Possibilities of Using Frame Structures of Industrial Buildings for Placing Wind Energy Generating Devices

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Abstract. The article deals with the highly relevant problem of finding additional sources of energy supply for industrial enterprises using alternative energy-saving energy sources. The author considers the possibility for using the energy potential of surface wind flows with the formation of a wind profile to fit conditions of applications in industrial buildings, as the central idea. The proposed concept is substantiated by the possibility of effective use of outdoor wind generators in construction of the supporting frame of industrial building. The method of integrating wind-driven generators into the structure of a multi-span industrial building is illustrated by the author in the case study of a completed pilot project. The author proposes a solution for a multi-span frame with the formation of a wind-driven transverse profile of the building. A new architectural & constructive solution fundamentally provides a possibility for rational placement of a supporting frame of additional wind-driven power plant with the use of wind turbines in a single integral configuration. Efficient types of turbogenerators were used in the form of built-in multi-row sections configured in the upper zone of the production building, with comprehensive maintenance of the said sections provided. The research results are recommended for wide implementation of such wind generator plants in design and upgrade of industrial buildings for multiple purposes with energy-efficient use of the structural features of their supporting frame. The author has substantiated the prospects for further comprehensive research.

1. Introduction

Development of the global economy is objectively accompanied by the all-encompassing growth of the global energy consumption with intensive use of non-renewable natural resources: oil, natural gas, coal. The inevitable consequences of the use of such energy carriers in processing industries and in power engineering sector are huge volumes of gases and toxic chemical compounds released into the earth's atmosphere, resulting in impaired condition of the Earth climate and biosphere [1].

Understanding consequences of these processes by the global community has determined the need to improve the global energy policy. One of the important milestones in this direction was the 2015 Paris UN Climate Conference. The main outcome of the Conference was the adoption of the comprehensive Agreement on the problem of all-round reduction of the absolute quantitative emissions into the Earth's atmosphere, prevention of the Earth's global warming, active use of new energy-saving technologies and renewable energy sources (RES) [2].
According to experts' forecasts, the global demand for electricity by 2040 will increase by 59%. Altogether, the share of the organic fuels in the global electricity production (primarily coal and oil) will decrease from 83% to 77%. The decrease in the share of the fossil energy sources will occur primarily due to the active use of renewable energy sources (RES): wind and solar power plants, existing hydroelectric power plants, nuclear power plants. By 2040, the share of "green energy sources" will account for up to 60% of the total increment in electricity production [3].

The comprehensive evaluation of the prospects for use of renewable energy sources shows the effectiveness of wind energy sources, which is explained by the possibility of their year-round use and the existence of the vast territories with meteorologically favorable conditions. These factors have become the dominating ones in the development of renewable wind energy in East Asian countries such as China, Japan, Korea, Taiwan and Mongolia [4]. At the same time, the global leadership in the use of wind power plants (WPPs) belongs to China, wherein currently the number of wind operating and under construction wind farms is more than 400, and they generate more than a third of the globally generated wind energy [5,6,7,8]. Altogether, according to the author, the prospects for the development of wind energy sector can be restrained by such accompanying negative factors as the need to allocate substantial land plots for large complexes of wind power plants represented by traditional tower bladed wind turbines with a horizontal rotor. According to experts, to install such plants in these countries it will be required to allot hundreds of thousands of square kilometers of land [4]. In the author's view, these factors in principle exclude installation of small groups of local wind power plants in the structure of cities and their industrial zones, as well as within the boundaries of suburban areas.

The analysis shows that for the conditions of wider use of traditional blade wind generators as local independent energy sources, it is possible to select fundamentally different methods of their layout. An example of such an original approach is the principle of wind turbine integration with the use of design structure of a single building. This technique has been successfully used in modern foreign practice in the construction of a number of energy self-sufficient high-rise public and business buildings in Bahrain, Guangzhou, London [9, 10], wherein traditional bladed wind turbines with a horizontal rotor were used. Nevertheless, despite the originality of the architectural composition, the use of these large-sized types of wind generators, according to the author, required substantial extra spatial dimensions for installation thereof in a building with limitation of their number.

As further demonstrated in the analysis made, a more perfect technique for the formation of a new type of energy-efficient building can be the use of fundamentally different compact wind generators in the form of multi-blade turbines with a rotor vertically or horizontally located in relation to the wind flow. Such devices are recommended in the patented developments of domestic designers in the form of structurally rigid multi-sectional turbine units with a multi-level arrangement of wind turbines [11]. The compact sectional structure of the wind turbines makes it possible to place such units as a single structural element in the structure of the overall load-bearing frame of the building. In the author's view, these solutions are promising for use primarily in the field of construction and retrofit of industrial buildings for a formation of energy self-sufficient production complexes of a new type [12,13,14].

2. Materials and methods

The modern domestic practice of industrial construction is represented by a wide variety of types of buildings, differing in number of storeys, the number and dimensions of spans, the types of building structures used, the nature of technological processes, and types of department conveyance and hoisting facilities. A fundamental feature of industrial buildings in the organization of production processes is securing a substantial margin of safety and rigidity to accommodate static and dynamic loads from the operation of the process equipment. Therefore, load-bearing metal or reinforced concrete frames of industrial buildings, as a rule, are structurally designed in the form of rigid frame schemes with the use of racks connected by elements of longitudinal and transverse ties, as well as
beam and rafter structures [15]. The aforesaid features make it possible to additionally integrate alternative wind energy sources into the structure of the frame of industrial buildings [16].

Another important factor associated with the architectural typology of industrial buildings is a wide variety of space-planning solutions and outlines of their transverse profile. In some cases, this is due to different elevations of adjacent spans because of large dimensions or multi-level layout of process equipment. Therewith, a common property of the major part of industrial buildings is a substantial elevation of roof structures, which may range from 8 to 30 meters or more. With regard to the wind characteristic of the surrounding space, this corresponds to the location of the building in an area of stable increased circulation of above-ground air flows. The analysis shows that these shaping features ensure a fundamental possibility of using the volumetric structure and elements of the transverse profile of industrial buildings in the active structural part of wind power plants [13,17].

The aforesaid properties of industrial buildings were methodically tested by the author in the course of scientific and experimental design with selection of examples of buildings from various sectors of the economy. In these experiments the production building was used as an integral functional and structural part of a wind power plant [18]. The type of wind generator in the form of a turbine with a horizontal axis of rotation was selected as an active element in generation of wind energy. These types of wind turbines are currently being investigated and recommended by domestic experts for active use. The advantages of these recommended types of wind generators are complete independence of their operation from the direction of the wind flow, high compactness, simplicity of design and absence of vibrations [11].

The specified type of wind generators, in principle, allows installation thereof almost close to the planes of the building envelope (to the floor covering or to the walls). Moreover, the listed qualities provide a fundamentally new integrated approach to the placement of these systems in the structure of the production building frame, allowing compact grouping of these devices in the form of blocks of structural multi-rotor sections. These spatially rigid sections are at the same time part of the structural frame of the production building. At the same time, the building envelope can be purposefully used as wind guide planes, focusing and additionally increasing the density of the wind flow and the efficiency of the wind generator [13, 19].

3. Results and discussion
This conceptual approach was tested in the course of experimental design studies performed at the Moscow State University of Civil Engineering. The object of the study was an industrial building for maintenance of aircraft facilities for the scheduled construction of a small passenger-and-freight airport located near Kholmsk town, Sakhalin Region. The extremely remote location of the airport on the island causes a high energy deficit during its subsequent operation. At the same time, this geographical area of the country is featured by intensive year-round circulation of air masses with high wind velocity of more than 10 m / s and wind pressure up to 0.73 kPa [20,21]. Thus, the wind factor was decisive in selection of an alternative energy source, which determined the organization of the entire general plan of the airport complex and the orientation of its main industrial buildings. The meteorological characteristics of the construction area and the estimated orientation of the main planning axes of buildings are given in figure 1.
Figure 1. Integrated scheme of the prevailing wind directions in the area of Kholmsk, Sakhalin region, with the choice of the optimal planning orientation of industrial buildings of the local airport.

Apart from that, the specific features of operation of such a facility as an airport were taken into account, whereat the use of traditional vane wind turbines on high masts would be dangerous during takeoff and landing of aircraft. In this case, the use of compact types of sectional wind turbines [10, 11], arranged in the structure of a single industrial building, was proposed as a fundamental solution.

In the adopted solution, the considered production facility is a processing complex designed for storage and maintenance of small aircraft. Taking into account the large volume of traffic, the layout solution of the complex was adopted as two similar hangars (each having 60.0x72.0 m dimension), interlocked in the form of stepped blocks of buildings displaced relative to each other. The system of these blocks along the front of the facades was oriented in the northwest direction perpendicular to the direction of the prevailing oncoming winds. In such a way, the conditions for the effective capture of wind flows by the turbine sections were potentially provided for [22].

For each building of the airfield complex under consideration, in accordance with the process flow diagram, the solution of the frame in steel structures was proposed on the structure of three spans having different heights. In such solution, the middle span is structurally represented by a multi-level rigid high-rise technical insert 6.0 m wide, which is used to accommodate the main engineering equipment of the entire building, as well as the main longitudinal pedestrian gallery. From the one side, it was resolved to place an 18-meter span of logistics distribution warehouse with a high-rise stacker crane on the central aisle, while on the other side, a substantially wide 36-meter span is
installed adjacent to it for roofed storage and maintenance of aircraft delivered from the airfield (Fig. 2).

With this structure of the building frame, a fundamental solution was adopted to place blocks of multi-rotor sectional wind generators in the uppermost part of the structurally rigid and highest central span. This arrangement makes it possible to form a type of building with a wind-driven aerodynamic profile. For this purpose the truss of a large 36-meter span was designed with a steep 30-degree slope towards the center, which determined its simultaneous use as a guide wind sail having a substantial area. For additional concentration of the wind flow, the frame structure of the rotor superstructure in the upper part was supplemented with a reverse and slope-symmetrical reflector truss, which provides an almost twofold increase in the density of the oncoming wind flow directed into the turbine working space. To effectively capture the wind flow, it was proposed in this scheme to implement the two-level placement of the wind turbines in the working section of the power plant with horizontal types of rotors used. This type of wind turbine, in contrast to traditional tower wing wind turbines, in addition to an efficient layout, provides a minimum level of noise and vibration [11]. In further practice, when designing such facilities, the number and capacity of installed wind turbines should be calculated in accordance with the main process, technical and economic characteristics of a particular enterprise and the wind characteristics of the climatic region of construction.

**Figure 2.** A diagram of the integration of a wind farm into the structural structure of the supporting frame of an industrial building.

An important feature of the proposed solution is also the convenient placement of large battery, technical and repair rooms of the wind farm in the same dimensions of the central bay-insert, in close proximity to the serviced units. This solution provides easy access and the possibility to continuously inspect or repair rotary turbines.

Moreover, in the further practice of designing such objects, it is advisable to use the above-described multifunctional insertion spans to form large battery stations of autonomous territorial
significance. This will determine the new specifics of such integrated production enterprises that combine the most important functions: main production, power generating complex with long-term storage of electricity. This will effectively meet the needs of the engineering and operational services of this remote airport, as well as the permanent residences of the operating personnel and the local population.

4. Conclusions
The proposed principle of forming an industrial bifunctional energy-active building for the placement and use of compact renewable sources of wind energy can be recommended primarily for widespread use in multi-span and different-height types of industrial buildings of various profiles. The proposed methods for the formation of bifunctional wind-driven types of buildings can also be recommended when developing projects for the reconstruction of industrial enterprises in different industries. The method of approbation of the developed design solutions with the setting of experiments using hydro-modeling methods shall become the important stage of such a search. It is obvious that the solution of such problems will require further comprehensive scientific research with participation of technologists, architects, designers, economists and builders.

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