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A Parametric Model Proposal for Energy-Efficient Building Design in the Cold-Arid Climate Region: A Case on Tabriz

Soğuk-Kurak İklim Bölgesinde Enerji Etkin Bina Tasarımı için Parametrik bir Model Önerisi: Tebriz Örneği

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ABSTRACT

Built environments are responsible for significant global energy consumption, greenhouse gas emissions, and environmental problems. Due to the rapid increase in the population in cities, the unplanned construction of the housing need has a share that must be addressed in the emergence of these problems. Therefore, today, the energy-efficient design of new settlements has become a current and essential approach. It has made it necessary to consider the decisions taken regarding the factors affecting building energy consumption before the design. In this direction, the effects of design parameters such as window ratio, balcony depth, material type, material color, insulation used, number of floors, basement floor usage, aspect ratio, and building orientation status on energy performance in the city of Tabriz with a cold-arid climate were analyzed with the Design-Builder program. Then, suitable criteria to reduce energy consumption were searched. By comparing the results obtained from the analyses, the effect of the appropriate architectural decisions regarding these parameters on energy saving has been determined, a guide for designing energy-efficient buildings has been created, and a model proposal has been provided.

Keywords: Building energy performance, design parameters, energy efficiency, residential building design, climate responsive design.

ÖZ

Kentsel yerleşmeler, küresel enerji tüketiminin, sera gazı emisyonlarının ve çevresel sorunların önemli bölümlerinden sorumludurlar. Kentlerde, nüfusun hızla artışı nedeniyle konut ihtiyacının plansız yapılaşmaları bu sorunların ortaya çıkmasında göz ardı edilemeyecek paya sahiptir. Bu nedenle günümüzde, yeni geliştirilecek yerleşmelerin enerji etkin olarak tasarlanması artık güncel ve önemli bir yaklaşım haline gelmiştir. Bu da, tasarım öncesi bina enerji tüketim miktarını etkileyen faktörlerle ilgili alınan kararların dikkate alınmasını zorunlu kılmıştır. Bu doğrultuda, çalışmada soğuk-kurak iklime sahip Tebriz kentinde pencere oranı, balkon derinliği, malzeme türü, malzeme rengi, yalıtım kullanımı, kat sayısı, bodrum kat kullanımı, en boy oranı ve bina yönlendiriliş durumu gibi tasarım parametrelerinin enerji performansına etkileri Design Builder programı ile analiz edilmiş, enerji tüketimini düşürmek için uygun kriterler araştırılmıştır. Analizlerden elde edilen sonuçların karşılaştırılması ile bu parametrelere ilişkin uygun mimari kararların enerji tasarrufundaki etkisi çıkarılmış ve enerji performanslı bina tasarımına yönelik bir kılavuz oluşturulmuştur. En son aşamada, elde edilen kılavuz sayesinde bir model önerisi de sunulmuştur.

Anahtar Kelimeler: Bina enerji performansı, tasarım parametreleri, enerji etkinlik, konut tasarımı, iklime duyarlı tasarım.

Introduction

With the technological developments during the Industrial Revolution, energy has a vital role in today's societies and has taken its place among basic needs. The increase in dependence on energy has led to a rise in consumption and has made it necessary to take measures at the level of government. Nowadays, practical steps have been taken to reduce the dependence on primary energy in different sectors and academic platforms. The fact that the built environment is responsible for 70% of global greenhouse gas emissions and uses more than three-quarters of primary energy (UN-Habitat, 2022) has brought improvements to be made in this area and the measures that can be taken at the building scale, even more critical.

One of the crucial factors affecting energy consumption in buildings is climate. Climate plays an active role in shaping cities' planning and architectural formation. Climatic data affecting architectural design are usually microclimatic features. Oliveira et al. (2019) discuss climatic elements related to local microclimatic and climatic behaviors in four categories: solar radiation, air temperature, wind, and humidity. Site selection and building spacing at the settlement scale and building form, orientation, building envelope, and space organization at the single building scale are known as the parameters affected by the climate in the design process (Shaterian, 2013). There will inevitably be an increase in the energy consumption of buildings by ignoring the climatic features. It is known that efforts are made to design buildings with high energy performance without sacrificing comfort and by using climatic design strategies, which have even been faced in traditional residences. There are many academic studies on this subject. For example, considering the energy consumption of traditional houses, it has been proved that the traditional houses of Tabriz, which are in the cold-arid climatic region, are climate-sensitive and consume less energy (Shadmand & Arslan Selçuk, 2022). Nowadays, considering the climatic characteristics, in addition to the use of high-performance materials and HVAC systems, the issue of ensuring energy efficiency together with thermal comfort is one of the focal central points of the research carried out (Wang et al., 2021). The role of building modelling and simulation programs in assessing the thermal performance of buildings is also examined in this context, and the potential of these tools is discussed (Siu et al., 2023). There are various studies on achieving energy efficiency in housing stock. In an illustrative study, it was demonstrated that through the implementation of a specific set of procedures, the energy consumption of residential buildings in China could be curtailed by a notable 18.52% ((Wang et al., 2023). Another study, which analysed the effect of settlement patterns on the amount of energy consumption, showed that the total energy consumption decreased by 10% by providing the optimum level of solar radiation gain thanks to appropriately designed buildings in mild temperature regions (Ratii et al., 2005). When the effect of settlement type on energy performance is analysed, it showed that by designing suitable settlement types, the potential to benefit from solar energy could be increased, and a 25% saving in total energy consumption can be achieved (Zhang et al., 2019; McKeen & Fung, 2014). It has also been shown that, in addition to building types, the number of people living in the building and the energy behaviour of the building occupants also play an effective role in energy consumption (Nayak et al., 2023). In another study, buildings' heating and cooling energy loads were analysed using the Bayesian network method. Considering the factors affecting energy consumption, the impact of appropriate decisions on energy consumption was calculated, and suggestions were made to reduce heating and cooling loads (Senarathne et al., 2022). A study investigating the thermal performance of residential buildings in different climate zones analysed the impact of the building aspect ratio on energy efficiency. The results show that significant gains in energy efficiency can be achieved by determining the correct building aspect ratios (Inanici & Demirbilek, 2000). The determination that the settlements with courtyards, which are in a compact form in the Mediterranean climate, consume less energy compared to the row, block, and point block settlements is another study that can be given to show that energy consumption can be saved by designing building forms suitable for climatic regions (Vartholomaios, 2017). In a study in which the effect of building envelope design on energy consumption is analysed by considering the thermal gain-loss balance, it has been revealed that increasing the transparency rate and improving the thermal insulation level of the opaque building envelope does not positively affect energy consumption in all cases (Van Esch, Looman, and Bruin-Hordijk 2012). A similar study showed that the decision regarding the thermal insulation used, considering the wall thickness, positively affects energy consumption (Sharston & Murray, 2020). Another study in a warm climatic region analysed the effect of the window-to-wall ratio in buildings on cooling and heating energy consumption. According to the findings of this study, it was observed that increasing the window ratio leads to an increase in cooling energy consumption and a decrease in heating energy consumption (Alghoul et al., 2017). In a similar study, the effect of the window-to-wall ratio on the amount of energy consumed for cooling, lighting, and ventilation was analysed. This study also discussed the role of simulation studies in the decisions made (Troup et al., 2019). Considering that the solar heat gain varies depending on the building form, transparency rate, and building orientation, which are the design parameters of the building, it is stated that the building forms show different thermal results depending on the climatic zones (DeKay & Brown, 2014). In this context, the role of direct solar energy utilization and solar-powered systems in reducing energy costs in different climate zones has also been debated (Hoseinzadeh & Azadi, 2017). In another study, simulation and experimental methods showed that using solar-ventilated windows in different climatic zones can improve indoor ventilation conditions and reduce energy consumption (Pang et al., 2017). In the literature, there are also studies on the development of models that calculate monthly and annual solar energy and ensure the optimum use of this energy, aiming for the highest gain (Chakkaravarthy et al., 2018). Another study examining the impact of insulation materials on energy consumption in the exterior of buildings found that using insulation would reduce energy consumption. In the same study, it was also shown that there is a correlation between the characteristics of the insulation and the amount of energy consumption (Yang & Jingjing, 2017). A study examining the impact of using phase change materials in a building covering energy consumption showed that these materials could significantly reduce heating and cooling loads (Kishore et al., 2021). Some studies have also shown that the impact of balconies on energy performance and thermal comfort can vary depending on the balcony's form, depth, and typology (Yuan et al., 2022; Mirabi & Nasrollahi, 2019). In a study investigating the effect of building orientation on energy consumption, the energy consumption of buildings designed in different directions was calculated, and according to the results obtained, the most accurate directions to reduce energy consumption were determined (Ashmawy & Neveen, 2018). Using the BIM program, another similar study revealed that the right decisions made in the orientation of buildings can lead to significant energy savings (Abanda and 2016). A study examining the impact of the number of stories on energy consumption revealed that the number of stories affects heating, cooling, and electricity consumption (Lai et al., 2016). Other studies on energy efficiency and comfort requirements of buildings have discussed the potential of functional materials and emphasized the importance of innovative materials for energy performance compared with conventional materials (Ebert, 2015; Pisello, 2016). In another study, the impact of design criteria on energy consumption in a high-rise commercial building was analysed, and the best scenarios were discussed (Langner et al., 2012). There are studies analyzing climate change's impact on energy consumption (Bai et al., 2020). Unlike previous studies, this study tried to examine the existing or possible effects of architectural design criteria on energy consumption and the impact and potential of these criteria. For this purpose, this study is detailed within the framework of energy and architecture. It is limited to the effect of the decisions about energy consumption based on window ratio, balcony depth, material type, material color insulation used, number of floors, basement floor usage, aspect ratio, and orientation status in Tabriz. This study is considered a guide in providing energy efficiency for buildings.

Material and Methods

This article aims to prepare and present sample data based on a comprehensive approach that will enable the right decisions to be made in designing energy-efficient artificial environments. The study analysed the effect of architectural elements and design parameters on building energy consumption in the Tabriz climate and investigated the appropriate criteria for reducing energy consumption. For this purpose, a box with an area of 100 m2 was designed, and analyses were made in the Design-Builder program. The effect of the decisions taken regarding the window ratio, balcony depth, material type, material color, insulation used, number of floors, basement floor usage, aspect ratio, and orientation of the buildings in the previously mentioned box was investigated on energy consumption. In this context, the parameters to be analysed were defined by considering the specific climatic conditions of Tabriz.[1] And the needs of the users. The identified parameters were input into the software, and during the process of defining and determining the boundaries of each parameter, various options and alternatives were evaluated. Additionally, climate data specific to Tabriz, such as heating and cooling degree days, outdoor temperatures, and solar radiation, were integrated into the program to ensure that the simulations produced realistic results.

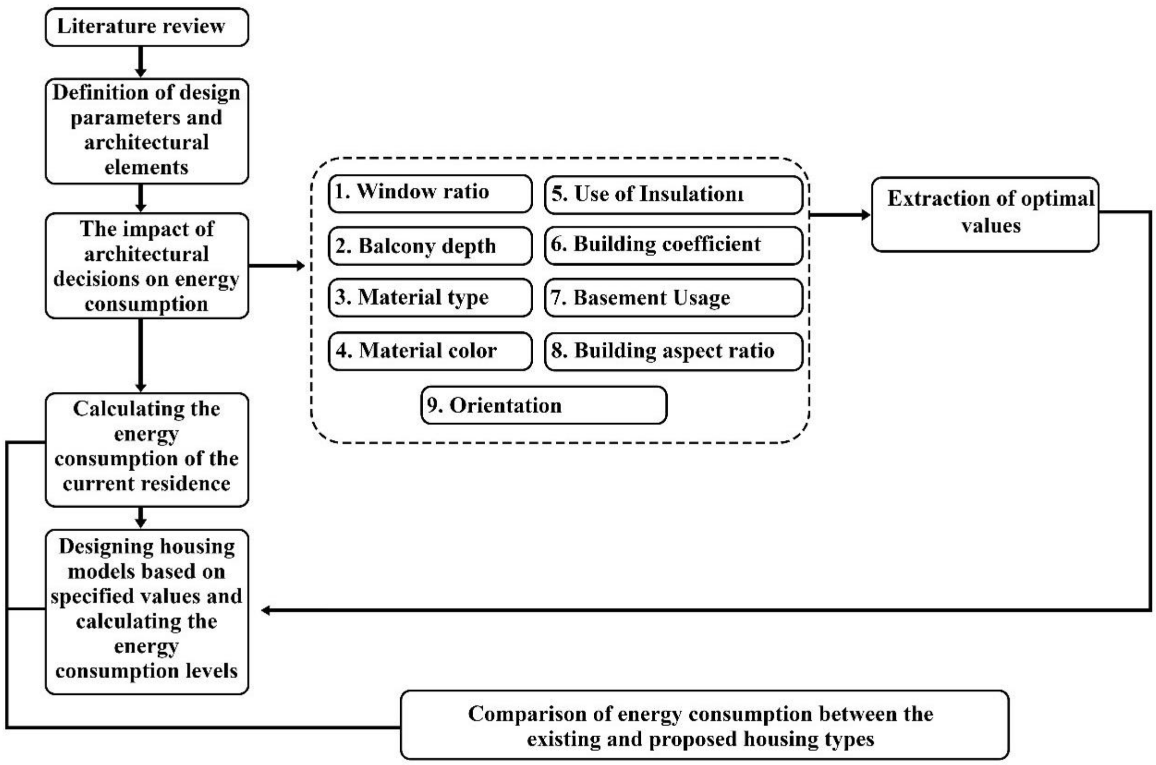


Figure 1. Flow chart of the study

During the analysis phase, the geometric and material properties of the architectural elements and design decisions were defined in the Design-Builder software. Various options and alternatives were also considered while defining and setting each parameter's boundaries. Furthermore, climate data specific to Tabriz, such as heating and cooling degree days, outdoor temperatures, and solar radiation, were integrated into the program to ensure realistic simulation results. The necessary settings were made to calculate the model's annual energy consumption in the simulation phase, and different scenarios were tested. Various alternatives were tested for each parameter in these scenarios, and their impacts on energy consumption were observed. The results were compared, and the optimal parameters that minimized energy consumption were identified.

The simulation results were thoroughly analysed in the analysis and evaluation process, and the parameters with the most significant impact and their optimal values were determined. In this context, the “scenario with optimal values” obtained from the analyses served as a guide for the design of new housing. Subsequently, a typical residential model in Tabriz was selected, and all of its information was transferred to the simulation program, where energy consumption was analysed. Following this, two buildings with the same area and spaces as the reference building were designed, and their energy consumption was calculated. These two building models utilized the optimal values obtained from the developed models. Finally, the energy consumption of all three buildings was compared, demonstrating the impact of appropriate architectural decisions on energy savings. The workflow of the study is shown in Figure 1.

[1] Tabriz is located in a cold climatic region (latitude: 38.13°, longitude: 46.28°), and this research is used as a case study.

Results

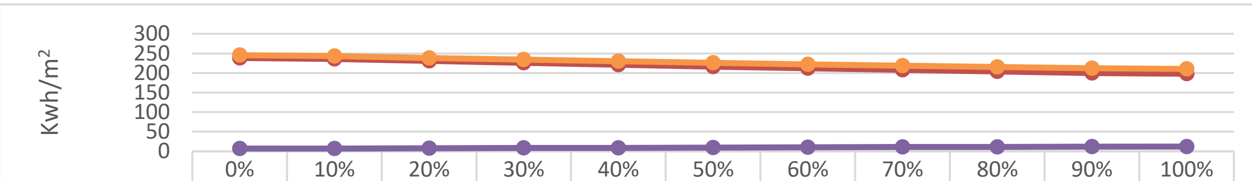
At this stage of the study, as shown in Figure 1, the decisions taken regarding the window ratio, balcony depth, material type, material color insulation used, number of floors, basement floor usage, aspect ratio, orientation status, and building energy consumption in Tabriz climate the effect on energy consumption has been analysed, and appropriate criteria have been investigated to reduce energy consumption. Since the impact of these elements and design parameters on the amount of energy consumption will be analysed in general, a box with an area of 100 m2 was designed at this stage and defined in the Design-Builder program, assuming that there is only one living space in the interior of the building instead of different units. Because a building with nonidentical interior spaces consumes different amounts of energy depending on the spaces' functions, the existence of these spaces may affect the energy analysis simulations at this stage and cause false results. For this reason, after the analyses, the more accurate positioning of the spaces was discussed regarding energy consumption, considering the optimum values based on the results obtained. In the last stage, the effect of positioning these spaces on energy consumption was analysed with the Design-Builder program.

Window Ratio

This section analyses the effect of the decisions made regarding the ratio of the windows used in the building to energy consumption. The analyses have tried to find the optimum ratio when using windows in only one direction, the optimum ratio when using the same ratio in all directions, and the optimum ratio of windows in the other directions while using 100% windows on the south facade.

The Effect of Windows[2] Used in One Direction on Energy Consumption

In this section, the effect of the window ratios in different directions of the buildings on the amount of heating and cooling energy consumption has been analysed, and the most appropriate window ratio for minimum energy consumption has been determined. The double-glazed window, standard in Tabriz today, was chosen for the analysis simulation. Each direction was considered separately to assess the effect of the window ratio used in the building's south, west, north, and east facades on energy consumption. While the impact of window ratios was analysed, no windows were used in other aspects of the building.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	238,27	235,5	230,58	225,65	220,93	216,4	212,05	207,87	203,69	199,83	198,04
Cooling	7,12	7,4	7,94	8,49	9,05	9,61	10,18	10,75	11,33	11,92	12,16
Total	245,39	242,9	238,52	234,14	229,98	226,01	222,23	218,62	215,02	211,75	210,2

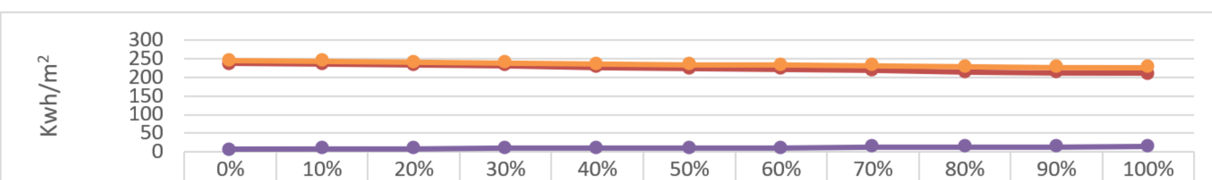
Figure 2. The effect of the window ratio on the south facade on energy consumption

South Front

At this stage, while windows were used on the south facade, no windows were used on the other facades. As seen in Figure 2, increasing the window ratio on the south facade caused a decrease in the heating energy consumed per square meter in the building and increased the cooling energy. In other words, when no windows are used on this facade, the energy consumed for cooling is at the lowest level, and the energy consumed for heating is at the highest. Total energy consumption is also at the lowest level when using 100% windows on the south facade. Therefore, when no windows are used on other facades, it is considered appropriate to use 100% windows on the south facade in terms of energy efficiency.

Western Front

When the effect of the window ratio on the west facade on the amount of energy consumption is examined, as can be seen in Figure 3, the energy consumed for heating is at the highest level when no windows are used on the western facade of the building, and the energy used for cooling is at the lowest level. The increase in the window ratio also caused a decrease in the heating energy and an increase in the cooling energy. The total energy consumption is lowest when using 100% windows. In other words, if no windows are utilized on the different facades, a window ratio of 100% on the west facade is considered appropriate for energy consumption.



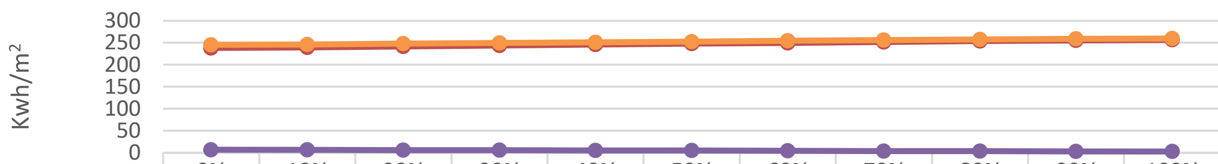
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	238,27	236,41	233,24	230,14	226,91	223,98	221,13	218,15	215,44	212,79	211,5
Cooling	7,12	7,51	8,23	8,95	9,69	10,44	11,2	11,95	12,71	13,49	13,81
Total	245,39	243,92	241,47	239,09	236,6	234,42	232,33	230,1	228,15	226,28	225,31

Figure 3. The effect of window ratio on energy consumption on the west façade.

[2] Use of double glass windows with insulated frames (U-factor: 0.80 W/m²K), unless stated otherwise.

Northern Front

When the effect of the window ratio on the north facade is analyzed, it is observed that as the ratio of windows used on this facade increases, the amount of heating energy consumption rises. In contrast, the amount of cooling energy consumption decreases. However, the increase in the ratio of windows on the north facade has led to a rise in energy consumption. In this case, the low ratio of windows used on the north facade will reduce the energy consumed in the building.

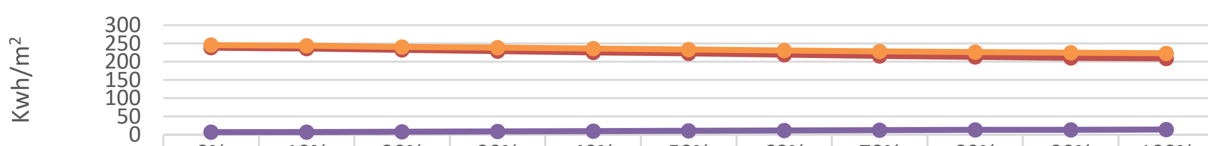


	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	238,27	239,45	241,59	243,77	245,75	247,75	249,79	251,86	253,71	255,58	256,66
Cooling	7,12	6,7	6,28	5,87	5,45	5,04	4,61	4,2	3,78	3,37	2,95
Total	245,39	246,15	247,87	249,64	251,2	252,79	254,4	256,06	257,49	258,95	259,61

Figure 4. The effect of window ratio on energy consumption on the north façade.

Eastern Front

The effect of the window ratio on the east facade on energy consumption is shown in Figure 5. When no windows are used on the other facades, the rate of using windows on the east facade is 0%, while the heating energy consumption is the highest and the cooling energy consumption is the lowest. The increase in the window ratio caused a decrease in the amount of heating energy consumption and an increase in the amount of cooling energy consumption. In short, when no windows are used on other facades, using 100% windows on the eastern facade will reduce energy consumption.



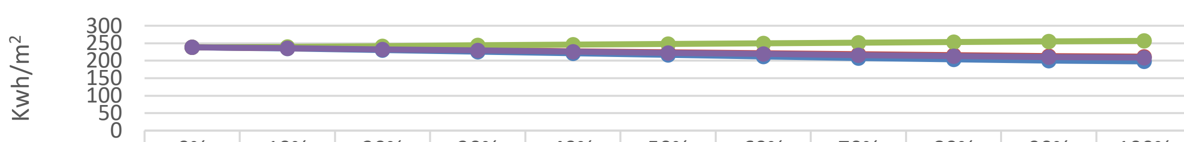
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	238,27	236,18	232,56	229,27	225,86	222,55	219,33	216,2	213,17	210,4	208,95
Cooling	7,12	7,49	8,23	8,98	9,76	10,56	11,36	12,19	13,02	13,84	14,21
Total	245,39	243,67	240,79	238,25	235,62	233,11	230,69	228,39	226,19	224,24	223,16

Figure 5. The effect of window ratio on energy consumption on the east façade.

The Effect of Using the Same Ratio of Windows in All Directions on Energy Consumption

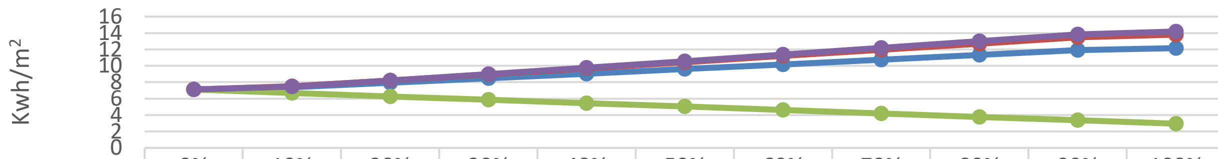
Having the same window ratio in all directions may reveal different results in the amount of energy consumption. For this reason, the energy consumption amount was analyzed using the same ratio of windows in all directions, and the results were compared. As shown in Figure 6, the increase in the ratio of windows on the south, west, and east facades reduced the heating energy consumption. However, the increased ratio of windows on the north facade has led to a rise in heating energy consumption. Among all aspects, the window ratio of the south facade has the most significant effect on the amount of heating energy consumption. The ratio of windows facing east and west has almost the same impact on heating energy consumption.

When the effect of the window ratio in all directions on the amount of cooling energy consumption is analyzed, as seen in Figure 7, the increase in the ratio of windows used in the south, west, and east directions caused an increase in the amount of cooling energy consumption. In the north direction, the increase in the window ratio has reduced the amount of cooling energy consumption. Since the change in the amount of cooling energy consumption in all directions is less than that of heating energy, comparing the total energy consumption is vital for deciding the window ratio.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
South	238,27	235,5	230,58	225,65	220,93	216,4	212,05	207,87	203,69	199,83	198,04
West	238,27	236,41	233,24	230,14	226,91	223,98	221,13	218,15	215,44	212,79	211,5
North	238,27	239,45	241,59	243,77	245,75	247,75	249,79	251,86	253,71	255,58	256,66
East	238,27	236,18	232,56	229,27	225,86	222,55	219,33	216,2	213,17	210,04	208,95

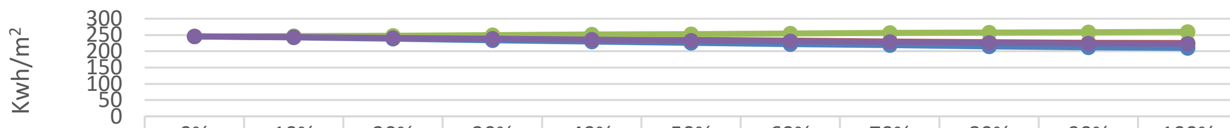
Figure 6. The effect of using the same ratio of windows in all directions on heating energy consumption.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
South	7,12	7,4	7,94	8,49	9,05	9,61	10,18	10,75	11,33	11,92	12,16
West	7,12	7,51	8,23	8,95	9,69	10,44	11,2	11,95	12,71	13,49	13,81
North	7,12	6,7	6,28	5,87	5,45	5,04	4,61	4,2	3,78	3,37	2,95
Doğu	7,12	7,49	8,22	8,98	9,76	10,55	11,36	12,18	13	13,82	14,19

Figure 7. The effect of using the same ratio of windows in all directions on cooling energy consumption.

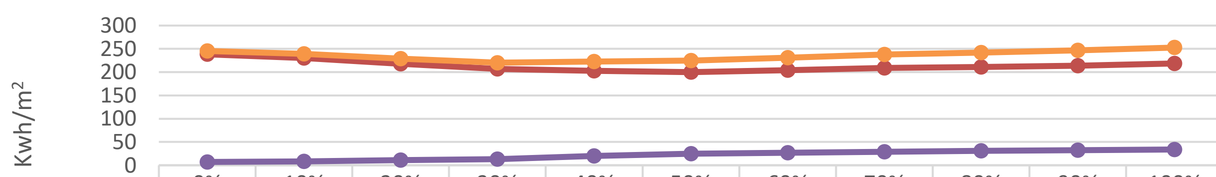
When the effect of the window ratio used in all directions on the total energy consumption is analyzed, As can be seen in Figure 8, the increase in the ratio of windows on the south, west, and east facades resulted in a decrease in total energy consumption. The increase in the window ratio on the north facade has led to an increase in total energy consumption. In addition, it has been observed that the window ratio of the south facade has a more positive effect on the amount of energy consumption compared to other directions.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
South	245,39	242,9	238,52	234,14	229,98	226,01	222,23	218,62	215,02	211,75	210,2
West	245,39	243,92	241,47	239,09	236,6	234,42	232,33	230,1	228,15	226,28	225,31
North	245,39	246,15	247,87	249,64	251,2	252,79	254,4	256,06	257,49	258,95	259,61
East	245,39	243,67	240,79	238,25	235,62	233,11	230,69	228,39	226,19	224,24	223,16

Figure 8. The effect of using the same ratio of windows in all directions on total energy consumption.

Since the windows on the north facade cannot receive direct sunlight, heat loss, especially in winter, increases energy consumption. For this reason, the small size of the windows used in this direction and the low number of them are considered appropriate regarding energy efficiency. Increasing the ratio of windows facing east and west reduces the amount of energy consumption. However, the use of east-facing windows is more recommended than west-facing windows, as it affects the amount of energy consumption less negatively and because it gains solar heat in the morning. When double-glazed windows are used in only one direction of the building, The large ratio of windows used in the south, west, and east directions will reduce the energy consumed. For this reason, the large ratio of windows used in the specified directions is considered appropriate for reducing energy consumption. Using the same ratio of windows in all directions, the amount of energy consumption was analyzed to extract the optimum ratio, shown in Figure 9. The results show that the increase in the ratio of windows in all directions causes an increase in cooling energy consumption. Regarding heating energy consumption, the window ratio decreases from 0% to 50% and rises from 50% to 100%. This indicates that when the same ratio of windows is used in all directions of the building, the appropriate window ratio for heating energy consumption is 50%, for cooling energy consumption is 0%, and for total energy consumption is 30%.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	238,27	230,58	218,15	206,99	202,67	200	203,86	208,77	210,84	214,11	218,93
Cooling	7,12	8,4	10,84	13,34	19,77	24,64	26,84	29,12	30,99	32,68	33,83
Total	245,39	238,98	228,99	220,33	222,44	224,64	230,7	237,89	241,83	246,79	252,76

Figure 9. The effect of the ratio of windows used at the same rate in all directions on energy consumption.

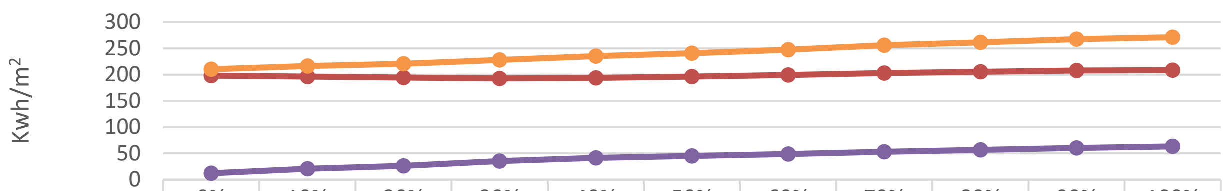
The energy analysis simulation results have shown that the windows used on the south facade are more effective in the amount of energy consumption in a positive way. It has also been observed that the optimum ratio of the windows used on the south facade is 100%. For this reason, in the next section, when 100% windows are used on the south facade, we tried to determine the appropriate window ratio in other directions.

The Effect of The Window Ratio of The Other Facades on Energy Consumption When 100% Of Windows Are Used on The South Facade

In this section, when 100% of windows are used on the south facade of the building, the optimum ratio of the windows used on the other facades has been determined. Since the window ratios of the western and eastern facades have almost the same effect on energy consumption, both are discussed under the same heading. The impact of the window ratio of the north facade was analyzed alone.

Western and Eastern Fronts

As seen in Figure 10, if the ratio of windows used on the south facade of the building is 100%, the ratio of windows used on the west and east facades has a minimum effect on the amount of heating energy consumed. The results show that when the ratio of windows used on the west and east facades is 30%, the amount of heating energy consumption decreases slightly, and the amount of heating energy increases with the increase of the window ratio from 30% to 100%. In addition, it was observed that the cooling energy consumed and the total energy consumption increased with the increase in the ratio of windows used on the west and east facades. In short, since the windows used on the west and east facades cause an increase in the energy consumption of the building, if the ratio of the windows used on the south facade of the buildings is of suitable size, the use of windows in these directions is not recommended in terms of energy efficiency.

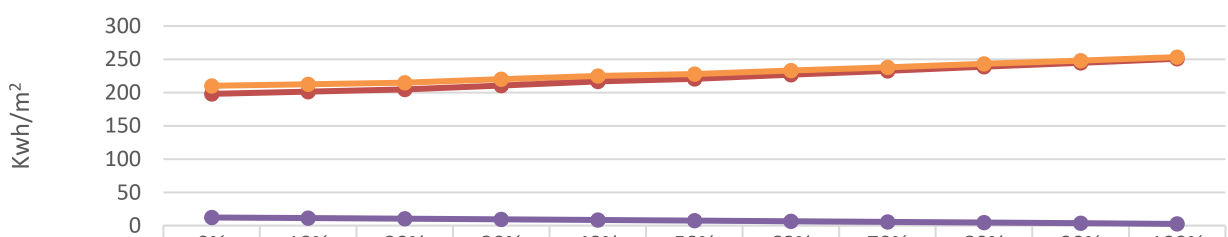


	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	198,04	195,96	194,39	192,7	193,77	195,96	199,18	203,01	205,24	208,05	208,41
Cooling	12,16	20,44	26,25	35,32	41,42	45,32	48,53	52,79	56,52	60,05	63,21
Total	210,2	216,41	220,57	227,85	235,13	240,96	247,69	255,99	261,25	267,53	271,16

Figure 10. The effect of window ratio on energy consumption on the west and east facades when 100% windows are used on the south façade.

Northern Front

As can be seen in Figure 11, if the ratio of windows used on the south facade of the building is 100%, and if no windows are used on the west and east facades, the increase in the ratio of windows used on the north facade causes an increase in heating and total energy consumption.

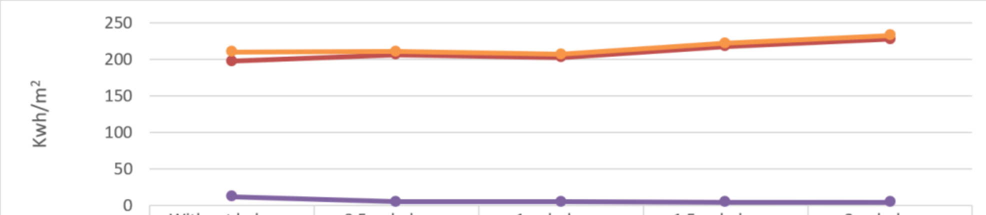


	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Heating	198,04	201,32	204,72	210,76	216,78	220,73	226,7	232,79	238,74	244,76	250,82
Cooling	12,16	11,2	10,22	9,26	8,3	7,32	6,35	5,39	4,41	3,44	2,48
Total	210,2	212,52	214,94	220,02	225,08	228,05	233,05	238,18	243,15	248,2	253,3

Figure 11. The effect of the window ratio on the north facade on energy consumption when 100% windows are used on the south façade.

Balcony Depth

Using balconies on the south facade of buildings is expected in Tabriz. This section has tried to determine the appropriate balcony size, which prevents unnecessary solar radiation in the summer and enables the use of solar energy in the winter. Therefore, to assess the effect of balcony size on building energy consumption, an energy simulation of balconies with different depths was made, and the results were compared. As seen in Figure 12, the results show that using a 1 m balcony from the south facade of the building reduces the total energy consumption.

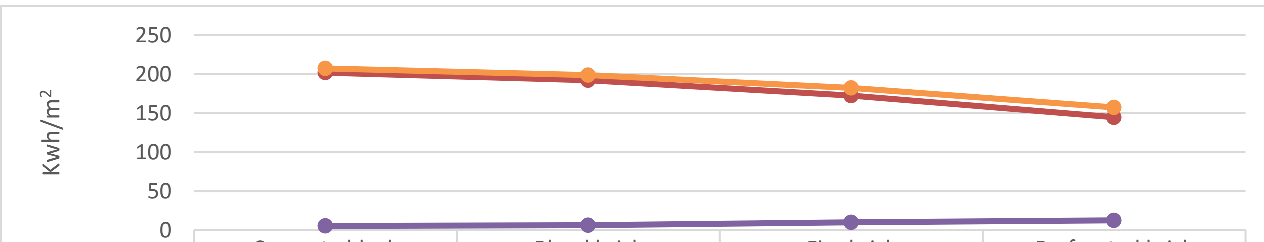


	Without balcony	0.5 m balcony	1 m balcony	1.5 m balcony	2 m balcony
Heating	198,04	205,76	201,99	217,76	228,19
Cooling	12,16	5,34	5,42	4,65	3,99
Total	210,2	211,1	207,41	222,41	232,18

Figure 12. The effect of balcony depth on energy consumption.

Material Type

This section analyses the effect of different materials on energy consumption. Concrete briquettes, blended bricks, fire bricks, and perforated bricks, widely used in building construction in Tabriz, were used for analysis simulation. 100% windows and a 1 m balcony were used on the south facade of the selected building. As shown in Figure 13, it has been determined that the material suitable for Tabriz's climate is a perforated brick in terms of total energy consumption, as expected, thanks to the U and R values of the materials.

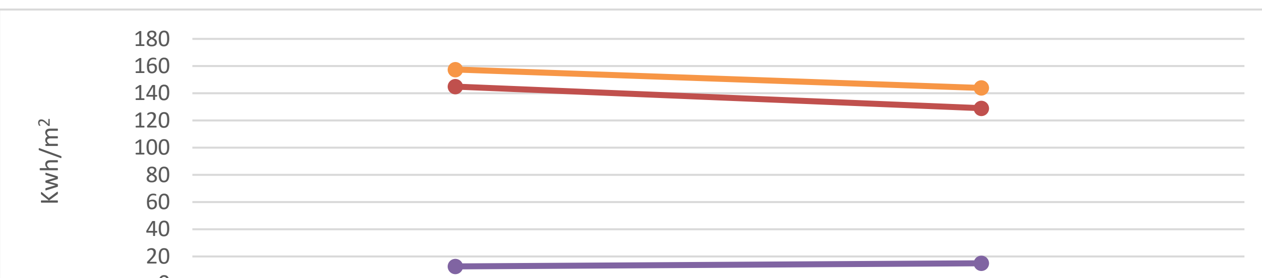


	Concrete block	Blend brick	Fire brick	Perforated brick
Heating	201,99	192,39	172,69	144,87
Cooling	5,42	6,43	9,89	12,58
Total	207,41	198,82	182,58	157,45

Figure 13. Effect of material type on energy consumption.

Material Color

This section analyses the effect of the color of the material used on the exterior on energy consumption. In the analysis simulation, the impact of the color of the exterior material on the energy consumption was calculated using light and dark-colored materials, and the results are shown in Figure 14. According to the data obtained, the use of dark colors causes the amount of heating energy consumption to decrease and the amount of cooling energy consumption to increase. However, when the total energy consumption results are compared, it has been observed that using dark colors provides energy efficiency.

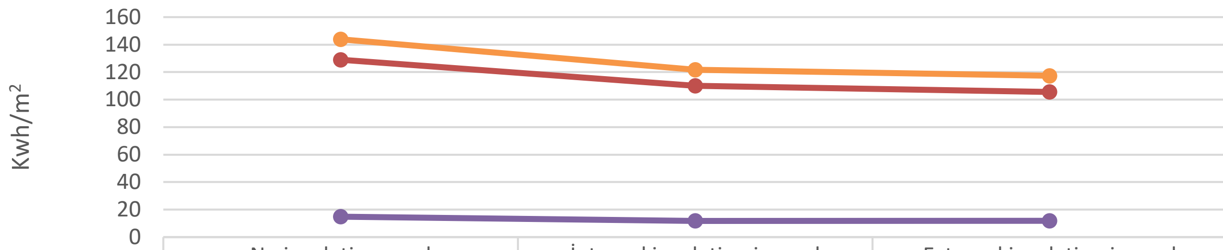


	Light color	Dark color
Heating	144,87	129,01
Cooling	12,58	14,87
Total	157,45	143,88

Figure 14. Effect of material color on energy consumption.

Use of Insulation

The use of insulation ensures that the amount of energy consumption in buildings is effectively reduced. This section analyses the effect of insulation usage on building energy consumption in the Tabriz climate. The simulation analyzed the energy consumption of an uninsulated building, which was insulated with 5 cm polystyrene from the inside, and a building insulated with polystyrene of 5 cm from the outside. The results show that the use of 5 cm thick polystyrene insulation has a positive effect on total energy consumption. It has also been observed that external insulation is more appropriate in terms of energy efficiency.

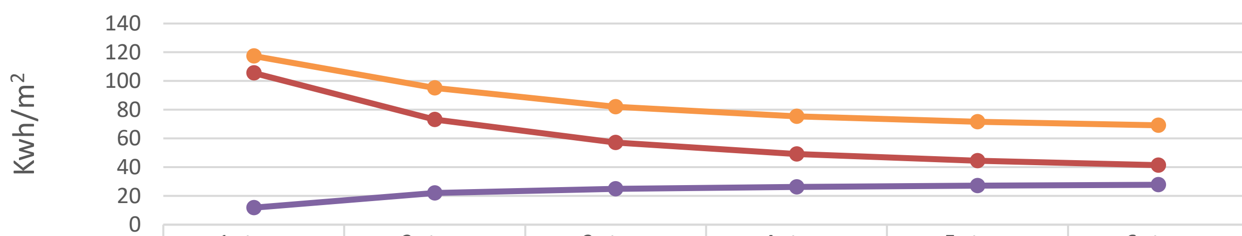


	No insulation used	İnternal insulation is used	External insulation is used
Heating	129,01	110,06	105,56
Cooling	14,87	11,77	11,83
Total	143,88	121,83	117,39

Figure 15. The effect of using insulation on energy consumption.

Effect of Building Coefficient on Energy Consumption

The number of floors of buildings is a factor that directly affects the amount of energy consumption. In this section, the effect of the number of floors in the building on the amount of energy consumption in the Tabriz climate is calculated, and the analysis simulation results are compared with each other. As shown in Figure 16, although the increase in the number of floors caused an increase in the amount of cooling energy consumption, the amount of heating and total energy consumption decreased.

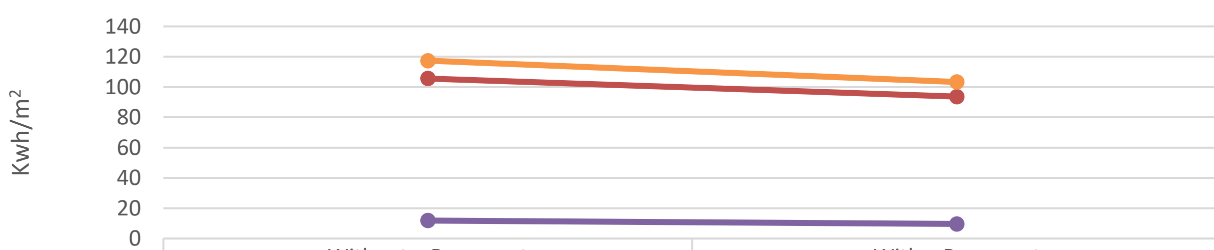


	1 story	2 story	3 story	4 story	5 story	6 story
Heating	105,56	73,13	57,1	49,17	44,5	41,41
Cooling	11,83	22,13	24,88	26,25	27,14	27,76
Total	117,39	95,26	81,98	75,42	71,64	69,17

Figure 16. The effect of floor number on energy consumption.

Basement Usage

As can be seen in Figure 17, the use of the basement floor has reduced both the heating energy consumption and the cooling energy consumption. Therefore, lower energy is needed when basement floors are used in the Tabriz climate.

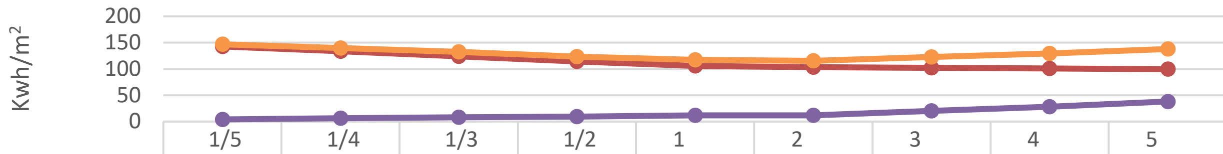


	Without a Basement	With a Basement
Heating	105,56	93,67
Cooling	11,83	9,62
Total	117,39	103,29

Figure 17. The effect of basement floor usage on energy consumption.

Building Aspect Ratio

At this stage, simulation analysis of different ratios of the building's east-west and south-north axes was compared. These ratios vary between 1/5 and 5/1. As shown in Figure 18, the elongation of the south facade caused a decrease in heating energy consumption but an increase in cooling energy consumption. When the total amount of energy consumption is examined, the lowest amount is observed when the ratio of the east-west axis to the south-north axis is 2/1.



	1/5	1/4	1/3	1/2	1	2	3	4	5
Heating	142,74	133,4	124,17	114,26	105,56	103,63	102,35	101,12	99,47
Cooling	4,07	6,25	8,37	9,13	11,83	11,77	20,12	28,26	38,13
Total	146,81	139,65	132,54	123,39	117,39	115,4	122,47	129,38	137,6

Figure 18. Effect of aspect ratio on energy consumption.

Orientation

This section compares the energy simulation results of 19 buildings located in different directions to find the most suitable direction to reduce energy consumption. The proportion of windows used on the south facade of the simulated buildings is 100%, and double glazing is used. The balcony depth is 1 m. The buildings are oriented with a 10-degree difference from west to east. As seen in Figure 19, the orientation of the building from the east to the south and west caused an increase in the amount of cooling energy. The results obtained show that the orientation of the building from east to south and west causes an increase in the amount of cooling energy. Orientation of the building towards east and west directions causes an increase in the amount of heating energy. The least amount of total energy consumption was observed when the building was oriented southward and south to east at an angle of 10 degrees.

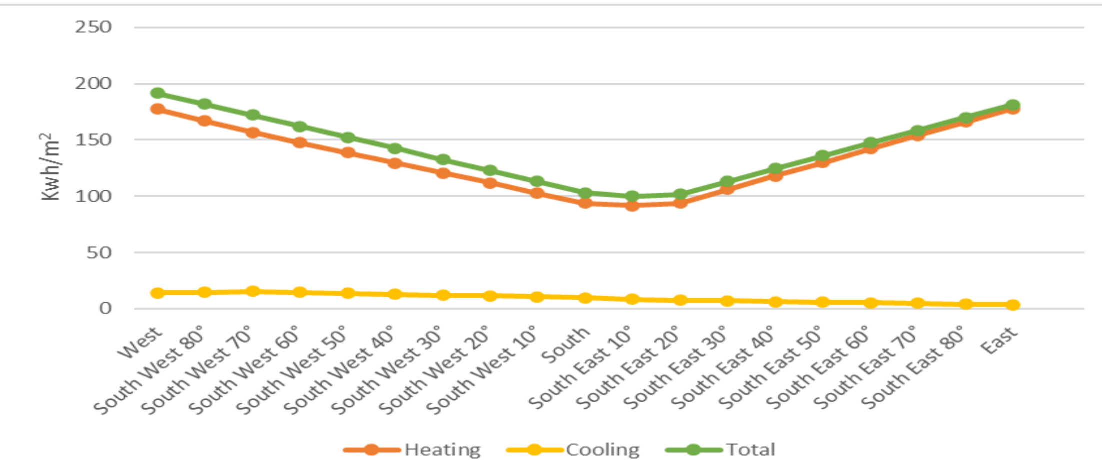


Figure 19. The effect of building orientation on energy consumption.

Discussions

Suppose the balcony mentioned above, material, color of materials, insulation, number of floors, basement floor, aspect ratio, and the effect of the orientation of the buildings on the amount of energy consumption are briefly discussed; in that case, simulation analyses have shown that the use of 1 m balconies reduces the amount of energy consumption. In terms of energy efficiency, it has been observed that perforated brick is a more suitable material than concrete briquette, blended brick, and firebrick. In addition, it has been determined that the use of dark-colored materials on the exterior has reduced the amount of energy consumption. The results also show that using insulation effectively saves energy consumption in buildings. Simulation analyses show that with the increase in the number of floors of the buildings, there is an increase in the amount of cooling energy consumption and a decrease in the amount of heating energy consumption and total energy consumption. In addition, the use of basement floors has also reduced the amount of energy consumed in buildings. The analyses have shown that in this climate, the elongation of the south facade of the buildings leads to a decrease in the amount of heating energy consumption. In contrast, the amount of cooling energy consumption increases. In terms of total energy consumption, when the ratio of the east-west axis to the south-north axis is 2/1, it shows that the lowest energy is consumed. To minimize the total energy consumption, orienting the building to the south and 10 degrees from the south to the east is considered appropriate. The most suitable architectural elements and parameters regarding energy efficiency are shown in Table 1.

The effect of the obtained values on energy consumption was analysed. In this context, an existing building was first taken as an example. While choosing the sample building to be analysed, a common building type in Tabriz was preferred. The selected structure is made with a reinforced concrete skeleton system and has a compact form. The dwelling in question consists of 4 floors, and the ground floor is used as a garage. The residence is north-south oriented, and its primary facade faces south. The building is oriented at an angle of 30 degrees from south to east and is located on flat land. The house selected for analysis used a north-south axis compact building form. The ground floor has a width of 8 m and a length of 9 m. There is a garage and a storage room on this floor. The other floors have the same plan and design. The width of these floors is 8 m, and the length is 11 m, and each floor has a living room, kitchen, two bedrooms, toilet, bathroom, balcony, and atrium. The ground floor has a gross area of 72 m2. The other floors have a gross area of 87 m2. There is a courtyard with a length of 5 m and a width of 8 m in the south of the building. The height of the building is 13.20 meters. The house's detailed project and technical specifications were used for the materials used in the house in question. Two buildings were designed based on the teachings enacted afterward. The designed buildings have the same square meters and spaces as the existing building we took as an example. The materials in these residences were selected based on the results obtained in the analysis to increase the energy performance. The materials of existing and designed residences are shown in Table 2.

Table 1. Suitable Architectural Elements and Parameters

Balcony	**Material**	**The color of the material used on the exterior**
A 1 m balcony is suitable for use.	Perforated brick is suitable to use.	Dark-colored materials are suitable to use.
Insulation	**Number of floors**	**Basement**
Insulation is suitable for use.	It is appropriate to increase the number of floors.	Basement floor use is suitable.
Aspect Ratio	**Orientation**	
The ratio of the east-west axis to the south-north axis is 2/1.	It is suitable for orientation at an angle of 10 degrees from south to east.	

While the first-designed building has the exact space positioning as the existing building, the climatic data is considered in the interior organization of the second-designed building. In other words, since the purpose of use of the spaces has an impressive role in the organization of the space, the second building was designed to benefit or protect from climatic effects. Units that do not have direct living spaces, such as bathrooms, toilets, and stairs, are preferred to be located on the secondary facade and living areas on the south facade. The plans for all three residences are shown in Table 3.

In the first step, the building was modelled using the Design-Builder program for the energy simulation of all three structures. Then, from the building shell elements, the factors that exist in the program analysis, such as the U values of the shell elements such as walls, doors/windows, roof, foundation/flooring, and the materials used in these elements, the thermal conductivity value and the HVAC system were used. In the simulation of the Design-Builder program, climate data per ASHRAE standards were used. After transferring data such as the model, climate data, application project data, and user profile to the program, the annual heating, cooling, and total energy consumption per square meter were calculated as a result of the simulation. As shown in Figure 20, when the heating energy consumption of all three buildings is compared, the energy consumption of the second building has decreased effectively compared to the example building. In addition, after the space organization of the second building, which was designed, it was observed that it consumes less energy for heating than both buildings. When the cooling energy consumption of the buildings is compared, the example building consumes the most energy with 27.17 kWh. The cooling energy consumption of the building, which was designed with the application of the results obtained from the energy simulation analysis, was effectively reduced by falling to 86.43 kWh. After the space organization was made in the designed building, it consumed the least energy, with an energy consumption of 77.34 kWh. When the total energy consumption of the buildings is compared, it is seen that the example building consumes the most energy with 234.3 kWh/m2. The energy consumption of the second building decreased effectively with the application of the results obtained from the energy simulation analyses and became 94.36 kWh. The least energy consumption was observed after the space organization was made in the building, designed for 83.28 kWh.

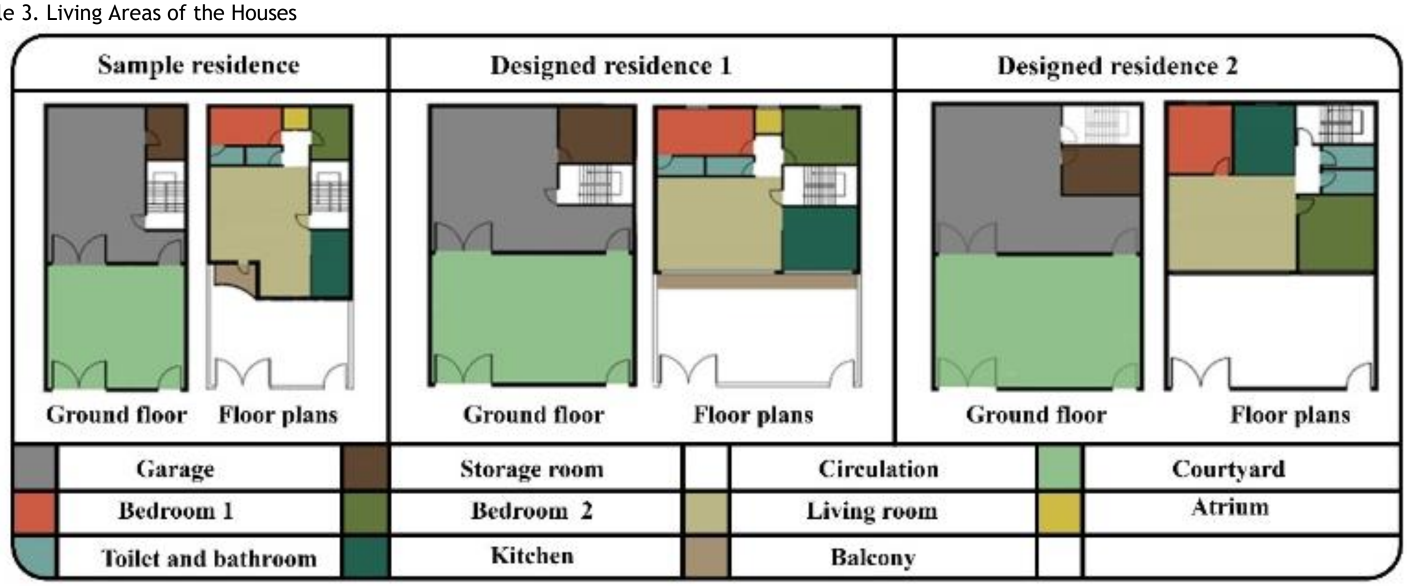
Conclusions and Recommendations

The guide and the developed parametric model for high-energy performance building design were applied to the cold-arid climate region within the scope of the study. The effects of the design parameters on the energy performance of the building were analysed, and the results were presented as suggestions for newly designed artificial environments. The study aims to show how effective the decisions made for the design parameters before the design is on the building's energy performance. According to the results obtained in the study, heating energy is proportionally more effective than cooling energy in total energy consumption due to the extended heating period in the cold-arid climate region. In such a manner, it has been shown that it is necessary to produce designs to increase the passive energy effect and reduce energy consumption by protecting and using climatic conditions to ensure energy efficiency. The guideline and the model developed within the scope of the study focused on optimizing the decisions to be taken during the preliminary design process to reduce the energy consumption of the houses, which have a significant share in the total primary energy use on a global scale, with a parametric approach. For this purpose, within the framework defined in the study, the design variables that affect the energy performance of the buildings were discussed, and the effects of design decisions on energy efficiency were evaluated by comparing the results obtained. To put it more clearly, in the study, in the city of Tabriz as a cold-arid climate region, the effect of the decisions taken regarding the window ratio, balcony depth, material type, material color, insulation used, number of floors, basement floor usage, aspect ratio and orientation of the buildings on energy consumption has been analysed. It has also been shown that an effective reduction in energy consumption can be achieved with the right decisions taken before the design. Since climatic data stands out as the main criterion that guides the design of buildings with high energy performance, it is anticipated that the guide and the model developed in the study will apply to different climatic regions in the future. Considering that the climate change and heat island effect experienced due to global warming will affect urban areas in the near future, it is crucial to update the study's results depending on the changing climatic data. In this way, the data obtained from the studies to be carried out will be a source that guides the stakeholders in the direction of energy efficiency and will make it possible to establish sustainable, climate- and environmentally sensitive environments. In future research, the impact of architectural elements and design decisions on energy efficiency can be evaluated together with cost efficiency. Ensuring cost efficiency while providing energy efficiency in buildings can be an essential topic for research in this context.

Table 2. Materials Used İn Buildings

		Material
Sample residence	**Wall**	**South wall (from inside to outside):** plastic paint + plaster coating + concrete briquette + exterior plaster + marble. Its total thickness is 26 cm. **West, east, and north walls (from inside to outside):** plastic paint + plaster coating + concrete block + exterior plaster. Its total thickness is 25 cm. Inner wall: consists of plastic paint + plaster coating + concrete briquette + plaster coating + plastic paint. Its total thickness is 15 cm.
	Windows/ Doors	A single-glazed 3mm window is used, and the exterior doors have single-glazed 3mm windows. Approximately 10 m^2 doors were used on the south facade of the ground floor. The same type of windows and doors were used systematically on the other building floors. Approximately 7.40 m^2 of windows and 2.20 m^2 of doors were used on the south facade of each floor. There are 5 m^2 windows on the north facade of the floors. Approximately 1.20 m^2 windows were used for the atrium on the roof of the building.
	Roof	The building has a flat roof. Roof (from top to bottom): asphalt is used + roof plaster + spoiled and concrete + concrete briquette + plaster + plaster coating + decorative paint. Its total thickness is 43 cm.
	Flooring	**The foundation slab (from top to bottom)** consists of mosaic tiles + adhesive mortar + foundation concrete + blockage + lean concrete + compacted soil. Its total thickness is 40 cm. Floor covering (from top to bottom): consists of gypsum plaster + blocking and concrete + concrete briquette + adhesive mortar + gypsum coating + decorative paint. Its total thickness is 40 cm.
Designed residences	**Wall**	**South wall (from inside to outside):** plastic paint + plaster coating + perforated brick + polystyrene insulation + exterior plaster + marble. Its total thickness is 31 cm. **West, east, and north walls (from inside to outside):** plastic paint + plaster coating + perforated brick + polystyrene insulation + external plaster. Its total thickness is 29 cm. **Inner wall:** plastic paint + plaster coating + perforated brick + plaster coating + plastic paint. Its total thickness is 15 cm.
	Windows/ Doors	Double-glazed 3mm windows are used, and the exterior doors used are insulated doors with double-glazed 3mm windows. Approximately 10 m^2 doors were used for the entrance on the south facade of the basement floor. The same type of windows and doors were used systematically on the other building floors. To increase the amount of solar gain and to have a more extended and transparent facade, a window with a ratio of approximately 100% was used on the south facade of each floor. To minimize heat losses, the opening amount on the north facade is kept to a minimum and is foreseen to be 5 m^2.
	Roof	The building has a flat roof. Roof (from top to bottom): asphalt + roof plaster + polystyrene insulation + deterioration and concrete + perforated brick + plaster + plaster coating + decorative paint. Its total thickness is 48 cm.
	Flooring	**Foundation slab (top to bottom):** mosaic tile + adhesive mortar + foundation concrete + blockage + It consists of lean concrete + compacted soil. Its total thickness is 40 cm. **Floor covering (from top to bottom):** consists of cladding + blocking and recommended concrete + perforated brick + leveling screed + plaster coating + decorative paint. Its total thickness is 40 cm.

Table 3. Living Areas of the Houses



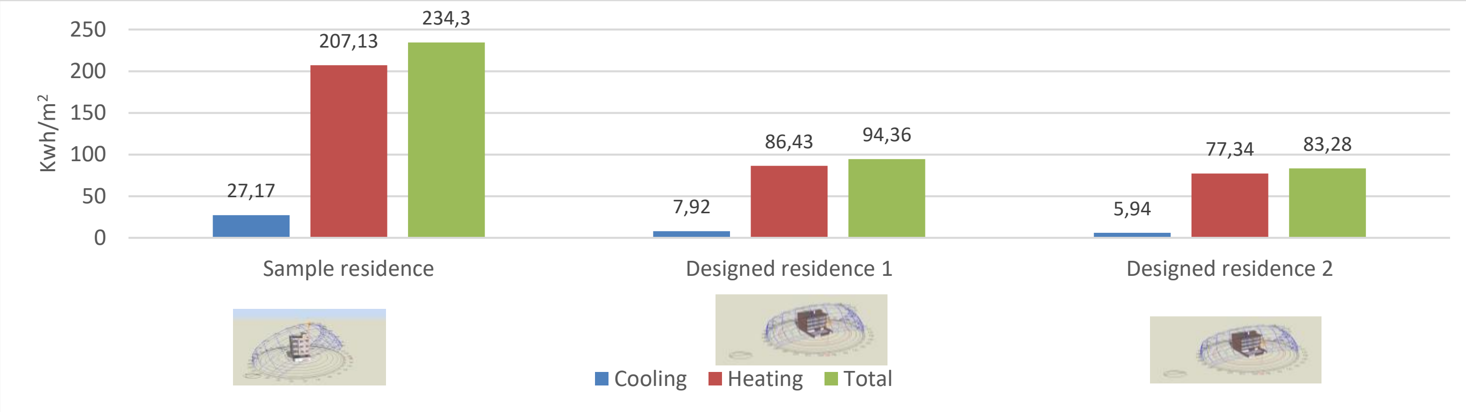


Figure 20. Energy consumption amount of buildings.

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Ethics Committee Approval Certificate: The authors declared that an ethics committee approval certificate is not required.

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References

Abanda, F. H., and Byers, L., (2016). "An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)" *Energy* 97: 517-527. https://doi.org/10.1016/j.energy.2015.12.135.

Alghoul, S. K., Rijabo, H. G., and Mashena, M. E. (2017). "Energy consumption in buildings: A correlation for the influence of window to wall ratio and window orientation in Tripoli, Libya" *Journal of Building Engineering* 11: 82-86. https://doi.org/10.1016/j.jobe.2017.04.003.

An, R., Ji, M., and Zhang, S. (2018). "Global warming and obesity: a systematic review". *Obesity Reviews*, 19(2): 150-163. https://doi.org/10.1111/obr.12624.

Ashmawy, R. E., and Azmy, N. Y. (2018). "Buildings orientation and its impact on the energy consumption." First Proceedings of Al Azhar's 14th International Conference On: Engineering, *Architecture and Technology* 2(3): 35-49. https://doi.org/10.21625/archive.v2i3.344.

Bai, L., Yang, L., and Song, B., (2020). "The impact of climate change on thermal climate zones and residential energy efficiency designs during the past decades in China." *Advances in Building Energy Research*, 14(3): 389-402. https://doi.org/10.1080/17512549.2019.1653367

Capeluto, I. G., and Shaviv, E. (2001). "On the use of 'solar volume'for determining the urban fabric." *Solar Energy* 70(3): 275-280. https://doi.org/10.1016/S0038-092X(00)00088-8.

DeKay, M., and Brown, G. Z. (2014). *Sun, Wind, and Light: Architectural Design Strategies*. New Jersey: John Wiley and Sons, 330-332.

Ebert, H., P. (2015). "Functional materials for energy-efficient buildings" *EPJ Web of Conferences 98*: 14-28. https://doi.org/10.1051/epjconf/20159808001.

Hoseinzadeh, S. and Azadi, R. (2017). "Simulation and Optimization of a Solar-Assisted Heating and Cooling System for a House in Northern of Iran." *Journal of Renewable and Sustainable Energy* 9(4): 045101. https://doi.org/10.1063/1.5000288.

Inanici, M. N., and Demirbilek, F. N. (2000). "Thermal performance optimization of building aspect ratio and south window size in five cities having different climatic characteristics of Turkey" *Building and Environment* 35(1): 41-52. https://doi.org/10.1016/S0360-1323(99)00002-5.

Kishore, R. A., Bianchi, M. V., Booten, C., Vidal, J., and Jackson, R. (2021). "Enhancing building energy performance by effectively using phase change material and dynamic insulation in walls." *Applied Energy* 283: 116306. https://doi.org/10.1016/j.apenergy.2020.116306.

Langner, M. R., Henze, G. P., Corbin, C. D., and Brandemuehl, M. J. (2012). "An investigation of design parameters that affect commercial high-rise office building energy consumption and demand." *Journal of Building Performance Simulation* 5(5): 313-328. https://doi.org/10.1080/19401493.2011.590607.

McKeen, Philip, and Alan S. Fung. (2014). "The Effect of Building Aspect Ratio on Energy Efficiency: A Case Study for Multi-Unit Residential Buildings in Canada." *Buildings* 4(3):336–54. https://doi.org/10.3390/buildings4030336.

Mirabi, E., and Nasrollahi, N. (2019). "Balcony Typology and Energy Performance in Residential Buildings." *IJETR* 9: 2454-4698. https://doi.org/10.31873/ijetr.9.12.40.

Naveen Chakkaravarthy, A., Subathra, M. S. P., Jerin Pradeep, P., and Manoj Kumar, N., (2018). "Solar irradiance forecasting and energy optimization for achieving nearly net zero energy building." *Journal of Renewable and Sustainable Energy* 10(3): 035103. https://doi.org/10.1063/1.5034382.

Nayak, B. K., Sansaniwal, S. K., Mathur, J., Chandra, T., and Garg, V. (2023). "Identifying building archetypes based on energy performance as the major criteria: a case of Jaipur, India." *Advances in Building Energy Research*, 17(4): 440-465. https://doi.org/10.1080/17512549.2023.2217204

Oliveira, Caroline Carvalho, F. V. Alves, Paulo Gustavo Macedo De Almeida Martins, Nivaldo Karvatte, Gabriela Cavalcanti Alves, R. G. De Almeida, Ariadne Pegoraro Mastelaro, and Eliane Vianna Da Costa E Silva. (2019). "Vaginal Temperature as Indicative of Thermoregulatory Response in Nellore Heifers under Different Microclimatic Conditions." *PLOS ONE* 14(10), 0223190. https://doi.org/10.1371/journal.pone.0223190.

Pang, Z., Xu, P., Lu, X., Qiu, S., Chen, L., and Hou, J. (2017). "Evaluation of the performance of a new solar ventilated window: Modeling and experimental verification." *Journal of Renewable and Sustainable Energy* 9(6): 065101. https://doi.org/10.1063/1.5006274.

Pisello, A. L., Castaldo, V. L., Rosso, F., Piselli, C., Ferrero, M., and Cotana, F. (2016). "Traditional and innovative materials for energy efficiency in buildings." *Key Engineering Materials*, 678: 14-34. https://doi.org/10.4028/www.scientific.net/KEM.678.14.

Ratti, C., Baker, N., and Steemers, K. (2005). "Energy consumption and urban texture." *Energy and buildings* 37(7): 762-776. https://doi.org/10.1016/j.enbuild.2004.10.010.

Senarathne, L. R., Nanda, G., and Sundararajan, R. (2022). "Influence of building parameters on energy efficiency levels: A Bayesian network study." *Advances in Building Energy Research*, 16(6): 780-805. https://doi.org/10.1080/17512549.2022.2108142

Shadmand, A., and Arslan Selçuk, S. (2022). "Lessons from traditional architecture in energy efficient building design: the case of traditional Tabriz houses." *International Journal of Environmental Studies*, 79(2): 245-264. https://doi.org/10.1080/00207233.2022.2033492.

Sharston, R., and Murray, S. (2020). "The combined effects of thermal mass and insulation on energy performance in concrete office buildings." *Advances in Building Energy Research*, 14(3): 322-337. https://doi.org/10.1080/17512549.2018.1547220

Shaterian, R. (2001). Climate and Architecture. Iran: Simaye Danesh. 41, 56.

Siu, C. Y., O'Brien, W., Touchie, M., Armstrong, M., Laouadi, A., Gaur, A., Jandaghian, Z., and Macdonald, I. (2023). "Evaluating Thermal Resilience of Building Designs Using Building Performance Simulation – A Review of Existing Practices." *Building and Environment*, 234:110124. https://doi.org/10.1016/j.buildenv.2023.110124.

Troup, L., Phillips, R., Eckelman, M. J., and Fannon, D. (2019). "Effect of window-to-wall ratio on measured energy consumption in US office buildings." *Energy and Buildings*, 203: 109434. https://doi.org/10.1016/j.enbuild.2019.109434.

UN-Habitat. (2022). *World Cities Report 2022*: The Value of Sustainable Urbanization. https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf

Van Esch, M. M. E., Looman, R. H. J., and De Bruin-Hordijk, G. J. (2012). "The effects of urban and building design parameters on solar access to the urban canyon and the potential for direct passive solar heating strategies." *Energy and Buildings*, 47: 189-200. https://doi.org/10.1016/j.enbuild.2011.11.042.

Vermeulen, T., Luque-Ayala, A., Buser, M., Gill, B., and Roy, B. (2019). "Reconsidering Smart Cities through the Fab City Initiative: Combining Making Spaces, Data Flows, and Governance." *Canadian Journal of Communication*, 44(3). https://doi.org/10.22230/cjc.2019v44n3a3487.

Vodenska, I., and Mignone, P. (2017). "The Emerging Renewable Energy Market." *International Advances in Economic Research*, 23: 289-290. https://doi.org/10.1007/s11294-017-9645-0.

Xu, J., Huang, J., Lou, M., Liu, J., and Jiang, Y., (2015). "Evaluation and optimization of a combined solar thermal system for providing both domestic hot water and space heating" *Journal of Renewable and Sustainable Energy* 7(6): 063103. https://doi.org/10.1063/1.4937346.

Zhu, Y., Li, H., and Zhang, X. (2020). "Parametric study on the performance of the building envelope design in relation to space heating in the Chinese hot summer and cold winter climate zone." *Advances in Building Energy Research* 14(2): 251-268. https://doi.org/10.1080/17512549.2018.15472