Integration of solar plants into energy systems in apartment residential buildings

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Abstract. Non-traditional renewable energy resources (solar radiation, wind energy, etc.), alternative thermal and electric generators have incontestable positive qualities in comparison with fossil fuel (natural gas, coal, fuel oil), classical systems: relative environmental friendliness, vast total reserves, low operational costs, reliability, ease of management. The scale of their implementation in the Central Black Earth Region can be limited by high initial capital investments, the value of the energy resource, and low awareness of the population. The article presents the results of modeling solar plants functioning during their integration into traditional energy systems of apartment residential buildings. In the article we demonstrate technical and economic indicators of projected and modernized engineering heating services in the city of Voronezh. The technically viable period of use is spring-summer-autumn. Economic indicators put solar systems into the experimental category.

1. Introduction
Today when projecting, building, exploitation and reconstruction of morally and physically obsolete apartment residential buildings apart from providing comfortable microclimate, great attention is paid to energy efficiency. Reduction of energy consumption may be achieved by using alternative sources of energy.

To meet the needs of population the builder develops apartments with larger living areas, and with several levels on the upper floors. During the heating period it leads to substantial rise of exploitation costs which are often compared to the income of the residents. The situation may be improved through the integration of solar plants into traditional energy systems for partial coverage of heating needs.

2. The methodology of determination of gross, technical and economic potential of the integrated solar plants
The expedience to use solar plants for heating needs and hot water supply in apartment residential buildings is justified by the data of gross, technical and economic potential of solar energy [1-8].

Alternative self-renewing energy sources have a number of advantages (ubiquity, large total inventory, relative environmental cleanliness), though, for the reason of wide territorial divergence, irregularity of supply they are limited in use.
There are several methods to determine gross potential of solar radiation on horizontal and vertical surfaces, though the results of the energy resource potential assessments are not always precise. Based on the processing of years-long statistics data of actinometric stations (table 1) the equations were obtained, cloudiness in Voronezh region is determined by means of correction factor (table 2) [1, 2, 3].

**Table 1.** Change of total solar radiation ($Q$) on the horizontal surface depending on geographical latitude ($\phi$), MJ/m², cloudiness adjusted.

| No | Symbols        | Approximation dependence                                                                 | Cloudiness adjusted |
|----|----------------|-----------------------------------------------------------------------------------------|---------------------|
| 1  | $Q_{January}$ | $-614.08 \cdot \ln(\phi) + 2586.09$                                                   | 0.52                |
| 2  | $Q_{February}$| $-600.56 \cdot \ln(\phi) + 2638.10$                                                   | 0.59                |
| 3  | $Q_{March}$   | $-0.16 \cdot \phi^2 + 5.41 \cdot \phi + 677.87$                                        | 0.54                |
| 4  | $Q_{April}$   | $-364.69 \cdot \ln(\phi) + 2108.73$                                                   | 0.58                |
| 5  | $Q_{May}$     | $-150.26 \cdot \ln(\phi) + 1444.03$                                                   | 0.67                |
| 6  | $Q_{June}$    | $0.00005571 \cdot \phi^5 - 0.01486526 \cdot \phi^4 + 1.57018502 \cdot \phi^3 -$ | 0.7                 |
|    |                | $-82.03553868 \cdot \phi^2 + 2117.99506113 \cdot \phi - 20707.95629264$              |                     |
| 7  | $Q_{July}$    | $0.00163130 \cdot \phi^4 + 0.34016927 \cdot \phi^3 - 26.31315104 \cdot \phi^2 +$ | 0.67                |
|    |                | $+896.02144210 \cdot \phi - 12226.70616884$                                           |                     |
| 8  | $Q_{August}$  | $-322.42 \cdot \ln(\phi) + 1988.98$                                                   | 0.68                |
| 9  | $Q_{September}$ | $-570.53 \cdot \ln(\phi) + 2779.51$                                                   | 0.61                |
| 10 | $Q_{October}$ | $-762.80 \cdot \ln(\phi) + 3343.38$                                                   | 0.52                |
| 11 | $Q_{November}$| $-650.10 \cdot \ln(\phi) + 2760.50$                                                   | 0.38                |
| 12 | $Q_{December}$| $-623.75 \cdot \ln(\phi) + 2596.38$                                                   | 0.40                |

**Table 2.** Adjusted coefficient of gross potential attenuation of solar energy (SE) for the Central-Chernozym region of Russia.

| Indicators |         Month of the year         | I    | II   | III  | IV   | V    | VI   | VII  | VIII | IX   | X    | XI   | XII  |
|------------|----------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
|            | The Central-Chernozym region     |      |      |      |      |      |      |      |      |      |      |      |      |
| SE for cloudless sky, J/m² | 163 | 268 | 530 | 670 | 851 | 876 | 882 | 717 | 528 | 333 | 195 | 135 |
| SE in conditions of cloudiness, MJ/m² | 84 | 142 | 289 | 385 | 565 | 620 | 590 | 473 | 326 | 176 | 80  | 50  |
| Coefficient of cloudiness $\psi$ | 0.52 | 0.53 | 0.55 | 0.57 | 0.66 | 0.71 | 0.67 | 0.66 | 0.62 | 0.53 | 0.41 | 0.37 |
| Stone steppe (Voronezh region, 51˚ 43' n.l.) |      |      |      |      |      |      |      |      |      |      |      |      |
| SE for cloudless sky, MJ/m² | 184 | 289 | 548 | 682 | 856 | 878 | 883 | 728 | 548 | 359 | 217 | 156 |
| SE in conditions of cloudiness, MJ/m² | 98  | 176 | 314 | 418 | 599 | 630 | 609 | 515 | 344 | 188 | 86  | 65  |
| Coefficient of cloudiness $\psi$ | 0.53 | 0.61 | 0.57 | 0.61 | 0.70 | 0.72 | 0.69 | 0.71 | 0.63 | 0.52 | 0.40 | 0.42 |
| Kursk (Kursk region, 51˚ 44' n.l.) |      |      |      |      |      |      |      |      |      |      |      |      |
| SE for cloudless sky, MJ/m² | 163 | 268 | 530 | 670 | 851 | 876 | 882 | 717 | 528 | 333 | 195 | 135 |
The results of modeling of solar system functioning in apartment residential building in conditions of the city of Voronezh

The facility under consideration is a new apartment residential building or a building subject to reconstruction due to moral or physical wear out, situated in the city of Voronezh. The basic characteristics of the building are represented in Table 3.

### Table 3. Basic parameters, characterizing the facility.

| Title of the parameter | Value of the parameter                                      |
|------------------------|-------------------------------------------------------------|
| 1. Type of the building | apartment residential building                               |
| 2. Number of floors    | 5                                                           |
| 3. Number of residents in an apartment | From the first to the fourth floor traditional heating system is used, on the fifth floor - the combined one |
| 4. Source of heat energy | From the first to the fourth floor traditional heating system is used, on the fifth floor - the combined one |
| 5. Azimuth of solar collector, degrees | 0                                                           |
| 6. Solar collector inclination angle, degrees | 52 (for the system of hot water supply); 62 (for the heating system and hot water supply) |
| 7. Time horizon        | 20 years                                                    |

The key parameters of the plant demonstrating its competitive characteristics have been determined in consideration with the results of the previously conducted experiments in this sphere [1-8]. They are shown in figures 1-3.

Modeling of integration of solar system into the energy system of an apartment building is shown on the example of one apartment located on the fifth floor. The main distinctive structural elements of the combined heat supply system are: a 12 m² solar collector, a 0.6 m³ water-storage tank, an automatic control and management system, antifreeze is used as a heat carrier in the solar circuit. The parameters of the alternative plant are in the optimal ratio and all the recommendations in the works [2, 4, 5, 8] are taken into account.

The diagrams and graphs presented in figures 1-3 confirm a sufficient level of gross and technical potential of solar energy in the Voronezh region. The value of the annual replacement rate of heat and hot water supply systems for solar plants is 14% and 44%, respectively. The economic efficiency of alternative heat generators constrains their large-scale implementation at the current cost of heat of 2262.71 rubles per Gcal in the city of Voronezh.
Figure 1. The level of monthly heat generation by the solar system of hot water supply in the climatic conditions of the city of Voronezh: a) replacement rate; b) heat generation by the solar plant and terminal unit.

Figure 2. The level of monthly heat generation by the solar plant of hot water supply in the climatic conditions of the city of Voronezh: a) replacement rate; b) heat generation by the solar plant and terminal unit.

Figure 3. Dependence of solar plant payback period a) of hot water supply, b) of heat supply on the cost of heat for the city of Voronezh.
The attractiveness and profitability of solar heat supply systems in the climatic and economic conditions of the Voronezh region can be achieved through the use of improved technical solutions (combined generation of thermal and electric energy in one design solution) [9] and lower equipment costs.

An example of the effective implementation of life cycles (design, construction, operation) of a solar system of hot water supply is a hotel located in the village of Babyakovo, Voronezh Region (figure 4). The reduction in capital investment and in payback period of the alternative heat generator was achieved through the own produced solar collectors and water-storage tank. In the summer months, the plant provides 100% coverage in the need for hot water.

![Figure 4. Overall view of the solar system of hot water supply in the village of Babyakovo, Voronezh region.](image)

4. Conclusion

In the conditions of the city of Voronezh, the use of solar systems of hot water supply is cost-effective. The replacement rate in the summer months varies from 80 to 88%, in winter - from 2 to 28%. The large-scale implementation of such energy systems is constrained by economic factors (the relatively low cost of fossil fuels, absence of soft loans, high initial capital investments), and low public awareness. An increase in the competitive characteristics of solar systems can be achieved with the global interaction of the state, developers and manufacturers. Today such facilities can be regarded as experimental. The annual increase in the cost of heat will lead to a decrease in the payback period of solar plants.

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