Creative city design / Vol. 5, No. 4, 2022, 10-29

Energy Consumption in the Traditional Houses based on the Cold and Dry Climate (Case Study: Mashhad's Traditional Houses)

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Submit Date: 05 Agust 2022, Accepted Date: 25 October 2022

ABSTRACT

Traditional Iranian architecture has always been held up as a model, showing how climatic elements like geometry, orientation, materials, configuration, and spatial structure can be used appropriately for a proper design. Due to the efficiency of this architecture in energy consumption, it is considered as a solution for modern architecture in this field. In traditional Iranian architecture, solutions such as winter and summer residences have been provided to optimize energy consumption in buildings with higher energy consumption. This study aimed to evaluates the energy consumption of traditional houses and measuring the efficiency of these buildings in the energy field. The research methodology with a quantitative approach is the simulation of energy performance. For this purpose, the traditional houses of Mashhad city are divided into three groups, one-way, two-way, and three-way firstly, and one sample is randomly selected from samples. The simulation tools are two plugins, Ladybug and Honeybee, on the Grasshopper platform. The energy consumption results have been compared and labeled based on the residential rate standard of Iran's National Standard Organization. The results show that different types of traditional residential buildings can be in acceptable categories of energy efficiency so that they can get the energy label. Moreover, it was revealed that the winter and summer residence solution in the larger buildings has a significant effect the energy consumption in the desired seasons. The innovation of this case study lies in the heart of its major conclusions, as the conducted analysis can compete with those presented in the literatur.

Keywords: *Traditional Building; Energy Label; Energy Simulation; Sustainability.*

1. Introduction

In recent years, buildings' energy consumption has increased exponentially worldwide [1], therefore, the equipment and facilities in residential buildings have led to energy consumption uplift for resident's comfort [2]. According to the United States Energy Information Administration (EIA) and the European Commission (Eurostat), about 21% and 27% of the total energy resources in the United States (USA) and the European Union (EU) were consumed by residential buildings in 2018 [3,4]. According to global statistics, energy consumption has doubled every decade, and it is about to reach 54% by 2025. It should be mentioned that more than 40% of the whole energy in the world is consumed in buildings which includes one-third of the global carbon emission [5]. The energy consumption evaluation of residential buildings can play an essential role in energy productivity plans [6]. In general, three numerical, simulation, and experimental methods determine the energy consumption of the building for labeling. The simulation method has high accuracy and low cost the proposed methods. Building energy performance simulation plans can be a valuable tool for evaluating the building energy performance during the design, construction, and operation phases [7]. The results of energy simulation in the productivity process can lead to energy usage in residential buildings' labeling mechanisms.

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As a unique mechanism of energy productivity plans, energy labeling has been introduced to influence energy consumption behavior for better use of resources [8]. Energy Use Intensity (EUI), as a determining factor in energy labeling, compares energy consumption in similar buildings with similar climates in terms of Comerford et al. (2018) [9]. The EUI of buildings defines the energy label of the building by the energy performance guidelines and different standard methods used in each region [10]. Energy labeling is a suitable and necessary tool to identify challenges in energy efficiency opportunities and policies [9].

Simulation, evaluation, and energy labels in traditional buildings can designate appropriate solutions and design solutions in new buildings to improve energy performance.

The energy consumption in traditional places is fundamentally different from those examined in modern buildings. Consequently, the essence of study in this field is more tangible in developing countries than in advanced countries lacking old-fashioned flats. The climate variations have not been investigated in traditional buildings in developing countries [11]. The high-energy consumption is attributed to the low construction quality in this area. Traditional buildings do not always have optimal energy consumption and must be renovated. For example, traditional Chinese pipe houses comprise about 27% of the total energy and heating load. Therefore, these buildings need to be renovated. Using thermal insulation in these homes can significantly reduce energy consumption [12]. On the other, thermal mass also has an essential effect on energy consumption. The optimal use of design features in a house can reduce heating and cooling energy requirements by up to 69%. Notably, buildings should be designed to blend well with the environment [13]. The methods proposed by the architects of traditional buildings, including sunken yards, can be the main contributor to energy consumption reduction. Furthermore, the effect of residence in collective decisions on the energy consumption of the building cannot be neglected [14]. It is noteworthy that in Iran, the average annual energy consumption has a growth of 10% [15]. The cooling and heating systems installed in the buildings are the main factors and include 40% of energy consumption in Iran. The role of passive design in reducing energy consumption seems essential, and traditional Iranian architecture has provided appropriate solutions.

In traditional Iranian architecture, the correct use of construction techniques and architecture is the determinant of efficiency in the building. The main questions raised here are as follows:

- What is the configuration of traditional buildings in Mashhad based on energy consumption?
- how much is the energy use intensity in the selected sample traditional buildings and how successful are these buildings in energy productivity?
- Are the selected traditional buildings able to receive energy labels based on today's standards?
- What strategies can be adopted to improve the energy performance of traditional buildings under investigation, and what strategies do the energy performance of traditional buildings define for the new buildings' design?

1.1. Research Background

The energy productivity improvement of buildings is a significant goal for most countries through building energy productivity labeling to achieve energy-efficient buildings [16]. Building energy labeling, also known as building energy performance certification (EPC), was first introduced in Europe in the early 1990s [17]. This idea has been successfully implemented in developed countries, and it is a powerful tool to help governments improve the energy consumption of buildings [18]. Also, this plan has been accepted in developing countries such as India [19], Brazil [20], and South Africa [21].

As said before, the determination of energy consumption of the building for labeling in this research regards the simulation method. In the past four decades of building energy simulation program development, only a few studies have focused on the ranking of buildings. However, the history of the building energy simulation process is very long. In 1971, the United States Postal Service sponsored developing a computer simulation program to analyze the energy consumption of postal facilities across the United States (USPS, 1971), which was one of the first energy simulation processes. Lokmanhekim [22] described the main structure of simulation plans, including four main sub-plans, which successively include load calculation, thermal load design, system simulation, and economic analysis. Also, Heidell and Taylor [23] were the first to investigate how a DOE-2 (DOE-2) simulation for a large office building matched the actual end-use energy consumption of the building calibrated by this calculated simulation.

Building energy labeling has a history of about three decades of research, development, and implementation. Murphy [24] investigated the building energy efficiency labeling scheme by examining differences between labeled and non-labeled homes. This research has shown that buildings with labels have better thermal performance than buildings without labels. Also, Las-heras-casas et al. [25] developed a modified algorithm for building energy performance certification, depending on the area for evaluating residential buildings. Also, Herrando et al. [26] developed a systematic approach to analyzing the discrepancies between the estimated and operational energy consumption of 21 faculty buildings located on the University of Zaragoza campus.

In addition, researchers have expanded the implementation of building energy productivity labeling from the national to the international level. Mlecnik et al. [27] reviewed the characteristics of existing labels in developed European countries and recommended reducing the complexity of these labels. In addition, they discussed the compatibility issue with developing the Energy Performance of Buildings Directive in Europe. Evans et al. (2017) identified key elements and practices in the implementation of building energy legislation in 22 countries.

Apart from building architecture, three groups of factors, including human, environmental, and physical, are influential in energy performance and, consequently, in energy labeling of residential buildings. Human factors include functional diversity, population, and comfort facilities [28]. Environmental factors include solar energy and natural ventilation. [29, 30, 31]. Physical factors include the heating, cooling, ventilation, and lighting system control [32, 33].

Due to the importance of energy efficiency in traditional buildings, many existing studies in the broader literature have examined this issue. To mention a few, a comprehensive study was carried out regarding the traditional building materials using CFD Fluent software for creating a virtual model and simulating the airflow in the interior of the building. It was revealed that the construction of a wall in the stabilized mud blocks conducts heat from the environment into the house. Further, this condition cools the buildings, leading to a significant level of thermal comfort in old homes without electrical appliances [34]. The study conducted on the traditional houses in China's mountainous regions indicated that the traditional houses are well adapted to the local climate during the summer. However, the indoor thermal comfort during the winter was not entirely satisfactory [35]. Besides, the study of Chinese indigenous buildings showed that the thermal environment of indigenous buildings in Turpan, China affects the residents' thermal adaptation behavior and thermal comfort. The obtained results indicated that the diverse spaces of the indigenous buildings in Turpan create various thermal environmental conditions for the buildings and stimulate the residents' thermal adaptation behaviors. Consequently, the residence's thermal comfort and adaptation are improved [36]. In another study, Timur et al. implemented thermal stabilization strategies in Anatolia's historical buildings. The authors analyzed the thermal behavior of a building considering its materials using the design-builder software. They found that interventions such as thermal insulation and adding glaze to windows can reduce energy consumption by up to 26.5% in cities and 30.4% in rural buildings [37].

The current study focuses on traditional products, considering the issue of energy consumption. Besides, the role of the central courtyard and its pattern in temperature regulation are examined. Notably, analysis tools such as Ecotech software are used [38]. The traditional buildings examined in this study are located in Mashhad. The authors will adopt architectural techniques based on the old styles to increase energy efficiency. Also, Open Studio [4], IDA ICE [5], Hani Bay, and Ladybug are utilized to modernize the traditional building of Iran [39]. The materials employed in traditional buildings can have a significant effect on optimizing the energy consumption of the building, and they can be used for modern buildings [40].

2. Materials and Methods

The quantitative approach as a research methodology is a functional simulation of energy. For this purpose, the traditional houses of Mashhad are divided into three groups, one-way, two-way, and three-way, firstly, one sample is randomly selected from samples. The simulation tools are two plugins, Ladybug and Honeybee, on the Grasshopper platform. The energy consumption results have been compared and labeled based on the residential rate standard of Iran's National Standard Organization.

2.1. Simulation

Energy simulation has been done on the three selected samples. The traditional houses of Mashhad, including one-way, two-way, and three-way firstly, are performed on two plugins of Ladybug and Honeybee on the Grasshopper platform.

Among the most accurate and up-to-date energy modeling software presented so far, the Honeybee and Ladybug plugins have received much attention as it uses Energy Plus and Open Studio engines for energy calculations.

As regards Figure 1, the selected samples are modeled in Rhino initially. Then, the thermal zones are created using Honeybee and Ladybug plugins in the Grasshopper environment, and Mashhad climate variables are applied. After that, the Energy Plus engine is used to simulate energy.

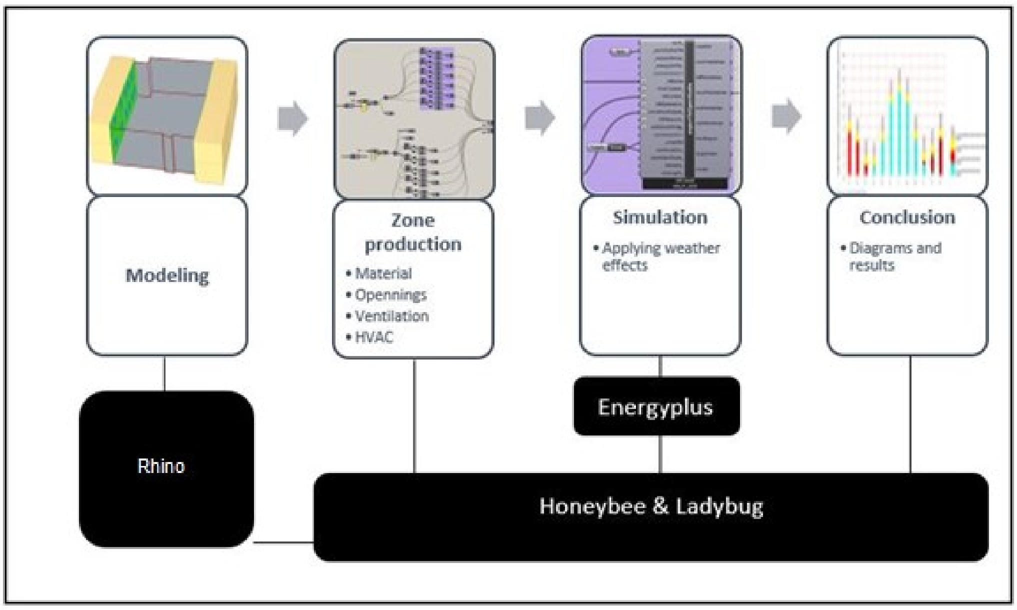


Fig. 1. The procedure of building simulation

The characteristics of the thermal and lighting materials used in the two simulation plugins, Honey Bee and Lady Bug, can be seen in Table 1. The essential characteristics of energy are defined as follows.

- Cooling set point (CoolingSetPt): In this research, the cooling set point is defined as the effective cooling temperature threshold, 24 degrees Celsius.
- Cooling setback point: Also in this research, the cooling setback point controls cooling reduction of the interior temperature if the space is empty, and it is considered to be 30 degrees Celsius.
- Heating set point (HeatingSetPt): In this research, the heating set point is defined as the effective cooling temperature threshold, 18 degrees Celsius.
- Heating setback point: The heating setback point controls the cool reduction of the interior temperature if the space is empty, and in this research, 15 degrees Celsius is considered.
- Daylight setting point (DaylightIllumSetPt): The Daylight setting point determines the sufficient light to turn on and off the electric lights, and in this research, 300 lux is considered.

Also, in this research, the materials of the simulated model have been defined based on the materials used in selected traditional houses. Accordingly, the materials of the walls are clay, plaster, bricks, and straw, and the materials of the roofs are bricks. It is straw, wood, and timber. All simulation settings can be seen in the table below.

Table 1. Materials and specifications used in the simulation (Source: Authors)

Wall materials	Plaster soil Thatch Brick
The roof material	Brick Thatch Wood Timber
coolingSetPt	24
cooling setback	30
heatingSetPt	18
heating setback	15
daylightIllumSetPt	300 lux

2.2. Location of Mashhad

Mashhad is the second most populous and second-largest city in Iran, attracting many religious tourists daily. It is located at 36 degrees and 17 minutes north latitude and 59 degrees and 36 minutes and 45 seconds east longitude. The maximum height of Mashhad is 1150 meters, and the minimum is 950 meters.

Table 2. The climate data in Mashhad (Kamyabi, Mrizaei, 2016) [41]

Climate	**Average temperature Celsius**		**Annual rainfall**	**Above sea level**	**latitude**	**Longitude**
cold and dry	1536	1535	2434	9929	3616	5938

Climate data of Mashhad 30-year-old

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**total**
AT[1*]	2.17	4.08	9.06	15.74	13.9	26.86	28.93	27.24	22.21	15.55	9.29	4.44	14.95
AminT[2*]	-9.96	-9.01	-4.34	4.2	7.54	13.68	16.62	14	8.17	1.53	-2.9	-7.08	2.69
AmaxT[3*]	16.69	20.25	26.22	32.35	36.42	40.01	40.56	41.88	37.30	32.81	25.61	19.85	30.45
Rainfall	31.33	37.51	56.39	44.18	25.64	4.92	1.35	1.14	2.70	7.00	17.27	25.78	255.21

[1*]AT: Average Temperature
[2*]AMinT: Average minimum temperature
[3*]AmaxT: Average maximum temperature

According to the coupon classification, which is based on rainfall and the average monthly and annual temperature, and the Ambrotic diagram, Mashhad has a cold, dry climate [40]. The main information regarding the climate conditions of Mashhad is given in Table 2.

3. Energy Label

The energy label is a numerical parameter that identifies the energy efficiency of the building, which is determined based on climatic conditions and type of consumption [42].

Table 3: climatic divisions of the country (national standard organization of Iran, 2011) [42]

raw	Climate type	maximum temperature average in summer	relative humidity average in summer	minimum temperature average in ,winter	relative humidity average in winter	City sample
1	Very cold	30-25	55-45	-5 تا -10	75-65	Sarab
2	cold	40-35	40-25	-5 تا -10	75-65	Tabriz
3	moderate and rainy	30-25	More than 60	5-0	More than 60	Rasht
4	Moderate and rainy	35-30	More than 50	5-0	More than 60	Moghan
5	semi-arid	40-35	45-20	5-0	60-40	Tehran
6	Warm and dry	45-35	20-15	5-0	50-35	Zahedan
7	Very hot and dry	50-45	30-20	10-5	70-60	Ahvaz
8	Very hot and humid	40-35	More than 60	20-10	More than 60	Bandar Abbas

In this standard, residential buildings are divided into two categories: small buildings with a valuable infrastructure area of less than 1000 square meters and large buildings with a valuable infrastructure area of more than 1000 square meters. To determine the energy consumption range of the building in each climate, first of all, the amount of primary energy consumption should be determined in a specific building. In the current buildings, energy consumption bills are a method to determine the energy consumption of the building, which, in the case of buildings being constructed, it is determined by calculating the amount of energy consumption.

Table 4. Energy consumption index of an ideal residential building in kWh / m^2 / year (national standard organization of Iran, 2011) [42]

Climate	Usage	
	Large residential	Small residential
1 and 2	102	111
3 and 4	106	156
5	87	83
6	75	86
7	138	150
8	118	130

The energy consumption range of the building is based on the energy ratio (R), which is determined in this standard from the result of the energy consumption index to the energy consumption of the building in an ideal state.

Where: 1 $$R = E_{act}/E_{ideal}$$

Annual energy consumption index of the existing building in terms of valuable infrastructure unit (kWh/m2/year)	E_{act}
The standard of Annual primary energy consumption of the ideal building (energy consumption range A) (refer to Table 4.)	E_{ideal}

Table 5. Determining the energy consumption category of the building based on the energy ratio R (national standard organization of Iran, 2011) [42]

Energy consumption category	Usage	
	Large residential	Small residential
A	R<1	R<1
B	1.0 ≤ R < 2.0	1.0 ≤ R < 1.9
C	2.0 ≤ R < 2.9	1.9 ≤ R < 2.7
D	2.9 ≤ R < 3.7	2.7 ≤ R < 3.4
E	3.7 ≤ R < 4.4	3.4 ≤ R < 4.0
F	4.4 ≤ R < 5.0	4.0 ≤ R < 4.5
G	5.0 ≤ R < 5.4	4.5 ≤ R < 5.0
The label is not assigned.	5.4 ≤ R	5.0 ≤ R

The main information regarding the selected samples is given in the next section, considering the simulation method and materials used for the considered analysis.

4. Selected Samples

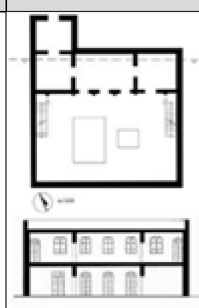
The scope of the research is the traditional houses of Mashhad.

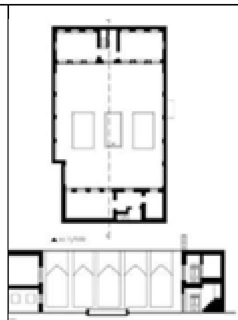
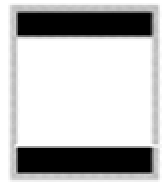
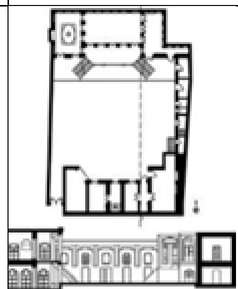
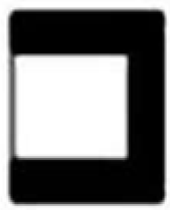
One of the significant features of traditional houses in Mashhad is that they are adaptive to the four seasons. The different elements need to be examined, such as winter residence, summer residence, central courtyard for water use, etc., to specify the energy efficiency correctly. The analysis is based on the cold and hot weather in winter and summer, according to which the residential spaces and the rooms are examined.

In this regard, the traditional houses of Mashhad have been divided into three general groups based on the configuration form, including one-sided, two-sided, and three-sided firstly, and the experts' opinions have confirmed their validity. Among the samples of each group, one sample is randomly selected.

One sample of each one-sided, two-sided, and three-sided type has been selected to compare different types of residential buildings.

Table 6. Some types of houses in the Qajar period of Mashhad (Source: Authors)

Building	Orientation	Plan	The type of the house	Picture
Tavakoli's House	North-South		one-sided 	

Amiri's House	East-West		Two-sided 	
Daroogheh's House	North-South		Three-sided 	

5. Simulation

Based on experts' opinions, three examples of traditional houses were selected from the traditional houses of Mashhad to simulate energy. Tavakoli house, with a one-sided form; Amiri house, with a two-sided form and Daroogheh house, with a three-sided form, were chosen. Energy simulation was performed on all three houses, and the results are as follows. Also, to find the energy ratio (R) for each building, the amount of ideal energy consumption (E *Ideal*) has been 83 k Wh based on the size and conditions of the selected houses.

5.1. Tavakoli's House Simulation

First, the simulation was done on Tavakoli's house, shown in figure 2. The total energy consumption in this house is 123.45 kWh, in whichdifferent sectors include cooling at 51.7 kWh, heating at 10.4 kWh, electric lighting at 24.9, kWh and electrical equipment at 36.2 kWh.

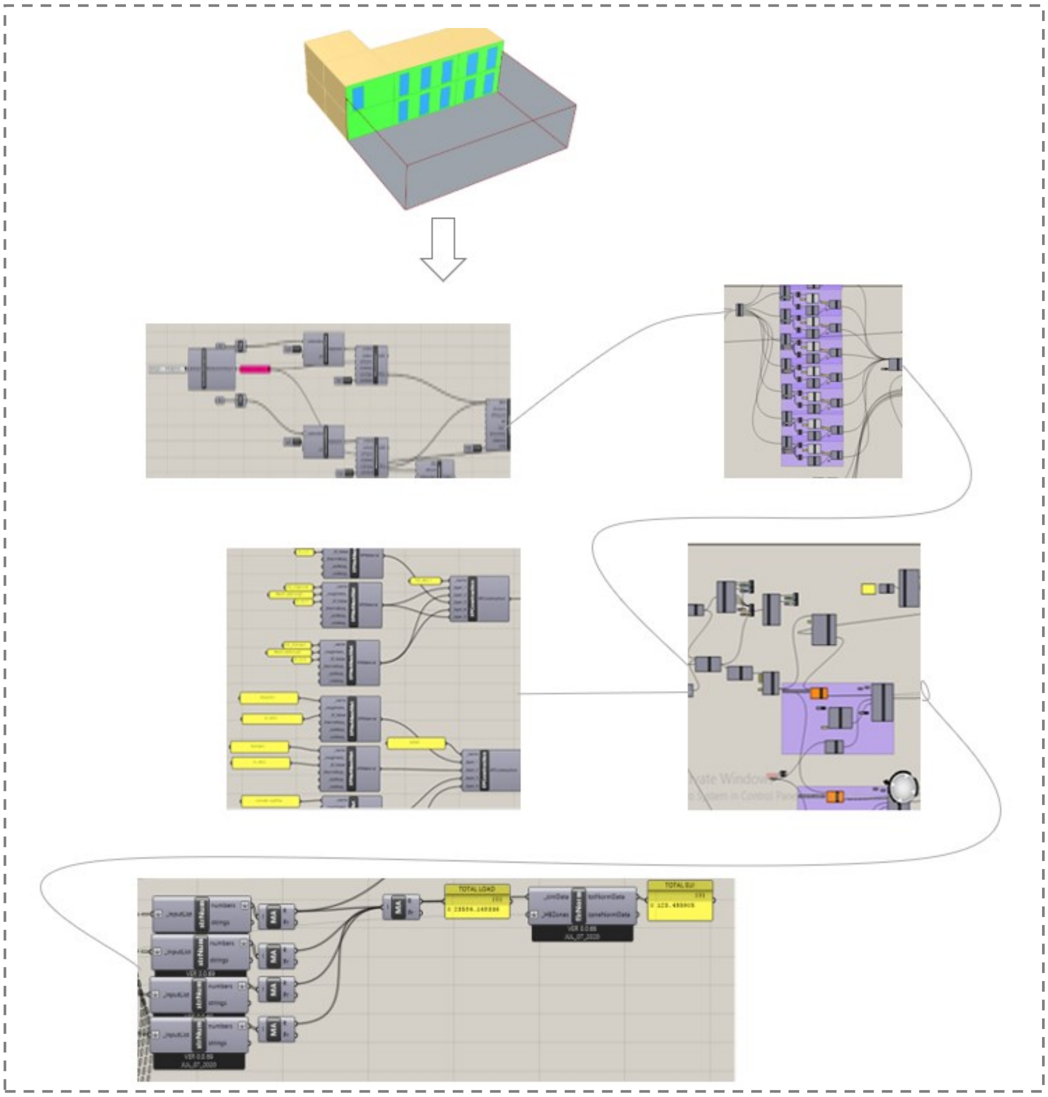


Fig. 2. Tavakoli's house simulation

Table 7. The significant results are based on the analytical parameters (Source: Authors)

Cooling	Heating	Electric light	equipment Electric	Total
51.7	10.4	24.9	36.2	123.45

Regarding the graph, the highest amount of energy consumption is related to July and August, as the time of maximum cooling energy consumption, which is due to the significant ratio of cooling energy to total energy consumption.

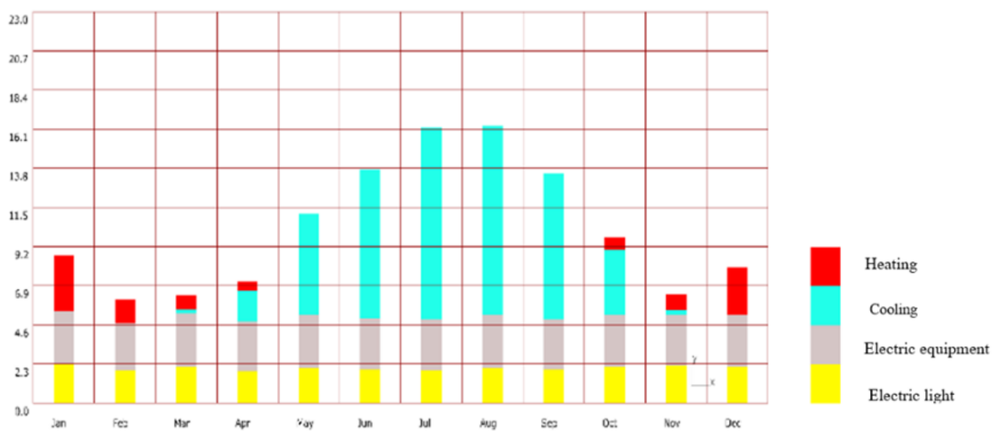


Fig. 3. The intensity of Tavakoli's house energy consumption in terms of kilowatt hours per square meter (Source: Authors)

According to the total amount of energy consumption in this house, the energy ratio is 1.48, and the energy range of this building is determined as B (B) based on the energy classification table.

As indicated in Equation 1, R is equal to 1.48. Therefore, the energy label B is assigned to this building, as shown in Figure 2.

Considering the natural ventilation in Tavakoli's house, the amount of energy consumption increases to 192.5 kilowatt hours. Therefore, the energy ratio (R) increases and becomes 2.3. Therefore, with the natural ventilation, energy consumption category of Tavakoli’s House is considered C.

5.2. Simulation of Amiri's House

Also, a simulation of Amiri's house has been performed, which is seen in figure 4. The total energy consumption in this house is 143.74 kWh. In the energy simulation of this house, different sectors, including cooling with 60.7 KWh, heating with 27.4 KWh, electric lighting with 19.3 KWh, and electrical equipment with 36.2 KWh, have been obtained.

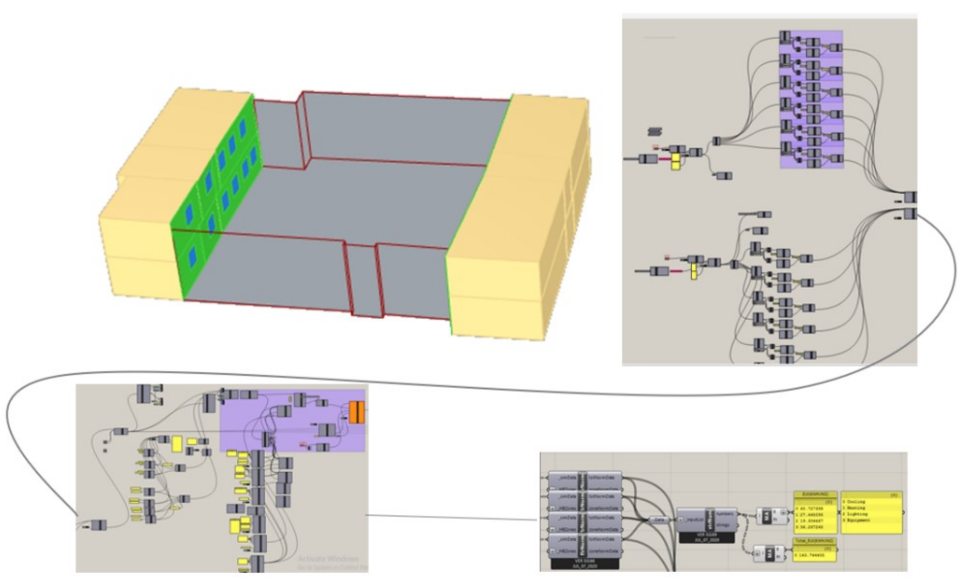


Fig. 4. Simulation of Amiri’s house and calculation of energy consumption intensity

In this house, heating consumption has increased significantly, and electric lighting consumption has decreased to a specific extent compared to Tavakli's one-sided house. Also, as can be seen in the graph, the highest amount of energy consumption is related to the month of July.

Table 8. The significant analytical parameters in Amiri's House (Source: Authors)

Cooling	Heating	Electric light	Electric equipment	Total
60.7	27.4	19.3	36.2	143.74

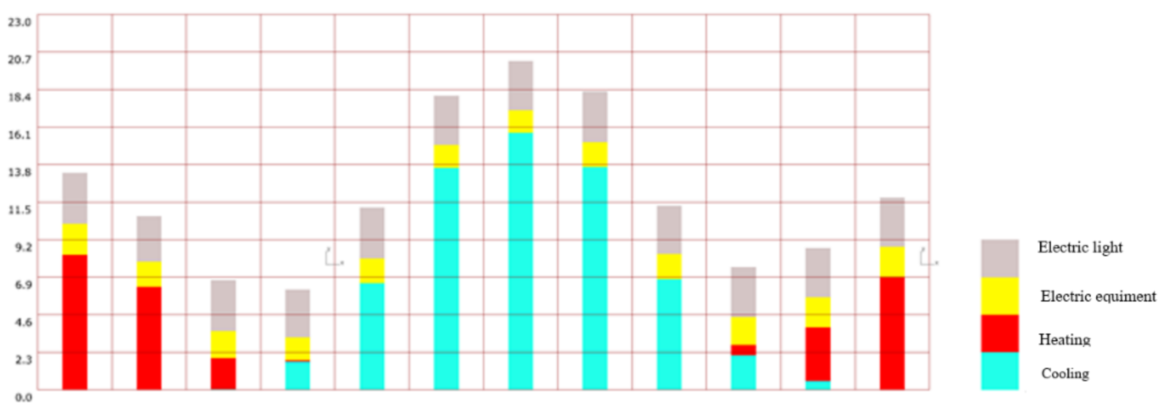


Fig. 5. The intensity of Amiri's house energy consumption in terms of kilowatt hours per square meter (Source: Authors)

As regards the result, E_{act} for Amiri's building is 143.74. Also, according to Equation 1, R becomes 1.73, and the energy label of Amiri's House becomes B.

For Amiri's house, considering natural ventilation, the total energy consumption is 750.34 kWh without receiving any label.

5.3. Daroogheh's House Simulation

Next, the simulation was performed on Daroogheh's house, which is presented in figure 6. The total energy consumption in this house is 157.59 kWh - which the contribution of different sectors including cooling at 31.3 kWh, heating at 36.25 kWh, electric lighting at 55.88 kWh, and electrical equipment at 1.34 Kilowatt hours.

The remarkable point of this house's energy simulation compared to Amiri and Tavakoli's is the significant reduction of cooling energy consumption by about 50%. Another point is the significant increase in the electrical energy of lighting in this house by up to 1.5 times. Also, the amount of heating energy has also increased.

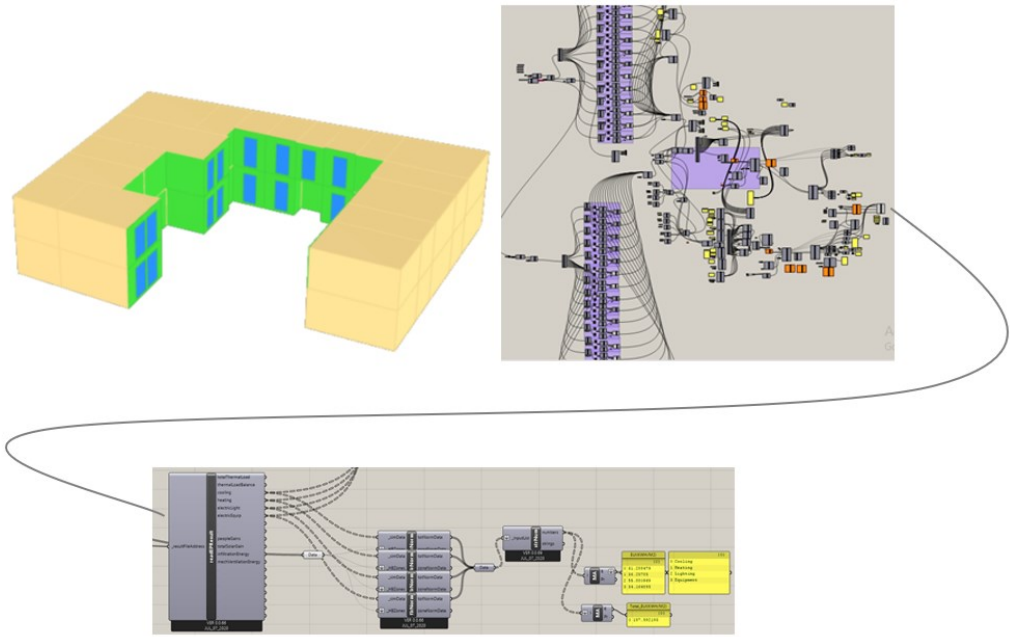


Figure 6. Simulation of the Daroogheh's house

Also, as can be seen in the graph, the changes in variance in energy consumption in different months has decreased, and in all months, energy consumption is almost the same. Nevertheless, the highest amount of energy consumption is related to July.

Table 9. The obtained results for the energy label of Daroogheh's building **(**Source: Authors)

Cooling	Heating	Electric light	equipment Electric	Total
31.3	36.25	55.88	34.1	157.59

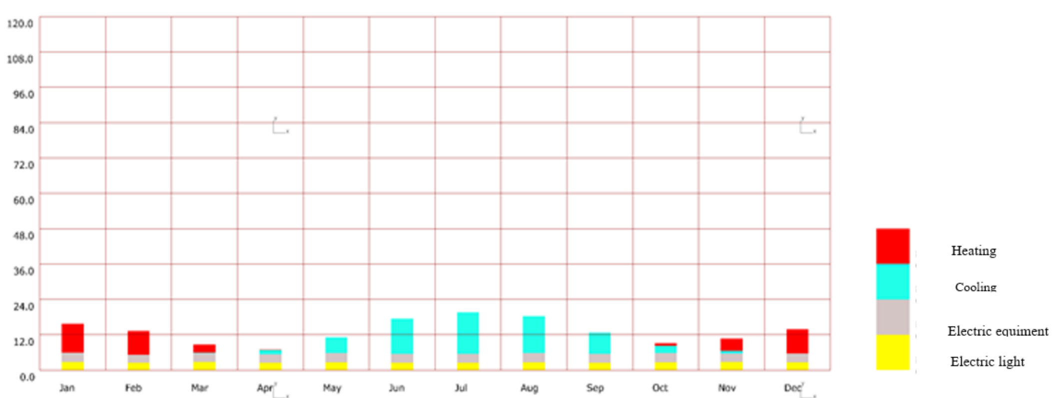


Fig. 7. The intensity of Daroogheh's house energy consumption in terms of kilowatt hours per square meter (Source: Authors)

As a result, E_{act} for Daroogheh's building is 157.59 and based on Equation 1, R becomes 1.8. As indicated in Table 5, the energy label of Daroogheh's House becomes B.

In Daroogheh's building, the total energy consumption has increased to 663.2 kilowatt hours with the natural ventilation in the building. Therefore, the energy ratio (R) is 7.9, and this traditional house also does not receive a label.

Based on the simulation findings, the one-way form operation in Mashhad can be evaluated as more favorable based on energy consumption. Also, using natural ventilation in all houses has significantly increased energy consumption. Therefore, it can be concluded that the continuous use of natural ventilation decrease energy efficiency in these traditional houses. Also, the findings show that the cooling operation of three-sided houses is much better than one-sided and two-sided houses. Considering that most of the energy consumption ratio is included in cooling energy, using a three-way form in the city of Mashhad can increase the efficiency of energy consumption under the condition of lighting and heating energy control. Also, based on the findings, it can be understood that the energy consumption of electrical equipment remains constant; therefore, the building form does not have much effect on the consumption of this equipment.

6. Results and Discussion

The solutions used in the architecture of the selec ted samples are considered for the residents' ther mal comfort and energy consumption reduction. In traditional houses, the orientation of the buildi ng is proportional to the climate as it makes the m ost use of sunlight and is protected from adverse winds. he main spaces in a traditional Iranian bui lding are usually located toward the south to rece ive light and employ the sun in the cold seasons Usually, the southern and northern fronts have m ore depth to make the best use of sunlight and ar e located in the main spaces.

Service spaces are located on the western and eastern fronts and have less depth. In Daroogheh's house, the main depth is related to the northern and southern spaces shown in Figure 2. The eastern part is a service space containing the lowest depth compared to other spaces. The central courtyard also has a significant effect on climatic conditions. In addition to penetrating the light into the building and heating it through solar energy radiation in winter, the introverted courtyard house acts as a cold trap due to its confinement. It provides shade, ventilation, and air conditioning using the building in summer.

But in these houses, residents' flexibility causes optimal climate operation. Residents of traditional houses significantly improve the energy performance of the building by changing their location in different seasons and the ventilation operation of the house. The results of this research show that only the central courtyard form in architecture does not improve the overall energy operation and the energy efficiency in traditional houses concerns the residents' flexibility.

In Daroogheh and Amiri's houses, the central courtyard is significantly used. A water basin element has been employed in the middle of the courtyard, providing both relative humidity and air conditioning.

This means that if the ventilation operation is controlled by the residents or placed in an intelligent format, the energy efficiency of the building can be increased significantly, even in the central yard. Nevertheless, with static performance, the best structure is one-way forms.

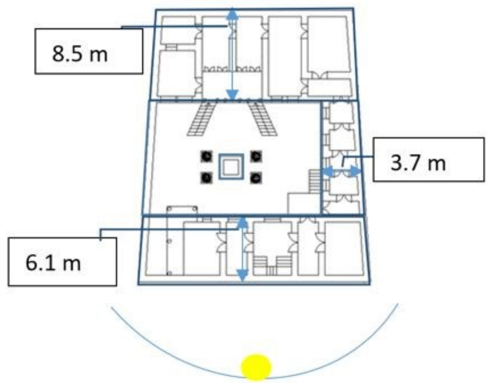
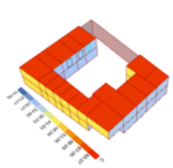
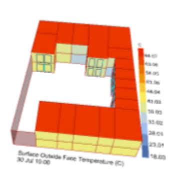
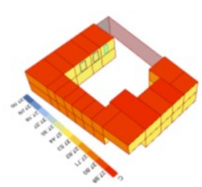
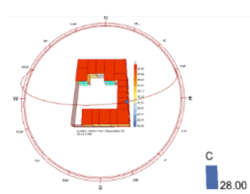
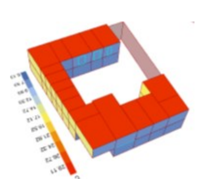
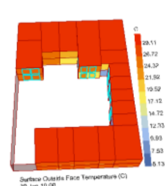
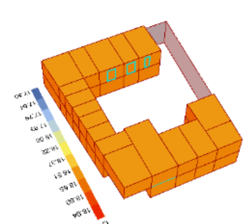
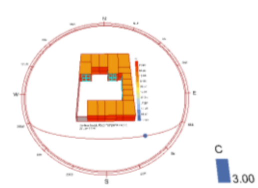
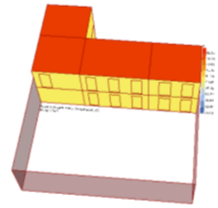
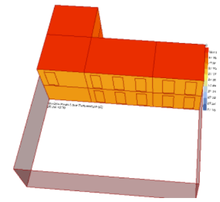
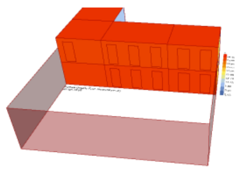
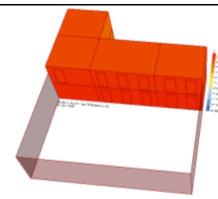
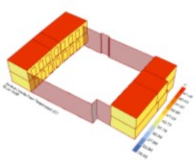
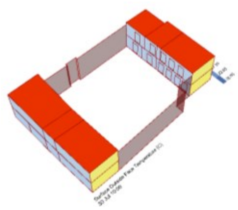
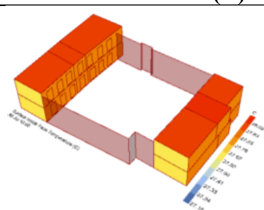
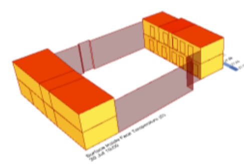
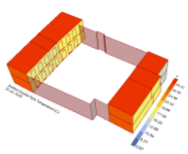
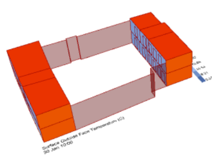
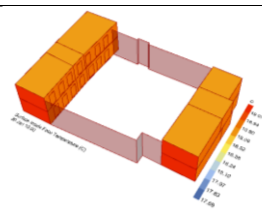
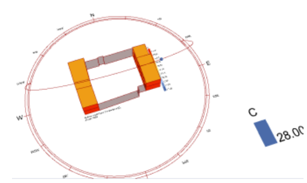


Fig. 8. Depth of space and the central courtyard of the Daroogheh's house (Source: Authors)

The table below shows the building's interior and exterior surface temperature for one hour in summer and winter. As it is known, the spaces that receive the light of the south have more temperatures in winter than the other fronts on the outer surfaces, up to about 15 degrees. The parts that are located in the south have a lower temperature in summer, up to about 10 degrees, with the parts that are located in the north most of these parts are used for summer.

Table 10. The indoor and outdoor surface temperature of different houses in winter and summer (Source: Authors)

Outer shell temperature of southern surfaces (C)	**Outer shell temperature of northern surfaces (C)**	**Inner shell temperature of southern surfaces (C)**	**Outer shell temperature of southern surfaces (C)**	**Time**
Daroogheh's house				
				At 10:30 a.m., July 30 (Summer)
				At 10 a.m. on January 30 (Winter)

Tavakoli's house				
				At 10 a. m., July 30 (Summer)
				At 10 a. m. on January 30 (Winter)
Amiri's house				
Outer shell temperature of the western front (C)	**Outer shell temperature of eastern fronts (C)**	**The inner shell temperature of the western front (C)**	**Inner shell temperature of eastern fronts (C)**	
				At 10 a. m., July 30 (Summer)
				At 10 a. m. on January 30 (Winter)

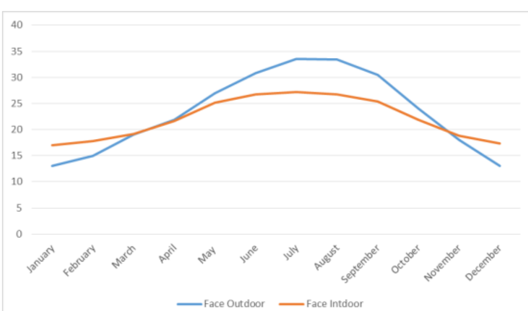
Typically, materials with high heat capacity are used in traditional Iranian houses, which prevents heat exchange inside and outside. The points with a 60 cm thick walls, as shown in Table 10, are also considered. The ceilings are usually the most sensitive points and have the highest heat exchange. The ceilings' exterior surfaces are the space's hottest points in summer compared to other facades and are the coldest in winter, according to the previous diagrams. The temperature difference between the roof's outer and inner shells is much higher than in other spaces. Thus, the materials used in the roof are of particular importance. Clay, wood, straw, and mat are also used. These materials, especially clay, mud, straw, and brick, with their high heat capacity, prevent heat exchange between the outside and inside spaces in hot and cold weather by absorbing the sun's heat during the day and releasing it at night. This condition leads to moderate internal temperature.

Table 11. Properties of materials used in Tavakoli, Amiri, and Daroogheh houses (Source: Authors)

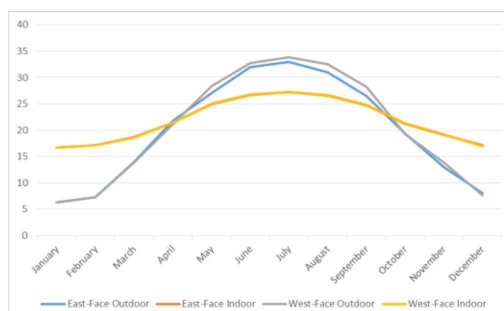
Materials	**R-VALUE (m ^{2}.k / w)**	**Special Weight**	**Thermal conductivity coeficient**
Brick	In a wall with 30 cm thickness: 0.27 As a roof surface with 5 cm thickness0.045 :	2000	1.1
Thatch 2 cm	0.016		
Mud 5 cm	On the ceiling:0.045	1770	1.1
Brick facade	In a wall with 10 cm thickness: 0.09		
Wood	As timbers with diameters of 15 cm, on the roof: 1.25	0.12	600

The thermal operation of materials in traditional houses is also related to the residents' flexibility or the smartness of the house significantly; so in traditional houses, with the resident's awareness of the thermal storage of materials in the houses, the windows were Regardless of this operation, this thermal storage can negatively affect the building's energy performance. In case, Amiri and Darogheh's houses have very low efficiency despite the favorable climate.

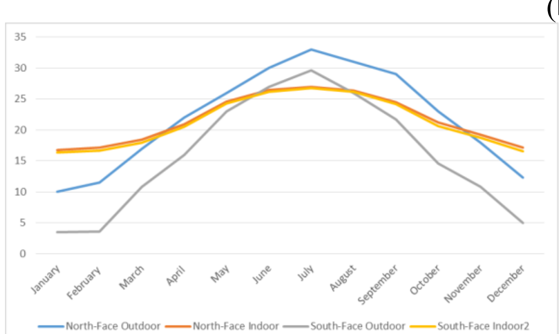
Considering Figure 9, there is a large temperature difference between the outer shell and the inner walls of the building, up to about 10-15 °C°C. This difference is more noticeable in the ceilings that, in some hours of the day on the hottest or the coldest days of the year, reach more than 15 °C°C. Therefore, at the architecture of this building, materials with a high heat capacity have been used to reduce heat exchange. On the south side, there is a difference of about eight °C in winter and about seven °C in summer, representing the importance of using summer and winter residences to minimize the energy consumption for cooling and heating.



(a)



(b)



(c)

Fig. 9. Comparison of internal and external surface temperatures in different directions of (a) Tavakoli's house walls, (b) Amiri's house walls, and (c) Daroogheh's house walls (Source: Authors)

Daroogheh's house was built based on three styles for saving energy; the north side and the sun's yard with the warmer weather are used in winter and are known as the winter residence. To be precise, the opposite of this action, namely the summer residence, takes place on the south side of the yard and behind the sun (Near). Besides, Daroogheh's house is simulated in winter and summer states. The heating and cooling in winter and summer quarters are represented in the diagrams in Figures 10-12.

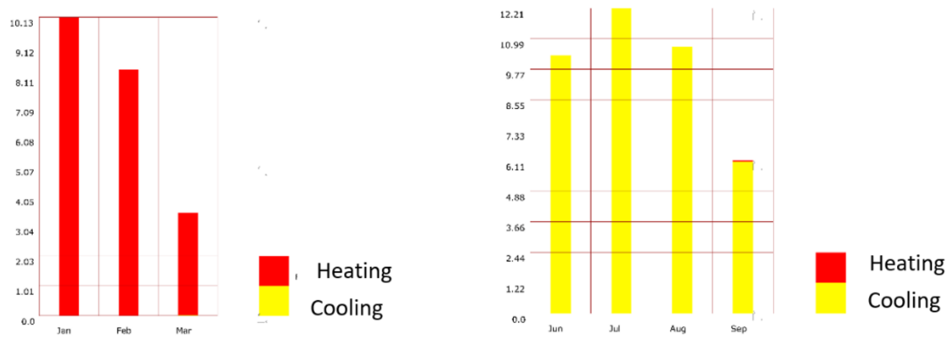


Fig. 10. Heating and cooling in the summer and winter quarters of the Daroogheh's house in general (Source: Authors)

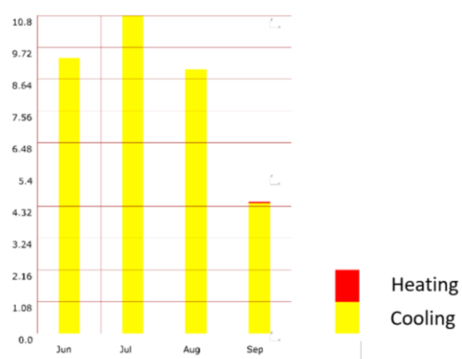


Fig. 11. Winter heating and cooling in the winter mode for three months (Source: Authors)

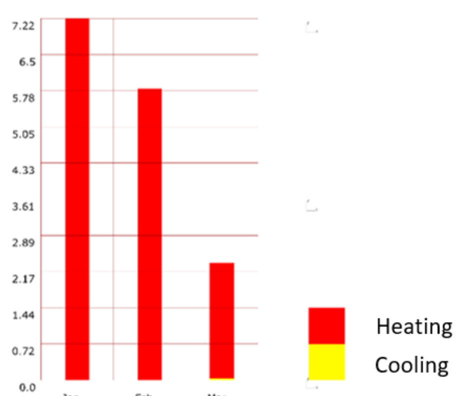


Fig. 12. Heating and cooling in summer mode for three months (Source: Authors)

As regards Figure 12 with the heating diagram, an approximation of a 30% reduction in heating over the entire three months in winter, according to the cooling diagram, in the case of the summer residence, a reduction of about 12% compared to the general situation is observed.
Finally, the main results obtained for the energy parameters of the selected three buildings are summarized in Table 12. According to the obtained results, it can be concluded that using ventilation significantly increases energy consumption as the highest value is related to Amiri's house. Due to the comparison between the samples, Tavakoli's house, with an intensity of 123.45, is more affordable.

Table 12. Performance comparison among the three buildings investigated in this study (Source: Authors)

	The intensity of energy consumption in a state without natural ventilation	**Energy label**	**The intensity of energy consumption in a state with consideration of natural ventilation**	**Energy label**
Tavakoli's house	123.45	B	192.5	C
Amiri's house	143.74	B	750.3	-
Daroogheh's house	157.59	B	663.2	-

7. Conclusion

In summary, the primary purpose of this study is to examine the energy efficiency in the traditional buildings situated in Mashhad, which belong to the Qajar era and are comparable with modern architecture. The style of these architectures in terms of energy standards and energy efficiency is considerable, which can be attributed to the accuracy of their architects in correctly using architectural elements such as orientation, geometry, and appropriate materials proportional to their climate. When natural ventilation is employed, energy consumption increases significantly, probably due to the many openings used in those buildings. These construction techniques, along with advances in modern technology, including double-glazed windows and thermal insulation, can significantly reduce energy consumption. The whole selected buildings are capable of getting energy label B without ventilation. With the one-sided architecture, Tavakoli's house consumed less energy due to its smaller area, followed by Amiri and Daroogheh's houses, respectively. Using natural ventilation, energy consumption increased sharply in Amiri and Daroogheh's houses. Amiri's house was built in an east-west direction, with an incredible effect on energy consumption. Iranian architecture has provided a suitable solution for these houses considering the summer and winter residences which experience the energy consumption reduction in the associated seasons. The results highlight the intelligence and ingenuity of its architects. Based on the three-month diagrams obtained, this initiative significantly affects heating and cooling in winter and summer, bringing an energy consumption reduction of 30% in winter and 12% in summer. Future studies are necessary to validate the conclusions that can be drawn from this study.
It can be concluded that, regardless of ventilation, the three-way and two-way forms have a favorable function in Mashhad's climate. However, the building energy performance varies significantly with alternative ventilation in the building. The residents' flexibility is influencing this issue. The residents' behavior can significantly improve energy performance by changing the ventilation process at different times. This issue is clear from the consumption of cooling energy in three-sided houses compared to two-sided and one-sided houses. Other researchers have mentioned this topic, such as Lidelöw et al. (2019) and Abu-Jdayil et al. (2019). Research shows that in the past, due to the lack of electrical and thermal equipment, the residents' behavior conformed to the climatic conditions. Nevertheless, in today's conditions, due to the lack of adaptation of the residents' behavior to the desired climate, the one-way form offers better performance than other forms. This form performs better with or without ventilation than the other two forms.

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