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Study of Passive Solar House SOLAR-SB

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Abstract

One of the first specially designed passive solar house on Russian Far East monitoring in winter 2015-16 has confirmed a high efficiency of a traditional architectural model of solar heating in the natural climatic conditions of the south part of region. Continuous examination of the passive system for the all cold season in the house without additional heating sources was held in the region for the first time. The revealed causes of system's high inertia in the morning hours, as well as a positive effect of additional solar warming of the house in the evening time, will allow developing measures in perfecting the passive solar systems of residential buildings in the region.

Keywords: *solar heating, solar house, solar architecture, ecological architecture, passive solar system.*

1. Introduction

Passive solar heated houses design in the Russian Far East was a design in drawings to the present. For this reason it was impossible to confirm the effectiveness of passive solar systems here, which also stopped their development in the mass construction. For example, in 2005, a designer company Argus-Art developed an experimental project design of a single-family eco-house Solar-5 (authored by Pavel Kazantsev, an architect) [5]. The active solar system of the eco-house was designed by Laboratory 07 of FEB RAS IMTP (Fig.1).

Fig. 1: Eco house Solar-5. Project views

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According to the lab calculations, the passive solar system accounted for up to 57% of the house heating during the cold season. (Fig.2). This result was mainly achieved via a non-standard architectural solution patented as invention of an energy-efficient architectural form RU2342507 and awarded at international and Russian exhibitions.

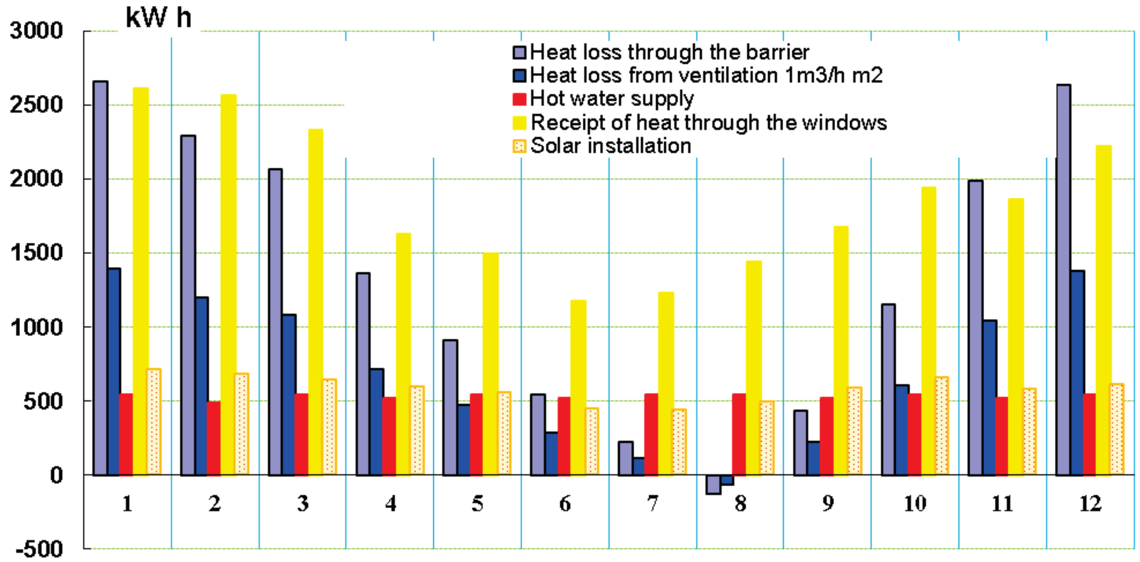

Fig. 2: Estimation of the heat balance of eco house Solar-5 throughout the year. According to the calculation, the contribution of passive and active solar heating system should reach 81%

In 2011, the FESPI/FEFU Technopark implemented a one-floor sample of the eco-house – a training-experimental eco-module Solar-5m (Fig.3); however, there was no opportunity to confirm the high expected properties of the passive solar heating in practical terms [3].

Fig. 3: Training-experimental eco-module Solar-5m

Therefore, in order to define the properties of the passive solar system in the conditions of south part of Far East, research was conducted in the winter of 2015-16 at the constructed single-family house with passive solar heating. The research was conducted jointly with the Training studio of resource-saving architecture within the Department of Architecture and Urban Planning in FEFU and Laboratory 07 of the FEB RAS IMTP – Energetics of the Underwater Robotic Complexes. Absence of the heating sources other than direct solar radiation during the observation period was the primary criteria for choosing the object. It is for this reason that measurements have been allowed in an uninhabited house with an incomplete interior finish, but practically closed external warm contour.

2. Specific features of the eco-house architectural solution

A single-family house with passive solar heating has become an object of this research. The house shell is made of pressed straw panels. The project design was developed in 2012-2013; the house has been under construction since June, 2014 in Primorsky Krai, Nadezhdinsky district, Novyi settlement. The design project was authored by architects Pavel Kazantsev (FEFU, Vladivostok) and Anna Lyashko (M-ARC, Vladivostok). The structural design and straw panel technology were developed by Domantas Surkys, Audris Krucius, Marius Tarvidas (Ecococon company, Vilnius, Lithuania). Customer: Vladimir Kazantsev (Fig.4, 5).

Fig. 4: General view of the house from the south-east in the winter of 2015-2016

Fig. 5: The design of the house at the end of construction

An architectural model traditional for temperate latitudes of the Northern Hemisphere was taken as a basis for structuring the passive solar system of the pilot straw eco-house Solar-Sb. A double-height atrium with a south-facing stained-glass window and dormer windows in the roof is a building core of the house. The atrium was to have included massive inner walls providing for the thermal inertia of the house, but in the process of construction they were replaced with a frame (Fig.6). Living room spaces open into the atrium. In depth the house is divided in 2/3 proportion of living space in the south and 1/3 of the buffer space from the north, with the account for the depth of solar ray penetration in winter. A sleeping area on the second floor also takes into account the effect of “heat sack” and reduces the heating expenses for the first floor area at night. The width of the house is increased providing for its exposure to the sun. The northern windward façade is blind; the roof pitch is lowered to the wearing floor of the second floor. Balconies in the shorter side of the house form intermediate half-open spaces providing for additional protection in bad weather conditions. They are supposed to reduce the façade overheating in summer (in combination with a vertical green screen) and cover the eastern façade from slanting rains.

Fig. 6: The interiors of the house during the observation period in the winter 2015-2016.

The works are not completed

The attic on the third level is a part of living space; however, it will be separated from the warm core of the house with heat-insulated dividers to ensure its seasonal use. In the first half of the summer, the windows in the opposite walls of the attic contribute to additional airing of the atrium through the divider opening by air draft under the roof ridge. A connected structure of the roof is the only innovation in the shape of the straw house: its angles are optimized for installing the solar collector of water heating system (the Sun in the late January) and the photoelectric system (the equinox solar altitude in Vladivostok latitude).

The major technical and economic features of the project are as follows: construction area 117 m^2., living space 133.7 m^2., total area 187.8 m^2. The type of passive solar system: Direct gain (Haggard, Bainbridge, et al., 2009). The windows are triple-pane selective Low-e Ro = 0.7-0.76 m^2 KW^{-1} (according to the design project), the area of southward stained-glass windows – 25.0 m^2, thermal area at the moment of observation – 24.0 m^2 light-grey concrete floor with 0.15 m insulation, without matte black coating. External walls are made of 3.0x0.8x0.4m straw panels with 120 kgm^{-3} density and 15% humidity level of the straw; the heat conductance in the panel center is U = 0.23 W $m^{-2}K^{-1}$.

3. Research provisions

Two types of measurements have been made. The first one involved operator's recording of internal air temperature with alcohol thermometers in three points: first, second floor and attic, and external air temperatures – near the northern façade at 9 a.m., 1 p.m., and 7 p.m. in order to reveal the general dynamics of internal (by levels of the indoor living space) and external air temperatures between December 14, 2015 and February 19, 2016 (the coldest period in southern Primorsky Krai, 68 days), (Fig.7).

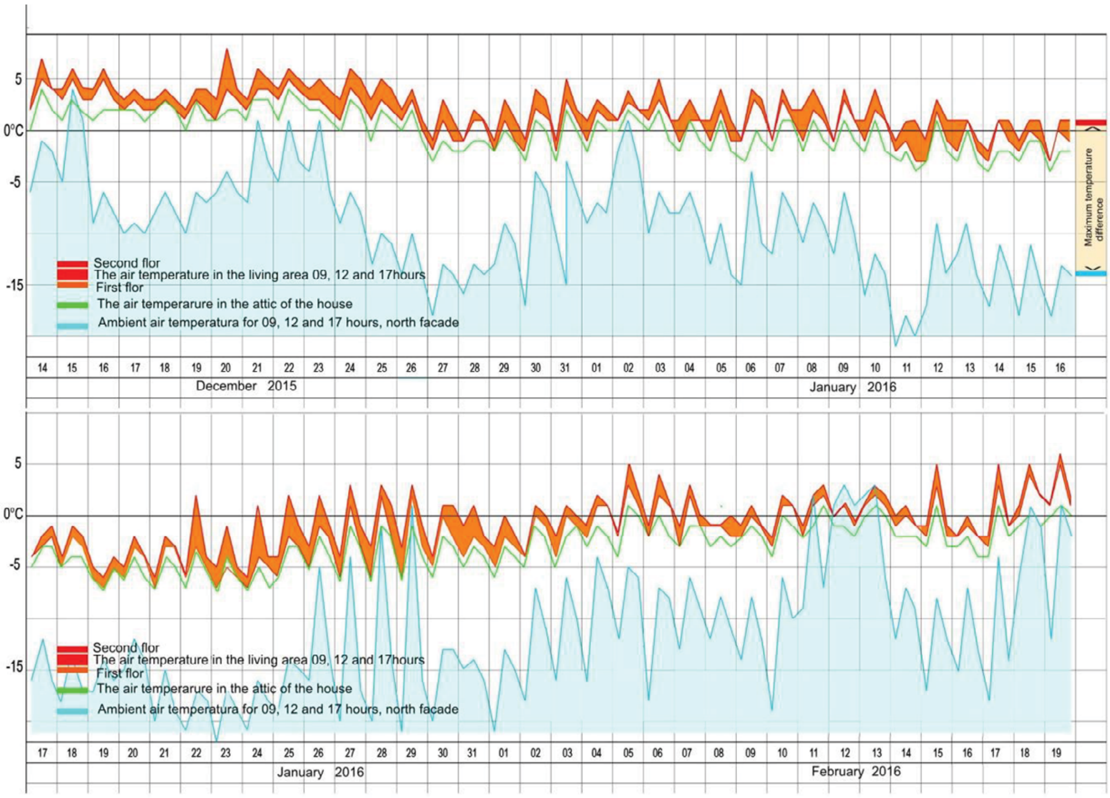

Fig. 7: Operator record results from December 14, 2015 to February 19, 2016

The second type of measurements involved a non-stop recording of external meteorological parameters at automated meteorological stations HOBO Weather Station between February 8 and March 14, 2016 (the complete observation period until March 31, 2016) including the speed and direction of winds, humidity, temperatures, and rate of solar radiation on horizontal surface tilted southward by 450, on southward vertical surface of the vertical stained-glass windows of the house as well as a non-stop recording of the 24-hour dynamics of temperature, air humidity indoors and the rate of solar radiation entering the house through the southward stained-glass window (Fig.8.).

The software developed by HOBOware Pro Onset Computer Corporation was used to assess the observation results at automated meteorological station HOBO Weather Station. Comparison of the data obtained from both types of measurements of the indoor air temperature at the level of 1st and 2nd floors between February 8 and February 19 has shown a high degree of similarity between the results of operator's recordings and observation results at the automated station.

4. Observation of passive solar system properties

Winter temperatures in Primorsky Krai. are much low than those in the same latitudes of the European part of Russia. However, substantial solar resources of the territory can compensate for its low temperatures. Thanks to its south latitude and monsoon climate, Primorsky Krai. has a high potential for developing the generation of thermal solar energy. Radiation balance in the north of the region is 1885 MJm^{-2}, in the south – 2010.2 MJm^{-2}, the length of the sunshine is 1900-2500 hours per year [1]. The majority of sunny days are observed in the cold season (Fig.9).

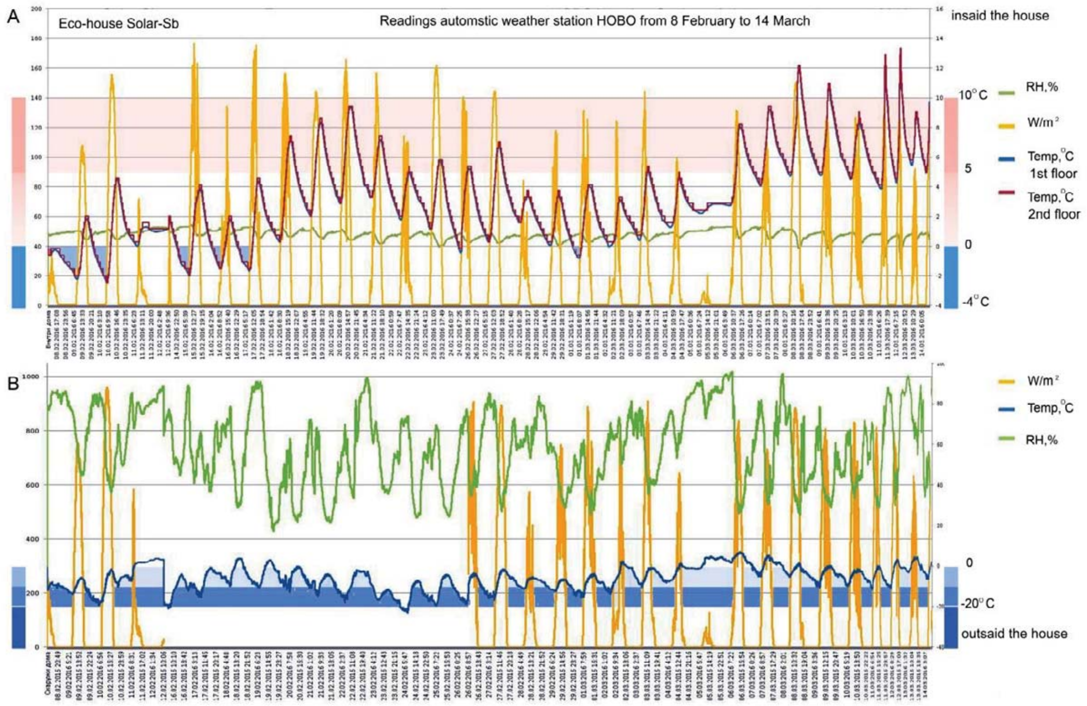

Fig. 8: General view of the readings of the automatic weather station from 8 February to 14 March

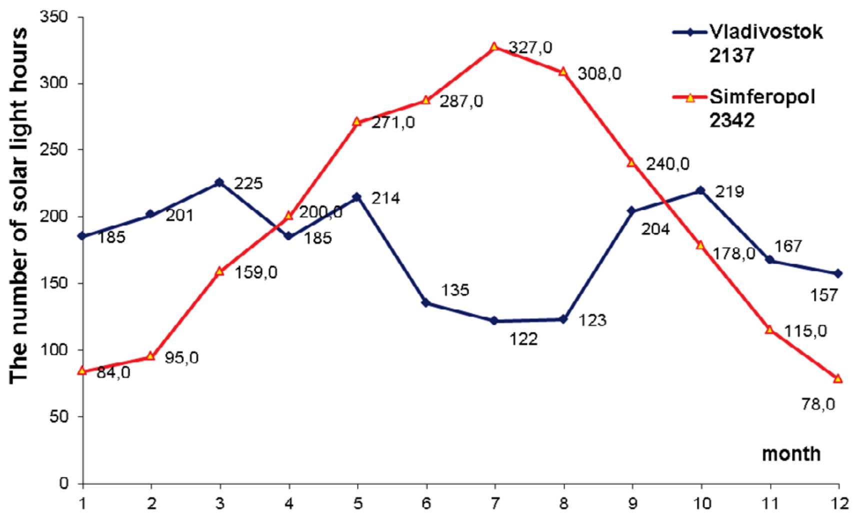

Fig. 9: Duration of solar glowing. Vladivostok and Simferopol

In general, during the observation period between December 14 and March 14, the air temperature in the living spaces of the house (1 and 2 floor) was around 0ºC. The temperature was slowly going down from positive numbers in December (+9ºC on December 20) until the mid-January, reaching the minimum numbers on January 9 after a two-day snowstorm (-7ºC at 13.00 and -4ºC at 17.00). The indoor air temperature started growing with the growing sunshine exposure comprising +7ºC at 1 p.m. on February 19 (Fig.10,11). Out of 92 observation days, the daytime air temperatures below 0ºC were recorded inside the living section of the house only during 6 days – January 17-21 and January 23. The temperature about -5ºC inside the house at night was registered only for 4 days. At the same time, the daylight air temperature -10ºC and below in the basin of the horticultural cooperative Serebryanka (Novyi settlement) was observed for 26 days, below -15ºC at night – for 34 days.

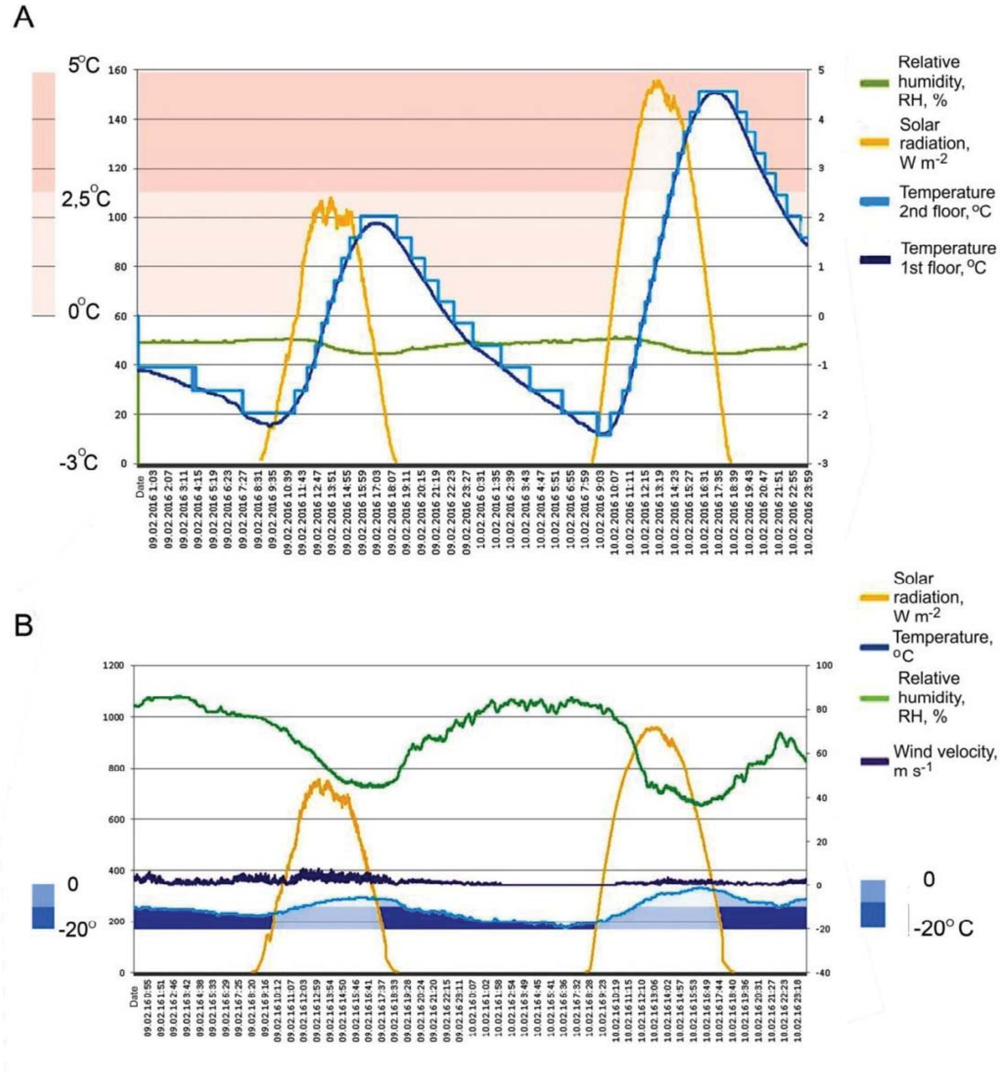

Fig. 10: General view of the readings of an automatic weather station on 9-10 February.

A - in the house, B - outside the house.

Maximal numbers of integral flow of solar radiation through the vertical southward stained-glass window of the atrium were 150 – 179 Wm^{-2} around noon – much lower than the numbers observed on the vertical outside surface of the house – 775 – 1039 Wm^{-2}. All figures and tables should be cited in the text, numbered in order of appearance and followed by a centered title. All table columns should have a brief explanatory heading.

Maximal difference between external and internal air temperatures in the coldest days with minimal cloud cover have reached 12 – 20ºC (for example, 11.01, 23.01., 9-10.02., 16.02). During the days with clear sky, the lowest temperatures inside the house were registered about 9 a.m., the temperature minimum held until 11 a.m. despite the incoming solar heat through the southwards stained-glass windows approximately from 9 a.m. Starting from 11 a.m., the air temperature in the house grew substantially reaching the maximal numbers by 5-6 p.m. when incoming solar heat through the southward window was already dramatically low. The observed maximum of internal temperatures lay behind the maximum by 3 hours approximately. (Fig.10,11; Tab.1,2)(days with clear sky and minimal outdoor temperature in February).

Good inertia properties of the house were also shown by the obvious consistency of indoor air temperatures regardless of dramatic changes in the outdoor air temperatures; for example, from -6ºC down to -21ºC in three days in January (9-11.01, Fig.7). High circadian dynamics of external temperatures can probably be attributed to the effect of the night air drainage and accumulation of cold air in the basin of the horticultural cooperative Serebryanka (Novyi settlement).

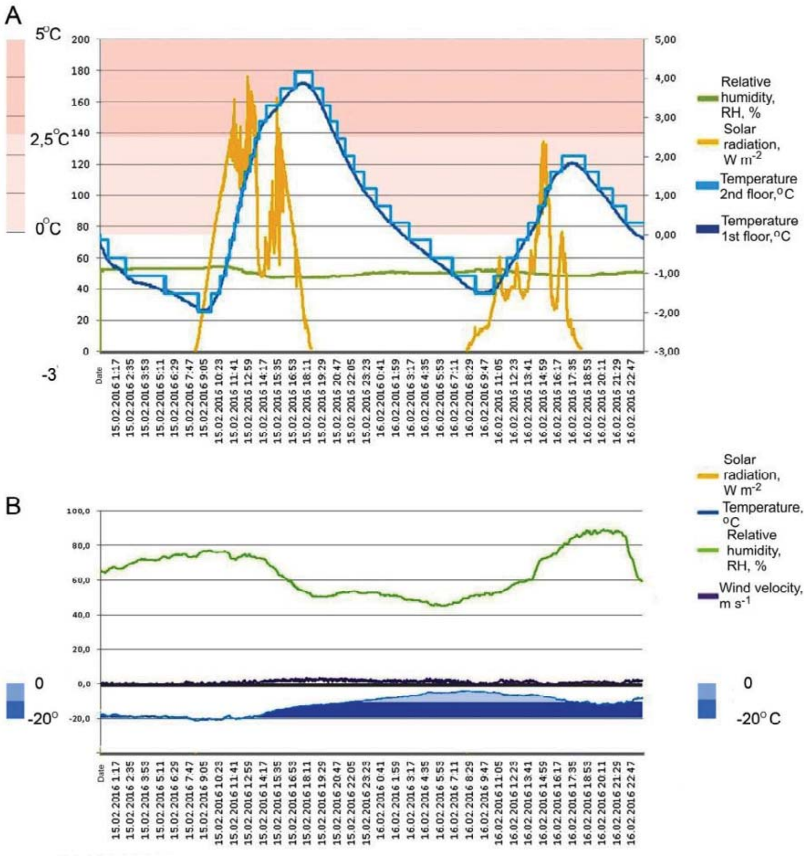

Fig. 11: General view of the readings of an automatic weather station on 15-16 February.

A - in the house, B - outside the house

Tab. 1: Sample readings automatic weather station on 9-10 February

Local time	0 09:00	10:00	13:00	14:00	17:00	18:00	21:00	24:00	03:00	06:00	09:00
Temperature, 1st floor, T°C	-2,18	-2,18	-0,59	+0,41	+1,89	+1,75	+0,49	-0,62	-1,27	-1,84	-2,39
Temperature, 2nd floor, T°C	- 1,97	-1,97	-0,6	+0,29	+2,03	+2,03	+0,73	-0,15	-1,05	-1,51	-1,97
Temperature outdoor, T°C	- 13,8	-13,1	-8,63	-7,38	-6,19	-6,73	-12,4	-14,6	-16,3	-18,2	- 16,8
Solar radiation	4.4	23,1	104,4	104,4	44,4	10,6	0,6	-	-	0 0,6	14,4

W m-², inside											
Solar radiation W m-², outside	29,4	179,4	738,1	775,6	334,4	90,6	0,6	-	-	0,6	1 58,1
Humidity in the house, %	50,25	50,25	49,25	47,25	44,75	44,75	47,25	49,25	48,75	49,75	50,25
Humidity outside, %	76,25	73,25	58,25	52,75	45,25	45,25	67,75	76,25	84,25	79,25	81,75
Wind velocity, NW, m s^{-1}	3,53	2,23	6,31	4,45	2,97	3,71	2.01	0,93	0,0	0,0	0,0

Tab. 2: Sample readings automatic weather station on 15-16 February

Local time	**18:00**	**21:00**	**24:00**	**03:00**	**06:00**	**09:00**	**13:00**	**14:00**	**18:00**	**21:00**	**24:00**
Temperature, 1st floor, TºC	+3,88	+2,37	+0,88	-0,7	-0,78	-1,41	-0,39	+0,05	+1,80	+0,79	-1,12
Temperature, 2nd floor, TºC	+4,15	+2,46	+1,17	+0,29	-0,6	-1,05	-0,15	+0,29	+2,03	+1,17	+0,29
Temperature outdoor, TºC	-15,8	-16,1	-17,6	-17,8	-20.2	-17.2	-9.7	-8,26	-5,05	-10,3	-8,38
Solar radiation W m-², inside	21.9	0,6	-	-	0.6	09,4	41.9	63.1	06,9	0,6	-
Humidity in the house, %	47,25	47,75	50,25	50,75	50,25	51,25	50,75	50.4	48,25	49,75	50,75
Humidity outside, %	56,25	58,25	65,25	66,25	73,25	71,75	52,25	50,75	51.25	80,75	59,25
Wind velocity, SE, , m s-1	0,3	0,3	0,56	0,0	0,74	1,86	2,41	1,3	0,16	0,56	2,41

5. Observation results

Disadvantages of the traditional scheme: Observation results have shown the need in adding a convectional solar system to work mostly in the morning to the passive system of solar heating of the house. They also seem to confirm a positive effect of additional solar heating of the house in the evening in February through the westward stained-glass windows (the total area of stained-glass windows is 12.5 m²; the amount of incoming solar radiation was not estimated).

Evaluation of the passive system contribution: As a result of unfinished interior works, the volume of space heated by the passive solar system was a third bigger than designed in the winter of 2015-2016. Thus, there were no dividers between the living and the buffer zones, there was no warm floor between the second level and the attic, and the attic was not insulated completely; the wind porches had not been built yet for the front and back doors. Also the interior straw panels were not covered with clay plaster. This partially explains a high inertia of the system in the morning hours of solar exposure as well as a substantial circadian dynamics of temperatures inside the house during the

observation period (in some days 6-7°C decrease from the day maximum to the minimum at 9 a.m.).
Nevertheless, to confirm the effectiveness of passive solar heating in the southern Far East, the data obtained can be taken into account. First of all the data of the passive system should be expected to improve after the warm contour of the attic is completed. Also, a passive solar system with direct gain was not designed as the main heating system, but the data obtained showed its high potential for contributing to the overall house heating system. It also took into account the fact that continuous monitoring of the passive solar system during the all cold period was carried out in the region for the first time.

6. Additional heating the house from renewable energy sources.

Taking into account the obtained data, we can propose that the traditional architectural solution can provide relatively comfortable conditions on a sunny winter day, replenishing up to 50% of the required heating. Since the number of sunny days per winter is about 80% it is possible to consider the autonomous system of generating heat from renewable energy sources for single-family houses in region.
In accordance with the project design, the passive solar system works together with the active solar system of heating and hot-water supply based on vacuum trickle collectors SUNRAIN TZ58-1800-25R1 (was not installed yet during the observation period). Photoelectric panels were supposed to support the autonomous functioning of the solar system of heating and water supply. But the system improvement may be proposed.
In the conditions of cold monsoon climate of Russian Far East, this design of a house needs a combined system of heating and cooling with a solar-geothermal heat pump (GSHP) [6, 7]. A hybrid system and seasonal accumulation of heat surpluses from the solar system and cold from the winter night air will provide for 90% of the annual heating and cooling. The remaining 10% will be used as electricity for devices, automatic equipment, a reverse-running heat pump and will be provided by the photoelectric panel. The exploitation results obtained for the hot-water supply and heating solar panels created by the Laboratory 07 of FEB RAS IMTP (Fig.12), [8], confirm the efficiency of using solar power in south part of Far East in a single-family house construction, which is of great importance in terms of preserving natural resources and establishing a prospective sustainable model of natural resource exploitation in the region.

Fig. 12: Experimental solar installation of hot water and heating.

7. Conclusion.

The research conducted in the constructed passive solar house in the winter of 2015-16 with no additional heating sources is relevant since it has confirmed a high efficiency of passive solar architectural solutions, even within a traditional architectural model of the solar house. High efficiency of a passive solar system and simultaneous use of a seasonal active solar system make it possible to consider dwelling houses autonomous from the heating utility networks in the region.

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