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Impact of Southern Window-to-Floor Area Ratios on the Thermal Performance of the Settlement in the Hot and Dry Climate (Case Study: Kashan City)

MohamadAli Karbasfuroosha[1], Fereshteh Habib[2*], Hossein Zabihi[3]

[1] Ph.D. Candidate, Department of Architecture, Pardis Branch, Islamic Azad University, Tehran, Iran.
[2]Assistant Professor, Department of Architecture, Pardis Branch, Islamic Azad University, Pardis, Iran.*
[3]Associate Professor, Department of Urban Planning, Sciences and Research Branch, Islamic Azad University, Tehran, Iran.

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ABSTRACT: A major party of generated energy is now used for heating and cooling buildings. Hence, it is beneficial to apply solutions that reduce the thermal load of buildings. However, solutions for energy consumption reduction always face barriers. Optimizing window proportions in energy consumption saving is highly influential in this case. The window is one of the main components that receives solar radiation energy but also serves as a thermal bridge transmitting energy from interior to exterior space. This study investigates the climate conditions of Kashan. It determines materials as constant variables to examine the impact of southern window-to-floor area ratios on the thermal performance of settlements in hot and dry climates to achieve higher efficiency of this element using simulation of different models through EnergyPlus software. This study then examines the cooling and heating load created in interior space considering variable elements of ratios, window elongation, and window-to-floor ratio, using single and double-glazed glass and its analysis considering meteorological data of this city using EnergyPLus software. Finally, the most optimum southern window-to-floor ratio was determined. This study aims to achieve efficiency and the highest impact of the southern side's window of a building on the thermal performance of the building by simulating various models through EnergyPlus software. This study has used the descriptive-analytical method, then analyzed the obtained results, and lastly outlined the priority of application among models as follows:1.38 ratio, 1 ratio, and 1.95 ratio. In contrast, the most optimum window ratio is a 15% window-to-floor ratio with 1.38 proportions and eastern and western elongation using double-glazed glass.

Keywords: *Southern Windows; Thermal Performance; Hot and dry climate; Kashan.*

INTRODUCTION

Housing demand has increased due to the growing population rate in metropolitans. The lack of balance between housing supply and demand, especially in megacities, has led to higher housing prices. Therefore, many urban residents have lived in small, inexpensive apartments. Apartment construction is indeed an accelerated version of housing problems, which was a novel solution in the past but now has led to a hidden wave of social and psychological issues (Poormohammadi, 2000). Nowadays, living space in city centers has faced many social, cultural, and particularly environmental problems due to population concentration causing low-quality of life in these spaces (Kokabi, 2007).

On the other hand, the quality of human life environment highly affects humans' body and mental health. According to the definition proposed by WHO, health means the state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity. Inappropriate housing causes depression, behavioral disorders, and nervousness (Tyson et al., 2002). Moreover, satisfaction with the quality of an environment leads to positive impacts on relationships between occupants (Zabihi et al., 2011). Moreover, the window is one of the major parts that receives solar radiation energy but also serves as a thermal bridge transmitting energy from interior to exterior space. Hence, windows are determinant in providing thermal comfort to occupants, so around one-third of

*Corresponding Author Email: ***fereshteh_habib@yahoo.com***

thermal loss in winter occurs through windows (Ebrahimpour & Mohammadkari, 2011).

On the other hand, windows can allow sun radiation energies to enter over the day, increasing interior space temperature. This specification of windows has linked the name of windows in different countries with its fundamental function, light, radiation, or wind control (Parsa, 2011). Lack of attention to the shape and proportions of the window towards geographical directions using similar windows and improper window-to-backward space area ratio led to many climate and environmental problems. These problems have diminished the efficiency of windows as the area connects inside and outside environments, so occupants have to use internal curtains to overcome a lack of privacy and undesired sunlight. Therefore, the window has become weak in transferring heat and unwanted noises from outside, preventing light and fresh air entrance (Tahbaz, 2018). One of the factors influencing energy transfer through windows is the direction the window faces. This impact differs in various areas and climates. For instance, a window towards sunlight can gain more radiation energy, or the energy transfer through a window exposed to wind differs from other windows. Overall, the best direction for placing windows in terms of energy is the direction through which maximum energy is received, minimum energy is lost in cold weather, and lowest energy is received in hot weather. This direction directly depends on the considered geographical location. For example, the best direction for solar energy gain in the cold season and not excessive energy gain in the hot season in Poland is in the southern direction to 10° towards the southeast (Chwieduk & Bogdanska, 2004). Since this topic and other subjects associated with building energy issues are relatively new, especially in Iran, the available studies do not have a long history, but some studies have been recently conducted in this field.

Dr. Lashgari et al. optimized the orientation of construction buildings based on the climate conditions of Ahwaz City, for instance. They concluded that the maximum energy is gained in the southeast sides of the building. The solar energy received on the surfaces is symmetrical in eastern and western directions over the year, while the western direction gains a minor amount of energy in cold seasons (Lashgari et al., 2011). According to a study that investigated optimum orientation for housing in a hot and dry climate, the best direction among four examined states in terms of maximum solar energy absorption was the direction in which the main axis of the building was 30° rotating around the north axis, so windows were towards the south (Faizi et al., 2011). This study aims to find the optimum south-facing window-to-floor area ratio to increase the thermal performance of settlements in hot and dry climates considering the climate conditions of Kashan with the same materials.

Literature Review

Many Persian and English papers, theses, books, and standards have been carried out on windows and their impact on light and heat. These studies are classified into several categories, including optimum window ratio in terms of solar radiation absorption and heat loss, accurate design of windows to achieve suitable daylight, and examining rate and way of impact of window's physical variables on the use of daylight. Among studies on the optimum size of windows regarding light and heat, Fayaz conducted a study to measure the optimum southern window ratio of residential buildings in Tehran and Ardabil to receive maximum solar radiation. This ratio equaled 10% of the floor area for a room with double-glazed windows and equaled 20% for single-glazed windows (Fayaz, 2012). Among available theses, Heirani Pour optimized the window dimensions considering light and heat factors in residential buildings located in cold climates (Heirani Pour, 2021), and Montaser Kouhsari examined the optimum dimensions of windows in terms of heat and light in residential buildings located in a moderate and humid climate in four main directions for sitting room. Window dimensions had a maximum 10% impact on energy consumption depending on the type of glass, heat rate and visible light transmitting through window glass, area of considered space, and window location (Montaser Kouhsari, 2014). In the second category of conducted studies on the accurate design of windows regarding illumination to achieve suitable daylight in apartments located in Tehran, 2.48% of the total interior areas of the room and 30% of skylight walls were highlighted for the southern side (Ahadi et al., 2016). Moreover, some foreign studies are available, and one of them has suggested the importance of daylight in space and ways to optimize it. The results of these studies indicated window-to-wall ratios of 50% and 25% and window-to-floor ratios of 17% and 35% (Sharifah Fairuz, 2013). Another study addressed the association between window-to-floor ratio (WFR) of space in providing suitable light, and results showed an optimum light amount for the room when WFR is less than 10% (Acosta et al., 2016). The available standards on windows considered in Topic 19 of National Building Regulations 2015 suggest the external light-transmitting wall surface for receiving daylight 1.9 of useful infrastructure and up to 25% of the external wall (Topic 19 of National Building Regulations, 2021). Topic 4 of National Building Regulations 2017 expresses that the required glass rate is at least one-eighth of floor area in residential spaces unless windows are placed only on one of the walls of the space, and the distance between that wall and the front wall is considered space is more than 4.50m; in this case, one-seventh of floor area is required (Topic 19 of National Building Regulations, 2021). Finally, in the category of studies that examined the impact rate and method of window physical variables on suitable daylight use, a study conducted in 2016 examined the geometry and location of windows in residential spaces expressing that energy consumption does not depend on the window shape by window's position is an effective factor (Acosta et al., 2016). Moreover, a Ph.D. thesis modeled the impact of window's physical variables on suitable daylight use in classrooms of secondary schools in Tehran in 2021 to provide optimum window patterns from students' viewpoint (Pournaseri, 2012). The mentioned studies have considered the connection between window and space, so some studies have been conducted on WFR and WWR. Also, window orientation has been examined on the southern side, and four orientations in some cases. The point that has caught the eyes of many researchers is the thought of optimization in energy consumption and reduction in artificial heating and illumination need. Such studies have a long history in developed countries. Dr. Jay Lee et al. studied window performance optimization in five cities in Asia's Continent: Manila, Taipei, Shanghai, Seoul, and Sapporo, with five different latitudes. The results showed that windows placed on the northern side of buildings in Manila and Taipei provided a maximum advantage for energy saving. The northern side was followed by southern, western, and eastern sides that provided less advantages. In the case of Shanghai, Seoul, and Sapporo, however, the southern side had the highest influence, followed by the northern, western, and eastern sides in the next ranks (Lee et al., 2013). Various factors affect the suitable orientation for window placement. A good view is one of the determinants that may indicate a stronger impact rather than the mentioned variables. Nevertheless, various conditions must be considered regarding windows' energy issues. In this case, a study conducted in the climate of Algeria indicated that building orientation does not significantly affect the interior temperature of the building if the building is fully thermal insulated (Hamdani et al., 2012).

MATERIAL AND METHODS

As mentioned, this study examines the impact of southern window-to-floor area proportions on the thermal performance of settlements in hot and dry climates. The research method of this study is descriptive-analytical. For this purpose, southern window-to-floor area proportions were examined in moderate climate conditions based on library studies, modeling, and computer simulation in the hot and dry climate of Iran-Kashan City. According to the physical nature of this study, seven plans with the same areas were modeled in two modes of single- and double-glazed glass, assuming a room insulated with similar materials through EnergyPlus software. Finally, heating and cooling loads created in room space were evaluated and compared with other models.

The Applied Meteorological Data

Meteorological data of Kashan was used in EPW format to simulate the thermal performance of the prepared model under a condition similar to the climate of Kashan City. In EPW format, meteorological data are inserted hour-to-hour. This file is one of the available meteorological files in Iran confirmed by producers of EnergyPlus software and uploaded to the online database of the Repository of free climate data for building

5.6 * 5.6	1
4.75 * 6.57	2
7.8 * 4	3
10.4 * 3	4
4.75 * 6.57	5
7.8 * 4	6
10.4 * 3	7

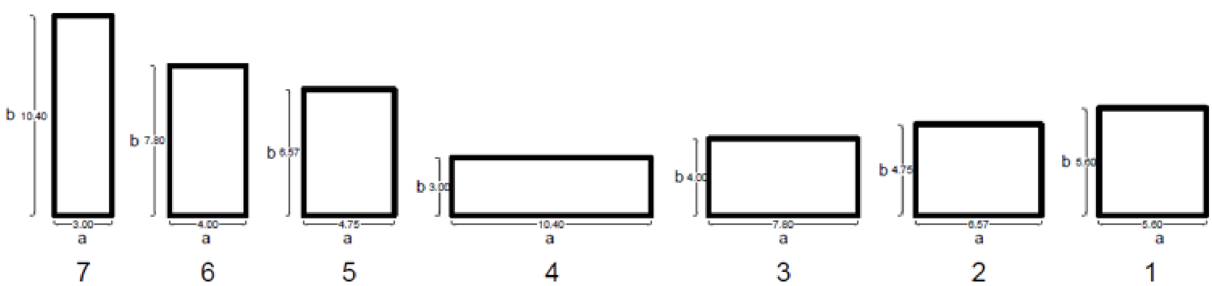


Fig. 1: Forms of studied plans

performance simulation sites.

Thermal Comfort Range of Residents Living in Kashan City

According to studies carried out on citizens living in Kashan and the temperature range of their thermal comfort, the thermal well-being range of Kashan in summer is 21.8°c-27°c, while this range equals 20.4°c-23°c in winter, and the relative humidity range equals 18%-53% (Sadeghi Ravesh & Tabatabaie, 2009).

Studied Models

The most common passive solar system is called direct gain. A direct gain system is designed by measuring window area and thermal mass required for heating interior space. Five plans with identical areas have been designed in this phase, assuming that heating and cooling loads have been assessed. Generally, the glass area in direct gain must equal 0.07 of the ceiling area, not exceeding 12%. In direct gain, double-glazed glasses are also recommended. WFR in winter spaces of Iran's hot and dry climate is around 50%. The results of ratios 30%, 20%, 15%, 12%, and 7% are presented herein. The first model is square, while other models are rectangular-shaped with east-west and north-south elongation. The ratio considered in model 2 is observed in most vernacular buildings of Kashan located in the summer part, which is chosen due to the past winter use of these spaces. The models (2&5), (3&6), and (4&7) have similar dimensions with different elongations (Figure 1).

Materials used in the model simulation

Tables 1 and 2 report the specifications of materials used in opaque and translucent walls for all models (Figure 1).

Simulating the thermal performance of proposed models

Table 1: Specifications of opaque walls for models 1 to 7

Wall type	Materials (from the outer layer to the inside)	Roughness	Thickness (m)	Heat conductivity coefficient (w / m-k)	Density (kg / m³)	Eigen heat (J / kg-k)
Wall	Ashlar	Rough	0.03	3.5	2800	840
	Cement mortar	Rough	0.02	0.55	1200	840
	Clay block - 1	Rough	0.1	0.79	2000	630
	Thermal insulation	Rough	0.05	0.040	40	1500
	Clay block - 2	Rough	0.1	0.79	2000	630
	Plastered	Rough	0.03	0.56	1500	109
Roof	(Mosaic (stone	Rough	0.03	3.5	2800	840
	Thermal insulation	Rough	0.08	0.038	80	840
	Clay block	Rough	0.25	0.79	2000	630
	Plastered	Rough	0.03	0.56	1500	109
Floor	Parquet	Rough	0.025	0.14	530	1880
	Concrete	Rough	0.2	1.6	2300	850

Table 2: Specifications of double glazing for models 1 to 7

Wall type	Layers (from outer layer to inner layer)	Thickness (m)
Double glazed window	Clear glass with low energy emission coating	0.006
	Xenon gas	0.006
	Clear glass	0.006

Simulation results have been reported in Tables 3 and 4. The order of diagrams is as follows:

-Table 3 reports the results of plans with insulated materials (Table 1) and single-glazed glasses structure (Table 2)

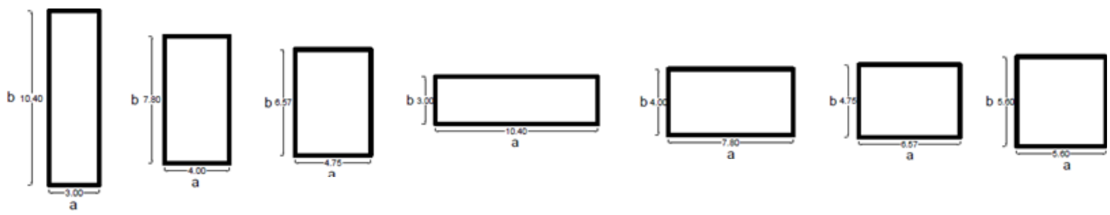
-Table 4 reports the results of plans with insulated materials (Table 1) and double-glazed glasses structure (Table 2).

RESULTS AND DISCUSSION

The following results are obtained from Tables 3, 4, and Figures 2-6:

Models 2 and 5, 3, 4, and 7 have similar dimensions with different elongations. Model 2 has east-west elongation, and model 5 includes north-south elongation. In all states of WFR,

Table 3: Room with insulated materials and single-glazed glass

7	6	5	4	3	2	1	number	
							module	
10.4 * 3	7.8 * 4	4.75 * 6.57	3 * 10.4	4 * 7.8	4.75 * 6.57	5.6 * 5.6	a × b	
0.29	0.51	0.72	3.47	1.95	1.38	1	Plan-to-door ratio	
-	-	38.92	42.66	38.56	37.94	38.6	50%	Win-dow-to-floor ratio
-	-	885.25	920.43	878.83	870.35	873.46		
69.54	59.07	54.81	64.79	56/5	54.77	55.39	30%	
740.25	669.29	643	674.62	636.23	628.75	632.09		
99.18	81.71	76.07	88.37	76.85	74.23	74.8	20%	
604.97	533.85	508.3	538.18	501.03	493.91	497.33		
121.18	100.69	94.02	108.15	94.15	90.87	91.4	15%	
537.33	467.12	441.97	469.23	432.61	425.63	429.06		
137.05	115.28	108.42	123.57	123.97	120.15	120.66	12%	
497.28	427.7	401.35	429.85	463.02	456.11	459.92		
170.25	146.73	138.94	156.25	139.62	135.52	135.93	7%	
429.97	359.36	333.97	359.81	324.24	317.47	320.88		

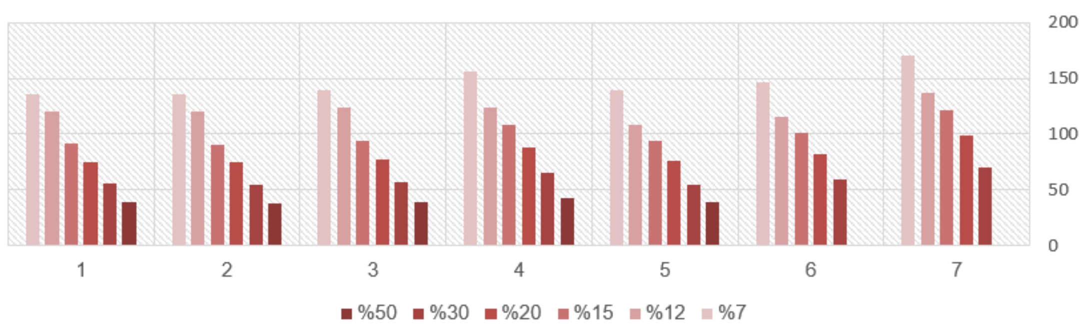


Fig. 2: Comparison between single-glazed glass in heating

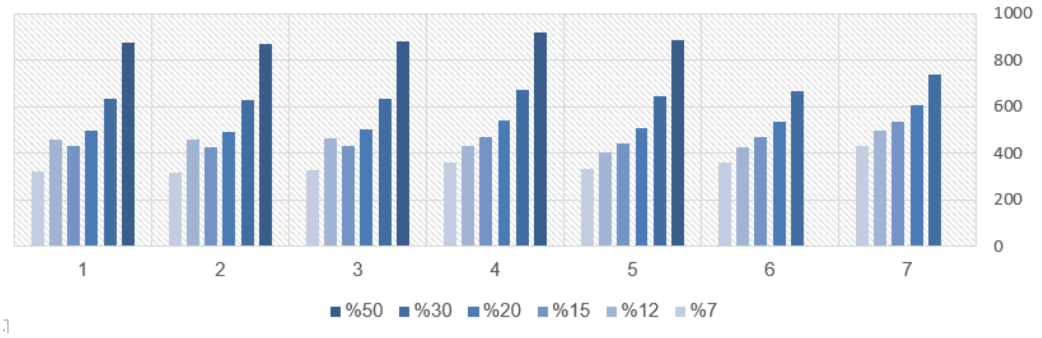
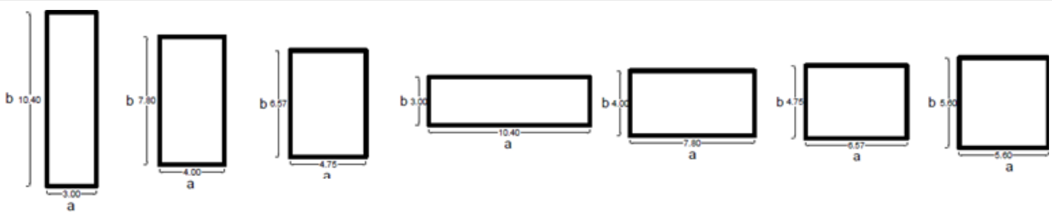


Fig. 3: Comparison between single-glazed glass in cooling

Table 4: Room with insulated materials and double-glazed glass

7	6	5	4	3	2	1	number	
							module	
10.4 * 3	7.8 * 4	6.57 * 4.75	10.4 * 3	7.8 * 4	6.57 * 4.75	5.6 * 5.6	a × b	
0.29	0.51	0.72	3.47	1.95	1.38	1	Plan-to-door ratio	
-	-	0	0	0	0	0	50%	Win-dow-to-floor ratio
-	-	662.88	690.83	653.64	646.68	650.07		
17.49	8.36	6.2	12.29	6/6	5.45	5.57	30%	
592.27	521.26	495.18	522.69	486.3	479.5	483		
59.14	42.38	37.23	49.48	37.56	34.8	35.09	20%	
502.82	432.42	407.07	434.58	398.57	391.8	395.27		
90.38	70.24	63.8	79.39	64.68	61.06	61.38	15%	
459.39	389.9	365	391.23	355.56	348.81	352.25		
112.28	90.47	84.23	100.27	100.46	96.32	96.65	12%	
434.1	365.23	339.72	366.83	401.66	394.93	398.75		
156.64	133.07	125.3	143.39	126.31	122.01	123.35	7%	
395.87	325.65	300.36	323.19	288.08	281.47	284.93		

east-west elongation is better in terms of both heating and cooling loads. The thermal performance of models 1 and 2 are highly similar, but model 2 (1.38 length-to-width ratio) is more suitable when Colling loads are considered. The minimum heating and maximum cooling requirements are observed in WFR of 50% in buildings with single- and double-glazed glass. This cooling requirement in model 2 is less than other models, so they are useful for the design of those rooms with a single winter application. The maximum heating and minimum cooling requirements are observed in a WFR of 7%. This heating requirement in model 2 is less than in other films. This ratio is useful for the design of rooms that are only used in summer. When WFR is downsized, the heating load increases (because the southern window gets smaller), and the cooling

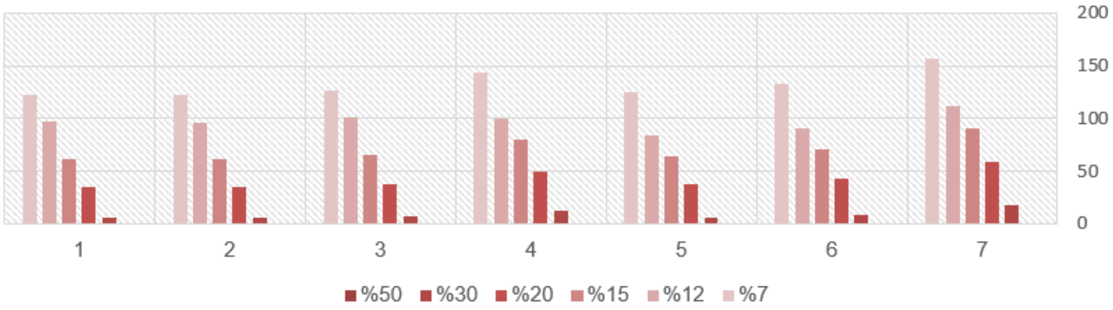


Fig. 4: Comparision between double-glazed glass in heating

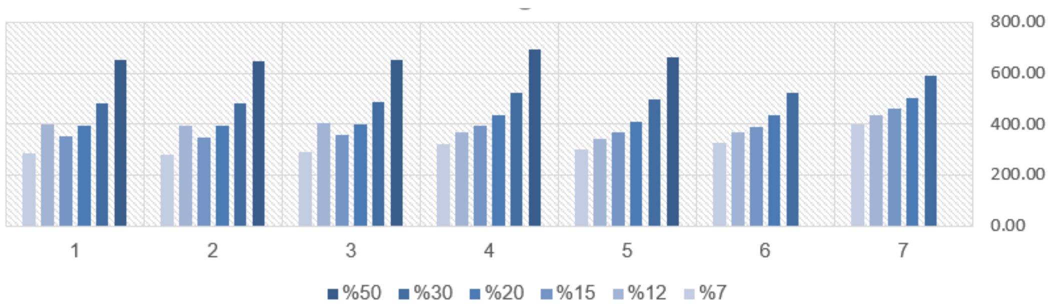


Fig. 5: Comparision between double-glazed glass in coolin'

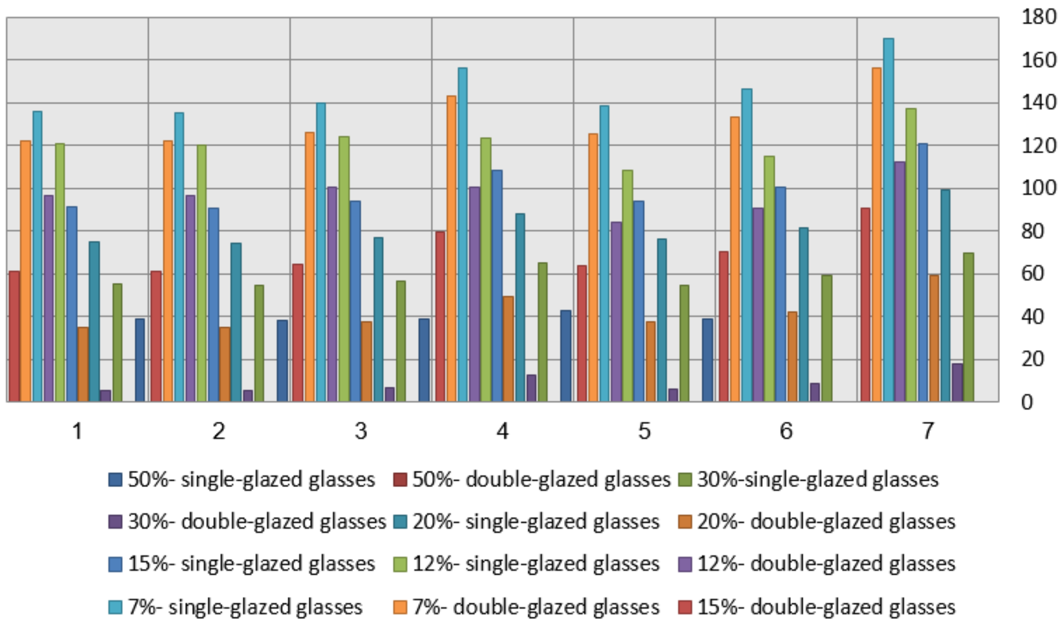


Fig. 6: Comparision between single-glazed glass and double-glazed glass in heating

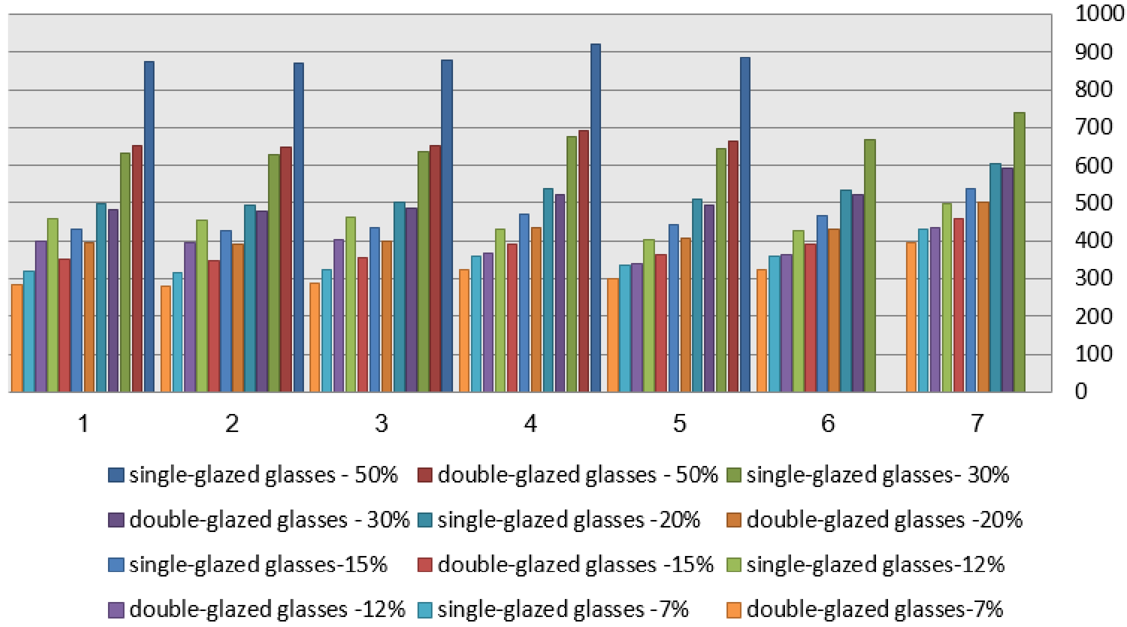


Fig. 7: Comparision between single-glazed glass and double-glazed glass in cooling

load decreases (a lower opening surface leads to less heat transfer to interior space). Although ratios 50% and 70% have the minimum need for heating and cooling loads, a WFR of 15% indicates the best performance in terms of annual climate moderation and providing occupants with thermal well-being. In comparison between Tables 4 and 5, model 2 is optimal in which the room with insulated materials and single and double-glazed glasses have been used so that the heating load in single-glazed glass with a 50% ratio has been decreased from 37.94 kWh to cooling load 29.81 kWh while cooling load with 7% ratio has increased from 36 kWh to 76.82 kWh (Table 3) (Table 4), (Figure 7).

According to the results of heating and cooling loads computations, the priority of using models is as follows: models 2, 1, and 3. According to different WFRs, 50% had the lowest need for heating load, the 7% ratio had the lowest need for cooling load, and the ratio of 15% was chosen as the optimum ratio over the year. Since the studied model is small. Heating-cooling loads do not show significant variations in different models of each table, while load difference is more seen in larger dimensions and elongations. Opaque and light-transmitting materials have a considerable impact on loads. Heating and cooling loads are reduced in the table of changing materials of walls and using double-glazed glasses. Hence, materials with low heat-transfer coefficients in opaque and light-transmitting walls have decreased the need for heating and cooling loads resulting in energy savings. Therefore, double-glazed glass decreases the need for cooling and heating load, and the most optimum window proportion is WFR of 15% with 1.38 proportion with eastern and western elongation and use of double-glazed glass (Table 5).

CONCLUSIONS

Examining the climate conditions of Kashan and determining materials as a constant variable, this study investigated the impact of southern window-to-floor area ratio on the thermal performance of settlements located in hot and dry climates to achieve high efficiency of this element simulating different models in EnergyPlus software. In the next phase, this study took proportions, window elongation, WFR, and using single-double-glazed glass as varying elements. It analyzed them considering meteorological data of this city through EnergyPlus software to assess cooling and heating loads created in interior space. Materials of walls, ceiling, and roof were considered constant variables, window glasses were considered single- and double-glazed forms, then different proportions were simulated, and finally, the most optimum southern window-to-floor ratio was determined. However, studies and simulations

Table 5: Results table

insulated materials and double-glazed glass	insulated materials and single-glazed glass	
East-west	East-west	Plan Extension
15	15	The optimal percentage of the window to the floor
2,1,3	2,1,3	Module

of this research have not been conducted on a certain basis and are limited to hot and dry climates, square and rectangular-shaped shapes with vertical and horizontal elongation, and used materials presented in tables. Therefore, a comparison between western-eastern and northern-southern elongations indicated that eastern-western elongation is better for heating and cooling loads in all WFR modes. The minimum need for heating and cooling is seen in buildings with single- and double-glazed glass with a southern window-to-floor ratio of 50%.

Moreover, model 2 needed less cooling compared to other models for designing rooms with a single winter application, while this model required maximum heating to design rooms with single summer use regarding the southern window-to-floor ratio of 7%. When WFR is decreased, the high heating load (due to downsized southern window) and low cooling load (lower opening surface) lead to lower heat transfer to interior space. Although 50% and 7% ratios of gas are the minimum need for heating and cooling loads, WFR of 15% outperformed in terms of annual climate moderation and providing thermal comfort for occupants. Finally, models 2, 1, and 3 were preferred to be used, and the most optimum window proportion was WFR of 15% with 1.38 proportion with eastern-western elongation and use of double-glazed glass. Further studies are recommended to examine new materials of translucent walls and window behavior in reducing the internal temperature in addition to other effective factors, such as ventilation and transiting light intensity.

AUTHOR CONTRIBUTIONS

M. Karbasfuroosha performed the literature review and model design, analyzed and interpreted the data, and prepared the manuscript text and edition. F. Habib and H. Zabihi prepared the manuscript text and manuscript edition. Compiled the data and manuscript preparation.

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CONFLICT OF INTERESt

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication and, or submission, and redundancy, have been completely witnessed by the authors.

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