Case Report

BIOMEDICAL
Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2024.55.008716

Examination of the Optimal Depth of Sunspaces in the South Facade of Residential Buildings with the Aim of Greater Efficiency

MohammadAli Karbasforoushha*

Islamic Azad University, Department of Architecture, Iran

***Corresponding author:** MohammadAli Karbasforoushha, Islamic Azad University, Department of Architecture, Tehran-west Branch, Tehran, Iran

ARTICLE INFO

Received: March 07, 2024

Published: March 13, 2024

Citation: MohammadAli Karbasforoushha. Examination of the Optimal Depth of Sunspaces in the South Facade of Residential Buildings with the Aim of Greater Efficiency. Biomed J Sci & Tech Res 55(3)-2024. BJSTR. MS.ID.008716.

ABSTRACT

One way to reach a building with higher energy efficiency is to use solar renewable energy, used to enhance the thermal performance of the building. In general, two ranges can be defined according to the depth for the solar spaces studied in this research, first, the depth of more than one meter, which can add living space to the building, and second, the depth of less than one meter, which is similar to the Trombe wall. They do not work and do not add a livable space to the building This study investigates the depth of the solar space in the heat load of the annexed settlement to this space with the aim of reaching the optimal depth of this element in order to reduce the heating load during the cold days of the year, and the minimum imposition of the excess cooling load in the summer by Design Builder and Energy Plus software with the method Descriptive-analytical analysis and then analyzed the results. Finally, according to the results of the calculations related to the heating loads in optimal winter conditions, the studied models of priority use are sunspace with an angle of 60 degrees, sunspace with an angle of 45 degrees, sunspace with an angle of 30 degrees, rectangular cube sunspace.

Keywords: Sunspace; Heating Load; Semi-Hot and Dry Climate; Kashan

Introduction

Energy is one of the elements for the development of countries. Energy sources in the world can be divided into three main groups, fossil fuels (oil, gas, coal, and so on), nuclear energy, and renewable energy (solar, wind, geothermal, biomass). Nowadays, with the increase in energy consumption, using renewable energy, especially solar energy, has become particularly important. The building sector is responsible for more than 40% of the total final energy consumption and more than 30% of the greenhouse gas emissions in developed countries, more than the industry and transportation sectors (Yang, et al. [1]). From this share of energy use, the residential sector makes up more than 60% (Balaras, et al. 2007). Improving the energy performance of buildings is one of the particular ways in new construction and existing buildings. There is a growing need to implement energy conservation measures in existing buildings due to their low replacement rate which is only 0.07% annually (Poel, Van Cruchten, & Balaras, 2007). Therefore, most of these buildings will still be functional until 2025 or even 2050 (Ürge Vorsatz, Danny Harvey, Mirasgedis, & Levine, 2007). To minimize energy inefficiency and waste in residential buildings, different performance strategies have been constantly promoted. The challenge is the fact that the surging innovations in the building sector should be examined to ensure that the targeted energy efficiency is acquired.

This needs attention to a combination of influencing parameters related to climate and configuration of the building envelope. In this term, the sun is the best energy source for natural, and artificial activity and different human technologies. The current environmental crisis, like global warming, climate pollution, and so on, is due to the overuse of fossil fuels. Thus, the best solution is to use natural energy such as the sun. The term solar thermal energy includes all cases of using solar heat, which is possible using various technologies. Solar energy is of the key renewable energy sources. This type of energy could be used in the building as active and passive ways. One of the most popular inactive solar systems is “sunspace.” Recent studies

DOI: 10.26717/BJSTR.2024.55.008716

show that if sunspace is added to the southern wall of the building, one can reduce its heating load (J. Schoenau, et al. [2]). Among the renewable energy resources, Iran has a great potential to use solar systems such as sunspaces. However, only a few studies have been carried out in Iran. Sadeghi et al. examined the various geometry and the shapes of solar shapes in the Tehran climate to find an optimal shape for the sunspace (Saghafi [3]). Safgafi & Yazarlou examined the effects of using the sunspace on heating load and only in Yaz hot area (Monge Barrio [4]).

Balilan examined the effect of using sunspace on the energy consumption in a building in London to emphasize the efficiency of these spaces in buildings (Balilan, et al. [5]). Gerick et al. examined the heating efficiency of four sunspaces with various shapes and dimensions in Portugal to present an optimal sample (Sadeghi, et al. [6]). Another study has been carried out to prove the efficiency of sunspaces that has led to the use of proper air conditioning in sunspace climate (Kalogirou [7]). A need is felt for an overall and holistic view and comparison of the effects of the stated systems on heating and cooling loads and in various climate types of the country. Thus, the study is an effort to examine and analyze the changes in heating and cooling loads affected by using sunspace in summer and winter, considering the various climate types. Attached sunspaces or conservatories are often referred to as sunrooms and function similar to Trombe walls. The only difference between the two systems is the availability of more space between the wall and the glass in the latter case, which could create a comfortable living space while affording energy efficiency advantages (Kesik [8]) (Figure 1).

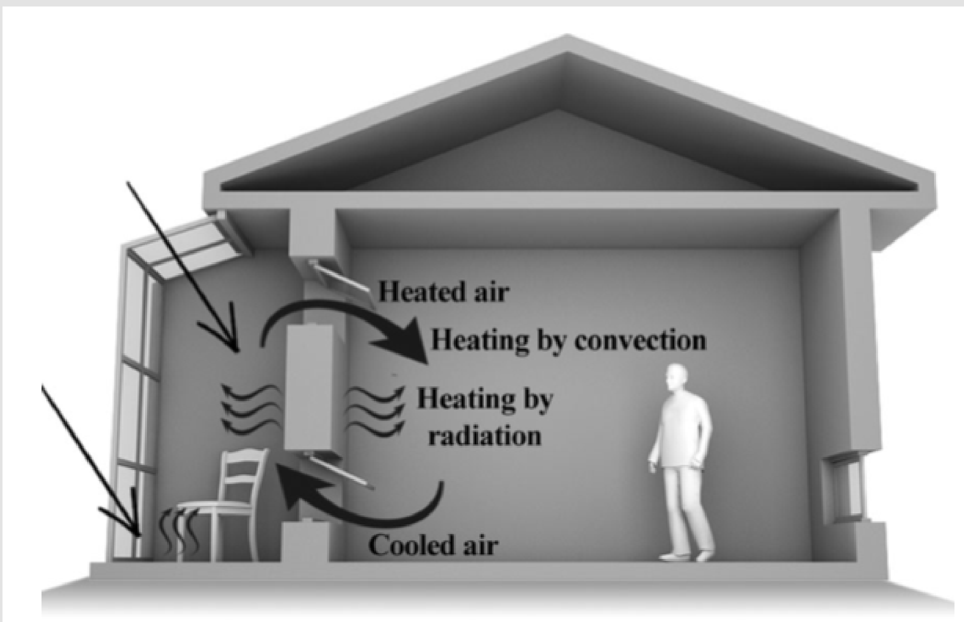


Figure 1: Sunspace with indirect heating mechanisms.

Most of the studies on sunspaces try to find solutions to maximizing the benefits of heating load in winter and avoiding overheating in the summertime. Aside from overheating in summer, one drawback of passive heating is that it can only happen through the south façade, although this issue can be addressed by facilitating heating energy distribution across the space (Konstantinou [9]). Schoenau, Lumbis, and Besant examined the thermal performance of four sunspaces in Saskatoon, Canada. In order to validate an analytical model, performance was monitored hourly while a simulation was conducted to account for the annual energy performance estimations Aelenei (Schoenau, et al. [10]). De Azevedo Leal, and Aelenei used a numerical approach to investigate the thermal performance of a sunspace in a residential building in Portugal. Orientation, sunspace configuration, natural ventilation of the sunspace and position and radiative properties of the shading devices were considered as design variables and their influence on thermal behaviour and the possible amount of energy saving were analyzed (Leal [11]). Bataineh and Fayez investigated the thermal performance of an attached sunspace to a building in Amman, Jordan.

Furthermore, they evaluated the impact of the orientation of the sunspace, opaque wall and floor absorption coefficients and the number of glass layers on thermal performance. Based on their results, sunspace can decrease heating load considerably in winter. However, it causes serious overheating in summer (Bataineh [12]). Bakos and Tsagas explored the thermal and economic aspects of

DOI: 10.26717/BJSTR.2024.55.008716

an attached sunspace in Greece. Thermal load was calculated by the degree-day method and, for economic performance, the LCC method was used (Bakos [13]). Oliveti, Arcuri, De Simone, and Bruno calculated the solar gains of the sunspace and the adjacent spaces in different regions of Italy based on several geometric configurations including a system of windows made up of clear double-glazing. They considered and analyzed the impact of factors such as different levels of exposure, optical properties and thermal aptitude of the opaque areas, the ventilation capacity and the shading mechanism (Oliveti, et al. [14]). Sánchez Ostiz, et al. [15] investigated thermal performance and design of two passive solar systems including attached sunspace with horizontal heat storage and an attached sunspace with vertical thermal storage. These two sunspaces were tested under the real conditions in two residential buildings in Spain. (Sánchez Ostiz, et al. [15]).

Monge Barrio and Sánchez Ostiz studied the behaviour of sunspaces as passive elements in summer for different climatic regions in Spain. The results show that sunspaces can be configured to perform efficiently in summer, even in extremely hot conditions (Monge Barrio [16]). Zhu, Liu, Yang, and Hu evaluated the thermal performance of new Yaodong dwellings by adding an attached sunspace to the old building located in the Zaoyuan village in Yanan City, China. By using EnergyPlus software, they conducted numerical simulations of heating and cooling energy consumption. Fernández-González assessed the thermal performance of five passive solar testcells including Direct Gain, Trombe wall, Water wall, Sunspace, and Roof pond by considering a control test-cell in Muncie, Indiana in order to identify the limitations of these passive solar heating systems (Fernández González [17]). Rempel, Rempel, Gates, and Shaw modelled a series of field-validated sunspaces in Pacific Northwest to quantify their thermal mass design issues and to investigate the impact of factors such as the sizing and ground configuration of floor-based thermal mass (Rempel, et al. [18]).

Lucas, Hoese, and Pontoriero analyzed and compared the thermal performance of three passive systems including Trombe wall, direct gain and sunspace, in a region with a continental Mediterranean climate. The results show that all mentioned passive systems gained solar radiation throughout all the seasons of the year. Among them, the Trombe wall joined to a sunspace provided the best results, with small energy gain in summer and high energy contribution in winter (Lucas, et al. [19]). Mottard and Fissore proposed a new thermal simulation model for an attached sunspace by paying attention to the internal long-wave radiation exchanges and solar radiation distribution within the sunspace. For validation, the calculated results were compared to the empirical data. Furthermore, a sensitivity analysis was used to determine the parameters of the model with the strongest impacts on energy performance (Mottard [20]). Babaee, Fayaz, and Sarshar proposed a design modification for sunspaces to enhance the thermal performance of dwellings in Tabriz, Iran which has a cold climate. Six sunspace configurations with different ratios of glazed to opaque surfaces were modelled and simulated to identify an optimum dimension of the sunspace. The orientation, the number of glazed surfaces, the direction and inclination angle of the surfaces, the glazing material, and the common wall material of the sunspace as design criteria were also assessed (Babaee, et al. [21]).

In this research, we seek to Examination of the Optimal Depth of Sunspace in the Residential Building climate of Iran (Kashan city), which, despite the reduction of the heating load in the cold days of the year, does not impose an excess cooling load on the building in the summer. In this regard, Common and diverse types of sunspaces with different depths and native and new materials were investigated. For this purpose, the residential houses of Kashan city were selected and the studies were done on the south facade of these settlements.

Research Method

As already stated, this study aims to examine the shape of sunspace in the heating load of hot and dry climates to reach the optimal shape to increase the efficiency of this element. Thus, considering the physical nature of this study, in the first step, using the average annual climatic data of Kashan and considering the materials listed in “Table 1 & 2”, and then using modeling and analysis in Energy Design Builder and Energy Plus, the average internal temperature of the dwelling adjacent to the sunspace, the heat absorption through solar energy (Solar Gains Interior Windows) and heat output via the glazing are determined and compared to these models and determine the model with optimal performance.

 DOI: 10.26717/BJSTR.2024.55.008716

Table 1: Specifications of opaque walls for models 1 to 4.

Wall Type	Materials (from the Outer Layer to the Inside)	Roughness	Thickness (m)	Heat Conductivity Coefficient. (w / m-k)	Density (kg / m^3)	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 4.

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

Examining Heating Load Reduction Solutions Using Sunspace

Recently, using solar greenhouses has become a popular solution to enhance the heating performance of buildings in winter. Solar greenhouses are a passive solar system usually consisting of a south-facing exterior room made mainly of transparent walls greenhouse. The greenhouse is a retaining space between the building and the external environment that allows a large amount of solar radiation to enter (Asdrubali, et al. [22]). Although using a greenhouse is very common in temperate climates, it has not found its status in hot and dry climates. Due to its hot and dry climate, the central regions of Iran have always been looking for solutions to deal with summer heat and have paid less attention to heating loads in winter. The solution for traditional Iranian houses is to use materials with a delay time [23,24]. However, due to the design movement of low-consumption and green buildings, this method does not have much place and effect in reducing heat exchange and energy consumption. Thus, it is necessary to comprehensively study the composition of indigenous buildings and other systems of passive solar design. Residential buildings in this climate have two sections, winter and summer quarters, whose inhabitants are settled due to seasonal changes. This section follows the combination of sunspace with the winter section of a native house. The hot and dry climate of Iran (Kashan), despite the reduction of heating load on cold days of the year, does not impose excess cooling load on the building in summer. Thus, the new Boroujerdi house, among the residential houses in Kashan, was selected, and studies were conducted based on its winter front.

Examining the Effect of Greenhouse Shape

This section has considered four models of sunspace designed and assumed with the same volumes, the depth of the greenhouse is 1.73, and its height is 3.00 meters, to study the heating, and cooling loads in the residential space joined to them at the height of 3.00, length of 5.27 and the width of 6.00 meters. The cases examined are: Sunspace, rectangular cube, Sunspace, a rectangular cube with an angle of 30 degrees, Sunspace, a rectangular cube with an angle of 45 degrees, Sunspace, a rectangular cube with an angle of 60 degrees (Figure 2).

 DOI: 10.26717/BJSTR.2024.55.008716

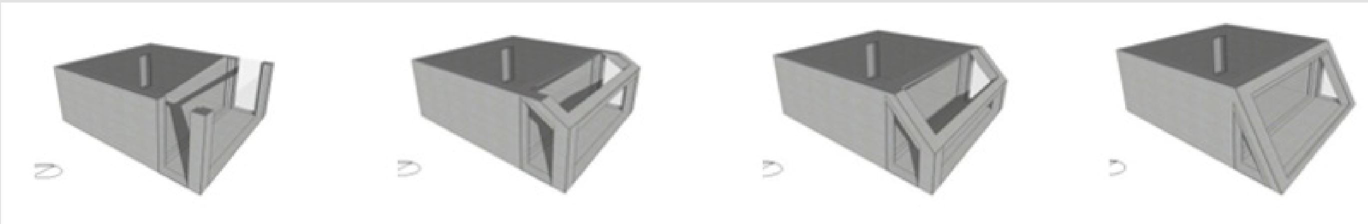


Figure 2: Various shapes of the greenhouses examined, model 1 to model 4, from left to right, respectively.

Climate Chart of Kashan

Kashan is in a climatic zone with relatively cold winters and hot and dry summers. It is one of the factors affecting the climatic components of air temperature. The following table is based on data obtained from the Meteorological Department in the 19-year period of Kashan (1999-2017). Concerning Kashan, it shows average monthly temperature, average minimum monthly temperature, average maximum monthly temperature, the number of sunshine hours, humidity and rainfall in Kashan synoptic station. The feeling of comfort is exposed to the radiant heat of the sun or any other source by examining these data in January, February, March, December, and November. It is relatively comfortable in about two months of the year, equal to April and October, and the five months of May, June, July, August, and September are in a state where it is not possible for people to feel comfortable without airflow and coldness due to evaporation (Figures 3 & 4).

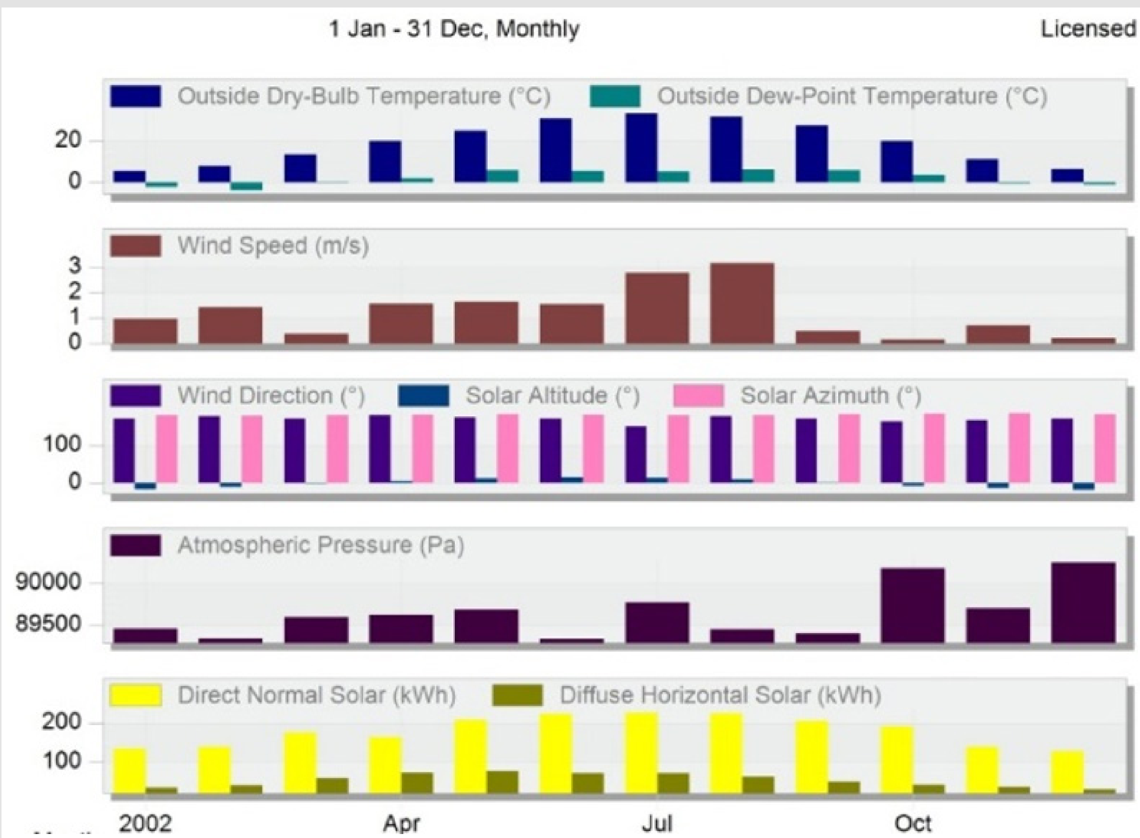


Figure 3: Chart and table of the monthly average of climatic data of Kashan (Source: Energy Design Builder).

 DOI: 10.26717/BJSTR.2024.55.008716

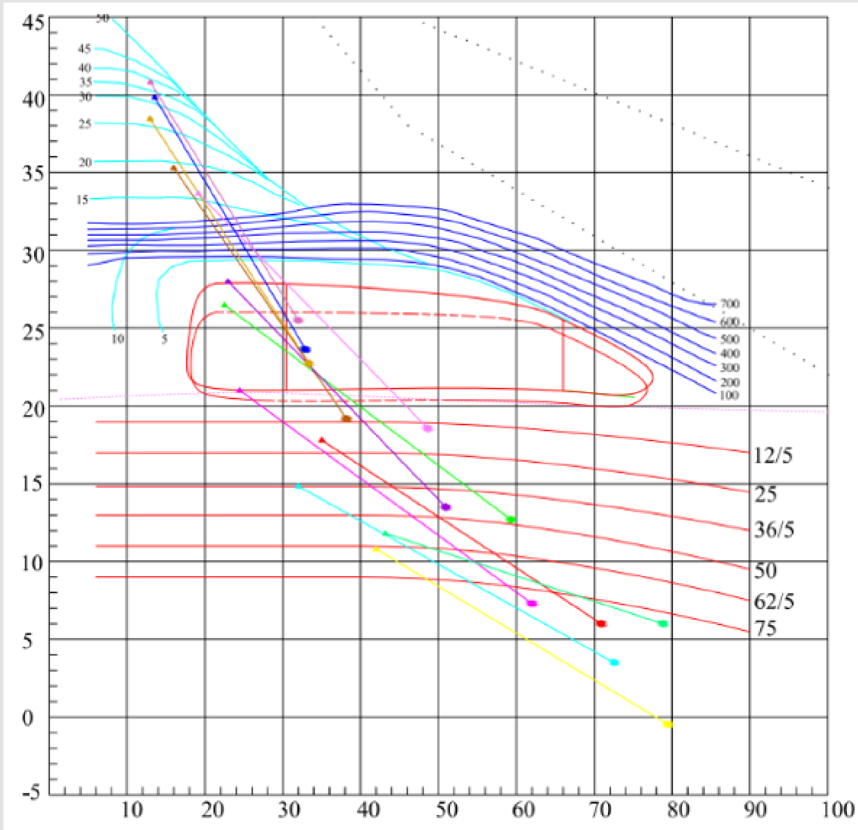


Figure 4: Olgyay table of human comfort range based on the monthly average of climate data.

Materials Used in the Model Simulation

The materials used for all models "Figure 2" are the specifications of the base state and the structures in Tables 1 & 2.

Simulation of Thermal Performance of Sunspace Models

In this section, four sunspaces "Figure 1" are designed and assumed that using software (Energy Builder Design and Energy Plus), the average internal temperature of the dwelling adjacent to the sunspace, the heat absorption through solar energy (Solar Gains Interior Windows) and heat dissipation was examined through the transparent wall (glazing). In all cases, the same climatic conditions based on climatic data of Kashan "Figure 2", "Figure 3", the dimensions of the settlement joining the sunspace in all models with a length of 5.27 m and a width of 6.00 m and a height of 3.00 m are considered. The wall, ceiling, floor, and glass materials specifications are considered based on the specifications listed in "Tables 1 & 2". Since our goal has been to reach a range of optimal heating and cooling load in the sunspace we intend to check the types of suitable depth of the sunspace assuming the materials listed in Tables 1 & 2, i.e. the use of building and insulating materials and double-glazed glass, so We divided the different depths of this space, and since the sunspace with a depth of fewer than 20 centimeters and a depth of more than 2 meters is not meaningful, therefore, the depth range of 0.2 meters, 0.5 meters, 1 meter, and more than 1 meter is also considered as the depth between Two intervals were selected. The direction of the said sunspaces facing south and the common wall of the room and the sunspace have been considered for direct heat transfer and exchange in a transparent manner (no thermal barrier).

The height of the sunspace is 3.00 meters, and in two cases, assuming the presence of a shade, 0.8 meters and without a shade, we have investigated the heating and cooling loads in this space. In all models, the common wall between the sunspace and the building material room, the volume of the room under investigation is 103.61 m3. The structure of other windows is according to Table 1. All the glasses are double-glazed according to Table 2 and the only common glass between the room and the sunspace is simple single-glazed. In the above table, in case 1, the model has an optimal canopy, summer ventilation, and heat transfer with the ground through the floor. In the case of case 2, only the summer performance of the model (without canopy, summer ventilation, and heat exchange) is assumed.

 DOI: 10.26717/BJSTR.2024.55.008716

Discussing the Influence of the Depth of the Sunspace

By examining Tables 3-6, the following results are obtained. According to the results of the calculations related to the heating loads in the optimal winter conditions, the studied models, the priority of use are sunspace with an angle of 60 degrees, sunspace with an angle of 45 degrees, sunspace with a 30-degree angle, rectangular cube sunspace. In the rectangular cube sunspace, we examine two modes; First, the sunspace has an optimal canopy, summer ventilation, winter night insulation, and heat exchange with the soil in contact with it. In this model, by reducing the width of the sunspace to 1 meter, the heating requirement of the room increases slightly. While the cooling load has been significantly reduced. In widths of less than 1 meter, the heating load is reduced, which in the best winter mode (2-4 V) has improved by about 21% compared to the base mode of its model (V0). The model has a variable behavior by reducing the width of the sunspace, and heating and cooling loads. In this optimal state (2-4 V), the heating and cooling load requirements have been reduced by 89.1% and 34.5%, respectively, compared to the existing state. In the second case, the sunspace without a canopy is summer ventilation and heat exchange with the soil.

Table 3: Sunspace, rectangular cube (energy plus).

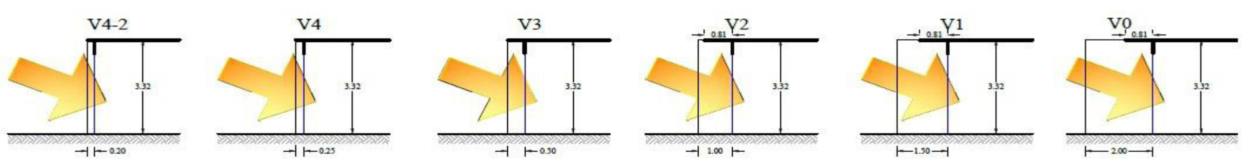
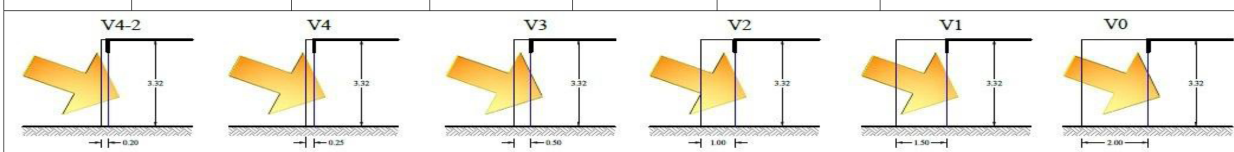
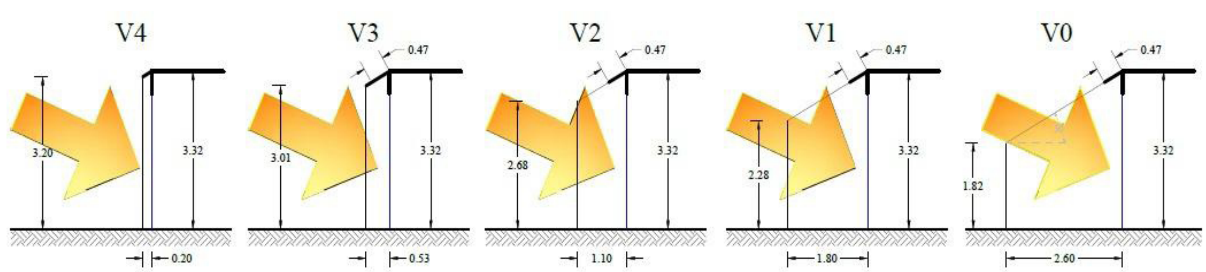
V4-2	V4	V3	V2	V1	V0	Model	
0/2	0/25	0/5	1	1/5	2	Width of sunspace (meters)	
31/83	33/72	34/53	43/07	41/55	40/35	Required heating load (Kwh)	
381/99	315/21	325/33	362/28	441/15	503/86	Cooling load	
							1
14/88	17/47	17/68	20/15	21/75	32/13	Required heating load (Kwh)	
899/49	901/28	1032/27	1195/08	1354/14	1400	Cooling load	
							2

Table 4: Sunspace, a rectangular cube with 30 degrees of angel (energy plus).

V4	V3	V2	V1	V0	Model
0/2	0/50	1	1/8	2/6	Width of sunspace (meters)
30/36	45/85	36/07	34/24	30/67	Required heating load (Kwh)
319/34	307/94	364/64	403/14	439/21	Cooling load



 DOI: 10.26717/BJSTR.2024.55.008716

Table 5: Sunspace, a rectangular cube with 45 degrees of angel (energy plus).

V4	V3	V2	V1	V0	Model
0/2	0/5	1	1/8	3/0	Width of sunspace (meters)
30/82	41/43	43/58	29/5	20/44	Required heating load (Kwh)
318/72	314/33	336/94	386/84	424/66	Cooling load

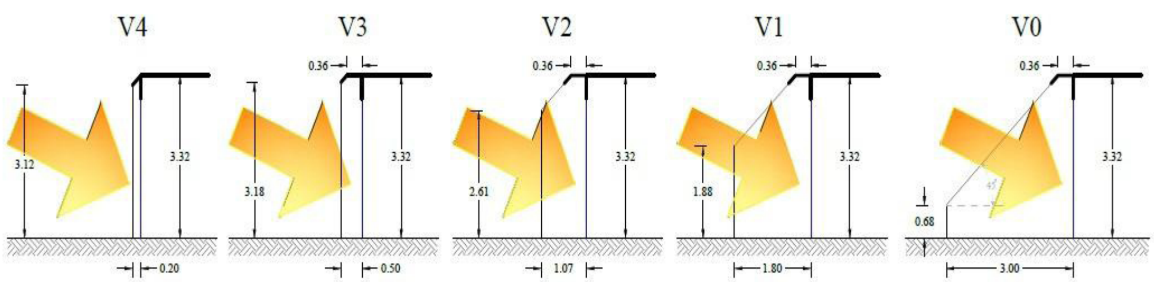
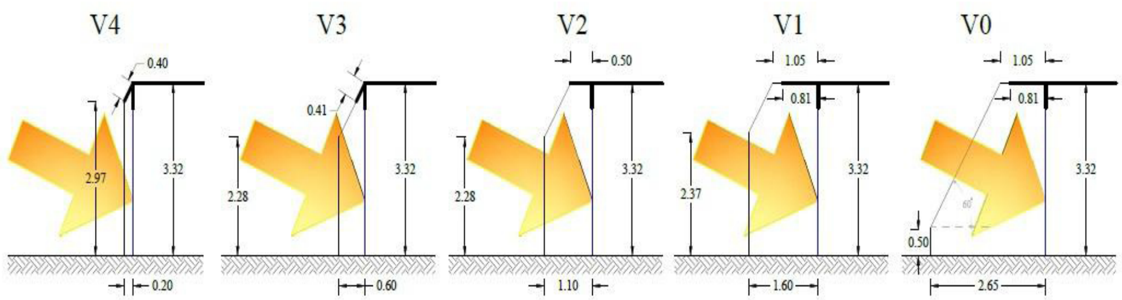


Table 6: Sunspace, a rectangular cube with 60 degrees of angel (energy plus).

V4	V3	V2	V1	V0	Model
0/2	0/5	1	1/6	2/6	Width of sunspace (meters)
32/67	10/57	6/53	14/94	0	Required heating load (Kwh)
314/03	387/33	419/98	420/92	554/06	Cooling load



In this model, the heating load of all cases is lower than in model 1, and there is a direct relationship between the width and the heating requirement of the space. also decreases, but they impose a huge cooling load on the building. In fact, for the second case where there is no canopy, it can be said: «The smaller width of the sunspace causes its better heating performance (Table 3). In the sunspace of 30 degrees, V0 mode with the largest width has almost the same heating requirement as V4 mode with It has the smallest width, but its cooling load is about 120kwh more than V4. The optimality of this model (V4) has about 89.7% reduction in heating load and 45.3% cooling load compared to the existing state (Table 4). V0 state is the optimal state of the rectangular cube sunspace with an angle of 45 degrees, which requires. The heating and cooling loads have be reduced by 93% and 27.2%, respectively. The V4 mode of this model, with a width of 0.2 meters, is only 10kwh more than the optimal mode, but it has a lower cooling load of around 106kwh (Table 5) The 60-degree model has the most optimal mode among these seven models. In this case, the heating requirement is zero and the cooling load is reduced by about 5% compared to the current state. As the width of the sunspace decreases, the heating loads increase irregularly, but the cooling loads decrease continuously. In this model. With less than half of the width of the optimal state, the V1 mode has a favorable heating and cooling load. and its cooling requirement has irregular changes and decreases for widths below 1 meter.

Its optimal mode has an improvement of 99.5% and 22% for heating and cooling loads, which considering the cooling load, this mode is more efficient than the optimal mode of 60 degrees (Table 6). In general, two ranges can be defined according to the width for the sunspaces studied in this research: first, widths of more than 1 meter that can add living space to the building, and second, widths of less than 1 meter. which act similar to Trombe›s wall and do not add livable space to the building. For the studied models, the following numerical relationship can be defined between the volume of the existing room and the appropriate volume of its sunspace: (if the volume of the room in contact with the sunspace is VR and the volume of the sunspace is VG)

1. The volume of the sunspace for the rectangular cube model is the same for each room; VG = 0.04 VR
2. The volume of sunspace for 60 and 45-degree models per room is equal to; VG = 0.42 VR
3. The volume of sunspace for 30 models per room is equal to: VG = 0.05 VR

Conclusion

The purpose of sunspaces in hot and dry climates is to reduce the heating load during the cold days of the year and to minimize the excess cooling load in the summer. A depth of more than 1 meter can add living space to the building and secondly, a depth of less than 1 meter that acts like a Trombe wall and does not add a living space to the building. In each of the studied models, if the sunspace is used, due to the importance of the cooling load in the city of Kashan on the hottest summer day, the model that has a lower excess cooling load and creates a suitable heating load in the winter season is determined as the optimal model. According to the results of the calculations related to the heating loads in optimal winter conditions, the studied models of priority use are sunspace with an angle of 60 degrees, sunspace with an angle of 45 degrees, sunspace with an angle of 30 degrees, rectangular cube sunspace. The 60-degree model has the most optimal mode among these seven models. The heating requirement in this mode is zero and the cooling load is reduced by about 5% compared to the existing mode. As the width of the sunspace decreases, the heating loads increase irregularly. but the cooling loads decrease continuously. In this model, the V1 mode having less than half of the width of the optimal mode, has a favorable heating and cooling load, so it can be concluded that the winterized spaces use the optimal V0 model and in the spaces for summer residents, it is optimal to use the V4 model. In addition, considering the small difference between the above two modes, if you move the sunspace and the shade in such a way that the shade is created in the summer and the shade is removed in the winter, it is possible to benefit from the optimal It is the most possible state.

Author Contributions

M. Karbasforoushha performed the literature review and model design, analyzed and interpreted the data, and prepared the manuscript text and edition. prepared the manuscript text and manuscript edition. Compiled the data and manuscript preparation.

Acknowledgement

I want to thank the personnel of the Sciences Library of the Tehran Branch. Department of architecture, Tehran-west Branch, Islamic Azad University, for helping us to gather the data and articles.

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.

References

1. Zhu X, Liu J, Yang L, Hu R (2014) Energy performance of a new Yaodong dwelling, in the Loess Plateau of China. Energy and Buildings 70: 159-166.
2. Schoenau GJ, Lumbis AJ, Besant RW (1990) Thermal performance of four sunspaces in a cold climate. Energy and Buildings 14(4): 273-286.
3. Saghafi MJ, yazarlou T (2015) "An investigation of the effect of sunspace on heating load reduction of winter occupated spaces of Yazd's traditional houses". Proceedings of International Conference science and engineering, dubai, uae.
4. Monge Barrio A, Sánchez Ostiz A (2015) Energy efficiency and thermal behaviour of attached sunspaces,in the residential architecture in Spain. Summer Conditions, Energy and Buildings 108: 244-256.
5. Balilanasl I, Sattarzade D, Ghane M (2013) "An investigation of sunspace placement in zero energy building design". Proceedings of 1st national Conference on clean energy, Hamedan, Iran.
6. Sadeghi H, kordjamshidi M, rafatjah A (2014) "An investigation of paper sunspace pattern for a residential building in tehran". Proceedings of the 1st International Conference and exhibition on solar energy, Tehran, Iran, p. 19-20.
7. Kalogirou SA (2014) Solar Energy Engineering Processes and Systems, Second Edition, Waltham: Academic, pp. 349-357.
8. Kesik T, Simpson M (2002) Thermal performance of attached sunspaces for Canadian houses. The eSim: Canadian Conference on Building Energy Simulation, Montreal, Canada, September, p. 11-13.
9. Konstantinou T (2014) Façade refurbishment toolbox: Supporting the design of residential energy upgrades (Doctoral Dissertation) Netherlands: Delft University of Technology.
10. Schoenau GJ, Lumbis AJ, Besant RW (1990) Thermal Performance of Four Sunspaces in a Cold Climate, Energy and Buildings 14: 273-286.
11. Aelenei D, De Azevedo Leal H, Aelenei L (2014) The use of attached sunspaces in retrofitting design: The case of residential buildings in Portugal. Energy Procedia 48: 1436-1441.
12. Bataineh KM, Fayez N (2011) Analysis of thermal performance of building attached sunspace. Energy and Buildings 43(8): 1863-1868.
13. Bakos GC, Tsagas NF (2000) Technology, thermal analysis and economic evaluation of a sunspace located in northern Greece. Energy and Buildings 31(3): 261-266.
14. Oliveti G, Arcuri N, De Simone M, Bruno R (2012) Solar heat gains and operative temperature in attached sunspaces. Renewable Energy 39(1): 241-249.

DOI: 10.26717/BJSTR.2024.55.008716

15. Sánchez Ostiz A, Monge Barrio A, Domingo Irigoyen S, González Martínez P (2014) Design and experimental study of an industrialized sunspace with solar heat storage. Energy and Buildings 80: 231-246.
16. Monge Barrio A, Sánchez Ostiz A (2015) Energy efficiency and thermal behaviour of attached sunspaces, in the residential architecture in Spain. Summer conditions. Energy and Buildings108: 244-256.
17. Fernández González A (2007) Analysis of the thermal performance and comfort conditions produced by five different passive solar heating strategies in the United States Midwest. Solar Energy 81(5): 581-593.
18. Rempel AR, Rempel AW, Gates KR, Shaw B (2016) Climate-responsive thermal mass design for Pacific Northwest sunspaces. Renewable Energy 85: 981-993.
19. Lucas IB, Hoese L, Pontoriero D (2000) Experimental study of passive systems thermal performance. Renewable Energy 19(1-2): 39-45.
20. Mottard JM, Fissore A (2007) Thermal simulation of an attached sunspace and its experimental validation. Solar Energy 81(3): 305-315.
21. Babaee F, Fayaz R, Sarshar M (2016) The optimum design of sunspaces in apartment blocks in cold climate. Architectural Science Review 59(3): 239-253.
22. Asdrubali, Francesco (2012) On the Evaluation of Solar Greenhouse Efficiency in Building Simulation during the Heating Period. Energies 5(6): 1864-1880.
23. Rasoulzade F, karimi demneh M (2015) Analysis and feasibility of climate design of a house equipped with solar space in Karaj city with the approach of optimal energy use. National Conference on Sustainable Architecture and Urban Planning with a human and environmental approach.
24. Zolfaghari A, Zarei A, Farsad A (2016) An Investigation on the Effect of Sunspace on Energy Consumption in Climatic Conditions of Tehran and Tabriz, Modares Mechanical Engineering, Proceedings of the Second International Conference on Air-Conditioning, Heating and Cooling Installations 16(13): 245-247.

ISSN: 2574-1241

DOI: 10.26717/BJSTR.2024.55.008716

MohammadAli Karbasforoushha. Biomed J Sci & Tech Res