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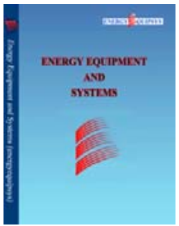

Toward the design of zero energy buildings (ZEB) in Iran: Climatic study

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ABSTRACT

In this research, a combination of passive and active methods is used to design a nearly zero energy building in four major climatic regions of Iran, including cold, mild, dry-warm, and wet-warm ones. The annual energy consumption analysis is performed using DesignBuilder® software. The passive strategies include Trombe Wall, blue roof, and thermochromic windows, and the active methods are using GSHP, LEDs with the linear controller, and photovoltaic systems. Also, the rainwater harvesting system is discussed, and the amount of rainfall which may be collected in different climates is summarized. The results show that Iran has a great potential to develop near zero energy buildings, especially in the cold region in which more than 60% reduction in annual energy consumption may be achievable.

Keywords: Zero Energy Building (ZEB); DesignBuilder; Passive Method; Active Method; Rainwater Harvesting.

1. Introduction

In Iran, buildings consume almost 36% of the annual energy usage, which is equal to 432 million barrels of crude oil in a year [1]. Not only growing costs of electricity generation but also fast depletion of the world energy resources lead engineers and architectures to examine and design Zero Energy Building (ZEB) in Iran. There a is number of definitions for ZEB or green buildings according to project purposes. These projects goal is to use resources more efficiently to minimize the building negative impacts on the environment. Using renewable energy resources [2], passive strategies such as Trombe wall [3] and green roof [4], and active techniques, e.g. Photovoltaic panels [5], controllable lighting [6] and heat recovery systems [7] are some of strategies to reduce the building energy consumption and its carbon dioxide emission.

In this research paper, the annual energy consumption of a typical two-story house is studied in various climatic regions of Iran. In addition, the abovementioned passive and active techniques are implemented to analyze their effectiveness in energy saving under multiple conditions. As another part of the research, using a rainwater harvesting system, it is tried to provide water requirement of the occupants. The goal of this work is to evaluate the combined effect of passive and active strategies and to design a near or net-zero energy building in Iran.

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The study presented in this paper traces the following steps:

1. Description of the sample residential building specifications;
2. Description of the passive strategies;
3. Description of the HVAC system;
4. Description of the lighting system and its controller;
5. Evaluation of the base and the modified building annual energy demand in different climates of Iran;
6. Evaluation of the required active photovoltaic solar system to meet the annual electricity demand of the modified building;

Evaluation of the water harvesting system in different climates of Iran.

2. Modeling

In this study, a two-story residential building with four bedrooms and a total area of 121 m² is investigated. The plans of the house are shown in Fig. 1 and its architectural and material specifications are explained in Tables 1 and 2, respectively. The building energy consumption is analyzed through DesignBuilder® software [8], which uses the EnergyPlus program [9] as a simulation engine. EnergyPlus is a whole building energy analysis program developed by the US Department of Energy (DOE) which can calculate the cooling and heating loads necessary to maintain the thermal control set points, conditions throughout the secondary HVAC system and coil loads, and the energy consumption of the primary plant equipment. For the base model, the lightening system has 5 W/m^2 normalized power density and the HVAC system is a CAV-heat pump whose heating and cooling setpoints temperature are 21℃ and 25℃, respectively. The final model in DesignBuilder® is shown in Fig. 2.

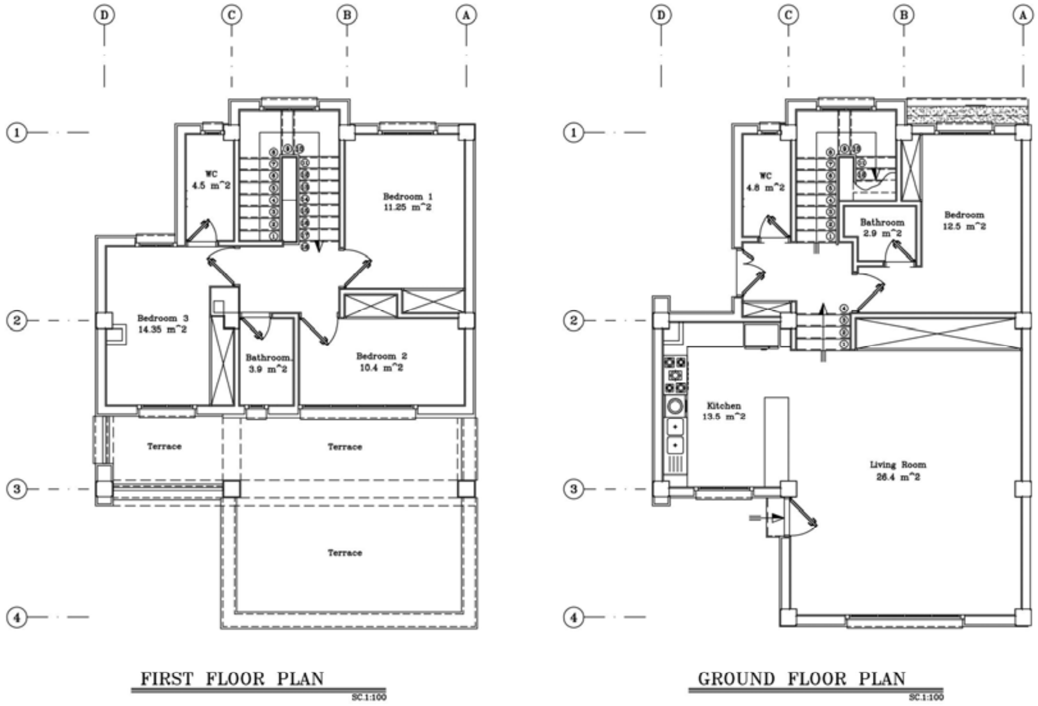

Fig.1. Architectural plans of the building

Table 1. Architectural specifications of the building spaces

Floor	Zone	Area (m^2)	Windows area (m^2)
Ground	Living room	26.4	5.8
	Kitchen	13.5	2.8
	Bedroom #1	12.5	1.7
	Bathroom #2	2.9	-
	W.C.	4.8	-
First floor	Bedroom #1	11.25	1.7
	Bedroom #2	10.4	5.8
	Bedroom #3	14.3	1.7
	Bathroom	3.9	-
	W.C.	4.5	-

Table 2. Material specifications of the building

Envelope	Material	U value (W/m^{2}K)
External wall	60 mm polyurethane + 240 mm concrete block + 10 mm plaster	0.309
Internal wall	25 mm gypsum plasterboard + 10 mm air gap + 25 mm gypsum plasterboard	1.639
Roof	60 mm polyurethane + 240 mm concrete block + 12 mm aerated concrete slab + 12 mm plaster	0.344
Door	Metal with 25 mm polyurethane core	2.823
Window	Double pane with two 6 mm clear glazing + 13 mm air gap	1.978

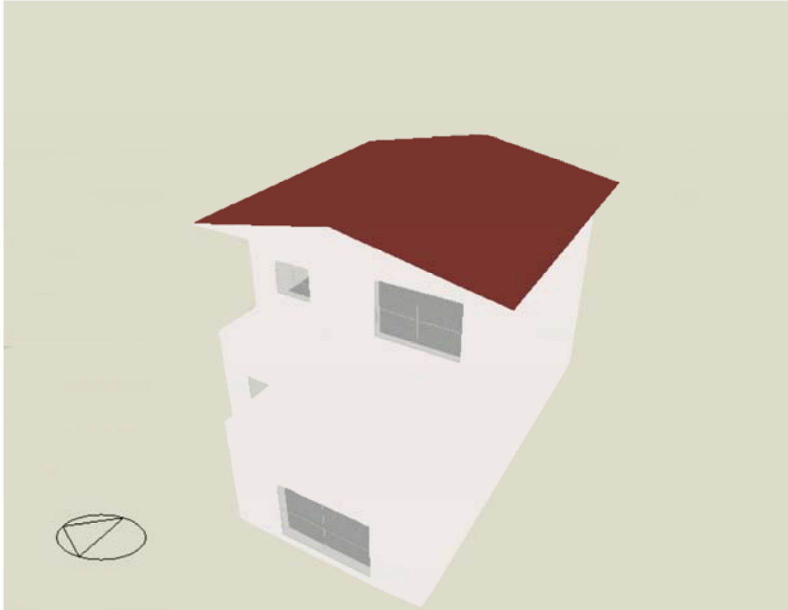

Fig.2. Model of the building in DesignBuilder®

3. Climatic Regions of Iran

Iran is located in the Middle East between latitudes 24° and 40° N, and longitudes 44° and 64° E with an area of about 1,648,000 km^2. Iran has a wide climate, from cold to hot, and from dry to humid. Figure 3 shows four main climatic regions of Iran, including cold, mild, warm-dry, and warm-humid [10]. In this study, Tabriz, Tehran, Yazd, and Bandar Abbas are selected as typical cities for these climatic regions, respectively, whose locations are summarized in Table 2.

4.Passive Strategies

Passive design takes advantages of a building site, climate, and materials to minimize the building energy requirement. Through many different methods available, three common ones are used in this study as below:

Trombe Wall: In this method, a wall is built on the winter sun-side of the building by an external layer including two 6 mm clear glazings with 13 mm air gap and a high heat capacity internal layer. Two layers are separated by 600 mm layer of air [12]. A schematic view of the Trombe walls simulated in DesignBuilder® is shown in Fig. 4.

Blue Roof: It is a combination of green roof and a drainage system which is explicitly intended to store water, usually rainfall [13] as shown in Fig. 5. In this study, the roof is split into two parts, one is pitched used for photovoltaic panels installation, and another one is flat designed as a blue roof. The area of each part is about 52 m^2. A schematic of the corrected house roof is shown in Fig. 4.

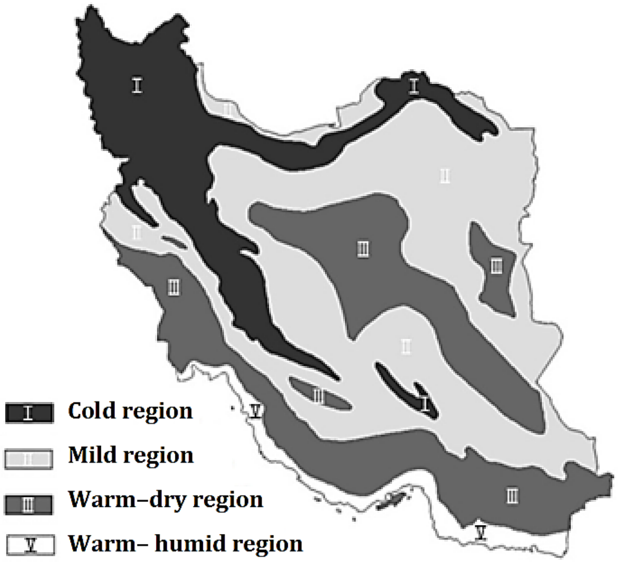

Fig.3. Climatic regions of Iran

Table 3. Characteristics of the representative cities [11]

City	Climate	Latitude	Longitude	Elevation
Bandar-e-Abbas	Warm-humid	27.20 °N	56.15 °E	10 m
Yazd	Warm-dry	54.21 °N	31.53 °E	1222 m
Tehran	Mild	35.68 °N	51.30 °E	1191 m
Tabriz	Cold	37.80 °N	46.25 °E	1361 m

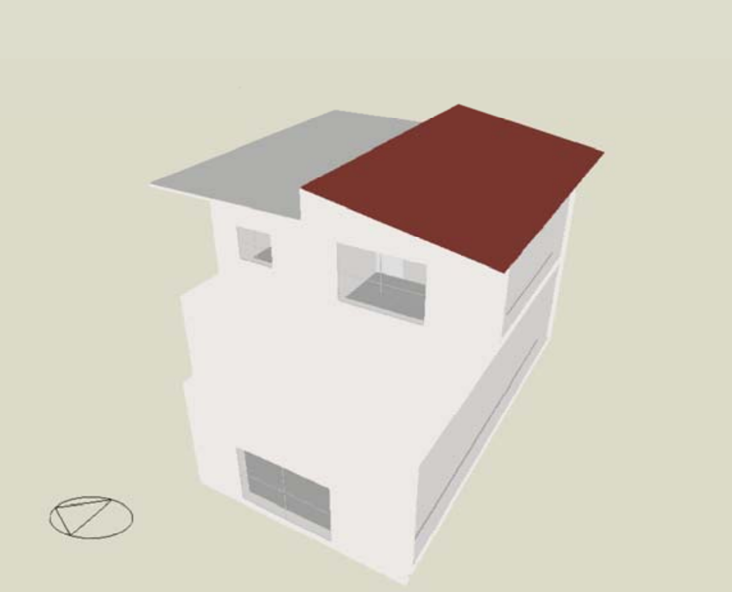

Fig. 4. Model of the building uses Trombe wall and blue roof in DesignBuilder®

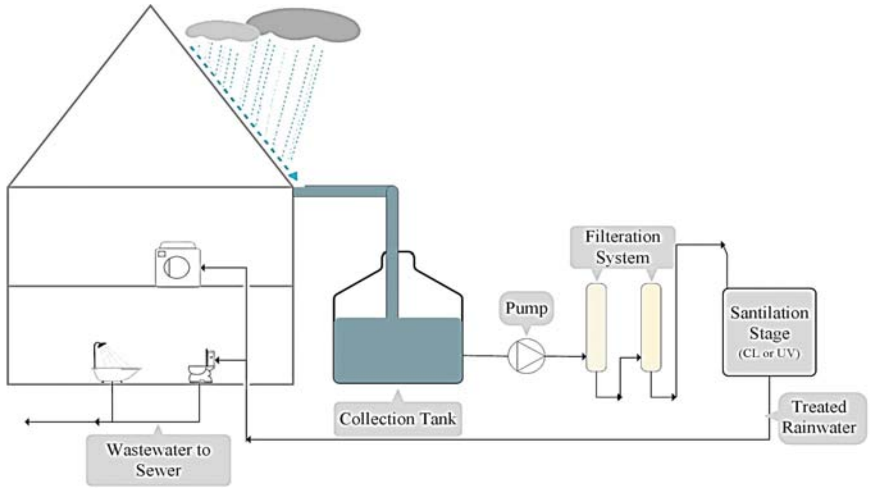

Fig.5. Schematic of the blue roof system

Thermochromic window: This type of glazing uses the direct sunlight heat to be tinted as necessary [14]. This kind of glazing not only reduces the heat load coming into the house but also uses the maximum daylighting. In this research thermochromic windows with 3-layer 6 mm genetic clear glazing and two 6 mm, air gaps are used whose U value is 1.723 W/m^{2}K.

5. Active Strategies

HVAC System: In this case study, the variable volume air (VAV) system is used to satisfy both heating and cooling loads whose hot/chilled water is provided by a ground source heat pump (GSHP). A schematic view of the HVAC system is shown in Fig. 6.

Lighting System:, In this case-study, LEDs with 2.5 W/m^2 normalized power density and a linear controller are implemented To reduce the lighting system energy consumption. The controller system decreases the LEDs input power as the daylight increases according to the diagram depicted in Fig. 7. In the figure, the minimum and the maximum input power fractions are set to 0.1.

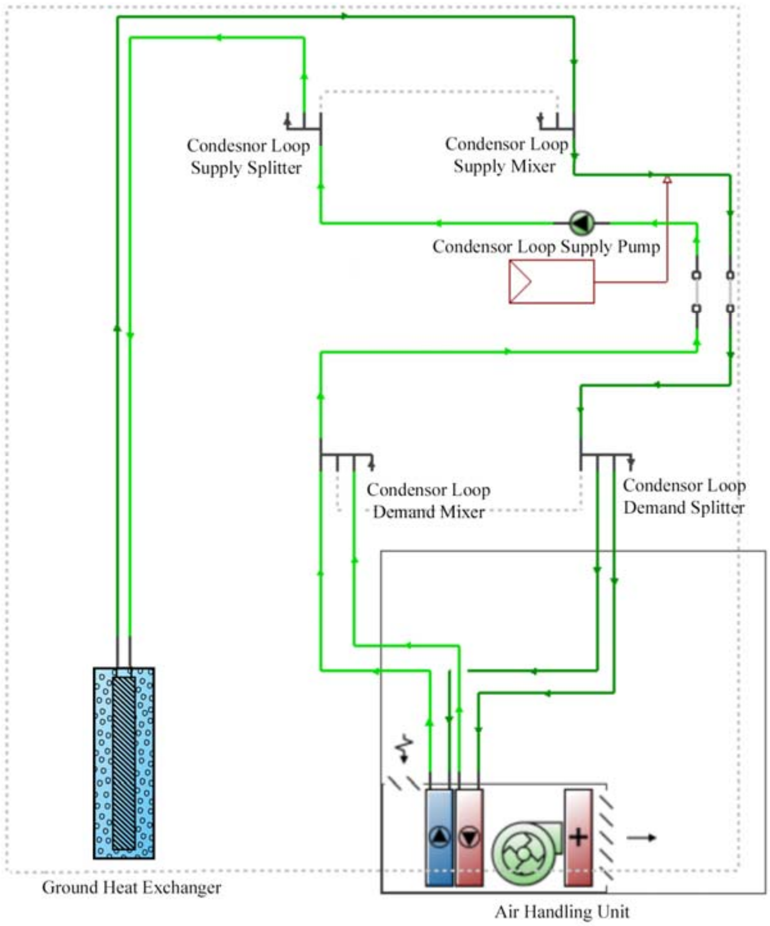

Fig.6. Schematic of the VAV-GSHP HVAC system [8]

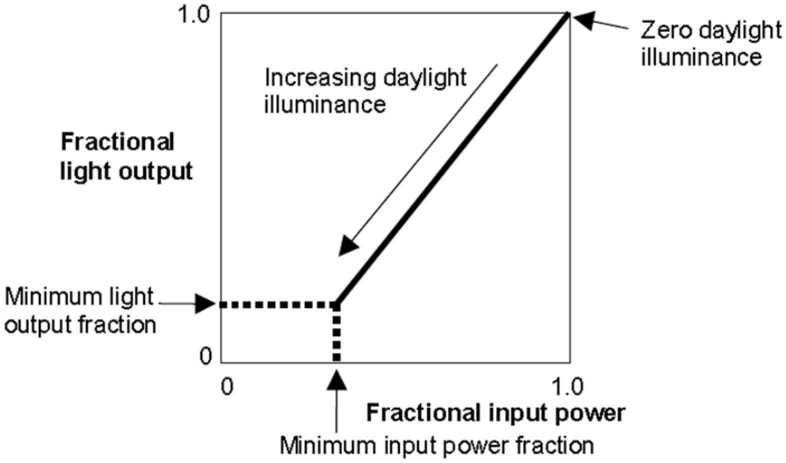

Fig.7. Schematic of the LEDs linear controller system [8]

Renewable Energy System: This kind of energy systems are designed to supply electrical devices with renewable and sustainable resources such as sunlight, wind, rain, tides, waves and geothermal heat which are indispensable parts of zero energy buildings. In this study, photovoltaic panels with charger unit, batteries, and inverter are used to collect the sunlight energy to produce electricity. A schematic view of the system is shown in Fig.8.

6.Rainwater Harvesting System

Rainwater harvesting is the accumulation and storage of rainfall to reuse on-site rather than allowing it to run off [15]. This system is also a form of the sustainable urban drainage system to alleviate flooding caused by storms. As it is mentioned before, in this study, the blue roof system is also used to collect the rainfall as shown in Fig. 5.

7.Results and Discussion

As mentioned previously, passive methods include a Trombe wall, blue roof, and thermochromic glazing. Active solutions include using VAV-GSHP HVAC system, LEDs with linear controller, and PV system. In Table 4, the effect of using combined strategies, except PV system, on the annual energy consumption of the building is summarized. The results show that the proposed combination of passive and active methods has the best result in the cold climate as Trombe wall can remarkably decrease the annual heating load in every climate.

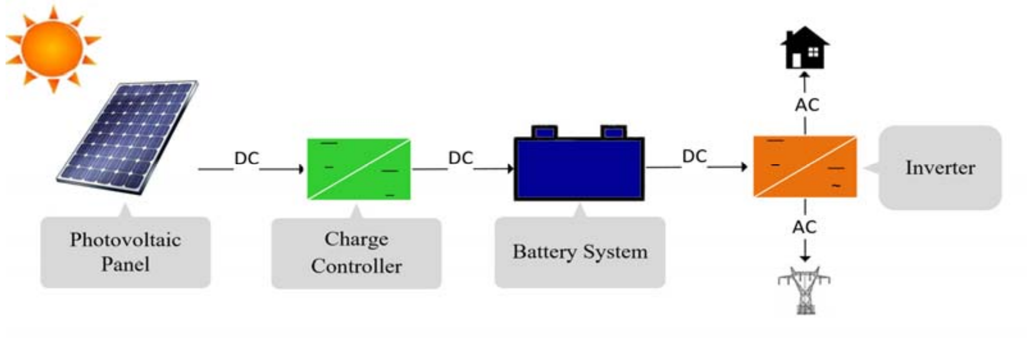

Fig.8. Schematic of the photovoltaic system

Table 4. The effect of energy saving strategies on the annual building energy consumption

City	Rotation (CCW)	Annual Energy Consumption (MWh)		Saving (%)
		Base Model	Modified Model	
Bandar-e-Abbas	0°	28.5	12.9	54.6
	90°	26.3	14.1	46.4
	180°	28.6	12.1	57.8
	270°	25.8	13.9	46.1
Yazd	0°	19.9	11.0	44.9
	90°	17.0	11.9	30.4
	180°	19.8	9.6	51.4
	270°	17.9	12.1	32.5
Tehran	0°	20.1	11.1	44.6
	90°	16.7	11.7	29.7
	180°	20.0	9.2	54.1
	270°	17.8	11.7	34.3
Tabriz	0°	21.7	9.4	56.6
	90°	19.9	9.8	50.7
	180°	21.6	8.4	61.1
	270°	21.0	9.8	53.6

So, the best result is achieved in the cold climate where the annual heating load is naturally high. In addition, the best direction is 180° as Trombe wall does not expose to the direct sunlight as has not any unfavorable effect on the cooling load, accordingly.

After simulation of the modified house energy consumption through DesignBuilder® and calculation of its annual electricity consumption, photovoltaic panels which can satisfy the requirements of the electricity demand can be chosen. Accordingly, in the required amount of PV panels is summarized in four typical cities of Iran. In this case study, it is assumed that the efficiency of PV and their inverter are 15% and 95%, respectively.

To design the rainwater harvesting system, eight-year mean monthly rainfall of the representative cities are extracted from Iran Meteorological Organization (IRIMO) [16] as shown in Fig. 9. As a result, an underground 1.5 m^3 polyethylene water storage tank is used to store the rainwater whose schematic view is shown in Fig. 5. According to the Iranian National Building Code, each person needs 150 liters water per day [17]. As a result, the annual demand for a four-member family is 219 m^3. As a result, in Table 6 the percentage of water which can be supplied through a rainwater harvesting system is also presented. Of course, the stored water is only used for irrigation and washing purposes, so these percentages are almost reasonable.

Table 5. The required PV panel area for the modified building in various climate of Iran

City	Photovoltaic Panel Area (m^2)
Bandar-e-Abbas	48.6
Yazd	35.0
Tehran	31.1
Tabriz	44.9

Table 6. The annual rainfall which can be stored using the rainwater harvesting system in various climate of Iran

City	Annual Harvested Water (m^3)	Percentage of Annual Water (%)
Bandar-e-Abbas	5.8	2.7
Yazd	2.0	0.9
Tehran	9.9	4.5
Tabriz	11.3	5.2

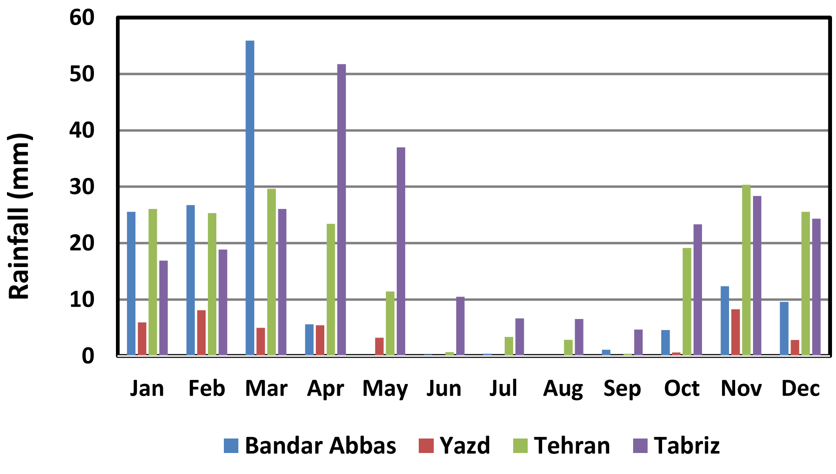

Fig.9. Mean monthly rainfall in four studied cities

8.Conclusion

This study aims to evaluate using active strategies, including ground source heat pump, controllable lighting and PV systems, and passive methods, e.g., Trombe wall, blue roof and thermochromic glazing in major climates of Iran. Building energy analysis using DesignBuilder® software showed it is a great potential to develop near zero energy buildings in Iran, especially in cold region where up to more than 60% annual energy saving is possible. Also, the rainwater harvesting system was discussed and the amount of annual collected rainfall in different climates of Iran was evaluated.

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