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Examination of the Optimal Shape of Solar Space in Reducing Winter Heating Load and Minimum Imposition of Summer Cooling Load in Semi-Warm and Dry Climates of Kashan

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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. The study examined the shape of the solar space in the heating load of the housing attached to this space in four rectangular cubes, 30-, 45-, and 60-degree angles for reaching the optimal shape of this element to reduce the heating load of cold days, and minimal imposition of excess cooling load in summer by Design Builder and Energy Plus software using the descriptive-analytical method and then analyzed the results. Ultimately, solar spaces with an angle of 60 degrees using double-glazed glass has been determined as the optimal form in reducing the heating load in winter and the minimum cooling load in summer at the same time.

Keyword: Solar Space; Heating Load; Semi-hot; Dry Climate; Kashan

Introduction

Energy is of the key 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 sun is the best energy source for natural, 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. In Iran, different studies have been carried out in recent years on the use of new energy, especially solar energy, and a large part of this research is related to the conversion of radiant energy into heat. Thus, given the significance of the issue in this paper, efforts are made to examine and analyze the methods of using solar energy as one of the key renewable energies in the building sector.

Literature Review

Solar energy is of the key renewable energy sources. This type of energy could be used in the building in active and passive ways. One of the most popular inactive solar systems is “solar space”. Recent studies show that if solar space is added to the southern wall of the building, one can reduce its heating load [1]. Among the renewable energy resources, Iran has a great potential to use solar systems such as solar spaces. However, only a few studies have been carried out in Iran. Sadeghi et al. [2] examined the various geometry and the shapes of solar shapes in the Tehran climate to find an optimal shape for the solar space [3]. Safgafi & Yazarlou examined the effects of using solar space on heating load and only in Yaz hot [4]. Balilan et al. [5] examined the effect of using solar space on the energy consumption in a building in London to emphasize the efficiency of these spaces in buildings [5]. Gerick et al. examined the heating efficiency of four solar spaces with various shapes and dimensions in Portugal to present an optimal sample [2]. Another study has been carried out to prove the efficiency of solar spaces that has led to the use of proper air conditioning in solar space climate [6]. 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 solar space in summer and winter, considering the various climate types.

Research Method

As already stated, this study aims to examine the shape of solar space 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 solar space, 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.

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	0.04	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 Solar Space

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 [7]. 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. 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 solar space 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 solar space designed and assumed with the same volumes, the depth of the greenhouse is 1.73, and its height is 3.00 meters, to study

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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: Solar space, rectangular cube, Solar space, a rectangular cube with an angle of 30 degrees, Solar space, a rectangular cube with an angle of 45 degrees, Solar space, a rectangular cube with an angle of 60 degrees.

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.

Materials Used in the Model Simulation

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

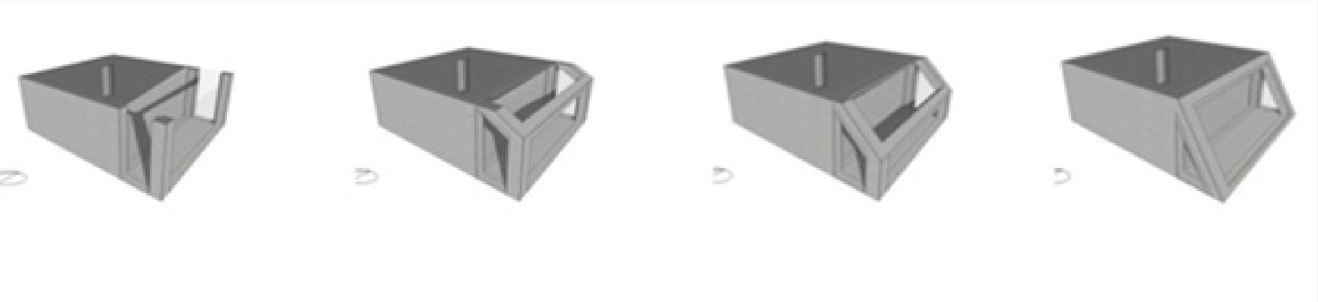

Figure 1: Various shapes of the greenhouses examined, model 1 to model 4, from left to right, respectively.

Simulation of Thermal Performance of Solar Space Models

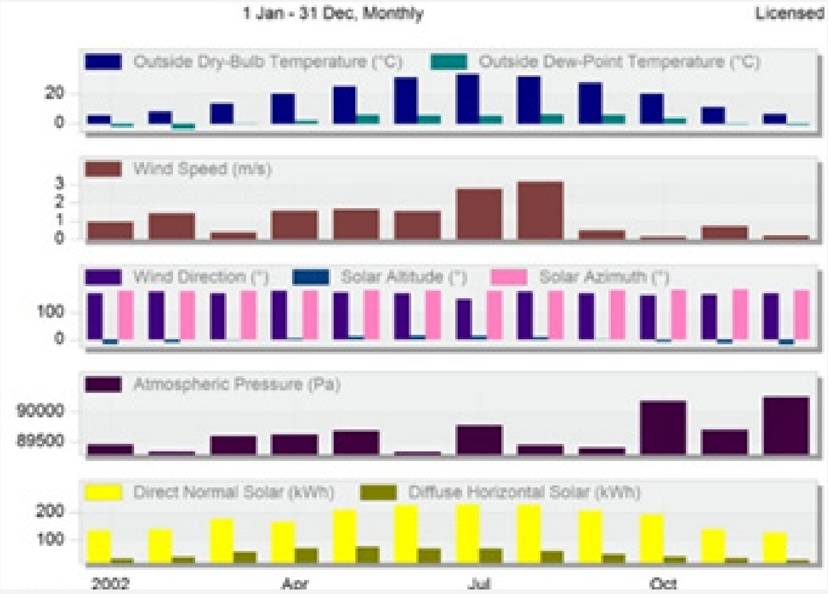

Figure 2: Chart and table of the monthly average of climatic data of Kashan (Source: Energy Design Builder).

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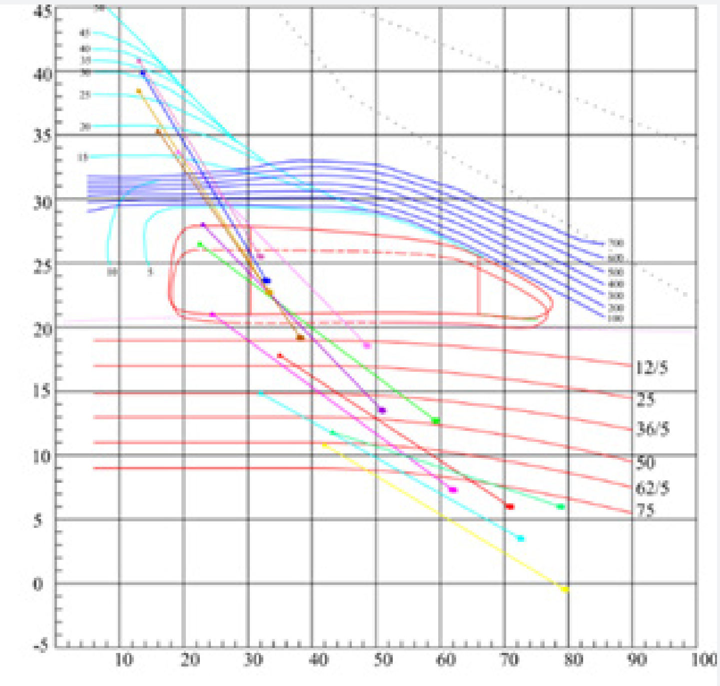

Figure 3: Olgyay table of human comfort range based on the monthly average of climate data.

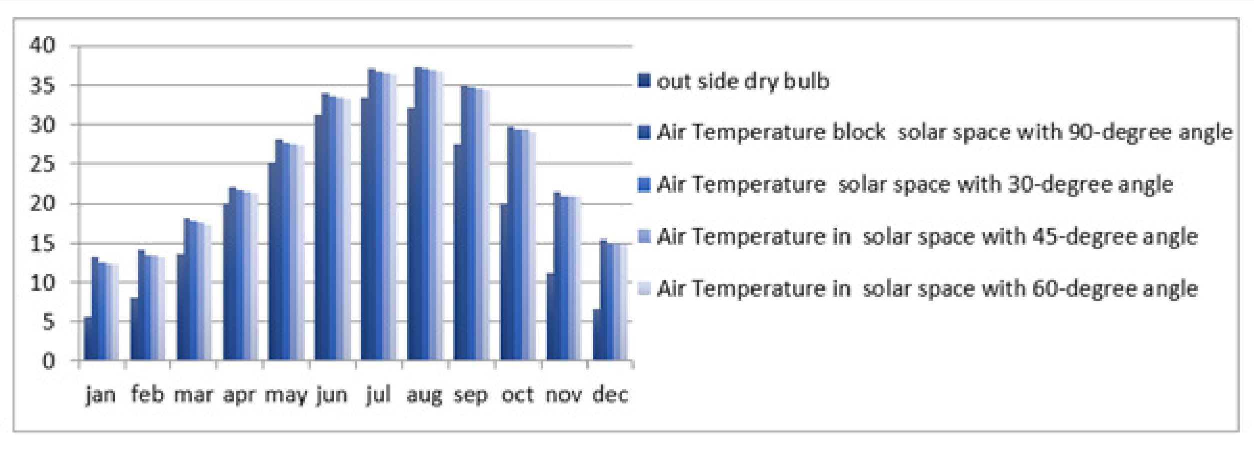

Figure 4: Comparison of inside Air temperature of various models of solar space.

In this section, four solar spaces (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 solar space, 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 2-4), the dimensions of the settlement joining the solar space 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 Table 1,2 (Figure 5-6).

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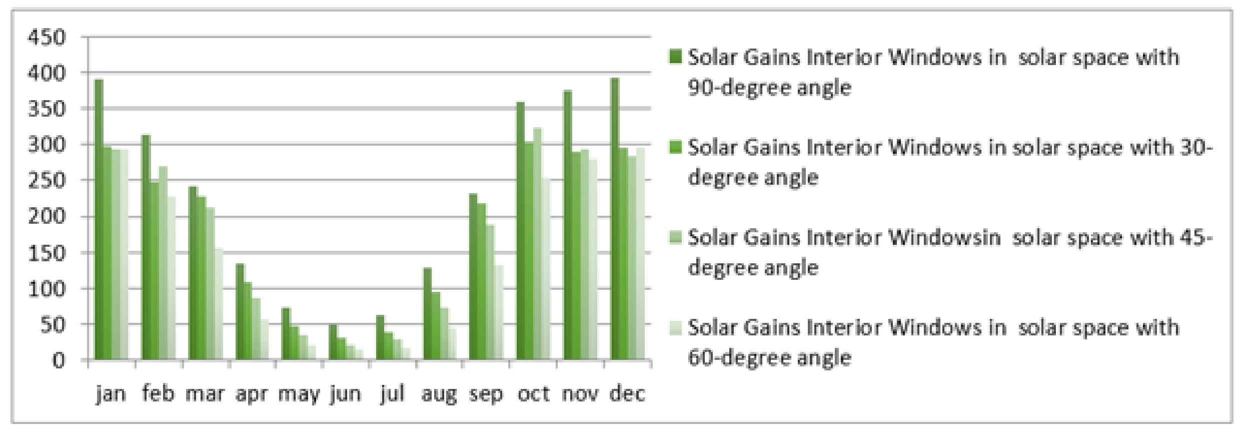

Figure 5: Comparison of heat balance of solar gains interior windows of various models of solar space.

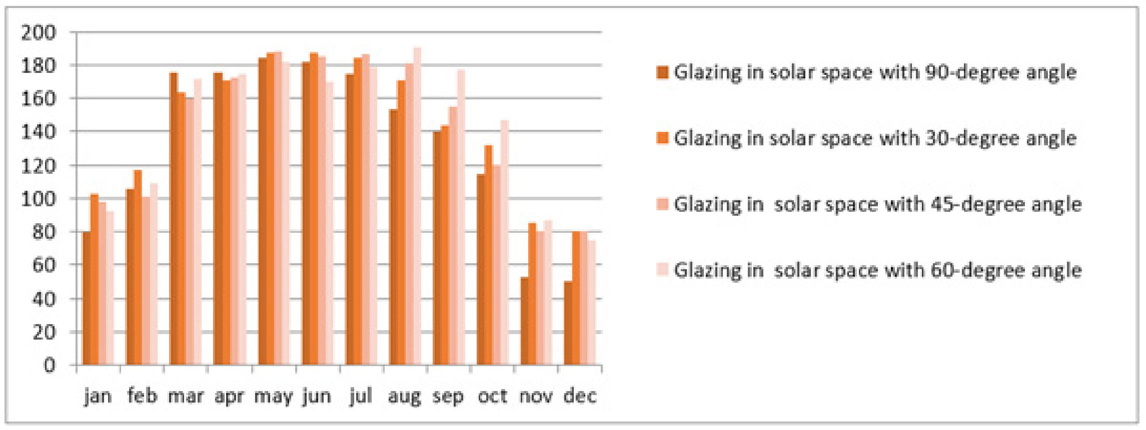

Figure 6: Comparison of heat balance of Glazing, walls, Ground floors, partitions and roofs (Kw/h) of various models of solar space.

Results and discussion

In examining the above tables and graphs, as is seen, using rectangular cube solar space in winter with an increase of 6.01 to 10.28 degrees has a significant contribution in reducing winter heating load. However, the same performance in hot seasons with an increase of 2.1 to 9.72 degrees imposes the highest cooling load in the settlement (Figure 1,7). The heat absorption through solar energy in this model compared to other models in October up to a maximum of 392.16 kwh of solar energy and in June at least 49.7 kwh, which is the highest value compared to other models in all seasons (Figure 2,8). The average heat output through the transparent wall in this model in the cold months of the year from November to February varies from 50.06 to 106.28 kwh, and in the warm months of the year, from April to September, is from 139.633 to 184.49 kwh. In this model, from July to January, the lowest rate compared to other models and in March and April is the highest rate compared to other models (Table 3) (Figure 3,9).

Examining the diagrams associated with the solar space model with an angle of 30 degrees shows that the model increases the indoor air by 5.4 to 9.76 degrees compared to the outside air in winter and increases the temperature by less than the 90° rectangular solar space model with a 90-degree angle of 0.52 to 0.61 degrees. However, the same performance in hot seasons by increasing the temperature from 1.63 to 7.14 degrees indoor air compared to outdoor air causes a cooling load in the settlement, which increases the temperature less than the 90° angle rectangular solar space model with a 90-degree angle of 0.28 to 0.47 degrees (Table 3) (Figure 1,7). The rate of heat absorption

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through solar energy in this model is up to 303.83 kwh of solar energy in October and at least up to 30.57 kwh in June (Table 3) (Figure 2,8). Average heat output through the transparent wall in this model in the cold months of the year, from November to February, is between 80.41 to 117.03 kwh, and in the warm months of the year, from April to September, it is from 143.73 to 187.69 kwh. In this model, in April, the lowest rate is compared to other models, and in January, February and June is the highest rate compared to other models (Table 3) (Figure 3,9).

Table 3: Comparison of digital data of different solar space models.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
5.75	8.04	13.66	20	25.18	31.2	33.42	32.05	27.52	20.02	11.16	6.51	Outside dry bulb
13.16	14.05	18.18	22.1	28.1	33.99	37	37.29	34.94	29.74	21.44	15.49	Air Temperature block solar space with 90-degree angle
390.7	313.3	242.7	133.9	72.03	49.75	62.56	128.29	232.1	359.5	375.5	392.1	Solar Gains Interior Windows IN solar space with 90-degree angle
79.81	106.2	175.9	175.8	184.4	182.2	175.1	153.48	139.6	114.9	53.15	50.06	Glazing block IN solar space with 90-degree angle
12.51	13.44	17.73	21.63	27.71	33.64	36.68	36.98	34.66	29.33	20.92	14.91	Air Temperature block IN solar space with 30-degree angle
297.5	247.4	227.5	109.4	47.3	30.57	39.69	94.83	218.7	303.8	288.9	296	Solar Gains Interior Windows IN solar space with 30-degree angle
102.9	117	163.5	170.5	187.6	187.3	184.6	171.16	143.7	131.8	84.95	80.41	Glazing block IN solar space with 30-degree angle
12.36	13.4	17.53	21.4	27.54	33.48	36.54	36.85	34.47	29.31	20.86	14.77	Air Temperature IN solar space with 45-degree angle
292.5	269.6	211.8	87.04	34.16	21.94	28.24	72.45	187.6	323.6	293.2	283.4	Solar Gains Interior Windows IN solar space with 45-degree angle
98	101.5	159.6	172.4	188.3	184.8	186.9	181.51	154.9	120.3	80.81	80.86	Glazing block IN solar space with 45-degree angle
12.32	13.18	17.25	21.21	27.38	33.28	36.37	36.75	34.32	29.08	20.83	14.83	Air Temperature IN solar space with 60-degree angle
293.1	228.7	155.8	57.57	20.27	15.61	17.75	44.66	133.1	254.4	279.9	295.5	Solar Gains Interior Windows IN solar space with 60-degree angle
92.69	109.3	172	175	182	170.1	179.2	190.45	177.4	146.8	86.59	75.26	Glazing block IN solar space with60-degree angle

Examining the diagrams associated with the solar space model with an angle of 45 degrees shows that this model increases the indoor air by 5.36 to 9.70 degrees in winter and causes 0.58 to 0.8 degrees less the temperature rise compared to the outdoor air and a rectangular cube solar space model with a 90-degree angle. However, the same performance in the warm seasons of the year causes a cooling load in the settlement by increasing the temperature by 1.4 to 6.95 degrees indoor air compared to outdoor air, which causes 0.44 to 0.70 degrees less temperature increase than the solar model relative to rectangular cube with 90 degrees angle of (Table 3) (Figure 1,7). The heat absorption through solar energy in this model in October is up to 323.60 kwh of solar energy, and in June, at least up to 21.94 kwh (Table 3) (Figure 2,8). The average heat output through the transparent wall in this model in the cold months of the year, from November to February, is between 80.81 to 101.55 kwh and in the warm months of the year, from April to September, from 154.97 to 188.36 kwh. In this model in February and March, the lowest value compared to other models in May and July is the highest rate compared to other models (Table 3) (Figure 3,9). Examination of the diagrams associated with the solar space model with an angle of 60 degrees shows that this model in winter increases the indoor air by 5.14 to 9.67 degrees compared to the outdoor air and compared to the rectangular solar space model with a 90-degree angle causes 0.61 to 0.87 less temperature rise.

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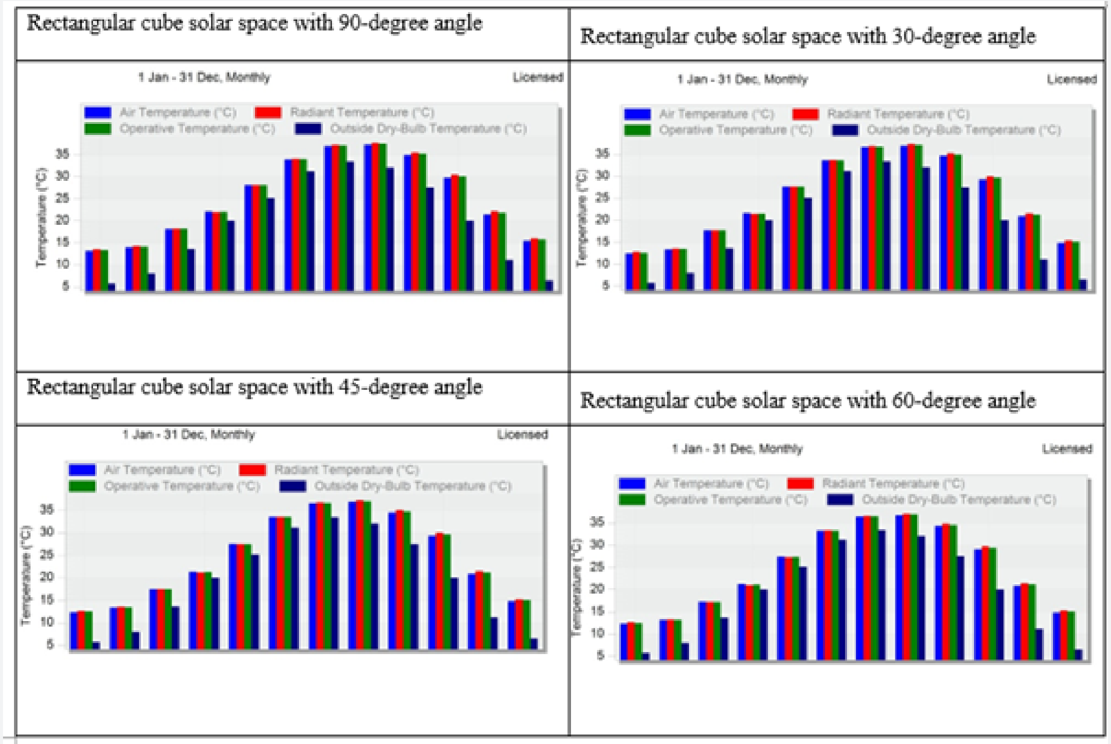

Figure 7: Average outside Dry-bulb Temperature, radiant temperatures and Air Temperature (co) in the settlement adjacent to the solar space.

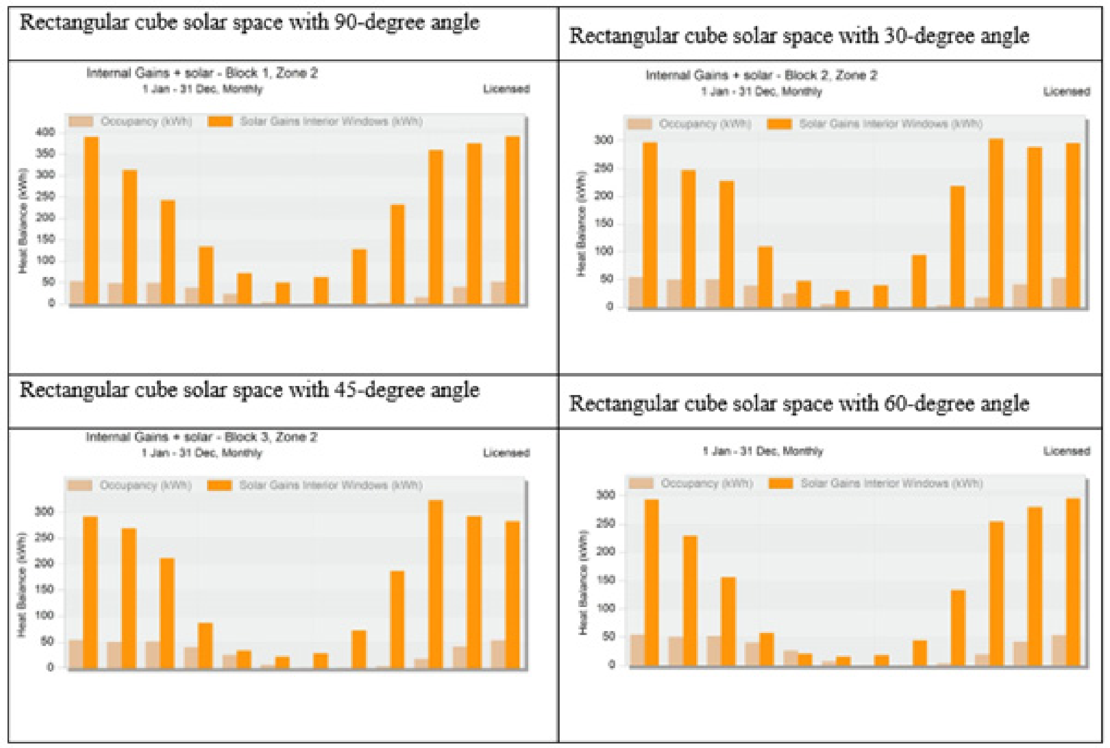

Figure 8: Heat balance of solar gains interior windows (Kw/h) in the settlement adjacent to the solar space

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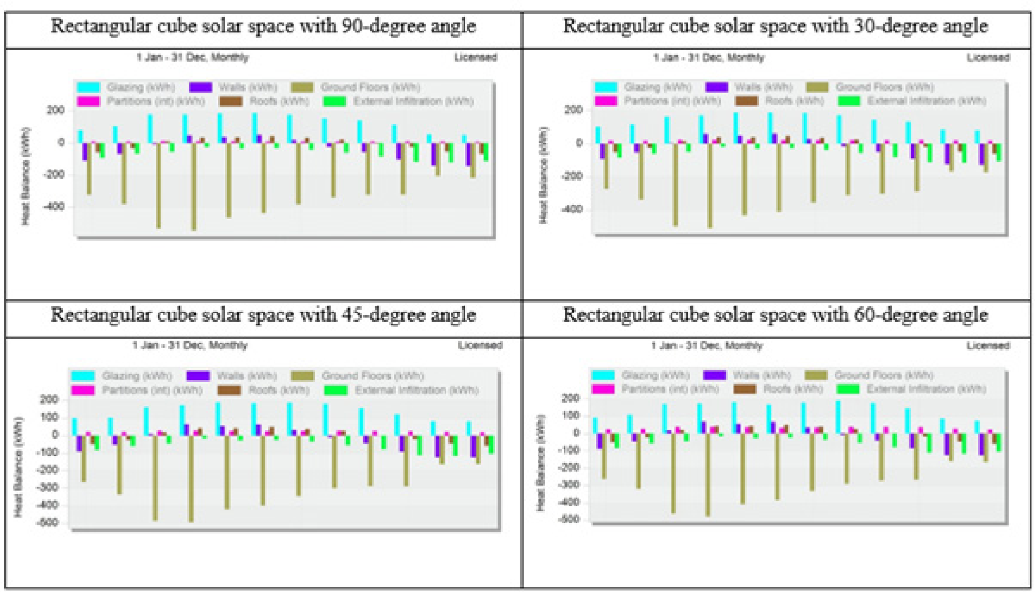
Rectangular cube solar space with 90-degree angle

Rectangular cube solar space with 30-degree angle

Rectangular cube solar space with 45-degree angle

Rectangular cube solar space with 60-degree angle

Figure 9: Heat balance of Glazing, walls, Ground floors, partitions and roofs (Kw/h) in the settlement adjacent to the solar space

Nonetheless, the same performance in hot seasons with an increase in temperature of 1.21 to 6.80 degrees indoor air relative to air outside imposes a cooling load on the residence, which increases the temperature 90 (Table 1,3) (Figure 1). The heat absorption through solar energy in this model is up to 295.53 kwh of solar energy in December and at least 15.61 kwh in June (Table 3) (Figure 2,8). The average heat output through the transparent wall in this model is between 75.26 to 109.32 kwh in the cold months of the year, from November to February, and between 170.15 and 190.45 kwh in the warm months of the year, from April to September. In this model, the lowest rate is in May and June compared to other models, and the highest rate is from August to November compared to other models (Table 3) (Figure 3,9).

Conclusion

The purpose of solar spaces in hot and dry climates is to reduce the heating load of cold days of the year and minimize the imposition of excess cooling load in summer. In all the models examined, in using solar space, the optimal model is determined as a condition with less excess cooling load and creates a suitable heating load in winter because of the significance of cooling load in Kashan on the hottest day of summer. Accordingly, solar space with an angle of 60 degrees has the lowest heating load in winter - a maximum of 0.87 degrees less than other models. However, it has the lowest cooling load in summer - a maximum of 0.89 degrees less than other models. Moreover, by comparing the heat absorption through solar energy and considering that the maximum radiant temperature generated in the model with an angle of 60 degrees, it occurs in December in the living space, unlike other models, and this is minimum in June. Ultimately, based on the average heat output through the transparent wall, one can see that the model with an angle of 60 degrees compared to the 90-degree model has a maximum increase of 37.86 kwh and a maximum of 12.05 kwh reduction in summer and a maximum of 33.44 kwh in winter. Thus, considering the short distance between the average heat output of the 60-degree model and other models, creating better temperature conditions in the settlements connected to this space and absorbing more radiant temperature indicates that the solar space with an angle of 60-degree is the optimal model among the models examined.

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