Model for the economic effects of modern glazing and solar panels in Russian conditions

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Abstract

Russian market of glazing contains all wide range of the well-known products including the most high-technology ones. In 2007 – 2008 new mass market thin-film solar panels became novelty on our market. Using of such panels in the opaque parts of the facades can potentially lead to significant savings of the heat and electricity funds.

Our work covers economic justification of high-technology glazing application and inclusion of solar panels facade elements based on comparably simple mathematical model with the conditions of Russia. The model takes into account the following characteristics: heat and electricity price dynamics, climatic conditions of the various Russian regions, location of the building on the ground. Previously there were no such thorough studies in these fields in Russia; some problems were considered for the first time.

The most interesting results of our work are:

- Optimization problem was posed for the energy-efficient properties of the glazing for the different conditions and combinations of the different glazing constructions in one project. Glazing with highest possible energy-efficient characteristics is money's-worth for the coldest regions.
- Analysis of the payback period for the solar panels showed that currently expenses for such constructions could be returned for the most part of the Russian territory. Taking into consideration declining of the panel prices this result may be regarded as very important for the future of the solar panels industry in Russia.

Keywords: climate, solar panels, numerical modeling, optimization.

1 Introduction

Alternative methods of energy production and saving take more and more attention nowadays. There is no surprise in that because traditional ways of energy production base on exhaustible resources. Our work deals with conservation of heat energy in building. This problem is very important for our country for many reasons.

Every resident of Russia and every enterprise excluding southern regions spends comparably enormous money for building heating. Specific consumption of energy in Russia exceeds numbers of advances countries tenfold. So special efforts must be initiated for increasing of energy consumption effectiveness. Buildings with high costs for electricity and heat became less interesting for customers these days. Comfort is demanded in combination with the lowering of energy expenses and these factors can be critical in competitive activity on the construction market.

All these reasons lead to raising interest in the modern types of glazing including solar panels. Today all types of modern glazing are introduced on Russian market so we can compare their effectiveness in the various conditions.

Another new architectural idea is the replacement of enamel glazing to the solar panels in full-glazing facades. Using of such panels in the opaque parts of the facades can potentially lead to significant savings of the heat and electricity funds, but the concept was not proven yet for the Russian climatic conditions. That was one of the problems which we considered for the first time.

Our work also covers economic justification of high-technology glazing application based on comparably simple mathematical model with the conditions of Russia. The model is simple in architectural terms but takes into account a lot of economical and physical characteristics: heat and electricity price dynamics, climatic conditions of the various Russian regions, location of the building on the ground.

2 Energy carriers costs forecast

First stage of our research included the forecast of the heat and electricity for the 10-years period at least. Of cause this part of work was not directly connected to glazing so here we discuss only general results.

After deep research of the field and some expert estimation we reduced the problem to model with stochastic time series. These time series was analyzed with ARIMA methodology. The ARIMA methodology was developed by Box and Jenkins in 1976. ARIMA is a complex technique but it is applicable in very wide range of series analysis.

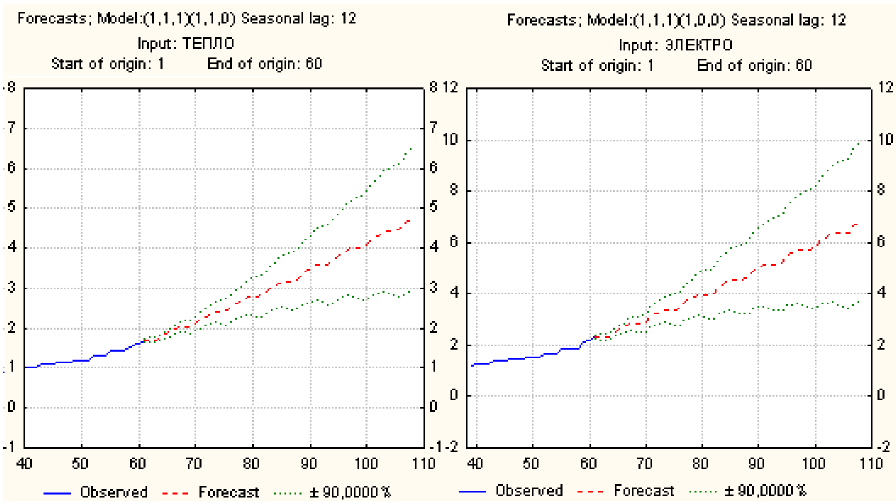

Figure 1. Forecast for the heat (left) and electric power (right) prices.

Figure 1 demonstrates forecasts for electric power and heat power prices. Starting data was provided by www.gks.ru and includes 10 years information.

3 Optimization of the heat cost for the building

In this work we considered that there are two main ways for heat costs reduction: application of energy-efficient glazing and additional unattended power source which can help with ventilation, conditioning etc.

In the climatic conditions of Russia, unfortunately, it is not possible fully exclude consuming of external power and heat. In our northern latitudes solar radiation per 1 m^2 is 3-5 times less than in Southern Europe. Also average amount of sunny days per year does not favor solar panel application. But as additional source of energy they can be used in any region. Zero-consuming building here is still kind of fantasy but external resources could be minimized.

3.1 Optimization model

Our problem statement is minimization of energy consumption by using of most effective IGU and solar panels. For the model we use comparably simple building project that was constructed in Orenburg city. This is the square in plan 9-m-high fully glazed office building.

Thermal characteristics of building envelope were calculated according to Building Codes SNiP II-3-79* and SNiP 23-02-2003 [2, 3].

According to them heating have to compensate heat loss during cold season and ensuring support of air predetermined temperature t_{in} inside.

Thermal balance equation looks like:

$$Q_{tot} = Q_{tr} + Q_{leak} - Q_{gen} - Q_s \qquad (1)$$

where Q_{tot} is total heat loss, [W]; Q_{tr} is transmission losses through envelope, [W]; Q_{leak} is cold air leakage, [W]; Q_{gen} is generation of heat inside building, [W]; Q_s is absorbed solar radiation, [W].

Q_{tr} is the most important part of the heat loss, so Q_{leak} and Q_{gen} could be ignored or simplified in most practical cases at least for modern office buildings. Average generated heat from 1 person for air temperature of 18 °C is 115.2 W.

Transmission losses could be found from the following equation:

$$Q_{tr} = (\sum_{i=1} S_i * k_i) * (t_{in} - t_{out}) \quad , \qquad (2)$$

where: $S(i)$ is the area of one envelope element or window, [m^2]; $k(i)$ is thermal conductivity coefficient for this element, [$W/(m^2*K)$]; t_{out} is average monthly outside temperature, [°C]; t_{in} is required inside temperature, [°C]. Equation (2) gives us Q_{tr} for every month of the year, so we can sum it to calculate total heat loss through envelope per year.

Absorbed solar radiation Q_s depends from region, position of the glazing and glazing characteristics.

Energy balance of the glazing can be calculated by the following formula:

$$E = U - f * S_f \ , \qquad (3)$$

where S_f is region-specific function, W/(m^2*K):

$$S_f = H/D, \qquad (4)$$

D is degree-day [K*day]; H is incident solar radiation without obstacles [KW*hour/m^2 or MJ/m^2]; f is shading coefficient; U is thermal transmittance (U-value) [W/(m^2*K)]; E is energy balance, i.e. energy flow through 1 m^2 of the glazing, [W/(m^2*K)].

So total absorbed solar radiation could be computed as a sum of energy, absorbed through different envelope elements:

$$Q_s = \sum_i Q_{s_i}, Q_{s_i} = E_i * A_{gl_i} * (t_{out} - t_{in}) \quad , \qquad (5)$$

where A_{gl_i} is area of i-th type of glazing, [m^2].

We took into account here that different types of the glazing could be used on the different sides of one building.

Annual consumption of the heat power, Q [KW*hour], was calculated according to the next formula:

$$Q = Q_{tot} \cdot T_{heat}, \qquad (6)$$

where T_{heat} is duration of heating period of the given region.

Let's summarize our optimization model:

$$\begin{cases} Q > Q_{norm}, \ Q_{norm} \text{ is heat power consumption for comfort temperature support.} \\ A_{gl}(i) * C(i) \rightarrow \min, \text{ where } C \text{ is cost per 1 m}^2 \text{ of } i\text{-th glazing.} \\ Q_{hp} * C_{hp} \rightarrow \min, \text{ where } C_{hp} \text{ is heating cost.} \end{cases}$$

This optimization problem was solved by linear programming methods with only one variable: U-value of the glazing. Here we took into account dependence between U-value of the glazing and its price for the selected types of IGU.

For the optimization we need to specify the following characteristics of the building (prices can be functions of time):

- S_i – area of every types of envelop construction;
- H – building height;
- k_i – heat transfer coefficient of every surface;
- U – U-value of glazing;
- f – shading coefficient;
- A_{gl} – glazing area;
- C_i – price per 1 m^2 of i-th type of the glazing with coefficient k_i;
- C_{hp} – heating price per KW*h;
- C_{el} – electric power price per KW*h;
- C_{panel} – price per 1 m^2 of the solar panel;

- P_p – nominal output of the solar panel in [KW];
- Region (climate conditions could be found in [4]).

3.1.1 Solar panels application

When we decided to include electrovoltaic elements in our model, we added the following considerations:

First of all, we need to know average annual consumption of electric power. Statistical data said that it lies between 80 and 150 KW*h/m^2 per year.

Secondly, actual output of the solar panel will be much smaller than its nominal peak output. Power P of the panel could be approximate as:

$$P\ (KW\bullet h/day) = P_p\ (KW) \cdot I\ (KW\bullet h/m^2\ per\ day) \cdot PR, \qquad (7)$$

where P_p is nominal output in [KW] of full solar panel; I is exposition of solar radiation on the surface in [KW•h/m^2 per day]; PR is productivity factor of the system.

Typical productivity factors are the following:

- 0.8 for the systems, interfaced to the power grid;
- 0.5 – 0.7 for the hybrid systems;
- 0.2 – 0.3 for the autonomous systems with the whole year exploitation.

3.1.2 Compared regions

For the illustration of the results we choose two regions: one of the northern regions of Arkhangelsk and Sochi as one of the most southern cities of Russia.

Sochi, both orientations:

orientation	***N/W***	***N/E***	***S/E***	***S/W***
U-value	5.80	5.80	5.80	5.80

Arkhangelsk:

orientation	***N/W***	***N/E***	***S/E***	***S/W***
U-value	2.70	2.70	2.70	2.70
orientation	***N***	***E***	***S***	***W***
U-value	2.62	2.51	5.58	2.50

Table 1. Optimal U-values for the various orientations of the building in Sochi and Arkhangelsk.

	City			
	Arkhangelsk		***Sochi***	
	orientation		***orientation***	
	N/E-S/W	N-S	N/E-S/W	N-S
Total heat loss	26 275.05	26 275.05	26 275.05	20 024.56
Total heat gain	173 561.73	163 260.14	295 150.56	291 248.24
Annual heating consumption	1 201.82	1 212.13	225.50	223.92
Heating cost, p	29 544 284.05	29 797 526.53	5 083 819.56	4 987 889.34
Glazing cost, p	3 149 358.66	3 149 358.66	3 149 358.66	3 149 358.66
Total cost, p	32 693 642.71	32 946 885.19	8 233 178.22	8 137 248.00

Table 2. Costs of the heat for the various orientations of the building in Sochi and Arkhangelsk.

To find productivity of solar batteries we use the following data: inner area of the building is 7464.09 m^2; estimated power output per 1 m^2 of solar panel in Sochi is 1239.28 KW per year, and 1183.25 KW per year in Arkhangelsk.

The model showed that inexpensive and low power batteries are preferable now. Other important result is that application of solar batteries could be cost recovery in the all Russia southward of Polar Circle, but payback period is up to 10 years for the northern regions. For the Sochi payback period for optimal solar panels from our selected set is about 5 years.

Analysis of building position on the ground shows that for the southern regions energy-optimal orientation is close to North-South orientation, but for the northern regions building have to be rotated to four-point orientation. It is rational result because for the south region south side of the building gives most energy, but for the north region north façade loses most energy.

4 Conclusion

In the course of our work we conducted economical analysis of state-of-the art glazing and solar panels in strict climatic conditions of Russia. Research took into account contribution of these constructions to the energy balance of the building. We tried to include in our set all representing mass production types of IGU and available solar panels. This is first attempt to do such observation for Russian market.

The most important obtained results are the following:

- Optimization problem for the glazing in building project between its price and energy-efficiency is stated. Corresponding program was developed.
- Some calculations for the set of IGU and symbolic project in various climatic regions were made.
- We calculated that it is possible to save up to 30% of heating costs by the optimization of the glazing and orientation of the building.
- Effectiveness of solar panel application was estimated. It was shown that contemporary solar panels are still insufficient in its price/efficiency ratio for the using on the most of

the Russian territory. But optimistic prognosis of price decreasing makes them very interesting in the nearest future.

5 References

[1] SNiP 2.04.05-68 “Heating, ventilation and air conditioning”.

[2] SNiP 23-02-2003 “Thermal protection of the buildings”.

[3] SNiP II-3-79* “Construction heat engineering”.

[4] SNiP 23-01-99 “Construction climatology”.

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