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A COMPARISON OF TRADITIONAL AND CONTEMPORARY BUILDINGS BY ENERGY EFFICIENCY AND GREENHOUSE GAS EMISSION: A CASE STUDY FROM TABRIZ-IRAN

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Abstract

Original scientific paper

It is evident upon a comparison between the examples of contemporary and traditional buildings that climate-responsive building design strategies of traditional buildings find increasingly lesser use in contemporary architectural designs and that traditional building culture has begun to disappear. Due to the increasing building stock with the expansion of city centers over the years, a higher amount of energy is required for heating, cooling, and ventilation, which leads to a higher amount of greenhouse gas emissions. The ever-increasing greenhouse gas emission is inevitably involved in the emerging global climate crisis. The present study investigated the climate-responsive design approaches adopted in traditional and current buildings in Tabriz, Iran. The study aimed to evaluate the effect of passive system strategies used in the design of traditional buildings in Tabriz on energy efficiency and to analyze current buildings in terms of annual energy consumption and greenhouse gas emissions with a view to the changing building stock both architectural and mechanical design terms. The results of the study suggested that transferring the climate-responsive architectural design experiences of the past builders to new generations was crucially important and that it was necessary to reduce the greenhouse gas emissions in newly constructed buildings through energy efficiency regulations and building standards as promulgated by the government.

Keywords: *Building energy efficiency, building envelope, building energy performance simulation, greenhouse gas emission, passive design strategies, vernacular architecture.*

GELENEKSEL VE GÜNÜMÜZDEKİ BİNALARIN ENERJİ VERİMLİLİĞİ VE SERA GAZI SALINIMI YÖNÜNDEN KARŞILAŞTIRILMASI: İRAN'IN TEBRİZ ŞEHRİNDEN BİR VAKA ÇALIŞMASI

Özet

Orijinal bilimsel makale

Günümüzdeki binalarla geleneksel bina örneklerini kıyasladığımızda, geleneksel binalarda kullanılan iklime bağlı bina tasarım stratejilerinin günümüzdeki mimari tasarımlarda kullanımının giderek azaldığı ve geleneksel yapı kültürünün kaybolmaya başladığı açıkça görülmektedir. Yıllar içinde şehir merkezlerinin büyümesiyle artan yapılaşma nedeniyle binaları ısıtmak, soğutmak ve havalandırmak için daha yüksek miktarda enerjiye gerek duyulmakta ve buna bağlı olarak daha yüksek miktarda sera gazı salınımının ortaya çıktığı gözlemlenmektedir. Artan sera gazı salınımının ise günümüze küresel iklim krizi olarak yansımasını kaçınılmaz hale getirmiştir. Bu çalışma kapsamında, İran'ın Tebriz kentindeki geleneksel ve günümüz mevcut binaları dikkate alınarak bu binaların iklime bağlı tasarım yaklaşımları incelenmiştir. Bu araştırmanın amacı, Tebriz'deki geleneksel binaların tasarımında kullanılan pasif sistem stratejilerinin binaların enerji verimliliğine etkisini değerlendirmek ve yıllar içinde hem mimari hem de mekanik tasarım yönünden değişen yapı stoğunu dikkate alarak günümüzdeki yapıları yıllık enerji tüketimleri ve sera gazı salınımları yönünden analiz etmektir. Bu araştırmanın sonucunda, geçmişteki yapı ustalarının iklimle uyumlu mimari tasarım tecrübelerinin kuşaktan kuşağa aktarılmasının önemi ve yeni inşa edilecek binaların devlet tarafından yürürlüğe konulması gereken enerji verimliliği yönetmelikleriyle ve bina standartlarıyla sera gazı salınımının azaltılması gerekliliği ortaya çıkmaktadır.

Anahtar Kelimeler: *Bina enerji performans simülasyonu, bina enerji verimliliği, bina kabuğu, geleneksel mimari, pasif tasarım stratejileri, sera gazı salınımı.*

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1 Introduction

Today, the efficient use of energy resources has become an important topic. Among those energy sources, fossil fuels are the most prevalently used type of fuel in the industrial, construction, transportation sectors, etc. today. Greenhouse gas emission as a result of the combustion of fossil fuels harms nature and all living organisms, causing adverse and irreversible global effects. There is a consensus among several scholars and scientists about the adverse effects of greenhouse gas emissions on a global scale.

Accordingly, the use of fossil fuels as an energy source increases the emission output of greenhouse gases such as CO_2 and leads to further warming of the atmosphere. It is of great importance to reduce greenhouse gas emissions, which are the main causes of global warming and climate change [1]. The cities expanded at an accelerated pace upon industrialization and rapid involvement of technology in daily life, and accordingly, there emerged a need for faster building construction due to the increased demand for residences. As the volume of building stock inflated the energy demand also increased to meet the comfort needs of the users. The rapidly evolved technology paved the way for the fact that the architectural features and building strategies of traditional buildings, which were a result of centuries of accumulation, lost their influence on newly constructed buildings. Furthermore, it is remarkable that new buildings are designed almost completely independent of climatic considerations due to modernization, technology, and several other reasons, and that the use of active systems aimed to provide user comfort is more popular in contemporary architecture [2].

Architects and engineers have a great responsibility in reducing the use of fossil resources in buildings. Countries that care about this responsibility adopt new standards and regulations each year as regards the energy efficiency and sustainability of buildings. Accordingly, energy savings of up to 90% compared to existing buildings were achieved based on the passive house concept developed in Germany in 1991 and the ecological and energy-efficient building design criteria [1]. The main design strategies that are considered important for passive house design include site selection, building orientation, the distances between buildings, building form and interior layout, and optical and thermo-physical properties of the building envelope. The total amount of energy needed by the building for heating, cooling, ventilation, lighting, etc. is optimized as a result of the development of strategies in balance with the climate zone, where the building is located. In addition, in case the energy needs can be met throughout the year through natural and renewable energy resources (solar, wind, geothermal, water, biomass energy, etc.) available in the relevant climatic zone it might be possible to construct zero-energy and even energy-plus buildings. A closer review would indicate that the traditional building examples feature most of those standards and design principles and that the builders of the past prioritized climatic considerations in their design and construction techniques. As regards building design in balance with climate, it is possible to use energy efficiently and construct environmentally friendly buildings with due consideration of certain parameters, including site selection, building orientation, building form, building materials, interior layout, etc., which are almost totally independent from technology.

The use of fossil fuels, which is considered the main cause of the climate crisis affecting the entire world, has a significant increase in Iran in recent years, as seen in Figure 1 and Figure 2. The construction techniques and building technologies offered by contemporary approaches as adopted in architectural design are associated with increased energy consumption and thus lead to a rapidly increased energy demand for the building sector in Iran.

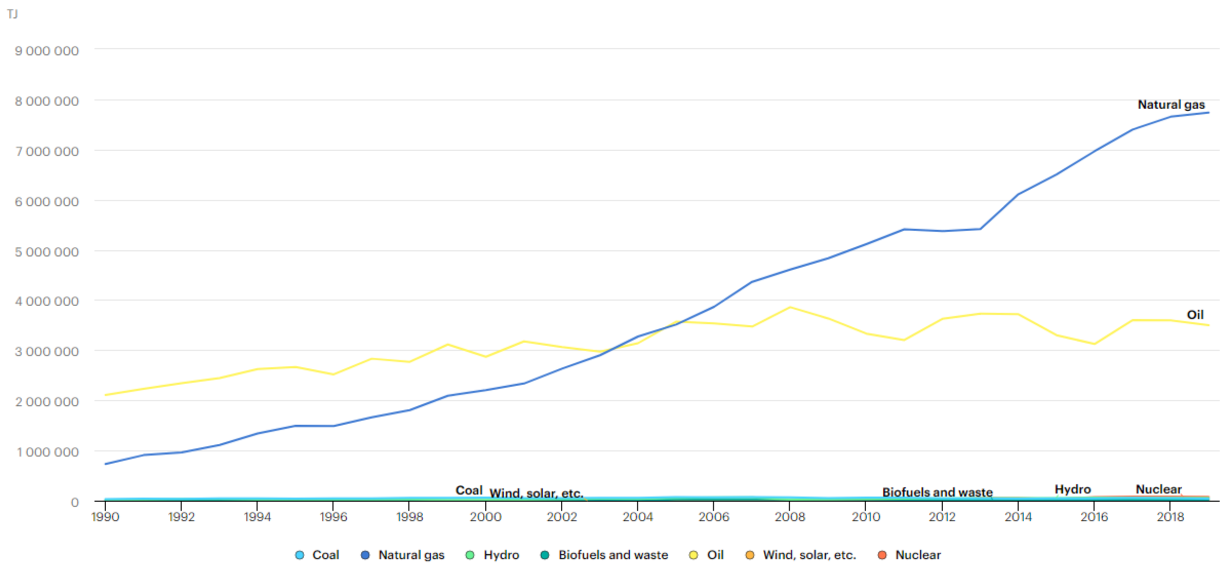


Figure 1. A distribution of Iran's total energy needs by energy resources [3].

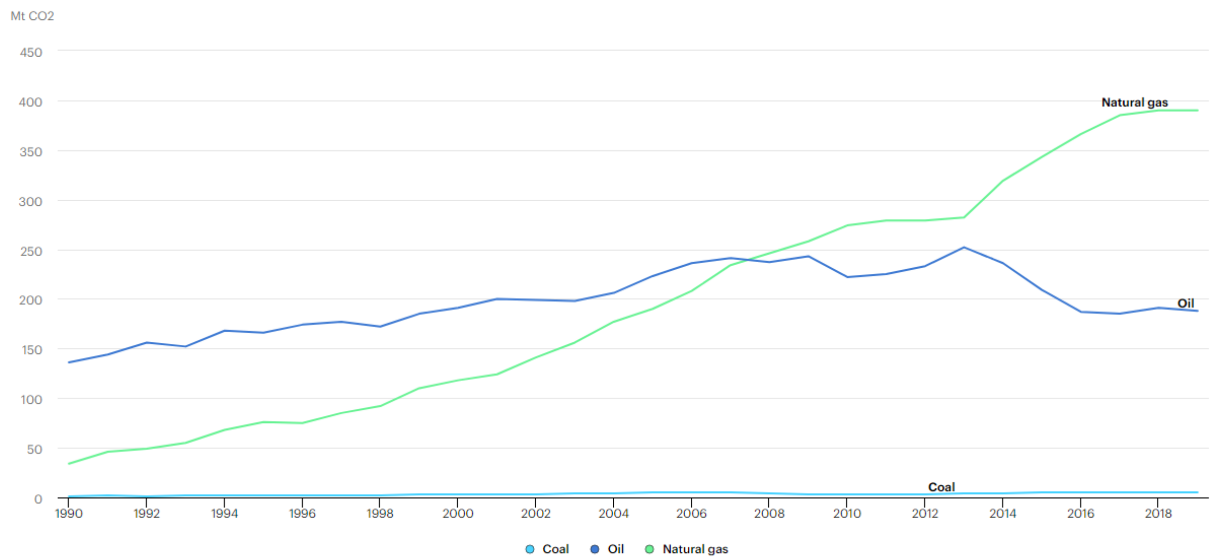


Figure 2. Distribution of CO_2 emission in Iran by energy sources [3].

Furthermore, climatic conditions are less regarded, if not entirely disregarded, in the design of new buildings [4]. Haeri's book titled: Architecture, Culture, and Nature, published in 2009 is one of the best research on Iran's traditional and contemporary residential buildings in the recent literature. [5]. Nevertheless, although the city of Tabriz, located in the northwest of Iran, has been one of the most important cities of Iran throughout history, it was excluded from the above book, and further, it has not been a subject of research except for a few theses [6]. Moreover, there are only a limited number of studies on the energy efficiency and environmental effects of buildings in Iran today.

As regards the energy requirement of buildings, it is very important to reduce greenhouse gas emissions by increasing the energy efficiency of buildings in certain climates, where fossil fuels are used extensively. Accordingly, the construction of energy-efficient buildings is of great importance in cold climate regions, where the heating need is high throughout the year, and a large amount of fossil fuel is used as a result. In this context, the city of Tabriz, located in the northwest region of Iran, is a good example for the present study. The present study compared the traditional and contemporary buildings in Tabriz by passive design strategies and construction techniques. The study aimed to analyze the climate-responsive design decisions in the construction of traditional buildings in Tabriz and to make suggestions for the efficient use of energy in new buildings. Therefore, the main objective of this research is to develop measures aimed to reduce the adverse effects on the environment through decreased CO_2 emission.

2 Research Methodology

The present study compared the energy performances of traditional and current buildings using the DesignBuilder building simulation tool. In the context thereof, the Gedeki house and the apartment building shown in Figure 22 (b) were taken as cases. Taking into consideration the façade characteristics (external wall materials, material thickness, glass, and transparency ratios), the annual electricity and natural gas demand of both buildings were compared. First, the climatic data of Tabriz region was used to analyze the energy performances of both buildings by using DesignBuilder building simulation tool. Thereafter, a building energy model of two sample buildings of 50 m^2 each, separately representing the facade features of both buildings. Despite long research in the scope of the present study, it was not possible to reach the information that should be incorporated to the energy model, including the floor and roof layers of the Gedeki house, the thickness of those layers, and the thermo-physical properties thereof. This was due to the fact the old sources did not provide sufficient technical information. As regards the new sources, there was no new research findings with respect to the technical features of the layers at the Gedeki house. Therefore, both buildings were assessed only as to their exterior walls, wall thicknesses, window properties and window to wall ratios, and accordingly the respective annual electricity and natural gas demands were compared upon analysis of their energy performances based on the aforementioned data. The annual electricity and natural gas demands for both buildings were multiplied by the Greenhouse gas emission conversion coefficients specified for Turkey, and the annual CO_2 emissions of the buildings were obtained. Consequently, considering the thermo-physical properties and window to wall ratios of the façades of the traditional and current buildings in Tabriz, the effects of those parameters on energy efficiency and CO_2 emission were analyzed.

DesignBuilder is a UK based building simulation tool that can be used to model all buildings with user friendly interface, which performs all of the energy analyzes by using the EnergyPlus infrastructure. Both of these simulation tools were tested by a number of other research studies, which confirmed their accuracy. Both of these tools are based on a detailed-dynamic methodology stated in EN 13790 - Energy performance of buildings - Calculation of energy use for space heating and cooling [27].

This International Standard gives calculation methods for assessment of the annual energy use for space heating and cooling of a residential or a non-residential building, or a part of it, referred to as "the building".

This method includes the calculation of:

a) the heat transfer by transmission and ventilation of the building zone when heated or cooled to constant internal temperature;
b) the contribution of internal and solar heat gains to the building heat balance;
c) the annual energy needs for heating and cooling, to maintain the specified set-point temperatures in the building – latent heat not included;
d) the annual energy use for heating and cooling of the building, using input from the relevant system standards referred to in this International Standard.

In the dynamic methods, an instantaneous surplus of heat during the heating period has the effect that the internal temperature rises above the set-point, thus removing the surplus heat by extra transmission, ventilation and accumulation, if not mechanically cooled. Also, a thermostat set-back or switch-off might not lead directly to a drop in the internal temperature, due to the inertia of the building (heat released from the building mass). A similar situation applies to cooling. A dynamic method models thermal transmission, heat flow by ventilation, thermal storage and internal and solar heat gains in the building zone.

Dynamic methods used for the calculation of energy need of heating and cooling shall have passed the validation tests in accordance with the relevant standards containing validation tests for detailed simulation methods as specified in Annex A of EN 13790.

In addition, for the aspects not covered by the validation tests, in the case of comparison of the energy performance level of buildings and/or for checking compliance with national or regional building regulations, the procedure shall be used as prescribed, or referred to, in this International Standard.

Consequently, the calculation shall be performed according to the following:

– partitioning into zones;
– transmission heat transfer characteristics;
– ventilation heat transfer characteristics;
– internal heat gains;
– solar heat gains;
– dynamic parameters;
– internal conditions [28].

In Figure 3, the main steps of methodology in this study are illustrated clearly.

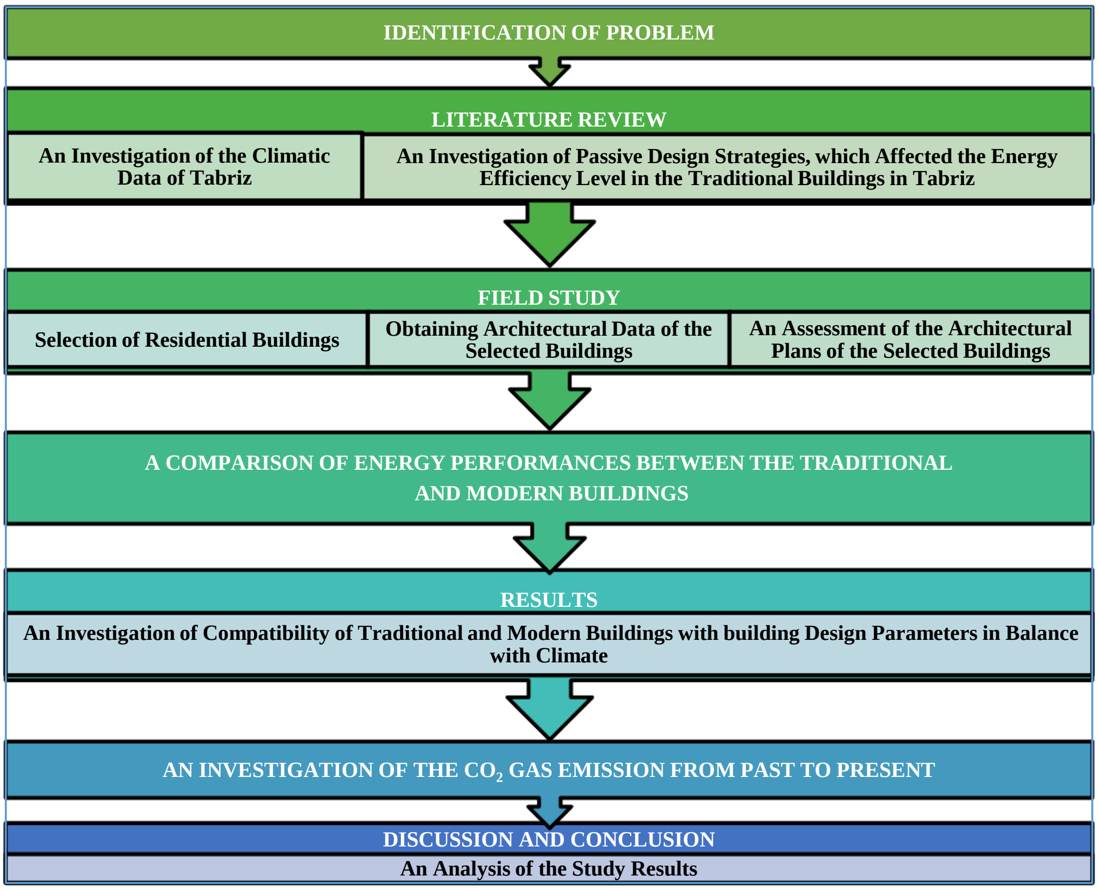


Figure 3. Methodological flow chart.

3 Architectural Design Parameters Affecting Energy Performance of Buildings

In building design, each design parameter has a different effect on the energy performance of the building [7]. The following parameters are of great importance in the design of buildings in balance with climate: building location, building scale and form, building orientation, volume organization, building spacing, and optical and thermo-physical properties of the building envelope. In particular, the absorbency, reflectivity, and permeability properties of the materials used in the design of the building envelope are of great importance concerning the heat loads lost and gained by the building throughout the year. Hereunder, brief information about the climatic conditions of the city of Tabriz was provided before the parameters in question are further scrutinized.

3.1 Climatic Data of Tabriz

Located in the northwest of Iran Tabriz city was established in a mountainous region with dominant cold climate characteristics. With a surface area of 2,167 km2, the city is located at the coordinates of 38°1'15"N - 38°8"N and 46° 5'E - 46°22'E, and has an average altitude of 1,345 m above sea level. The land slope is in the range of 0-8 degrees towards the city center and to the western direction [9]. Figure 4 shows the location of Tabriz on the map of Iran.

Figure 4. Location of East Azerbaijan state and Tabriz city on Iran map [8].

As seen in Figure 5, the east, northeast, west, and south-west directions are the most important wind directions in Tabriz, where the dominant wind blows from the east and northeast directions (Central Asia and Siberia).

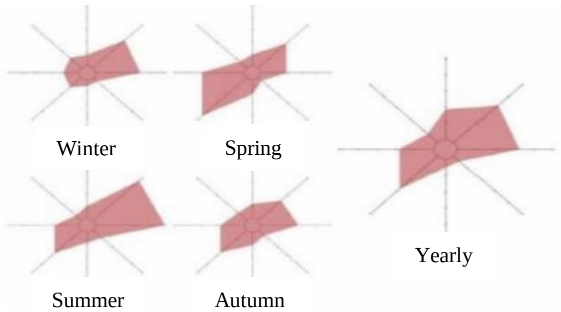


Figure 5. The wind direction in Tabriz [9].

The wind blowing from the northeast direction is associated with heavy snowfalls during the winter season. The wind blowing from the west and southwest, which is under the influence of the humid air of the Atlantic Ocean, the Mediterranean, and the Black Sea, is considered moderate throughout the year and leads to precipitation in the spring season [9-11].

The angle of the sun in Tabriz is almost vertical in summer and 40 degrees from the horizon in the winter. The sun angle is given in Figure 6 [9].

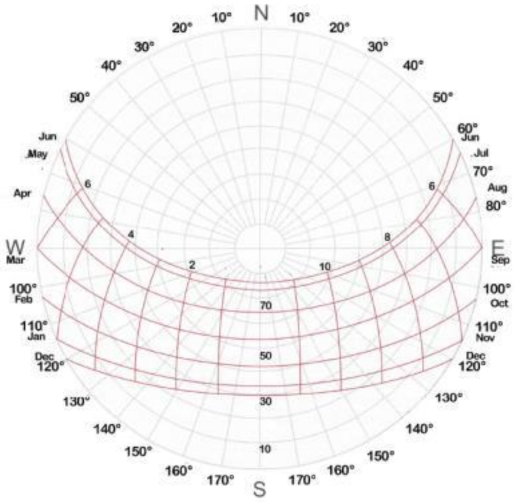


Figure 6. Sun angle in Tabriz [9].

3.2 Passive Design Strategies for Cold Climate Zone

3.2.1 Site Selection

In a cold climate zone, the building should be built on inclined land to leverage the high radiation of the sun and to be protected from cold winds. Accordingly, it is possible to benefit from the available solar radiation at a higher level by ensuring that the sun rays are perpendicular to the facade of the building, especially during the winter season.

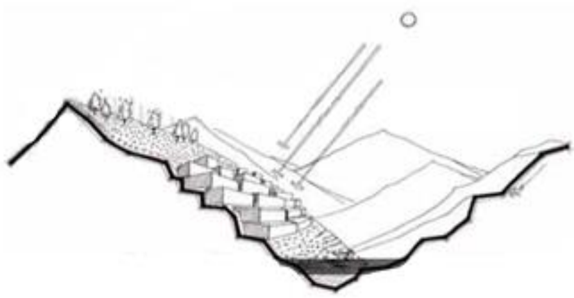


Figure 7. Positioning of the building in the cold climate zone [13].

3.2.2 Building Orientation

It is necessary to make due consideration of the building orientation to benefit or be protected from climatic conditions such as solar radiation and wind speed. As can be seen in Figure 8, different climate zones have particular effects on building orientation.

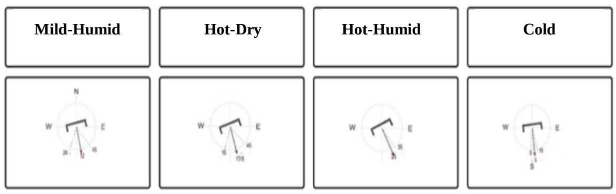


Figure 8. Suitable building orientations by climatic zones [9].

In the city of Tabriz with a cold and snowy climate, the most suitable building orientation was determined as

10º from the south to west and 15º to the east. The ideal building orientation was determined as 20º from the south to west and 45º from the east [12]. This orientation ensures that the buildings benefit from the sun and beneficial wind and are protected from the cold wind.

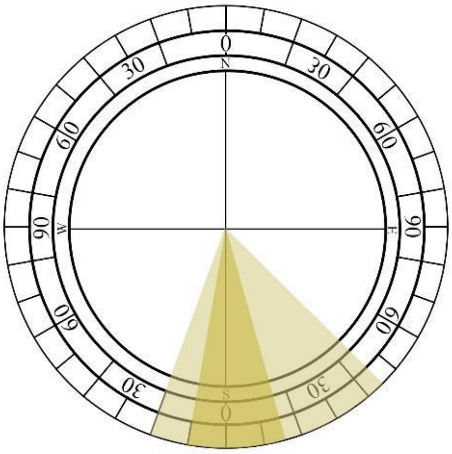


Figure 9. Orientation angles for suitable and ideal insolation for the city of Tabriz [12].

3.2.3 The Distances Between Buildings

Buildings should be constructed side by side or close to each other to protect each other from the east-west wind. Furthermore, the buildings should have distant spaces in-between in the south direction to benefit from the high solar radiation.

3.2.4 Building Form and Interior Layout

In the cold dry climate zone, buildings should be designed on a smaller scale and in a compact structure so they can be protected from the cold and the heat losses of the building envelope can be reduced. The walls should be thick, the windows should be small, and the interior spaces should be designed with low ceilings and small volumes across that region for heat protection.

It is possible to classify the interior layout criteria in a certain way in buildings. Those criteria are as follows:

- Spaces that generate and radiate heat due to their functional use should be positioned in line with the general space requirement.
- The places, which are desired to be constantly warm, should be surrounded by short-term heating spaces.
- The combinations of warm and less warm spaces should be separated from the external environment through buffer zones.

In addition, introverted architecture is used in traditional houses in that climate zone. Except for the windows facing the courtyard, there are no windows on the exterior of the building. In addition, the courtyard walls protect the building from the cold winds outside similar to a filter.

3.2.5 Material Properties of the Building Envelope

It is required to use materials with high heat capacity during the selection of materials that will be used in the building envelope across the cold climate regions. A review of traditional buildings in this climate zone, suggests that certain materials, including stone, adobe, and wood are mainly used on the facades of the buildings as seen in Figure 10.

Figure 10. The materials of the envelope of a traditional building located in Tabriz.

Moreover, it is necessary to pay due attention to the facade and dimensions of the windows and doors to be used. The traditional building examples of Tabriz are characterized by few or no windows on the eastern and western facades of the building to ensure the privacy of the family. Whereas, the windows on the south façade positioned in the courtyard are larger to benefit from the sun, and fewer windows are used on the north-facing façade.

4 Passive System Characteristics of Traditional Residential Buildings of Tabriz

4.1 Mojtahedi Residence

The Mojtahedi residence is an example of a traditional residential building from the late Qajar period and the early Pahlavi period. With a history that dates back to more than 100 years, the building was built on 1,400 m2 land. The building was designed to include a basement, high entrance, and first floor [10].

4.1.1 Building Orientation

The Mojtahedi residence was positioned on the north-south axis on its plot as seen in Figure 11.

4.1.2 Building Form and Interior Layout

In this residential example, the volume was designed by choosing a compact form that would ensure the least contact with the outside atmosphere. As seen in Figure 12, the entrance to the building was through the outer courtyard on the north and south façades.

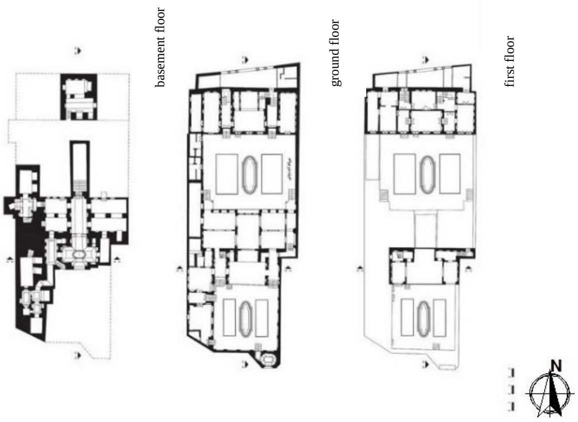


Figure 11. Floor plans of the Mojtahedi residence [10].

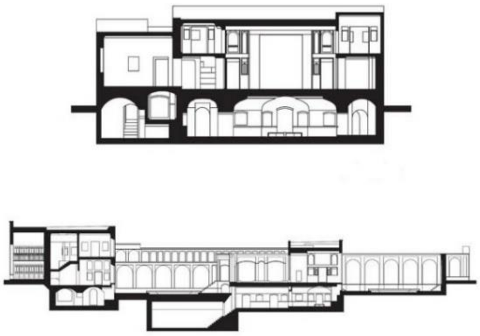


Figure 12. Sectional views of the Mojtahedi residence [10].

The windows of the building face the inner and outer courtyards. The largest room, which is called "Tenebi", which is most frequently used by the residents and where the guests are received, is located on the south side of the building to benefit from the sun, while the other rooms are located on the north. As can be seen in Figure 13, the courtyard of the building was built 1-1.5 meters below the ground level. Therefore, heat loss from the ground-based walls and floors of the building envelope during the cold winter season was prevented. Furthermore, the courtyard protects the building from the effects of cold wind in winter, functioning as a buffer zone.

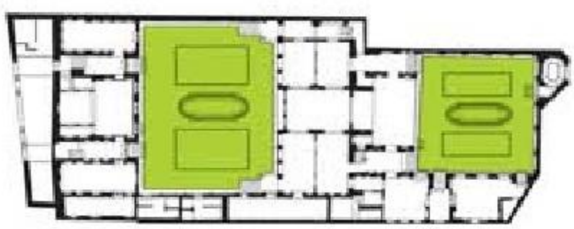


Figure 13. Plan view of the inner courtyards of the Mojtahedi residence [10].

There is a living room with a pool in the basement of the building as seen in Figure 14. During the summertime, the pool is filled with cold water, ensuring that the space is fresh and cool. Moreover, the pool is filled with hot water in winter, and the upper floors are heated thanks to the latent heat by evaporation.

Figure 14. Room with pool [10].

4.1.3 The Distances Between Buildings

Surrounded by neighboring buildings on the eastern and western facades, the building is protected from the cold winter wind coming from the east and west directions.

Figure 15. A View of Mojtahedi residence [14].

4.1.4 Material Properties of the Building Envelope

As seen in Figure 16, the façade of the building was made of materials with high heat capacities such as adobe and stones. North-facing windows were built in a narrow and long form to make use of the most of solar radiation. Stained glass windows called "Orosi" were used to protect from the higher amount of solar radiation during summer.

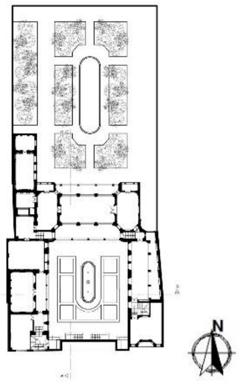
Figure 16. A view of the courtyard of Mojtahedi residence [10].

4.2 Gadeki residence

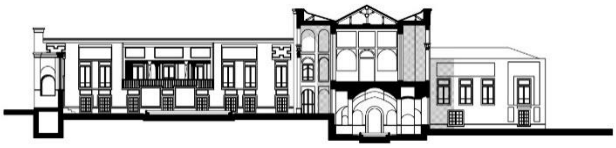
Gadeki residence was built during the Qajar period (160 years ago) as the personal residence of the Governor of Tabriz. The building was also used as an armory in the past, and it is now used as the Faculty of Architecture [10].

4.2.1 Building Orientation

The residence was constructed on land with 1,340 m^2 area throughout the north-south axis.



(a)



(b)

Figure 17. Floor plan and section of the Gedeki Residence [25].

4.2.2 Building Form and Interior Layout

This building was also built using an introverted architectural design approach. Entrance to the building was provided through passages called “Dalan” from the northern and southern directions. The guest room and bedrooms of the building were designed to face the iwan and the courtyard to the south and north to ensure maximum use of the sun. As can be seen in Figure 17, a part of the building was built at a lower elevation from the ground level.

4.2.3 The Distances Between Buildings

As seen in Figure 18, the heat losses were minimized by constructing the building in a compact form and adjacent to the surrounding buildings.

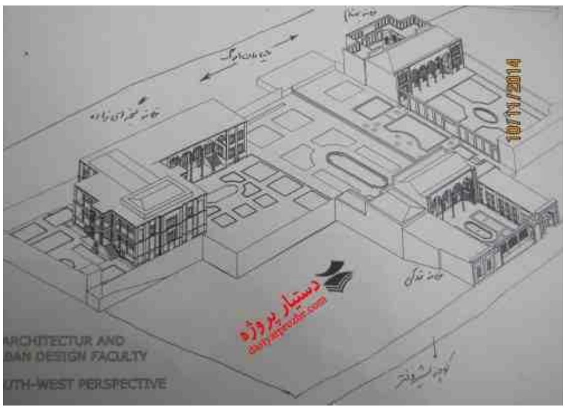


Figure 18. Three-dimensional view of the Gedeki Residence [15].

4.2.4 Material Properties of the Building Envelope

Generally, materials with high heat capacity were used in the building envelope. As in the Mojtahedi residence, stone, adobe, and wood materials were used in this residence, and wider and higher windows were used to benefit from the daylight in the guest room of the building, called "Tenebi", while the windows of the other rooms were narrower and longer.

The walls of the building are about 1 meter thick, protecting the building against cold and wind throughout the winter. A mortar material, namely “saruç”, was used for moisture control on the floor of the building. This mortar is a composition of certain materials, including lime, earth, fertilizer, and straw.

Figure 19. A view of the courtyard of Gedeki Residence [26].

5 Passive System Characteristics of Contemporaneous Residential Buildings in Tabriz

5.1 Building Orientation

The plans shown in Figure 20 belong to the examples of contemporary in Tabriz, and both buildings are placed on the north-south axis.

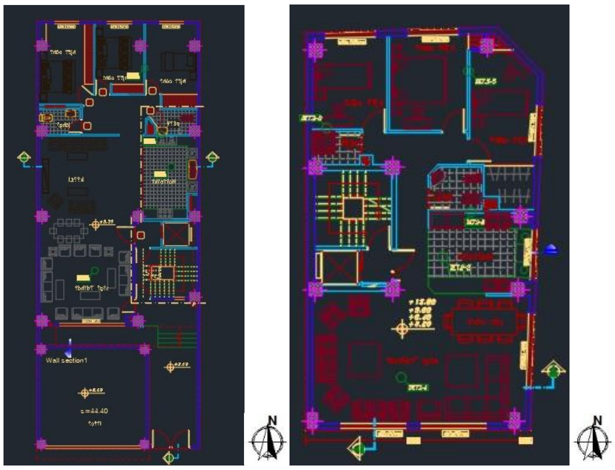


Figure 20. Floor plans of contemporary residences.

5.2 Building Form and Interior Layout

Both buildings are multi-floor reinforced concrete apartment buildings, unlike traditional residential buildings. The guest rooms in the buildings built in the rectangular form are placed on the south side, the bedrooms are on the north and the kitchens are on the east. Both buildings are designed based on an open plan by combining the living room and kitchen, and the windows on the south side are long and high to provide a higher level of light into the halls.

(a)

(b)
Figure 21. Interior views of contemporary residences.

5.3 The Distance Between Buildings

Figure 22 (a) is the building of the plan seen in Figure 20 (b), and its surroundings are relatively open with windows facing north and south. Nevertheless, it is designed adjacent to the next building and therefore, heat loss from the west façade is reduced. Figure 22 (b) is the building of the plan shown in Figure 20 (a) and is adjacent to another building located on the western façade. The northern, southern, and eastern façades feature windows and are built at a distance from the surrounding buildings.

(a) (b)
Figure 22. Building distances of contemporary residences.

5.4 Material Properties of the Building Envelope

The walls of these buildings are approximately 20 cm thick and were built using perforated bricks and reinforced concrete. It is well-established that insulation materials are not usually used in buildings.

(a) (b)

Figure 23. A view of contemporary reinforced concrete apartment buildings.

6 Developments in Building Energy Efficiency in Iran (Regulation 19)

Iran is an energy-rich country and 40% of those resources are consumed by buildings in Iran [16]. Fossil fuel accounts for a large part of this consumption, and therefore, as the human population and the number of buildings in Iran increase, the volume of greenhouse gas emissions has increased over the years. As seen in Figure 24, greenhouse gas emissions from buildings in Iran have increased remarkably over the years, and greenhouse gas emissions of buildings increased by approximately 361% between 1990 and 2019. However, the steps taken by the Iranian government to improve building energy efficiency are rather premature.

There are 22 different regulations enacted by the Ministry of Roads and Urban Development Deputy for Housing and Construction of Iran. In that context, Regulation 19 includes provisions as regards energy savings in buildings. Although those regulations were executed by the ministry, it is well-established that new buildings mostly fail to comply with the relevant provisions, since they are not subject to inspection.

According to Regulation 19, the experience of industrialized countries urges the necessity of developing rules and regulations compatible with prevailing conditions in each country. In this context, in 1991, the first edition of Section 19 of the National Building Regulation was inked under the title of energy savings, and a large part of the said regulation included rules on thermal insulation of the outer shell of buildings. Unfortunately, the rules set out in that edition were disregarded in most of the construction projects, both public and private, due to the unpreparedness of the construction industry in Iran.

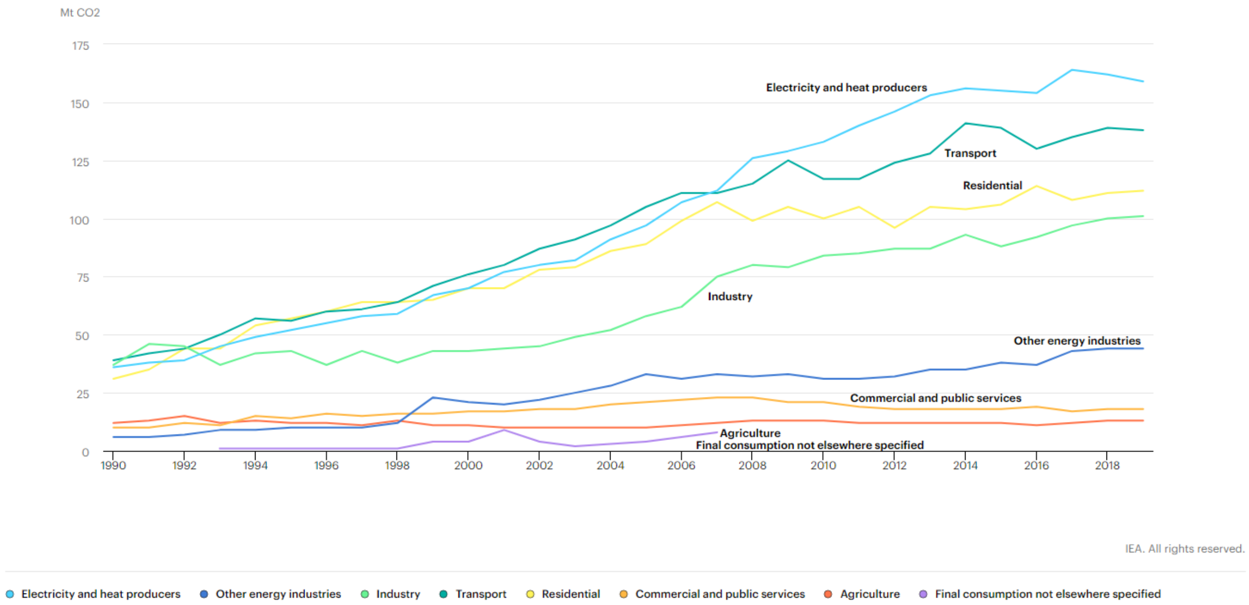


Figure 24: A distribution of the change in CO_2 emission in Iran by sectors (1990-2019) [3].

Subsequently, a guide containing the fundamentals of thermal insulation in buildings was published in 1999 according to the said regulation. Upon the second edition in 2002, it was anticipated that the construction sector and especially the government projects in Iran would better comply with energy-saving provisions than before, thanks to the elimination of uncertainties in the previous edition and the provision of necessary additional information. The criteria as prescribed in the 2nd edition were still premature compared to the relevant regulations in place in the industrialized countries. It is hoped that necessary steps would be taken to better meet international standards in the field of energy consumption in the not-too-distant future [16].

7 A Comparison of Energy Performances Between the Traditional and Modern Buildings

When traditional and new houses in Iran are compared in terms of the building envelope, the materials used in the facade, the size of the windows, the glass, and the window to wall ratios show great variability.

Considering the architectural features of Tabriz houses from past to present, it is noteworthy that some construction methods, cultural values, and spaces have disappeared [17].

When we compare the local materials used in the past with the materials of today, we can see that the use of local materials is superior in terms of environmental sustainability, building energy efficiency, and greenhouse gas emissions [18].

According to Jong Jin Kim, reducing the consumption of energy resources and designing according to the life cycle and humane design are considered the basic principles of sustainable architecture [19].

In this context, when we consider the life cycle stages, the use of local materials causes less energy consumption and ultimately less carbon emission in the acquisition of raw materials, production, transportation, and all stages of the material [18].

The energy used for heating, cooling, and lighting in buildings is directly related to the used building materials [20].

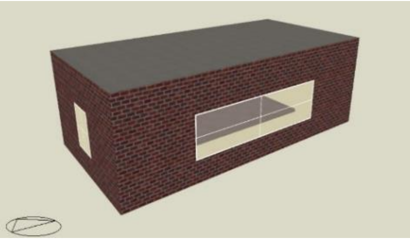
The contribution of building materials with high thermal mass to the reduction of energy consumption of the building in hot-dry and cold climates is quite high [21].

Considering the annual thermal gains and losses of the building, the heat transmission coefficients of the materials as well as the wall thickness of the building materials play an important role in the annual energy consumption of the building [22].

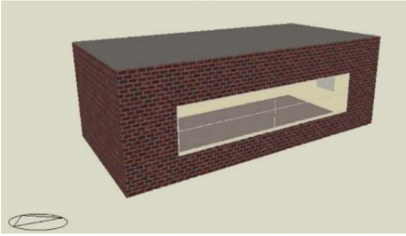
Thick walls, which are no longer used in today's architectural design, have provided acoustic and heat insulation in traditional architecture, allowing people to live a comfortable life indoors.

Architectural strategies used in traditional and local buildings are designed to use less energy, and traditional architecture aims to use the least energy for heating and cooling by developing in a balanced way with the climate [18].

Materials such as brick, plaster, lime, and mud brick are generally used on the exterior walls of traditional houses in Tabriz [23], and the wall thickness varies vis-a-vis the facade orientation (north, south, east and west) and floors of the building. For the purposes of the present study, the external wall thicknesses on each facade of the Gedeki house were calculated separately and the average wall thickness was taken in the energy model, namely "*traditional*". Whereas, the wall layers and wall thicknesses of the apartment building shown in Figure 22 (b) are the same on all facades. Accordingly, the layers on all facades were taken the same for the said building in the relevant energy model, namely "*modern*". Figure 25 shows the energy model views of the samples with an area of 50 m^2, representing traditional and modern buildings by façade characteristics.



(a)



(b)

Figure 25. The views of energy models of traditional (a) and modern (b) buildings.

The exterior wall materials and material thicknesses of the traditional building case are shown in Figure 26. Table 1 shows the thermo-physical properties of the materials used in the construction of the traditional building.

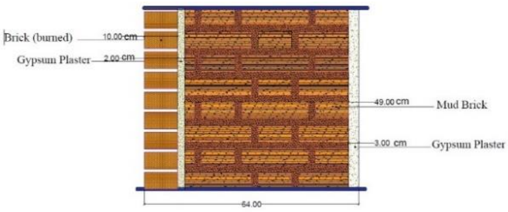


Figure 26. Exterior wall materials of the traditional building.

Table 1. Thermo-physical properties of the exterior wall materials of the traditional building.

Material	Thickness (m)	Conduction Coefficient (W/m.K)	Specific Heat (J/kg.K)	Density (kg/m^3)
Brick (burned)	0.100	0.85	840.00	1500.00
Gypsum Plaster	0.020	0.40	1000.00	1000.00
Mud Brick	0.500	0.75	880.00	1730.00
Gypsum Plaster	0.030	0.40	1000.00	1000.00

The materials of the exterior walls of current buildings in Tabriz are generally designed using such materials as brick, plaster, cement mortar, aerated BIMS and the thickness of the external walls of those structures generally does not exceed 20 cm. Figure 27 indicates the exterior wall materials and material thicknesses of the modern building case. Table 2 shows the thermo-physical properties of the materials used in the construction of the modern building.

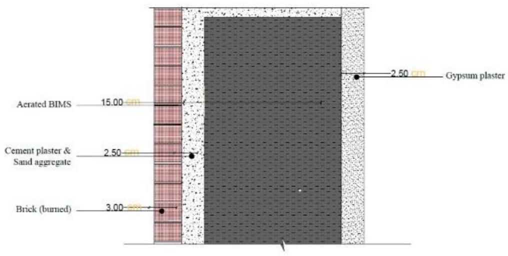


Figure 27. Exterior wall materials of the modern building.

Table 2. Thermo-physical properties of the exterior wall materials of the modern building.

Material	Thickness (m)	Conduction Coefficient (W/m.K)	Specific Heat (J/kg.K)	Density (kg/m^3)
Brick (burned)	0.030	0.85	840	1500
Cement plaster & Sand aggregate	0.025	0.81	840	1680
Aerated BIMS	0.150	0.30	840	1.000
Gypsum plaster	0.025	0.40	1.000	1.000

The form of the Gedeki house in question was designed in a U shape. Some of the southern, eastern and western facades face the inner courtyard, and there are no windows on those facades since Tabriz is exposed to the cold winds coming from the eastern and western directions. In the present study, the window to wall ratio of each facade of the Gedeki house was calculated and those window to wall ratios were used in the energy model of the traditional building representing the Gedeki house. As regards the apartment building, there are windows on the northern, southern, and eastern sides of the building, and since the west side is adjacent to another building, there are no windows on that façade. The window to wall ratios of the apartment building in question were used in the energy model of the modern building. Window to wall ratios of traditional and modern buildings are provided in the tables below.

Table 3. Window to wall ratios of the modern building.

Orientation	Window to Wall Ratio (%)
North	31
South	12
West	0
East	12

Table 4. Window to wall ratios of the traditional building.

Orientation	Window to Wall Ratio (%)
North	28
South	26
West	13
East	16

Large windows, known as 'Orosi', were used on the south and north facades of the Gedeki house. Those windows increased the window to wall ratios on the facades where they were located. Nevertheless, the windows on the east and west facades are much smaller compared to those windows.

The building envelope is a design element that separates the interiors from the exterior atmosphere and maintains a great impact on the energy conservation of the interiors. Thus, double façade strategy is considered one of the best choices in terms of managing the energy transfer between the interiors and the exterior atmosphere. Upon a review of the traditional houses in Tabriz, it was evident that the double-glazing technology as in the Gedeki house was used for centuries [24].

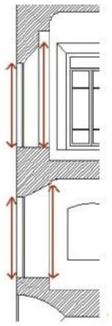


Figure 28. Cross sectional view of the Orosi windows in the Gedeki house [24].

The reviewed resources did not include any data with respect to the technical properties of these windows, except that the Orosi windows were double glazed and their frames were made of wood. The windows of the apartment building in the study were also double glazed and their frames were made of polyvinyl chloride (PVC). It was assumed for the purposes of the present study that the glazing used in the energy model of the traditional and modern buildings had the same properties, and their thermo-physical properties are shown in Table 5.

Table 5. Thermo-physical properties of the windows of the traditional and modern buildings.

Material	**Thickness (m)**	**Conduction Coefficient (W/m.K)**	**Solar Heat Gain Coefficient (SHGC)**
Generic Clear Glass	0.004	1.00	0.74
Air	0.010	-	-
Generic Clear Glass	0.004	1.00	0.74
Polyvinyl chloride (Frame)	0.020	0.17	-
Wooden (Frame)	0.020	0.19	-

Using the aforementioned building data, the building energy models of the traditional and modern buildings were generated and the energy performances of the buildings were simulated using the climatic data of Tabriz. For the purposes of simulation, the heating and cooling set-point temperatures of the indoors of both buildings were assumed 21ºC and 24ºC, respectively. The annual natural gas and electricity demands of the buildings are shown in the figures below.

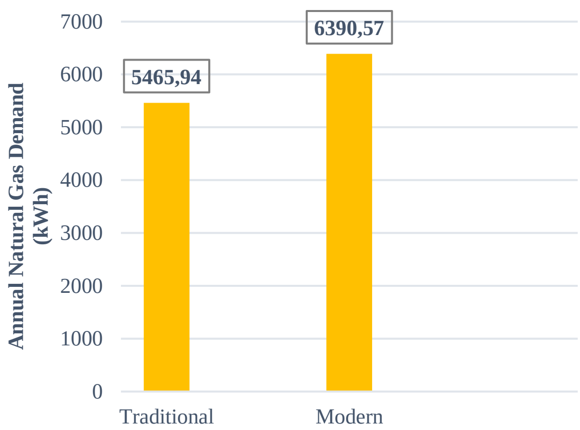


Figure 29. Annual natural gas demands of the traditional and modern buildings.

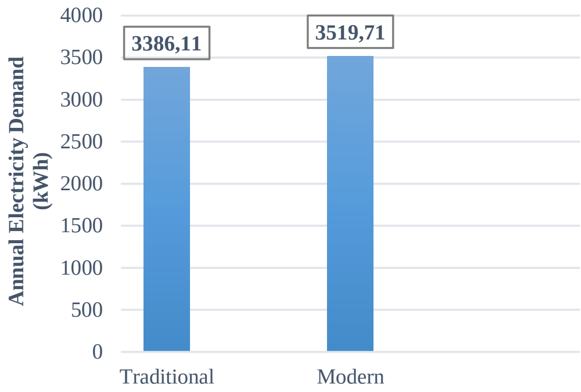


Figure 30. Annual electricity demands of the traditional and modern buildings.

As indicated in Figure 29, the annual natural gas demand of the modern building is higher compared to that of the traditional building. The fact that insulation materials are not used on the external walls of the current buildings in Tabriz may account for the foregoing. Therefore, the heat losses from the external walls during the heating period are higher compared to the traditional buildings. Accordingly, those buildings maintain a weaker performance compared to the traditional buildings in terms of heating energy performance. Figure 30 shows that the annual electricity demand of the traditional building is less compared to that of the modern building. The windows are the weakest components, where thermal changes associated with the building envelope are high. They can lead to major changes in the thermal behavior of the indoors by inducing high heat gains during the summer period and high heat losses during the winter period. The window to wall ratio should be less in order to reduce heat transfer in cold and dry climates. It is also recommended to use fewer or even no windows at all on facades that are exposed to cold winds.

For each kilowatt hour of electricity and natural gas, the respective emissions are 0.626 and 0.234 kg of CO_2 in Turkey. Figure 31 shows annual greenhouse gas emissions in traditional and modern buildings. Therefore, since the energy performance of the modern building is lower compared to that of the traditional building, it uses energy resources less efficiently and emits a higher amount of CO_2 per year.

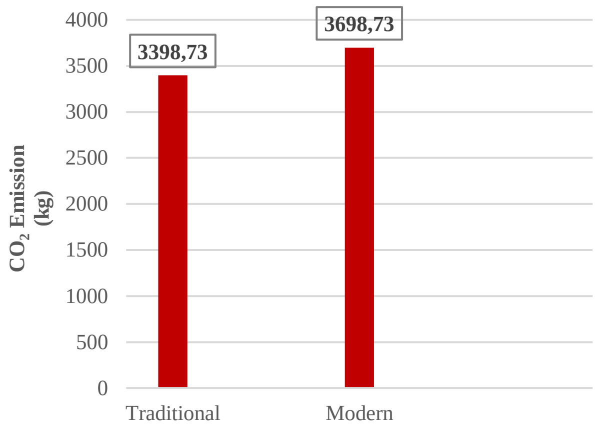


Figure 31. Annual CO_2 emission of traditional and modern buildings.

8 Conclusion

Upon a review of the traditional houses of Tabriz in question, both residential buildings had common features, which reflected the architectural design approaches compatible with cold climatic conditions. The buildings have a courtyard plan and adopt an introverted architectural style. The windows open to the courtyard and there are no windows on the exterior of the courtyard to ensure the privacy of the family. The buildings prevented heat losses substantially throughout the year through this Islamic culture. The buildings were designed to be approximately 1-1.5 meters below the ground level to take advantage of the heat of the soil during the cold winter season. In addition, the building façade was constructed with thick walls and with building materials featuring high heat capacity, ensuring heat preservation of the interior throughout the year. Buffer zones such as corridors and Dalans, which are placed next to the entrance of the building, protect the spaces such as the living room, kitchen, and bedroom in the interior of the building against dynamic changes in the external atmosphere.

Whereas, a review of the new building examples in Tabriz is indicative of the fact that, similar to the traditional buildings, the buildings were located on the north-south axis. The scale and direction of the land used do not change since the contemporary buildings in question were built in place of the demolished old buildings. Therefore, the building spacing did not change either. The interior design of the newly built buildings is generally based on an open plan and there are no buffer zones such as corridors, Dalans, and courtyards to prevent heat losses. The rate of transparency of the exterior facades of contemporary buildings is higher compared to the traditional buildings. Therefore, although the lighting level of the interior spaces is increased, the fact that the exterior walls are generally thinner compared to traditional houses is associated with increased heat loss throughout the year due to lack of due insulation. As a result, a higher amount of energy is required to heat and cool the building throughout the year.

In conclusion, the fact that the contemporary buildings in Tabriz, Iran, are built without due consideration for climatic conditions and the use of passive building design principles, increases the amount of energy required for heating, cooling, and ventilation in such buildings. The fact that the said need for energy is mainly met from fossil sources leads to higher volumes of greenhouse gas emissions, contributing to environmental pollution. The Iranian government should assume a critical duty in terms of building energy saving. The laws and regulations enacted by the government in the field of energy efficiency should improve the implementation and auditing mechanisms in both the private and public sectors, raise the awareness of the citizens, and reduce the use of fossil fuels upon increased investment in the field of renewable energy.

The present study analyzed the energy performances of building cases representing traditional and modern buildings in Tabriz using the DesignBuilder building simulation tool. As a result of the analysis, the annual natural gas and electricity demands of the traditional building was less compared to that of the modern building. In a cold climate region, like where Tabriz is located, the thickness of the external walls of the traditional building and the thermo-physical properties of those walls, considerably increase the annual energy performance of the building and ensure more efficient use of energy resources. The fact that the walls of the modern building are much thinner and uninsulated compared to the traditional building, significantly reduces the annual energy performance. Furthermore, despite the fact that the thermo-physical properties of the window glazing in both buildings were the same, the heat transfer from the glasses differed between the buildings due to different window to wall ratios. Since Tabriz is located in the cold climate region, the most effective way to reduce the heat transfer from the building windows in the relevant region is to reduce the window to wall ratios. Consequently, the higher insulation of the external walls of the building and the lower window to wall ratios would visibly reduce the amount of greenhouse gas emissions in new constructions to be built under the climatic conditions of Tabriz.

Declaration

The authors declare that the ethics committee approval is not required for this study.

Acknowledgments

There is no conflict of interest between the authors.

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