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Prioritization of the effective factors in reducing energy consumption in a residential building using computer simulation

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ABSTRACT

BACKGROUND AND OBJECTIVES: According to the latest energy balance sheets, the average energy consumption in the residential sector of Iran is about 41% of the total energy consumption in the country. Increasing the energy efficiency of buildings can decrease the annual energy consumption in the residential sector and, thereby, the energy costs of families. The objectives of this study were to evaluate and prioritize the effective factors in reducing the energy consumption in residential buildings in the north of Iran using the climatic conditions analysis.

METHODS: In the first step, the amount of energy consumption in the cooling and heating section was estimated in the base conditions, and in the next step, the amount of energy consumption was calculated. The obtained results were compared with each other with the help of optimization strategies for energy consumption using the Design Builder software. Finally, a set of effective factors were determined to be involved in decreasing the energy consumption.

FINDINGS: The results showed that application of the LED lamps instead of the conventional fluorescent lamps could decrease the energy consumption by 980.4 kWh. Moreover, changing the materials of the walls and ceiling, using the polyurethane foam insulation with the thickness of 20 mm, and using the double-glazed UPVC windows reduced the energy consumption by 770 kWh. Energy reduction of about 101.5 kWh was also obtained after external movable awning and internal blind.

CONCLUSION: The most commonly used materials were analyzed by the Design Builder software. The analysis was done by integrating building architecture engineering (the best form of orientation and facade) based on the reasonable costs of consuming common materials in the area. The obtained results can be used for both evaluating the energy efficiency in residential buildings and producing a comfortable living environment in a moderate and humid climate.

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INTRODUCTION

According to the latest energy balance sheets, the average energy consumption in the residential sector of Iran is about 41% of the total energy consumption in the country (Energy Balance, 2017; Amani and Kiaee, 2020). This rate is more than the average energy consumption in the residential sector in the world and almost ten times greater than the average energy consumption in the advanced countries such as the United States and some European countries. Considering the built environments, residential buildings are among the main generators of environmental externalities (Ingrao *et al.,* 2018). From the total amount of energy consumed, 71% is used in household and heating sections, 22% is used in water circulation and 7% is used for general domestic purposes. Increasing the energy efficiency in the buildings can decrease the annual energy consumption in the residential sector and, thereby, the energy costs of families (Stephens, 2011). Common approaches for supplying sustainable energy are oriented towards providing the energy required in the buildings by decreasing the amount of used fossil fuels and increasing the amount of used renewable energies. The past architecture in Iran, relying on knowledge, experiences and precious patterns, has represented intelligent strategies in this field. This architecture has managed to establish a specific harmony with the environment and, by following it, has been successful in utilizing the forces of nature or confronting the difficult climate conditions (Yazdan Panah and Heidari, 2015). However, the point which cannot be ignored is that 95% of these buildings have a high energy consumption, so that 43% of the total social energy consumption in Iran belongs to energy consumption of the buildings. Therefore, supporting ecological energy saving and developing green buildings have become important activities in Iran (Amani, 2018). Table 1 shows an overall review of the previous studies on building energy efficiency rendered by energy simulation software. These studies have been extracted from popular databases, including Science Direct, Emerald, ASCE, and Taylor and Francis. The covered issues are the buildings' energy saving and efficiency evaluated by the Energy Plus simulation software.

Table 1 indicates that no study has evaluated the building energy efficiency by prioritization of effective factors in residential buildings based on the Design Builder simulation software. In this study, for the first time, the most commonly used materials are analyzed by the powerful Design Builder software. This was done by integrating building architecture engineering (the best form of orientation and facade) for the first time. The main objective of this study is to analyze the impact of the factors involved in reducing energy consumption in buildings using the climatic conditions analysis in Namakabroud, Chalous. For this purpose, the obtained climate data and basic building information were transferred to the software and energy outputs were monitored during one year. In the next step, after changing the design of the building and analyzing it by the software, the optimum conditions of energy consumption was achieved. Finally, the most effective factors were prioritized based on the output of the simulation software. The study was carried out during 2018 to 2019.

MATERIALS AND METHODS

Software selection

There are many strategies for evaluating the energy consumption of a building and measuring its energy efficiency. One of these strategies is building construction and application of measurement devices for collecting internal temperature, amount of the internal energy consumption and other climate and energy parameters of the building. Building construction and measurement of the design theories have high costs. Nowadays, if modeling and analysis tools are used tools during the design, the energy consumption will be able to evaluate for the building and its efficiency (Ashrae Committee, 2013; Amani and Kiaee, 2020). There are various types of software for modeling the building energy and its measurement. However, based on the need for evaluating the total building energy, defining the HVAC system and estimating the effects of sunlight and climate factors on the building, the Design Builder software was selected in this study. Design Builder - which is the most advanced and powerful software for energy modeling - was utilized as a research tool. Since it has the ability to model all aspects of the building, it was also used to simulate the building from different aspects such as building materials, building architecture, cooling and heating systems, lighting systems, home appliances, hot water consumption, etc. (Baghaei Daemei *et al.,* 2016; Yang and Zhang

Table 1: Previous studies on building energy efficiency using the energy simulation software

Type of buildings	Climate	Focus of paper	Simulation tools	References
Highly glazed buildings	Hot and humid	Assessment of the design of an adaptive biomimetic facade as a practical solution for enhancing energy efficiency.	Revit-2016 Ecotect-2011	Sheikh and Asghar, (2019)
Factory buildings	Temperate	Improvement of prevailing methodologies used in the assessment of energy efficiency	Energy building simulation	Weeber *et al.*, (2018)
Residential building	Mild	Providing a model based on Integrated Nested Laplace Approximation to predict the energy performance	Design Builder Energy Plus	Braulio-Gonzalo *et al.* (2016)
Residential building	Hot, sultry summers and cold, foggy winters.	A multi-criteria approach based on multi-attribute utility theory to assess alternative energy efficiency measures, explicitly considering both environmental and economic criteria.	Design Builder Energy Plus	D'Agostino *et al.* (2019)
Traditional building	Hot-dry	Assessment of the effects of building form and settlement texture on heating and cooling loads	Design Builder Energy Plus	Kocagil and Oral. (2015)
Historical building	Hot desert	Assessment of energy efficiency in Egypt	eQuest Design Builder Energy Plus	Fahmy *et al.* (2019)
Residential building	Warm temperature	Impact of VGS on building energy performance.	Design Builder Energy Plus	*Kalani et al.* (2017)
Residential building	Tropical equatorial	Benchmarking of residential buildings in Brunei Darussalam	Design Builder Energy Plus	Shabunko *et al.* (2018)
Residential building	Oceanic, cool and humid	Assessing the potential impact of a compartmentalization system retrofit strategy on energy	Design Builder Energy Plus	Carlsson *et al.* (2019)
Residential building	Both warm and moist climates	Simulating occupant behaviour on air conditioning	Design Builder Energy Plus	Yao (2018)
Residential, small office and large office buildings	Temperate	Urban-scale building energy consumption database assessed by Energy Plus models	Design Builder Energy Plus	Ding *et al.* (2019)
-	Temperate	Assessment of building energy efficiency rate using simulation tools	BIM Design Builder Energy Plus	No (2012)
Office buildings	16 locations of different climates	Investigation of energy savings potential of several common HVAC system re-tuning measures	Design Builder Energy Plus	Fernandez *et al.* (2015)
Residential building	1) Hot and humid 2) Mild and dry 3) Dry and cold	Reduction of energy consumption by green roofs in three different climates of Iran	Design Builder Energy Plus	Ebadati and Ehyaei (2018)

2015). Design Builder 4.2 software works based on computational engine of Energy Plus 8.3 and is capable of calculating the amount of ambient energy absorption during a year, calculating the amount of energy loss, separating energy consumption from functions of heating and cooling, designing and calculating the awnings, designing and defining HVAC, defining the solar systems such as solar cell and solar collector, optimizing and estimating the light, etc. This software can compute based on Ashrae 90.1 and 2007, 2010. To obtain .epw file for energy calculations in the coordinates and regions which were are not in the database of the Design Builder software, Meteororm 7 software was utilized as a maker of the Design Builder software. Moreover, the Climate Consultant software was used to obtain the thermal comfort and the earth temperature in the site. The method used in this study followed three steps: 1) Energy optimization actions in the building; 2) Estimation and evaluation of energy by the software according to the optimal actions; 3) Prioritization of the factors affecting the energy consumption.

RESULTS AND DISSCUSSION

Climate data

To obtain .epw file for energy calculations in the coordinates and regions which were not in the database of the Design Builder software, Meteororm 7 software was utilized as a maker of the Design Builder software. Moreover, the Climate Consultant software was used to obtain the thermal comfort and the earth temperature in the site. In Chalous city, the summers are hot, muggy, dry, and clear and the winters are long, cold, and partly cloudy. The temperature typically varies within 42-88 °F and rarely drops below 34 °F or exceeds 92 °F during the year (Fig. 1).

The warm season (from June 5 to September 22) lasts for 3.6 months and has an average daily temperature of over 81 °F. The hottest day of the year is August 6, with the highest and the lowest temperatures of 88 °F and 77 °F, respectively. The cold season (from December 4 to March 25) lasts for 3.6 months and has an average daily temperature of below 59 °F. The coldest day of the year is January 29, with the lowest and the highest temperatures of 42 °F and 52 °F, respectively (Fig. 2).

As can be seen in Fig. 2, the average high (red line) and low (blue line) temperatures in day are within 25th-75th and 10th-90th percentile bands respectively. The thin dotted lines are the corresponding average temperatures perceived. Fig. 3 shows a brief characterization of the entire year with average hourly temperatures. The horizontal axis is the day of the year, the vertical axis is the hour of the day, and the color is the average temperature for the given hour and day.

Site position

Namakabroud town is located at a distance of

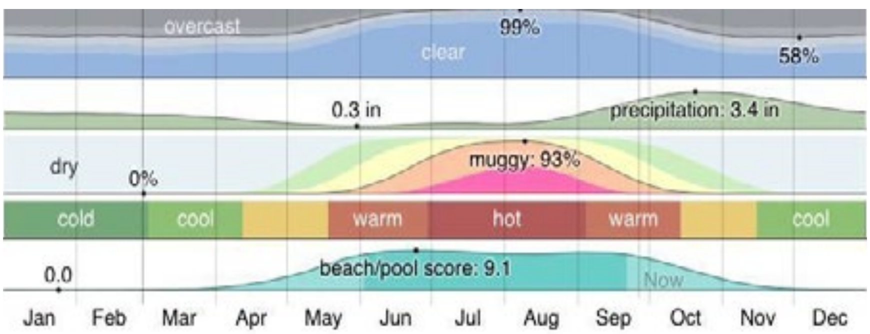

Fig. 1: Weather data of Chalous city

Fig. 2: Average high and low temperature

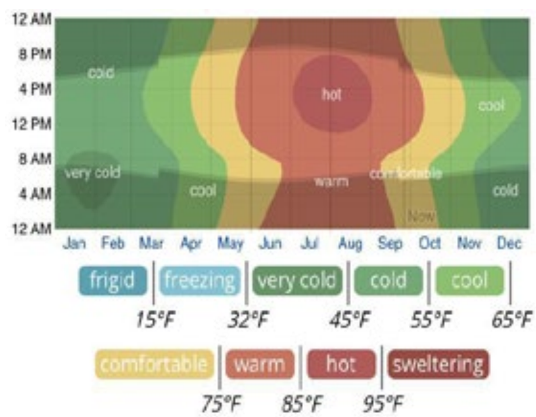

Fig. 3: Average hourly temperature

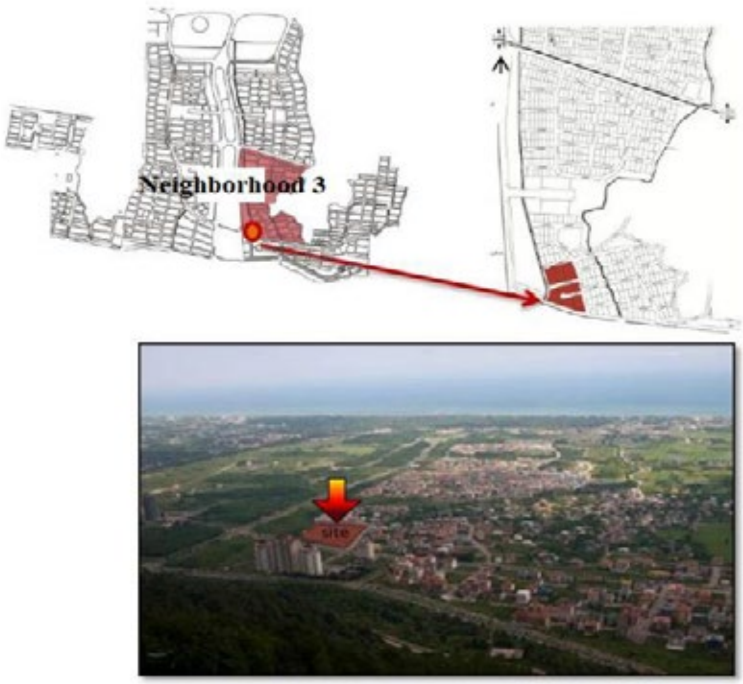

Fig. 4: Position of the studied site in Namakabroud city

92 km from the west of Chalous in Mazandaran province. It is restricted to the Caspian Sea in the north, to Alborz mountain range in the south, and to the agricultural lands in the west and east. The town has been designed on an area of 651 hectares and different phases of executive operations in it are currently in progress. It consists of five residential neighborhoods with recreational, athletic, service, commercial, cultural, religious, health and education centers (Namakabroud, 2018). The project is located at the south of neighborhood 3 in the residential tower site. This neighborhood, with an area of over 367,000 m^2, is located in the east of the town and reaches neighborhood 2 in the south (Namakabroud, 2018). Fig. 4 shows the location of the studied site.

The surrounding area of the site is mainly used for residential purposes and covered with villas and towers. Some parts of these residential spaces have not been constructed.

Building information

The initial steps in optimization of energy consumption are modeling of the climate and calculation of the amount of energy consumption in the building at different periods of the year. These steps require a comprehensive information about dimensions of the building, walls and equipment (Kharbouch *et al.,* 2017). The case study, with an area of about 200 m^2, is a residential building located in the Namakabroud, Chalous (Fig. 5). This building has a capacity for 5 persons and has two floors with 3 bedrooms, a living room, a kitchen, a restroom, a bathroom and a terrace exposed to fresh air in three directions. This study was performed in two fundamental steps. First, the amount of energy consumption in the base conditions was calculated, and next, the amount of energy consumption in the optimum conditions was calculated using the optimization strategies. Fig. 5 and Table 2 represent the plan of the building before making the modifications for optimization of energy consumption.

Building orientation

Orientation of the building has a very significant role in supplying a part of thermal requirements of the internal sections naturally. The sunlight received by the building surface and the heat produced during the day can provide a large amount of the required

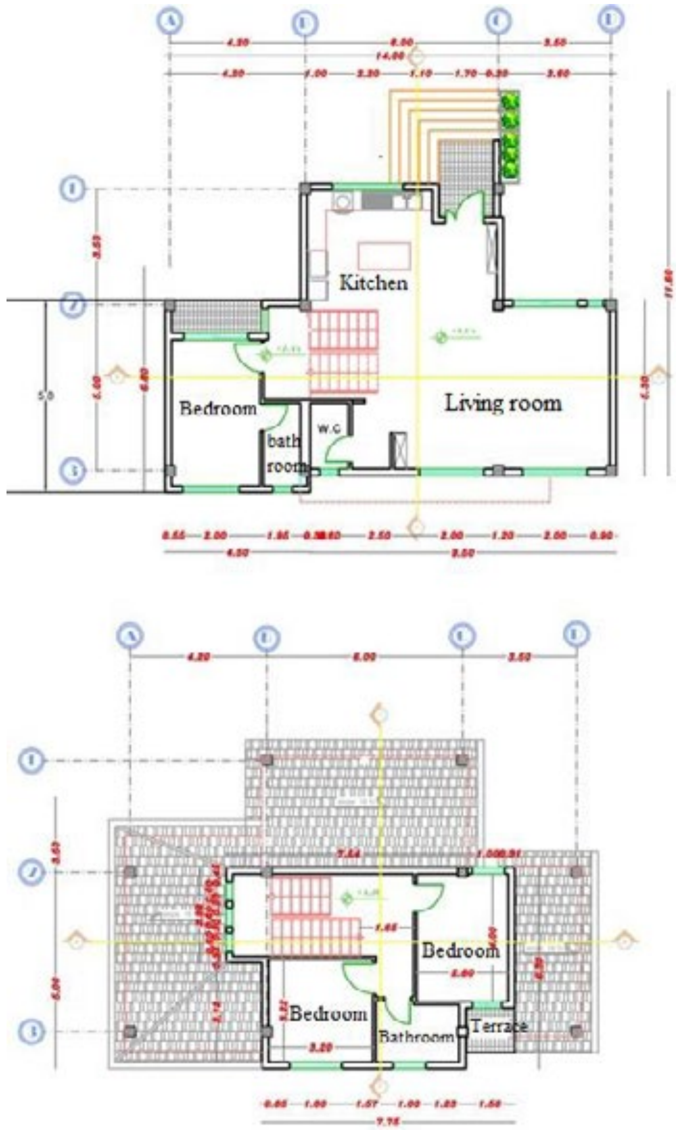

Fig. 5: Plan of the first and the second floors of the building in the base conditions

Table 2: Definition of the materials

Residential building materials before modifications	
Wall	Repairing the cement mortar, ceramic brick, plastering
Window frame	Aluminum without thermal bridge
Glaze	Single-glazed clear glass without awning
Celling	Asphalt, concrete slab, plastering
Residential building materials after modifications	
Wall	Repairing the cement mortar, ceramic brick, polyurethane foam, Plastering
Window frame	UPVC
Glaze	Double-glazed clear glass without awning
Celling	Asphalt, concrete slab, polyurethane foam, plastering

energy in the building (Amani and Soroush, 2020). The building orientation towards south is very effective in utilizing solar energy. Therefore, the southern walls where the sunlight is pass through or in the coldest day of the year from 9 AM to 3 PM contribute to higher utilization of the sunlight. Furthermore, the position of the building is important in protecting the building against undesirable winds during the year. On the other hand, the desirable winds are used to provide natural ventilation and reduce the inside temperature (BNRI, 2010). Using the software features, the climate file of Namakabroud was obtained by entering the geographic coordinates, the height above sea level and other information such as beginning and end of winter, beginning and end of summer, etc. Using the geographical files and the sub-components, the software can determine the best orientation of the building in degree (Saleh Ahangar, 2015). According to the software calculations in the given climate, the building was planned and established in the eastern-western direction between the angles of 10-15° to the west axis and 45° to the east axis. To provide the best thermal conditions inside the building, the frontage was oriented towards the south.

Energy optimal actions in building

The energy conservation opportunities, called ECO, are a set of actions that lead to the reduction of the energy consumption in the building. The principle idea in ECO is to permit daylight, heat and air flow to enter the building only when they are useful and to eliminate them when they are not useful (IjazIqbal *et al.,* 2018). In this study, optimization of energy consumption was performed into 7 steps:

1) Insulating the external walls of the building: The walls are able to save the heat because of having a high thermal capacity (the high mass). The heat or cold in the space can be saved in the mentioned elements and emitted into the environment when they are needed. In this way, the extreme temperature fluctuation inside the building is decreased. Requirements of the thermal elements with a high thermal capacity depend on the types of space. In the spaces that are continuously used round the clock, a high thermal inertia is obtained and a thermal insulation for the external side of the building shell is recommended. In the spaces with a discontinuous round the clock use, the thermal inertia should be as low as possible and a thermal insulation for the internal side of the building shell is recommended (BNRI, 2010). Considering the residential usages in this study, a polyurethane foam insulation with a thickness of 20 mm and a specific weight of 25 kg.m^3 was utilized in the external walls and ceiling. In the base conditions, the wall materials were transferred from the external layer to the internal layer, and repairing with the sand cement mortar 1, ceramic brick 20 and plastering 4 was performed (heat transfer coefficient was U = 1788). In the optimum conditions, the wall materials were transferred from the external layer to the internal layer and repairing with sand cement mortar 1, ceramic brick 10, polyurethane foam 2, brick 5 and plastering 4 was rendered (heat transfer coefficient was U = 0.831).

2) Using double-glazed windows: Since thermal insulation of glass is low, windows play an important role in energy loss. Application of double-glazed windows can decrease the cooling and heating loads by decreasing the load obtained from the natural air infiltration, reducing the glass conductive load, reducing the glass radiant load (Zakeri-Khatir *et al.,* 2015). In this study, in the base conditions, the building windows had single-glazed clear glasses with the heat transfer coefficient of U = 5778 and the frame materials were made up of aluminium without thermal bridge with the heat transfer coefficient of U = 5881. In the optimum conditions, the double-glazed clear glasses with the heat transfer coefficient of U = 2665 and UPVC frame materials with the heat transfer coefficient of U = 3476 were used.

3) Constructing the terrace on the north and south sides: Natural ventilation is highly important in obtaining a maintainable building. Terrace is a different architectural element regarded as an interface for natural ventilation and reduction of energy consumption in the building. It is of high importance due to providing the residents with temperature comfort by presenting a better ventilation and also preventing the use of ventilation devices. In this study, the intended building had no terrace in the base conditions. However, in the optimum conditions, it was analyzed after including two terraces on the north and south sides.

4) Using the internal venetian blind: Another way for decreasing energy consumption (only applied in the warm season and cooling load reduction) is to add internal awnings to all windows based on time schedule. In the base conditions, no internal blind

was considered, while in the optimum conditions, a Louvre Drape blind with medium transparency and open texture was used.

5) Using external movable awning: The thermal effect of direct sunlight which passes through a glass wall or a window without an awning is very significant. If a window does not have an awning or its awning does not have any effect, the sunlight will pass through the window and directly influence the internal space by its thermal effects. The heat produced in the internal space would be preserved inside the building by glasses, and by continuous radiation of sunlight into the building, the internal temperature would be increased excessively. Adding external awnings to all the windows would decrease energy consumption and is performed only in the warm season and for reduction of cooling load. When natural light is utilized in the warm season, these awnings protect the building from direct sunlight. The awning protrusion is 1 m above and beside the windows.

6) Using smart lighting control: Using lamps along with lighting can produce a great heat and this heat can contribute to heating the home in the winter. Since they extremely increase the cooling load in the summer, it is recommended to use the LED lamps, which have lower electricity consumption and heat production, in the lighting.

7) Reducing the total area of the windows: The amount of sunlight passes through the window is very important in terms of heat transfer. If the amount of the sunlight passes through the window is less than that of the heat transfer to the outer shell, the heat transfer will be reduced. The adequate level of sunlight supplied for internal spaces is responsible for decreasing the heat transfer to the outside (Zhang *et al.*, 2011). Decreasing the total area of the windows in a building can always be contemplated as an effective conservation opportunity. The higher heat transfer in the window rather than in the wall is mainly due to: 1) the lower conductive heat transfer coefficient of the walls compared to the windows, and 2) the relatively higher sunlight heating load transfer in the windows rather in than the walls in the summer. The heat transfer coefficient of a normal wall is in the range of 0.5 and 3 and the heat transfer coefficient of a normal window is in the range of 2.5 and 5 $W.m^2$ for 1 °C of temperature difference. In this study, the ratio of window to wall reduced from 20.5% to 14%.

Energy estimation

It was attempted to evaluate the amount of the energy required for the building during the year. For this purpose, the design assumptions such substituting the double-glazed UPVC window with the single-glazed aluminum window, utilizing the polyurethane foam insulation with thickness of 20 mm instead of the brick walls without isolation, using an internal Louvre Drape blind based on schedule to decrease the absorption of heat and sunlight in the summer, utilizing external movable awning to provide shadow in the summer, decreasing the ratio of window to wall from 20.5% to 14%, and placing the terrace in the north and south sides according to the available technical maps were assessed. To measure the energy consumption of the building and the optimum amount, the variables and assumptions were applied based on the standard model of ASHRAE 140-2007. The effects of modifications on energy consumption are listed in Table 3 and Fig. 6.

Cost benefit analysis

Iran has a variety of climates due to its large area. Due to the fact that energy consumption is proportional to the climate, the Ministry of Energy of Iran has divided the country into four tropical regions. Table 4 shows these regions and their warm months. The study area falls within tropical region 4. To calculate the electricity price, the Ministry of Energy of Iran published the tariffs in tropical region 4 in 2018 (Tables 5 and 6) (Ministry of Energy, 2018).

In bills of the tropical regions with warm and non-warm days, energy consumption is calculated based on the coefficients presented in Table 4 (Minstry of Energy, 2018). The average price of energy consumption per kWh in a year can be calculated using the data given in Tables 4, 5 and 6. As previously shown in Table 3, the amount of total energy consumption in the building was 6544.42 kWh per year before the optimization modifications. Therefore, the price of the bill could be calculated from the consumption line of 500 to 600 kWh per month presented in Tables 5 and 6. According to the specifications expressed by the Ministry of Energy, in tropical region 4, three months were considered to be warm, and nine months were regarded non-warm. Considering the coefficients for the warm and non-warm months in Table 4, the average price of annual energy consumption for the consumer was calculated

Table 3: The effects of modifications on energy consumption based on the type of modification

Modifications	Before modifications	After modifications	Amount of kWh variation	Amount of reduction (%)	Cost benefit ($US)
Changing the materials - Transferring from the external layer to the internal layer - The unit of the thickness is cm. - Unit U= w/m2-k	Wall materials: Repairing the cement mortar (1), ceramic brick (20), plastering (4), U=1.788 Ceiling materials: Asphalt (1), concrete slab (20), plastering (4), U=2.518 Window materials: Single-glazed clear glass without awning (0.6), Sgl Clr 6 mm, U=5.778 Frame materials: Aluminum without thermal bridge, U=5.881 Total cooling and heating energy: 3074.27 kWh	Wall materials: Repairing the cement mortar (1), ceramic brick (10), polyurethane foam (2), brick (5), plastering (4), U=0.831 Ceiling materials: Asphalt (1), concrete slab (20), polyurethane foam (2), plastering (4), U=0.900 w/m2-k Window materials: Double-glazed clear glass without awning, Dbl Clr 6 mm/13 mm air, U=2.665 w/m2-k Frame materials: UPVC, U=3.476 Total cooling and heating energy=2304.27 kWh	770 (kWh)	25.05%	1250.26 $US
External movable awning and internal blind	Does not have Total cooling and heating energy: 3074.27 kWh	External awning for the summer with a protrusion of 1 Louvre Drape blind with medium transparency and open texture inside the building. Control: Sensitive to external temperature and amount of sunlight: base temperature of outside: 22°C/amount of base sunlight: 120 W.m^2 Total cooling and heating energy: 2972.77 kWh	101.5 (kWh)	3.3%	903.25$US
Lighting lamp	Fluorescent Total lighting energy: 3470.15 kWh	LED Total lighting energy: 2489.45 kWh	980.4 (kWh)	28.26%	1469.16 $US
Window-to-wall ratio (WWR)	WWR: 20.5% Total cooling and heating energy: 3074.25 kWh	WWR: 14% Total cooling and heating energy: 3004 kWh	70.27 (kWh)	2.3%	887.03$US
Northern and southern terrace	Does not have Total cooling and heating energy: 3074.27 kWh	Has base on plot proportions Total cooling and heating energy: 3062.52 kWh	11.75 (kWh)	0.3%	856.68$US
Amount of variations	Heating and cooling: 3074.27 Lighting: 3470.15	Heating and cooling: 1939.91 Lighting: 2489.45	1134.36 (kWh) 980.40 (kWh)	36.90% 28.26%	1439.39 $US 1469.16 $US
Total amount of variations	6544.42 kWh	4429.36 kWh	2115.06 (kWh)	32.32%	2908.55 $US

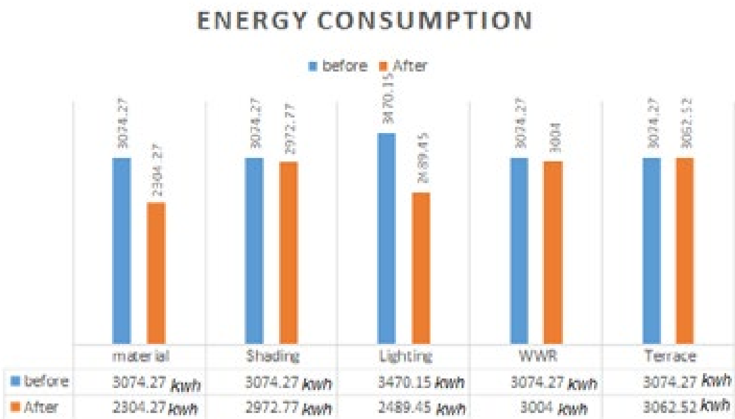

Fig. 6: The effect of modifications on energy consumption based on the type of modification

as $US 0.80 per kWh using Eq. 1.

[(0.80 ($US) * 9 * 1) +(0.61 ($US) * 3 * 1.3)]/12=$US 9.5/12=$US 0.80 (1)

After the optimization modifications, the amount of total energy consumption in the building was obtained as 449.36 kWh per year (Table 3). Therefore, it was possible to calculate the price of the bill from the consumption line of 300 to 400 kWh per month presented in Tables 5 and 6. Based on the specifications proposed by the Ministry of Energy, in tropical region 4, three months were considered to be warm, and nine months were regarded non-warm. Considering the coefficients for the warm and non-warm months in Table 4, the average price of annual energy consumption for the consumer was estimated as 0.52 $US per kWh using Eq. 2.

[(0.55 ($US) * 9 * 1) + (0.32 ($US) * 3 * 1.3)]/12 =6.23 ($US)/12=$US 0.52 (2)

The costs of electricity consumption before and after modifications were estimated to be $US 5207.7 and $US 2299.2, respectively. Moreover, the saving rate was calculated as 2908.5 $US. The cost saving was calculated for each item separately.

Table 4: Coefficients for calculation of bills in tropical regions

Tropical regions	Coefficient of warm months	Coefficient of non-warm months
Tropical region 1	4	1
Tropical region 2	3	1
Tropical region 3	2	1
Tropical region 4	1.3	1

Table 5: Tariffs for non-warm months in tropical region 4

Average monthly energy consumption (kWh)	Basic price per kWh ($US)
0 to 100 (kWh)	0.12
Surplus 100 to 200 (kWh)	0.14
Surplus 200 to 300 (kWh)	0.30
Surplus 300 to 400 (kWh)	0.55
Surplus 400 to 500 (kWh)	0.63
Surplus 500 to 600 (kWh)	0.79
Surplus 600 (kWh)	0.87

Table 6: Tariffs for warm months in tropical region 4

Average monthly energy consumption (kWh)	Basic price per kWh ($US)
0 to 100 (kwh)	0.09
Surplus 100 to 200 (kWh)	0.11
Surplus 200 to 300 (kWh)	0.20
Surplus 300 to 400 (kWh)	0.32
Surplus 400 to 500 (kWh)	0.46
Surplus 500 to 600 (kWh)	0.61
Surplus 600 (kWh)	0.73

Table 7: Prioritization of the optimization strategies for energy consumption in the building according to the amount of energy reduction in each section

Design strategy	Amount of reduction in energy consumption (kWh)	Percentage of reduction in energy consumption
LED lamp	980.4 (kWh)	26.26%
Using window and thermal insulation in walls and ceiling	770 (kWh)	25.05%
External and internal awning	101.5 (kWh)	3.3%
Reducing the window area	70.27 (kWh)	2.3%
Terrace	11.75 (kWh)	0.3%
Total variation	2115.06	32.32%

Prioritizing the effective factors in energy consumption

In the first step, the energy consumption was estimated in the base conditions, and in the second step, the amount of energy consumption in the optimum conditions was calculated. The software calculations and comparison of them showed that the proposed strategies can lead to 32.32% reduction in the annual energy consumption (Table 3). The obtained results indicated that application of the LED lamps instead of the conventional fluorescent lamps had the most significant effect on reduction of energy consumption and could reduce it by 980.4 kWh (28.26%). Changing the materials of the walls and ceiling, using the polyurethane foam insulation with the thickness of 20 mm and application of double-glazed UPVC windows led to 770 kWh (25.05%) reduction in energy consumption and were considered as the second priority. Compared to other methods, awning did not have a significant effect on reduction of energy consumption and it was considered as the third priority. Since the external movable awning along with internal blind resulted in 101.5 kWh (3.3%) reduction in energy consumption, its application seemed to be unnecessary in all the climatic regions. To determine the necessity of using the awning, the climate of the region must be precisely studied for warm hours in a year. To avoid a warm house, all window should be placed in shadow at different sides of the building based on the warm hours of the year and the angle of sunlight. Decreasing the area of windows was found to be in the fourth priority. Since reduction of the window area can reduce the energy consumption by 70.27 kWh (2.3%), the large- or small-sized windows, if placed in accurate orientations, may not have a significant effect on energy consumption. In both base and optimum conditions, the windows were oriented towards the best direction, and terrace had the least effect on energy consumption in the studied building. The southern and northern terraces decreased the energy consumption by 11.75 kWh (0.3%). Therefore, it was concluded that the existence of terrace in the given climate did not have a significant effect on energy consumption. The total heating and cooling variation in base and optimum conditions was 1134.36 kWh (36.90%). Moreover, the total lighting variation was 980.40 kWh (28.26%). Generally, the optimization strategies proposed in this study reduced the energy consumption by 2115.06 kWh (32.32%). Table 7 demonstrates the prioritization of the optimization strategies for energy consumption in the building according to the amount of energy reduction in each section.

Investigation of the previous studies published in popular databases (Table 1) revealed that no studies yet have been done on energy efficiency using prioritization of the effective factors in residential buildings based on the Design Builder simulation software. The results obtained in the present study showed that the used materials (with the exact specifications) have the largest effect on energy efficiency in the studied building (Table 3). The modifications carried out for optimization of energy consumption in the building were: changing the wall materials by adding polyurethane foam, using a UPVC window with double-glazed glass instead of a plain aluminum window with a single-glazed glass, application of an awning with 1 m protrusion, using Louvre Drape blinds with medium transparency and open texture, using the LED lamps instead of the conventional fluorescent lamps, reduction of the window to wall ratio from 20.5% to 14%, and designing the terrace at the northern and southern sides. Generally, the annual energy consumption was reduced from 6544.42 kWh before optimization to 4429.36 kWh after optimization. Simultaneous application of the proposed optimization strategies led to a saving of $US 2908. The software calculations showed that the thermal insulation with a thickness of 20-30 mm was the best option in the given climate according to the National Building Regulations-Energy Conservation data (Table 3) (BNRI, 2010). The results indicated that the thicknesses higher or lower than the mentioned range would not be optimal in terms of costs and energy saving in different seasons (winter and summer). The Design Builder software efficiently analyzed all data and the applied materials and provided the best output.

CONCLUSION

A residential villa in Namakabroud, Chalous was stimulated using the Design Builder software. For this purpose, the most commonly used materials in the building were analyzed by the Design-Builder software. The analysis was done by integrating building architecture engineering (the best form of orientation and facade). It was based on the reasonable costs of the common materials in the area. To provide the internal space with the best thermal conditions, the building frontage was designed toward the south. In the first step, the amount of energy consumption was calculated in the base conditions, and in the second step, the amount of energy consumption was estimated in the optimum conditions. The obtained results indicated that application of the LED lamps instead of the conventional fluorescent lamps, by reducing the energy consumption by 980.4 kWh, had the largest effect. Changing the materials of the walls and ceiling, changing the windows and frames, using the polyurethane foam insulation with the thickness of 20 mm and using a double glazed UPVC window, by reducing the energy consumption by 770 kWh, were in the second priority. The amount Application of the external movable awning and the internal blind, with an energy reduction of 101.5 kWh, had not a significant effect on energy consumption and was placed in the third priority. Moreover, reducing the total area of the windows was in the fourth priority. Finally, the presence of terrace had the lowest effect on energy consumption in the studied building. The results presented in this study can be useful in evaluating the energy efficiency in residential buildings and producing a comfortable living environment in north of Iran.

AUTHOR CONTRIBUTIONS

. Amani performed the conceptualization, methodology, investigation, validation, and supervision. F Tirgar Fakheri performed the data collection, software, simulation, and validation. K. Safarzadeh performed the literature review and writing - original draft.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interests regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

ABBREVIATIONS

BIM	Building Information Modeling
Clr	Clear
Dbl	Double
ECO	Economic Cooperation Organization
Eq	Equation
epw	Economic and political weekly
HVAC	Heating, ventilation, and air conditioning
IV	4
LED	Light-emitting diode
Km	Kilometer
kWh	kilowatt-hour
mm	Millimeter
Sgl	Single
UPVC	Unplasticized polyvinyl chloride
WWR	Window-to-Wall Ratio
%	Percent
$US	Dollar United State
°F	degree Fahrenheit

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