Energy Conservation in High-Rise Buildings Based on Environmentally-Friendly Renewable Energy Sources

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Abstract. The article describes technical proposals on energy conservation in high-rise buildings based on environmentally-friendly renewable energy sources. These include: the use of hybrid wind and solar power plants and vortex wind-driven power plants (aerogenerators) with a vertical axis to utilize both the energy of horizontal wind flows at height level and the energy of ascending airflows. The general principles of building hybrid wind and solar power plants for energy conservation in high-rise buildings are set forth based on the analysis of prior art. A vortex wind-driven power plant (aerogenerator) allowing the use of low-speed winds and low-temperature heat fluxes, reduction of low-frequency vibration and enhancement of stability is proposed.

1. Introduction

Resource conservation and environmental protection are two interlinked pressing problems which receive considerable attention throughout the world. The total energy-saving potential in Russia is estimated at 30–40% of the total consumption of primary energy resources [1].

An important component of energy conservation is the construction of energy-efficient buildings using environmentally friendly alternative energy. Since the cost of land for construction in all the urban centers, high-rise construction is used. Thus, the main part of the housing stock in Moscow is represented by 16-22-story buildings. The total number of such buildings is more than 4,500 [2]. However, research and methodological bases of energy conservation in high-rise buildings based on renewable energy sources have not been yet developed. Therefore, development of science-based technical proposals on energy conservation in high-rise buildings based on environmentally friendly renewable energy sources is most pressing technical task.

2. Results and discussion

The task may be formulated as follows: To draft technical proposals on energy conservation in high-rise buildings based on environmentally friendly renewable energy sources.

To solve the task, it is necessary to study and work out the following issues:
- choice renewable energy sources for energy conservation in high-rise buildings;
- elaboration of proposals on environmental properties of energy sources;
- justification for the efficient utilization of the chosen energy sources;
- analysis of prior art;
- elaboration of technical recommendations on the plants to be designed.
2.1. Choice renewable energy sources.

It would be feasible to choose them in view of specific geographic region. The review of renewable energy sources in Russia suggests the following conclusions:

- zones of effective use of wind-driven power plants in the constituent territories of the Russian Federation are: the oblasts (or regions) of Arkhangelsk, Astrakhan, Volgograd, Kaliningrad, Kamchatka, Leningrad, Magadan, Murmansk, Novosibirsk, Rostov and Tyumen; the krais (or territories) of Krasnodar, Perm, Primorsky and Khabarovsk; the republics of Dagestan, Kalmykia, Khakassia and Sakha (Yakutia); and the autonomous districts of Nenets, Chukotka and Yamalo-Nenets [3, 4];

- the most promising zones in terms of using solar panels: Kalmykia, Stavropol Krai, Rostov Oblast, Krasnodar Krai, Volgograd Oblast, Astrakhan Oblast and other regions in the southwest, Altai, Primorye, Chita Oblast, Buryatia and other regions of Western and Eastern Siberia and the Far East [3, 4];

- hybrid wind and solar power plants which combine solar panels and wind generators are the most popular. They successfully replace low-power gas turbines, fuel oil boilers, and diesel generators, especially those located in the zone of distributed power generation. By 2020, the global market of such plants can reach USD 65 billion. Their use can increase the share of renewable sources in electricity production from 5% to 15% by 2035 [5].

Thus, the simultaneous use of various types of alternative energy, such as wind and solar, is most effective. To provide energy conservation in high-rise buildings, it is advisable to use hybrid wind and solar power plants, because they use all the advantages and compensate for the disadvantages of individual sources.

2.2. Elaboration of proposals on ensuring environmental properties of energy sources.

To formulate such proposals, it is advisable to review the environmental properties of the elements of hybrid wind and solar power plants: wind-driven power plants and solar power plants.

The environmental properties of the wind-driven power plants can be improved by the use of wind turbines with a vertical axis. They have the following advantages [6, 7]: reduced initial rotation speed (from 1.3 m / s); no vibration to the ground; no need to install high poles; environmental friendliness (noise level does not exceed 35 dB); no need to trace a wind direction; utilization of not only horizontal, but ascending wind flows as well.

The environmental issues associated with the use of solar power plants are currently being successfully addressed by using environmentally friendly technologies for the production and disposal of solar panels containing cadmium telluride [8].

Thus, proposals on ensuring the environmental properties of energy sources can be formulated as follows:

- to use wind turbines with a vertical axis;
- to use environmentally friendly technologies for the production and disposal of solar panels.

2.3. Justification for the efficient utilization of the chosen energy sources.

A number of studies [9, 10] show that the use of solar and wind energy in buildings makes it possible to save up from 11% to 15% in energy consumption per year. In our country the pattern when the energy from renewable energy sources is converted into heat and hot water has proved to be the most popular and economically viable one. This pattern has several advantages [10]:

- heating is the main energy-consuming item at any house in Russia;
- the pattern consisting of wind turbines and automatic control system becomes much less complicated;
- the simplest automatic control system can incorporate only few thermal breakers;
- a common water boiler for heating and hot water supply may be used as an energy storage device;
- the heating system consumes less energy; - a room temperature can be maintained within a broad range from 19 to 25 °C, and a temperature in hot-water supply boilers - within a range from 40 to 60 °C without adversely affecting the consumers.

It is well known that in the cold and warm period of the year the wind velocity increases depending on height [11]. To estimate the relationship between wind velocity and height, various models are used, such as the Ekman spiral, logarithmic law, and power law [11, 12, 13]. These models make it possible to estimate wind velocity \( v \) at height \( h \), when wind velocity \( v_0 \) at height \( h_0 \) is known. For example, the power law wind velocity change as a function of height is [11, 12, 13]:

\[
V_h = V_0 \left( \frac{h}{h_0} \right)^a,
\]

where
- \( V_h \) – wind velocity, m/s, at a height \( h \), m;
- \( V_0 \) – wind velocity, m/s measured at a height \( h_0 \), m (as a rule, wind velocities are measured at a height of 10–15 m, and in this case \( h_0 = 10—15 \) m);
- \( a \) – index of a power which depends on the type of terrain and is established experimentally; in [11] for major city centers it is recommended to take \( a = 0.33 \).

We obtain the dependence of the wind velocity at a height of 50 meters (approximately the roof level of a 16-story building) on the wind velocity at a height of 10 meters, taking into consideration the ratio (1). To that end, we substitute the indicated height values in the formula to obtain the linear dependency (function)

\[
V_{50} = 5^{0.33} \cdot V_{10} \approx 1.7 \cdot V_{10},
\]

where
- \( V_{50} \) – wind velocity, m/s, at a height of 50 m;
- \( V_{10} \) – wind velocity, m/s, at a height of 10 m.

The graph of the dependency is presented in Figure 1 that clearly shows that starting with a wind velocity of 3 m/s at a height of 10 m at a height of 50 m, the wind velocity will be higher than 5 m/s, which is the boundary of the zone of effective use of wind-driven power plants [3, 4].

![Figure 1](image-url)
Thus, the use of wind-driven power plants installed at roofs of high-rise (more than 16-story) buildings is economically efficient even at wind velocity 3 m/s at a height of 10 m.

In addition, on sunny days during the warm season the outer surfaces of buildings are exposed to solar radiation, as a result of which their temperature increases dramatically and differs significantly from the ambient temperature. The temperature difference produces a convective heat flux directed upwards the building, and the so-called near-surface (boundary) layer of heated air appears. In a number of works it was shown that ascending air flows at a height above 50 m can have a speed of 2 to 5 m/s [12, 13]. The energy of these air flows can be used by vortex wind-driven power plants.

Thus, to ensure energy conservation in high-rise buildings it would be feasible to use vortex wind-driven power plants with a vertical axis to utilize both the energy of horizontal wind flows at height and the energy of ascending air flows.

2.4. Analysis of prior art.

Some studies [14, 15] contain analysis of experience in the use renewable energy sources to provide energy efficiency and classification of wind-driven power plants on top of buildings. Let's consider some of such prior art presented in Figure 2 [15].

![Figure 2 - Options of prior use of the wind-driven power plants on top of buildings:](image)

- a) the first option is to place a wind turbine with a horizontal rotation axis in the upper part of a high-rise building;
- b) the second option is to place a wind turbine with a vertical rotation axis in the upper part of a high-rise building;
- c) the third option is to confine a wind turbine in a building;
- d) the fourth option is to mount wind turbines to the side of a building;
- e) the fifth option is to install wind turbines between buildings

The most interesting option is the project (sixth option) of high-rise building CleanTechnologyTower (Chicago, USA) based on the concept of “biomimicry”. The unique tower envelope has symbiotic relationship with the environment. Wind turbines at the building’s corners capture wind at its highest velocity as it accelerates around the tower. The turbines become denser as the tower ascends and wind speeds increase. At the tower’s apex, where wind speeds are highest, a domed double roof cavity captures air, creating a large wind farm; negative pressures ventilate the interior. The dome is shaded by photovoltaic cells that capture the southern sun [16].

To analyze these 6 options, it is advisable to apply the following evaluation criteria listed in an order of importance in view of urban conditions: operational safety; environmental friendliness (low level of vibration and noise); cost of construction, installation and operation; possibility of installation in existing buildings; effective use of wind and solar energy; easy control; television interference.

The results of the analysis of 6 options against the above criteria are presented in table 1.
Table 1. Characteristics of the options of the use of wind-driven power plants installed on top of buildings.

| № of option | Operation safety | Environmental friendliness | Cost of construction, installation and operation; | Evaluation criteria | Effective use of wind and solar energy; | Easy control | Televison interference |
|-------------|------------------|-----------------------------|--------------------------------------------------|---------------------|----------------------------------------|-------------|------------------------|
| 1           | Low No envelope  | Low Horizontal wind-driven power plant is used | High due to the high installation costs         | Yes                 | High                                   | Low 1 powerful wind turbine | High Blade wind-driven power plants cause television interference [16] |
| 2           | Low No envelope  | High Vertical wind-driven power plant is used | High Additional architectural project is required | No                  | High                                   | Low 1 powerful wind turbine | High |
| 3           | Low No envelope  | High Vertical wind-driven power plant is used | High Additional architectural project is required | No                  | High                                   | Low 1 powerful wind turbine | High |
| 4           | Low No envelope  | High Vertical wind-driven power plants are used | High Additional architectural project is required | No                  | High                                   | High Many small-sized wind turbines | High |
| 5           | Low No envelope  | High Vertical wind-driven power plants are used | High Additional architectural project is required | No                  | High                                   | High Many small-sized wind turbines | High |
| 6           | High The protective dome is available | High Vertical wind-driven power plants are used | High Additional architectural project is required | Yes                 | High A domed double roof cavity captures air. The dome is shaded by photovoltaic cells | High Many small-sized wind turbines | Absent due to the shaded dome. |
Thus, the analysis of prior art allows us to formulate the following general principles of hybrid wind and solar power plants for energy conservation in high-rise buildings:
- to ensure safe operation and the absence of television interference, it is advisable to cover the wind turbines with a dome having a double roof cavity that captures air (wind flow);
- to ensure environmental friendliness and easy control it is advisable to use a variety of vortex wind-driven power plants in a modular design;
- to guarantee efficient use of solar energy, it is advisable to shade the dome by photovoltaic cells;
- to reduce the cost of the project it is advisable to use the existing high-rise buildings.

2.5. Elaboration of technical recommendations on the plants to be designed.

With due consideration of the above principles, the Don State Technical University, (Rostov-on-Don) has developed the utility model of vortex wind-driven power plants which can be used for energy conservation in high-rise buildings [17].

The purpose of the proposed device is to increase the period of safe operation eliminating low-frequency vibration and increasing the stability of the device by creating a rigid structure, securing the rotor in at least two bearing assemblies, and also reducing the center of mass of the device by installing an EMF generator at the level of the lower part of the socket supports.

The essence of the utility model is illustrated in Figure 3, which presents the proposed design of the device for converting the kinetic energy of wind into mechanical energy.

![Figure 3. Design of the vortex wind-driven power plants](image-url)

The work of the vortex wind-driven power plants. While rotor blades 7 are aired by a wind, rotor shaft 2 begins to rotate creating velocity differences between the air levels in the space between lower 17 and upper 4 cross-sections of socket 5, as a consequence of which a steady vortex airflow arises converting the energy from the wind into mechanical energy to rotate the wind wheel consisting of disk 6 and blade 7, and rotor shaft 2. Rotor shaft 2 through bearing assembly 15 is connected to power...
cross-head 13 at the level of the lower part of supports 9 of socket 5. As a result, vibrations in the vertical plane reduces due to no respond of supports 9 to socket 5 in the vertical plane.

Socket 5 is installed on, at least, three supports depending on the stability needed, for example, when three supports are installed the advisable angular distance between them is 120 °; and when four supports are installed it is - 90 °, etc.

Reduced vibrations and oscillations of shaft 2 in the horizontal plane are provided by bearing assembly 1 that connects rotor shaft 2 to power cross-head 3 rigidly connected to socket 5 at the level of upper cross-section 4 of the socket.

The spatial arrangement of EMF generator 10 on power cross-head 13 reduces the height of the centre of mass of all the rotating elements and of the whole device in general, which increases its stability and, consequently, decreases the respond of the bearing assemblies at the upper and lower cross-sections of the sockets, and the life of the bearing assemblies extends to simplify the operational technology.

Thus, the proposed vortex wind-driven power plant makes it possible to use low-speed winds and low-temperature heat fluxes, to reduce the low-frequency vibration and to enhance the stability.

3. Conclusions

1. The analysis of opportunities of renewable energy sources has shown that to ensure energy conservation in high-rise buildings it is feasible to use hybrid wind and solar power plants.

2. The following proposals on ensuring the environmental properties of energy sources are formulated: too use wind turbines with a vertical axis; to use environmentally friendly technologies for the production and disposal of solar panels.

3. In Russia the pattern when the energy from renewable energy sources is converted into heat and hot water has proved to be the most popular and economically viable one.

4. The analysis of wind velocity and air flows near high-rise buildings enables to conclude that for the purpose of energy conservation in high-rise buildings it is feasible to use hybrid wind and solar power plants and vortex wind-driven power plants with a vertical axis to utilize both the energy of horizontal wind flows at height level and the energy of ascending airflows.

5. The analysis of prior art allows us to formulate the following general principles of hybrid wind and solar power plants for energy conservation in high-rise buildings:
   - to ensure safe operation and the absence of television interference, it is advisable to cover the wind turbines with a dome having a double roof cavity that captures air (wind flow);
   - to ensure environmental friendliness and easy control it is advisable to use a variety of vortex wind-driven power plants in a modular design;
   - to guarantee efficient use of solar energy, it is advisable to shade the dome by photovoltaic cells;
   - to reduce the cost of the project it is advisable to use the existing high-rise buildings.

6. The vortex wind-driven power plant that enables to use low-speed winds and low-temperature heat fluxes, to reduce the low-frequency vibration and to enhance the stability is proposed and patented.

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