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A study on the payback period of building energy consumption optimization in different situations

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Abstract

Buildings are the main pillars of social and economic development of countries and they consume a huge amount of energy and natural resources. This energy consumption is $30-50\%$ on average. The present study aims to investigate the effect of the locations of buildings around neighboring buildings and pathways on the payback period of optimization. The research scope includes common residential apartments in Tehran. According to the research method, we consider 6 similar residential blocks in different lighting situations. Using simulation in Design Builder software, we calculate their energy consumption and then optimize their energy consumption. The optimization variables are as follows: the material of the outer wall (clay or LECA) and the façade (stone or brick), the type of window glass (plain or low-emissivity), the type of gas between the layers of the window glass (air or argon), and the ratio of the window to the surface of various directions the building. The optimization goals include the minimization of energy consumption and construction cost. Design Builder software and genetic algorithm are used to optimize the variables. After optimization, the 6 selected optimized blocks are then calculated in the simulation software and their energy consumption is calculated and compared with the results before optimization. The research results indicate that the mean reduction in energy consumption is 77% in the northern blocks, 65.2% in the southern blocks, and 71% in all blocks, and the optimization results in the northern blocks are about 12% better than the southern blocks. Given the proposed optimization changes, we calculate and compare the increase in the construction cost of each block. The results indicate that the mean increase in the construction cost is 1.6% in the northern blocks, 2.7% in the southern blocks, and 2.2% in all blocks, and the increase in the costs of building northern blocks is about 1.1% less than southern blocks. According to the prices of electricity and gas in Iran, we measure the annual energy cost saving and the results indicate that the payback period of optimization is about 7.7 years in the northern blocks, 13.8 years in the southern blocks, and 10.8 years in average, and the calculations indicate that if the mean global energy prices prevail in Iran, this time reduces to 6 months.

Keywords: residential building, energy consumption, building location, design Builder, optimization, construction cost, payback period
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Introduction

The end of the 20th century faced the rapid growth of industry followed by the increase in energy consumption and the low primary resources, especially fossil resources, the harmful effects of fossil fuels on the environment, and the

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emergence of concepts such as sustainability and sustainable development to fulfill current needs without endangering the future generations' needs, the need to reduce energy consumption, especially fossil resources, and energy production from other sources, such as atomic energy, wind energy, and geothermal energy.

Buildings are the main pillars of the social and economic development of countries and consume most of the energy and natural resources [1]. This sector has an energy consumption of $30-50\%$ on average and produces $40-50\%$ of greenhouse gases [2, 3, 4, 5, 6]. Based on the Iran Energy Balance Sheet of Iran in recent years, about 33% of the energy produced is related to the domestic, commercial, and public sectors, or the construction sector [7].

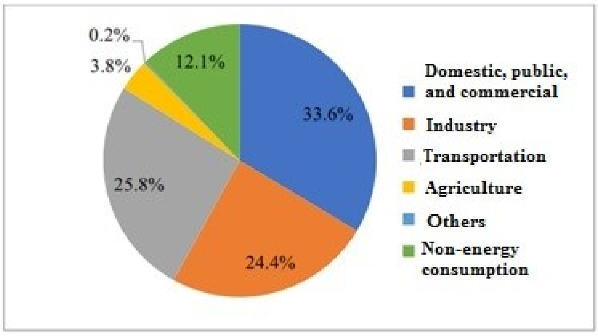

Figure 1: The contribution to energy consumption in different regions of Iran [7]

Buildings are divided into residential, service, and administrative sectors. Even though there is no comprehensive research on the contribution of each sector to energy consumption in all countries, the results of studies in some countries indicate that residential use has a greater contribution to energy consumption compared to other uses [8]. Based on the data published by the Statistical Centre of Iran, about 84% of the planning permissions issued in municipalities are related to residential uses [9]. In a residential building, energy consumption depends on parameters that can be divided into external, human, and construction factors [10]. External factors include climatic conditions, geographical location, density, and location of adjacent buildings. Human factors include the number of residents, the residents' age, and their behavior. Construction factors refer to the physical characteristics of buildings and include many items. Given that the construction in Iran is generally performed by people who are not professionally qualified for it and also the general movement is towards reducing subsidies and their reform, it is the right of the home buyers to know the amount of energy consumption and costs of buildings in the future. As mentioned, external factors, including the location of a building around neighboring buildings and pathways affect the amount of energy consumption of a building. The present research seeks to measure the effect of the location of a building around the pathway on the cost of energy consumption optimization.

Literature review

Choosing the optimal building variables from a set of possible options is a research field that we investigate in the research background. The use of numerical optimization methods in energy consumption in buildings has attracted researchers' attention since the 80s. According to Shi et al. [11], D'Cruz et al. [12] conducted the first research on optimization and published it in 1983. This research optimized design variables such as the direction and shape of the building with the aim of suitable lighting, cost, and space. Shi et al. believe that even though an energy simulator or a valid algorithm is not used in this article, the method is according to the optimization principles. It became gradually clear that multi-objective optimization methods are more suitable for construction variables because they allow the examination of a wide range of variables along with different and sometimes conflicting objectives and also provide a set of non-dominated optimal solutions (Pareto front). [13] Since 2000, the integration of energy simulators and optimization algorithms has increased significantly [11] and various optimization methods and tools have been prepared in a way that there are dozens of optimization methods for various applications, including buildings, and evolutionary algorithms constitute a significant part of them. Optimization algorithms often seek to optimize one or a combination of the following goals: 1- Energy consumption, 2- Environmental consequences, 3- Residents' comfort, and 4- Construction cost

Yavari et al. examined the effect of the height of residential buildings in Tabriz city on energy consumption. To this end, they considered three different types of buildings including 3-4-floor apartments, 8-10-floor apartments, and villas,

and 3-4 buildings were selected from each category in a certain area of the city to analyze their energy consumption. Then the amounts of their gas and electricity consumption were recorded in different seasons and compared. The results indicated that 3-4-floor apartments had the highest optimal consumption among the 3 options [14].
Sajadi and Baniassadi investigated the effect of phase change materials on energy consumption in different climates. Based on their results, the optimal thickness of the mentioned materials was 2-4 cm and the innermost layer of the wall was the most suitable place for their placement [15].

Mirhashmi et al. studied the optimization of thermal performance of windows. Their results indicated that optimizing the window glass, frame, and profile with minimum cost could reduce the heat transfer coefficient of the entire window by 37%. Based on their results, adding the second layer decreased the transfer coefficient by about 50%, but adding the next layers had an effect of less than 12%. The researchers believed that since the light passing through the window did not decrease significantly with the increase of layers, the performance of the windows was acceptable in terms of the amount of light transmission inside the building [16].

Bagheri and Makarizadeh examined the effect of window surface on energy consumption in 4 climates of Iran, including hot and dry, hot and humid, temperate, and cold, and provide an optimal level according to the health necessities of using the light outside [17].

Ramin et al. used mathematical equations to solve a multi-objective optimization problem. The objective functions of this research were as follows: wall cost, life cycle energy consumption, carbon monoxide emission, and water consumption. The researchers assumed a hypothetical wall with the main material thickness of 20 cm, but the thickness of the thermal insulation varied from 1 to 15 cm. Four different wall compositions were considered based on the change in the layout of the thermal insulation and structural materials. Weighting the objective functions, the researchers turned the multi-objective problem into a single-objective problem and used the normalization method to equate the functions considering that each function had its limits [18].

Caldas and Norford analyzed the optimal selection of cooling and heating systems and building envelope variables, including building shape, materials in the walls, and the location of windows with the help of GA and DOE-2 with the aim of construction and operation cost [19].

Wang et al. optimized the shape of green building design and some variables such as window-to-wall ratio to minimize environmental consequences and cost using GA [20].
Penna et al. combined MATLAB and TRNSYS optimization tools to optimize desired variables, including lighting and air conditioning systems, and wall and ceiling insulation to achieve a zero-energy building [21].

Znouda et al. combined CHEOPS and GA thermal software to minimize building energy consumption and its cost and indicated that energy simulation software along with optimization tools were suitable ways to optimize non-linear building variables [22].

Alaidroos and Krarti used the genetic algorithm to optimize different variables of the building envelopes of a two-floor villa in 5 different climates of Saudi Arabia. The five variables included roof insulation, external wall insulation, type of glass, external wall materials, and window awnings. Reducing the building life cycle cost and increasing thermal performance were the goals and EnergyPlus software was used in this research [23].

Kusiak et al. optimized the air conditioning system of an office building with the help of a neural network algorithm and multi-objective bird nest optimizer to minimize energy consumption and increase the thermal comfort of the residents [24].

Cooper optimized the outer wall and its insulation thickness by combining the EnergyPlus software and the bird nest algorithm to optimize the annual energy consumption and cost [25].

Yousefi and Gholipour [26] pointed out research by Hamdy et al. who indicated that more than 40% of researchers had used the genetic algorithm for optimization over the past several years [27].

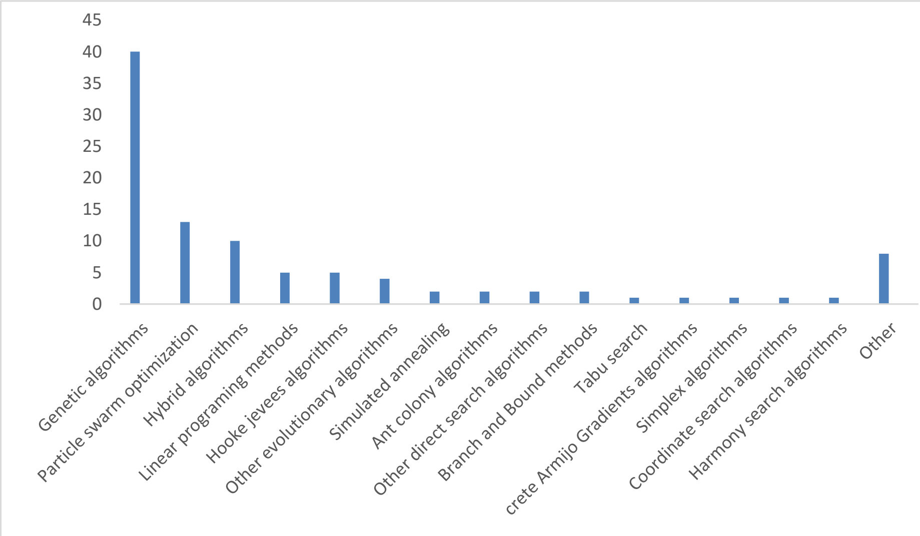

Figure 2: Comparison of the frequency of optimization algorithms [27]

Yousefi and Gholipour [26] mentioned the research by Palonen et al. who compared several existing and relatively well-known optimization tools as presented in the following table.

Table 1: Comparison of optimization software features [26]

Group	**Optimizer software**	**Energy computing engines**	**Free**	**Performing multi-objective optimization**	**Performing parallel computing**	**Some other studies that used this optimizer**
Specific energy optimizers	Opt-E-Plus	Energy Plus	Yes	No	No	
	GENE_ARCH	DOE-2	Yes	Yes	No	[28]
	BEopt^{TM}	DOE-2,TRNSYS	Yes	No	No	
	TRNOPT	TRNSYS	No	Yes	No	
	MultiOpt2	TRNSYS	No	Yes	Yes	[29]
	JEPlus+EA	Energy Plus, TRNSYS	No	Yes	Yes	[30][31][32]
General optimizer	GenOpt		Yes	No	Yes	[33][34][35] [36][37][38][39]
	ModelCenter		No	Yes	Yes	[31]
	ModeFRONTIER		No	Yes	Yes	[30][32]
	DAKOTA		Yes	Yes	Yes	
	iSIGHT		No	Yes	No	
	MATLAB Optimization Toolboxes		No	Yes	Yes	[33][34][35][36]
	MOBO		Yes	Yes	Yes	[37]

Research background

In research on the performance of the southern greenhouse on the reduction of heat loss in an apartment in Shahrud city, the results indicated that the greenhouse in the south of the building decreased the heat loss of the adjacent space by about 33% and prevented the heat exchange directly between the adjacent and external spaces of the building [40]. Research on the effect of the middle cavity on the performance of the cooling energy consumption of an extensive double-skin façade in a hot and humid climate (Kish Island) indicated that the cavity depth played an effective role in reducing the cooling energy and the two-skin facade with a depth of 50 to 70 cm was the most optimal distance in reducing cooling energy consumption compared to other distances in low-rise office buildings in a hot and humid climate [41]. Research on the economic analysis and evaluation of energy consumption based on the type and ratio of windows using simulation models (case study: a residential unit in Tehran) indicated that energy consumption

decreased by 20.3% only by using windows with high efficiency and optimal ratios. According to the current price of fuel in Iran and the payback period of 17.8 years, which were obtained from the economic analysis, additional initial costs would be compensated by adopting the proposed policies [42]. Research titled the creation of middle courtyards in urban blocks for reducing the consumption of energy resources (case study: low-rise residential apartments in Tehran) indicated that the form of the middle courtyard with the lowest surface-to-volume ratio decreased the cooling load in summer by 18.35 kWh/m^2 compared to the existing status. The reduction of heating load in winter was also equal to 6.67 kWh/m^2 [43]. Research on the relationship between energy consumption and opening ratio in high-rise office buildings indicated that the opening ratio and the annual energy consumption of the research model had a direct relationship as the reduction of the opening ratio by up to 20% could reduce energy consumption by 17% of the annual consumption in the basic model [44]. Research on the effects of indoor sunshades on energy consumption using simulation models indicated that only an optimal indoor shading system could reduce energy consumption in the housing sector of Tehran even by 14% [45]. Research on the methodology of choosing energy simulating software in the architecture, the final certain software of the research was finally introduced from the combination of the results in two theoretical and practical fields [46]. In an article by Barzegar and Heidari [47], the built area and the number of residents in the building do not directly affect the energy consumption of residential buildings in Shiraz, but the residents' behaviors and the type of construction directly affect the amount of energy saving. Ebrahimpour and Karimi Vahed [48] investigated the effects of the facade and its color on the energy consumption of a university building in Tabriz. According to EnergyPlus software, their results indicated that if light colors were used instead of dark colors in the facade, it was possible to save about 9% in annual energy consumption in the climate of Tabriz. Arabzadeh and Kazemzadeh [49] used energy simulator software to examine the effects of parameters such as diversity of façade in exterior walls, the thickness of the insulation of the exterior walls, diversity of materials in the roof, the thickness of the roof insulation, types of glass, and size of windows on the thermal load, and the energy consumption rate of the building. Ghafari et al. [50] simulated a 5-floor single-unit residential apartment in DesignBuilder software and examined the effects of various elements, including windows, roof, floor, and insulation in a combination on amounts of cooling and heating energy of buildings. Based on the research results, if all points considered by the authors are applied in buildings, the energy consumption of buildings is saved up to 44% in Tehran. Farhanieh and Sattari [**?**] examined the effects of external wall insulation on the energy saving of Iranian buildings and found that choosing the right insulation for external walls could decrease the building energy consumption by 35%. According to this study, the external wall had the greatest impact on energy consumption.
According to previous studies, four factors affect the thermal performance of buildings: 1-Design, 2- Materials, 3- Environmental factors, and 4- Residents' behavior [51, 52, 53, 54, 55].

Research methodology

1- Selection of six similar residential blocks in different locations

We consider six different residential blocks in terms of location. These blocks are completely similar in terms of land area, built area, number of floors, heating, and cooling systems, and other characteristics of the sample building, and the only difference between them is the location in an alley as three blocks A, B, C are in the north and three blocks D, E, F in the south. Block A receives light from the south and west. Block B receives light only from the south. Block C receives light from the south and east. Block D receives light from three directions, north, south, and east. Block E gets light from the north and south. Block F receives light from north, south, and west. In terms of location, these six blocks are representatives of the majority of common residential buildings in Tehran.

2- Choosing the right software for simulating and calculating energy consumption

As shown in Figure 4, different software for building energy consumption simulation are compared in terms of five criteria: 1- accuracy, 2- usability, 3- intelligence, 4- interoperability, 5- process adaptability, and thus DesignBuilder software has a better status compared with other software. According to the above-mentioned content, DesignBuilder is considered for simulation.

3- Entering the data of blocks' characteristics and climatic conditions into the software and calculating the energy consumption

We need to enter two series of data into the software to simulate the sample building in DesignBuilder and calculate the energy consumption level:

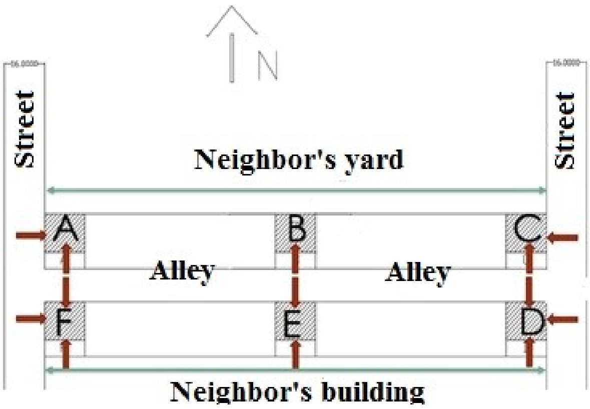

Figure 3: Location of six selected blocks

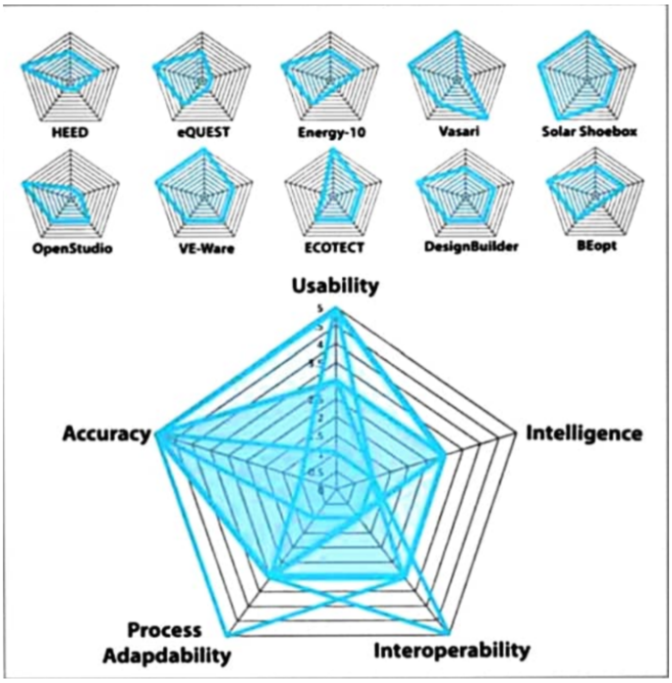

Figure 4: Comparing the performance of different simulation software and calculating energy consumption [56]

1- The data about building characteristics, such as materials and types of heating and cooling systems as presented in Table 2.
2- The data about the climatic status of Tehran, such as wind direction and amount of radiation as presented in Table 5.

4- Validation of results

We use two methods to validate the results:
The first method: Comparison of electricity and gas bills
The second method: Comparison with the results of similar research

5- Optimization

Variables and objectives should be identified for optimization. The following table presents the variables. The optimization goals include the minimization of construction costs and energy consumption.

Table 2: General characteristics of six sample blocks

Characteristics of sample blocks	**Use**	**Number of floors**	**Number of units**	**The location around the pathway**	**Eastern and western neighbors**	**Materials of the roofs**	**External walls**	**Materials of the roof**
	Residential	5 floors on pilot	10	Different	5 floors on pilot	Joist and polystyrene	Clay without thermal insulation	Tar paper
	Eastern and western interruption joint	Heating system	Cooling system	The materials of windows	Number of residents	Building age	Facade material	Light side
	8 cm	Package	Water cooler	Plain double glazing with air	27	10 years	Travertine	Different
	Land area	Built area of each unit	Total built area	Location in Tehran	Northern WWR	Southern WWR	Western WWR	Eastern WWR
	$320m^2$	$105m^2$	$1125m^2$	District 5	21%	41%	25%	25%

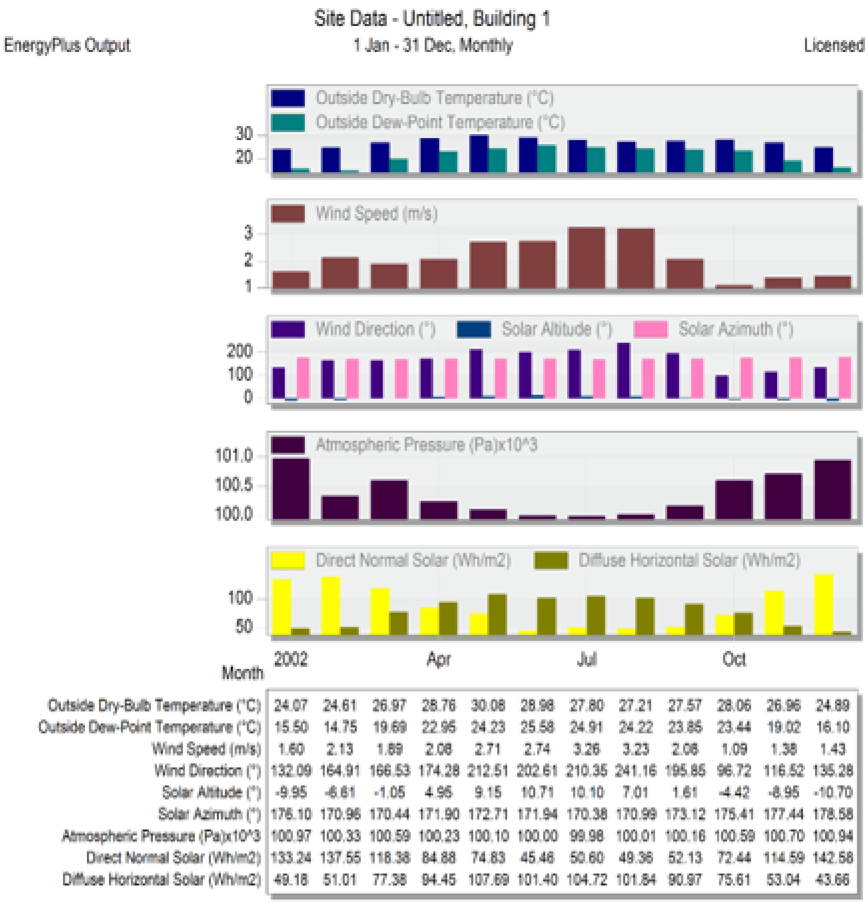

Figure 5: Geographic information of the 6-block site according to the meteorological synoptic table of Tehran at Mehrabad station

6- Entering data about characteristics of the optimized blocks into the software and comparing the amount of consumption with the pre-optimization

7- Economic analyses

In this step, the amount of increase in construction cost and the amount of energy saving cost due to the optimization of each block are calculated and compared separately.

Table 3: Optimization variables

Row	Variables		Decision space
1	External wall	External layer	Stone Brick
		External layer	Clay block Clay block with thermal insulation LECA LECA with thermal insulation
2	Windows		Plain 3-cm double glazing
			Plain 3-cm double glazing with argon low-emissivity 3-cm double glazing low-emissivity 3-cm double glazing with argon
3	Southern WWR of all blocks		30%, 40%, 50%, 60%
4	Northern WWR in the southern blocks		20%, 30%, 40%, 50%
5	Eastern WWR of blocks C and D		20%, 30%, 40%, 50%
6	Western WWR of blocks A and F		20%, 30%, 40%, 50%

Research results

1- Comparison of energy consumption

Figure 6 shows the results of energy consumption of 6 blocks extracted from DesignBuilder.

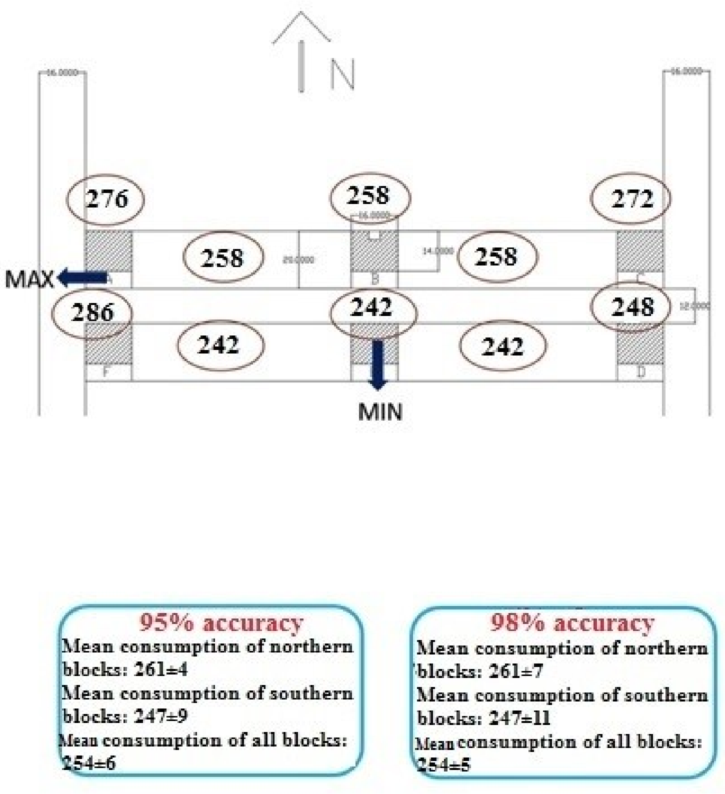

Figure 6: Comparison of energy consumption of six blocks in kWh/m^2/year

As shown, the mean energy consumption is 261 ± 7 kWh/m2/year in the northern blocks, 247 ± 11 kWh/m2/year in the southern blocks, and 254 ± 5 kWh/m2/year in all blocks with 98% accuracy. Northern blocks consume about 5%

more energy higher than southern blocks. The highest energy consumption is related to block F with about 11% more than the mean, and the lowest consumption is related to block E with about 5% less than the mean.

We use two methods to validate the results:

The first method: Comparison of electricity and gas bills

To this end, we collect the electricity and gas bills of all 10 units of a block (Block E) for the last year and add the amounts of consumption to calculate the real energy consumption of the building per year. It should be noted that the electricity consumption in the bills is in kWh and the gas consumption is in m^3, which must be multiplied by 10.4 to be converted to kWh.

Table 4: Comparison of simulation results in DesignBuilder with electricity and gas bills on block E

Electricity bill in kWh	Gas bill in m^3	Gas bill in kWh	Total energy consumption based on bills	Results of electricity consumption in the software	Results of gas consumption in software	Results of total consumption in software	Percentage of gas consumption difference	Electricity consumption difference percentage	Total difference Percentage
78260	12852	133660	211920	91256	163908	255164	18%	14%	17%

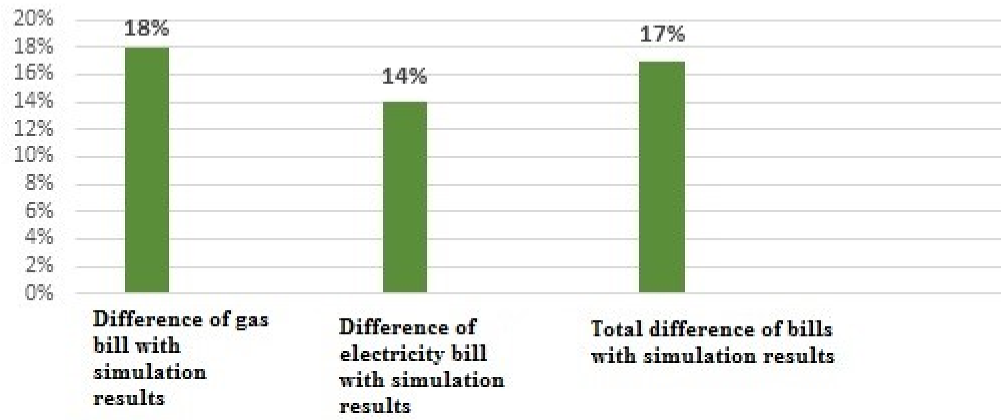

Figure 7: Difference between results of Design Builder with the electricity and gas bills of block E

The second method: Comparison with results of other studies

In the article "Household gas reform plan", the gas consumption of a 4-member family is estimated to be about 75 GJ or 20833 kWh/year; in other words, each person consumes an average of 5208 kWh/year of gas per year. In our research, each person in block E consumes 6037 kWh of gas per year which is about 14% different from the results of the mentioned article. The following reasons can be mentioned for the difference between simulation results and electricity and gas bills:

1- The meteorological data in the model is prepared based on the data of the last 40 years and it is thus not completely consistent with the status of the last year when the bills are considered.

2- Under real conditions, about 10% of the interior space is dedicated to cabinets, closets, and bathrooms, which are non-thermal spaces; hence, thermal and cooling loads are overestimated.

2- Optimization

The following table presents the results of optimizing the variables of each block with the mentioned goals using DesignBuilder with the help of the genetic algorithm.

Table 5: Summary of optimization results by DesignBuilder using the genetic algorithm

Block	External wall layer	Internal wall layer	Plain or low-emissivity	Argon or air	Southern WWR	Northern WWR	Eastern WWR	Western WWR
A	Stone	LECA with thermal insulation	Low-emissivity	Argon	60	-	-	25
B	Stone	LECA with thermal insulation	Low-emissivity	Argon	55	-	-	-
C	Stone	LECA with thermal insulation	Low-emissivity	Argon	50	-	45	-
D	Stone	LECA with thermal insulation	Low-emissivity	Argon	60	35	30	-
E	Stone	LECA with thermal insulation	Low-emissivity	Argon	45	25	-	-
F	Stone	LECA with thermal insulation	Low-emissivity	Argon	40	35	-	35

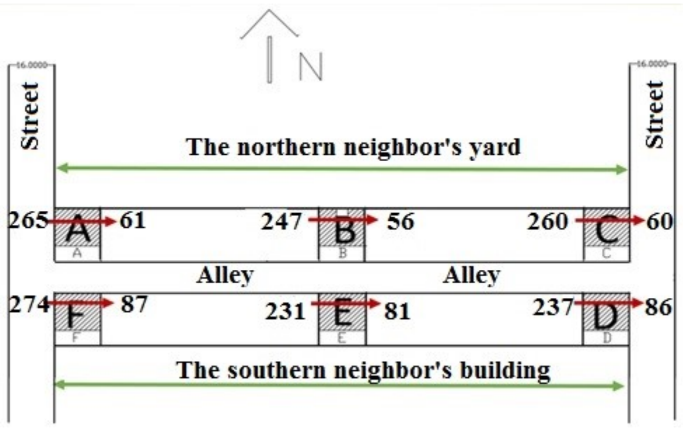

Figure 8: Comparison of energy consumption of blocks in kWh/m2/year before and after optimization

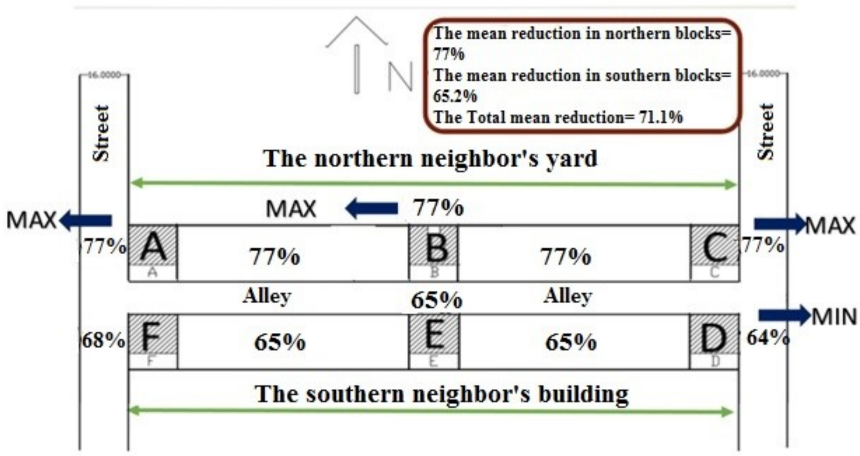

Figure 9: Comparison of percentage of reduction in energy consumption of blocks after optimization

3- Comparison of energy consumption before and after optimization

After finding the optimization results, we recalculate all six blocks in the simulation software and their energy consumption and compare them with the previous ones. Figures 8, 9, and 10 present the results.

The following results are obtained according to the above figure and the comparison of the energy consumption reduction percentages of the six blocks:

1- The mean reduction in energy consumption is 77% in the northern blocks.
2- The mean reduction in energy consumption is 65% in the southern blocks.

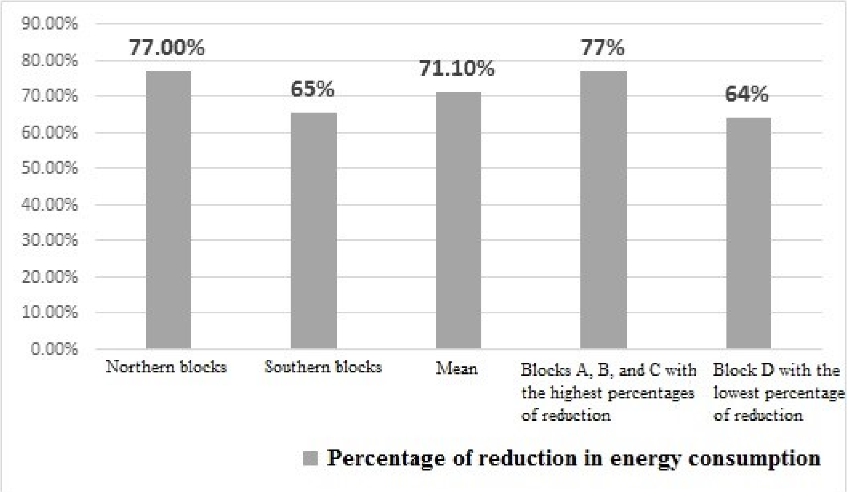

Figure 10: Comparison of percentage of reduction in energy consumption of northern and southern blocks after optimization

3- The mean reduction in energy consumption is 71.1% in all blocks.
4- The highest reduction in energy consumption is related to blocks A, B, and C.
5- The lowest reduction in energy consumption is related to block D which receives light from three north, south, and east.
6- The results of energy consumption optimization of the northern blocks are about 12% better than the southern blocks.

3- Economic analyses

A- Increase in construction cost due to optimization

According to optimization in previous sections, it reduces about 70% of the energy consumption in the operation phase, and thus we are seeking to investigate and analyze the increase in the cost of construction due to the optimization.

Table 6: Implementation cost of various components of window, wall, and thermal insulation

Components of window, wall, and thermal insulation	Price of m^2 in Tomans
Double glazing glass	577260
Argon	19170
Frame	513000
low-emissivity envelope	128250
Clay 20 wall, mortar, and labor	123255
LECA 20 wall, mortar, and labor	179880
2-cm Plastofoam	35000
Prices of a plain double glazing window and frame	1090260
Prices of a double glazing low-emissivity with Argon and frame	1237680
Prices of LECA wall and total 2-cm plastofoam	214880

Several changes occur in the optimization according to the following table:

1- Changing a Plain double-glazing window with air to a plain low-emissivity double-glazing window with argon
2- Changing the external clay walls to external LECA walls and 2-cm plastofoam thermal insulation
3- Changing the ratio of the window to the area according to the above-mentioned optimal ratios

To calculate the above-mentioned optimization cost in each block, we need to measure the suitable area of the window in each block and its remaining, i.e. the suitable area of the external wall, and then estimate the cost of changing the plain double-glazing window with air to double-glazing low-emissivity window with argon, and changing the clay

Table 7: The area of windows and external walls on four directions of each block in m^2

Current status of blocks	The southern area (m^2)	Percentage of glass in the southern area	Net southern area (m^2)	Southern glass area	The northern area (m^2)	Percentage of glass in the northern area	Net northern area (m^2)	Northern glass area	The eastern area (m^2)	Percentage of glass in the eastern area	Net eastern area (m^2)	Eastern glass area	The western area (m^2)	Percentage of glass in western area	Net western area (m^2)	Western glass area	Total area without glass	Total glass area (m^2)
A	240	40	144	96	240	-	240	-	210	-	210	-	210	25	157	53	751	149
B	240	40	144	96	240	-	255	75	210	-	210	-	210	-	210	-	819	171
C	240	40	144	96	240	-	240	-	210	25	157	53	210	-	210	-	751	149
D	240	40	144	96	240	20	192	48	210	25	157	53	210	-	210	-	703	197
E	240	40	144	96	240	20	192	48	210	-	210	-	210	-	210	-	756	144
F	240	40	144	96	240	20	192	48	210	-	210	-	210	25	157	53	703	197

Table 8: The area of windows and external walls of four directions of each block in m^2 after optimization

Block optimization	The southern area (m^2)	Percentage of glass in the southern area	Net southern area (m^2)	Southern glass area	The northern area (m^2)	Percentage of glass in the northern area	Net northern area (m^2)	Northern glass area	The eastern area (m^2)	Percentage of glass in the eastern area	Net eastern area (m^2)	Eastern glass area	The western area (m^2)	Percentage of glass in western area	Net western area (m^2)	Western glass area	Total area without glass	Total glass area (m^2)
A	240	60	96	144	240	-	240	-	210	-	210	-	210	25	53	157	599	301
B	240	55	108	132	240	-	255	75	210	-	210	-	210	-	210	-	783	207
C	240	50	120	120	240	-	240	-	210	45	95	115	210	-	210	-	665	235
D	240	60	96	144	240	35	84	156	210	30	63	147	210	-	210	-	453	447
E	240	45	132	108	240	25	60	180	210	-	210	-	210	-	210	-	612	288
F	240	40	144	96	240	35	84	156	210	-	210	-	210	35	74	136	512	388

external wall to LECA wall and plastofoam thermal insulation for each block separately, as presented in the following tables:

As shown, the mean increase is 1.6% in the construction cost of northern blocks, 2.7% in southern blocks, and 2.2% in all blocks. The increase in the construction cost of the northern blocks is about 1.1% less than the southern blocks. The highest increase is related to block D with 3.8% and the lowest is related to block B with 1.5%.

B- Comparison of the increase in construction cost and the decrease in energy consumption

As mentioned, the optimization aims to lead to a slight increase in the construction cost and significantly decrease energy consumption. We examine to find any relationship between the increase in construction cost and the decrease in energy consumption in each block as follows.

Results

1- The best performance is related to block B, in other words, it has the highest reduction in energy consumption with the lowest increase in construction cost.
2- The worst performance is related to block D, in other words, it has the lowest reduction in energy consumption with the highest increase in construction cost.

Table 9: Calculation of optimization cost in each block

Block	Plain double glazing area (m^2)	Clay external wall without insulation area (m^2)	Double glazing low-emissivity glass with Argon area (m^2)	LECA external wall without thermal insulation area (m^2)	Current glass price (toman)	Ideal glass price (toman)	External wall price (toman)	Ideal wall price (toman)	Difference between current and ideal prices (toman)	Percentage of increase in construction price
A	149	751	301	599	162448740	372541680	92564505	128713120	246241555	2.6%
B	171	819	207	783	186434460	256199760	100945845	168251040	137070495	1.5%
C	149	751	235	665	162448740	290845800	92564505	142895200	178727755	1.9%
D	197	703	447	453	214781220	553242960	86648265	97340640	349154115	3.8%
E	144	756	288	612	156997440	356451840	93180780	131506560	237780180	2.6%
F	197	703	388	512	214781220	480219840	86648265	110018560	288808915	3.1%
Mean weight of northern units (10 blocks)									152153227	1.6%
Mean weight of southern units (10 blocks)									254020447	2.7%
Total mean weight (10 blocks)									203086887	2.2%

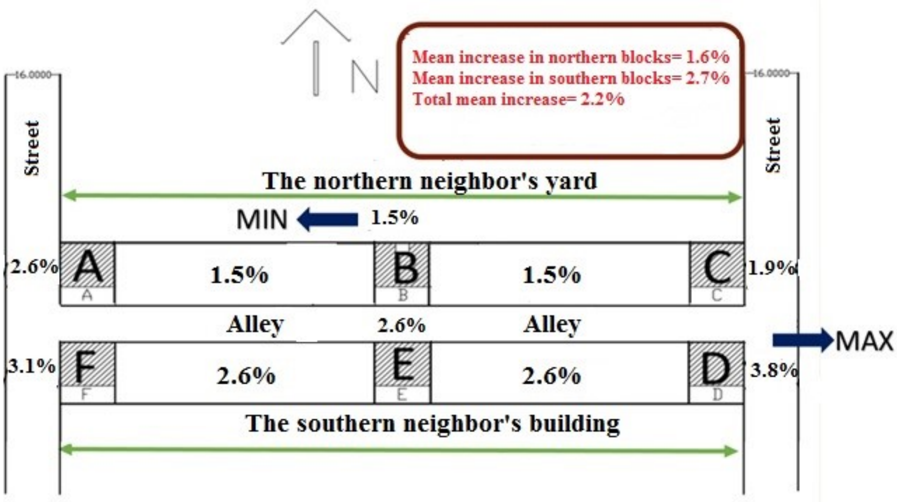

Figure 11: Percentage of increase in construction cost per block due to optimization

3- The performance of the northern blocks is better than the southern, in other words, they have a higher reduction in energy consumption with a lower increase in construction cost.

4- Block performance from best to worst is as follows: $1-B, 2-C, 3-A, 4-F, 5-E, 6-D$

C- Payback period

As mentioned, the mean increase in construction cost is 2.2% and the mean decrease in energy consumption is 71.1%. We want to examine the payback period in the case of optimization with the above-mentioned measures, considering the increase in construction cost. To this end, we calculate the amount of energy cost saving before and after optimization according to the electricity and gas prices in Iran as presented in Tables 10, 11, and 12.

To calculate the payback period of optimization, we just need to divide the optimization cost by the energy cost saved for each block separately per year. Table 14 presents its calculations and Figure 14 shows its results.

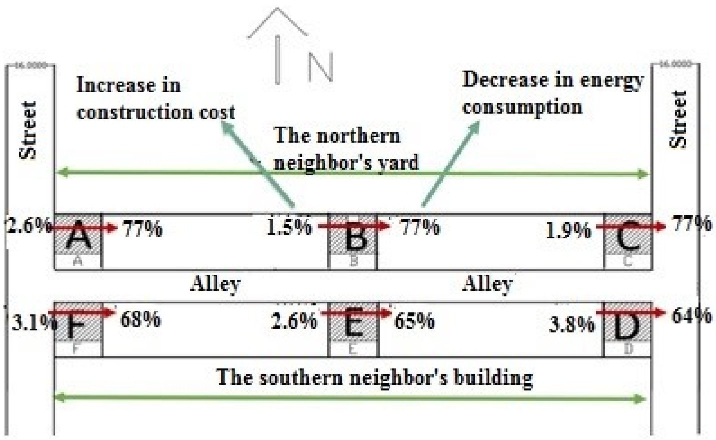

Figure 12: The amount of increase in construction cost and decrease in energy consumption in each block

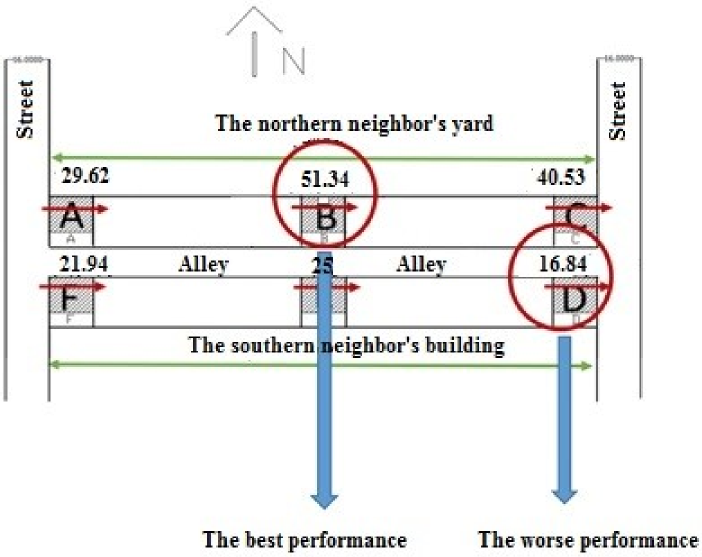

Figure 13: Cost efficiency index (reduction in energy consumption divided by the increase in construction cost) in each block

Results

1- The best performance is related to block B, in other words, the payback is returned for optimization within the shortest time.

2- The worst performance is related to block D, in other words, the payback is returned for optimization within the longest time.

3- The performance of the northern blocks is better than the southern, in other words, the payback is returned for optimization in a shorter period.

4- The performance of blocks from best to worst is follows: $1-B, 2-C, 3-A, 4-F, 5-E, 6-D$

D- Comparison with the price of electricity and gas in other countries and the global price of a barrel of crude oil

The price of energy is very cheap in Iran and the government pays a heavy subsidy for it. Therefore, the mean payback period due to optimization is about 11 years because despite a large saving in electricity and gas consumption, since the electricity and gas consumption has a low price in Iran, this payback will result in delay. To better clarify the issue, we compare the status with another country and the price of a barrel of crude oil in the world. We consider Iraq because of its closer status to Iran in terms of oil and gas reserves than other countries. According to the calculations,

Table 10: Gas consumption tariff in cold months of 2021 [57]

Range of consumption	1	2	3	4	5	6	7	8	9	10	11	12
Climate 1	Up to 300	301-400	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100	1101-1200	1201-1300	More than 1300
Climate 2	Up to 250	251-350	651-450	451-550	551-650	651-750	751-850	851-950	951-1050	-051-1150	1151-1250	More than 1250
Climate 3	Up to 200	201-300	301-400	401-500	501-600	601-700	701-800	801-900	901-1000	1001-1100	1101-1200	More than 1200
Climate 4	Up to 150	250-251	251-350	351-450	451-550	551-650	651-750	751-850	851-950	951-1050	1051-1150	More than 1150
Climate 5	Up to 75	76-150	151-250	251-350	351-450	451-550	551-650	651-750	751-850	950-951	951-1050	More than 1050
Tariff (rials)	414	690	966	1352	1893	2651	3711	5195	7274	10183	14256	19959
Gas tariff after optimization							Gas tariff before optimization					

Table 11: Gas consumption tariff in hot months of 2021 [57]

Range of consumption	1	2	3	4	5	6	7	8	9	10	11	12
Climate 1 to 5	Up to 45	46-95	96-145	146-195	196-245	246-295	296-345	346-395	396-445	446-495	496-545	More than 545
Tariff (Rials)	1350	1500	1800	1980	2178	2396	2635	2899	3189	3508	3858	4244
Gas tariff after optimization							Gas tariff before optimization					

Table 12: Household electricity tariff in 2021 [?]

Average energy consumption per month (kWh/month)	Base price of kWh/month (rials)
0-100	913
More than 100 to 200	1061
More than 200 to 300	2278
More than 300 to 400	4100
More than 400 to 500	4710
More than 500 to 600	5925
More than 600	6534

the following figure shows the payback period if the gas and electricity prices in Iran become similar to Iraq, which is closer to reality.

Assuming the equal electricity and gas prices of Iran and Iraq, the payback period is about 0.8 years in the northern blocks of Iran, 1.8 years in the southern blocks, and 1.3 years on average, which is approximately 12% of the payback period with the current prices of electricity and gas in Iran, in other words, the payback period will be 8 times later than the prices of Iraq, assuming the prices of electricity and gas in Iran. The payback period is calculated assuming the prices of Iran and Iraq and the average global energy price, and Figure 17 shows the results.

Table 13: Calculations of electricity and gas cost savings in different blocks after optimization

Block	Before optimization							After optimization						
	Average monthly gas consumption in m^3	**Gas tariff in Rials**	**Average monthly electricity consumption in kWh**	**Electricity tariff in Rials**	**Monthly gas consumption cost in Rials**	**Monthly electricity consumption cost in Rials**	**Annual gas and electricity consumption cost**	**Average monthly gas consumption in m^3**	**Gas tariff in Rials**	**Average monthly electricity consumption in kWh**	**Electricity tariff in Rials**	**Monthly gas consumption cost in Rials**	**Monthly electricity consumption cost in Rials**	**Annual gas and electricity consumption cost**
A	1513	11447	82	913	17319311	74866	21681565	266	1418	27	913	377188	24651	748437
B	1477	11447	70	913	16907219	63910	21055583	239	1418	25	913	338902	22825	680582
C	1482	11447	81	913	16964454	73953	21244781	251	1418	28	913	355918	25564	733870
D	1204	11447	88	913	13782188	80344	17502754	421	1418	33	319	596978	30129	1077922
E	1307	11447	72	913	14961229	65736	18742307	428	1418	27	913	606904	24651	1024097
F	1598	11447	81	913	18292306	73953	22838203	501	1418	26	913	710418	23738	1137358
Mean Weight of northern units	1481	11447	72	913	16954152	66010	21137101	243	1418	26	913	344432	23282	692696
Mean Weight of southern units	1326	11447	75	913	15176433	68019	19027941	435	1418	28	913	616263	25108	1040806
Total mean	1404	11447	74	913	16065293	67015	20082521	339	1418	27	913	480348	241195	866751

Table 14: Calculations of payback period in different blocks

Block	**Annual saving in Tomans**	**Optimization cost**	**Payback period**
A	20933138	246241555	12
B	20375001	137070495	7
C	20510911	178727755	9
D	16424832	349154115	21
E	17718210	237780180	13
F	21700845	288808915	13
Mean weight of northern units	20444406	152153327	7
Mean weight of southern units	17987136	254020447	14
Total mean	19215771	203086887	11

Table 15: Electricity and gas prices in Iraq

Energy carrier	Unit	Country	Price
Electricity	m^3	Iraq	¢42.5
Gas	kWh	Iraq	¢10

Conclusions and suggestions

If the optimization is performed with the above-mentioned measures, the construction cost will increase by 2.2%, and the energy consumption during operation will decrease by 1.71%. In the case of optimization, this additional cost imposed on the construction phase due to optimization will return within 10.8 years, assuming the current prices of energy carriers in Iran.

According to the International Energy Organization, Iran is at the top of the energy subsidy paying countries due to paying about 70 billion dollars in energy subsidies and about 15% of the gross domestic product (about $25 billion for gas and about $16 billion for electricity). This policy is being reformed, in other words, the payment of subsidies will be reduced or reformed. In the status quo, the optimization of buildings is not much welcomed due to the cheapness of electricity and gas compared to other countries of the world, but if the prices of electricity and gas approach the real prices, the optimization will be noticed by people. Even the residents of old buildings may also reduce their electricity and gas consumption by adopting measures. Some suggestions are offered in this regard:

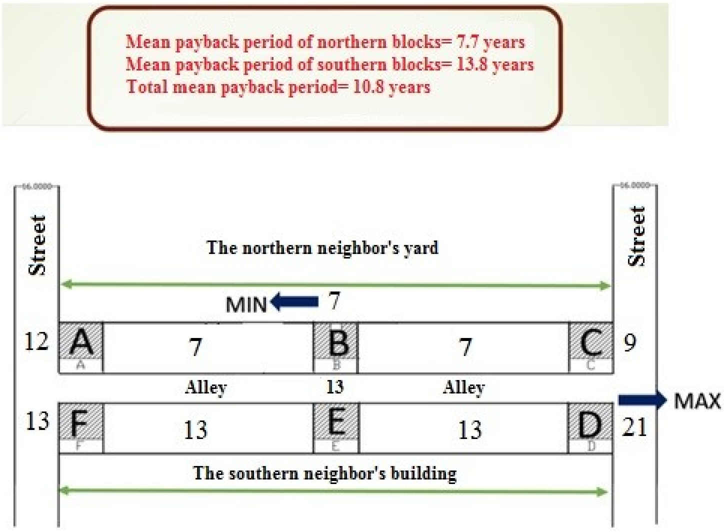

Figure 14: Payback period in different blocks after optimization

Table 16: Calculations of payback period in different blocks assuming the equal electricity and gas prices in Iran and Iraq

Block	The annual saving in Tomans	Optimization cost	Payback period
A	189531900	22612155	1.3
B	185100600	137070495	0.7
C	186680700	178727755	1
D	125639100	349154115	2.8
E	135618300	237780180	1.8
F	168876900	288808915	1.7
Mean weight of northern units	185376600	152153327	0.8
Mean weight of southern units	137918700	254020447	1.8
Total mean	161878500	203086887	1.3

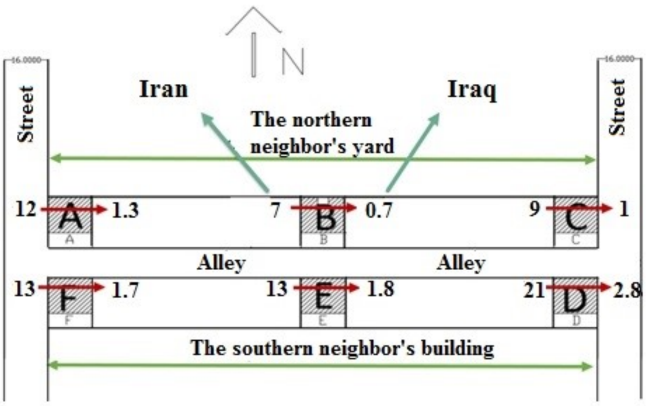

Figure 15: Comparison of payback period with electricity and gas prices in different blocks in Iran and Iraq

1- Reforming the construction laws

A- Issuing the construction certificate: It is suggested to add an energy label attachment according to standard 14253 to the necessary documents for issuing a construction certificate, and if the energy consumption

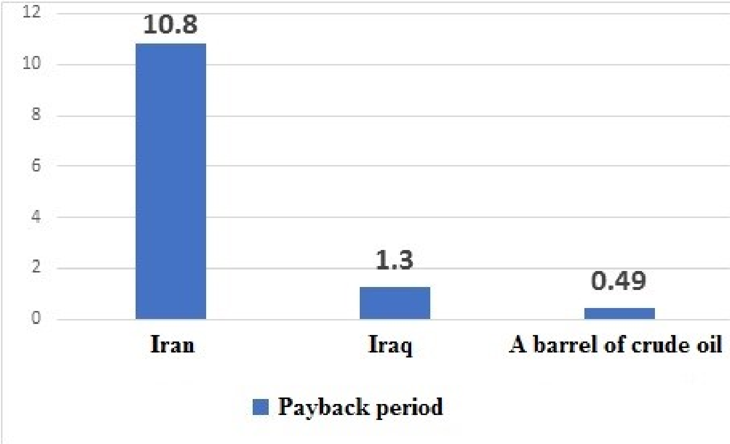

Figure 16: Comparison of optimization payback period assuming electricity and gas prices in Iran and Iraq and the price of a barrel of crude oil in the world

exceeds a certain amount, refuse to issue a certificate for that property.

B- Supervision of construction: If the rules about energy consumption reduction are not followed properly, it is suggested to provide the possibility of stopping the construction operations by the institutions supervising the construction, such as municipalities, the engineering system organization, and not allow to continue working under any circumstances, including paying a fine in the commissions of Article 100 of the Law of Municipalities.

C- Construction Completion: It is suggested that the building's energy label and the exact amount of its consumption should be mentioned in the technical certificate of the building, which is prepared after the construction completion so that the buyer of a building will be aware of the amount of energy consumption of the building and its economic consequences before buying.

2- Revision of electricity and gas tariffs

The tiered electricity and gas tariff system should be revised and reformed so that firstly, high-consumption subscribers pay the prices of exported electricity and gas, and secondly, the household's financial ability decile can be seen in the system. For example, why it is necessary to pay electricity and gas subsidies to people who live in the higher deciles of society even if they consume little? It is worth noting that the current tiered system is only defined according to consumption.

3- Provision of economic incentives

A- Certificate issuance: It is suggested to consider discounts in the certificate issuance fee during its issuance for buildings that consume less than a certain amount of energy, obtained from the tariff and energy subsidy reforms.

B- Optimizing existing buildings: it is suggested to provide low-interest loans for optimizing existing buildings, obtaining from the tariff and energy subsidy reforms as the installments can be paid from the saving energy consumption.

C- Supporting the production of suitable materials and equipment: It is suggested to pay low-interest loans, obtained from tariff and energy subsidy reforms for the construction and also tax facilities for the operation of factories producing materials and equipment that help reduce consumption, such as insulation and windows.

4- Education

A- High school education: It is suggested to teach the topic of energy saving and its economic and environmental consequences in textbooks.

B- Higher education: First, the topic of energy consumption saving and its economic and environmental consequences should be included in general courses. Secondly, the number of courses related to energy consumption in architecture should increase, the energy consumption simulation should be included in the syllabus of some courses, and the amount of energy consumption should be a criterion for professors' judgment in some courses such as architectural design. Thirdly, the very small share of architectural energy courses should increase in higher education.

C- Broadcasting: First, the energy-saving subject and its economic and environmental consequences should be taught to the general public. Secondly, specialized programs should be provided for specific audiences, including designers, builders, and those involved in the construction industry.

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