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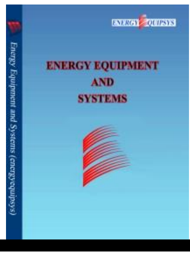

Sensitivity analysis and energy optimization in residential complex in warm and semi-humid climates of Iran (Dezful)

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ABSTRACT

Building energy optimization based on sensitivity analysis, considering all parameters influencing energy consumption, has not been so far implemented in Iran. Among the few previous works in this line, only one or two factors have been investigated. Thus, the present study can be introduced as the most complete one of its kind. To this end, the researchers first simulated energy consumption in a building located in the city of Dezful, southwestern Iran, with a hot and semi-humid climate, through the Quick Energy Simulation Tool (eQUEST) to illustrate thermal load for an assortment of important parameters. Then, they extracted some relationships using the SPSS Statistics, to connect energy (namely, electricity and gas) used in the building with the factors concerned. Finally, validations were performed to check the results via converting the data into neural networks and employing a genetic algorithm (GA) at each level of the study. The error between the software results and the annual gas bills was 9.2% and the error between the regression function and the measured values was >1%. Moreover, optimization error was about 4.3%. The results demonstrated that equipment power density and heating system efficiency were respectively among factors that could significantly affect electricity and gas consumption rates in buildings located in the climate in question.

Keywords: Sensitivity Analysis, Energy Optimization, Residential Complex, Hot Climate, Dezful, Iran.

1. Introduction

Energy conservation is now recognized as one of the most significant challenges in the world. Over recent years, growing concerns about environmental consequences of energy consumption and global warming have also doubled the importance of this point; therefore, fundamental steps have been taken in nearly all industrial countries in recent decades to change consumption patterns using different tools including the development of rules and regulations. In this respect, the building sector is consuming about 40% of available energy and producing 30% of the world's greenhouse gases. Respecting the undeniable role of energy in the development and economic cycle of a country along with the limited energy resources and given the remarkable share of energy produced in a country spent on cooling and heating for residential buildings, addressing

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methods for reducing energy consumption and achieving optimization is today a necessity in each country [1]. Energy consumption in buildings is on the rise due to a variety of factors such as climate change, increase in household energy consumption, growth in the real estate sector, diversity of modern home appliances, variations in industry structure, excessive energy consumption in current buildings, as well as inadequate government oversight. Therefore, efforts to control and manage energy consumption are of utmost importance [2]. Despite the magnitude of this issue, intensifying day-by-day, not much work has been thus far performed in this field in Iran. Among the studies fulfilled in this line, only one or two influential factors have been examined.

In the present study, all the parameters affecting energy consumption in a building are considered and the role of each one is correspondingly determined using weight coefficients. The relationships that link heating and cooling energy consumption in the building to the effective parameters are then obtained, and at the end, the given parameters are chosen so that the energy consumption of the building is optimized. The results of this research can be exploited by architects, civil engineers, and facility engineers to design, build, and estimate building energy consumption in buildings in the climate in question (i.e., hot and semi-humid). In general, all institutions and organizations working in the building sector, such as the Construction Engineering Organization (CEO), municipalities, and the Department of Environment (DoE), can benefit from the study results. The innovations of this research can be summarized as follows:

- Determining parameters affecting energy consumption in a building
- Extracting experimental relationships between building energy consumption and effective parameters
- Selecting parameters influencing energy consumption in a building to optimize it

2. Research Background

With reference to the latest data on energy consumption, in commercial and residential buildings, around the world, Allouhi [3] had concluded that it was necessary to make decisions and policies and to manage the energy sector in buildings in a fundamental manner. Ornetzeder [4] had further discussed relationships between energy consumption patterns and users' levels of satisfaction, comfort, and well-being. As elaborated in their results, even low energy consumption in office buildings could create a high level of well-being. Moreover, Sekki et al. [5] had reported that newly established buildings could consume less energy but electricity consumption could increase as the lifespan of the buildings was added. Ashrafian et al. [6] had analyzed three buildings with the same geometry but properties of different envelopes in three climatic regions in Turkey, indicating that the materials of the walls and the types of climates could have a great influence on the heating and cooling performance of the buildings.

Another study in Seoul by Jang [7] had used 96 apartment blocks as the sample and had examined residents' behaviors along with the performance of electrical appliances and lighting. The results had represented that residents' behaviors and performance of the appliances and lighting were among factors affecting energy consumption in buildings. Modeling a building's information for a duplex country house in Johor, Malaysia, Shoubi [8] had similarly settled that shapes and conditions of materials used in a building were the most influential factors in the amount of energy consumed in a building. Raji et al. [9] had comparably modeled the information of an office building in the Netherlands using the specialized design of the Builder (BU) software to analyze the effect of four parameters viz. window type, glass-to-wall ratio, canopy type, and roof type on energy consumption in the building concerned. In addition to determining the impact of the given parameters on energy consumption in the building, they had developed an optimal design for the building envelope. Exploring the effects of eight different types of windows on heating, cooling, and lighting energy savings, they had found out that the window inside the building (namely, two layers of clear glass with a middle layer of air) and that outside the building (i.e., transparent single-layer glass) had the most significant energy-saving effects (7.5%). Besides, the influence of the window-to-wall ratio had been investigated. Generally, the higher the ratio, the more the brightness and the more heat energy of the sun received during the day. Moreover, entering more energy into the house during the day in winter would lead to the loss of more heat energy. In another section of the research, different types of canopies had been analyzed and simulated. Accordingly, using canopies with electro-chromic glasses could conserve the most energy in the building. At the end of the study, four different types of roofs had been also examined and simulated.

In high-rise buildings, the effect of the roof on the amount of energy consumed decreases based on the height of the building and the number of floors. In a study, Alaidroos et al. [10] had surveyed how to improve the energy performance of residential buildings in Saudi Arabia through optimizing design parameters associated with building envelopes. These parameters included wall insulation, roof insulation, window-to-wall ratio, window transparency, and type of canopy installed on windows. Optimization had been additionally completed based on reducing costs and saving more energy. This had been done for five different climates in Saudi Arabia and a villa residential building had been accordingly modeled on the EnergyPlus software. Their research had revealed that the percentage of energy savings could increase by augmenting the thickness of the insulation installed on the exterior walls and the roof of the building. The solar heat gain coefficient (SHGC) had further indicated the amount of energy absorption from the sun, which could heavily depend on the transparency of the glass. The lower the factor, the better it was in hot and cold climates. The U-factor VAVE3 could also vary based on the thermal conductivity of the glass. In other words, the lower the glass, the better the thermal insulation. Their research had also represented that the higher the protrusion of the window and the thickness of the outer walls, the greater the percentage of energy storage.

Furthermore, You et al. [11] had shown that window size was an important factor in building energy consumption in some climates. Solar radiation penetrating directly into buildings through windows could thus greatly affect heating and cooling load. Zhao et al. [12] had similarly examined fundamental parameters in the design of tall buildings and their impact on cooling and heating energy consumption, in different climates in China (i.e., 18 cities with five different climates). They had realized that as the inlet air rate of seams and windows was augmented, the consumption of heating energy could increase, the cooling energy could remain almost constant, and the total energy could be amplified in all climates. As the thickness of the wall and its insulation increased, the consumption of heating energy could decrease, the cooling energy could remain roughly constant, and the total energy could reduce. To such an extent the window heat-transfer coefficient increased, the heating energy could enhance, and the cooling temperature could remain constant. As the window glass-absorption coefficient increased, the heating energy could also remain constant, and the cooling energy and total energy could go up. Their research had ultimately confirmed that the best direction to minimize building energy consumption, whether heating or cooling, was the south direction. Changing the direction of west and east, the total energy of the building would also rise by 5%. Statistical analyses by Jia and Lee [13] had further disclosed that factors influencing energy consumption in cooling systems in Hong Kong were window-to-wall ratio and overall heat-transfer coefficient of the walls.

In this vein, the genetic algorithm (GA) refers to a search technique to find an approximate solution for search engine optimization and issues. The given algorithm is a special type of evolutionary algorithm that uses biological techniques such as inheritance and mutation. GAs and neural networks are widely employed today in optimizing various industrial systems. Using a multifunctional GA, Chen et al. [14] had respectively boosted the output power and the efficiency of a thermoelectric generator to 5.4% and 51.9% and had concluded that the multifunctional GA was a powerful tool for designing the geometry of a thermoelectric generator to achieve maximum efficiency and its best performance. Habibollahzade [15], investigating the effect of performance parameters, energy, and energy indicators on photovoltaic/thermal panels, had further obtained a system by multi-objective optimization via a multifunctional GA.

It should be noted that the use of GAs and neural networks to moderate energy consumption in buildings has become popular in recent years. For the first time, González [16] introduced a neural network to predict hourly energy consumption in a building. The performance of this neural network in predicting temperature and energy consumption was then compared with actual values, which were very accurate. Bogdan et al. [17] also compared the results of such an algorithm with experimental data. The parameters they selected were ceiling, exterior walls, windows, as well as sunlight from ceiling, walls, and windows. Karatasou and Santamouris [18] correspondingly designed a neural network to predict energy consumption in a building, which had predicted energy consumption hour-by-hour. In a survey comparing actual values of an office building in Greece, it had been suggested to work with great precision. Naji et al. [19] further estimated energy consumption in a building through artificial intelligence using the extreme learning machine (ELM). They had first performed various simulations for different thicknesses and insulations of the building through the Energy Plus software. For this purpose, a total number of 180 different simulations had been conducted for different thicknesses and insulations of the building, then the answers obtained from the GA and the neural networks had been compared with the ELM based on those simulations. Likewise, Ruiz et al. [20] designed a neural network to predict energy consumption in public buildings. They had also combined the network with a GA to save energy, to improve energy efficiency, and to optimize intelligent building systems without affecting residents' well-being, aimed to improve the results of previous studies.

In a joint effort, Caldas and Norford [21], from the University of California and the University of Massachusetts, utilized a multifunctional GA to optimize energy consumption in a building. The parameters concerned were determination of size and location of windows on walls, the composition of building walls, building envelopes, as well as design of heating, ventilation, and air conditioning (HVAC) systems. Additionally, Magnier and Haghighat [22] employed a neural network to study the behavior of a residential building and then combined it with a GA to optimize its energy consumption. In a joint study, Pornkrisa and Chaiwi [23], recruiting a multifunctional GA, selected initial costs and energy consumption as target functions and reflected on the effect of time parameters during the day, envelopes, and window-to-wall ratio on the building. In this study, different parts of Thailand including administrative, medical, educational centers as well as hotels and hypermarkets had been surveyed. Different neural network algorithms had been also compared for predicting library energy consumption in China in another study by Li et al. [24]. To find a suitable way to reduce energy consumption, Giancola [25] similarly conducted a study on buildings located in hot and dry climates of Madrid, Spain, to reduce energy consumption and to provide cooling and thermal comfort for residents of buildings in such climates. This study had evaluated and had optimally developed the parameters involved in the design of building envelopes and had obtained positive results in saving energy consumption in a building before cooling.

The simultaneous use of electricity and heat generation systems is one of the most effective ways to lower energy consumption rates. Electricity generation from renewable sources should be thus maximized on-site to minimize consumption. In a study by Kyritsis [26], examining energy in office buildings in southern Europe and comparing them with other buildings, it had become clear that energy production at the site of its use was an effective step in saving money as well as reducing consumption and waste. Sameti and Haghighat [27] further used a mathematical programming method and optimized a simultaneous system for generating electricity and heat by considering cost function as a target one for seven residential and office complexes in four different scenarios in a new part of Suurstoffi neighborhood in Switzerland, so that annual energy costs had been minimized by up to 40%.

The approach developed by the European Union to decrease energy consumption is also to build zero-energy buildings. For example, Goggins [28] examined the implementation of EU guidelines for the construction of zero-energy buildings in Ireland. For a country like this, with a temperate-oceanic climate, one way to achieve such a building was to compress the air in envelopes. In this regard, Jin [29] surveyed a residential building in China with the ability to meet the average needs of a family and the thermal simulation of the interior and the geometry of the building. He finally estimated the electrical energy required by the sun and hot water collectors for this building as well as the hardware and software needed to achieve a building with zero net energy consumption. Accordingly, positive results were obtained for the development and use of this technology as much as possible.

Moreover, building materials can be one of the factors affecting energy consumption in a building. In this regard, Payá [30] compared two buildings with the same geometry and direction but different materials. One building had been made of wool and the other one had a lattice structure. The results of this study revealed that energy consumption in buildings made from wool was 7.3% lower than other buildings due to better insulation in summer. Installing smart systems is thus one of the standard requirements in residential buildings. In smart buildings, environmental benefits and energy savings are thus expected to be taken into account. However, problems such as sensor failure and controller strategy defects may lower performance and increase power consumption [31].

Another way to reduce energy consumption is to apply special insulations in the structure of buildings. Vacuum insulated panels (VIPs) are currently one of the most effective thermal insulation solutions with high performance in the global market. The performance of such panels is from three to six times better than air [32]. For instance, Ibrahim et al. [33] investigated the effect of thermal insulation thickness of a building on the amount of energy savings and related costs. To do this, they used a special type of insulation called silica aerogel and tested it in a laboratory-made building in France. Then, considering the parameters of energy consumption reduction at the same time to reduce the costs, they determined the optimal thickness for the mentioned insulation, in the range of 4.4-1.7 cm. The return period of the capital would be in the range of 2.7-1.4 and will be used in accordance with the climatic conditions of the region. Using the DesignBuilder software, Ran et al. [34] further found that designing a green roof was one of the ways to optimize energy consumption in a building in Shanghai, China, which could reduce energy consumption up to 26.7%. Horn et al. [35] also achieved a significant reduction in building energy consumption via a combination of modifiers in the outer shell of buildings. The use of phase change materials had accordingly saved thermal energy and mitigated energy consumption.

Song et al. [36] correspondingly employed the Quick Energy Simulation Tool (eQUEST) to import the actual information and specifications of an office building into the software and to simulate it in order to determine the effect of different variables on building power consumption. The concrete and rectangular building was a part of a university library in northern China, whose plan had been consequently drawn and simulated in the eQUEST with a slight simplification. After analyzing the simulation results, the findings had revealed that the highest power consumption rates had been equal to 872000 kWh in June and the lowest ones had been 327300 kWh in February, which was only 37.5% of electricity consumption in June. As well, the energy consumption of lighting equipment had been calculated as a large proportion of the total energy consumption of the building. Based on the simulation information, a linear regression had been established between light intensity (namely, equipment power density) and annual power consumption. Additionally, the highest energy consumption rate in the university library building was respectively related to the energy consumption of the air conditioning system, the lighting system, and the power consumption of other equipment, equal to 49%, 35%, and 16% of the total energy consumption of the building.

In this regard, Mottahedi et al. [37] proposed a model of multivariate linear regression, suitable for predicting building energy consumption, in two different climates of the United States in altered building envelopes. In this study, they examined seven different shapes (i.e., envelopes) of the building (including shapes: H, T, rectangles, etc.) and utilized the eQUEST to simulate and then analyze it statistically. Multiple linear regressions were also employed to predict energy consumption for each climate. Regression coefficients had shown how annual energy consumption in a building could increase or decrease based on the selected building envelopes (depending on the sign and the value of regression coefficients). The results of this study had further demonstrated a remarkable relationship between building envelopes, climate, and energy consumption rate. It had been also reported that the main parameter in energy consumption in cold and dry climates was related to heating in a building space, while there was not much difference between heating and cooling uses of a building in a warm coastal climate. T-shaped buildings also had the highest energy consumption in both climates. Finally, they had found that regression models could be exploited to estimate total energy consumption at the early stages of design, considering various building parameters (including envelopes and other design parameters).

3. Research Method and Statement of Problem

In this study, there were attempts to reflect on all factors affecting energy consumption in a building as much as possible, to determine the role of each one depending on the software ability using weight coefficients, and to optimize it via the obtained results. This study aimed to find factors with the greatest impact on energy consumption in a residential building in hot and semi-humid climates and the role of each factor in energy efficiency to reduce energy consumption. The main approach in this study was to use simulations, so the eQUEST was selected to achieve this goal. This software was chosen based on its special capabilities in analyzing the energy of a building as compared to similar software, its new and academic nature, as well as its comprehensiveness in terms of focusing on all factors that affect building energy consumption. The eQUEST also contains an analysis of compliance with the California Energy Code, namely, the Energy Efficiency Standards for residential and non-residential buildings, new construction, remodels, and additions [38]. As the software has been widely employed around the world over the past two decades, the accuracy of its calculations and results can be assured. In this software, the climate data of cities in different countries, including Iran, can be also used in TMY2 format. The simulation process in this software is additionally proportional to the basic and effective parameters in building energy consumption, which includes 50 steps e.g. city in which a building is located, type of building use, and the total area of infrastructure. As well, choice of cooling and heating equipment, the geographical direction of a building, number and height of floors, as well as details of ceilings, floors and walls e.g. colors, materials, insulations, amount of penetration, and air discharge are among other parameters. Details of doors and windows including dimensions, materials, areas of glasses, sizes, and type of awnings, curtains, or shutters installed, place of doors and windows relative to the sun, maximum number of people present in each room, amount of fresh air supply for each person, lighting and equipment, and so on are also listed in this respect. In most research studies, there is a large amount of data, which includes a large volume of calculations. Therefore, it is necessary to use suitable statistical analysis software such as the SPSS Statistics, as one of the most popular and powerful software.

There are three basic steps in data analysis using the SPSS Statistics. First, the raw data are imported and stored in a file. The required analysis is then selected and called, and finally, the desired results and outputs are chosen for evaluation [39]. In this section, the information and the results were obtained from changing various parameters affecting energy consumption of the building using the eQUEST in the previous step, as a matrix (155 rows in 21 columns, the first 19 columns are independent variables and the last two columns are related to dependent variables). They were created in an Excel file and entered into the SPSS Statistics. The purpose of using statistical analysis performed by this software was to generalize the results of research observations in its selected sample to the main population, done by a regression model of multivariate linear type. It is of note that, this type of regression has the ability to examine the effect or non-simultaneous effect of all independent variables on the dependent variable and to calculate the extent of this effect (namely, weight and impact factor of each parameter). To do this, first, the conditions and the considerations related to the use of regression were evaluated according to the number and the nature of the research data and then the regression coefficients were determined until the final regression model, as a separate multivariate linear equation for electricity and gas consumption, was achieved. The parameters examined in this study are shown in Table 1. As well, Table 2 illustrates the specifications of the building in question in this study.

Table 1. Variable parameters provided by eQUEST

x_1	Ceiling insulation
x_2	Floor insulation
x_3	Exterior wall insulation
x_4	Concrete thickness of the exterior wall
x_5	Window height
x_6	Type of glass
x_7	Protrusion of canopy above the window
x_8	Protrusion of side partition of window
x_9	Daylight sensor
x_{10}	Optical power density
x_{11}	Equipment power density
x_{12}	Thermostat cooling temperature management
x_{13}	Thermostat heating temperature management
x_{14}	Pressure difference caused by HVAC system fans
x_{15}	Cooling system efficiency
x_{16}	Heating system efficiency
x_{17}	Hot water temperature consumed by gas
x_{18}	Hot water temperature consumed by electricity
x_{19}	Fresh air drainage and supply

Table 2. Characteristics of the building examined

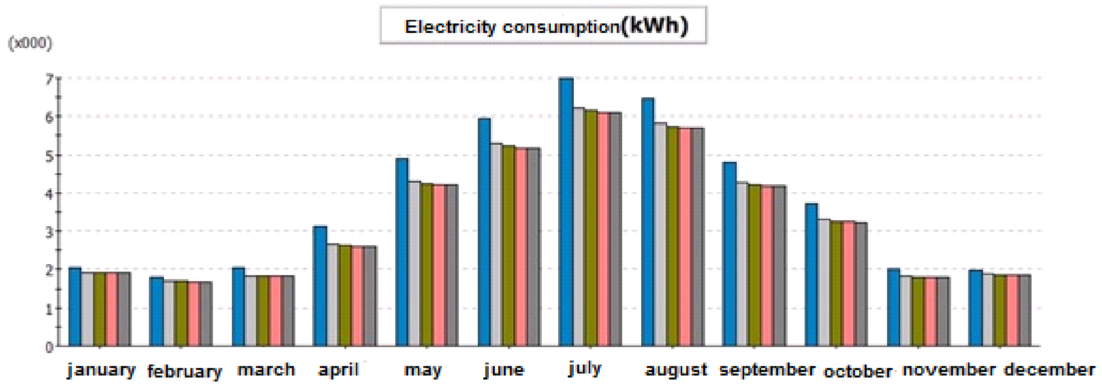
Type of building use	Residential
Number of stories	Two units of a three-story building
City and climate region	Dezful: hot and semi-humid
of useful infrastructure Area	4618 ft^2
The orientation of wall with window	Westside
Number and area of each window	6 ftx4.25 ft -2 for each floor
Plan dimensions	44 ft × 37 ft
Building structure	The upper three floors are above the parking lot, each floor has two isomorph units, and the surrounding of the construction is connected to the open air.
Floor-to-floor height in each story	10 ft
Floor-to-ceiling height in each story	9.5 ft
Roof shape	Flat roof with no attic
Cooling equipment	Direct expansion (DX) coil system (gas split cooler)
Heating equipment	Furnace (torch)
The geometric shape of the building (plan)	Corners (44 ft × 36 ft with a smaller side comprising the front door and windows
Roof structure	From inside 1-inch thick plaster, 6-inch-thick concrete pitch-black outer coating, internal and external lack of insulation

Exterior wall structure	Inside plaster (1 in), concrete (4 in), the outer coating of aluminum foil, inner and outer lack of insulation
Ground floor structure	Parking top, inside the ceramic array, 10-inch-thick concrete, without interior and exterior insulation
Air penetration	For central and peripheral areas of both buildings, 0.5 frequency of air change per hour (ACH)
Middle floors	6-inch thick concrete with 1-inch plaster inner coating, ceramic coating, no insulation
Building doors	Matte-type metal entrance with a central layer of polyurethane on the west side of the building 6 × 6.7 ft^2
Type of glass	6mm rubber PPG single-wall glass, VT:0.91 U-Value:1.03-SHGC:0.9
Window dimensions	Aluminum frame-type without insulation and 1.5-inch frame width, floor height threshold 3 feet, and dimensions of each window 6 × 4.25 ft^2
Number of windows per floor	2
Skylight	No
Usage and usage hours	Residential, residents attend from 7 pm to 7 am, 3.5 people per unit
Internal uses	Indoor lighting, cooking and other equipment (including refrigerator, freezer, TV, hairdryer, and washing machine)
External uses	Consumed hot water
Adjusting air conditioning system	Both the heating and cooling systems have automatic adjustment, no economizer (saving)
Thermostat temperature	It is 78°F for the cooling system and 68°F for the heating system
Project temperature	It is 75°F for the cooling system and 71.6°F for the heating system
Air conditioning operation hours	Saturday to Wednesday, 7 pm to 7 am, Thursdays 2 pm to midnight, Fridays and holidays non-stop
Consumed hot water	It is provided by a gas water heater with an output temperature of 120°F and 2.5 gallons per day per person

4. Data Analysis

4.1. EQUEST Analysis

First, using the eQUEST, information about energy consumption (i.e., electricity and gas) in the building concerned was obtained in the baseline, and then each parameter was changed only to examine its effect on heating and cooling energy consumption in the building via altering the parameters. With the help of this information, statistical analysis and regression were fulfilled and the role of each parameter as well as the relationship between effective parameters and energy consumption in the building was determined. Finally, energy consumption in the building was optimized using a GA. It should be noted that the eQUEST offers variable parameters in an Energy Efficiency Measure Wizard to change the parameters and the components of a building and to observe changes in building energy consumption. These parameters were a total of 19 for the building model in this research. Considering the multiplicity of these variables, characterizing the extraordinary ability of the software, the present study is the most complete research of its kind completed so far in Iran. As an example, the results of roof insulation changes in five different implementations are illustrated in Figs. 1 and 2. Figure 1 shows that, by increasing the thickness of the roof insulation from non-insulated to 14 inches of insulation, electricity consumption is also reduced, which is higher in the warmer months of the year due to higher electricity consumption rates. As well, Fig.2 depicts that, adding to the thermal insulation of the roof insulation can slightly augment the gas consumption rate, which is higher in the colder months of the year. This occurs due to reduced absorption of conductive heat transfer due to the sunlight on the roof; therefore, the lower the angle of the sun, the more the differences in the results. The numbers in Table 1 below show power consumption in terms of one thousand kilowatt-hours and those in Table 2 represent gas consumption in terms of millions of the British thermal unit (BTU) in different months of the year and throughout the year. Besides, similar diagrams are obtained for other parameters.



		january	february	march	april	may	june	july	august	september	october	november	december	total
1	executive	2.05	1.80	2.03	3.14	4.89	5.94	6.99	6.47	4.79	3.71	2.00	1.99	45.79
2	executive	1.93	1.70	1.83	2.67	4.31	5.29	6.24	5.81	4.27	3.31	1.81	1.88	41.06
3	executive	1.92	1.69	1.82	2.63	4.26	5.22	6.16	5.74	4.22	3.27	1.81	1.87	40.61
4	executive	1.92	1.68	1.82	2.60	4.23	5.18	6.11	5.70	4.19	3.24	1.80	1.87	40.34
5	executive	1.91	1.68	1.81	2.59	4.21	5.17	6.10	5.69	4.18	3.23	1.80	1.86	40.24

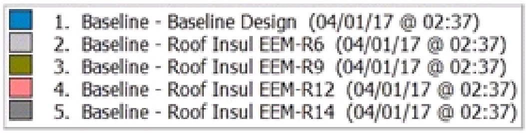
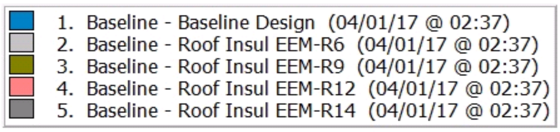
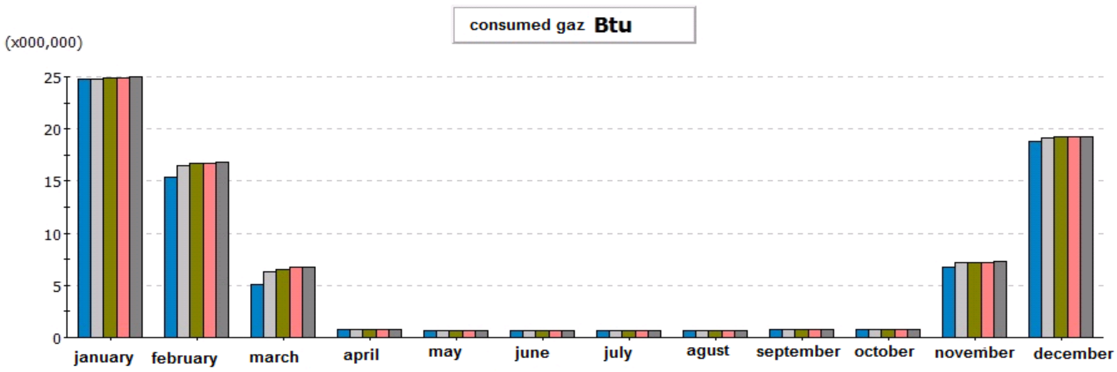


Fig.1. Power consumption results using changes in roof insulation parameter





														Total
1	executive	24.73	15.43	5.11	0.83	0.67	0.66	0.67	0.69	0.73	0.81	6.74	18.85	75.91
2	executive	24.83	16.54	6.35	0.83	0.67	0.66	0.67	0.69	0.73	0.81	7.18	19.17	79.11
3	executive	24.90	16.68	6.57	0.83	0.67	0.66	0.67	0.69	0.73	0.81	7.21	19.23	79.63
4	executive	24.94	16.76	6.70	0.83	0.67	0.66	0.67	0.69	0.73	0.81	7.24	19.27	79.95
5	executive	24.96	16.79	6.76	0.83	0.67	0.66	0.67	0.69	0.73	0.81	7.25	19.28	80.09

Fig. 2. Gas consumption results using changes in roof insulation parameter

4.2. SPSS Statistics Analysis

In this step, the information and the results obtained from changing 19 different parameters of the building using the eQUEST in the previous step are created as a matrix in an Excel file and introduced to the SPSS Statistics analysis. In the multivariate regression analysis, each record also has different values in several independent variables and one dependent variable. A predicted dependent variable is further obtained by a linear combination of several independent variables. The linear composition, or the resulting regression according to the following equation is

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n \quad (1)$$

In this formula, β_1 to β_n are slope coefficients for variables x_1 to x_n and β_0 refers to a constant value. Values β_1 to β_n are additionally calculated so that the values of the actual dependent variable (y) and the values of the predicted dependent variable ($\hat{y}$) are as close to the sample data as possible. The basic condition for using a linear regression equation is the existence of a meaningful linear correlation between independent and dependent variables. A multivariate correlation coefficient is also utilized to examine this condition. A suitable indicator for determining the correlation between two quantitative variables is the Pearson correlation coefficient. The coefficient for the statistical population is defined as

$$r_{xy} = \frac{\overline{x.y} - \bar{x}.\bar{y}}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}}. \quad (2)$$

In Eq. (2), $\bar{x}$ is the mean of independent variables and $\bar{y}$ stands for the mean of dependent ones. The up-line of the variables also shows their average. The correlation coefficient is always between negative one and positive one [40].

It should be noted that the correlation coefficient test is done to make sure that the correlation between two variables is not by chance or accidental, and there is enough proof for further correlation investigations. If the correlation coefficient is close to 1 or -1, the regression line on data is proper as an appropriate model but if it is near to zero, the fit of the regression line will be low as an inappropriate model. In this respect, the coefficient of determination is the square of the correlation coefficient and represents what percentage of dependent variable changes is explained by independent variable ones. The problem of the coefficient of determination is that it cannot change as much as necessary by adding some dependent variables, so it is better to report the adjusted coefficient of determination along with the coefficient of determination. This coefficient is accordingly adjusted based on the number of independent variables and indicates a more realistic value, achieved by

$$r_{adjust}^2 = 1 - \frac{(N-1)(1-r^2)}{N-P-1}, \quad (3)$$

in which r^2 refers to the coefficient of determination, N is the number of total observations, and p indicates the number of predictor variables [40].

The results of regression analysis for electricity power consumption are illustrated in Table 3. The adjusted correlation coefficient for the model is also 0.9736, elaborating that more than 97% of annual variations in electricity consumption can be determined by its linear relationship with the predictor variables, which is acceptable.

Table 3. Results of multivariate correlation indicators for annual electricity consumption

Multivariate correlation coefficient (r)	Coefficient of determination (r^2)	Adjusted coefficient of determination	Mean standard deviation
0.9884	0.9769	0.9736	0.56509

Another analysis that should be considered is the analysis of variance (ANOVA), performed to measure the effect of using regression in estimating dependent variable values in comparison with unpaired preliminary data. Deviations from the regression results are accordingly divided into two parts: deviations in which the independent variable x is not used to calculate the fit, and the other one is deviations divided whenever the independent variables x are used in the fit. Therefore, the more the deviations associated with not using x than the deviations when using x, the more appropriate the resulting model. If this value is small, the regression model is not appropriate. If none of the independent variables x is utilized to determine the equation, the fit will be the same as the proposed model, and the extent of deviations from Eq.(4) will be calculated, called the total sum of squares:

$$SST = \sum (y_i - \bar{y})^2 \quad . \tag{4}$$

If independent variables x are employed in the calculation, the line is fitted (meaning regression); therefore, deviations are obtained from

$$SSE = \sum (y_i - \hat{y})^2 = \sum e^2 \, , \tag{5}$$

which is called the sum of squared errors. Using the difference between the two values mentioned above, the sum of squared regression is obtained as

$$SSR = SST - SSE = \sum (\hat{y}_i - \bar{y})^2 . \tag{6}$$

If the SSR is zero, the regression is not applicable at all and the model is inappropriate, but the higher the value, the more appropriate the linear regression model. Eq.(7) is now used to calculate the test statistics:

$$F = \frac{MS_R}{MS_E} . \tag{7}$$

In Eq.(7), MS_R characterizes mean squared regression and MS_E refers to mean squared error. The former is divided by its degree of freedom related to itself (viz. the number of independent variables) and the latter is obtained by the division of the degree of freedom related to itself (namely, the total number of random variables minus the independent variables minus one). If F is bigger than $SSR/_{SSE}$, the regression model is suitable, and the larger the model, the more appropriate the model [40]. Table 4 shows the results of this analysis. Table 5 also illustrates the final coefficients and the regression models for annual electricity consumption rates. Accordingly, the first line is the value of the width of the origin (namely, constant value) of the regression equation. The first column β is coefficients or real coefficients of regression that will be placed in the equation. These coefficients indicate the relative share of each variable in predicting the dependent variable; in other words, which of the parameters has the greatest impact on the dependent variable. With reference to the information in Table 5, the regression equation using the variables with significant coefficients will be as follows:

$$y = 127.536 - 0.847x_1 - 0.083x_2 - 0.544x_3 - 0.693x_4 + 1.546x_6 - 0.243x_7 - 0.064x_8 + 0.011x_9 + 5.957x_{10} + 12.691x_{11} - 0.909x_{12} - 0.009x_{13} + 9.487x_{14} - 3.774x_{15} + 0.031x_{16} + 0.073x_{18} + 0.322x_{19}$$

Table 4. Model ANOVA for annual power consumption

Source of changes	Sum of squares	Degree of freedom (df)	Average sum of squares	F-statistics
Regression	SSR=1834.5	19	MS_R=96.5	302.3
Error	SSE=43.1	135	MS_E=0.319	
Total	SST=1877.6	154		

Table 5. Coefficients of the impact of the model components for annual power consumption

Variables	Impact factors		
	Coefficients	**Standard deviation error**	**F-statistics**
Constant value	127.536	3.770	33.833
x_1	-0.847	0.027	-17.732
x_2	-0.083	0.027	-3.067
x_3	-0.544	0.027	-20.172
x_4	-0.693	0.053	-13.194
x_5	0	0.216	0
x_6	1.546	0.453	3.410
x_7	-0.243	0.100	-2.427
x_8	-0.064	0.100	-0.637
x_9	0.011	0.003	3.711
x_{10}	5.957	0.517	11.532
x_{11}	12.691	1.078	11.777
x_{12}	-0.909	0.027	-33.725
x_{13}	-0.009	0.027	-0.326
x_{14}	9.487	0.246	38.633
x_{15}	-3.774	0.091	-41.480
x_{16}	0.031	0.693	0.045
x_{17}	0	0.012	-0.032
x_{18}	0.073	0.012	6.215
x_{19}	0.322	0.365	0.884

According to Eq.(8), three parameters having the most significant effects on building electricity consumption are presented in Table (6).

The above steps must be taken to calculate annual gas consumption, whose results are given below.

Tables 7, 8, and 9 respectively show the results of regression analysis, ANOVA, and weight coefficients for building gas consumption. According to the information in Table 9, the regression equation for gas consumption using the variables with significant coefficients will be illustrated in Eq. (9).

$$y = -227.788 + 0.394x_1 - 0.001x_2 - 4.885x_3 - 9.896x_4 - 4.868x_6 + 0.5511x_7 + 0.571x_8 - 0.019x_9 - 3.877x_{10} - 7.673x_{11} + 0.052x_{12} + 7.043x_{13} - 10.674x_{14} - 0.186x_{15} - 115.089x_{16} + 0.125x_{17} - 0.217x_{18} + 3.954x_{19}$$

Table 6. Three parameters with the highest impact factor on electricity consumption

Parameters	Name	Impact factor
x_{11}	Equipment power density	12.691
x_{14}	HVAC system fan power	9.487
x_{10}	Optical power density	5.957

Table 7. Results of multivariate correlation indicators for annual gas consumption

Multivariate correlation coefficient (r)	Coefficient of determination (r^2)	Adjusted coefficient of determination	Mean standard deviation
0.9666	0.9343	0.9251	5.34716

Table 8. Model ANOVA for annual gas consumption

Source of changes	Sum of squares	Degree of freedom	Average sum of squares	F-statistics
Regression	SSR=54822.951	19	MS_R=2885.418	100.917
Error	SSE=3859.930	135	MS_E=28.592	
Total	SST=58682.881	154		

Table 9. Coefficients of the impact of model components for annual gas consumption

Variables	Impact factors		
	Coefficients	Standard deviation error	F-statistics
Constant value	-227.788	35.669	-6.386
x_1	0.394	0.255	1.545
x_2	-0.001	0.255	-0.005
x_3	-4.885	0.255	-19.146
x_4	-9.896	0.497	-19.910
x_5	0	2.039	0
x_6	-4.868	4.291	-1.134
x_7	0.5511	0.947	0.582
x_8	0.571	0.947	0.603
x_9	-0.019	0.028	-0.671
x_{10}	-3.877	4.888	-0.793
x_{11}	-7.673	10.197	-0.752
x_{12}	0.052	0.255	0.203
x_{13}	7.043	0.255	27.629
x_{14}	-10.674	2.324	-4.594
x_{15}	-0.186	0.861	-0.216
x_{16}	-115.089	6.556	-17.556
x_{17}	0.125	0.111	1.126
x_{18}	-0.217	0.111	-1.954
x_{19}	3.954	3.452	1.146

Table 10 respectively outlines three parameters with the greatest effects on building gas consumption according to Eq. (9).

4.3. Energy Consumption Optimization

As the eQUEST and the regression analyses are fulfilled, the final step is to optimize energy consumption. According to the simulation results of the building concerned in the present study using the eQUEST, it was observed that up to 19 parameters (each one investigated in at least five different states although this number was up to 10 cases for some parameters) can be analyzed in the energy meter manual of this software. To determine which of the 19 parameters are optimal, one must choose from the possible ones. Therefore, it is necessary to implement innovative methods with high computational speed including GAs. Hence, the target function should be initially defined to perform the optimization process.

Table 10. Three parameters with the highest impact factor on gas consumption

Parameters	Name	Impact factor
x_{16}	Heating system efficiency	-115.089
x_{14}	Air pressure created by HVAC system fans	-10.674
x_4	Concrete thickness of the external wall	-9.896

It should be noted that 19 parameters were considered in this study, and it was necessary to select those with the least energy consumption or cost. In order to use the GA and to optimize, the following steps should be taken:

1. Creation of a random initial population of 100 members
2. Determination of intersection type, i.e., the two-point intersection is used, and a population of children with a coefficient of 0.4 of the initial population is selected.
3. Mutations in new generation population and determination of population coefficient of mutants with a coefficient of 0.2
4. Determination of coefficient of mutation application in mutant organs by 0.05
5. Determination of the number of variables (n=19)
6. Determination of range of changes for each variable with five choices
7. Determination of the number of generation steps by 100 times
8. Definition of a function specifying number of times target function is called

5. Validation

The results of the eQUEST, the SPSS Statistics regression analysis, and optimization outputs were validated at the end of the study.

5.1. EQUEST Validation

The results obtained from the eQUEST analysis could be evaluated in two ways. The simplest and the most reliable way was to compare them with the electricity and gas bills of the building, in which the energy and gas consumption of the building could be compared both annually and periodically. The electricity and gas consumption of the building in the full year were compared by the eQUEST and thus the amount of electricity or gas consumed on this bill, over one year, would be determined.

Instead of one year, the same procedure can be performed over two months (for any two months of the year) as conducted in this study for both electricity and gas consumption annually and two months. Another method used to validate the results is to perform air conditioning calculations of a building and to calculate heating and cooling load using governing equations and compare them with software results. This method, known as computational validation, can be employed for the whole year or any number of months of the year. However, since manual validation requires a temperature outside the mean one, it is obvious that the time interval matters.

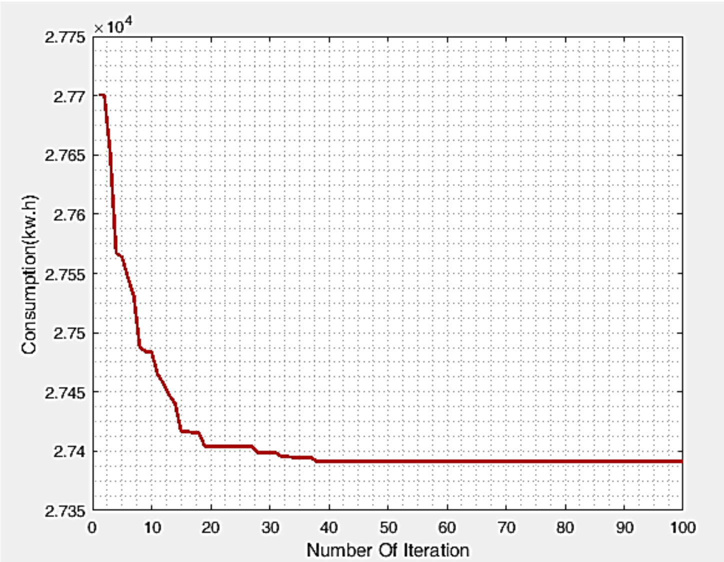


Fig.3. Optimization based on the electricity consumption rate

Table 11. Algorithm outputs for all three types of consumption

Row	Parameter type	Electricity consumption	Gas consumption	Electricity and gas consumption
1	Roof insulation	Polyurethane R-14	Without insulation	Polyurethane R-14
2	Ceiling insulation	Polyurethane R-14	Polyurethane R-14	Polyurethane R-14
3	Exterior wall insulation	Polyurethane R-14	Polyurethane R-14	Polyurethane R-14
4	Wall concrete thickness (inches)	12	12	12
5	Window height (foot)	4.75	4.25	5.25
6	Glass heat transfer coefficient	0.31	.9	0.31
7	Depth of window (foot)	2.4	0	2.4
8	Distance from window edge (foot)	1.8	0	0
9	Daylight utilization percentage	0	30%	0
10	Lighting system power (W/ft^2)	0.1	0.9	0.1
11	Equipment power (W/ft)	0.1	0.5	0.1
12	Thermostat cooling temperature (°F.)	86	86	86
13	Thermostat heating temperature (°F.)	60	60	60
14	Fan power	0.25	2.25	0.25
15	Cooling system efficiency	10%	9%	10%
16	Heating system efficiency	0.95	1	1
17	The temperature of hot water consumed by gas (°F.)	130	110	110
18	The temperature of hot water consumed by electricity (°F.)	120	130	110
19	Amount of air change cfm/ft^2	0.2	0.2	0.2

Moreover, the accuracy of the mean temperature and other environmental factors such as the direction of the sun's rays will be reduced. It is therefore recommended to shorten the period e.g. for a more accurate calculation, such as one month. As the present study aimed to compare the three methods of the software, billing, and computation, the period was determined by two months due to the issuance of the bills within two months. Table 12 lists the results of software validation with the bills for consumption during the two months of November and December as well as for the whole year for gas consumption. The gas energy obtained for the gas bills is additionally obtained by multiplying the volume of gas consumed by the building at a gas thermal value with an average of 9410 kcal/m^2 [41].

The research results were then re-validated by manual calculation of the gas energy consumed using the heat transfer relationships. In all calculations, the optimum (thermal comfort) temperature was 22°C (equal to the software interior design temperature) and the outside design temperature was the average 24-hour temperature for November and December in the city of Dezful, which was 16.5°C [42]. The total heat transfer consisted of the following sections, each one calculated separately.

1. Heat transfer from building walls, including walls, ceilings, floors, doors, and windows
2. Heat transfer caused by the sun's rays
3. Heat transfer due to air penetration (including natural and forced ventilation)
4. Energy and heat needed to supply a building with hot water
5. The heat generated by the electric lighting system
6. The heat generated by residents' body metabolism
7. Miscellaneous heat exchanges

Table 13 compares the results of the software and the computational method. The amounts of gas consumed are expressed in BTU.

Table 12. Comparison between eQUEST analysis results and amount of building gas bills (BTU)

Period	eQUEST analysis	Gas bills	Error
November and December	25.59×10^6	22.8×10^6	12.2%
Annual	75.91×10^6	69.49×10^6	9.2%

Table 13. Comparison between eQUEST analysis results and building gas consumption calculations in November and December (BTU)

eQUEST	Computational method	Error
25.59×10^6	21.42×10^6	16.3%

5.2. Regression Model (SPSS) Validation

To evaluate the accuracy of the regression models obtained from the SPSS Statistics, their values were compared with the eQUEST analysis ones. This was performed by setting the values of a selected record from all available cases. The selected record was related to the changes in the pressure parameter created by the HVAC system fans with a modified value of 0.75, which was obtained by placing energy in the equations obtained for electricity and gas. It was fulfilled by inserting the values of the selected record in Eq.(8) (y=41.05) and introducing the values of the same record in Eq. (9) (y=80.76). Table 14 shows the error percentage.

5.3. Optimization Validation

The written code performs the optimization using the data obtained by the eQUEST and the GA, which calculates the energy consumption function as the sum of the energy consumed per item and carries out the optimization accordingly. To validate this code, one can replace the energy consumption prediction function obtained from the regression analysis for electricity and gas and compare the results in both states (using the sum of the energy consumed per parameter and the energy-consumption prediction function as the target functions). If Eq. (8) is utilized to represent the power-consumption regression function, as the target function of the program, and executed, then Figure 4 will be obtained.
Table 15 presents the relative error resulting from Diagrams 3 and 4.

Table 14. Comparison between regression model results and eQUEST equilibrium values

Error	eQUEST	Regression (SPSS)	Energy
0.1%	41.09	41.05	Electricity ($\times10^3 kWh$)
0.75%	81.37	80.76	Gas ($\times10^6 Btu$)

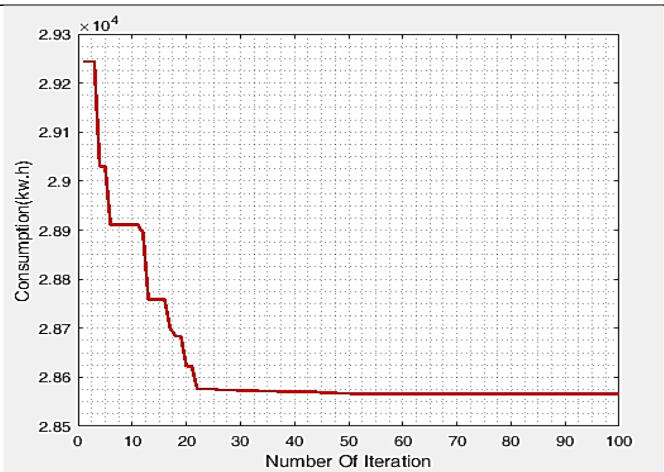


Fig. 4. Output results of optimization of electric power consumption along with regression function as the objective function

Table 15. Comparison between optimization results of the electrical energy consumption by changing the target function (kWh)

Regression	eQUEST	Error
28565	27391	4.3%

6. Conclusion

Limited fossil resources, high annual growth of energy consumption, technical and economic inefficiency of energy consumption, and about one-third of total energy loss in consumption processes, as well as growing environmental problems resulting from it in Iran, reveal the need to manage energy consumption and efficiency much more. Over recent years, some awareness and attention to uncontrolled increase in energy consumption and the existence of various restrictions on the development of production resources have led to comprehensive studies around the world on ways to diminish energy consumption and at the same time not to toughen development and growth in countries. In developing countries, factors such as rapid population growth, urban development, improved living standards and welfare, as well as industrial and commercial development have raised the need to expand energy consumption. Nowadays, in all countries, energy conservation in residential complexes is one of the most important concerns. Because of restricted available resources and growing needs for energy consumption, studying new methods to reduce and optimize energy consumption becomes of utmost importance. In this respect, different factors can affect energy consumption in a building, varying from climate to climate. This makes it very complicated to perform calculations theoretically and manually. Investigating and analyzing energy in a building based on types of materials, sizes of walls, types of climate, etc. can thus make the work of building designers easier. In this research, all the factors affecting the energy consumption of residential complexes based in the hot and semi-humid climate of Iran were investigated as the first attempt. In the beginning, a residential building in the city of Dezful, in southwestern Iran, located in a hot and semi-humid climate was modeled using the eQUEST, and the exact specifications of the building were clarified. The reason for choosing this software was its perfect ability. Then, according to the capabilities of the software, each of the parameters affecting the energy consumption of the building such as wall thickness, insulation thickness, type of glass, window height, etc. were changed in several different states to obtain the new energy consumption of the building. Then, in order to understand the share of each variable in energy consumption, the energy consumption of the building related to these factors, and factors playing a greater role in building energy consumption, the results in the form of an Excel file were imported into the SPSS Statistics. Upon performing correlation and variance tests in order to use the SPSS Statistics analysis and to ensure the use of this analysis, the weight of each parameter in the energy consumption of the building and the overall relationship between cooling and heating energy of the building and effective factors were achieved based on Equations (8) and (9). In these equations, the overall value of the coefficient of each parameter showed the importance of that parameter in energy consumption; therefore, the larger the coefficient, the greater the dependence of energy consumption on that parameter. On the other hand, the positive sign of the coefficient represented the direct relationship and the negative sign indicated the negative relationship between energy consumption and that parameter. The results demonstrated that equipment power density and heating system efficiency respectively had the greatest influence on the electricity and gas consumption of the residential building in the climate in question. Therefore, to decrease the electricity consumption in the given building, it was necessary to use low-power electrical things. Also, the best solution to reduce the gas consumption of the building was to employ a heating device with high thermal efficiency. The other important factors affecting the reduction of building electricity consumption were the fan power of the air conditioning system and the light power density, which could be decreased by moderating these two cases. These results raised the necessity of using energy-saving light bulbs instead of high-consumption ones. Among other factors, multiplying the insulation thickness of external walls was the most influential factor in lowering the gas consumption of the building.

The validations done in this research represented that the eQUEST could calculate the energy consumption of a building with an acceptable approximation. Moreover, a multivariate linear regression model with its very high accuracy could connect the energy consumption of a building with effective factors and provide the main factors affecting energy consumption. Using these relationships, the effect of each parameter on the energy consumption of a building can be achieved with high accuracy, easily, quickly, and with no need for practical changes in its structure. Considering the power of GA based on the study results, genetic optimization can help designers choose better materials (here, materials that decrease energy consumption). Employing the GA, the optimal values of the parameters minimizing electricity, gas, and energy consumption of the whole building were also mentioned according to Table 11. Finally, it is suggested to complete this for a building in other directions of the same climate, for one in the same direction but in other climates in Iran, and even for buildings with different administrative, educational, and industrial uses in different climates and directions.

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