Passive Solar Systems in Low-Rise Housing Architecture in Southern Primorye

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Abstract. This article examines the effectiveness of passive solar technologies in individual housing construction in the climatic conditions of southern Primorye. Three versions of the architectural solution of the passive solar heating "Direct Systems" model selected as the object of research, compositionally differ in the architecture of the enclosing structures interacting with the thermal massive and the location of the thermal massive in the planning structure of the house. In version 1, design of an additional roof slope shading the living area reduced the area of the south-facing stained glass and the efficiency of the passive system but solved the problem of light comfort in the house. Solar heat gains compensate heat losses by 57%. In version 2, the atrium stained-glass window open to the sun creates an uncomfortable light regime, which was compensated by a sun-shading glass unit. The loss of thermal radiation from the sun on the stained glass was almost 80%, but due to the large area of the stained glass, the contribution of the passive solar heating system remained similar to version 1 - about 50%. In version 3 of a simplified solar house of minimal dimensions, the heat-receiving stained glass window and the thermal massive are placed in the entrance zone. This placement of the passive system made it possible to maintain light comfort, and in general, a decrease in the heated volume of the house made it possible to compensate for heat losses by 94%. As these data show, with a careful architectural solution of passive solar systems, in the climatic conditions of southern Primorye engineering heating systems of a low-rise residential solar house, including renewable energy systems, can be considered as auxiliary.

1. Introduction

The need for practical application of passive solar technologies in Primorye may be great. As part of the implementation of the state “Far Eastern Hectare” program, more than 21 thousand people received land in the Primorsky Territory at the beginning of 2020, and more than half of them - for housing construction [7]. The bulk of the allocated plots is not provided with engineering networks, and in these conditions it is at least unreasonable to refuse to use "free" solar energy. At the same time, with significant solar resources [3], there are only a few passive solar houses in the Primorsky Territory. The effectiveness of passive solar technologies is questioned by most architects and developers, or they do not understand that we are talking about the architectural solution of the house, and not about solar collectors or photovoltaic panels. Therefore, the purpose of this study was to assess the effectiveness of the use of passive solar technologies in individual housing construction in the climatic conditions of the region.
2. Theory and method

Passive solar technologies, as the basis for the formation of the architectural image of a living space, are not know-how of the XX-XXI centuries. They were used in the most ancient buildings of man. Widespread in the 19th century greenhouses based on timber frame and then metal structures laid the foundation for the widespread use of the greenhouse effect in the architecture of public, and then residential buildings [1,8].

The basis of the architectural solution of a modern individual residential building with passive solar heating is the calculation of its geometry, taking into account the annual variation of solar coordinates and the local climate. The geometry of a solar house should first of all provide insolation visibility of thermal massive, interiors, and external active solar systems in cold weather, shading of thermal massive and interiors when overheated, and also provide comfortable light climate for humans throughout the year [2,9]. With all the variety of architectural solutions of a solar house possible within the framework of these requirements, they are based on three basic models of passive solar systems: Direct Systems, Indirect Systems, and Isolated Systems [4,10].

This study examines the efficiency of using variants of the simplest model of passive solar heating, defined in these classifications as "Direct Systems", in the climatic conditions of the most intensively developing southern part of Primorsky Territory. Efficiency was assessed by the contribution of passive systems to meeting the general heating needs of an individual residential building during the cold season, from November to March inclusive.

3. Experience and results

The variants of passive solar houses based on the “Direct Systems” model considered in the article differ in the design of the enclosing structures interacting with the thermal massive: a solid vertical stained glass window (version 2 and 3) and a stepped stained glass window with a cut-in roof slope (version 1). As well differ as the location of the thermal massive in the planning structure of the house: - residential area (version 1 and 2), and the entrance area (version 3). Common to all versions is the location of the main thermal massive - a concrete monolithic slab - in the floor at elevation 0.000.

Version 1. Basic methods of shaping, implemented in the project of eco-house Solar-5: U-shaped house in plan, stretching from east to west and deployed with the inner "open" side to the south; roof built into the southern stained-glass window, providing shading of the living area; energy-saving stained-glass windows that occupy the entire southern facade in two rows: the main stained-glass window and ridge windows, providing a comfortable light climate in the northern part of the building; pitched roof with a slope from 26° to 45°, facing north, which provides a minimum area of the northern facade; deep overhangs from the south combined with indoor and outdoor sun shading (figure 1). When designing Eco-house Solar-5, patented solutions in the field of energy-efficient architectural forms of the house were used - patent for invention Ru 2342507 “Energoeffektivnoye zdaniye Ekodom Solar 5” and utility model patent Ru 103374 “Energoeffektivnoye zdaniye Solar 5”.

The passive solar heating system of the eco-house Solar-5 in a simplified version includes: thermal massive of floor at elevation 0.000 (area 25.9 m², volume 3.9 m³) and the Trombe wall (4.3 m², 0.9 m³), sunlit directly through the stained glass windows with a southern orientation (stained glass area 33.4 m², type of energy-saving selective double-chamber glass unit Low- e tipe, $R_u = 0.73$ (m²·°C)/W. Total area of the house - 132.8 m², heated volume - 430.3 m³. External walls - frame, filled with mineral wool insulation, $R_o = 5.7$ (m²·°C)/W.

According to the calculated data, the energy-saving architectural form will allow the passive solar system in normal winter weather conditions ($-14°C$, north wind speed of 5-10 m/s) to compensate for 57% of the home's heat needs. The total contribution of passive (architecture) and active (collectors) solar systems for the heating season is 81% (figure 2, calculated data by A.V. Volkov for the climatic conditions of southern Primorye) [5].
Figure 1. Version 1 - Solar-5. Architects - Pavel Kazantsev, designer - Tatiana Belousova.

Figure 2. Calculation of solar heat gain and heat losses of eco-house Solar-5 (Alexander Volkov).

In version 2, the Solar-Sb eco-house, the floor thermal massive is located in a two-height atrium with a stained-glass window to the south and dormers in the roof. The atrium was also supposed to include massive interior walls of 4.8 m³, providing additional thermal inertia of the building, but during construction they were replaced with a frame. The living rooms open into an atrium. In terms of depth, the house is dissected in the proportion of 2/3 of the southern living rooms and 1/3 of the buffer space from the north, taking into account the depth of penetration of sunlight in winter. The
sleeping area on the second level takes into account the "heat bag" effect, which allows you to save on heating the first floor at night. The house is also stretched in latitude, which ensures maximum exposure to the sun. The northern windward facade is blind, the roof slope is lowered to the marks of the finished floor of the second level. Balconies at the ends of the house should reduce overheating of the western facade in summer (in combination with a vertical green screen) and shelter the eastern facade from slanting rain. The attic on the third level is residential, but it will be cut off from the warm core of the house by an insulated ceiling. In summer, windows at opposite ends of the attic contribute to additional ventilation of the atrium due to a draft under the ridge of the roof (figure 3).

Figure 3. Version 2 - eco-house Solar-Sb design: architect Pavel Kazantsev, designer Anna Lyashko, constructions Marius Tarvidas and Audris Krucius, Ecococon, Lithuania.

The passive solar heating system at the time of the observations included: a thermal massive formed by a light gray concrete slab without a black matte cladding, with a section of 0.15 m, laid on insulation, area 24 m², volume 3.6 m³. The house uses selective double-glazed windows of the Low-e type \( R_s = 0.76 \) (m²·°C)/W, the area of south-facing stained-glass windows is 44.9 m². The total area of the house is 187.8 m², according to the project, the heated volume without utility rooms, sanitary facilities and an attic is 406.3 m³, at the time of observation - the heated volume is total houses within the boundaries of the roof and walls - 510.5 m³. External walls - straw panels produced by the Lithuanian company Ecococon, \( R_s = 8.1 \) (m²·°C)/W.

The monitoring of the indicators of the passive solar system of the individual residential eco-house Solar-Sb was carried out in the winter of 2015-2016 (figure 4). During the observation period, the house was uninhabited and was not heated - there were no other heat sources besides solar. Weather conditions during the observation period were milder than the calculated ones [6]. The house, with all the imperfections (construction was completed in September 2016), accumulated and retained solar heat quite well. The maximum daytime temperatures inside the house in sunny frosty weather were within +2⁰ +7 °C, the difference between outside and inside temperatures on sunny frosty days was 12⁰ - 20 °C. The contribution of the passive solar system is estimated according to the test results at
50%, with 20% of the use of the sun’s thermal energy coming to the surface of the stained glass (the effect of the sunscreen membrane on the southern stained glass).

![Graph](image)

**Figure 4.** A sample of readings from an automatic weather station from February 8 to March 14, 2016.

In version 3 - for the A-DROP eco-module, a simplified architectural and structural scheme is applied, in order to organize the in-line production of components and taking into account the implementation by unskilled construction workers. At the heart of the architectural solution is a parallelepiped with a height of 3.6 m, covered with a pitched roof, with a southern slope angle of 60⁰. The thermal massive is moved from the living area to the entrance area of the house. This made it possible to separate the functions of solar heating and natural lighting and eliminate possible light discomfort in the living area. At the same time, the entrance, residential (elevation 0.000) and sleeping areas (mezzanine at elevation 2.800 above the residential area) constitute a common space without partitions. The entrance area on two levels provides intensive convection heat exchange with the sleeping and living areas (figure 5).

The passive solar heating system includes a thermal massive of the entrance zone in the form of a concrete slab with a section of 0.15 m with an area of 8.7 m², and a thermal wall with a section of 0.2 m with an area of 2.8 m², finished in matt black porcelain stoneware. The thermal massive and wall are illuminated by the sun through the stained-glass windows of the southern (12.0 m²) and eastern (3.0 m²) orientation, the energy-saving selective Low-e type double-glazed window unit, \( R_0 = 0.73 \) (m²·°C)/W. In the morning hours, compensating for the inertia of the main passive system, additional heat input is provided by a solar air convector located on the eastern facade with an area of 3.0 m². The total area of the house is 38.9 m², the heated volume is 105.4 m³. Similar to version 1, the outer walls are a frame filled with mineral wool insulation, \( R_0 = 5.7 \) (m²·°C)/W.
According to the calculated data, the passive solar architecture of the A-DROP autonomous eco-module - a direct heating system and a heating solar air convector - in normal winter weather conditions (-14°C, north wind speed of 5-10 m/s) compensates for 83% of the heat needs of the house. The total contribution of the passive solar system for the heating season from November to March is calculated to be 94% of the heating needs of the eco-module. The active solar system is designed only for hot water supply of the house, with the permanent residence of a family of 3 people. It is proposed to supplement the heat energy deficit with a small-sized pellet stove (Figure 6).

4. Discussion
The architectural features of the considered eco-houses should also include the solution to the problem of combinatorics of architecture and active solar systems, namely, a solar water heating installation...
and a photovoltaic system. Installing active solar systems on buildings with traditional architecture, whose shape is not tied to the annual variation of solar coordinates, tends to reduce the efficiency of these systems. This can be offset by "extra" solar collectors or photovoltaic, which increases the cost of the system. In the versions considered, the angles of the southern slopes of the roof were selected taking into account the maximum heat transfer from active solar systems. For solar heating systems in winter for southern Primorye, a roof angle of 58° (60°) was chosen, for solar hot water supply and photovoltaic systems 47° (45°) (articulated roof in version 2). Including in versions 1 and 2, the effect of direct solar radiation reflection by the southern slope of the roof into the area of solar collectors placement at low solstice was proposed (utility model patent Ru 103374).

5. Conclusions
In version 1, the introduction of an additional roof slope shading the living area, reduced the area of the south-facing stained glass and the efficiency of the passive system, but solved the problem of light comfort in the house. Receipts of solar heat compensate for heat losses by 57% (heated volume 430.3 m³, stained glass area 33.4 m², thermal massive 4.8 m³). In version 2, the atrium stained-glass window open to the sun creates an uncomfortable light regime, which was compensated by a sun-shading glass unit. At the same time, the loss of thermal radiation from the sun amounted to almost 80%, but due to the large area of the south oriented stained-glass window, the contribution of the passive solar heating system remained close to option 1 version - about 50% (actual heated volume 510.5 m³, stained-glass area 44.9 m², thermal massive actual 3.6 m³). Here it is also necessary to take into account the milder than the calculated weather conditions during the observation period. In version 3 of a simplified solar house of minimal dimensions, the heat-receiving stained glass window and the thermal massive are placed in the entrance zone. Such placement of the passive system made it possible to preserve light comfort, while reducing the heated volume of the house made it possible to compensate for heat loss by 94% (heated volume 105.4 m³, stained glass area 15.0 m², thermal mass 1.8 m³).

A distinctive feature of passive solar architecture is the dependence of the architectural form of buildings on the direction and intensity of action of vector climatic factors. In the monsoon climate of southern Primorye, which is characterized by a high thermal contrast of the horizon sides unusual for Russia, taking this factor into account increases the efficiency of passive solar systems. As the assessment of the three versions of the simplest “Direct Systems” model shows, with a competent architectural solution of passive solar systems, engineering heating systems of a low-rise residential solar building, including renewable energy systems, can be considered as auxiliary. Replacement of engineering systems for heating individual residential buildings is also important from the point of view of saving natural resources and sustainable development of southern Primorye.

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