loss: to utilize efficient equipment.

D'Agostino and Mazzarella [40] have provided different available difinitions and conspets for ZEBs and compared them. Conti *et al*. [41] have carried out a cost-benefit analysis for a building, while hybrid photovoltaic/thermal solar collectors have been used in order to achieve a near ZEB. Yang *et al*. [42] have investigated the effect of implementing ZEBs on energy consumption of the residential sector in China. Mahdavi Adeli *et al*. [43] have investigated an optimization methodology on the energy consumption of a building to reach an optimum thermal comfort. Esbati *et al*. [44] have studied the effect of using a phase change material on the energy saving factors of a university building in Iran and demonstrated that through utilizing these materials the loss was reduced and the overall energy saving status was improved. Keyvanmajd and Sajadi [45] have studied different climates in Iran for applying ZEBs and reported that there was a viable possibility for this approach in this region.

According to the International Energy Agency statistics in 2011 [46], the total primary energy supply was increased by 1.6% and the total final consumption was increased by 1.7% over the previous year. In 2011, the portions of industry, transport, residential, non-energy use, commercial, agriculture, and other sectors with respect to the total final consumption were 28.7%, 27.4%, 23.2%, 9.2%, 8.0%, 2.1%, and 1.4,%, respectively. The portion of the residential part, 23.2%, illustrates the importance of this part.

In Iran, according to energy balance in 2011 [47], the portion of the residential sector with respect to the total energy consumption was about 37%. This portion was 35% in 2012 [47].

Eradicating the stability of the greenhouse gas concentration requires a severe decrease in the global emissions of carbon dioxide. Among all the human activities that led to the generation of greenhouse gases, energy consumption is the biggest source of emitting these gases [48]. According to the world energy balance in 2011, the portion of the residential in CO_2 emission was 9.2% of the other parts that were energy consumers.

Iran is ranked among the 10-top emitter of CO_2 countries in 2012, according to the IEA reports. The important point is that these 10 countries emit two-third of the world's CO_2 emissions. In 2009, the portion of the residential section in CO_2 emissions of Iran was 26% of the total CO_2 emissions of this country.

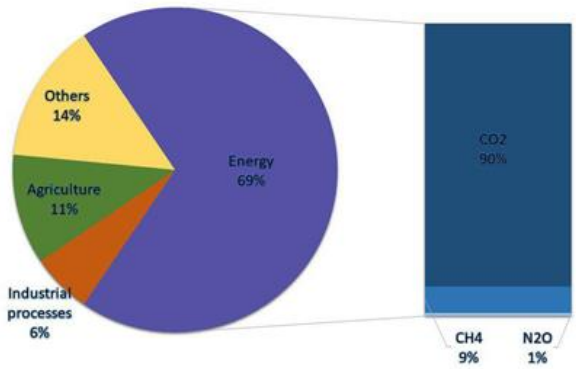

Figure 1. Portion of global anthropogenic GHG.

Therefore, energy consumption and pollution from fossil fuels can be decreased by concentrating on the residential sector in terms of energy consumption, energy consumption optimization, and also replacing energy carriers by renewable energies. In particular, the concept of the ZEB has been proposed to achieve these goals [49–53].

In this work, a new scheme is proposed to investigate the effect of implementing fast-construction and pre-fabricated ZEBs and a benchmark is performed between the typical buildings and the proposed scheme in terms of energy consumption, economic, and carbon dioxide emissions. Thus both types of buildings are simulated in energy plus and the outputs are compared.

2. Climate Surveys

Exploring the available samples of ZEBs illustrates the fact that these environmentally friendly buildings can be built at every place in the world [54–58]. In fact, the design, optimization, and equipment of renewable energy production must be appropriate for a place in which the building is supposed to be constructed. ZEBs are strongly dependent on the climatic and geographical conditions.

Iran lies between the latitudes of 24° and 40° N, and the longitudes of 44° and 64° E. It is located in a region that is among the highest levels of receiving the solar energy. According to the experts, Iran is a country in which it has about 300 sunny days per year in more than two-thirds of its area, and the average solar radiation is 4.5 to 5.5

kWh/m^2 per day. Thus Iran has been introduced as one of the countries that have a great potential for the solar energy. However, the notable point is the existence of different climates across this country. The four climatic divisions of Iran suggested by Ganji can be used in order to categorize these climates [59]:

1. Mild and wet climate;
2. Cold climate;
3. Hot and dry climate;
4. Hot and wet climate.

In this investigation, it was intended to perform a case study in Yazd. Yazd is located at 31.8948° N 54.3570° E, 1200 m above the sea level. The location of this region is demonstrated in figure 2. This city is located in the hot and dry climate of Iran. Prolonged dry heat and intense temperature difference between winter and summer and the intense difference between the day and night temperatures are the climatic features of this region.

Figure 2. Location of Yazd Province in the map of Iran.

According to the NASA statistics, in this climate, solar radiation is more than the average solar radiation of Iran and the total solar radiation in Yazd is 7.23 kWh/m^2 per day. This illustrates the great potential of solar energy in this city. Thus the solar energy can be used for the energy supply of ZEBs by utilizing appropriate and efficient equipment.

3. Procedure

First, a typical house was designed and all of its equipment and costs were described. A reference status was created in order to determine how much the designed ZEB was optimized and efficient, which was the final target. Then a ZEB was designed with the same dimension and plot as the typical building, and similar to the former procedure, the equipment and costs of ZEB were described. The SketchUp software was utilized for the architectural design of the building. Afterward, the energy consumption and production as well as the costs and payback period were calculated using BEOpt, which is one of the interfaces of EnergyPlus and is a specialized software in the field of energy and buildings. Finally, the results of these two buildings were compared. The heat transfer between walls, windows, and surrounding was calculated based on the following basic heat transfer equation:

$$Q = U.A.\Delta T \quad (1)$$

where Q denotes the heat load, U states the overall heat transfer coefficient of the material, A is the surface area, and ΔT indicates the temperature difference between two zones. The heat load was calculated and an energy balance was formed to find out the thermal loss or energy waste.

Since the authors aimed to design a building with a fast construction, a pre-fabricated building (conex) was employed instead of a house. Thus from then on, in this paper, ZEB is equal to a zero energy pre-fabricated building.

4. Required Data

According to the manufacturers, the useful life of a pre-fabricated building is 30 years. Therefore, all calculations were done based on this period. It is worth noting that the world prices of all equipment were considered, so a conversion rate was applied as follows: 1 U.S. dollar = 42000 IR. Rials (for calculation of the utility costs in Iran).

Furthermore, information such as inflation rate, discount rate, mortgage interest rate, mortgage period, marginal income tax rate, subsidies for using renewable energy production systems, PV compensation (annual excess sell back rate), and utility rates (electricity and natural gas) was required. It should be noted that the Ministry of Power considers some changes for the electricity rate in different seasons and different hours of a day according to their tabulation. However, the main table for the electricity rate is unique throughout the country. Table 1 shows the base rates of electricity.

Table 1. Basic price of electricity in Iran [60].

Average electricity consumption per month (kWh/month)	Price per kWh ($)
0-100	0.012
100-200	0.014
200-300	0.03
300-400	0.054
400-500	0.062

500-600	0.078
More than 600	0.086

According to the Ministry of Power, Yazd is in region 3, so the electricity rate of this city from the first of July until the end of August is calculated from the listed values of table 2. This ministry also considers some changes in the electricity rate for the peak and low load hours. These changes were also entered into the software. The average of subscription for the gas bill in the second half of a year is $0.487, and this amount is considered for all year round because some houses are vacant and these buildings do not have any gas consumption (decreasing gas consumption causes decreasing subscription). According to the Central Bank of Iran, the inflation rate is 13%, the discount rate is 10%, the mortgage interest rate is 13%, the mortgage period is 12 years, and the marginal income tax rate is 20%. The government pays 50% of the initial cost of using renewable energy systems as a subsidy and also purchases $0.287 per each produced kW.

Climatic information of Yazd was provided from the library of EnergyPlus as a file in the .epw format and applied to the software. Thus all calculations were done considering the weather of Yazd.

Table 2. Basic price of electricity in region 3 of Iran.

Average electricity consumption per month (kWh/month)	Price per kWh ($)
0-100	0.0096
100-200	0.011
200-300	0.02
300-400	0.032
400-500	0.046
500-600	0.06
More than 600	0.072

5. Usual Building

The area of this building is 90 square meters (15*6), as shown in figure 3. In BEOpt, orientation is defined as the direction faced by the front of the house. Thus the orientation of the typical building is east.

This building contains a hall, a kitchen, a toilet, a bathroom, and 2 bedrooms. Figure 4 shows how these zones are assembled and figure 5 shows the area of each zone.

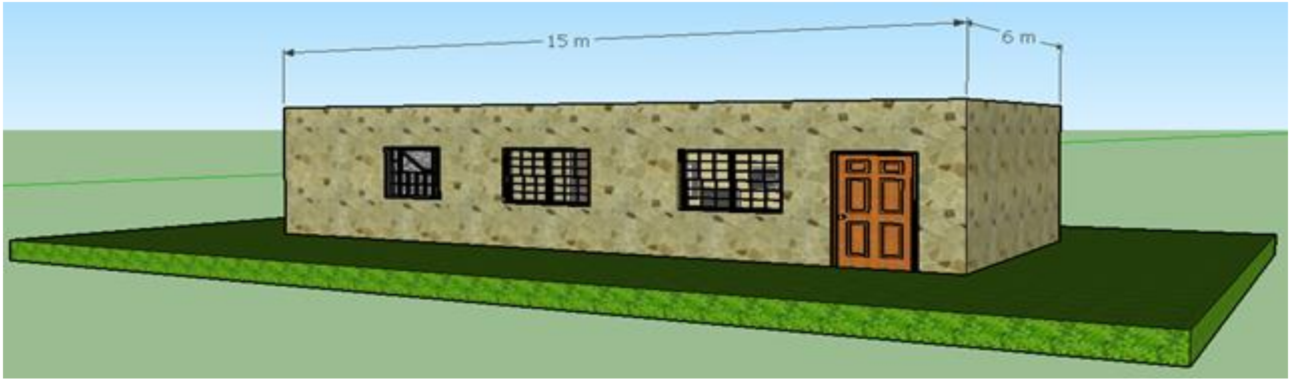

Figure3. Building overview.

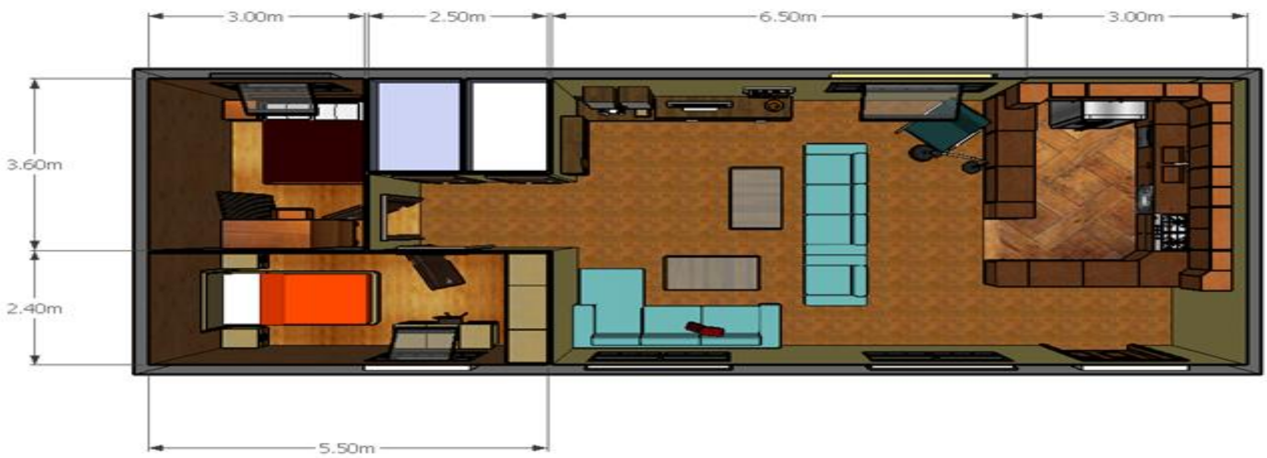

Figure 4. Placement of each zone.

Figure 5. Area of each zone.

Windows are placed on four sides of the building and cover 18% of the wall in which the window is placed. Windows are simple with a U-Value of 4.315 W/m^{2}k, lifetime of 30 years, and the associated cost is 220.66 \$/m^2. The door area is 3.716 m^2, and made out of wood with a U-Value of 2.725 W/m^{2}k, the lifetime is 30 years, and the related cost is 113.024 \$/m^2.

In order to comprehend the effect of natural ventilation on the reducing energy consumption, mechanical ventilation with a flow rate of 51.9 cfm, a total power of 15.6 w, a lifetime of 18 years, and the cost of $45 is used instead of natural ventilation. A room air conditioner with a lifetime of 12 years and a cost of $360 for cooling and a boiler with an electric heater, a lifetime of 24 years, and a cost of $1933 for heating were employed. Since the usual cooling setpoint is much less than the standards and the heating setpoint is much more than standard, first, 20.5 °C for cooling set point and 23.9 °C for the heating setpoint were considered. However, since the considered cooling setpoint was less than the considered heating setpoint, the software could not calculate, and then it was considered as the average amount for both cooling and heating setpoints, although the first values were closer to reality. Since the cooling system could not reach the defined target (cooling setpoint) alone, 45 W ceiling fans with a lifetime of 11 years and the cost of $400 were used as an auxiliary system.

A standard electric water heater with the energy factor of 0.92, the tank volume of 113.56 L, the setpoint of 51.6 °C, a lifetime of 13 years, and the cost of $460 was utilized for the hot water supply. The associated piping system was not insulated.

Incandescent lamps formed lightening of this building. The number of lamps was considered in a way to provide a standard amount of lux. The lifetime of these lamps is 1.78 years and the costs are $0.215 per square meter of each area in which lightening is required.

The appliances and fixtures of this building contain a side freezer refrigerator with an annual electric use of 718 kWh, a lifetime of 17.4 years, and the cost of $1140, an electric oven with 120% usage, a lifetime of 30 years, and the cost of $94, and finally, a clothes washer with 120% usage, a lifetime of 14 years, and the cost of $590. Plug loads were considered 4 times more than average of the world for this building (according to an unofficially published statistic by the Ministry of Power, this is yet less than average of energy consumption in Iran), for a better perception of thrift in energy consumption.

6. Designed ZEB

Since Iran is located in the northern hemisphere, it is predictable that the optimum orientation is south. Optimizing the orientation of the building causes reduction in the energy consumption due to a decline in demand. This causes a thrift of about 615 kWh in the annual energy consumption, while no additional cost is inflicted. CO_2 emissions are reduced by 0.1 metric tons/yr by this thrift.

A polyurethane sandwich panel with a thickness of 200 mm and a heat transfer coefficient of 0.09 W/m^{2}K was used as the exterior walls [61]. The optimum metal coating of the sandwich panels is aluminum with a light color covering. The cost of the walls is about 71.58 \$/m^2. Using these walls instead of the typical walls of the building causes reduction in the energy consumption due to the decline in energy loss. This causes a thrift of about 14078 kWh in the annual energy consumption, and CO_2 emissions are reduced by about 3 metric tons/yr by this thrift. Using these panels for the roof of the conex decreases the annual energy consumption by about 15544 kWh and also decreases CO_2 emissions by about 3.1 metric tons/yr. Finally, using these panels for the conex floor decreases the annual energy consumption by about 102.6 kWh and also decreases CO_2 emissions by about 2.1 metric tons/yr.

According to enough temperature difference between night and morning in this climate, using thermal mass has an appropriate effect on reducing the energy consumption. Dry-wall and PCM have thicknesses of 12.7 mm and 3.3 mm, and the specific heats of 0.84 kJ/kgK and 2.09 kJ/kgK, respectively [62]. The PCM melting temperature and cost are 22.7 °C and 27.66 $/m^2, respectively. Using these thermal masses for the exterior walls decreases the annual energy consumption by about 1026 kWh and also decreases CO_2 emissions by about 0.2 metric tons/yr. Using these thermal masses for ceiling decreases the annual energy consumption by about 850 kWh and also decreases CO_2 emissions by about 0.15 metric tons/yr.

According to the software output, less energy consumption is not reached by increasing the area of windows. The optimum window to wall ratio is 15% for the northern and southern walls and 0% for the eastern and western walls. Windows are triple-glazed with an insulated frame, a U-value of 0.96 W/m^{2}K, a lifetime of 30 years, and the cost of 618.08 $/m^2 [63]. Using these windows with the mentioned area decreases the annual energy consumption by about 5455 kWh and also decreases CO_2 emissions by about 1.2 metric tons/yr. Shading, especially in the summer, reduces energy consumption. According to the software output, the optimum interior shading in the summer is 95%, and in the winter, it is 0.5%. This cause reducing the annual energy consumption by 264 kWh. The exterior shading (overhang) effects are more than the interior shading on reducing energy consumption. Using overhang with a depth of 60.96 cm, an offset of 15.24 cm, a width extension of 30.48 cm, and the cost of 107.64 $/m^2 leads to reduce the annual energy consumption by about 733 kWh and reduce CO_2 emissions by about 0.15 metric tons/yr. The optimum door is a steel door with an area of 1.85 m^2, the U-value of 1.135 W/m^{2}K, a lifetime of 30 years, and the cost of 103.87 $/m^2. Using this door with the mentioned area decreases the annual energy consumption by about 410 kWh and also decreases CO_2 emissions by about 0.1 metric tons/yr. Reducing the energy consumption because of door and window area changing is due to the decline in the demand, and reducing the energy consumption because of door and windows material changing is due to the decline in the loss.

Natural ventilation was used in this conex. Using natural ventilation instead of mechanical ventilation decreases the annual energy consumption by about 1114 kWh and also decreases CO_2 emissions by about 0.1 metric tons/yr. The boiler, central air conditioner, and ceiling fan are used for the heating and cooling of this building. The central air conditioner has an air flow rate of 315.8 cfm/ton, a lifetime of 16 years, and the cost of $3560. The ceiling fan has a power of 20 W, a lifetime of 12 years, and the cost of $55. The boiler has a heating input ratio of 1.02, a design temperature of 65.5 °C, a lifetime of 24 years, and the cost of $933. A cooling setpoint of 26.6 °C and a heating setpoint of 17.22 °C were considered so as to reduce the energy consumption by heating and cooling. Using these heating and cooling systems with the mentioned setpoint decreases the annual energy consumption by about 26954 kWh and also decreases CO_2 emissions by about 5.9 metric tons/yr. Reducing the energy consumption, because of changing the cooling and heating systems, is due to both the decline in demand and the decline in the loss.

A solar water heater with an area of 5.94 m^2, a tank storage of 363.4 L, an R-value of 1.761 m^{2}K/W, a lifetime of 30 years, south azimuth, a 60 degrees tilt, and the cost of $7554 was used as the main water heater, and an electric tankless water heater with an energy factor of 0.99, a design temperature of 51.6, a lifetime of 20 years, and the cost of $1640 as the assistant water heater. The pipes are insulated with an R-value of 0.35 m^{2}K/W and a cost of 25.16 $/m. Using this water heating system decreases the annual energy consumption by about 5778 kWh and also decreases CO_2 emissions by about 1.2 metric tons/yr. Reducing energy consumption because of using this system is due to the decline in demand.

Since using some equipment such as solatube and optical-fiber has not been widespread yet, LEDs were used for lightening of the the designed building. The number of lamps is considered in a way that provides a standard amount of lux. The lifetime of these lamps is 78.28 years and the cost is $4.3 per square meter of each area where lightening is needed. Using these lamps instead of incandescent decreases the annual energy consumption by about 1994 kWh and also decreases CO_2 emissions by about 0.6 metric tons/yr. Reducing energy consumption because of using LEDs is due to the decline in demand.

According to the BEOpt output, the optimum appliances and fixtures for this building contain a top freezer refrigerator with an annual energy consumption of 348 kWh, a lifetime of 17.4 years, and the cost of $975.41, an 80 % usage of oven with a lifetime of 30 years, and the cost of $94, and an energy star clothes washer with a lifetime of 14 years and the cost of $662. Using this refrigerator instead of the one that has been used in the typical building decreases the annual energy consumption by about 1231 kWh and also decreases CO_2 emissions by about 0.3 metric tons/yr. Using this oven instead of the one that is used in a typical building decreases the annual energy consumption by about 791 kWh and also decreases CO_2 emissions by about 0.1 metric tons/yr, and using the clothes washer instead of the one that is used in a typical building decreases the annual energy consumption by about 909 kWh and also decreases CO_2 emissions by about 0.2 metric tons/yr. Reducing energy consumption because of using these appliances and fixtures is due to the decline in both the demand and loss. The plug loads were considered to be about 0.25 of the world average (this amount is acceptable according to the developed countries). This will reduce the annual energy consumption of 22114 kWh and also reduce CO_2 emissions by about 4.9 metric tons/yr. Reducing energy consumption because of decreasing plug loads is due to the decline in demand.

The average solar radiation in Yazd is 7.23 kWh/m^2. Besides solar energy, wind power utilization is also feasible in this city because of its good wind condition but since the solar radiation in Yazd is great, this kind of energy is only used to provide the required energy for our building. PV panels of 12 kW with a system loss fraction of 0.14 (due to wiring resistance losses, dust, module mismatch, etc.), an inverter efficiency of 0.96, south azimuth, 30 degrees tilt, PV lifetime of 25 years, the inverter lifetime of 10 years, and cost of 3.42 $/W were used. The annual energy produced by this equipment is 59920 kWh.

7. Results and Discussion

As declared earlier, optimizing and reducing energy consumption are the two defined priorities in a ZEB. The energy consumption of the designed ZEB is reduced significantly by using new equipment in comparison with a typical building. The annual energy consumption in ZEB is about 7009 kWh, while it is about 131191 kWh in a typical building. It means that 124182 kWh energy consumption is reduced by replacing the typical type of buildings with ZEB. This reduced energy consumption causes about 27.4 metric tons of reduction in CO_2 emissions.

According to the software output, the annual energy-related cost in a typical building is $3105, and it is just $44 in ZEB. The value of the produced electricity in ZEB is $4906 per year. These numbers illustrate an annual profit of $4862, while ZEB does not suffer from an annual $3105 for utility bills of a typical building. The schematic comparison of a ZEB and a typical building is demonstrated in figure 6.

BEOpt considering economic factors such as inflation rate, discount rate, etc. declares that the payback period is about 5.5 years due to the fact that the constructing costs of ZEB is about $40000 more than a typical building. The overt annual benefit after 5.5 years is the value of the produced electricity by the equipment of ZEB; subtracting the utility bills of this building calculated by $4862 and the covert annual benefit after 5.5 years is not to pay the utility bills of a typical building ($3105). These overt and covert benefits are the individual benefits. While the social benefits of the widespread use of ZEB such as the absence of environmental problems, paying the penalty to the UN is not required because of an excessive release of greenhouse gases, utilizing energy produced by power plants in other sectors, etc. are too much and are very significant.

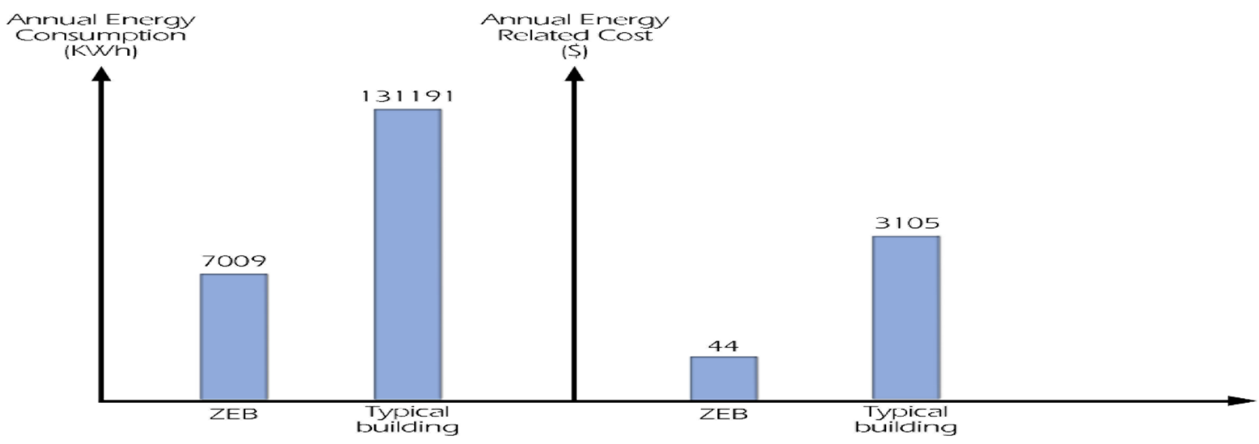

Figure 6. Comparison of a ZEB and a typical building.

7. Conclusion

In this investigation, the ZEB building approach was proposed to monitor its effect on the economic and environmental statuses in the city of Yazd in Iran. The proposed structure was simulated in energy plus software, and the results were extracted. The summarized findings were obtained as follow:

- Energy consumption was reduced by about 124.18 MWh by replacing a typical building with a ZEB. There is the Zanbagh power plant with a capacity of 97 MW in the suburb of Yazd. Ideally, this plant will produce 849720 MWh per year if it works with all of its capacity at all times of the year. This means that we can neglect the energy production of this plant by replacing 6843 typical houses with ZEBs by considering just a reduction in the energy consumption of a ZEB.
- Considering the energy production of a ZEB, the generated power of the power plant can be neglected by replacing 14181 typical houses with ZEBs. If considering both factors of reduction in the energy consumption and the energy production of a ZEB, 4616 typical buildings are required to be replaced by ZEBs to neglect the production of the Zanbagh power plant. It is worth noting that this number is obtained without considering the efficiency of the plant.
- It is pleasant to express that the annual CO_2 emissions reduce about 126478.4 metric tons by replacing that number of typical houses with ZEBs.

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