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Research of Application of Renewable Energy Sources and Energy Saving Technologies in Residence Houses Construction in the Central Part of Russia

Sergey M. Karabanov [1], Valeriy V. Kirakovskiy [2], Pavel P. Bezrukikh[3] and Pavel P. Bezrukikh (Jr.) [4]

[1] Ryazan State Radio Engineering University, Ryazan (Russia)

[2] Promgrazhdanproject Ltd., Ryazan (Russia)

[3] G.M. Krzhizhanovsky Power Engineering Institute JSC, Moscow (Russia)

[4] LUCOIL JSC, Moscow (Russia)

Abstract

Application of energy saving technologies and renewable energy sources is one of the main directions in residential building. The central part of Russia has moderate continental climate with the average temperature of -10.6 °C in January and in July - + 19.7°C, the heating season lasts for about 200 days. Therefore the solution of energy saving problem is important. The paper presents the research results on determining optimum conditions of renewable energy sources choice, on definition of architectural solutions for construction of a power efficient house, the monitoring results of power supply system operation of the house and its operation costs.

Keywords: *architecture, energy saving, renewable energy*

1. Introduction

Energy saving is the most important goal in residential building. Now, when the prices for electricity, public services constantly grow, it is necessary to look for new approaches for the problem solution of the energy operation costs reduction.

The central part of Russia, in particular, Ryazan region, has moderate continental climate. The average temperature in January is -10.6 °C, in July - + 19.7°C, the heating season lasts for approximately 200 days. This data determines to a large extent the design and technological approaches to the energy saving problem solution in residential building.

The paper presents the research results for the choice of renewable energy sources for energy and heat supply of a residential house: photovoltaics, wind power, solar collectors and heat pumps; approaches to the energy-efficient house design, the monitoring results of the house energy system and maintenance costs.

2. Approaches to house design

A multifamily residential house located in Russia, Ryazan region, Rybnoe town (latitude 54 north, longitude 39 east) was chosen as the object for the project engineering design (Fig. 1) [1].

The basic house features:

- number of floors – 2,
- number of sections – 2,
- architectural volume – 3902 m^3,
- total house area – 713.5 m^2,
- common corridors and common areas – 52.2 m^2,

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- total apartments area – 622.6 m^2,
- living space – 322.4 m^2,
- number of apartments – 13, including:
  - one-room – 1,
  - two-room – 9,
  - three-room – 3.

Fig. 1: Multifamily residential house with hybrid power supply

As a whole, the measures implemented at the house design can be divided in the following groups (Table 1): Group 1 – heat loss reduction; Group 2 – reasonable consumption of energy resources; Group 3 – independent power generation for reduction of operating costs on living space maintenance by the house tenants; Group 4 – introduction of automated CONTROL SYSTEMS of the house, in particular, control of consumed energy resources.

Tab. 1: The complex of power-efficient solutions used in the house

Group 1	Group 2	Group 3
- heating-up of the building: basement, basement area, walls, attic floor, roof; - installation of glass units with low-emissivity glass; - equipping of entrances with lobbies; - application of door closers for front doors; - installation of supply-extract ventilation system with heat recuperation.	- installation of motion sensors in common areas; - LED equipment for courtyard lighting; - application of energy-saving lamps in apartments; - one button electric power switching off; - meridian orientation of the house; - horizontal distribution of the house heat supply system; - apartments decoration using light colours.	- installation of bivalent heating system using low-potential heat of lower layer of the Earth (heat pump); - installation of PV modules generating emergency power, and for courtyard area lighting; - installation of water heating vacuum solar collectors.
Group 4		
- installation of **consumed resources meters** in each apartment; - installation of meters registering the consumption of the house energy resources; - installation of independent meters registering power resources generated and consumed by the equipment using renewable energy sources.		

The applied design and technological concepts allow to cut expenses for the house operation, to make direct observations, measurements of quantitative and qualitative changes of maintenance by the tenants of the multiafamily residential house having a high class of power efficiency.

Due to space-planning solution of the house the biggest area of windows is located in the south. The outside walls of the house are made of ceramsite concrete with external heat insulation. To minimize the heat loss through walls, base, attic floor and roof the modern heat insulating materials have been used. The windows consist of three chamber glass units with low-emissivity glass. The staircases are equipped with lobbies with automatically closing doors and reliable pressurization system. The heating of the house is made as a bivalent plant: geothermal heat pumps and a block boiler room with condensation boilers, having a heat meter in each apartment.

3. The analysis of renewable energy sources operation for energy and heat supply of the house

In order to choose a renewable energy source for power and neat supply it is necessary to take into account the following factors:

- geographic location of the house and climate pattern of the place;
- the building characteristics (area, architectural volume, building location);
- power consumption of the building (energy consumption and heat flow rate) during a year.

The use of combined power sources (wind-solar power stations, solar collectors, heat pumps) for heat and energy supply is optimal. The present paper studies the application of power from a PV power station and wind generator for electrical power generation. A heat pump was used for heat supply and solar collectors – for hot water supply.

3.1. The use of wind-solar power

When analyzing the wind-solar power station operation the scheme for monitoring the power generation was used (Fig. 2) [3]. The monitoring data was used for working out recommendations for the house engineering and building. Figure 3 shows simulation and the average value of solar and wind power generated during the investigated period. The calculation was carried out by standard methods on the basis of total month irradiation data and the most apparent wind speeds [3].

For calculation the simple models of the components were used.

- Power generated by a PV generator is directly proportional to irradiation (when using PV modules with good fill factor, 36 cells in series).
- Current of the wind generator is proportional to the cube of wind speed of up to 14m/sec (stronger wind was not taken into account due to its small probability).
- The storage battery charge efficiency was considered to be constant, the depth of discharge (DOD) was equal to70 % (in order to exclude overdischarge losses), the battery operating range was 20 … 28 V. The battery overcharge losses were not taken into account.

We observed coincidence of the calculated and monitoring data. The deviation does not exceed 20%. The largest deviation is observed in winter. It is connected with more cloudy weather during last years. This period is considered to be more critical and is characterized by shortage of power, especially as far as photovoltaics is concerned: it does not exceed 20 kWh/kW that is 5 times less than that of wind energy – up to 100 kWh/kW. In summer solar energy dominates (up to 140 kWh/kW) while wind energy is not more than 25 kWh/kW. Such different potential of wind and solar energy results in irregular power supply of consumers.

Below the most optimal proportions of nominal capacity of the wind and PV generators ($P_{nomwind}/P_{nomPV}$) are analyzed. The optimization was conducted by minimum irregularity of average monthly power production according to the formula:

$$\frac{\sum_n |(P_{average} - P_n)|}{P_{average}} = min \qquad (1)$$

where $P_{average}$ - simple average of power production for the investigated period (one year or one season), P_n-monthly power production (n=1 … 12).

Figure 4 shows the obtained curve shapes for different proportions of nominal capacities of wind and PV generators.

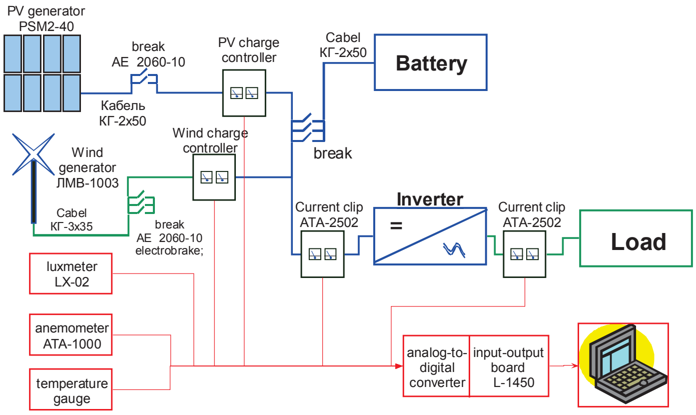

Fig. 2: Monitoring scheme

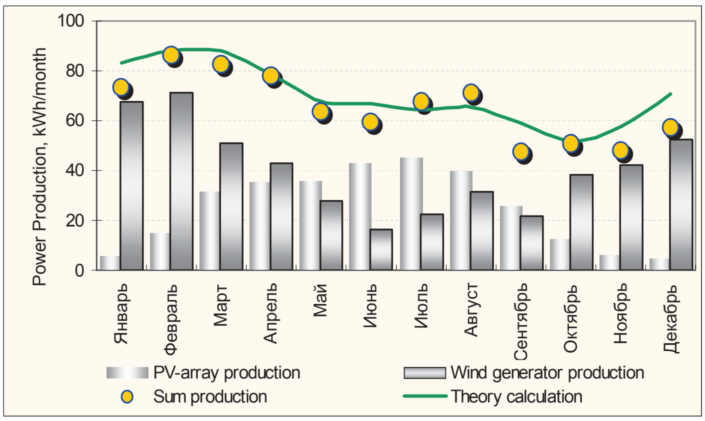

Fig. 3: Monitoring data

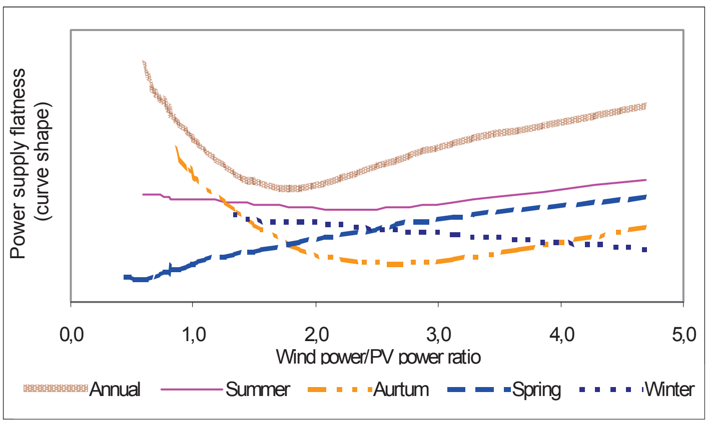

Fig. 4: The curve shapes for different proportions of nominal capacities of wind and PV generators. X-axis is the wind and PV generator ratio; y-axis is the change of the output power in dimensionless units (the figure shows only the curve form).

The flat trend of curves in winter and summer indicates the absence of influence of PV generator power increase on the character of power supply in winter and increase of the wind generator power in summer.

In spring, and especially in autumn, the variation of the power ratio is usually extreme. The optimal ratio for spring is 0.6, for autumn – 2.5-3. The optimal proportion for the whole year is 1.9.

The choice of proportions depends on the character of load consumption, its criticality to power supply irregularity in different seasons or in a year, and also on the proportion of the prices per watt of wind and solar energy. In the station under consideration the proportion of 2.35 is realized.

When designing the house only a PV power station was used as it was difficult to locate a wind generator in the apartment complex. A PV power station had to provide power supply of the house communal facilities (stairs, corridors), a courtyard territory and a heat pump. The calculated peak power of the PV station was 7.5 kW. For the calculation the procedure developed in [2] was used.

Monthly electrical energy generation E_{pv} for a PV generator is determined by the following equation:

$$E_{pv} = G_m(\beta) \cdot S \cdot \eta_{pv} \cdot (1 - \eta_{cable}) \cdot \eta_{mp} \quad (2),$$

where S is the PV generator area, η_{pv} - conversion average efficiency of a PV module, η_{cable} - cable losses (value 0.03), η_{mp} – losses identified by absence of mpp tracking (value 0.8).

The coefficient η_{mp} allows for losses appearing when mpp tracking system is absent. The application of MPP tracking device in the system results in necessity to calculate hourly amounts of solar irradiation and also to have the data of monthly average temperature.

For a battery the stored energy was calculated by:

$$E_{bat} = E_{pv} \cdot \eta_{bat} \qquad (3),$$

where ηbat - conversion mean efficiency of battery. The battery capacitance was calculated by

$$C_{bat} = \frac{E_{bat}}{DOD} \cdot (N+1) \qquad (7),$$

where N – quantity of sunless days, DOD – depth of discharge.

Input data for the calculation is the monthly amount of global solar irradiation for the given region, geographic latitude, modules slope (season optimisation is provided). The programme allows to calculate the required quantity of PV modules to provide load power supply during specific period of time and to calculate storage battery minimum capacity taking into account sunless days. The calculation data was taken from [3].

PV power plant structure:

Peak power – 7.5 kW

PV modules – RZMP-235-T, 32 pcs.

Inverter – TripleLinx 8k, 1 pc.

Storage battery – 200A2/12Bx32

3.2. Heat pump choice

In order to use heat pumps the information about the source of low potential heat, power consumed by the pump, necessary volume of the released heat was analyzed. The heat pump scheme and its structure was chosen taking into account this data.

Corsa-30 (Russia) geothermal heat pump with the rated heat power of 24 kW was used for the house heat supply. This heat pump can operate at high temperature modes (to warm a heat carrier up to +80°C) maintaining a high operation factor of renewable natural heat. To provide pump operation the electric energy of 6.4 kW is necessary. The power is supplied from a PV station. Copeland scroll compressor was used in a heat pump. The compressor has a high transformation ratio of 3.14: the ratio of obtained heat power to consumed energy.

3.3. Solar collector choice

For solar collector use optimal operation time when the collectors work effectively, providing the house with hot water, was chosen.

On the basis of design works the system of vacuum solar collectors, EE-SHS/250 (12 collectors) and EE-SHS/100 (6 collectors), was chosen and installed. The system used Cordivari boilers. The system provides 210 liters of hot water (55°C) during 6 months per year (May-September). The designer and installer of the hot water supply system is EnergEco (Moscow, Russia).

Fig. 5: Solar collectors for seasonal (summer) water heating

4. Architectural and other solutions

Ventilation in the apartments is made as supply-extract system of recuperation, returning the heat of removing air at venting.

The system of natural and controlled forced ventilation provides energy saving and prevents mould growth on the house enclosing structures.

Flat solar collectors for seasonal (summer) water heating in a hot water supply system and a PV power plant accumulating electric power from PV modules were installed (Fig. 5).

Illumination of the courtyard area and common areas is carried out from the combined power supply system with the application of a PV station. Motion sensors providing electric light switching off have been installed at each entrance. For street lighting LED lamps are used.

Energy-efficient electrical equipment is installed in apartments and common areas. In each apartment the light is switched off with one button.

The whole building and each apartment is equipped with an automated power consumption measurement system.

5. Economic aspects of the project

During the development of the project the comparison of different options of its realization has been made (Table 2).

Tab. 2: Comparative characteristics of variants of power and material saving in a 13-apartment house in Ryazan region

Variant	Total cost, mln. Rub	Cost of 1 m^2	Saving
Traditional	17.7	27 500	-
With effective heat insulation of enclosure structures and use of effective insulating glass units	25.7	40 000	50%
With application of heat pumps and PV modules	34.1	53 000	90%

Table 3 shows the technical-and-economic indexes of the project.

Tab. 3: Technical-and-economic indexes

Indexes	Energy efficient house	Standard house
Apartment area, m^2	644	644
Estimated costs, kRub.	30 036	19 964
Cost of 1 m^2, Rub.	46 640	31 000
Building heat losses, kW	19	27
Savings due to architectural solutions, kWh/m^2	20	-
Power from renewables, kWh/m^2	46.1	-

The value of the building energy efficiency according to the calculations is 98 kWh/m^2 per year whereas the target energy efficiency is 66.4 kWh/m^2.

The monitoring of the house economic efficiency within 3 years has shown that total operational costs decrease twice.

6. Research results

1. It is established that for uninterruptible power supply of the house in this territory, taking into account meteorological data and use of the previously developed calculation program, the optimum ratio of capacities of the PV and wind generator is 2:1. The 7.5 kW PV generator was developed and installed.

2. It is defined that for the chosen region the optimum time for solar collector use is May - September. For providing the house with hot water a solar collector with the capacity of 2100 liters per days is used.

3. A 24 kW heat pump providing year-round heat supply was installed on the ground.

4. The following design solutions have been developed:

- the requirements for thermal insulating materials were established and the materials were chosen;
- energy efficient ventilation system was chosen;
- lighting system was chosen;
- automated accounting and control systems of energy carrier for each flat and the house was chosen;
- power and heat supply system monitoring during 3 years demonstrating stability of all systems operation was carried out;
- the house operating costs monitoring was done. It was established that the costs were two times lower.

6. Conclusion

The paper shows the possibility of efficient application of renewable energy sources for power and heat supply of a residential house in the central part of Russia. The multipurpose use of renewable energy and energy efficient architectural and design solutions allowed to decrease considerably (two times) the house operation costs.

7. References

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