

Eco-efficiency of passive solar heating

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Abstract. The article presents calculations of the energy efficiency of direct solar heating and sunspace, located on the building facades of various orientations, in the climatic conditions of the southern coast of Crimea. The share of compensation for heat losses due to passive solar heating has been determined. The calculation of the environmental effect of passive solar heating systems has been done.

1 Introduction

In regions with a large amount of solar radiation during the heating period [1-6], it is advisable to use the passive solar heating installation not only to save fossil fuels, but also to obtain a positive environmental effect. The eco-effect of passive solar heating is due to the reduction of CO₂ emissions into the atmospheric air, by burning of fuel to heat buildings.

The works [5-10] is devoted to study the passive solar heating. The relationship between energy efficiency and the level of carbon dioxide emissions is investigated in the works [8,9]. Improving the energy efficiency of buildings is one of the factors ensuring the biosphere compatibility of cities and settlements [7,11].

2 Objective and tasks of research

The object of research is a passive solar heating devices. The purpose of the research is to determine the ecological efficiency of direct solar heating and sunspace on the various facade orientations of a building.

This work is divided in three main parts :

- calculation of the energy efficiency of direct solar heating and sunspace, designed on various facades of the building in the climatic conditions of the Yalta city ;
- determination of the compensation share for building heat losses due to passive solar heating ;
- calculation of the environmental effect of the most profitable options for the device of passive solar heating.

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3 Materials and methods

The paper uses analytical methods for calculating heat losses and inputs, as well as calculating the environmental efficiency of passive solar heating, based on construction regulatory documents of the Russian Federation [2-4]. To conduct research on the definition and comparison of the environmental efficiency of passive solar heating, a rectangular building of 10m x 10m x 3m, a floor area of 100 m², a heated volume of 300 m³ being considered in this article. Two types of devices were chosen: direct solar heating (or a window) and sunspace, which are arranged on different facades of the object. The glazing area of passive solar heating devices is 2.5m x 4m = 10 m² (Fig. 1). Sizes of sunspace: 2m x 4m x 2.5m, floor area 8 m².

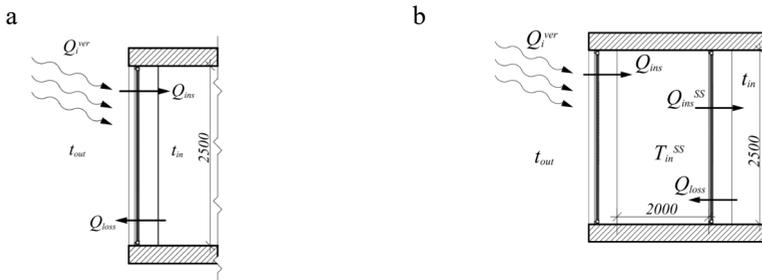


Fig. 1. Solar heating devices: a - direct solar heating; b – sunspace

City of construction is Yalta. Estimated period: November - March. To calculate the heat losses, the heat transfer resistance of the enclosing structures is assumed to be the minimum allowable in accordance with [3]: the heat transfer resistance of walls $R_{wall} = 2.3 \text{ m}^2 \cdot \text{°C}/\text{W}$, floor and ceiling $R_{floor} = 2.84 \text{ m}^2 \cdot \text{°C}/\text{W}$. In the designs of devices for passive solar heating, a single-chamber double-glazed window with ordinary glass in wooden window cover is adopted, with heat transfer resistance $R_{win} = 0.35 \text{ m}^2 \cdot \text{°C}/\text{W}$; shading coefficient by opaque elements is $\tau_1 = 0.8$; the relative transmittance of solar radiation is $\tau_2 = 0.76$ [2]. The temperature inside of the heated volume is assumed to be $t_{in} = +20 \text{ °C}$, the temperature of the ground is $t_{gr} = +5 \text{ °C}$, the average monthly temperature of the outside air is taken in accordance with [4] and shown in Table 1. Indicator of the average monthly total solar radiation entering the vertical surfaces with actual conditions of cloudiness for 1 hour, heat input and heat loss are calculated on the basis of formulas [3], as well as [2] and shown in Table 1.

Table 1. Initial data

	Average monthly solar radiation on vertical surfaces with average cloud conditions for 1 hour [Wh/m ²]								Monthly average outdoor temp. [°C]	Average monthly heat loss through enclosing structures without passive solar heating [kW·h]
	N	NE	E	SE	S	SW	W	NW		
NOV	23.6	24.8	41.2	69.7	89.0	71.2	41.2	24.8	+ 9.5	1.45
DEC	16.7	16.9	27.5	49.7	65.3	49.7	27.5	16.8	+ 6.3	1.73
JAN	20.6	20.2	32.1	53.9	69.7	55.8	32.1	20.6	+ 3.9	1.94
FEB	32.2	32.5	47.2	67.4	82.7	70.5	46.6	32.5	+ 4.2	1.91
MAR	50.6	53.1	78.5	98.3	109.5	101.4	78.5	53.7	+ 6.0	1.75

4 Results and discussion

4.1 Calculation of heat input through the construction of passive solar heating devices

Heat input during direct solar heating, Q_{ins} , Wh, shown in Table 2 and was calculated by the formula:

$$Q_{ins} = Q_i^{ver} \cdot \tau_1 \cdot \tau_2 \tag{1}$$

where Q_i^{ver} – average monthly specific total solar radiation arriving on the vertical surface of the i -th orientation, under actual cloud conditions in 1 hour, Wh/m²; τ_1 – coefficient of shading by opaque elements; τ_2 – coefficient of relative penetration of solar radiation.

Table 2. Direct solar heating calculation results

	Average monthly heat input through direct solar heating for 1 hour [Wh]							
	N	NE	E	SE	S	SW	W	NW
NOV	143.6	150.8	250.2	423.5	540.9	432.6	250.2	150.8
DEC	101.5	102.6	167.0	302.1	397.0	302.1	167.0	102.2
JAN	125.3	122.6	195.1	327.4	423.7	339.4	195.1	125.3
FEB	195.9	197.8	287.0	409.8	502.8	428.4	283.3	197.8
MAR	307.5	322.6	477.1	597.7	665.5	616.5	477.1	326.4

To get into the heated room, the sunlight must pass through two layers of glazing and, therefore, the heat input through the sunspace is calculated by the formula:

$$Q_{ins}^{SS} = Q_i^{ver} \cdot \tau_1^2 \cdot \tau_2^2 \tag{2}$$

It is also necessary to take into account that the average monthly temperature inside an unheated sunspace will be higher than the outdoor air temperature. Sunspace will serve as a buffer room, and therefore the heat loss through the building envelope will be reduced. The temperature inside the sunspace T_{in}^{SS} , °C, shown in Table 3 and calculated by the formula:

$$T_{in}^{SS} = \frac{\sum t_{out} \cdot \frac{A_i}{R_i}}{\sum \frac{A_i}{R_i}} \tag{3}$$

where t_{out} – outdoor air temperature for the building envelope of the i -th orientation, °C; A_i – area of the enclosing structure of the sunspace i -th orientation, m²; R_i – resistance to heat transfer enclosing structures of the sunspace of the i -th orientation, m²·°C/W.

Table 3. Sunspace calculation results

	Average monthly heat input through the sunspace for 1 hour [Wh]								Temp. inside the sunspace [°C]
	N	NE	E	SE	S	SW	W	NW	
NOV	87.3	91.7	152.1	257.5	328.9	263.0	152.1	91.7	+13.8
DEC	61.7	62.4	101.5	183.6	241.4	183.6	101.5	62.1	+12.1
JAN	76.2	74.5	118.6	199.1	257.6	206.4	118.6	76.2	+10.8
FEB	119.1	120.3	174.5	249.2	305.7	260.5	172.3	120.3	+11.0
MAR	187.0	196.1	290.1	363.4	404.6	374.8	290.1	198.4	+11.9

4.2 Determination of the compensation share for building heat losses due to passive solar heating

The results of calculations of heat loss of the building using direct solar heating, with a glazing area of 10 m² on different facades of the building has been shown in Fig. 2. and also, the level of heat loss of the object without direct solar heating.

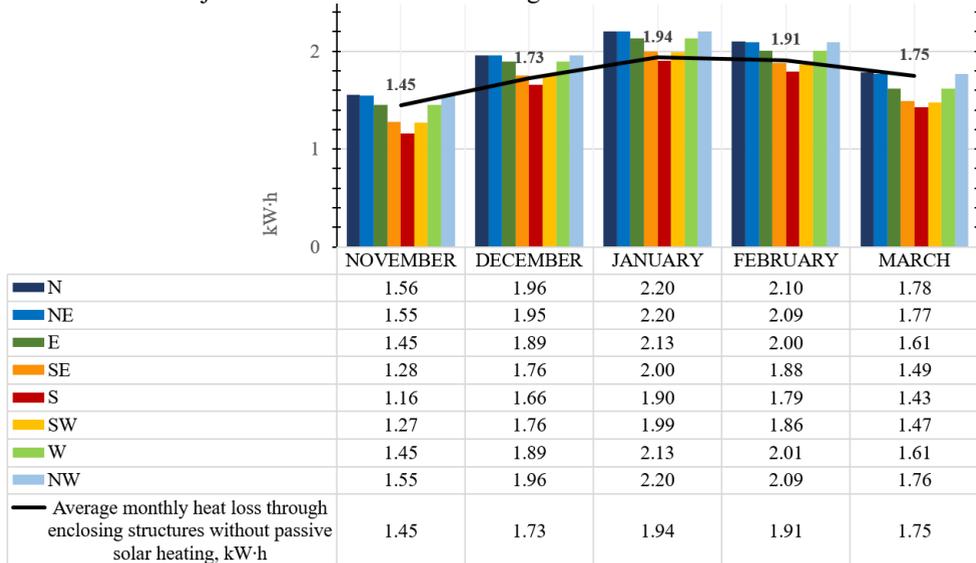


Fig. 2. Heat loss of a building with direct solar heating

A stable positive energy effect from direct solar heating is observed only on the south facade. When direct solar heating is located on other facades a stably negative energy effect is observed (this means that the heat input through the window does not exceed the heat loss through it), and only in November and March does the positive energy effect appear in the SE and SW of the window orientation.

If the direct solar heating structures are located on the southern facade, the share of compensation for the total heat loss of the building with a heated area of 100 m² will be from 1.7% in January to 19.8% in November.

The results of calculations of heat loss of a building with the sunspace, considering the temperature inside it, is shown in Fig. 3. Sunspace with a glazing area of 10 m² alternately located on different facades of the construction site.

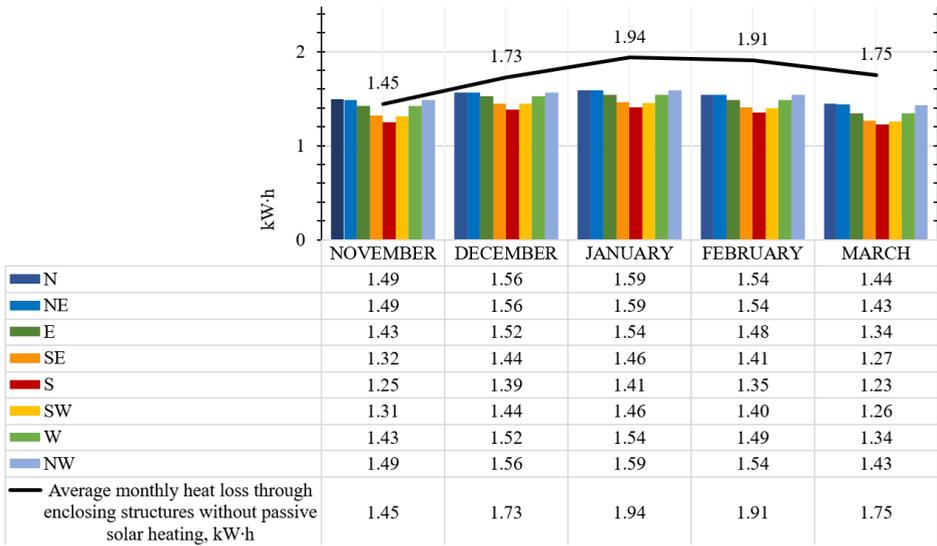


Fig. 3. Heat loss of the building with the sunspace

4.3 Calculation of the environmental effect of passive solar heating

The work [8] describes an algorithm for converting the fuel saved by passive solar heating into mass of non-carbon dioxide CO₂. Provided that natural gas is used for heating with a three-atom gas volume in the combustion products of gaseous fuel V_{rO2}, equal to 1.05 m³/m³, every saved kWh of thermal energy reduces CO₂ emissions by 2.87 kg. Table 4 presents the results of a monthly reduction in CO₂ emissions due to the use of passive solar heating (in Table 4, direct solar heating deals only with south orientation).

Table 4. Eco-efficiency of passive solar heating

	Monthly average CO ₂ emissions reduction [kg/month]								
	sunspace								direct gain
	N	NE	E	SE	S	SW	W	NW	S
NOV	-	-	41.4	259.2	406.7	270.6	41.4	-	592.2
DEC	342.9	344.3	427.9	603.3	726.6	603.3	427.9	343.8	139.1
JAN	743.7	740.2	834.3	1006.1	1131.1	1021.7	834.3	743.7	71.9
FEB	712.7	715.0	819.6	963.6	1072.6	985.4	815.3	715.0	231.4
MAR	656.6	676.2	876.8	1033.3	1121.4	1057.8	876.8	681.1	696.9

5 Conclusion

1. Excess heat, and, consequently, a positive environmental effect, in the climatic conditions of the Crimea with direct heating is consistently observed only on the southern facade of the building. The 10 m² window opening with the simplest design (single-chamber double-glazed window) allows to reduce the total heat loss of a building with a heated area of 100 m² from 2 to 20% during the heating period. With SE and SW orientation a positive result is observed only in November. February and March: the heat loss is reduced by 11-15%.

2. Excess heat energy and a positive environmental effect when building has sunspace, with a glazing area of 10 m² outside and inside, takes place in all months and in any orientation of

the sunspace, with the exception of the NE-S-NW direction in November. The best result in arranging sunspace on the south facade: cost reduction by 13.6-30% during the heating period.

3. In one month of the heating period, direct heating with an area of 10 m², located on the southern facade, reduces CO₂ emissions by 70-690 kg.

4. Sunspace, located on the southern facade, leads to a reduction in CO₂ emissions of 400-1100 kg per month.

Due to the fact that translucent structures have high thermal conductivity, their presence in the construction site leads to an increase in heat loss of the building (even taking into account the higher temperature inside the sunspace compared to the outdoor air temperature). Taking into account passive solar heating, translucent structures become sources of heat, as well as a way to save fuel and, accordingly, reduce CO₂ emissions.

To obtain the maximum effect, both direct heating and sunspace should be located on the southern facade of the building. This causes the device sun protection for the hot period of the year. It is worth noting that sunspace in all senses is a more advantageous solution. Firstly, a positive effect from sunspace in the months of the heating period is observed at any orientation, which makes it possible to use it, for example, when reconstructing existing buildings in order to increase their energy and eco-efficiency. Secondly, the sunspace itself is the sun protection element of the building. In the summer months, when the angle of incidence of sunlight at noon reaches its maximum value, the roof structure of the sunspace cuts off these rays, preventing them from entering the living quarters. For thermoregulation of indoor air in a sunspace, it is enough to open the outer glazing.

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