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Research Paper

Energy-Efficient Design of Conventional High-Rise Buildings by Façade Modification in Cold and Dry Climates; Case Study of Mashhad City Running Head: Façade Modification of Conventional Tall Buildings

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Abstract
Energy-efficient buildings reduce energy demand. The parameters of the building envelope, as an interface between the interior of the building and the outdoor environment, can greatly influence energy consumption. The main objective of this study is to optimize the parameters of buildings' envelopes for reducing energy consumption while considering the common style of architectural design in cold-dry regions. The case study research methodology is used to investigate the effect of various openings characteristics on the energy performance of the building. This paper studied one of the stories of a high-rise residential building as the case study and component blocks were used for the rest of the stories. To find an energy-efficient model for the buildings' façade, considering the effective parameters, numerous simulations were performed by the EnergyPlus as an energy simulation engine. The factors analyzed in this article included the type of glazing, the type of window frame, the window-to-wall ratio (WWR), and shading placement. The results show that a combination of Low-E glazing and Argon gas with a 5.98% reduction, a UPVC window frame with a 0.36% reduction, a WWR of 30% with a 1.57% increase, an overhang shading with 20cm thickness and 15cm depth with a 1.12% reduction in annual energy consumption can cause a total reduction of 2.45% in annual energy consumption compared to the initial model. These changes did not compromise the required lighting for the interior spaces while reducing the energy consumption of the building.

Keywords: *Building façades, Energy-efficiency, High-rise buildings, Energy simulation, Energy reduction, Cold-dry climate.*

1. INTRODUCTION

Increase in the urban population and the high cost of land, the residential buildings are built high-rise. Buildings consume a significant part of the energy to create comfortable conditions. Therefore, there are short- and long-term plans for issues related to energy management strategies (Keeble, 1988). Energy consumption in the building sector in Iran is more than twice the global average (Nasrollahi et al., 2013). Most of the energy in buildings is used to maintain a comfortable indoor environment in terms of thermal comfort – cooling and heating, and air quality. The harmonization between climatic conditions and architectural design and construction technology is effective at saving energy (Yao, 2013).

The envelope of a building is the interface between the interior of the building and the outdoor environment. The volumetric display of a building consists of floor, ceiling, and façade. Since the façade is the interface between the interior and the exterior space, heat exchange takes place through it. In high-rise buildings compared to the low-rise, due to having more stories, and having more contact with the outside environment through the façade rather than the roof, so, major heat transfer takes place through the façade (EN, 2008). Therefore, the façade of a building is of special importance especially in controlling the total annual energy consumption. In this study, the energy consumption is considered for heating, cooling, and electric lighting in the climatic conditions of Mashhad. The city of Mashhad, with cold and dry weather

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conditions, has hot summers and cold winters. The effective factors for the façade of the building also include the type of glazing, the type of window frame, the window-to-wall ratio (WWR), and shading device placement. It is worth mentioning that other items of the façade are less effective in building energy consumption. However, these factors, such as exterior wall materials, are considered fixed and defined to achieve more accurate results.

2. RESEARCH BACKGROUND

Energy-efficient buildings contribute significantly to reducing energy consumption and greenhouse gas emissions; (Parsaee et al., 2021). Most of the energy-saving measures have been conducted on the residential buildings' façade as the most appropriate way to save energy (Arumägi & Kalamees, 2014; Calero et al., 2018; Patterson et al., 2014; Weber et al., 2020).

Optimization has reduced energy consumption by about 44.6 to 56.7% through the retrofit of buildings in Italy (Cellura et al., 2011). To reduce energy consumption through the building's envelope, instructions, rules, and regulations have been developed (Carlo & Lamberts, 2008; De Almeida et al., 2011). Designers sometimes encounter challenges and contradictions, such as ensuring maximum utilization of daylight and reducing energy consumption (Mehdizadeh Saradj & Maleki, 2014).

Controlling the transmission of energy through all the components of the façade can greatly save energy. When designing and renovating a building, the properties of the material, such as the amount of heat transfer, must be taken into account (Rosso et al., 2017; Wu et al., 2016).

Providing solutions on the façades of high-rise residential buildings has reduced energy consumption for cooling by 30 to 40% compared to conventional homes by using a cross-ventilated double-skin façade (Farrokhzad, 2014; Kim et al., 2013; Leigh et al., 2004).

The use of photovoltaic (PV) systems (Boyano et al., 2013) and building integrated photovoltaic (BIPV) systems (Peng et al., 2011) is the active solution for reducing energy consumption. However, the usage of these systems in the façade of high-rise residential buildings entails challenges and benefits (Kosorić et al., 2018). Using sustainable strategies such as the green wall (Najafi et al., 2015; Wu et al., 2016), or double skin façade (Leigh et al., 2004) were efficient in reducing the cooling and heating demand in summer and winter, respectively

In the construction of new buildings, the opinion of residents in using the building energy standard and choosing the most appropriate source of energy should be considered in the construction strategy (Gustavsson et al., 2010; Kumar et al., 2017; Siller et al., 2007). There have also been other studies on residents' surveys on how to choose strategies that affect building energy service demand (Achtnicht & Madlener, 2014; Alanne et al., 2007; Cholewa & Siuta-Olcha, 2010; Cholewa et al., 2011; Filippín & Larsen, 2009; Meyers et al., 2010). Meeting the various physical and psychological needs of human beings, following the weather and geographical conditions, available materials, and local threats for each region, is a practice that is developing over time in the cultural and social sectors (Liao & Xu, 2015; Powell et al., 2018; Sanaieian et al., 2014). Optimization measures have focused on building elements such as walls, ceilings, and windows (Asadi et al., 2014; Shao et al., 2014). Moreover, by selecting materials with the appropriate thermal conductivity (Košir et al., 2018), and considering the appropriate thickness for the façade, it is possible to maintain heat in winter and cold in summer (Yao et al., 2018; Yun et al., 2007).

For example, in winter, materials with high thermal mass absorb heat during the day and release heat slowly when the heat source is lost (Balaras, 1996). In the past, buildings used thick load-bearing walls due to structural limitations, but today, due to the construction of tall buildings, light walls are used that are not able to store energy like traditional buildings. However, there were other challenges to the energy efficiency of the façade for traditional indigenous architecture, such as aesthetics, function, and structure (Yun et al., 2007).

The insulation of building elements is another solution to energy optimization measures in residential buildings (Chidiac et al., 2011; Tadeu et al., 2015). Various other factors such as the type and material of window frames and the window-to-wall ratio also affect the annual energy consumption of the building (Leskovar & Premrov, 2011; Vaisi & Kharvari, 2019).

The geometric settings of the façade of a building also affect the more efficient use of daylight and increase the energy efficiency of the façade. The extent of these effects is determined by various measurements of the annual energy consumption cycle (Lulic et al., 2014; Lute & Lute, 2016). For example, although a larger WWR is beneficial by adding solar gain in the winter, it can cause the interior space to overheat during the summer (Lartigue et al., 2014). However, in cold climates, the maximum use of transparent or opaque façade and gaining the maximum solar energy can affect ambient temperature and brightness, resulting in the reduction of energy consumption (Griego et al., 2012; Myers & Pohl, 1992; Salari & Javid, 2017).

The results of the analysis of a school indicate the effectiveness of various design parameters such as orientation, the optimal ratio of window to wall, organization of space, canopy, and form according to energy consumption and has resulted in a 31% reduction in energy consumption (Zomorodian & Nasrollahi, 2013). The other effective parameter on the annual energy performance is overhang shading features and the shadow created on the façade of the building (Alibaba & Ozdeniz, 2016; Gabrielli & Ruggeri, 2019; Mirshojaeian Hosseini et al., 2020).

The area of the household unit, the number, age, daily activities, socio-economic characteristics of households, and their overall environmental behavior have a significant impact on the energy consumption of a building (Ahmad et al., 2017; Fan et al., 2017; Takahashi & Kurosawa, 2016; Yeh & Yuen, 2011).

An effective method to obtain the optimized façade parameters is to learn from traditional indigenous houses, as the product of long-time adaptation with the local climate, as carried out by Mirshojaeian et al. (Mirshojaeian Hosseini et al., 2020) through comparison of traditional and modern façades.

Energy efficiency standards in Iran are provided for the whole vast country, while due to the climatic diversity of the country, the need for their development is felt regionally and even for each city.

Finding the characteristics of each of the façade parameters in the design of the construction of new high-rise buildings in the cold and dry climate of Mashhad is the main objective of this paper. However, the basis of these parameters is taken from conventional buildings in the area, which have been optimized gradually over time. Considering the different modes for each of the parameters as well as the effect of these factors on each other, the best modes of facade parameters will be suggested for consideration in future designs.

3. RESEARCH QUESTIONS

- Which façade parameters affect the annual energy consumption of high-rise residential buildings in Cold-dry Climate?
- What is the contribution of each parameter in reducing annual energy consumption?
- What are the physical characteristics of an energy-efficient template for the façade of high-rise residential buildings in Mashhad?
- How much would be the energy consumption reduction rate in the optimal model compared to the current building?

4. RESEARCH METHOD

Various simulation programs have been developed to provide optimal design solutions for the building by simulating the building and measuring its exact energy consumption (Myers & Pohl, 1992). The development of statistical models using economic, social, and demographic criteria, building characteristics, location, temperature, and energy prices have been carried out to estimate the current costs of domestic energy consumption in the United States (Salari & Javid, 2017).

In the present research, regarding the study of methods about increasing energy efficiency and creating thermal comfort conditions for residential buildings, first, one of the first high rise building blocks of “Apartemanhaye Mortafa” residential complex in Mashhad, with 10 stories, 435 m^2 each, and 5 residential units, built in the 1970s by a French company, was selected as a case study.

The DesignBuilder software, based on energy plus simulation engine, is used for the simulation of building. The accreditation of the use of this software for the analysis and calculation of building energy has been carried out in previous research (Gabrielli & Ruggeri, 2019). Moreover, calculating the energy consumption of buildings in the EnergyPlus has been expressed in many studies (Blanco et al., 2016; Boyano et al., 2013; Wang et al., 2014; Yuce et al., 2016).

Due to the heat exchange between the stories of a building, one story of the studied high-rise residential building was modeled, and the upper and lower stories, due to their effect, were modeled as component blocks in the DesignBuilder software. Due to the geographical characteristics of the site, this building with an east-west direction has the highest level of sun exposure in different seasons in the northern and especially southern fronts for using the sunlight and daylight. So, in the analysis of a simulation by the DesignBuilder software, some alternative changes were made to various parameters, including window-to-wall ratio, the type of glazing, shading device placement, and the type of window frame of the main fronts (north and south). On the east and west fronts, in a part of the building, only the windows of the two bedrooms and the small windows of the bathroom and toilet, were considered unchanged in all analyses.

Two-person families per apartment unit with specific levels of occupation are listed in Table 2. The cooling and heating system was defined according to Table 1. Also, the climatic characteristics of the Mashhad climate were loaded in the software by epw [1] climate file. Interior spaces were also defined according to the current functional situation according to Fig. 1. Specifications of the materials of interior and exterior walls, floor and ceiling, and the exterior wall section of the façade were also defined according to the current situation of this building in the software according to their thermal resistance. In the simulation, the variables were considered according to Table 1.

Fig. 2 shows the steps and processes of modeling and simulation in the DesignBuilder software. Then, each parameter was defined separately and its variables were determined, and the results obtained in the tables related to each parameter, included the annual consumption of heating, cooling and lighting energies, the energy consumption (kWh/m^2), and the change in consumption by percentage compared to the original model of the building for the consumption of heating, cooling and lighting energies. Finally, by comparing the proposed variables, where the percentage of a reduction in energy consumption (kWh) is higher than the original model, a model for the optimal design of the parameters in the studied building was developed. The type, characteristics, and size of façade materials were specified in the selected model according to Table 2. In this modeling, the technical and general specifications of the building were defined according to Table 3.

[1] Any simulation in the software requires a regional climate file. Energy modeling and simulation programs usually perform calculations on an hourly basis to determine the internal conditions of a building, and the first step in this process is to use valid weather data.

Table 1. Type and Status of Variables in the Simulation

independent variables		Dependent variable	Controlled variables
WWR	7 type	Overal energy consumption of the building based on electrical energy consumption	the materials of interior and exterior walls, floor, and ceiling
Shading device	12 type		
Glazing type	11 type		
Window frame type	9 type		

Table 2. Construction Details of the Cases Study Existing Building

Components	Details
Floor and ceiling	concrete 12 cm, air gap 40 cm, gypsum board 2 cm
Roof	flat roof with stone cover 3 cm, concrete 12 cm, air gap 40 cm, gypsum board 2 cm
external wall	brick façade 5 cm, cement mortar 2 cm, cement block 15 cm, air gap 5 cm, cement block 15 cm, gypsum board 3 cm,
Partitions	gypsum plasterboard 3 cm, cement block 15 cm, gypsum plasterboard 3 cm
Windows frame	Aluminum (Normal) (4 cm) with the material thickness (0.05 cm)
windows	single-glazed tinted glass (6 mm)
Shading device	Overhang with projection (60 cm)
HVAC system	Hot water radiator, mechanical ventilation (supply and extract)

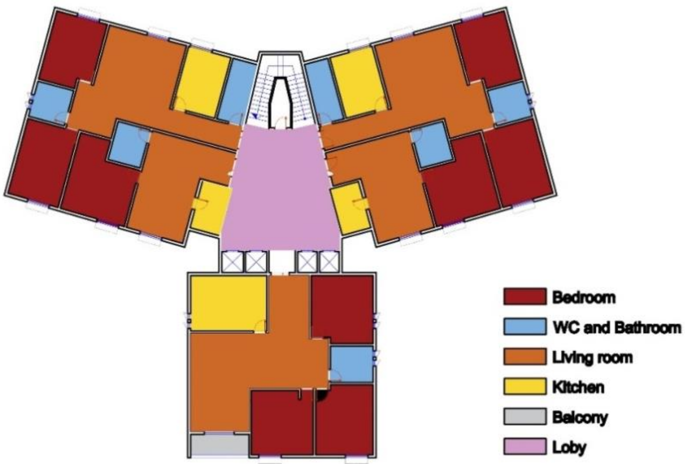

Fig 1. A Typical Residential Floor Plan and the Orientation of the Building

a. The type of energy-efficient glazing: Of the 11 types of studied various glazing types, the glazing stated in table 1, has been selected as the current glazing and the calculation of the difference between the annual energy consumption of other glazings and the current glazing was carried out to determine energy-efficient glazing type.

b. The type of energy-efficient window frame: 9 types of window frames were studied and one of which was selected as the reference for the current situation (Table 2) and the calculation of the difference between the annual energy consumption of each window frame and the window frame (reference) was done to determine an energy-efficient window frame.

c. The energy-efficient window-to-wall ratio: the ratios of 16% 20% 25% 30% 30% 40% 50% 60% were studied, the ratio of 16% was selected as the reference for the current situation (Table 2) and the calculation of the difference between the annual energy consumption of other ratios and the 16% ratio was done to determine an energy-efficient window-to-wall ratio.

d. The type of energy-efficient shading device: 12 types of shading devices were studied and one of which was selected as the reference for the current situation (Table 2), and the calculation of the difference between the annual energy consumption of other shadings and the reference shading was done to determine energy-efficient shading.

In software programs for modeling and simulating energy, it should be noted that the behavioral definition of people who use space is involved in energy consumption, and the number of people in space, the method of using electrical appliances, metabolism type, and the amount of temperature required in ambient comfort conditions, etc., are among the factors affecting energy consumption, which were defined in the software and can be seen in Table 3.

Table 3. Sensitivity Analysis of Building Parameters

Building parameter	Unit	Values
External wall heat transfer coefficient	$W/m^2 K$	0.924
Partition wall heat transfer coefficient	$W/m^2 K$	1.425
Roof heat transfer coefficient	$W/m^2 K$	0.576
Heating setpoint temperature	C^o	22*
Cooling setpoint temperature	C^o	26*
Metabolic	-	0.9
External vents operation schedule	-	Summer cooling*, off
Occupancy density	people/m2	0.0188* - 0.0229*
Occupancy schedule	-	Compact Schedule
Minimum outside fresh air	l/s person	10
Mechanical ventilation schedule	-	Compact Schedule
Miscellaneous equipment	W/m2	3.58
Lighting (Target illuminance)	lux	100-150
Glazing type	-	Clear
WWR	Percent	16

*The base case settings of the reference model that led to the validated model.

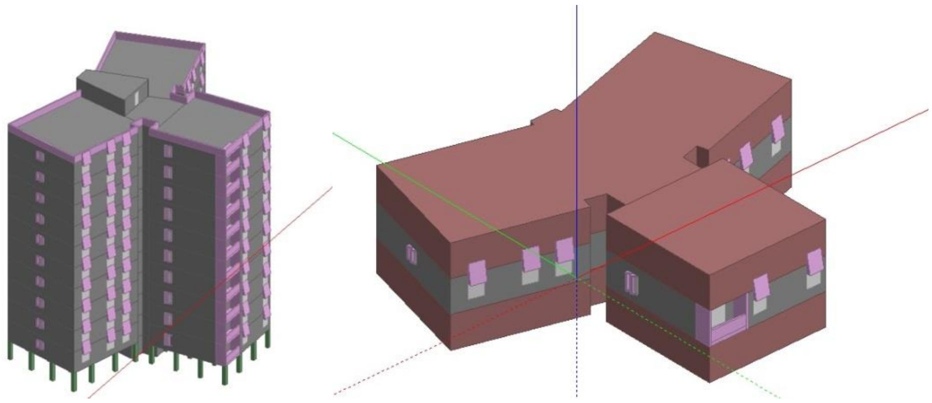

Fig 2. The 3D Model of the High-rise Apartment Building in Mashhad Simulated in DesignBuilder.

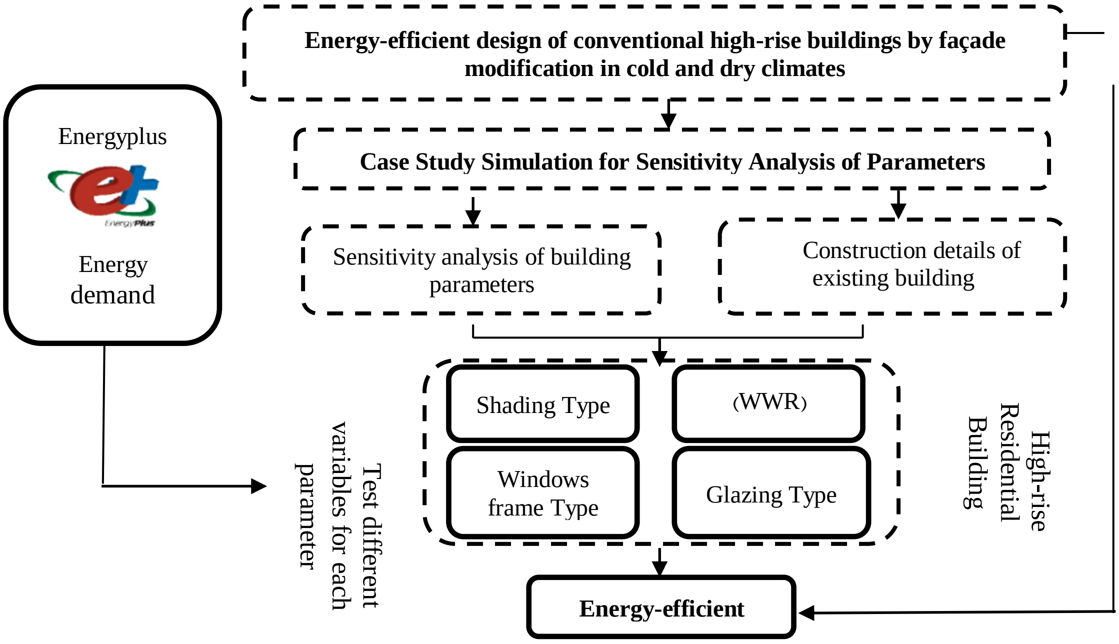

Fig 3. The Applied Process of Research in the Paper

5. MASHHAD CITY CLIMATE

The city of Mashhad is the capital of Khorasan Razavi province with an area of 328 square kilometers. Its approximate geographic location is 35°43' to 37°8' north latitude and 59°15' to 60°36' east longitude, in the valley of the Kashaf River, between the two mountain ranges of Binalood and Hezar-masjid. The average height of the city is about 1,050 meters above sea level (maximum of 1150 meters and a minimum of 950 meters). The city of Mashhad has a variable but temperate cold and dry climate, with hot and dry summers and cold and humid winters. Winds in Mashhad mostly blow from southeast towards the northwest. The maximum temperature in summer is 43 degrees above zero and the minimum one in winter is 23 degrees below zero. Between the driest and wettest months, the difference in precipitation is 54 mm. Temperature changes throughout the year are by 24.5°c as shown in Table 4.

6. HIGH-RISE RESIDENTIAL BUILDINGS

Depending on the number of stories, residential buildings are divided into two categories: high-rise and low-rise. According to the Ashrae standard, residential buildings with more than four stories are considered high-rise buildings (Yeh & Yuen, 2011). The development of technology for the construction of high-rise buildings and considering the tools to achieve this development in today's societies are important. Today, Iran is developing and urban life has greatly increased, the value of urban land is increasing, and the need for housing is essential for all strata of the society. However, due to rising land prices, most housing developers have begun building high-rise residential buildings. The city of Mashhad, as the second metropolis in Iran, is facing significant growth in the construction of high-rise residential buildings.

As mentioned earlier, the façades of high-rise buildings have a large surface in contact with the outdoor environment. Therefore, they are very important in building energy consumption. Energy policies based on the National Building Code in Iran are mandatory for high-rise buildings. But the lack of a clear model and criterion for the buildings' façade in this area prompted us to look for a model for the façade's constituent elements.

Simulation analysis is an accurate measure of a building's energy consumption. And selecting specific parameters helps to increase the reliability of this analysis. The choice for this analysis can be proceeded by two methods. The first method is that the parameters of a story (window-to-wall ratio, the type of glazing, shading device, and the type of window frame) were used as a reference (taken from case study) and were analyzed by simulation. Then, it can be generalized to the whole façade. The second method is to simulate the whole building and evaluate the whole façade, which increases the probability of error in calculating energy due to the large volume of information in this method. Following the research, by adopting the correct method (Ho-Seon et al., 2007), and given that all the stories of the studied building are of the same type, one story with 5 apartment units, was considered as a model sample for numerical calculations and an annual energy consumption reference. This model was defined as a representative of the whole building. In the second method, the total energy ratio of a building is calculated based on the average energy consumption of the whole units because the units of the last and first stories consume more energy than other units (Hoes et al., 2009). Generally, residential buildings in Mashhad use radiator heating systems or ceiling fan coils. The middle floors of the building are connected and have reached thermal equilibrium. This can have a direct impact on the energy consumption for heating in the building.

Table 4. Mashhad climate parameters (source: Meteorological of Khorasan-Razavi province)

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	0.5	3	7.4	13.5	19.4	23.4	25	23.6	19.4	13.9	8.5	3.8
Min. Temperature (°C)	-5.5	-2.3	1.3	6.9	12.4	15.4	17.1	15.1	10.7	5.6	1	-1.7
Max. Temperature (°C)	6.6	8.3	13.5	20.1	26.4	31.4	33	32.1	28.2	22.2	16	9.3
Avg. Temperature (°F)	32.9	37.4	45.3	56.3	66.9	74.1	77.0	74.5	66.9	57.0	47.3	38.8
Min. Temperature (°F)	22.1	27.9	34.3	44.4	54.3	59.7	62.8	59.2	51.3	42.1	33.8	28.9
Max. Temperature (°F)	43.9	46.9	56.3	68.2	79.5	88.5	91.4	89.8	82.8	72.0	60.8	48.7
Precipitation / Rainfall (mm)	30	35	55	44	27	4	1	1	2	12	17	23

7. DISCUSSION AND RESULTS

7.1. Glazings

Glazing plays a key role in absorbing, transmitting, and reflecting sunlight. If the absorption and transfer of sunlight to the inside, through glazing, is controlled, it will lead to less heat loss in winter and less heat gain in summer and thereby reducing energy consumption.

Glazing plays a role in energy consumption for lighting. By choosing the appropriate glazing, one can also use the daylight to a high degree. The choice of glazing depends on the climatic conditions of the area, the intensity of the radiation, and the radiation angle. Table 5 shows the technical specifications of the glazing used. The solar heat gain coefficient ((SHGC) (It is the amount of solar radiation that is received through the window as a transfer or absorption and is released inside.)) is defined as the amount of solar radiation that enters the building through the window. Depending on the weather conditions, glazing with the right U-value can be selected. For example, for areas with extreme heat, glazing with a lower solar heat gain coefficient (SHGC) should be used. Table 6 shows the energy consumption of 10 types of glazing. The ratio of the difference in their total annual energy consumption is shown in Fig. 4.

Table 5. The Specifications of Glazing Types

Type	U-Value (W/m^2 K)	SHGC	VT	Description Glazing
Type - A	5.778	0.620	0.534	[Sgl]: Tinted 6 mm (Bronze)
Type - B	2.667	0.479	0.381	[Dbl]: Clr 6 mm/8 mm Arg/Clr 6 mm
Type - C	2.196	0.139	0.07288	[Dbl]: Clr 6 mm/8 mm Arg/Ref 6 mm
Type - D(ref)	5.778	0.819	0.881	[Sgl]: Clr 6 mm
Type - E	2.567	0.703	0.781	[Dbl]Clr 6 mm/10 mm Arg/Clr 6 mm
Type - F	2.014	0.131	0.07288	[Dbl]: Clr 6 mm/13 mm Arg/ LOW-E 6 mm
Type - G	1.960	0.691	0.744	[Dbl]: Clr 6 mm/13 mm Arg/Ref 6 mm
Type - H	1.930	0.683	0.738	[Trp]: Clr 3 mm/6 mm Arg/Clr 3 mm/6 mm Arg/ Clr 3 mm
Type - I	1.383	0.289	0.294	[Trp]: Clr 3 mm/6 mm Arg/Clr 4 mm/6 mm Arg/ LOW-E 3 mm
Type - K	2.667	0.479	0.381	[Dbl]: Clr 6 mm/8 mm Arg/ Tinted 6 mm (Bronze)
Type - M	2.511	0.704	0.781	[Dbl]: Clr 6 mm/13 mm Arg/Clr 6 mm

Table 6. Simulation Results Obtained for Different Glazing Types

Glazing Type	Annual heating demand			Annual cooling demand			Annual lighting demand			Total Annual Percentile differenc e (%)
	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	
Type - A	26141/03	5/79	60/09	6703/42	-8/06	15/41	3856/12	2/87	8/86	2/66
Type - B	25216/14	2/05	57/97	6352/38	-12/87	14/60	3943/86	5/21	9/07	-0/66
Type - C	27480/45	11/21	63/17	5450/79	-25/24	12/53	4317/16	15/17	9/92	4/19
Type – D (ref)	24709/12	0	56/80	7291/27	0	16/76	3748/4	0	8/62	0
Type - E	23498/5	-4/89	54/02	6982/25	-4/23	16/05	3774/66	0/7	8/68	-0/41
Type - F	23155/32	-6/28	53/23	6670/57	-8/51	15/33	3781/95	0/89	8/69	-5/98
Type - G	27280/33	10/4	62/71	5433/48	-25/47	12/49	4317/13	15/17	9/92	3/58
Type - H	23047/14	-6/72	52/98	6923/61	-5/04	15/92	3784/79	0/97	8/70	-5/57
Type - I	23568/57	-4/61	54/18	6365/59	-12/69	14/63	4164/13	11/09	9/57	-4/61
Type - K	25083/86	1/51	57/66	6394/47	-12/29	14/70	3890/11	3/78	8/94	-1/06
Type - M	23496/21	-4/9	54/01	7007/52	-3/89	16/11	3772/2	0/63	8/67	-4/12

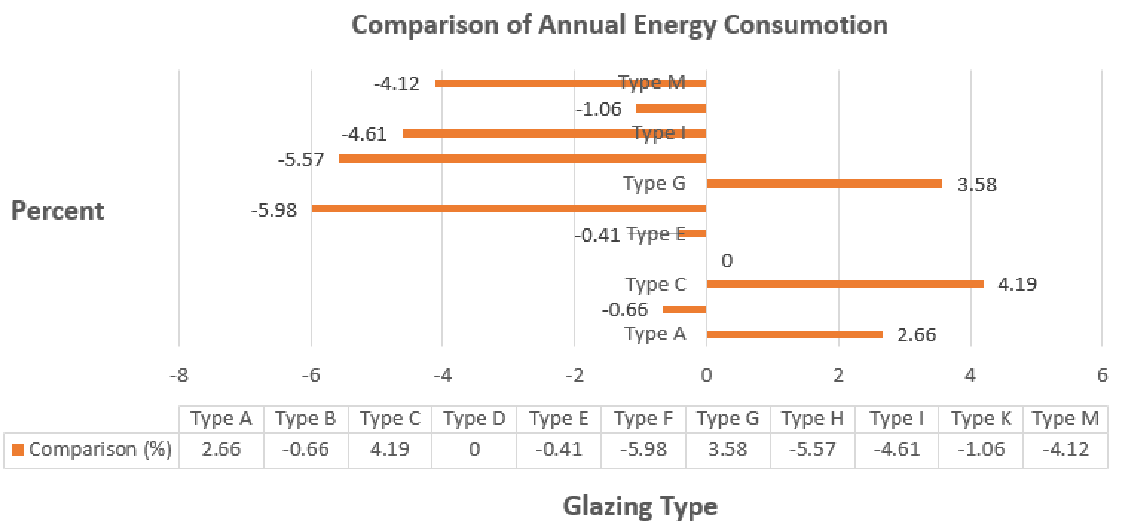

Fig 4. Comparison of Annual Energy Consumption with Variant Glazing Types

7.2.1. Window-to-Wall Ratio (WWR)

The window-to-wall ratio has greatly influenced energy consumption in different climates. In traditional Iranian architecture, it was generally the best option to control openings and windows for natural ventilation and to create conditions of comfort, considering the climate of each region. Generally, in cold climates, the window-to-wall ratio is less. In warm climates, the window-to-wall ratio is equal, and in humid climates, this ratio is more to create air draft. It should also be noted that daylight can be a source of natural light for a building. Whenever the window-to-wall ratio decreases, more energy is needed to provide lighting during the day. But today, with the advancement of technology and manufacturing technology for window frames and glazing, the level of windows can be controlled according to the climatic conditions of the region. In the analysis performed to optimize, different variables of window-to-wall ratio (WWR) were simulated (Table 7). So, the best option of the proposed variables, with the least energy use to provide cooling and heating, as well as the least energy to provide lighting, was identified.

Table 7. Description (WWR)

WWR	North (WWR) Percent	South (WWR) Percent
Type 1	16	16
Type 2	20	20
Type 3	25	25
Type 4	30	30
Type 5	40	40
Type 6	50	50
Type 7	60	60

7.2.2. Window to Wall Ratio Description

The façade of the studied building, on the north and south sides, has 3 parts of the façade and the dimension of each plane of the façade is 3.40*12.5. Due to the great effect on improving energy consumption, only the openings and windows of the north and south façades without shadings were examined. The average area of the façade in each face is 42.5 square meters, which includes 3 windows of size 1.5m * 1.5m, and then their total area is 6.75 square meters. The WWR in the studied building was 16%. This ratio is very different from the ratio in high-rise buildings that have a lot of openings in their façade to provide a suitable view as one of the conditions of stability (Raji et al., 2016). The results of analysis and simulation with different percentages for testing different ratios of window-to-wall and calculating their energy consumption are shown in Table 8. The variables considered for the window-to-wall ratio to analyze the energy simulation of the studied building, and the ratio of the difference in their total annual energy consumption is shown in Fig. 5.

7.3. Shading Device

The infiltration of daylight into the building can have many consequences. Proper shading can control the radiation of this light and take advantage of it. By adopting an appropriate strategy, the maximum efficiency of daylight can be obtained by calculating the angle of sunlight in different seasons of the year as well as different hours of the day on each of the building fronts. Balancing the use of daylight on the one hand, and preventing the increase in temperature resulting from radiation inside the building, on the other hand, emphasize the role of shadings and shadows more than ever. Shadings have a wide variety, including interior elements such as curtains and exterior elements that are fixed or movable or in the form of recessed or protruded arches that include different dimensions and sizes. The shadings discussed in this study are exterior fixed shadings on the façade of the studied building, which have been simulated and analyzed with different shapes and dimensions (overhangs and side fins) (Fig.6.) The technical specifications of different shadings according to the survey conducted on the façade of traditional houses in Mashhad are presented in Table 9 (Mirshojaeian Hosseini et al., 2020). The results of analysis and simulation with different variables of shading for calculating their energy consumption are shown in Table 10. And the ratio of the difference in their total annual energy consumption is shown in Fig. 7

Table 8. Simulation Results Obtained for Different Window-to-wall ratios

WWR (%)	Annual heating demand			Annual cooling demand			Annual lighting demand			Total Annual Percentile difference (%)
	Total heating (kWh)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	
16	24709/12	0	56/80	7291/27	0	16/76	3748/4	0	8/62	0
20	24756/54	0/19	56/91	7547/78	3/51	17/35	3733/69	-0/39	8/58	0/8
25	24193/77	-2/08	55/62	8160/56	11/92	18/76	3723/21	-0/67	8/56	0/91
30	23832/7	-3/54	54/79	8761/52	20/16	20/14	3717/75	-0/81	8/55	1/57
40	23323/48	-5/6	53/62	8822/76	21	20/28	3720/51	-0/74	8/55	0/32
50	23018/84	-6/84	52/92	10891/64	49	25/04	3711/65	-0/98	8/53	5/24
60	22164/21	-10/29	50/95	13335/34	82/79	30/66	3709/07	-1/04	8/53	9/67

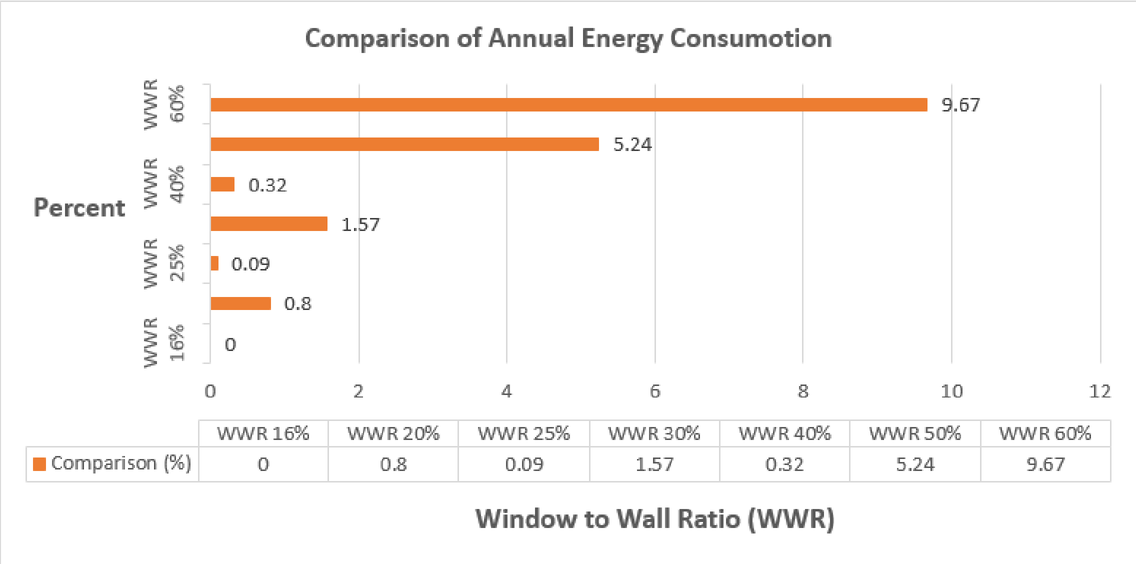

Fig 5. Comparison of Annual Energy Consumption with variant Window to Wall Ratio (WWR)

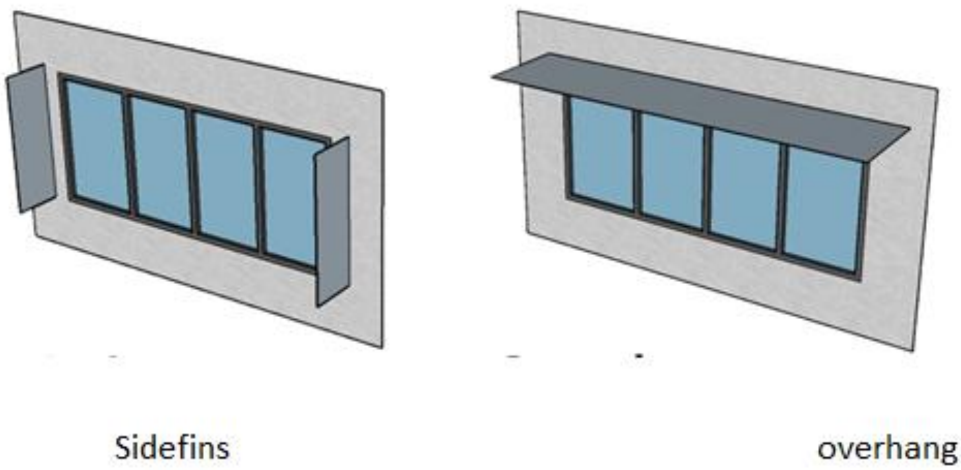

Fig 6. The Shading Device Types of Side Fins and Overhangs

Table 9. Description of the Shadings Device

Type	Thickness Shading	projection Shading	Side fins	Overhang
Shading A	-	-		
Shading B	0.2	0.4		×
Shading C	0.2	0.5		×
Shading D (Ref)	0.3	0.6		×
Shading E	0.2	0.2	×	×
Shading F	0.2	0.3	×	
Shading G	0.2	0.3	×	×
Shading H	0.2	0.1	×	×
Shading J	0.2	0.15		×
Shading I	0.1	0.3		×
Shading K	0.3	0.7		×
Shading M	0.2	0.15	×	×

Table 10. Simulation Results Obtained for Different Shadings

Shading	Annual heating demand			Annual cooling demand			Annual lighting demand			Total Annual Percentile difference (%)
	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	
Shading A	23615/01	-4/42	54/29	8039/85	10/26	18/48	3734/12	-0/38	8/58	-1
Shading B	24438/96	-1/09	56/18	7344/75	0/73	16/88	3746/34	-0/05	8/61	-0/6
Shading C	24665/12	-0/17	56/70	7236/78	-0/74	16/64	3747/13	-0/03	8/61	-0/02
Shading D(Ref)	24709/12	0	56/80	7291/27	0	16/76	3748/4	0	8/62	0
Shading E	24473/42	-0/95	56/26	7356/42	0/89	16/91	3742/97	-0/14	8/60	-0/5
Shading F	24351/53	-1/46	55/98	7585/47	4/03	17/44	3765/76	0/46	8/66	-0/12
Shading G	24955/26	0/99	57/37	7063/86	-3/11	16/24	3777/13	0/7	8/68	0/13
Shading H	23942/82	-3/1	55/04	7714/24	5/8	17/73	3735/54	-0/34	8/59	-0/99
Shading J	23859/14	-3/43	54/85	7753/72	6/34	17/82	3734/33	-0/37	8/58	-1/12
Shading I	24210/35	-2/01	55/66	7485/89	2/6	17/21	3742/05	-0/16	8/60	-0/86
Shading K	25090/92	1/54	57/68	7093/65	-2/66	16/31	3754/02	0/14	8/63	0/53
Shading M	24208/59	-2/02	55/65	7528/44	3/25	17/31	3739/79	-0/22	8/60	-0/76

7.4. Window Frame

The windowpanes need a frame, which due to architectural design and also for an easier installation of the glazing, these frames are also divided into smaller parts so that some of them can be used as openings for natural ventilation and others are considered as fixed. The materials and thickness of these frames affect the heat exchange between the indoor and outdoor environment through the façade. In traditional architecture, wood was generally used as a material for window frames due to its ease of construction and implementation, as well as its abundance. Due to its high heat resistance, wood has a very low heat transfer coefficient and as an available traditional material, it has been a very suitable option for optimizing thermal behavior. But with the advent of modernity, iron window frames have replaced wooden ones, and since then, aluminum window frames have been used. Today, with the advancement of technology, Thermal Break Aluminum and UPVC window frames are used. These two materials have been proposed as materials approved by the National Building Regulations of Iran to save energy. Table 11 shows the studied variables of window frames. In this section, the window frame simulation analysis was performed with different materials and thicknesses, and to determine the most efficient window frame with the lowest annual energy consumption, the comparison of variables with the reference was done (Table 12). A comparison of the annual energy consumption of each of the variables is shown in Fig. 8.

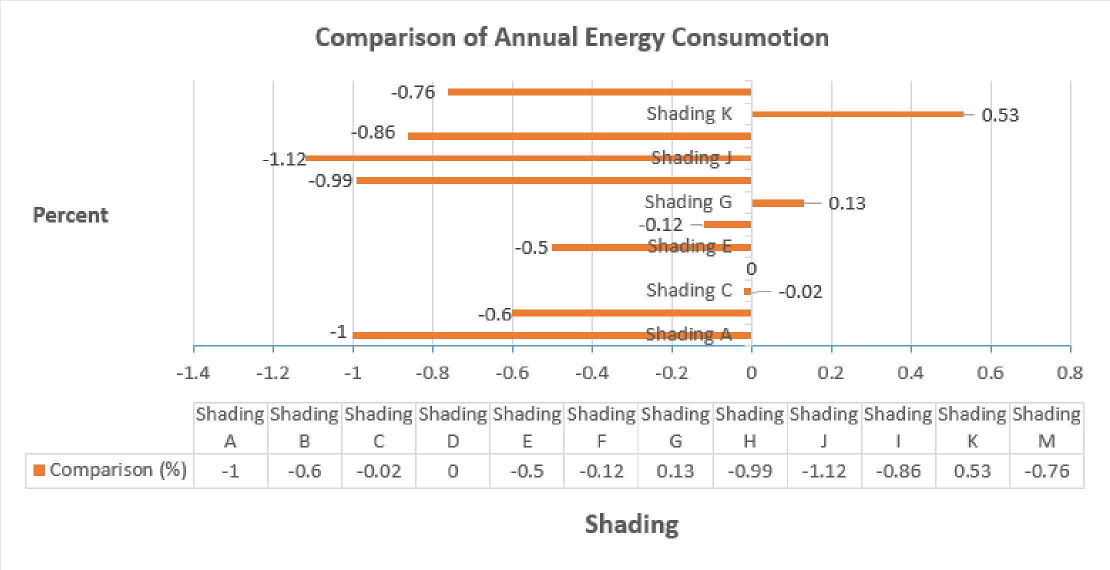

Fig 7. Comparison of Annual Energy Consumption with various Shadings

Table 11. The Description of various Windows Frames

Type	Materials	U-Value	Thickness of Layers (mm)	Frame Thickness (cm)
Frame A	Aluminum Thermal Brake	4.19	2 - 5 - 2	4
Frame B	UPVC	3.476	20	4
Frame C	Aluminum Thermal Brake	4.70	2 - 7 - 2	4
Frame D (Ref)	Aluminum Normal	5.881	5	4
Frame E	Wooden	3.633	20	4
Frame F	Painted Wood	3.633	20	4
Frame G	Steel	5.13	2- 5 - 2	4
Frame H	Aluminum Thermal Brake	5.14	2 - 5 - 2	4
Frame I	Aluminum Thermal Brake	4.35	2 - 7 - 2	4

Table 12. Simulation Results Obtained for Different Window Frames

Farame	Annual heating demand			Annual cooling demand			Annual lighting demand			Total Annual Percentile difference (%)
	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	Total heating (kW h)	Percentile difference (%)	Heating/ conditioned area (kW h/m2)	
Frame A	24689/71	-0/07	56/76	7292/86	0/02	16/77	3748/4	0	8/62	-0/04
Frame B	24577/45	-0/53	56/50	7293/14	-0/06	16/77	3748/5	0	8/62	-0/36
Frame C	24684/33	-0/1	56/75	7293/3	-0/02	16/77	3748/4	0	8/62	-0/06
Frame D (Ref)	24709/12	0	56/80	7291/27	0	16/76	3748/4	0	8/62	0
Frame E	24585/89	-0/49	56/52	7291/83	0/01	16/76	3748/6	0	8/62	-0/34
Frame F	24582/63	-0/51	56/51	7293/45	0/02	16/77	3748/5	0	8/62	-0/34
Frame G	24641/7	-0/27	56/65	7286/35	-0/06	16/75	3748/4	0	8/62	-0/2
Frame H	24695/59	-0/05	56/77	7292/38	0/01	16/76	3748/4	0	8/62	-0/03
Frame I	24690/05	-0/07	56/76	7292/83	0/02	16/77	3748/4	0	8/62	-0/04

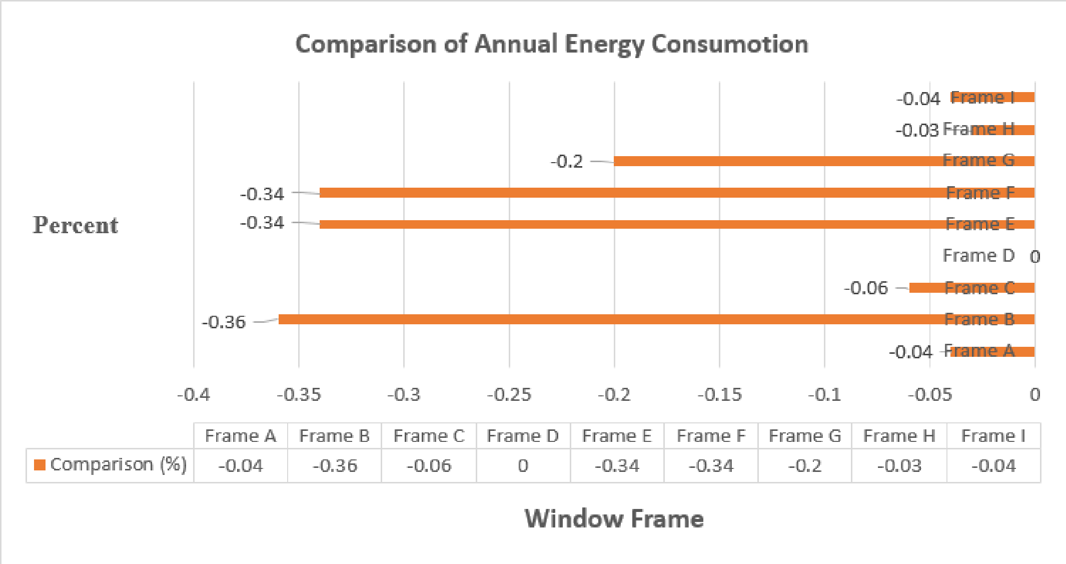

Fig 8. Comparison of Annual Energy Consumption with Various Window Frames

7.5. Side Parameters affecting the Energy Efficiency of the Building through the Building's Envelope

Due to the large envelope of the building, several parameters affect the energy consumption of the building, and in this study can not be paid to all of them, and only the 4 main parameters of the façade of the studied high-rise residential building were discussed. Other influential factors include window dimensions, O.K.B, window height, terrace, façade shape in different directions (north, south, east, and west), etc., which some researchers have studied in their studies. Moreover, other researchers can study the effects of affecting factors on energy consumption through the façade and analyze the calculation of changes in energy consumption according to the methodology of the present study.

8. CONCLUSION

So far, different methods have been studied to evaluate the improvement of building energy consumption in different countries (Ashrafian et al., 2016; Raji et al., 2016; Wang et al., 2015). However, in the present study, the simulation of a high-rise residential building in cold and dry climate of Mashhad city in Iran was evaluated. In the studied building, 4 main and effective parameters in the annual energy consumption of the building through the façade, including the type of glazing, the window-to-wall ratio, the type of window frame, and shading device were analyzed by the DesignBuilder software and EnergyPlus engine.

The results show that this high-rise building needs many changes to its façade to reduce its total annual energy consumption. After a careful evaluation of the façade, the following results were obtained by simulation to optimize the thermal behavior of the building:

- By analyzing the types of glazing, it was found that glazing model F with the total annual energy consumption of 33607.84 kW / h in the climatic conditions of Mashhad, due to severe summer radiations, can reduce the average annual energy consumption to 2140.96 kW / h compared to the original model of the current situation with the total annual energy consumption of 35748.79 kW / h. Table 6 shows calculating the energy consumption of the variables of the glazing type.
- The use of UPVC window frames model B is much more suitable than ordinary aluminum window frames. This frame and the thickness of its components also affect the total annual energy consumption of the building, and with the total annual energy consumption of 35619.12 kW / h can reduce the average annual energy consumption to 129.68 kW / h compared to the original model of the current situation with the total annual energy consumption of 35748.79 kW / h. Also, a Thermal Break aluminum window frame is not much different in energy consumption from the UPVC model and is more efficient. Table 12 shows calculating the energy consumption of the variables of the window frame.
- As it turns out, in cold climates, a lower window-to-wall ratio (WWR), due to the lower use of glazing in the façade (glazing) has a high heat transfer coefficient compared to other façade materials) will result in less energy consumption for the building. However, according to the conditions of architectural design, having a pleasant view and daylight, the appropriate percentage for optimization should be considered. After observing the appropriate window-to-wall ratio, to make appropriate use of sunlight and daylight and also the existence of effective heat in winter, as well as the optimal use of viewing conditions in this high-rise building, the conclusion was that the window-to-wall ratio of 30% can be expressed as an option tailored to the conditions (energy consumption, view, and daylight). With the total annual energy consumption of 36311.97 kW / h compared to the original model of the current situation with the total annual energy consumption of 35748.79 kW / h, it did not reduce energy consumption but increased it. The amount of increase in the total annual

energy consumption was 563.18 kW / h. However, according to previous explanations, this increase is not large, and the conditions of the architectural design of view and the efficiency of daylight should be considered as well. Table 8 shows calculating the energy consumption of the various window-to-wall ratios (WWR).

- Due to the climatic characteristics of Mashhad, to prevent the intense sunlight from entering in hot summers and having an appropriate use of the thermal energy obtained from this radiation during the winter, it was found that shading model J with the total annual energy consumption of 35347.19 kW / h compared to the original model of the current situation with the total annual energy consumption of 35748.79 kW / h can reduce the total annual energy consumption. The amount of decrease in the total annual energy consumption was 401.60 kW / h. Table 10 shows calculating the energy consumption of the various shadings.
- Based on the results, it was found that the selected window frame does not have much effect on the annual energy consumption of a residential building. But this does not mean that it is appropriate to use any type of window frame and by using the obtained Energy-Efficient pattern, UPVC and Thermal Break aluminum can save energy and provide environmental comfort.
- By having an energy-efficient model (Table 13) to improve the thermal behavior of the building and using the most appropriate option of each parameter, a simulation was performed and analyzed, and it was found that this model with the total annual energy consumption of 34873.08 kW / h, with the energy consumption for heating of 23313.32 kW / h, the energy consumption for cooling of 7807.26 kW / h and the energy consumption for the lighting of 3752.5 kW / h, can reduce the total annual energy consumption compared to the original model. The amount of decrease in the total annual energy consumption was 875.71 kW / h. Table 14 shows the technical specifications of each of the related variables. Figure 9 shows the monthly energy consumption of the energy-efficient model.
- Due to the climatic conditions of Mashhad, the buildings are usually east-west and have the highest façade surface on the north and south sides. In the studied building, the two main façades were considered. One of the limitations of this study was to consider 4 parameters of the façade of the building to clarify their impact on the total annual energy consumption, and other effective factors and variables were considered constant to show the role of the main parameters of the façade and to determine the most suitable model for optimizing these 4 parameters.

Fig. 10 shows the monthly energy consumption and the simulation results with the best options for building optimization (window-to-wall ratio of 30%, UPVC window frame, glazing model F, and shading model J).
This model can cause a total reduction of 2.45% in annual energy consumption compared to the initial model. These changes did not compromise the required lighting for the interior spaces while reducing the energy consumption of the building. If these changes are made in today's buildings, which generally do not comply with the climatic design conditions on the envelope, and only the aesthetics of the facade is important to the builders, we will imagine a greater difference in reducing energy consumption.

Table 13. The Description of Energy-efficient Façade Parameters

Parameter	Description
Glazing	[Dbl]: Clr 6 mm/13 mm Arg/ LOW-E 6 mm
WWR	30 %
Shading device	Overhang- projection Shading 15 cm
Windows Frame	UPVC

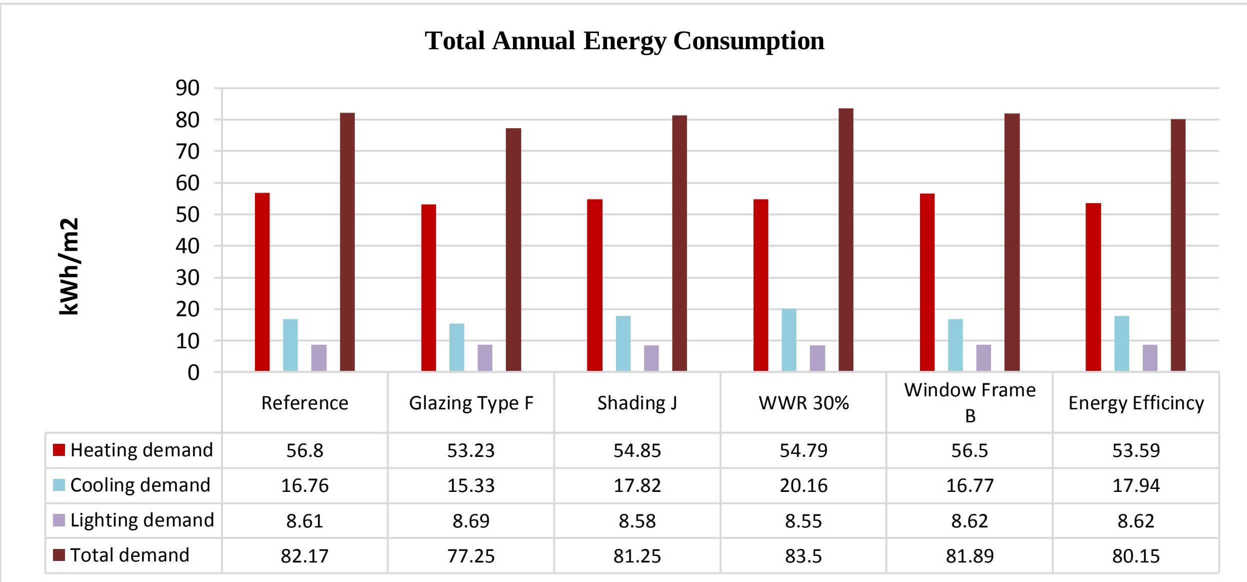

Fig 9. Total Annual Energy Consumption Energy-Efficiency Pattern

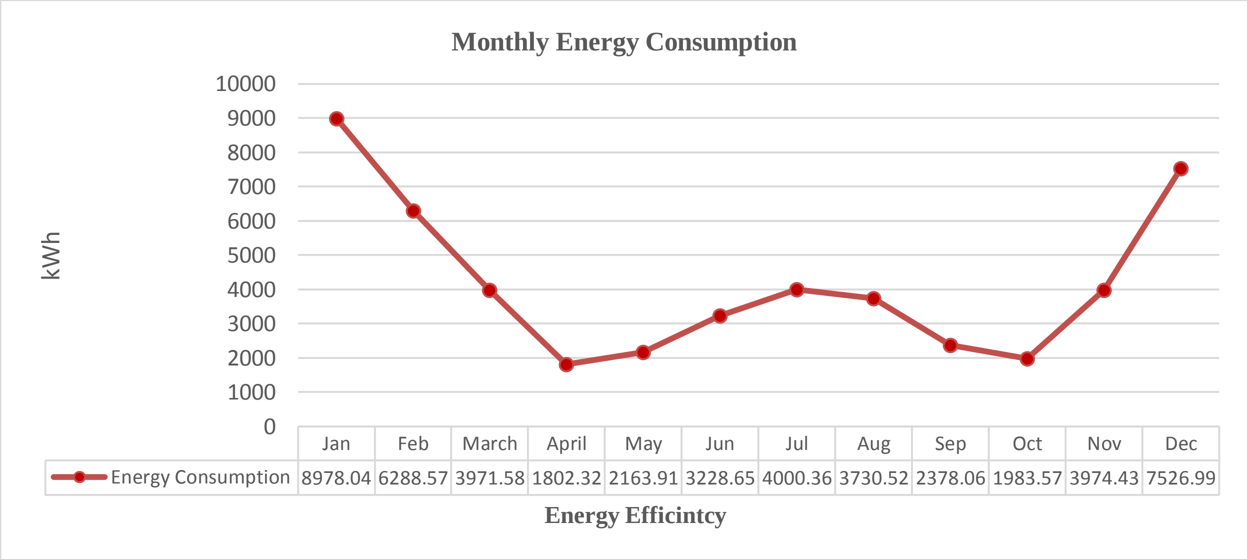

Fig 10. Monthly Energy Consumption Energy Efficiency Pattern

In the present study, by emphasizing the importance of observing climatic conditions for better energy efficiency of high-rise buildings and emphasizing the need to address the façade of the building as the main element of heat exchange between indoor and outdoor environment, the generalization of the results to other similar climatic regions can be advised:

- The present study was conducted in cold and dry climates, which can be generalized to similar climatic regions, and as a strategic model in improving thermal behavior and improving the energy efficiency of buildings (especially in Central Asian countries).
- The proposed methodology (first the climatic analysis of the traditional indigenous houses of an area, and then modeling for contemporary houses) can be used as a model for similar studies.
- It is important to pay attention to the energy consumption of high-rise residential buildings, especially in developing Asian countries with the support of abundant fossil fuels (oil). The countries also need further study to improve energy consumption patterns.
- The use of architectural design strategies to reduce building energy consumption (Except for the techniques of using materials and insulation).
- The identification of the parameters affecting energy consumption through the façade of a building and the determination of the impact of each of the parameters by energy consumption calculations.
- As shown in other studies, in climates with cold winters and hot summers, the lower WWR will lead to the lower energy consumption of the building. However, it is necessary to consider other architectural conditions and their impact on the behavioral and psychological characteristics of residents that are dependent on environmental conditions such as view and the rate at which the interior spaces benefit from the depth of sunlight penetration and intensity of light penetration.
- Using the WWR of 30%, relying on the experiences of traditional indigenous homes in cold and dry climates (cold winters and hot summers) (Mirshojaeian Hosseini et al., 2020) and using the appropriate strategy to use shadings to control sunlight and create conditions for a comfortable indoor environment, can create an appropriate view and help improve the energy efficiency of the building.

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