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Simulation and Analysis of Passive Parameters of Building in eQuest: A Case Study in Istanbul, Turkey

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Abstract**—**With rapid development of urbanization and improvement of living standards in the world, energy consumption and carbon emissions of the building sector are expected to increase in the near future; because of that, energy-saving issues have become more important among the engineers. Besides, the building sector is a major contributor to energy consumption and carbon emissions. The concept of efficient building appeared as a response to the need for reducing energy demand in this sector which has the main purpose of shifting from standard buildings to low-energy buildings. Although energy-saving should happen in all steps of a building during the life cycle (material production, construction, demolition), the main concept of efficient energy building is saving energy during the life expectancy of a building by using passive and active systems, and should not sacrifice comfort and quality to reach these goals. The main aim of this study is to investigate passive strategies (do not need energy consumption or use renewable energy) to achieve energy-efficient buildings. Energy retrofit measures were explored by eQuest software using a case study as a base model. The study investigates predictive accuracy for the major factors like thermal transmittance (U-value) of the material, windows, shading devices, thermal insulation, rate of the exposed envelope, window/wall ration, lighting system in the energy consumption of the building. The base model was located in Istanbul, Turkey. The impact of eight passive parameters on energy consumption had been indicated. After analyzing the base model by eQuest, a final scenario was suggested which had a good energy performance. The results showed a decrease in the U-values of materials, the rate of exposing buildings, and windows had a significant effect on energy consumption. Finally, savings in electric consumption of about 10.5%, and gas consumption by about 8.37% in the suggested model were achieved annually.

Keywords**—**Efficient building, electric and gas consumption, eQuest, passive parameters.

I. Introduction

THE increasing rate of environmental damage is so faster than recovering and human activity consequences are a real threat to the earth [1], and climate change adds to these challenges. Between 20% and 40% of the total energy used in the world is related to the building sector which exceeds other major sectors such as transportation and industry. Also, with increasing standards of living, energy consumption is increased dramatically [2].

According to the relative sources, the development of Turkey has lead to an increase of 6% of primary energy demand annually [3] and 125% CO_2 emissions from 1990 to 2014. Turkey has planned a 21% reduction in greenhouse gas emissions until 2030 [4] and has used some strategies to improve energy efficiency and protection of the environment. Meanwhile, energy efficiency is a critical issue for both new and existing buildings. The efficient building concept depends on different parameters such as design, technological equipment, building materials, and the use of renewable energy sources. In this study, the main focus is on passive parameters.

II. Efficient Building

The efficient building is a kind of eco-friendly and sustainable building that uses much lower energy and resources through all steps of the life cycle without sacrificing comfort and quality. Efficient buildings are not only energy-efficient but also are cost-effective throughout the life span.

Architecture characteristics have a high impact on the energy demand of buildings; thermal comfort and air quality are important factors of efficient buildings and help to minimize energy consumption.

The Passive House Institute declares space heating/cooling energy consumption of houses should not be more than 15 kWh/m^2/year[1], while the primary energy demand should not exceed 120 kWh/m^2/year and an airtight building shell should be no more than 0.6/h pressure [5]. These technical specifications can become reality through passive design strategies such as a proper design following the climate and function of the building, as well observing some principles such as daylight, natural ventilation, shading devices, orientation on the site, optimized geometrical properties, surface-to-volume ratio, thermal insulation, and openings, help to maintain a comfortable temperature so energy requirement for cooling and heating is decreased [6]. Another part of passive parameters is using renewable sources such as utilizing solar power and recycling methods for reducing waste including gray water [5].

Two important items for efficient buildings are investigated in the following section.

A. Materials

The effective material selection which has suitable thermal conductivity (U-value)[2] is critical for designers and also resources of materials are extremely important to minimize emissions. Materials affect the whole life cycle of a building and consist of preparation, transportation, construction, operation, maintenance, and demolition; besides, a variety of technologies is effective [7], [8].

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[1] kWh/m^2/year is amount of energy consumption for a square meters in a year.
[2] U-value is the rate of transfer of heat through a structure.

The energy consumption of some common materials like steel, cement, brick, concrete, and ceramic is high, and as such, the CO_2 emissions are considerable. Based on relative resources, 76.69% of the total emissions of buildings are related to the material preparation stage [9].

$B. CO_2$ Emission

Global warming has become a vital issue and control of that is an important task. According to the Inter-governmental Panel on Climate Change (IPCC), more than one-third of global energy use is relative to the building sector and 19% of energy-related carbon emission [10]. Also, the International Energy Agency mentioned that CO_2emissions should be reduced by 77% in the building sector until 2050 to keep global warming below the 2 °C target [11]. However, passive parameters lead to use of energy correctly; for example, changing 1 °C air condition temperature can save 4.5 kWh[3] of electricity a day, which equates to a reduction of 3.3 kg of greenhouse gas emissions [9].

III. Methodology

In this study, after defining the efficient building, declaring the necessity of that, and introducing some important parameters, the area of the site, which has an impact on energy performance, was analyzed and then simulated by eQuest as a base model.

eQuest is a quick energy simulation tool that allows users to develop a 3-dimensional model of a building. eQuest calculates the gas and electric consumption of a building on a monthly basis during the year, and the consumption amount of each parameter separately; for example, the electric consumption of the lighting system. It calculates according to different items such as location, orientation, wall/roof construction, window properties, as well as HVAC[4] systems, day-lighting, and various control strategies, and also can evaluate design options for any single or combination of energy conservation measure.

In the second step, some input passive parameters were changed to indicate the rate of effect which each parameter had. In the last part, useful parameters that had a positive effect on the energy performance of the building were selected and combined to present a final scenario that had better energy performance in comparison with the base model.

IV. Study Area

Climate condition is the main factor that guides the designer. The case study is located in Istanbul, Turkey (located at 41.01°N 28.95°E and 37 m above sea level). Research has shown that the most common climate classification has been released by Wladimir Köppen. According to the Köppen-Geiger climatic classification, Turkey is indicated in the Mediterranean climate region. Another important source for studying the area is classification of TS 825 which is based on heating degree-days and average temperatures [12]. It is an obligatory document that determines the thermal properties of envelope materials according to its climate zones, although it has some criticism by researches because cooling loads and heat stochastic have been neglected. Moreover, according to the Weatherbase web site, detailed numerical data is mentioned in the following step [13].

1) Average temperature of the year: 14.4 °C
2) Highest recorded temperature: 37.8 °C (in July)
3) Lowest recorded temperature: -8.9 °C (in January)
4) Warmest month on average: July with 23.3 °C
5) Coldest month on average: January with 5.6 °C
6) The average precipitation of the year: 640.1 mm
7) The month with the most precipitation: December with 101.6 mm
8) The month with the least precipitation: August with 15.6 mm

Fig. 1 Location of Istanbul, Turkey

The main features of the Mediterranean climate are extreme summers since there are mild-winter conditions. In such a climate, one of the influential parameters can be shading devices which are the perfect solution to protect from rain and take advantage of sunlight during the winter while avoiding it during the summer. Natural veneration is another important parameter for common usage spaces which is achieved by suitable orientation and openings. For example, west and east-facing windows are small to protect from sunlight during summer days, but large north-facing windows lose heat due to being located on shaded sides and directly affected by harsh and cold winds; however, proper windows should have a suitable size, provide daylight, desirable air circulation, and a good view. Common usage spaces are usually located in the southern section of buildings to maximize the benefits of sunlight through large windows [14], [15].

The specific property of the Mediterranean climate buildings is a courtyard. It provides an optimal space by maximizing solar radiation, protecting from severe winds, and providing good ventilation; therefore, a courtyard can be a suitable solution for harsh weather conditions [15]. Moreover, local materials for the envelope of buildings are adobe, clay, earth, brick, and stone.

V. Case Study

In this research, the Energy Institution building of Istanbul Technical University in Istanbul was analyzed as a base model. The weakness of the building is measured to reach

[3] kWh (kilowatt-hour) is a unit of energy equal to 3600 kilojoules.
[4] HVAC is abbreviation of heating, ventilation, and air conditioning.

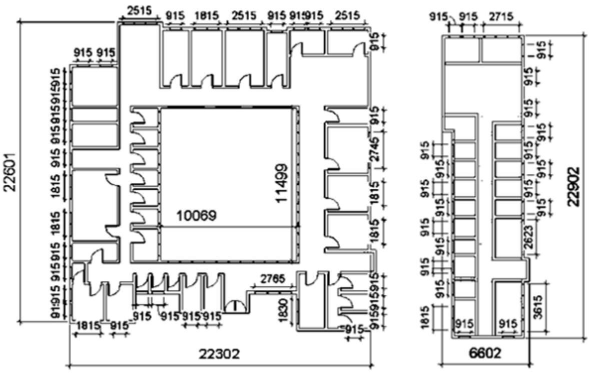
better energy performance by discovering true implementation.

The building has two floors with a courtyard, as shown in Fig. 3. The total area of two floors was 466 m^2, consisting of a 344 m^2 ground floor and 122 m^2 first floor, as shown in Fig. 2. The building has a courtyard and large windows consistent with buildings in the Mediterranean climate; this parameter allows for maximum use of daylight and ventilation in all spaces. There are three stairwells with wide corridors, while three toilets plus a butler's pantry comprise the wet areas. Vegetation and trees are planted around the building to control the impact of sunlight, wind, and rain during different weather conditions. The window-to-wall ratio in all directions was about 20%. The ceiling height throughout the building was about 3.5 m and a flat exterior roof.

It was assessed to have two thermal zone types: functional zone (ZF), which contains daytime-occupied spaces such as classrooms and offices, and service zone (ZS), which consists of spaces that are generally unoccupied such as lavatories and corridors (Table I).

TABLE I
SEPARATE ZONE OF THE BASE MODEL

Zone type	Area m^2	Comfort condition
ZF	280	Yes
ZS	186	No



(a plane) (b plane)

Fig. 2 Plane of the base model: (a plane) is for the ground floor and (b plane) is for the first floor

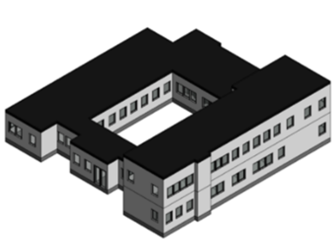


Fig. 3 Simulation of the base model

A. Envelop Details of the Case Study

Some important envelope design variables are identified for efficient buildings. They are building orientation, roof and wall solar absorption, window-to-wall ratio, and overhang projection ratio. The U-values or thermal conductivity of building envelope components and their thickness are the main parameters of materials that have high impacts on building performance. Table II shows information about the existing materials in the case study. Moreover, another trait of the building is that all of the interior spaces have good natural lighting; the windows were designed to maximize daylight conditions in the base model.

TABLE II
U-VALUE OF MATERIALS IN THE BASE MODEL

Building components	Material	U-value
Interior doors	Wood door panel	-
Exterior doors	Glass Aluminum	1.8 (W/m^{2}K)[5]
Windows	Glass Aluminum	1.8 (W/m^{2}K)
Ground floor	Structure, Steel Bar Joist Layer Oak Flooring EIFS, Exterior Insulation Concrete Masonry Units	0.57 (W/m^{2}K)
Interior floor	Structure, Steel Bar Joist Layer Oak Flooring Concrete Masonry Units	0.57 (W/m^{2}K)
Outside Walls	Paint Plaster EPS Concrete Masonry Units	0.57 (W/m^{2}K)
Roof	EIFS, Exterior Insulation Damp-proofing Concrete, Precast	0.38 (W/m^{2}K)

B. Space Conditioning of the Case Study

Most parts of the building rely on natural ventilation for cooling while small sections had air conditions.

The base model did not have a central cooling system except offices that had air conditioners, and the heating source was hot water coils. The case study was an academic faculty that did not need energy consumption during the night so the maximum time of energy usage was estimated as 12 hours during the open days and also, the schedule of eQuest was adjusted according to the academic calendar to be close to the real energy consumption in the building. Moreover, 186 m^2, which was equal to 40% of the total area in the building was corridors. Since the building was generally used by young people, 23 °C was considered sufficient to provide a comfortable condition for office work and study.

C. eQuest Results for Base Model

eQuest is an energy simulation tool to predict the energy consumption of a building; it indicates the rate of effect each parameter on energy performance (electric and gas consumption during the life span of a building.

According to the simulation results, the electric consumption of the base model was 63.16 kWh*1000 and the gas consumption was 728.78 Btu*1000,000[6] (Table III). The gas consumption was due to space heating and the maximum electric consumption was relative to equipment and area light.

[5] W/m^{2}K (watts per square meter-kelvin) is the thermal transmittance.
[6] BTU is a unit of heat (the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit).

Therefore in this situation, the electric price was $6568.64, and the gas price was between $5195.25 to $5818.68. (Turkey's electric price is $104 per thousand kW h [16] and gas ranging between $250 to $280 per thousand m^3 [17]).

VI. Changing Parameters

A. Environment Trees

Istanbul has a Mediterranean climate (temperature -8.9 °C to 37.8 °C) [13] with local winds due to the high buildings around the base model. Trees protect the building from direct sunlight during the warm days and being deciduous allow for greater sunlight penetration during the cold months. As well, trees have a cooling effect through a process known as 'transpiration cooling' and can protect the building against severe winds. According to the sources, trees reduce urban surface temperature by 2-9 °C and air temperature by about 1-5 °C, and increase relative humidity by 10-20%, especially at nighttime [18]. Trees cannot be entered as an eQuest input for simulation, so other objects similar to trees were considered on different sides of the building, then, the energy consumption was calculated. In the north and west sides of the building, subsequently, energy consumption was improved 0.41% and 1.6%, on the other hand, the gas consumption showed worse results with 0.13% and 2.17%, respectively Because of this matter the north part is selected (Table IV). The reason for this situation could be the sunlight and winds which penetrated the building.

B. External Walls

The effect of external walls U-value on energy consumption was examined and other materials were suggested for walls to decrease the U-value [19]. Thermal conductivity had a high impact on the level of energy consumption but not always a positive impact. The effect of thermal conductivity depends on various parameters such as climate. The U-value of the external walls was decreased by 0.09 W/m^2k (Table XII). The result of eQuest showed a 9.4% positive effect on electric consumption and an impressive effect on gas consumption of about 43% (Table V). According to the results, insulation had a high effect on energy consumption. Therefore, it could be one of the vital parameters between a variety of passive strategies.

C. Roof

Roof insulation is significantly effective in reducing cooling and heating loads. In this step, the U-value of the walls decreased by about 0.01 W/m^2k by increasing thickness of the roof insulation (Table XII) [20].

The results of eQuest indicated a 6.57% improvement in electric consumption and 29% in gas consumption (Table VI). Thus, the roof could be another important factor in the passive system.

D. Rate of Exposed Envelope

The ratio of the external envelope surface area to volume has a high impact on building energy performance (a long, thin building has a large external envelope area compared to a cube or a sphere building). In this research, the height of walls on each floor was decreased one foot and contact of building with the ground was increased by one foot during the simulation process.

Finally, by reducing the overall building exposure by three feet, electrical consumption (0.8%) and gas consumption (7.25%) decreased (Table VII).

E. Shading Devices

The balance between sunlight and shadow is a fundamental part of building design due to the changing angle of sunlight during different seasons, which has a strong effect on energy efficiency and thermal comfort. Sunshades protect the building from direct sun light and rain. In the simulation process, upper window sunshades are considered as 1 foot and 0.25 foot for bar sunshades in front of the windows, respectively. The result of eQuest declares that electric consumption of the cooling system decreased during the summer days; in other words, shading devices protect the building from heating up especially in the east and west sides. However, the gas consumption of the heating system increased.

As a result, electric consumption improves 0.4% by using east shading tools and 0.9% using west shading tools, whereas they had a negative impact on gas consumption by 0.3% and 0.4%, respectively (Table VIII).

F. Window/Wall Ratio

According to the existing documents, the ratio of the window/wall was 20% in the base model which means that 20% of the exposed walls were formed from windows that had higher thermal conductivity than walls. The base model had windows with 1.8 W/m^2k U-value and walls with 0.57 W/m^2k U-value so thermal conductivity of windows was higher than the exterior walls. In this paper, the area of windows was declined by 50% to indicate the rate of impact on energy consumption although eliminating half of the windows is impossible.

TABLE III
Electric and Gas Consumption of the Base Model (kWh)[7]

Base	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electric	4830	5000	4870	5070	5710	4780	5840	6490	4960	5410	4760	5430	63160
Gas	51176.07	41173.55	29477.08	15682.23	4999.79	149.46	0	0	345.82	7918.78	27739.17	34925.27	213584.33

[7] eQuest calculate the gas consumption base on BTU but all of them converted to kWh to compare easily during the research,

TABLE IV
EFFECT OF ENVIRONMENT TREES ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model A	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
Shading object in the North	62900	213874.47
Shading object in the South	63260	221930.99
Shading object in the East	63160	215817.53
Shading object in the West	62160	218235.37

TABLE V
EFFECT OF EXTERNAL WALLS U-VALUE ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model B	Yearly Electric	Yearly Gas
Base Model (U-value of walls = 0.57)	63160	213584.33
Model B (U-value of walls = 0.48)	57240	121697.76

TABLE VI
EFFECT OF ROOF U-VALUE ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model C	Yearly Electric	Yearly Gas
Base Model (U-value of roof = 0.38)	63160	213584.33
Model C (U-value of roof = 0.37)	59010	151555.84

TABLE VII
EFFECT OF EXPOSED ENVELOP RATE ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model D	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
Model D	62680	198092.59

TABLE VIII
EFFECT OF SHADING DEVICES ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model E	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
North window shades & fins	63110	213727.93
South window shades& fins	63160	214633.52
East window shades& fins	62900	214372.69
West window shades& fins	62580	216474.01
All window shades & fins	62280	216474.01

TABLE IX
EFFECT OF WINDOW/WALL RATIO ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model F	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
Dec. 50% North windows	63160	213584.33
Dec. 50% South windows	63160	213651.74
Dec. 50% East windows	63160	213584.33
Dec. 50% West windows	63160	213809.99

The eQuest results show that the window/wall ratio did not have any effect on electric consumption however gas consumption was raised due to the heating system. This matter is pertinent to the heating inside of the building by sunlight through windows (Table IX). Therefore, this alternative could not be a suitable technique for this building.

G. Window and Door Typess

The windows and exterior doors were examined. The existing windows were double low-E glass with 1.8 W/m^{2}k U-value and aluminum frames, the exterior door had almost the same U-value as in the base model. In this scenario, triple low-E glass windows with 0.5 W/m^{2}k U-value which had wooden frames with 0.22 W/m^{2}k U-value [21] and doors with 1.3 W/m^{2}k U-value are suggested [22] (Table XII).

The result of the eQuest simulation indicated a positive effect on electricity consumption by about 0.2% and on gas consumption by 0.5% (Table X). Therefore, it could be an effective parameter for the final scenario.

TABLE X
EFFECT OF WINDOWS' AND DOORS' U-VALUE ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model G	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
Model G	63010	212605.47

H. Lighting

The large proportion of the total electric consumption was relative to the lighting system. The lighting system not only uses energy but also released heat, especially the older electric bulbs were so inefficient (about 90% of produced energy is thermal) [23], which indirectly increased the air conditioning load, thereby increasing energy consumption. The main goals of this study were saving energy and a suitable lighting level without sacrificing comfort and quality by replacing lamps or their design and the application of contemporary energy technologies like automatic sensors; for instance, LED lamps were 50% more effective [23], [24] Therefore, decreasing 30% of light load is attainable by substituting the lamps with more efficient versions.

As a result, when light load is decreased by 30%, the annual electric consumption is improved by 9% in eQuest modeling, while the results show a slight overall increase in the amount of gas consumption (Table XI). eQuest software calculates based on light intensity and pre-defined inputs, therefore, modifying the details of the lighting system is not possible.

TABLE XI
EFFECT OF LIGHTING SYSTEM ON ELECTRIC AND GAS CONSUMPTION (KWH)

Model H	Yearly Electric	Yearly Gas
Base Model	63160	213584.33
Decreasing light load 30%	57480	215474.64

TABLE XII
U-VALUE OF SUGGESTED MATERIALS FOR BUILDING

Building components	Material	U-value
Interior doors	Wood door panel	1.1 (W/m^{2}K)
Exterior doors [22]	Epoxy resin panels Aluminum	1.3 (W/m^{2}K)
Windows [21], [22]	Glass Wood frame	0.5 (W/m^{2}K) 0.22 (W/m^{2}K)
Ground floor	Structure, Steel Bar Joist Layer Oak Flooring EIFS, Exterior Insulation Concrete Masonry Units	0.57 (W/m^{2}K)
Interior floor	Structure, Steel Bar Joist Layer Oak Flooring Concrete Masonry Units	0.57 (W/m^{2}K)
Outside Walls [19]	Limestone wall Reinforced concrete wall Rock wool insulation Plasterboard	0.48 (W/m^{2}K)
Roof	EIFS, Exterior Insulation Damp-proofing Concrete, Precast	0.37 (W/m^{2}K)

TABLE XIII
ELECTRIC AND GAS CONSUMPTION OF FINAL SUGGESTED MODEL (KWH)

Base	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electric	4350	4430	4330	4460	5040	4350	5340	5960	4440	4770	4220	4810	56510
Gas	47181.51	37803.23	26909.78	14187.57	4495.71	123.08	0	0	290.14	7224.20	25432.70	32053.18	195701.13

VII. SUGGESTED MODEL

Each of the effective passive parameters was investigated separately then useful parameters that decrease energy consumption were selected to suggest a final model. In summary, helpful parameters were environment trees, insulation, decreasing U-value of materials (Table XII), shading devices, rate of exposing, window/wall ratio, and improving the lighting system (Table XIV). In the next step, the results of the baseline model were compared with the suggested model to determine the effect of the overall changes in energy consumption.

The results indicated that the electric consumption decreased by 10.5% and gas consumption decreased by 8.37% in comparison with the base model (Table XIII). Consequently, annual expenses related to utilities were reduced. The annual cost for electricity was $5877.04, with a saving of about $692, while for gas it was between $4760.25 to $5331.48, a saving of about $435 to $487.

TABLE XIV
COMPARISON THE RESULTS OF ELECTRIC AND GAS CONSUMPTION (KWH)

Variable Parameters	Electric	Gas
Base Model	63160	213584.33
Shading object like trees in the North	62900	213874.47
Shading object like trees in the South	63260	221930.99
Shading object like trees in the East	63160	215817.53
Shading object like trees in the West	62160	218235.37
U-value of walls = 0.48 from 0.57	57240	121697.76
U-value of roof = 0.37 from 0.58	59010	151555.84
Decreasing the Rate of Exposed Envelope	62680	198092.59
North window shades & fins	63110	213727.93
South window shades& fins	63160	214633.52
East window shades& fins	62900	214372.69
West window shades& fins	62580	214484.06
All window shades & fins	62280	216474.01
Dec. 50% North windows	63160	213584.33
Dec. 50% South windows	63160	213651.74
Dec. 50% East windows	63160	213584.33
Dec. 50% West windows	63160	213809.99
Dec. U-value of windows & doors	63010	212605.47
Saving light 30%	57480	215474.64
Final scenario	56510	195701.13

VIII. CONCLUSION

Energy has become a hot topic in the world and a high rate of energy consumption is relative to the building sector. Passive parameters are the initial stage for efficient buildings. In this study, an energy institution in Istanbul, Turkey was considered as a base model to indicate the effect of some passive parameters on energy consumption. Next, the ideal parameters were selected based on the eQuest results to suggest an efficient final model for the building that saves not only energy but also money.

The eQuest results showed that the electric consumption of the base model was 63160 kWh and the gas consumption was 213584.33 kWh, annually[8].

1) Maximum positive effect was relative to decreasing thermal conductivity of the external walls by 1.1 kWh. Thermal insulation decreased consumption of electricity by 9.4% and of gas by 43%.
2) Maximum negative influence was relative to existing trees on the south-facing facade of the building. Planting trees on the south side of the building increased electric consumption by 0.15% and gas consumption by 3.9% due to blocking the sunlight in this direction.
3) The U-value of the walls, the lighting system, U-value of the roof, western tree planting, shading tools of west windows, envelope exposure, northern tree planting, shading tools of east windows, and U-value of windows, are some parameters which have a positive impact on the energy consumption in the building and their rate of effectiveness is from the highest level to the lowest, respectively.
4) Some helpful strategies for gas consumption are considering the U values of walls and roofs, rate of envelope exposure, and U value of the windows respectively [9].

In the final scenario, electric consumption was 56510 kWh, and gas consumption was 195701.13 kWh, annually. These results show an annual decrease in the consumption of electricity by 10.5%, and of gas by 8.37%. The final results confirmed the impressive decrease in the overall energy consumption and a positive effect on the environment.

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