New solutions for solar energy: aesthetics and return on investment

V L Ruposov¹ and A Belikov²

¹Irkutsk National Research Technical University, 83, st Lermontov, Irkutsk 664074
²Baikal State University, 11 Lenin St., Irkutsk 664003
E-mail: ruposov@istu.edu

Abstract: Improving the aesthetic requirements of the design elements led to the fact that the solar panel and solar tiles are design element. Solar roof tiles are a new technology and have increased their energy efficiency and aesthetics over the 10 years of their existence. An alternative technology of thermoelectric generators has a lower level of efficiency, but at the same time it can work even without solar radiation. The analysis of the payback of solar panels showed that the sensitivity of the use of technology depends not only on the cost of the equipment itself, but also on the cost of traditional energy sources. The prospects for new solutions will depend on the reduction in the cost and increase in the cost of electricity for the household consumer.

Siberia makes effective use of solar cells, is associated with a large number of sunny days per year. The central and eastern part of Siberia is located in favorable areas for solar energy. The southern regions of Siberia are one of the highest regions in Russia in terms of the amount of solar radiation. The features of the distribution of total solar radiation are shown in Figure 1. The development of solar energy does not have high rates in the regions of Siberia for the following reasons:

- High cost of solar cells and devices for storing electricity.
- Long winters, which reduce solar energy efficiency as shown in Figure 2.
- Abundant snowfall, reduces the efficiency of the solar cell to zero.
- Low cost of electricity, for example, in the Irkutsk region for household consumers, the cost is 1.17 rubles per kWh for cities, and even lower for rural areas.
- Aesthetic features of solar panels.
- Sophisticated roof structure with solar panels.

All these drawbacks are collectively very strong brake on the development of solar energy in the private house building. Especially when installing solar panels on the roof of buildings. When building a private house, the project tries to provide for the creation of a roof using solar panels. It is necessary to consider not only the technological features of the creation of the roof, but also the ability to create a specific design. The purpose of this article is to consider the proposed design solutions and identify the payback parameters of solar energy elements. To achieve the goal, two tasks must be solved. The first is related to the proposals on the market for new design solutions for solar energy and the prospects for the technologies being introduced. The second challenge is the cost-effectiveness of these solutions.
Solar energy technologies are relevant for the territory of Siberia, where there is a sufficient amount of solar radiation and a high cost of creating infrastructure [1], but there is a demand for the construction of modern individual housing [2]. This is especially associated with the development of
ecological tourism, when solar energy brings minimal impact on the environment, while allowing you to create a certain comfort of human stay in a given area [3].

It should be noted that solar energy uses not one technology, but a series of solutions in this area. The main technical implementations of solar energy were reviewed. The very first methods of using the energy of the sun were solar panels, which from their use in space were applied on earth and are now being successfully mass produced and are constantly increasing their efficiency.

The issue of embedding solar panels in urban architecture and various design solutions have been discussed in the literature [4, 14] since the beginning of the appearance of solar panels. Over the past decade, many publications have appeared discussing the possibility of updating the architecture of cities and buildings, taking into account the use of modern solar installations [5, 15, 16].

In 2011, Colorado, USA, implemented solar panels based on photovoltaic tile technology. Dow offered solar shingles, not as standalone solar panels, but as a roofing material with innovative properties. The company now offers various solar roof tile solutions (see Figure 3).

For designers who are interested in creating facilities with a high level of energy saving, and even those who plan to obtain BREEAM and LEED certificates, the use of such solutions is very promising. The use of solar panels in the construction of buildings can be a fashionable step, this is due to low efficiency. Now mass-produced panels have 10-20% efficiency. It should be noted that due to the variable angle of incidence of sunlight during the day and year, the efficiency without re-tuning the panel will be lower. Researchers are improving the efficiency of solar cells, so a joint development of the French company Soitec and the German Fraunhofer Institute have developed panels with an efficiency of up to 46%.

Initially, solar roof tiles were much less efficient than solar panels. So the first serial samples had an efficiency of only 10%, then by 2020 new thin-film photocells based on copper-indium-gallium selenide (CIGS) appeared on the market, which made it possible to increase the efficiency to 19.9%. Therefore, both solutions energy efficiency close to each other [6]. But such a promising direction as the use of thermoelectric modules as solar cells cannot yet approach even 10%. Therefore, the technology based on the temperature gradient associated with solar radiation does not yet have commercial prospects.

Even Russian manufacturers decide the issue of creating solar panels with certain design solutions, for example, the Federal State Budgetary Scientific Institution "Federal Scientific Agroengineering Center VIM" (VIESH) have developed modules made of solar cells of various shapes, such as pseudo-square, square and circle and sizes (100 and 125 mm). Cells are used both single-sided and double-sided to generate power from both sides and increase the electrical output. The unusual arrangement of solar cells allows the creation of various ornaments (see Figure 4), which brings individuality to architectural solutions. The Company uses various types of glass and filling in between. Compared to standard solar modules, such solutions allow you to diversify the appearance of buildings through pattern, color and transparency [7].
At the same time, the solar roof tile solution has more possibilities for creating new designs and imitating existing solutions for roofing. One of the reasons for the higher potential of such solutions is the ability to solve two problems at once. Building roofing and installation of solar cells. In the classical installation of solar panels, the need to create the roof remains, but this is necessary to implement special design elements for mounting solar panels. In Russia, they are experimenting with the creation of solar tiles from recycled plastic materials [8].

More massive solutions for the production of various types of solar roof tiles are associated with the creation of photovoltaic thin surfaces. Various countries (Italy, USA, Germany, etc.) are engaged in the production of such materials, one of the leading manufacturers is the Italian company Tegola. Consider the device of the TegoSolar photovoltaic roof tile manufactured by this company. It consists of a PVL 68 photovoltaic cell fixed to a bituminous base. PVL 68 cell consists of galvanic cells, which, in turn, are made of amorphous silicon "triple compound" obtained in the process of vacuum evaporation - a thin silicon film in 3 layers is deposited on a stainless steel carrier foil and sealed on both sides with polymers (ethyl vinyl acetate EVA, Tefzel® ETFE fluoropolymer). The Tefzel® polymer coating on the face of the PVL 68 element makes it UV and weather resistant [9] (Figure 5).

It should be noted some of the advantages of TegoSolar photovoltaic tiles, easy integration into the roof and relatively quick installation, does not require additional load-bearing structural elements, durable, not afraid of damage (does not contain glass), you can walk on it, weather-resistant, non-reflective surface, the polymer coating is self-cleaning by means of conventional rain [9]. The material is flexible in contrast to other solutions [12, 13].
In 2016 it was first introduced solar shingles Tesla Solar powered by Tesla. I. Mask's company immediately offered an aesthetic solution to the problem of creating a roof from solar tiles. Therefore it has been proposed several solutions for the design of roofing materials. The technology developed by Tesla makes it possible to hide the solar cells themselves behind the surface layer. The design of this tile turned out to be varied, shown in Figure 6.

The main strategy for the implementation of solar shingles is design diversity, originally planned to create four options, the most common roofing materials in North America. It is a shingle in four styles:

- Tuscan - under the clay tiles, typical for Italian and Mediterranean architecture;
- under slate - in the form of a classic "aged" slate in the western style;
- textured - with deep grooves, creating the effect of a noble aged texture;
- smooth - with a luxurious polished surface.

The main feature of Tesla tiles is that the photocells, due to the well-thought-out angle of inclination under which they are located inside the panel, are invisible from the ground, they can only be seen when viewed from above. The roof tile consists of three layers are shown in Figure 7:

1. Tempered glass - the outer layer, which provides reliable protection for the entire structure;
2. The colored mesh film - the middle layer of this sandwich - provides a natural looking roof and at the same time is transparent to sunlight;
3. The bottom layer is a high efficiency solar panel that generates electricity.

For the production of Tesla Solar shingles, quartz glass is used, which ensures durability, even in comparison with traditional slate or bituminous shingles [11].
For the northern territories, including Siberia, the sun is abundant in summer and shines more than 12 hours a day, and in winter the sunny day is extremely short, the efficiency of year-round use of even solar tiles is low. Solutions based on thermoelectric generators can be used. The construction of the proposed shingles will consist of three layers. The top layer is ceramic, transparency for thermoelectric modules is not needed, even a black surface will be more effective. The bottom layer will consist of a polymer material that allows you to completely isolate from external influences on the thermoelectric module of the Peltier type. When heated in the sun, there will be a temperature difference between the sun side and the inner surface. The maximum temperature gradient will be 50–60 °C. Despite the low level of efficiency (less than 5%) for such modules, the advantage will be the operation of the tiles, both during the daytime and at night, when the temperature gradient is reversed. Moreover, the maximum temperature gradient in winter can be 40-50 °C.

To calculate the cost-effectiveness of solar tiles take data previously calculated in [6]. The calculation will be made on the example of a two-family block house. We will not take into account the heating costs, let us take the average electricity consumption for household appliances in the amount of 9.3 kW * h / day. Let us take the level of solar radiation for the latitude of the city of Irkutsk. The average annual energy production by a solar battery per day is assumed to be 0.265 kW * h / m² [6, 12]. To generate 9.3 kW * h / day we need 36 m² of solar panels. Considering that a ready-made solution costs about 10 thousand rubles / m². Therefore, we can calculate the cost of solar panels in the amount of 360 000 rubles. And with the cost of electricity in Irkutsk 1.17 rubles per kW / hour, the payback period will exceed 90 years. Therefore, an analysis was carried out, at different costs of electricity and at different capital costs for the purchase and installation of solar tiles.
Figure 9 shows that the relationship between the cost of electricity and the payback period is non-linear, so this curve can be called logistic. Consequently, the curve has optima. The influence of the cost per square meter of solar tiles also has a non-linear relationship.

The increase in the aesthetics of solar panels and the appearance on the market of solar tiles can be attributed to the trend of increasing requirements for the appearance of building structures. New technologies are leading to an increase in the aesthetics of innovation, and in some cases even to the invisibility of solar cells through sophisticated solutions. The research payback for new solar solutions for private homes is highly dependent on the cost of traditional energy sources. The payback at the current cost of solar tiles will be less than 20 years, only if the cost of traditional sources is above 5 rubles per kW / hour.

References
[1] Mashovich A, Ruposov V and Moskvitin V 2018 Developing a model of effective growth for small and medium business for sparsely populated and remote areas within the framework of the green economy concept (based on the example of the Irkutsk region) MATEC Web of Conferences 212 08011
[2] Mashovich A, Ruposov V and Moskvitin V 2018 Development of technology of production of powlines for conducting works with the use of local types of raw materials in low-populated and district areas Proceedings of universities. Investments. Building. The property 8 pp 112-121
[3] Zaiatdinov O, Mashovich A, Gavrishchuk V and Ruposov V 2018 Modern and traditional ways of ensuring the fire safety of tourist industry objects in relation to Olkhon Island Baikal Science: Ideas, Innovations, Investments: Collection of materials of the All-Russian Scientific and Practical Conference - Irkutsk: FGBOU VO IRNITU pp 84-90
[4] Farkas K, Frontini F and Maturi L 2013 Designing photovoltaic systems for architectural integration MC Munari Probst, C Roecker IEA SHC Task 41
[5] Sarettab E, Caputoa P and Frontinia F 2019 A review study about energy renovation of building facades with BIPV in urban environment Sustainable Cities and Society 44 pp 343-355
[6] Bykova I and Bazhenova E 2017 Advantages of a transition from solar panels to solar roof tile
StudArctic Forum 7(7) pp 41-47

[7] Panchenko V 2014 Review and applications of solar modules developed and produced by viesh Bulletin VIESH 4(17) pp 20-29

[8] Panchenko V 2019 Planar photoelectric roofing panels in the form of tiles In the collection: Fedorov Readings pp 288-294

[9] Kalashnikov M P 2020 Study of the air environment state in the building for the storage of perishable products Proceedings of Universities. Investment. Construction. Real estate 10(2) pp 206–211

[10] Ageenko M V and Deyenkov A I 2015 Photogalvanic tiles Science Magazine. Engineering systems and structures 4(21) pp 49-51

[11] Patent RF 2493338 Photoelectric bitumen tiles, method to manufacture photoelectric bitumen tiles and method to lay photoelectric roof. Kappelli Ful'vio, Tegola Kanadeze SPA. Declared 23.01.2009. Published 20.09.2013 Bull. 26

[12] Panchenko V 2018 Solar Roof Panels for Electric and Thermal Generation November Applied Solar Energy 54(5) pp 350-353

[13] Patent US 8,713,861 B2. Roof tiles and related systems. William Gilbert, Gisele Ford. Declared Nov. 7, 2013. Published May 6, 2014 Bull. WO2012/078491 (In USA)

[14] Patent US 8,196,360 B2. Photovoltaic solar roof tile assembly system. William Gilbert, Clark & Brody. Declared Jul. 12, 2007. Published Jun. 12, 2012 Bull. 11/643,825 (In USA)

[15] Ferruccio F and Robert J H 2016 Energy Return on Energy Invested (EROEI) for photovoltaic solar systems in regions of moderate insolation Energy Policy 94 pp 336-344

[16] Reinders A, Doudart de la Grée G, Papadopoulos A, Rosemann A, Debije M G, Cox M and Krummer Z 2016 Leaf Roof – Designing Luminescent Solar Concentrating PV Roof Tiles EU PVSEC 2016 At: Munich, Germany

[17] Doudart de la Grée G C H, Papadopoulos A, Debije M G, Cox M G D M, Krummer Z, Reinders, A H M E and Rosemann A L P 2015 A new design for luminescent solar concentrating PV roof tiles Proceedings of the 42nd Photovoltaic Specialists Conference