Identification and Prioritization of Energy Consumption Optimization Strategies in the Building Industry Using Hybrid SWARA-BIM Model

Abstract

Considerable energy consumption of the building industry has become one of the most crucial problems of all countries. Considering the concept of sustainability, a satisfactory solution must be found in order to reduce energy consumption in the mentioned industry. Therefore, this study aims to identify and prioritize energy consumption optimization strategies in the building industry. Required data were collected using existing literature, interviews, questionnaires, and simulations through Building Information Modeling (BIM) tools. Strategies were identified and categorized into five groups according to their nature. According to the final results, “Using renewable energy resources (P53)”, “Using efficient insulation materials (P46)” and “Using suitable materials (P31) having 100%, 35%, and 17% efficacy, were introduced as major contributors to the energy consumption optimization. Obtained results of this study can be used in the building industry in order to reduce energy consumption, and move through sustainability.

Keywords

Energy consumption optimization; Building Information Modeling (BIM); Simulation;
Energy efficiency, Sustainability.

1. Introduction

Human activities are widely known as one of the most effective contributors to climate change and emissions of greenhouse gasses that are produced by them. They are also one of the main factors of global warming. Therefore, changes are needed in energy consumption, housing, mobility, and food sectors to reduce the negative consequences of human activities. Buildings, meanwhile, have an important role in the mentioned issue since they produce more than 8.6 million metric tonnes of CO_2 each year [1-4]. As long as the buildings consume over 40% of the produced energy, 30% of natural resources of the globe, and produce 30% of the greenhouse gasses, sustainable construction would be a growing market in the future of the construction industry [2, 5-8].

Currently, more than 50% of the world's population lives in cities and this number will reach nearly 70% by 2050. It is anticipated that the mentioned city residents will consume approximately 75% of global energy and emit around 70% of the world's carbon dioxide [9]. Although the detrimental effects of energy consumption in buildings are being investigated by institutes and scientists, there are numerous uncertainties in the mentioned topic that must be declared to have a comprehensive perspective of energy consumption in buildings [10]. Researchers have delved into the concept of energy and introduced four main solutions for energy efficiency in buildings including passive building design, using low energy materials, using efficient types of equipment, and integrating renewable energy technologies for different applications [7]. For instance, some researchers proposed using active and passive energy consumption optimization strategies [3, 10-15]. Another solution can be the construction of Zero Energy Buildings (ZEBs). Net Zero Energy Buildings (NZEB) or ZEBs are buildings in which the amount of annual energy consumption is less than energy production. Consequently, the annual energy consumption of such buildings from the energy grid would be zero [9, 16, 17].

If the design, construction, and maintenance phases of building construction projects are according to the concept of sustainability, a significant amount of energy can be saved in countries. To do so, the proper evaluation of alternative designs, selection of systems, allocation of the energy budget, compliance with energy standards, and economic evaluations are necessary, which should be met mostly before and sometimes during the construction phase [18].

An exhaustive study regarding all the parameters of the building's energy consumption strategies is more preferable to investigating each parameter separately. Several studies have been conducted considering a limited number of parameters such as building's lifecycle [19-24], carbon dioxide emissions[25-30], and thermal comfort of residents [31-36], in which different perspectives and analysis methods including Multi-Criteria Decision-Making (MCDM) methods were used [5, 11, 37, 38]. However, very limited studies have conducted a thorough analysis in which a large number of design parameters are discussed and analyzed. Meanwhile, several previous studies suggested Building Information Modelling (BIM) and Life Cycle Assessment (LCA) for integrating modeling and assessment to quantify and reduce the detrimental effects, as well as simplifying the data optimization [17, 37, 39, 40].

According to the U.S. National BIM standard, BIM is defined as a shared knowledge resource for information about a reliable basis during its lifecycle [38]. BIM includes different dimensions. These dimensions, which are in different stages of the project, can play a significant role in the comprehensive perspective of designers and also stakeholders. The third dimension of BIM (3D) refers to the three-dimensional characterization of the building objects [41]. The fourth dimension (4D) refers to the time-schedule management, which is analyzed by time scheduling methods. The fifth dimension (5D) is considered as the modeling of costs, and more specifically, lifecycle costs of the building [42-44]. The sixth dimension (6D) BIM is related to the environmental behavior of the building and as a trended nomination, the sustainability of the building. The last dimension (7D) refers to maintenance schedules and facility management [45].

Although sustainability and BIM take place in the 6D modeling, other dimensions can also affect the sustainability criteria of the project. Because the sustainability definition and the global awareness of that have been altering over time, it is possible to have other aspects such as cost, comfort, facility, and other parts of the BIM influencing the sustainability of projects [45]. The consumption of energy in buildings is a part of sustainability and it should be categorized in 6D BIM. Therefore, the thermal aspects of the building are a key factor that should be investigated since it has the main proportion of operational energy consumption [46]. Even though there are many studies on reducing the consumption of energy in buildings, few studies used integrated modeling with a vast perspective in the design process. The capability to achieve a holistic view of the factors of energy consumption, together with being able to have an insight over all stages of the building construction, has been a gap in the literature.

2. Literature review

Several studies mention the policies and technologies to create a schematic approach for managing the critical building information and other specifications of BIM. Nevertheless, despite the growing research on BIM and its underlying potential in sustainability, the development of green BIM is still immature and unsystematic [37, 39]. Chel and Kaushik mentioned that the best stage for designing and checking the energy efficiency of buildings is before the construction phase [7]. Gaffarianhoseini et al. introduced a conceptual framework with several modules for developing software solutions and energy management of buildings [47]. Hosseini et al. investigated the barriers to the adoption of BIM, ranked the causes contributing to the disuse of BIM in construction projects, and identified the policies and technical issues as the most important obstacles to the BIM application [48]. Shadram and Mukkavaara conducted a study over a trade-off between operational and embodied energy for several materials in various locations [17]. Nizam et al. investigated embodied energy in buildings with a BIM-based tool [49]. Gerrish et al. used interviews to probe into the application of BIM in the energy management of buildings [50]. Beazley et al. conducted research and concluded that current problems in the energy efficiency of residential buildings can be reduced by better-informed design decisions and greater continuity of project data throughout project phases [51]. Sanhudo et al. reviewed BIM tools and software in energy retrofitting and introduced Revit as the most potential application for modelling energy scheme of the building [52]. Najjar et al. investigated the application of BIM in life cycle assessment and simulated several material combinations and mathematic equations to calculate the amount of energy that can be saved during the project period [53].

As it is seen, whereas some parameters which affect the energy consumption of buildings have been investigated, a thorough study on the parameters that are essential for the energy management of buildings is not conducted. In addition to this information, we may notice that the previous research cannot show an all-embracing view toward the importance of other parts of the environment, separated from the building, such as trees, together with the building envelope, in an integrated model. The novelty of this research is having a holistic view of all parameters that are responsible for increasing the energy consumption of buildings in an integrated BIM model.

3. Research methodology

The research methodology of the current study includes three main stages. The first stage was associated with the identification of energy consumption optimization strategies in the building industry. To do so, a vast study was conducted through the existing literature such as journal papers, documents, books, online resources, and holding interviews with experts. It was followed by the second stage, which was weighing the identified strategies from the previous stage. A questionnaire was designed and distributed among energy experts. Next, the results were gathered and analyzed by Stepwise Weight Assessment Ratio Analysis (SWARA) method. Finally, in the last stage, strategies that had the most weights were used in BIM simulation to assess their impact on energy consumption optimization. A case study building in Shiraz, Iran was simulated using BIM and the effect of each strategy was obtained. The mentioned methodology is illustrated in Figure 1.

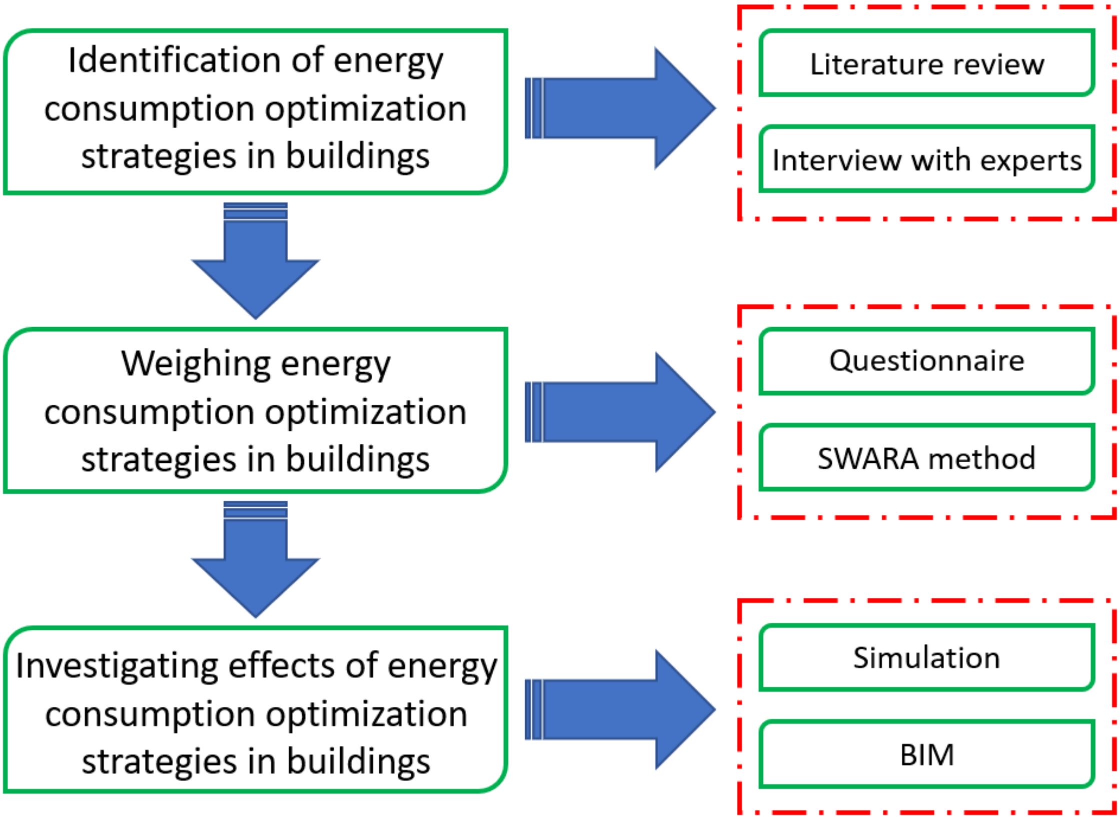

Figure 1. Research methodology

3.1. Questionnaire

Questionnaires are considered as one of the most useful means of gathering experts' opinions. In the current study, six types of questionnaires were designed and distributed among energy experts in order to weigh different categorizations of energy consumption optimization strategies, and also rank strategies in their own groups. Experts were asked to rank energy consumption optimization strategies using 5-point Likert scale, in which 1 stands for the least effectiveness and 5 stands for the most effectiveness.

The reliability of a questionnaire is very crucial in researching. To check the reliability of the designed questionnaires, Cronbach's alpha test was used. Cronbach's alpha coefficient value ranges between 0 and 1, and values higher than 0.7 are considered acceptable values [54-56]. In this research, the initially designed questionnaires were first distributed among 20 energy experts to check the reliability.

After gathering the data, the mentioned coefficient value was calculated using SPSS software. Obtained results illustrated Cronbach's alpha coefficient values of the design questionnaires were more than 0.9 in all the questionnaire types, which proves the reliability of the mentioned questionnaires. Table 1 illustrates the result of Cronbach's alpha test.

Table 1. Cronbach's alpha values of different questionnaire types

Questionnaire	Purpose	value
A	Obtaining weights of energy consumption optimization strategies groups	0.961
B	Obtaining weights of energy consumption optimization strategies in the "Technical Equipment (G4)" group	0.932
C	Obtaining weights of energy consumption optimization strategies in the "Construction Specification (G3)" group	0.981
D	Obtaining weights of energy consumption optimization strategies in the "Architectural Design (G1)" group	0.975
E	Obtaining weights of energy consumption optimization strategies in the "Law and Environment (G5)" group	0.956
F	Obtaining weights of energy consumption optimization strategies in the "Behavior and Operation (G2)" group	0.977

3.2. The SWARA method

SWARA method was introduced and exploited by Keršuliene et al. for the first time [10, 57, 58]. This technique is regarded as one of the most accurate MCDM (Multi-Criteria Decision-Making) methods according to researchers [59, 60]. The SWARA method has been used in many studies related to energy in buildings. For instance, Balali et al. weighed different criteria for selecting the best passive energy consumption optimization strategy using the SWARA method [10]. Ruzgys et al. applied the mentioned method to evaluate external wall insulation in residential buildings [61]. Ighravwe and Oke used the SWARA method as a part of their study for selecting a suitable maintenance strategy for public buildings according to sustainability criteria [62].

In the current research, the SWARA method was used in order to weigh and rank the identified energy consumption optimization strategies in buildings. To do so, a questionnaire was designed and distributed among experts. Respondents ranked the identified strategies using 5-point Likert scale, in which 1 and 5 stood for the least and most impact on energy saving, respectively. Obtained results were then analyzed by the SWARA method. The procedure of applying the SWARA method is explained below [58, 63-68]:

1. Identification of energy consumption optimization strategies in buildings.
2. Sorting the identified strategies in terms of relative importance in descending order according to the respondents' answers.
3. Calculation of comparative average value (s_j) by comparing the second important ($j-1$) criterion to the first criterion (j).
4. Calculation of coefficient k_j, which stands for comparative importance, as follows:

$$k_j = \begin{cases} 1 & j = 1 \\ s_j + 1 & j > 1 \end{cases} \quad (1)$$

5. Determination of recalculated weights (q_j):

$$q_j = \begin{cases} 1 & j = 1 \\ \dfrac{q_{j-1}}{k_j} & j > 1 \end{cases} \quad (2)$$

6. Calculation of relative weights of the strategies w_j as follows:

$$w_j = \frac{q_j}{\sum_{m=1}^{n} q_m} \tag{3}$$

Where n stands for the number of energy consumption optimization strategies.

3.3. BIM tools

After obtaining weights of the identified energy consumption optimization strategies in each group, the most important strategies were selected for further investigation. A building, as a case study, was simulated and the effects of each selected energy consumption optimization strategy were accurately calculated. To do so, two BIM tools including Revit and Green Building Studio were exploited. Obtained results of this stage clearly illustrated how much the strategies can be useful in reducing energy consumption in buildings.

4. Results and discussion

4.1. Sample Size

Experts who were involved in buildings' energy projects of Shiraz, in both industry and academia, were considered as the sample size of this study. One of the most important points of using questionnaires in studies is the calculation of required experts for filling the questionnaires out. To do so, the mentioned number was calculated as follows [69]:

$$SS = \frac{z^2 p(1-p)}{c^2} \tag{12}$$

Where SS, z, p and c stand for the calculated sample size, the confidence level value, percentage picking a choice, and confidence interval, respectively. Then, the corrected sample size was according to the following formula:

$$Corrected\ SS = \frac{SS}{1 + (\frac{SS-1}{pop})} \tag{13}$$

Where pop stands for the population. Corrected SS for the response rate was then calculated according to the following formula:

$$Corrected\ SS\ for\ rr = rr * corrected\ SS \tag{14}$$

Where rr stands for response rate.

In the current study, 560 experts related to the topic of energy optimization in buildings were identified. In order to get a suitable result, p, z, c and rr were considered 0.5, 0.95, 0.1, and 0.92, respectively. The final calculation illustrated that at least 490 experts are required to give their opinions. To have more precise results, this study considered 500 experts. It is universally accepted that more experienced experts usually express more accurate scores. Therefore, experts with experiences of more than 15 years were the largest part of the respondents. General information regarding experts is illustrated in Table 2.

Table 2. General information regarding experts

Category	Classification	Number
Occupation	Architectural designer	160
	Project manager	100
	Contractor	70
	Supervisor engineer	60
	Consultant engineer	40
	Technical expert	40
	Structural Engineer	30
Sex	Male	410
	Female	90
Experience (years)	<5	40
	5-10	60
	10-15	90
	>15	310

4.2. Identification and categorization of energy consumption optimization strategies in buildings

The first step in this stage was to identify energy consumption optimization strategies in buildings. To do so, a thorough investigation was conducted through the existing literature including journal papers, books, documents, and online resources. Also, a number of experts were interviewed to add any missing strategies. Finally, 29 energy consumption optimization strategies were found for the building industry. This stage was followed by categorizing the identified energy consumption optimization strategies according to their nature. The mentioned identified strategies, and also their categorizations are illustrated in Table 3.

Table 3. Energy consumption optimization strategies in buildings

Sign	Measures	Category
P11	Designing buildings according to the optimum estimation of investment cost	Architectural Design (G1)
P12	Designing buildings according to the optimum estimation of human resources cost	
P13	Using passive cooling systems	
P14	Using proper glazing	
P15	Using passive heating systems	
P16	Considering the building orientation	
P17	Considering the building shape	
P21	Considering energy prices in bills	Behavior and Operation (G2)
P22	Considering occupant comfort	
P23	Using energy controlling systems	
P24	Considering the peak of energy demand	
P25	Considering the usage of the building	
P26	Considering O&M of the building	
P31	Using suitable materials	Construction Specification (G3)
P32	Recycling materials	
P33	Suitable building retrofit	
P34	Using efficient shading devices	
P41	Using efficient cooling systems	Technical Equipment (G4)
P42	Improving the efficiency of appliances	
P43	Using suitable energy grids	
P44	Using efficient heating systems	
P45	Using efficient fenestration materials	
P46	Using efficient Insulation materials	
P47	Using efficient lighting systems	
P48	Using suitable ventilation systems	
P51	Considering the climate in building design	Law and Environment (G5)
P52	Considering energy efficiency protocols	
P53	Using renewable energy resources	
P54	Designing a suitable green area	

4.3. Weighing energy consumption optimization strategies

In this stage, energy consumption optimization strategies were weighed and ranked. To do so, data collection was conducted through other types of questionnaires.

Questionnaire type B was designed to prioritize different categorizations of energy consumption optimization strategies (G1-G5). Then, questionnaire types C-G were designed to rank energy consumption optimization strategies in their groups. All the questionnaires were designed and distributed among experts, and finally analyzed using the SWARA method. According to the obtained results, the "Technical Equipment (G4)" group was the most important category among all the groups with a weight of 0.231. Also, in the strategies' categorizations themselves, "Using efficient Insulation materials (P46)", "Using suitable materials (P31)", "Considering the building orientation (P16)", "Using renewable energy resources (P53)" and "Using energy controlling systems (P23)" were the top strategies in "Technical Equipment (G4)", "Construction Specification (G3)", "Architectural Design (G1)", "Law and Environment (G5)" and "Behavior and Operation (G2)" categories, respectively. Information regarding the mentioned prioritizations is illustrated in Tables 4-9.

Table 4. Weights of energy consumption optimization strategies groups

Group	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
G4	---	1	1	0.231	1
G3	0.067	1.067	0.937	0.217	2
G1	0.031	1.031	0.909	0.210	3
G5	0.168	1.168	0.778	0.180	4
G2	0.132	1.132	0.687	0.159	5

Table 5. Weights of energy consumption optimization strategies in the "Technical Equipment (G4)" group

Strategy	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
P46	---	1	1	0.160	1
P47	0.031	1.031	0.970	0.156	2
P45	0.247	1.247	0.777	0.125	3
P48	0.016	1.016	0.765	0.123	4
P42	0.025	1.025	0.747	0.120	5
P41	0.054	1.054	0.708	0.114	6
P44	0.098	1.098	0.645	0.103	7
P43	0.077	1.077	0.599	0.096	8

Table 6. Weights of energy consumption optimization strategies in the "Construction Specification (G3)" group

Strategy	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
P31	---	1	1	0.318	1
P34	0.174	1.174	0.851	0.270	2
P32	0.243	1.243	0.685	0.218	3
P33	0.130	1.130	0.606	0.192	4

Table 7. Weights of energy consumption optimization strategies in the "Architectural Design (G1)" group

Strategy	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
P16	---	1	1	0.183	1
P14	0.050	1.050	0.952	0.175	2
P17	0.202	1.202	0.792	0.145	3
P15	0.097	1.097	0.722	0.132	4
P13	0.023	1.023	0.705	0.129	5
P11	0.100	1.100	0.641	0.117	6
P12	0.027	1.027	0.624	0.114	7

Table 8. Weights of energy consumption optimization strategies in the “Law and Environment (G5)” group

Strategy	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
P53	---	1	1	0.308	1
P51	0.225	1.225	0.816	0.251	2
P54	0.024	1.024	0.797	0.245	3
P52	0.269	1.269	0.628	0.193	4

Table 9. Weights of energy consumption optimization strategies in the “Behavior and Operation (G2)” group

Strategy	S_j	$K_j = s_j + 1$	q_j	w_j	Rank
P23	---	1	1	0.202	1
P25	0.270	1.270	0.787	0.159	2
P21	0.047	1.047	0.751	0.151	3
P24	0.150	1.150	0.653	0.132	4
P22	0.073	1.073	0.609	0.123	5
P26	0.062	1.062	0.573	0.115	6

4.4. Investigating effects of energy consumption optimization strategies

The last aim of this study was to investigate the amount of energy saving for the identified energy consumption optimization strategies. To do so, top strategies in each of the mentioned groups (G1-G5) were selected. To be more specific, for the top three groups (G4, G3, G1), the most two important strategies were simulated using BIM. Also, for the last two groups (G3, G2), only the top strategy was selected and simulated. To conduct the simulation, various types of BIM software were used. Information regarding the mentioned point is illustrated in Table 10.

Table 10. Usage of BIM tools in different stages of the simulation

Stage	BIM software
An initial draft of the building	Autodesk AutoCAD
3D modeling of the initial idea	Autodesk Revit
Material specification insertion	Autodesk Revit
Modeling HVAC system	Autodesk Revit
Energy conceptual and analytical design	Autodesk Revit
Energy analytical calculation	Green Building Studio
Annual energy consumption comparison	Insight 360

4.4.1. Simulating "Technical Equipment (G4)" energy consumption optimization group

In this group, the first and second ranks were "Using efficient Insulation materials (P46)" and "Using efficient lighting systems (P47)", respectively. Regarding the former, the simulation was conducted through the information provided by the Iranian Construction Engineering Organization. According to the mentioned organization, the most efficient insulation materials in Iran are "Rockwool", "Polystyrene", and "Polyurethane". The thermal resistance of the insulation materials was gathered from the most well-known companies in the Iranian construction industry. Thermal details and the weight of the materials were then inserted into BIM software precisely, and simulation was conducted. According to the results, both "Rockwool" and "Polyurethane" can reduce energy consumption by approximately 35%. Details of simulating this strategy are illustrated in Figure 2.

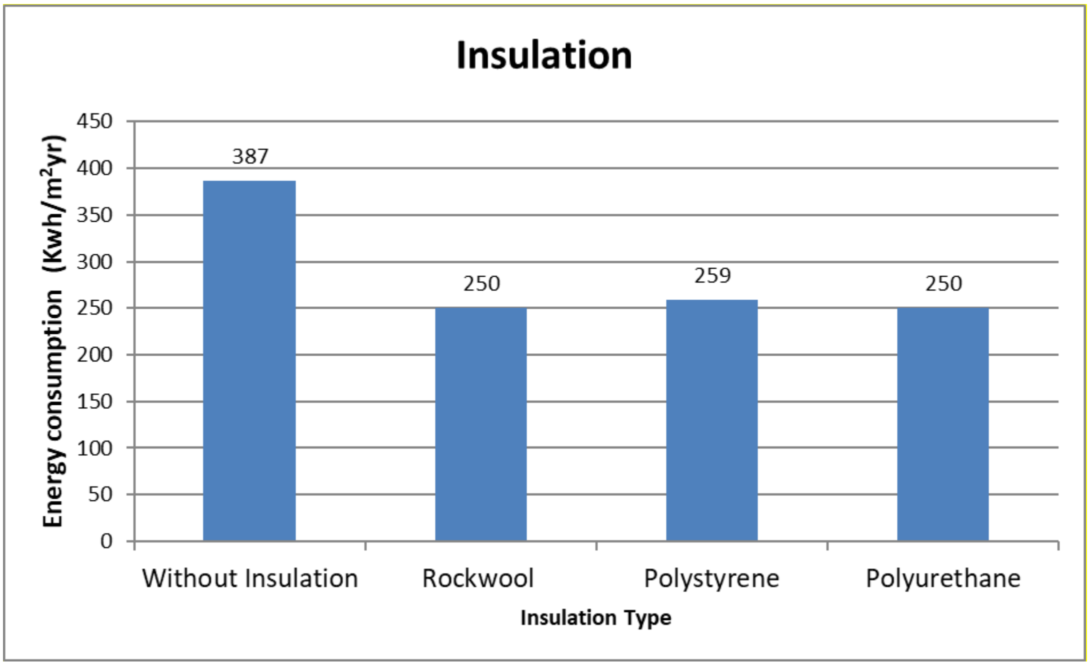

Figure 2. Simulation details of “Using efficient Insulation materials (P46)”

Regarding the latter, also, it is known that lighting in buildings, as an active criterion, can have a profound influence on the energy consumption of the building, and therefore more efficient lighting systems have been invented during recent years. In this research, the lighting system has been modeled and studied by several efficient modern lighting systems. The consumption of the lighting system in the initial model was 10 watts per square meter and by changing the lighting system, the consumption of the building changed to 3.23 watts per square meter, using effective Light-emitting diodes (LEDs). According to the results, the mentioned lighting system can reduce energy consumption by about 10 percent. Details of simulating this strategy are illustrated in Figure 3.

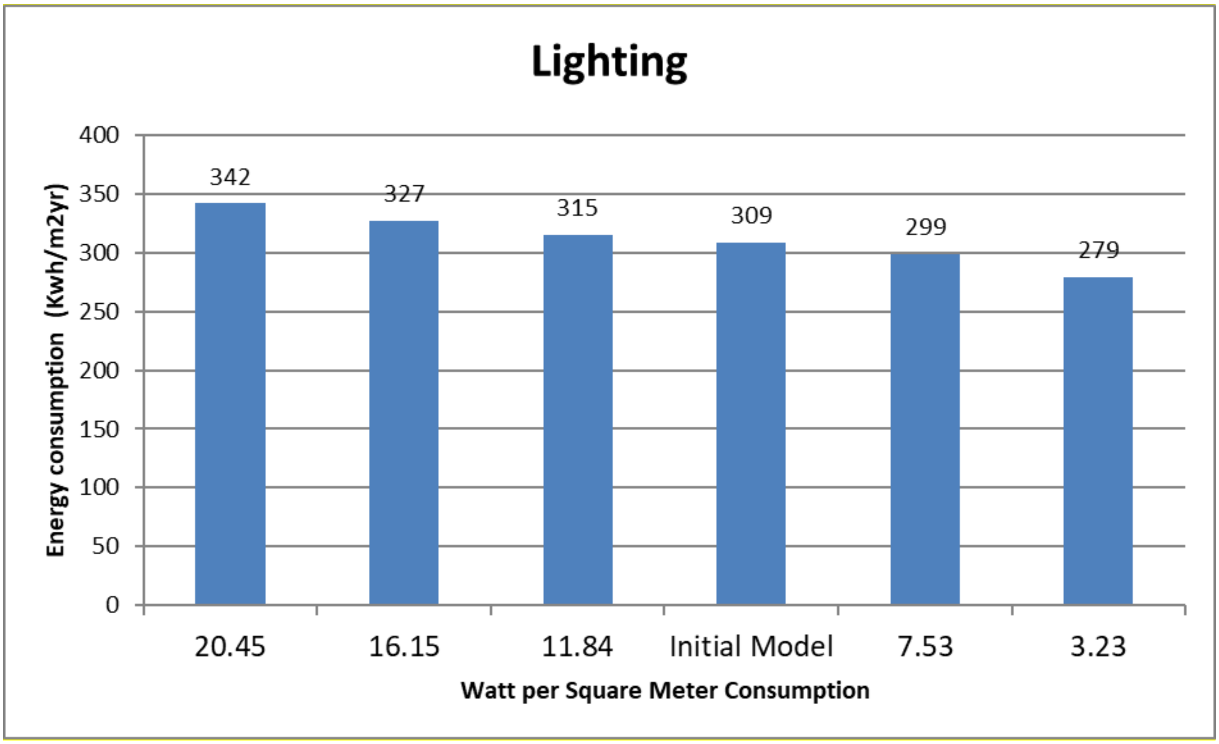

Figure 3. Simulation details of "Using efficient lighting systems (P47)"

4.4.2. Simulating "Construction Specification (G3)" energy consumption optimization group

The first and second ranks in this category were "Using Suitable Materials (P31)" and "Using Efficient Shading Devices (P34)", respectively. Regarding the former, an inquiry was made from the Construction Engineering Organization to gather the information of most common materials in Shiraz, Iran. "Clay Blocks", "Cement Blocks" and "Autoclave Blocks" were the most common materials being used in roofs and walls. Using the mentioned materials, different composite walls were modeled in BIM. According to the results, using "Autoclave Core Composite Wall", the maximum energy consumption reduction can be derived, which is approximately 23%. Details of the mentioned simulation are shown in Figure 4.

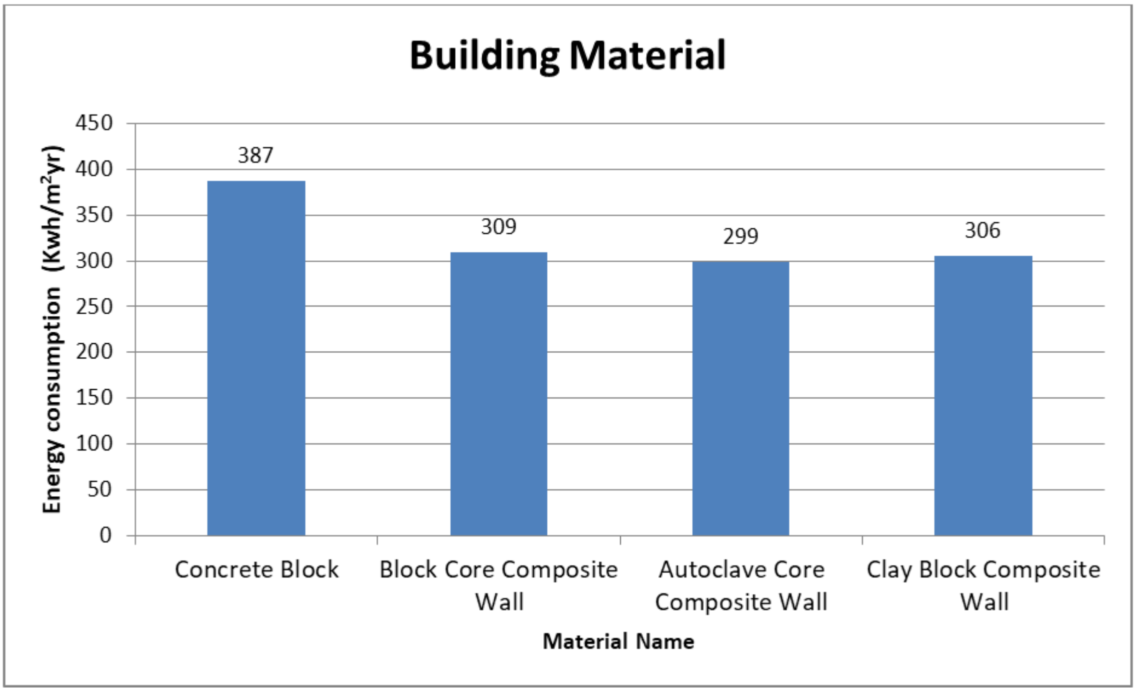

Figure 4. Simulation details of “Using Suitable Materials (P31)”

As the second rank in this group was “Using Efficient Shading Devices (P34)”, the windows of the initial model, locating at the south and north of the building, featured horizontal shadings. Thus, the total energy consumption, while the length of the shadings is a proportion of the window height, was calculated. The results are shown in Figure 5 and Figure 6. As a result, it is seen if the shading length is half of the window height on the south elevation, the total energy consumption will be the minimum (about 1.13% reduction in energy consumption). However, shading for northern windows is not suggested due to the negligible amount of energy consumption reduction.

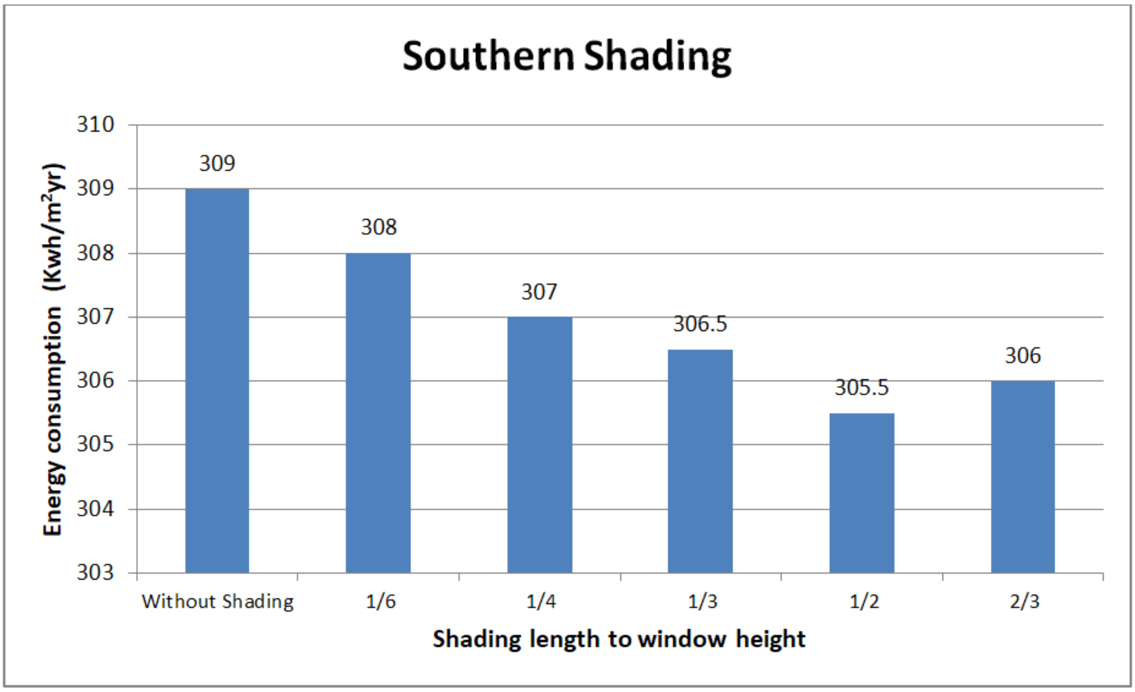

Figure 5. Simulation details of "Using Efficient Shading Devices (P34)", South.

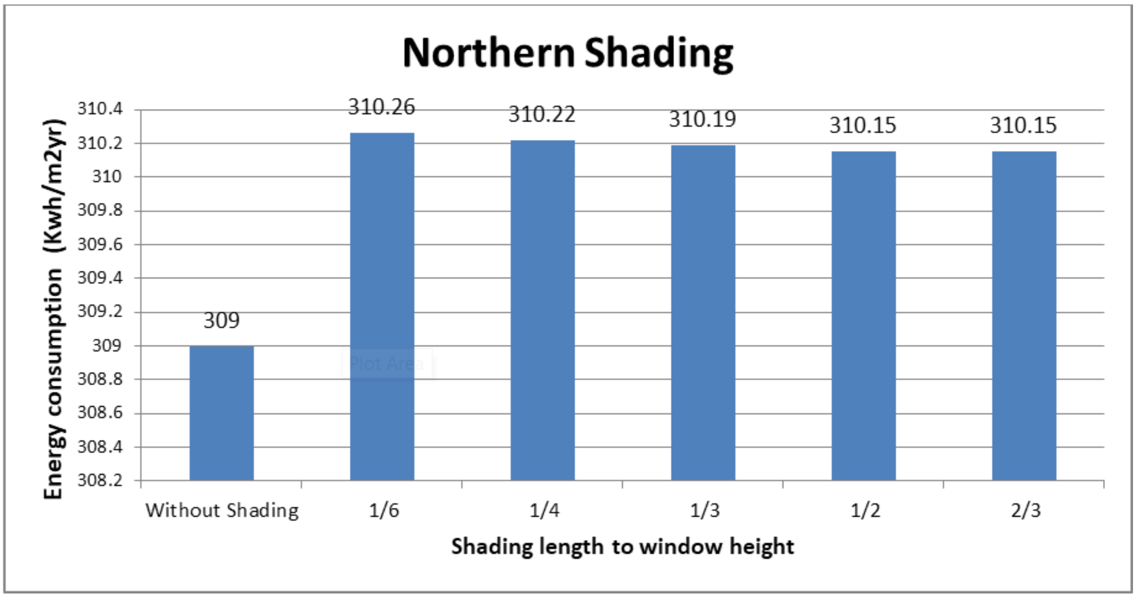

Figure 6. Simulation details of "Using Efficient Shading Devices (P34)", North.

4.4.3. Simulating "Architectural Design (G1)" energy consumption optimization group

In the current group, "Considering the Building Orientation (P16)" and "Using Proper Glazing (P14)" were the most important strategies. To identify the efficacy of building orientation in total energy consumption, the initial model was rotated 45 degrees clockwise. Accordingly, measures were taken to shape Figure 7, in which the total consumption of the building is depicted. As it is seen, 225 and 90 degrees of clockwise rotation have the least and the most consumption of energy, respectively.

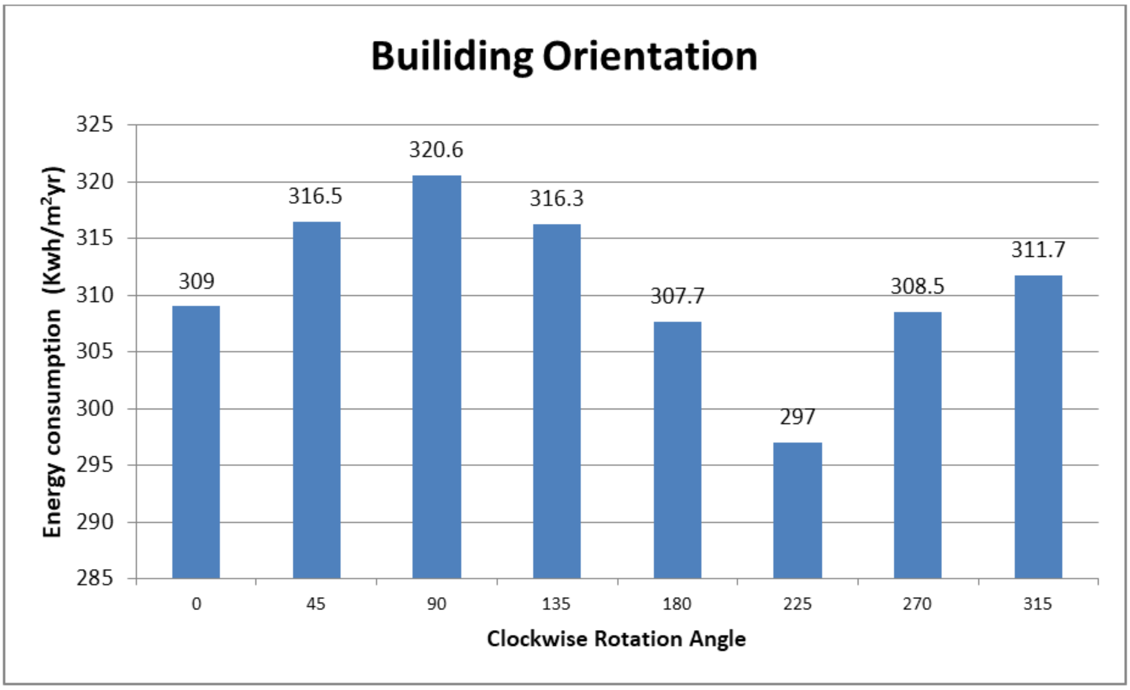

Figure 7. Simulation details of "Considering the Building Orientation (P16)".

As the latter strategy in this group was "Using Proper Glazing (P14)", the Windows to Wall Ratios (WWRs) of glazing systems for every four exterior walls of the building were studied. Therefore, the effects of various WWRs on energy consumption are shown in Figures 8 to 11.

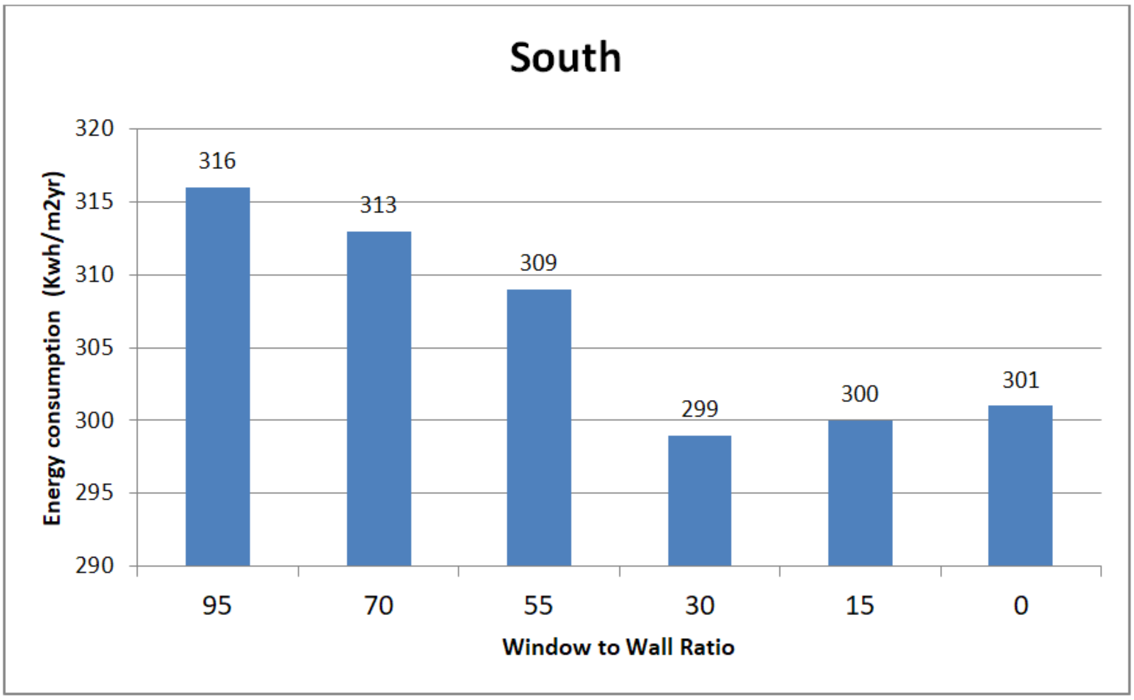

Figure 8. Simulation details of “Using Proper Glazing (P14)”, South.

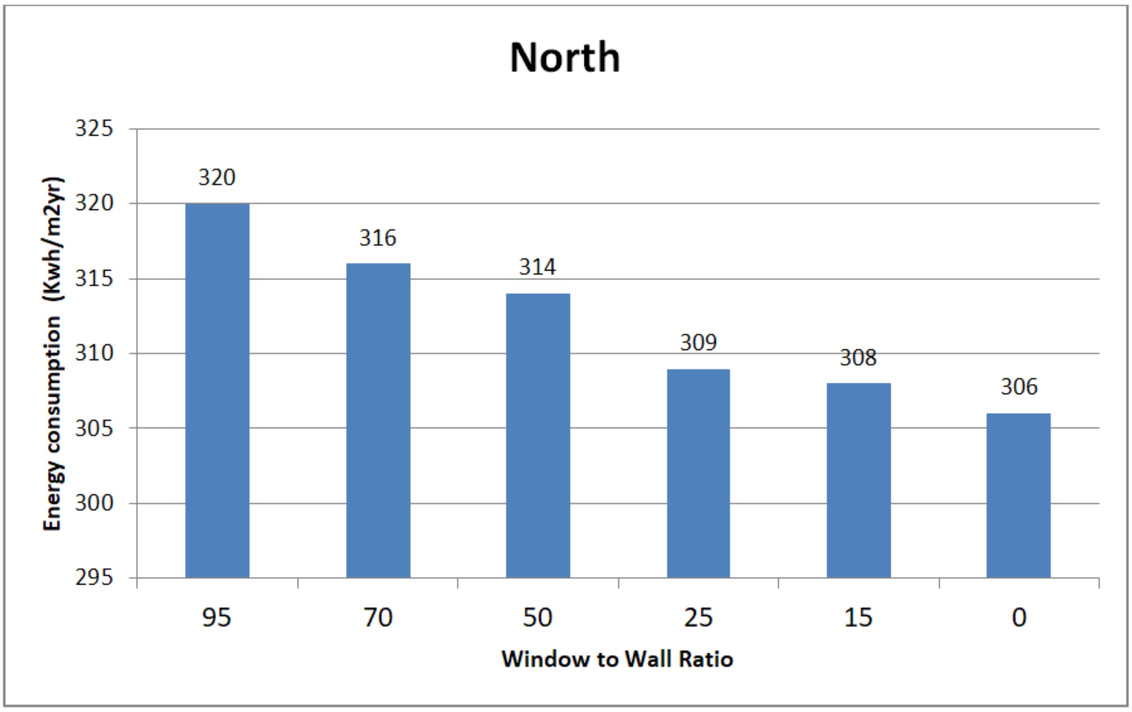

Figure 9. Simulation details of “Using Proper Glazing (P14)”, North.

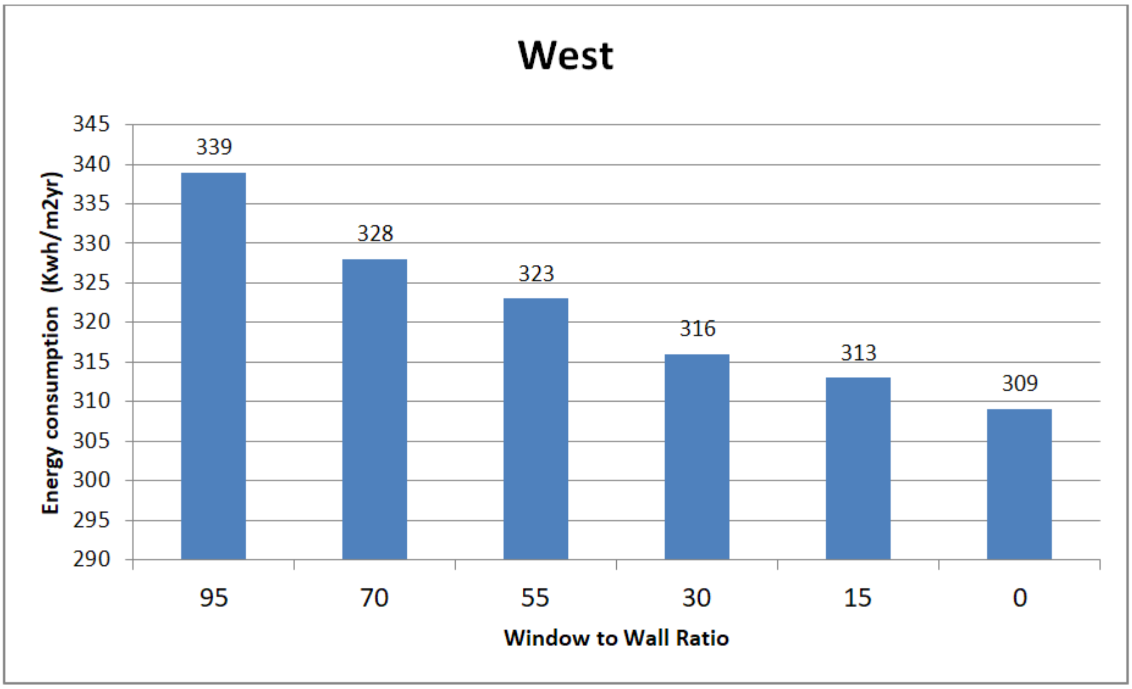

Figure 10. Simulation details of “Using Proper Glazing (P14)”, West.

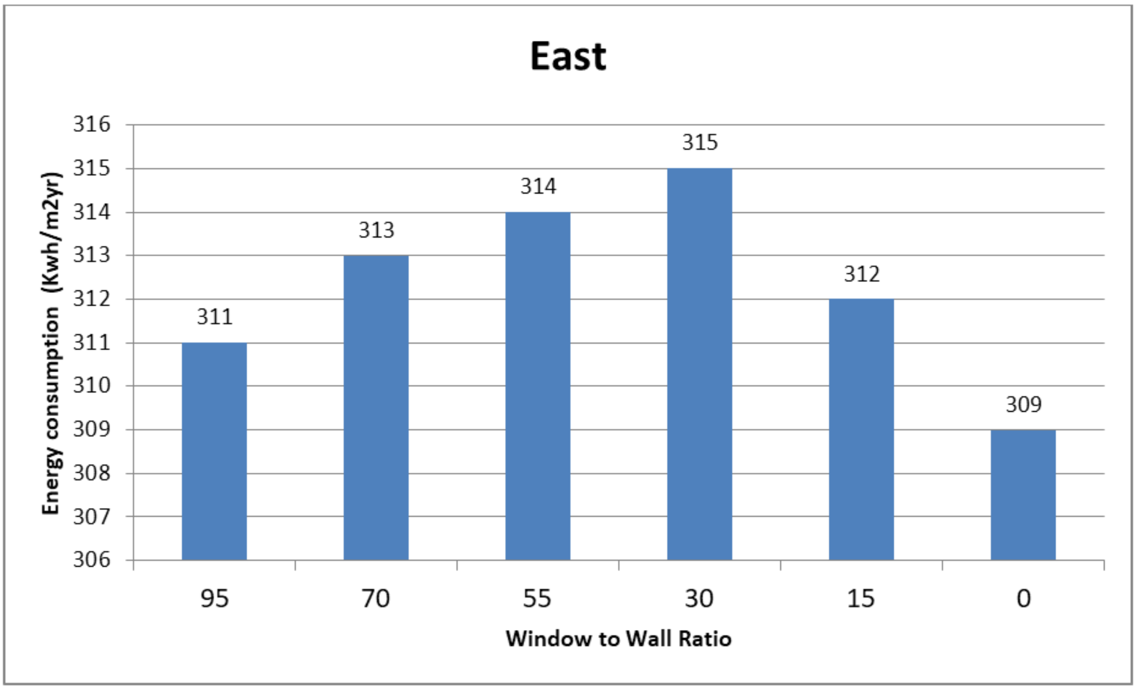

Figure 11. Simulation details of “Using Proper Glazing (P14)”, East.

4.4.4. Simulating "Law and Environment (G5)" energy consumption optimization group

In this group of energy reduction strategies, the most important one was "Using Renewable Energy Resources (P53)". This strategy, in contrast with others, was related to energy production, rather than energy reduction strategy. In this regard, the total energy, used from the grid, was calculated and is shown in Figure11. With the efficiency of 18% percent in photovoltaic panels, by covering 85 percent of the roof, the annual energy consumption of the building from the grid would be zero. This sustainability criterion is essential in achieving the architectural standards of the Net Zero Energy buildings (NZE).

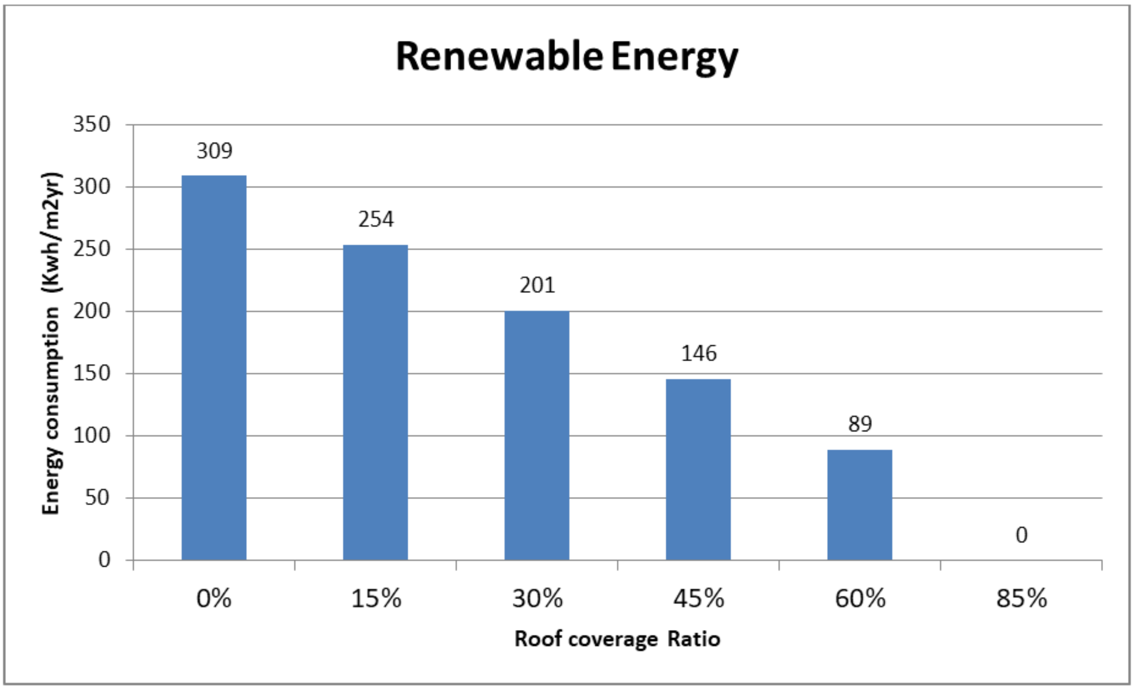

Figure 12. Simulation details of "Using Renewable Energy Resources (P53)"

4.4.5. Simulating "Behavior and Operation (G2)" energy consumption optimization group

In this group, "Using Energy Controlling Systems (ECSs) (P23)" was identified as the most important strategy. The most common ECSs are "Occupancy Monitoring" and "Daylight Controlling Systems". With the utilization of sensors and a central processor, the energy-related behavior of the occupants can be monitored. Moreover, Daylight controlling systems can analyze the potential and the needed light for satisfying the operational demands. Using these smart controllers can have influences on the total energy consumption of the building. 2% of energy reduction in total consumption is the result of the application of these systems which in comparison with the needed investment is a satisfying improvement.

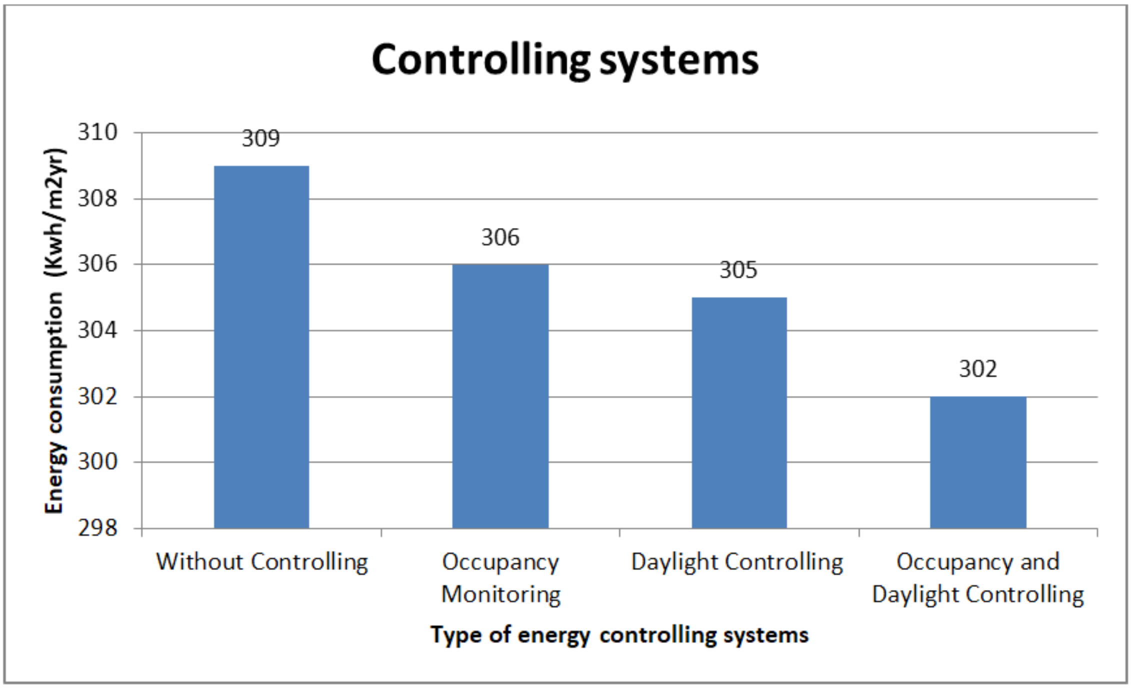

Figure 13. Simulation details of "Using Energy Controlling Systems (ECSs) (P23)"

4.5. Rank of the identified energy consumption optimization strategies according to BIM

To compare the efficacy of each optimization strategy, the total energy reduction was compared with the initial energy consumption. "Using Renewable Energy Resources (P53)" was the most effective strategy to reduce the energy consumption from the power grid and able to convert the building to an NZE building. In the second place was "Using efficient Insulation materials (P46)" with 35% of energy reduction. Complete details of strategies are illustrated in Table 11.

Table 11. The rank of the identified energy consumption optimization strategies according to BIM

Rank	Sign	Effectiveness
1	P53	100%
2	P46	35%
3	P31	23%
4	P47	10%
5	P14	4.2%
6	P16	4%
7	P23	2%
8	P47	1%

4.6. The U-Mann Whitney test

To double-check the reliability of the questionnaires, the perception of the respondents was analyzed with the Mann-Whitney test. Therefore, the respondents were separated into two groups, including academics and construction industry experts. The results are shown in Table 12. As it is seen, "Using Renewable Energy Resources (P53)" has an asymptotic significance less than 0.05 which shows different perceptions among the experts. This stems from the concept of the energy-saving definition and the fact that renewable energies cannot reduce energy consumption, and they reduce the energy that should be supplied by the power energy grid. Although renewable energies have a profound effect on the demanded energy production in power plants, using renewable energies cannot reduce the waste of energy in buildings [70].

Table 12. Results of U-Mann Whitney test

Sign	Strategy	Asymp. Sig.
P11	Designing buildings according to the optimum estimation of investment cost	0.222
P12	Designing buildings according to the optimum estimation of human resources cost	0.474
P13	Using passive cooling systems	0.244
P14	Using proper glazing	0.240
P15	Using passive heating systems	0.492
P16	Considering the building orientation	0.432
P17	Considering the building shape	0.581
P21	Considering energy prices in bills	0.653
P22	Considering occupant comfort	0.418
P23	Using energy controlling systems	0.074
P24	Considering the peak of energy demand	0.062
P25	Considering the usage of the building	0.497
P26	Considering O&M of the building	0.589
P31	Using suitable materials	0.077
P32	Recycling materials	0.370
P33	Suitable building retrofit	0.251
P34	Using efficient shading devices	0.052
P41	Using efficient cooling systems	0.154
P42	Improving the efficiency of appliances	0.062
P43	Using suitable energy grids	0.192
P44	Using efficient heating systems	0.964
P45	Using efficient fenestration materials	0.533
P46	Using efficient Insulation materials	0.164
P47	Using efficient lighting systems	0.750
P48	Using suitable ventilation systems	0.091
P51	Considering the climate in building design	0.068
P52	Considering energy efficiency protocols	0.561
P53	Using renewable energy resources	0.044
P54	Designing a suitable green area	0.470

4.7. Factor analysis test

The Confirmatory Factor Analysis (CFA) is a statistical method to study the underlying factors which are effective in the results. A factor is an unobservable variable influencing the measures and it accounts for the correlation among the observed measures [71]. To investigate the accuracy of the strategy categorization, the Factor Analysis method has been utilized in this study. To calculate the factor weights in each category, AMOS software was employed. The standardized values of more than 0.4 show the integration between the factors in each group. These weight of the CFA method are shown in Table 13. It can be seen that “Considering energy prices in bills (P21)” and “Considering Energy Efficiency Protocols (P52)” weights are less than 0.4. For the former one, this issue originates from the concept of energy bills. The prices in bills are economic factors that can affect the users’ behavior. In the latter, the legal strategies are different from environmental strategies, and with paying attention to the categorization of “law and environment” the factor value and the reason are justified.

Table 13. Results of Factor analysis test

Sign	Strategy	Standard Weight
P11	Designing buildings according to the optimum estimation of investment cost	0.47
P12	Designing buildings according to the optimum estimation of human resources cost	0.42
P13	Using passive cooling systems	0.54
P14	Using proper glazing	0.77
P15	Using passive heating systems	0.57
P16	Considering the building orientation	0.72
P17	Considering the building shape	0.69
P21	Considering energy prices in bills	0.37
P22	Considering occupant comfort	0.79
P23	Using energy controlling systems	0.69
P24	Considering the peak of energy demand	0.61
P25	Considering the usage of the building	0.75
P26	Considering O&M of the building	0.59
P31	Using suitable materials	0.68
P32	Recycling materials	0.62
P33	Suitable building retrofit	0.51
P34	Using efficient shading devices	0.43
P41	Using efficient cooling systems	0.82
P42	Improving the efficiency of appliances	0.87
P43	Using suitable energy grids	0.66
P44	Using efficient heating systems	0.53
P45	Using efficient fenestration materials	0.45
P46	Using efficient Insulation materials	0.61
P47	Using efficient lighting systems	0.78
P48	Using suitable ventilation systems	0.86
P51	Considering the climate in building design	0.61
P52	Considering energy efficiency protocols	0.34
P53	Using renewable energy resources	0.65
P54	Designing a suitable green area	0.52

5. Conclusions

Buildings are responsible for consuming a considerable amount of energy. In light of the dramatic increase in energy consumption of the mentioned sector, a satisfactory solution must be found. Therefore, in the current study, energy consumption optimization strategies were identified, prioritized, and the efficacy of the most important strategies for reducing the total energy consumption of the buildings was investigated. At first, 29 strategies have been identified and categorized into five groups including “Architectural Design (G1)”, “Behavior and Operation (G2)”, “Construction Specification (G3)”, “Technical Equipment (G4)” and “Law and Environment (G5)”. In order to prioritize the groups and strategies, the SWARA method was employed and the weights of the strategies were conducted. According to the results, G4, G3, and G1 were the most important categories. The most important strategies in the mentioned groups were “Using efficient Insulation materials (P46)”, “Using suitable materials (P31)” and “Considering the building orientation (P16)”, respectively. Building Information modeling was employed to calculate the efficacy of the most important strategies in all the 5 groups, and “Using renewable energy resources (P53)”, “Using efficient insulation materials (P46)”, “Using suitable materials (P31)”, and “Using efficient lighting systems (P47)” with 100%, 35%, 23%, and 10% efficacy, were introduced as the major contributors to the energy consumption optimization.

The method used in this study can be exploited in similar problems of the building industry as well. Obtained results of this study can be used in both Shiraz, Iran, and also cities having similar situations all around the world. Due to the high potential of energy saving of the identified energy consumption optimization strategies, they are highly suggested to be used by the authors.

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