Original Paper

Building design based on zero energy approach

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Abstract. *In recent years, the energy crisis has become one of the most challenging issues in the world. The need to minimize the use of fossil fuels,* *due to the increase in environmental pollution caused by excessive use, on the one hand, and the exhaustion of these resources, on the other hand, has made it necessary to use renewable energies as a suitable alternative. The purpose of this study is to build a design based on a zero-energy approach in Qazvin City, Iran. Research hypotheses have been investigated for providing solutions to reduce energy consumption and use renewable resources in zero-energy buildings. The research method employed is descriptive-analytical. DesignBuilder software is used for simulation and dynamic thermal analysis of the structure. Based on the results of the research, the theory of designing and building zero-energy houses in Qazvin City can be achieved with the stated methods.*

1. Introduction

Global warming, environmental pollution due to the combustion of fossil fuels and the increasing acceleration towards the end of non-renewable sources have led to an ever more serious energy crisis and numerous related damages (Belussi *et al.* 2019; D'Agostino and Mazzarella 2019; Ravishankar *et al.* 2020). Modern architecture, despite the valuable achievements and changes it brought with it, also created complex problems in the environmental field.

In this century, the world is witnessing the increasing destruction of its environment due to the production of greenhouse gases, and atmospheric pollutants, and the increase in the consumption of finite resources. Following these changes and the issues that came with it, to find an answer to improve the situation, mankind reached a new concept called sustainable development. and as a result, due to the important role of the built environment in the course of sustainable development, sustainable architecture has attracted the attention of many experts (Wu and Skye 2021; Magrini et al. 2020). One of the three important areas that sustainable development emphasizes is environmental issues. The limited and high pollution of fossil sources as the main source of energy supply until today has given rise to a lot of attention to clean and renewable energy sources such as solar, wind, geothermal, and other new energies (Liu *et al.* 2019; Chen 2019; Feng *et al.* 2019; Kosonen and Keskisaari 2020). Meanwhile, the use of renewable energy in the building sector (such as the use of small wind turbines, photovoltaic panels, geothermal energy, and solar water heaters) along with passive solutions can significantly reduce energy consumption and consequently reduce the harmful effects caused by the consumption of fossil fuels (Daemei *et al.* 2016; Ferrara *et al.* 2019; Natanian and Auer. 2020; Attia and Gobin 2020; Jareemit *et al.* 2022; Manzoor *et al.* 2022).

Considering the above contents and the critical conditions of fossil energy consumption in the country on the one hand and insufficient attention to renewable energy sources on the other hand, the purpose of this research was the feasibility of designing a building with a zero-energy approach in Qazvin City, Iran.

2. The need for research

The proposed vision for sustainability is to move towards the design of zero-energy buildings. In practice, there will be many obstacles, but, considering Iran's limited energy resources, solutions must be designed to move towards their construction.

Until 1973, due to the cheap price of energy carriers and the relative lack of knowledge of environmental problems, one of the most basic criteria for measuring the progress of each country was the annual per capita energy consumption in those countries. With the increase in energy prices and the emergence of environmental problems, the issue of increasing productivity and preventing environmental pollution gave a new dimension to this criterion. Among the goals related to the energy sector in different countries, improving efficiency and optimizing energy consumption have gained priority. This priority is due to various factors, the main ones of which are:

- Maintaining the world's exhaustible reserves due to the limitations of energy supply and the growth of its demand.
- Reducing the harmful environmental effects caused by the combustion of fossil fuels.
- Improving economic efficiency and global competitiveness about the necessary costs for investment in the energy sector.

Due to the economic and social conditions of Iran, the increase in the price of energy carriers does not make many energy-saving plans economical. Therefore, low-cost or no-cost ways to reduce energy consumption in buildings are of particular importance. Architectural methods that reduce energy consumption are cost-free and sustainable methods, and even if the price of energy increases, both economically and environmentally, they are more suitable than other methods. Although energy-saving with architectural design can be used in all countries, it is particularly appropriate for Iran due to its economic, social, and cultural structure.

The price of electricity and total energy demand are highly dependent on each other. When electricity prices are high and energy demand is high, backup generators such as gas turbines and coal plants are used more. Reducing energy production at this time makes electricity production more environmentally friendly and less dependent on fossil fuels. In addition to reducing the cost of electricity, knowing that electricity is produced in an environmentally friendly way can be an important incentive for consumers to invest in smart energy management. In addition, if many households use smart energy management, this can reduce peak consumption and reduce the capacity of backup power plants.

Energy consumption in buildings accounts for one-third of the country's annual energy consumption. Therefore, it is very important to provide solutions that can reduce energy consumption in this sector. Compliance with even the smallest details in this respect can have a great effect on reducing consumption in the building. The first step to achieving this goal is to find the weaknesses of contemporary architecture and provide solutions to improve them.

Energy consumption in the building depends on the structure and geometric form, the way its different components are designed, and the climatic conditions. Other factors such as occupation and use of spaces, operation of equipment and facilities, and their maintenance pattern are of secondary importance. On the other hand, technical developments and a variety of methods in the field of construction and operation of buildings are of great importance in the field of energy consumption, starting from the building design stage and continuing until the stage of its use and operation.

Architectural solutions are collections of passive design methods, energy efficiency methods, or renewable energy utilization methods that are used in a building to reduce various construction problems and achieve the goal of building design. A set of solutions is used to reduce the total energy consumption in a building (for example, heating, cooling, lighting, plug-in loading, etc.).

In the context of the built environment, the concept and analysis of net energy do not have validated calculation methods. In building energy evaluation, usually only the use of energy in the form of electricity or fossil fuels is considered, without considering other energy sources in the building construction process, such as material production. Some environmental assessment methods, such as Leadership in Energy and Environmental Design (LEED) or the BREEA ESG advisory service, also consider issues such as material selection, transportation, etc (Johansson, 2012). It can be argued that net energy analysis is indirectly used in these methods. For example, reuse and recycling of buildings and products (which effectively saves energy in the extraction, manufacturing, processes, and transportation industries). They are processed by the ranking method (Agharabi and Darzi, 2023).

Due to the great effect of architectural design on the amount of energy consumption of buildings, finding factors that reduce energy consumption and using them in the design of buildings will significantly reduce their energy consumption. In this respect, to reduce energy consumption, building designers should reduce the energy loss in the building.

The investigations conducted on the fabric of biological-native complexes show that humanity been paying attention to the use of non-renewable energies for a long time and by gaining experience over time, has created a method that can be referred to as the background of modern climate design. Experiences show that not paying attention to in modern design means losing a huge part of sustainable quality in design. This has made the recognition and evaluation of climate effects on traditional structures and structures the most important program and priority in reducing energy consumption, using natural resources instead of mechanical systems, and creating a comfortable, healthy, and durable living space. Today, with new and inappropriate constructions in valuable local contexts that have increased the use of non-renewable energy to achieve thermal comfort, the use of local design patterns is emphasized more and more (Aram et al., 2022).

3. Method

The focus of this research is to reduce energy consumption in the building by using passive solutions to reduce energy consumption with high economic justification and to achieve a logical balance between the amount of energy consumption and its production through renewable energy sources and the power grid. The research method is based on a combination of descriptive-analytical methods, causal research methods, and simulation. "The best and at the same time the most convincing method to establish a causal relationship is a careful experiment in which the influence of latent variables is controlled, the concept of actively changing x and observing its effect on y" (Groat and Wang, 2016, p.186).

The testing tool of the research is a simulation by DesignBuilder software, used for thermal analysis of the building and the effect of environmental factors on it. Among the capabilities of this software are the calculation of the cooling and heating load of the building, the effect of passive solutions on the amount of energy consumption, visualization, and quantitative estimation of the effect of solar radiation on the openings and other surfaces of the building. The software can calculate the amount of energy consumption in hours, days, months, and years based on weather information and active and inactive measures considered for the building and help designers make appropriate decisions in the field of building energy consumption based on real information.

The validity of DesignBuilder software has been proven in previous studies and the website of the software[1] demonstrates various examples that attest how the results of the simulation in this software are valid and recognized both by institutes and decision-making authorities of many countries, including the United Kingdom. Among the research that has been carried out using this software, we can refer to Masnadi and Heidari (2010), in which the amount of heat loss of the roof of a building with different structures such as flat roof, double-shell roof, green roof, and roof pond, was calculated and at the end, the appropriate option was selected in terms of the effect on energy consumption and the cost of design.

Aram et al. (2022) also investigated the study of buildings from the point of view of energy consumption, using the software to determine the effect of various architectural factors such as orientation, area of openings, shade, and natural ventilation.

To achieve the goal of designing a building with zero energy, the amount of reduction in energy consumption using passive methods is considered as 3 independent simulation changes:

1. Using thermal insulation and combining it with materials with suitable capacity and thermal resistance according to the climatic conditions.
2. Designing a suitable awning for the openings according to the path of the sun to reduce the cooling load.

[1] https://designbuilder.co.uk/

Taking advantage of natural ventilation according to the principles of Venturi and Bernoulli and the effect of the chimney, taking into account the direction of the wind during the hot season. (The Venturi effect (Giovanni Battista Venturi, 1797) is a direct consequence of the Bernoulli principle. It describes the effect by which a constriction to fluid flow through a tube causes the velocity of the fluid to increase and therefore the pressure to decrease, Venturi effect is a physical phenomenon related to fluid flow. Examples of this phenomenon can be seen in many urban and natural places. For example, when on a windy day, the door of the building is difficult to open, or when walking in a narrow urban channel that is surrounded by buildings, this phenomenon and dynamic effect can be understood. The phenomenon that causes the door to open is called the Venturi effect. This principle is based on the natural tendency of the fluid to equalize the pressure in two or more zones. The Venturi effect is used in buildings for natural ventilation and cooling of the environment).

After these calculations, there is a need to equate the energy produced from renewable energy sources, which are used according to the potentials available on the site, with the energy consumption of buildings in the cooling, heating, lighting, and equipment sectors. In this plan, according to the location of the design site in the urban area and the existing needs, it is connected to the network, and a period of one year was chosen to estimate the statistics and calculation criteria. Another part that is needed in this research is complete climate information in Qazvin City and design based on this to increase energy efficiency in the designed units. For this purpose, various climatic information including sunshine and hours of sun, wind flow, temperature, precipitation, and relative humidity were collected from meteorological synoptic stations of Qazvin province and the design of the building was based on various aspects such as the level of openings, orientation, how to properly use renewable energy, etc.

3.1 Area of study

The site considered for research is in Qazvin City. Qazvin has a population of about 800,000 people and its area is 1423 square kilometers (Agharabi and Darzi 2023). The site is surrounded by residential contexts in the west and south. The northern side of the site is also covered by an open area, which also leads to a residential context. The eastern side is adjacent to a large boulevard and further east there is also a residential town. The presence of open space in the eastern part of this site and its alignment with the direction of seasonal breezes and the prevailing direction of Qazvin wind, especially in summer and also, the location of the site in the northern part of Qazvin, make the area selected for this research of high environmental value (Figure 1).

Figure 1. The scope of the site considered for design

3.2 Climate studies

In the design of a project by the architect, collecting the necessary information regarding the design platform is one of the initial steps to achieve a suitable design. In this research, firstly, the climate information was taken from the statistics and data of Qazvin synoptic stations during the years 2013-2022. Then, to determine the influence of each of the inactive methods in different seasons of the year, the bioclimatic form of the Givoni construction, which is one of the most reliable and best forms, was used to design buildings compatible with the climate of the region. In the construction bioclimatic form of Givoni, information data from the climate, such as relative humidity and average minimum and maximum monthly temperature, are specified in the figure, these data are analyzed and finally the conditions and principles that should be considered for climate design are specified (Givoni, 2011; Shakoor, 2011).

In this research, the mentioned figure is drawn based on the climatic data of Qazvin synoptic station, and the lines of each month were marked on the figure

(1. April, 2. May, 3. June, 4. July, 5. March, 6. August, October 7, November 8, December 9, December 10, February 11, March 12) and according to the definition of different ranges in shape and their overlapping with the drawn lines, suitable passive solutions for Qazvin climate were obtained. In addition, wind flow analysis was also studied to optimize the design of residential buildings (Figure 2).

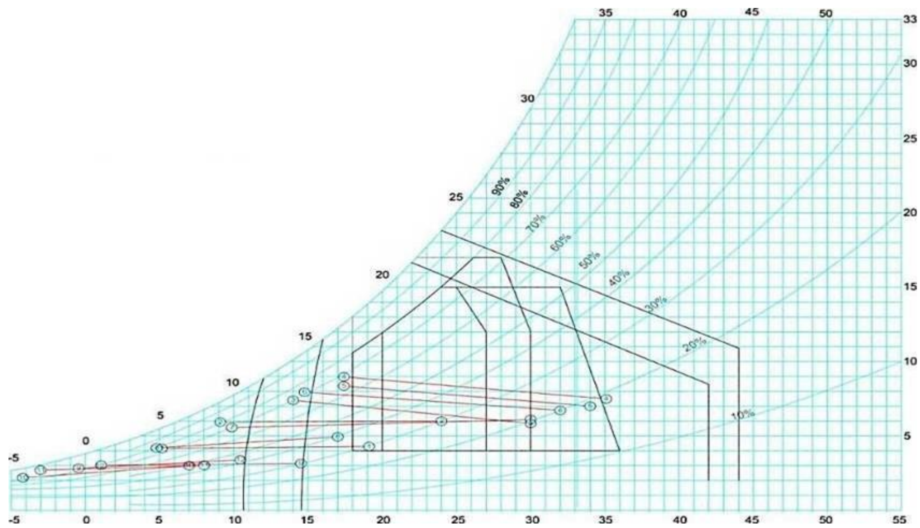

Figure 2. Qazvin construction bioclimatic form

3.3 Givoni table analysis

According to the bioclimatic table of the Givoni building, which was obtained based on the ten-year statistics (2013-2022) of Qazvin airport synoptic station, it can be seen that it is within the comfort zone in the spring and in the mornings in April. Solar heating can also be used, and mechanical heating is sometimes required at night. In May, the thermal capacity of the material is sufficient in the mornings in the comfort zone and at night, and in June, the need for air conditioning is felt to some degree in the mornings, and the thermal capacity of the materials is sufficient at night. During the summer season, during the day, and especially in August, evaporative cooling and drafts of air are needed for cooling, and at night, the outside space is within the comfort zone. It should be noted that it is better to prevent the penetration of the sun's heat into the building during the whole of summer and June. With the beginning of the autumn season and in October, it is in the comfort zone in the mornings, and comfort conditions can be achieved at night using thermal mass. The conditions in November are such that solar heating is needed during the day and mechanical heating is needed at night. Starting from December and throughout the winter, in addition to using active heating systems, solar heating should be used during the day and mangrove capacity at night. In general, according to the obtained information, the design of a building with a climatic approach in Qazvin should be such that in cold seasons it will benefit from materials with high thermal capacity and resistance along with solar heating and in hot seasons, in addition to the use of natural sunlight and evaporative cooling systems, the penetration of the sun into the building should also be prevented.

3.4 Determination of airflow

To obtain the parameters of the wind speed and direction at different times of the year in Qazvin city, the authors collected information by analyzing the 5-year statistics of seasonal Wind rose of Qazvin City (2018-2022) which are available in the quarterly journals of Qazvin Meteorological Organization (Janzadeh & Zandieh, 2022). This is the context and by obtaining information on the predominant direction of the seasonal wind, maximum speed, average speed, and dispersion of wind direction at 6:30, 12:30, and 18:30, the current research tries to design an optimal building for maximum benefit from natural ventilation in summer and protection from cold winter winds by using special measures. Due to the impossibility of including all analytical tables in this section, only its results are stated. According to the obtained information, the prevailing wind direction in all seasons is mainly southeast, while the western wind is also considered the dominant wind in winter, spring, and summer. In the morning hours, in the spring, summer, and autumn seasons, the wind blows from the north and northeast, and in the winter, at noon and in the afternoon, the wind blows from the west and south. The average wind speed in the spring, summer, autumn, and winter seasons is 3.3, 3.2, 3.1, and 3.4 respectively. Moreover, in the early morning the wind is sometimes dominant from the north and northeast. Between 9:30 and 15:30, the prevailing winds are from the southeast, which are more intense in summer, while from 15:30 to 21:30, in summer and autumn, the prevailing winds are from the east and south-east, and winter from the west. In addition, winds with a speed of more than 12 meters per second, which are considered unfavorable winds, generally blow from the southwest and northwest. This can be very important in the orientation of the building and the design of the openings in late spring and summer for cooling through natural ventilation as well as protecting the building against cold and high-speed winds.

4. Results

In this section, we will first discuss the effect of each of the passive solutions considered in this research on the reduction of energy consumption in the building. Then, an attempt is made to provide this reduced amount of energy consumption by photovoltaic cells and solar water heaters. The design considered in this research is a neighborhood unit with a zero-energy approach in a land area of 19,000 square meters in the northeastern part of Qazvin City. This project consists of 8 two-story residential buildings, where two units are designed on each floor in three-bedroom (175 square meters) and two-bedroom (145 square meters) types. Considering the amount of area required for the installation of renewable systems and the lack of space on the roofs for the installation and operation of photovoltaic systems, a part of the site with a size of 500 square meters in the southern part has been considered for the installation of these systems. In this plan, in terms of social sustainability and improvement of visual quality, in addition to designing an open space in the center of the neighborhood unit, which is intended to fulfill communication and emotional needs, as well as encourage sports and physical activities, to reduce atmospheric and noise pollutants and also for air quality and visual beauty, in addition to the green space designed in the center and sides of the site, the existing bodies are also covered with green walls (Figure 3).

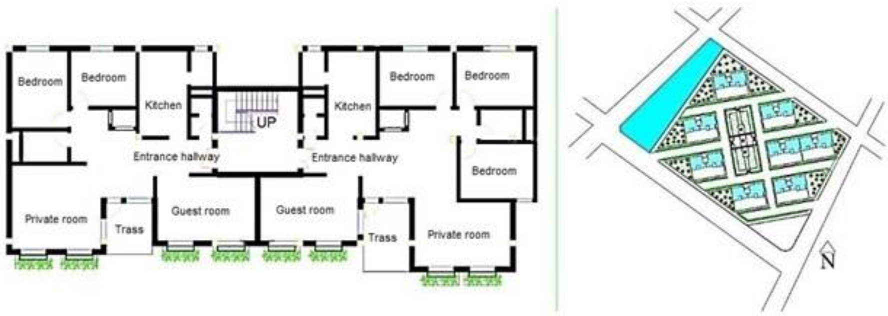

Figure 3. Design site (right), plan of three-bedroom and two-bedroom residential units (left)

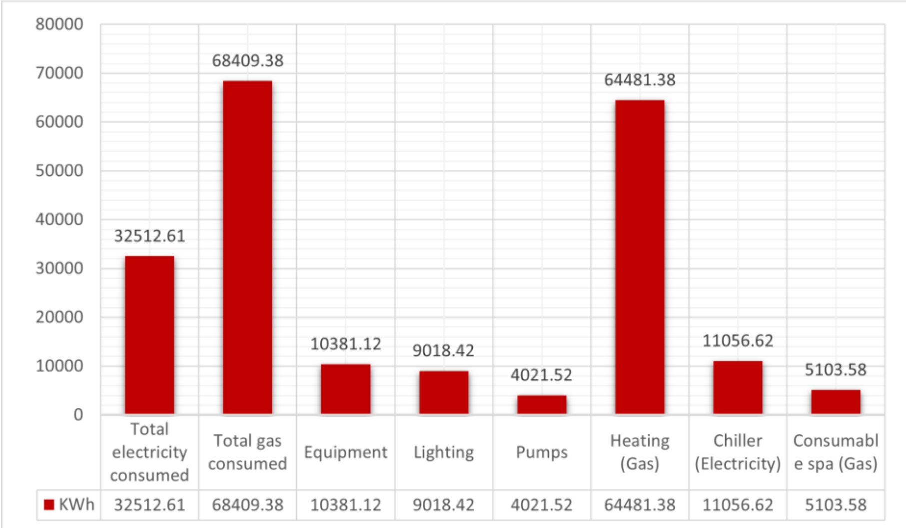

Figure 4. The amount of energy consumed by each section in a residential unit (4 units).

Figure 4 shows the energy consumption of one of the residential units designed in the building with the mentioned conditions, which includes two two-bedroom units and two three-bedroom units, using common materials, without any measures to reduce energy consumption.

To reduce the energy consumption before changing the materials by replacing the fan coil system instead of the radiator system for ambient heating by 25597.03 kilowatt hours (37%), a reduction in natural gas consumption is observed. It is worth mentioning that the fan coil system has been used for cooling, which has good efficiency among cooling systems. Taking this into account, the natural gas consumption of 4 residential units will reach 44591.62 kilowatt hours and the electricity consumption will reach 31804.25 kilowatt hours (Figure 5).

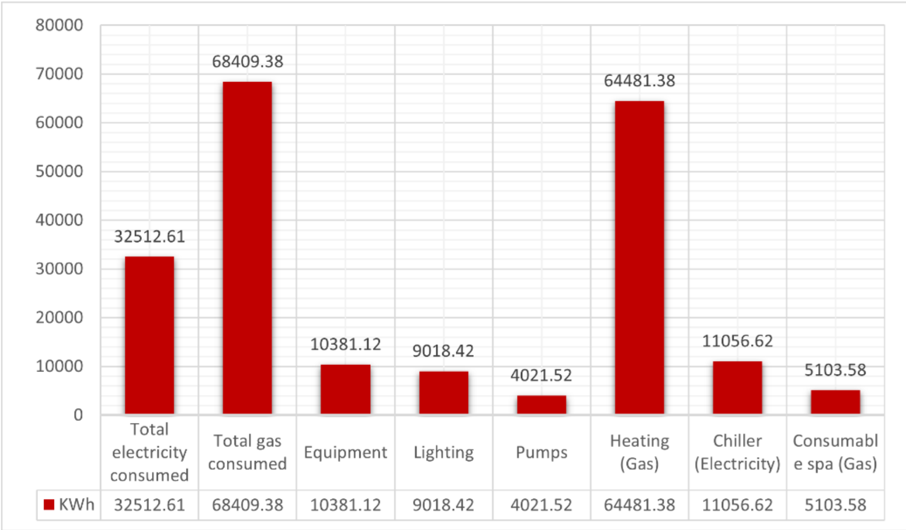

Figure 5. Amount of energy consumed by sections in 4 residential units using fan coils.

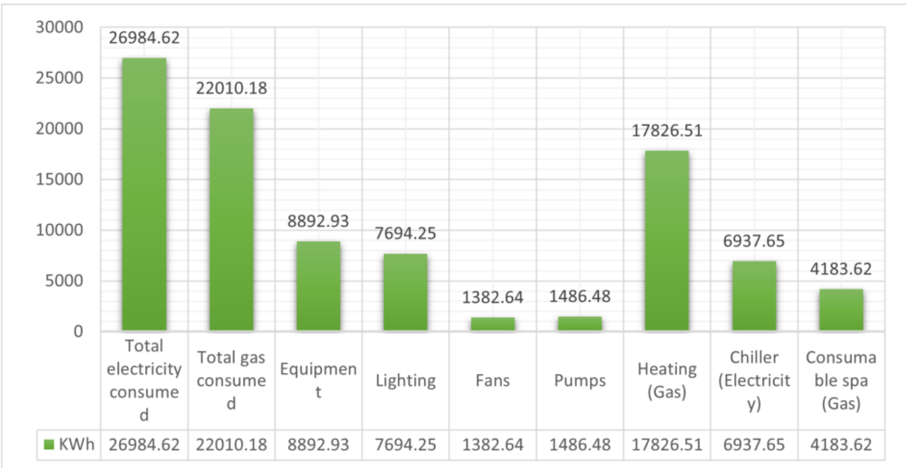

Figure 6. Amount of energy consumed by sections in residential units using thermal insulation and heat capacity of materials.

Figure 6 shows the energy consumption of the building by using materials with suitable heat capacity and using thermal insulation. The walls are made of double-walled walls with Lyca blocks and polystyrene insulation, and the roof structure is block beams with thermal insulation.

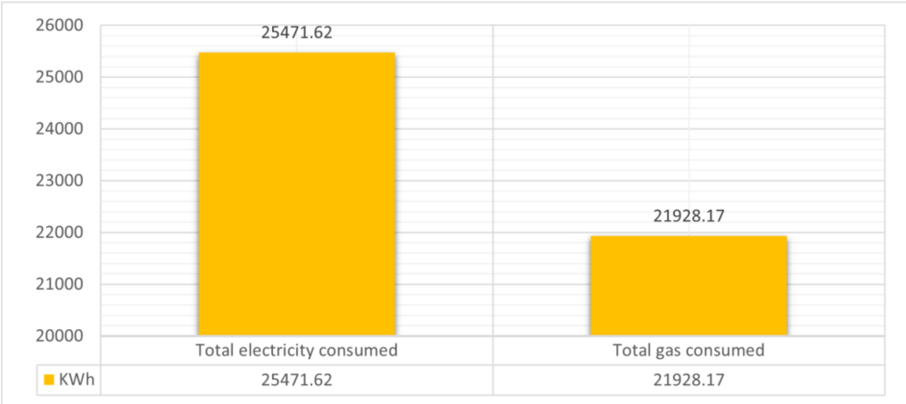

Figure 7. Annual energy consumption using the awning.

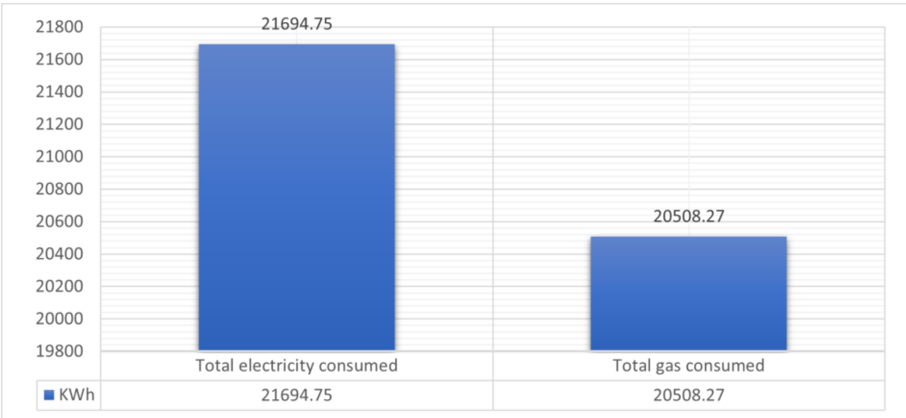

Figure 8. Energy consumption of residential units (3 units) using natural ventilation and awning.

In the next step, the effect of the two variables of awning and natural ventilation was evaluated in order and a stepwise manner on the reduction of energy consumption, the results of which are shown in Figure 7 and 8. The specifications of each variable are as follows:

- Awnings are placed on all the windows of the south wall, which according to Watson's table (Watson and Labs, 1983) have dimensions of 1.6 x 1.5 meters, with a depth of 0.80 and a width of 2.10 meters, according to the simulation data in DesignBuilder software. During the hot period (June 15 to August 15) open the glass surface is open so that 90% is covered by awning. This is important for the cold period (December 15 to February 15) where it covers less than 2%.

- Natural ventilation has been created both through the transverse and through the chimney effect to reduce the cooling load. In such a way that the air enters the ventilation channel from the lowest level of the building, i.e., the pilot, which has the highest positive pressure, and from the end of the channel, which is due to the venturi effect by two valves located opposite each other, and also has a higher temperature than the lower levels. The building has the highest negative pressure in the entire channel chamber, and it exits. This pressure difference creates an upward airflow in the building, which causes the suction of the incoming airflow from the openings into the building. It is worth noting that the use of natural ventilation in these buildings is only for the hot period and in the cold seasons the valves of the ventilation channels are closed.

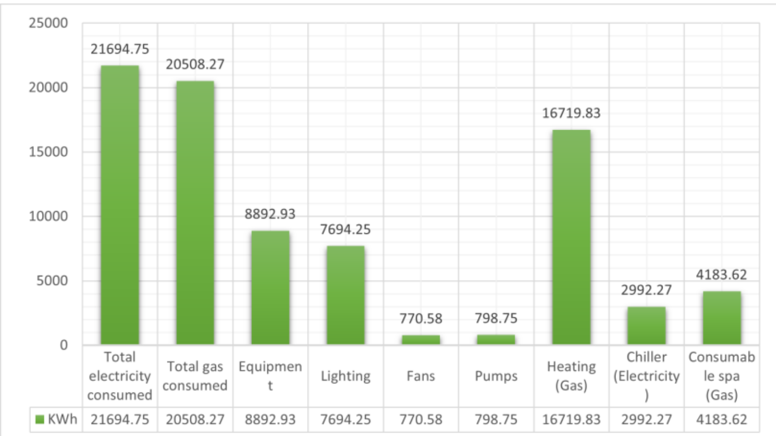

Figure 9. The amount of energy consumption in residential units (4 units) after the application of passive solutions by sector.

During the hot period energy was exported to the energy network and the amount of energy needed for heating that uses natural gas was purchased from the network. In other words, it can be sent to the national power grid during the hot season when the amount of electrical energy produced by the photovoltaic panels exceeds the needs of the buildings in the neighboring unit and, instead, in the cold season, the same amount of natural gas from the energy grid to meet the heating needs of the buildings can be received. For this purpose, to create a balance between the electrical energy exported to the network and the natural gas received, which is from the available data and the use of solar water heaters equal to 15,5429.1 kilowatt hours per year for the existing 8 buildings, it is necessary to use 395 photovoltaic modules. In this case, 850 modules are generally required for 32 existing residential units, and these modules are placed in the form of photovoltaic arrays on the roofs of buildings and the place designed for their deployment on the southeast side of the site (Figure 9).

5. Discussion and Conclusion

We believe this research can be a step towards institutionalizing zero energy buildings in the city of Qazvin and even at the level of Iran as a whole. The solutions presented in this article, including the use of fan coil systems for heating residential spaces, lead to a 37% reduction in energy consumption compared to the radiator system. Moreover, using thermal insulation and materials with high thermal capacity, using suitable awnings and also using suitable benefits and the principles of natural ventilation in the hot season, reduce energy consumption by 35%, 3.4%, and 14%, respectively.

Another important point discussed in this research is the possibility of providing energy to residential units after using passive solutions to reduce energy consumption by using renewable energy systems in such a way that using 457 photovoltaic modules of 265 watts and 26 solar collectors can meet the electricity and hot water needs in 32 residential units (8 buildings with 4 units).

In addition, if 850 photovoltaic modules are used according to the potentials in the design site and the planned locations for the installation of these systems, it is possible to export electricity to the network equal to the amount of natural gas needed for environmental heating. Finally, according to the definitions in the field of zero-energy buildings, a zero-energy system connected to the grid with an annual energy balance was achieved in the form of a neighborhood unit. It should also be mentioned that in this research, the maximum number of modules can be reduced by improving the efficiency of cells and using modern systems, which is also true of solar hot water systems.

One of the important obstacles to achieving the goal of this research is the high cost of benefiting from solar energy systems. It is hoped that by making appropriate decisions in this regard by politicians and officials, it will be possible to see an adjustment and justification of costs in this sector.

Achieving a suitable model in the field of reducing energy consumption in one of the main consumer sectors, i.e., housing, can be considered as one of the most important and strategic issues today in Iran, as in other countries. Therefore, the promotion and development of projects such as the one proposed in this research in the form of a neighborhood unit can imply progress in the direction of preserving the environment and consequently saving energy consumption and increasing national incomes in addition to improving the quality of life in urban environments.

The principal feature of this study is the passage from theoretical to practical steps proposed in the field of zero-energy buildings, which requires a comprehensive change of attitude towards extending research of this kind and it requires far more support than is available today. If achieving sustainable energy seems possible due to the increasing progress of technology, it is important to have international support, determine the priorities of economic policies, attract foreign financial resources, and promote the participation of the private sector in investment, while also extending educational and research programs. If realized, this process can guarantee national interests in the international strategic environment in achieving sustainable energy and sustainable development, preventing pollution caused by the combustion of fossil fuels and enhancing the development of remote areas.

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