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THE ELECTRICAL SUPPLY SYSTEM FOR THE EXPERIMENTAL «ZERO-ENERGY» BUILDING (300 m²) BASED ON RENEWABLE AND ALTERNATIVE ENERGY SOURCES

The results of the design and implementation of power supply system project for a pilot «zero-energy» building based on renewable and alternative energy sources have been presented. CDF-model to determine the optimal conditions for the arrangement of wind energy installations within the building has been developed.

Keywords: passive house, zero-energy building, energy efficient building, wind power facility, and solar electrical panel.

Throughout the whole history of civilization, the mankind has been using the natural energy (wind and water mills and, today, their more advanced versions, wind and hydroelectric turbines). The full utilization of the main source of renewable energy, the Sun, was limited by technological level of civilization. The progress in studying the solar energy over the past 20—30 years has enabled its use not only for research purposes, but also for the production of heat and electricity. The application of renewable technologies can be a key to guaranteeing wealth and high living standards for the future generations.

According to the New York Times, the cost of solar and wind energy started going down five years ago and fell rapidly in 2014. Such a successful use of «green» energy in the US has been achieved due to government subventions. However, the analysis has showed that even without government support the alternative sources can compete with the conventional ones. According to *Lazard* consulting, today, in the US, the price of solar power has dropped to 5.6 cents per kilowatt hour, that of wind energy has downed to 1.4 cents, while the electricity generated from the combustion of natural gas costs about 6.1 cents and that from coal is priced at 6.6 cents. According to the analysts, without subventions, the solar kilowatt would cost 7.2 cents, the wind one would sell for 3.7 cents. In Europe, the leader in the use of renewable energy is Denmark. About 43% of the country's electricity is generated by wind. Over the next five years, the country plans to reach 55%.

Ukraine has powerful resources of wind energy: the annual wind energy potential is 30 TW × h/year (according to the Research and Engineering Center for Wind Energy Study of the National Academy of Sciences of Ukraine). Based on statistical meteorological data on the speed and frequency of wind, the zoning of Ukraine has been made depending on wind speed and the specific wind energy potential at different heights has been determined for each zone [1]. The use of wind turbines to generate electricity on an industrial scale is feasible for the regions of Ukraine, where the average annual wind speed is about 5 m/s: the Azov-Black Sea coast, Odessa, Kherson, Zaporizhia, and Mykolaiv Oblasts and in the area of the Carpathians. It should be noted that in addition to developing the commercial wind power, in Ukraine, it is necessary to develop the non-profit «countryside» or «household» wind energy engineering, These small independent power systems for remote areas can facilitate the decentralization of energy supply and allow Ukraine to diversify energy sources.

The potential of solar energy in Ukraine is high enough for widespread implementation of facilities for heat and electricity generation in almost all areas. Fig. 1 shows the energy of solar radiation reaching the Earth annually per 1 m^2 horizontal surface in regions represented by five Ukrainian cities. For the 6 months of the warm period, the Earth's surface gets a large share of the annual solar energy.

The average annual solar radiation per 1 m^2 surface on the territory of Ukraine ranges from 1,070 kW × h/m^2, in the northern part of Ukraine, to 1,400 kW × h/m^2, in the south. According to meteorological observations, in the last ten years, Ukraine had from 100 to 200 sunny days yearly, depending on the region. The average annual potential of solar energy in Ukraine (1,235 kW × h/m^2) is higher than, for example, in Germany (1,000 kW × h/m^2 or in Poland (1,080 kW × h/m^2). This provides great opportunities for effective use of thermal power equipment. Under these conditions, the solar station can work with efficiency of 60% or more for 9 months, in the southern regions of Ukraine (from March to November), and for 7 months, in the northern areas (from April to October). The photo-energy equipment can be operated efficiently throughout the year.

The world practice of building the energy efficient buildings with zero energy balance and their power supply systems is based on the use of solar energy systems (photovoltaic panels) and hybrid electric energy generation (wind + sun). In addition, there are such popular solutions as maximum use of daylight, optical fibers, and accumulation of electric energy. The use of wind power in urban areas is limited. The zero-energy houses are equipped with energy-efficient equipment and devices [2,3].

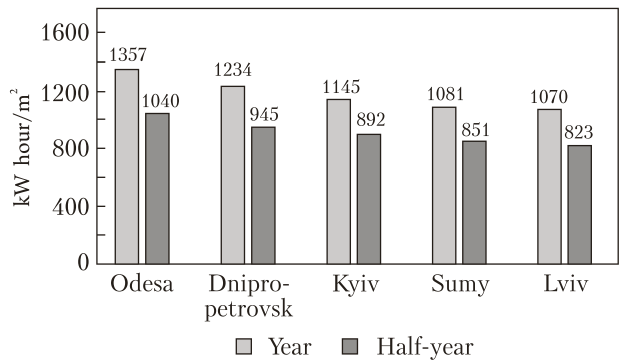

Fig. 1. Solar radiation energy arriving at the Earth's surface

PURPOSE OF THE RESEARCH

Pursuant to the Innovative R&D Project Contract no.34 of March 17, 2014, between the Presidium of the National Academy of Sciences of Ukraine and the Institute of Engineering Thermophysics of the NAS of Ukraine, the purpose of study carried out at the Institute is to design conceptual approaches and innovative engineering solutions for the creation of a pilot passive-type building having a total area of 300 m^2, within the territory of the Institute, and to bring this structure to the level of zero-energy building. In addition, it was necessary to assess the feasibility of a set of measures for optimizing the energy consumption of this building to the standards of Western-type zero-energy houses, creating a «smart» house and implementing it as Micro Smart Grid 0-Energy system. To this end, the following measures have been taken:

- The world experience of construction of zero-energy buildings and their power-supply systems has been analyzed;
- The necessary and the most effective equipment for power supply system of pilot passive zero-energy building has been chosen;
- A numerical 3D model for determining optimal conditions of wind station installation within the building for the power supply system has been developed;

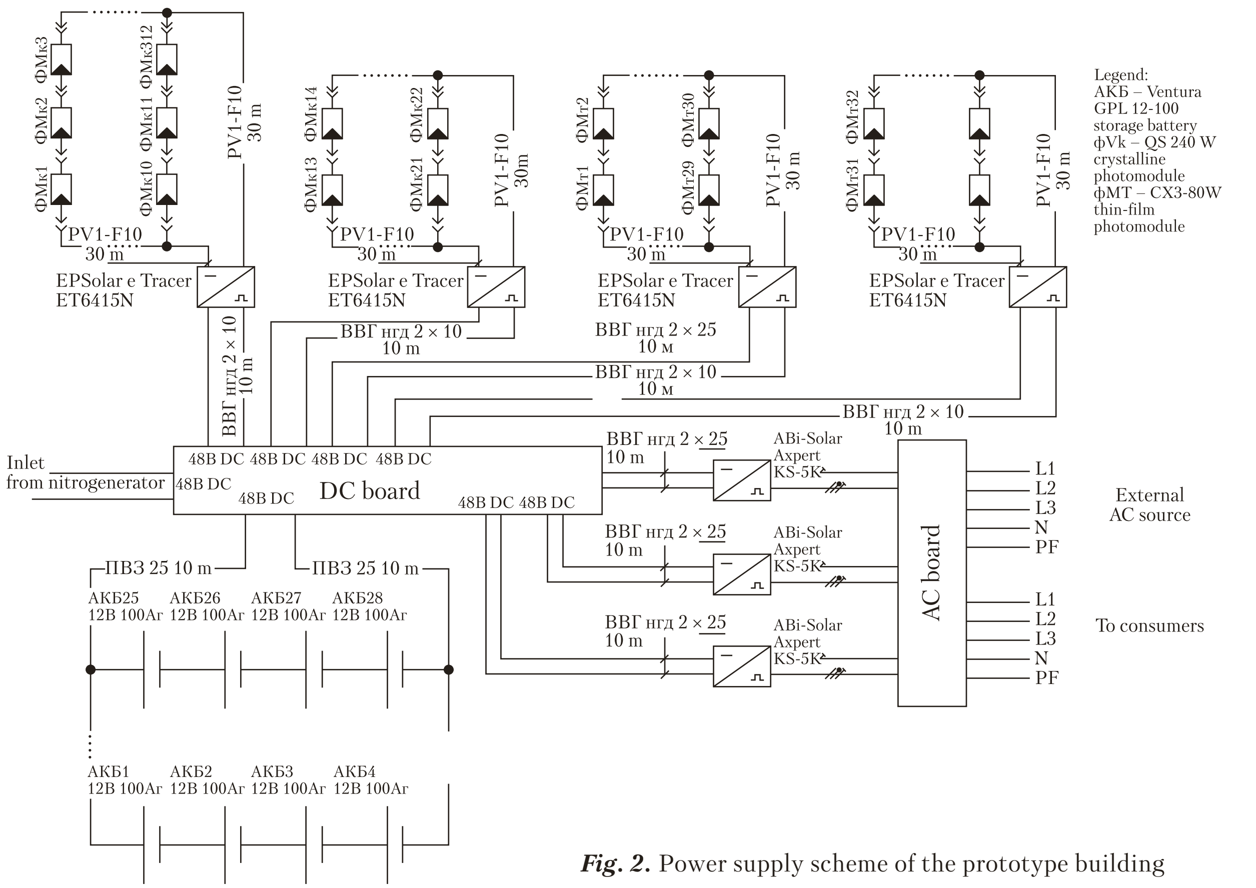

Fig. 2. Power supply scheme of the prototype building

- ✦ A power supply system for the passive zero-energy building has been designed on the basis of renewable and alternative energy sources.

«Zero net site energy use» building means that the energy generated in the building and on the adjacent site from renewable sources is equal to the energy consumed by the building. The analysis of world practice [4] has showed the trends, motivation, and methods for reaching zero energy balance. A typical approach is to combine the passive house technology with solar collectors, heat pumps, photoelectric modules, and low-temperature heating systems.

The pilot house created at the Institute is a full-scale sample (four floors and a loft, with a heated area of 266.6 m^2) for testing, under real climate conditions, both separate structures and the building as a whole, as well as its advanced power supply system based mainly on renewable and alternative sources.

In the building, like in the laboratory, throughout the year, the researchers carry out automated continuous measurements (with a frequency from 1 minute to 1 day) of temperature fields, heat fluxes, humidity, pressure, air consumption, heat carrier and electricity consumption, luminosity, and external climate parameters. All readings are archived in electronic form. There are options of IR imaging and pyrometrical measurements. Also, the project foresees measuring the heat transfer properties of construction materials and structures under operating conditions and their long-term transformations. For the time being, inside the building, there have been more than 400 sensors for controlling temperature, heat fluxes, humidity, etc. Long-term measurements are made in the building structures, subsurface heat exchangers, rooms, and in the air. Climatic measurements, including the insolation, are carried out as well. The

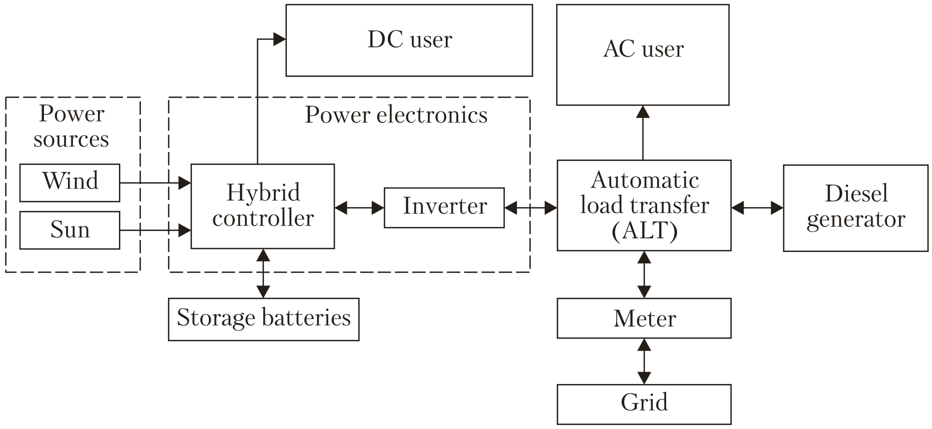

Fig. 3. Structure of power supply system on the basis of renewable energy sources

climate conditions are measured regularly, using a portable automated meteorological station; the insolation is metered at various angles, in all cardinal directions, with the help of specially designed pyranometers (solarimeters).

The zero-energy building conception foresees a wide range of approaches to generation, saving, and metering of energy [2]. The Institute's pilot zero-energy building has an autonomous polyvalent heat pumping system [3]. The heat pump and seasonal storage tanks are located on the semi-basement floor. The prototype is heated by low- and medium-temperature heat pumping systems such as warm water floor (typical and capillary), warm electric floor, warm water wall, air fan coils, air heat wall curtain. A backup cogeneration system is planned to be used for generating electricity and heat energy. It is based on an electric generator having an output of up to 4 kW (electricity) and 5 kW (thermal energy). A backup computerized boiler operating on biofuel and having an output of 5–6 kW thermal energy is used for heating [3].

Electricity supply is based on solar energy (a system of photoelectric element with a power of 10.7 kW (with an electric accumulation for 10 hours of operation) and wind energy (a horizontal wind generator at a height of 30 m). The solar elements are located on the shed roof, southward. The scheme of power supply is showed in Fig. 2.

ELECTRICITY SUPPLY TO THE BUILDING

For the climate conditions of the northern Ukraine it is advisable to use an autonomous hybrid solar-wind system. This system enables uninterrupted power supply at the expense of renewable and alternative energy sources. The selected hybrid system of power supply consists of wind turbine, solar modules, inverter, charge controller, and electric power storages. The energy sources are polycrystalline and thin-film photo modules located on the shed roof, southward, and *Fortis Montan*a wind generator having an output of 5 kW, installed at a height of 30 m. The electricity generated by wind turbine and photo modules charges accumulator stations through rechargers; from the accumulator stations the electric energy comes to inverter where direct current transforms into alternating current (220 V/50 Hz).

Combining various sources of renewable energy it is possible to create a power supply system for the pilot system, which meets requirements for output, time of uninterrupted performance, and costs. Fig. 3 shows a structural scheme for combination of wind and solar energy in the power supply system of zero-energy prototype.

CHOICE OF MAJOR EQUIPMENT

The operation of the complex is based on three basic parameters:

Table 1

Technical Parameters of *QSolar QS-240W*

Parameter	Value
DC voltage, V	24
Voltage at maximum output, V	30.5
Open circuit voltage, V	37.7
Nominal output of solar panel, W	240
Type of silicon	polycrystalline
Short circuit current, A	8.42
Current at maximum output, A	7.87
Efficiency, %	14.6
Weight, kg	20
Dimensions (length, width, height), mm	1655×992×45

Table 2

Technical Parameters of 80 W *Calyxo CX3* Photo Modules

Parameter	Value
Nominal output of solar panel, W	80
Voltage at maximum output, V	47
Open circuit voltage, V	62.8
Short circuit current, A	2.01
Current at maximum output, A	1.72
Efficiency, %	12
Weight, kg	1200×600×6.9

1) The output is ensured by the inverter (selected on the basis of peak transient load of all consumers that can be connected simultaneously);

2) Time of uninterrupted performance in the absence of wind or in the case of weak wind, in the absence of sunrays or under weak insolation is determined by capacity of electric power storages (A×hour) and depends on output and time of consumption;

3) The rate of charging electric power storages (kW×hour) depends on the output of wind turbine and solar station, as well as on *a)* wind speed, height of mast, and landscape (more powerful generator is needed in the case of weak wind or if electricity is consumed regularly, in small quantities) (for the wind turbine); *b)* solar activity, season and time of day (for increasing the system output, additional, more powerful photo modules are installed) (for the solar plant).

In order to speed up the rate of storage charging, several feed elements are used simultaneously and connected to one electric power storage.

For selecting feed elements and service equipment, the following factors were taken into account:

- Quantity of electricity required for the prototype monthly;

Table 3

Estimated Generation of Electricity by Solar Plant

	Insolation on horizontal surface, kW×hour/m^2	Air temperature, °C	Insolation, kW×hour/m^2	Energy from photo modules, kW×hour
January	28.0	–4.20	42.4	339
February	48.0	–3.70	70.4	596
March	88.0	1.90	109.6	947
April	122.0	8.50	135.7	1163
May	185.0	15.20	191.6	1621
June	178.0	18.00	176.0	1470
July	176.0	19.10	175.6	1459
August	156.0	18.50	170.0	1418
September	101.0	14.10	119.9	999
October	67.0	8.00	95.5	802
November	29.0	1.30	40.3	317
December	21.0	–2.00	32.6	247

- Required time of autonomous operation during the windless and dark periods or during the periods when energy consumption from storages exceeds rate of charging power storages from energy source (this parameter determines quantity and capacity of power storages);
- Maximum load on the power grid (for the peak hours, to select the AC inverter).

SOLAR STATION

According to preliminary estimates, the total power consumption of the prototype (provided energy saving technologies are implemented) will not exceed 100 kW×hour monthly. The diagram in Fig. 4 (see the color insert), shows the complexity of ensuring stable electricity generation using solar energy in December. The average insolation in December, in Kyiv (slope of receiving surface is 33°) totals 1,121 kW×hour/m^2 daily.

The power supply system consists of 22 *QSolar QS-240W* polycrystalline modules, each having an output of 240 W, and of 60 *Calyxo CX3* thin-film photo modules made of cadmium telluride, each having an output of 80 W. The parameters of modules are given in Tables 1 and 2, respectively.

The amount of electricity generated by solar plant has been estimated with the help of PVSyst software, on the basis of Meteonorm data (see Table 3).

Hence, the annual production of electricity by the photo modules totals 11 378 kW×hour. This system is remarkable for a high flexibility and scalability, ability to be fed from any AC sources, and a high efficiency of solar energy utilization due to the use of a high input voltage (about 600 V) inverter and the monitoring of maximum output point in the inverter.

WIND GENERATOR

A portion of electricity required for the prototype monthly should be generated by wind turbine. At a consumption rate of 1500 kW×hour monthly, the average hourly consumption should be

Table 4

Wind Generator Parameters

Parameter	Value
Nominal output, kW	5
Output voltage, V	380/220, three phases
Nominal wind speed, m/s	8
Diameter of wind wheel, m	6.7
Орієнтація за вітром	With the help of кіля
Навітряне положення	With respect to the mast
Total weight, kg	200
Height of mast, m	30

Table 5

Estimates of Electricity Generation by Wind Generator

Month	Energy, [kW×hour]
January	300
February	247
March	507
April	283
May	330
June	249
July	205
August	286
September	156
October	261
November	255
December	390

Table 6

Wind Speed and Direction

Rhumb	N	N-E	E	S-E	S	S-W	W	N-W
Wind rose	4 %	6 %	13 %	10 %	17 %	14 %	21 %	8 %
Average wind speed, m/s	3.4	3.9	3.4	3.0	3.4	3.2	5.0	4.7

2083 W×hour. The rate of storage charging from the wind generator should be, at least, the same.

In Kyiv and Kyiv Oblast, the average annual wind speed is quite low. In addition, the wind generator is installed in urban area, which means that the generator can operate with a load of up to 70÷75 % of the nominal output. Under these conditions, in order to ensure power storage charging from the generator at a rate of 2083 W × hour, taking into consideration the solar modules, it is advisable to install a wind generator with a nominal output equal to, at least, the average hourly consumption. *Fortis Montana* wind generator having an output of 5 kW, with an embedded lead-acid battery charge controller is used to transform wind energy into DC with a voltage of 48 V for charging power storages. Hence, in the urban areas of the Kyiv city, the wind generator with a nominal output of 5 kW can ensure up to 3.75 kW output. The parameters of *Fortis Montana* wind generator are given in Table 4. The amount of electricity generated by *Fortis Montana* wind generator installed at a mast of 30 m has been estimated by the Institute for Renewable Power Engineering of the NAS of Ukraine (Table 5).

Thus, *Fortis Montana* wind generator installed at a 30 m high mast can generate 3469 kW×hour annually, 9.504 kW × hour daily, at average, and 285.12 kW × hour monthly, at average.

Table 7

Technical Parameters of *Axpert Abi–Solar KS–5K* Inverter

Parameter	Value
Nominal output, kW	5 kVA/4
Shape of output voltage	Sinusoid
Output voltage, V	230 ± 5%
Output frequency, Hz	50
DC voltage, V	48
Free load consumption, W	< 50
Current consumed by inverter, A	20
Charge current (pulse-width modulation), A	50
Voltage of power storage, V	48
Dimensions, mm	120 × 295 × 468

Table 8

Parameters of *Ventura GPL12-100* Power Storages

Parameter	Value
Nominal voltage, V	12
Capacity, A×hour	100
Working temperature range, °C	–15— +50
Maximum charge current, A	19.5
Cycling charge voltage, V	14.5—14.9
Buffer charge voltage, V	13.6—13.8
Temperature effect on capacity 40 °C /25 °C /0 °C/ –15 °C	102% /100% /85% /65%
Maximum discharge current (5 s), A	650
Dimensions, mm	330×172×224
Weight, kg	29.6
Technology	AGM

WIND GENERATOR LOCATION

In order to identify the optimal location for the wind turbine, a CFD-model has been developed and aerodynamic conditions on the site where the prototype is placed have been modelled (Fig. 5, see the color insert).

The buildings and structures are modelled as rectangles keeping their geometric dimensions and configuration: *1—4* the Institute buildings (20 × 60 × 11 m); *5* — test production (a building of sophisticated configuration occupying an area 60 × 60 m, height is 9 m, distance between the shops is 20 m); *6* — garage (35 × 17 × 3 m); *7* — voltage transforming plant (8×15×4 m); *8* — zero-energy prototype building (10 × 8 × 13 m); *9* — building no.5 (71 × 17 × 29 m). The size of computational area are x = 295 m, y = 320 m, z = 60 m were determined depending on the height of the tallest building in the complex.

The initial data on wind strength and speed within computational area correspond to the data of the Zhyliany weather station, with wind speed and direction measured during 2 years with an interval of averaging of 3 hours. The further

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processing of data allowed the Institute researchers to build a wind rose (see Fig. 6, see the color insert) and to determine the average wind speed by 8 rhumbs (see Table 6).

One can see, that in the area of study, western and south-western winds prevail.

RESULTS OF CFD-MODELLING

The results of CFD modelling are showed in Figs. 7—14 (see color inset).

Sensitivity to spatial discretization:

Speed factor

$$K_s = \frac{U - U_{in}}{U_{in}}; \quad (1)$$

Wind flux strength

$$P = C_p A \frac{\rho U^3}{2}; \quad (2)$$

Turbulence intensity

$$I_t = \frac{\sqrt{\frac{2}{3}K}}{U}; \quad (3)$$

Normalized kinetic energy of turbulence

$$TKE = \frac{K}{U_{in}^2}. \quad (4)$$

The numerical model of transport processes for the interaction of wind flux in the surface layer of atmosphere with the complex of buildings and structures compactly arranged in urban area has enabled obtaining 3D fields of speed and pressure in the wind flux, as well as speed factor, wind flux strength, turbulence intensity, and kinetic energy of turbulence required for solving the problem of optimal arrangement of wind turbine in urban areas. Hence, it has been established that the most efficient way of situating the wind turbine is to place it alongside of the building no.5.

CONTROL, STORAGE, AND PROTECTION HARDWARE

For preventing the emergency charging of the power storages from photoelectric converters and for raising the efficiency of energy consumption from the photo modules, *EPSolar eTracer ET6415N* charge controllers are used. Devices for the protection from overload with an option of cutting from DC are foreseen in order to ensure the safe operation and maintenance of the charge controller. The solar plant of 22 crystalline (output 5280 W) and 60 thin-film photo modules (output 4800 W) requires 4 charge controllers. The system is equipped with a special cable with additional insulation, which enables reducing solar energy losses on the way from the solar panels to the controller by 5–40%. To increase the output power, 3 *Axpert KS–5K* inverters are connected in parallel (see parameters in Table 7). The *Axpert KS–5K* inverter provides a constant load of 4 kW and a short-term (up to 5 s) load of 8 kW. The maximum permissible short-term load for the parallel connection of 3 inverters is 24 kW.

For preventing the inverter damages, over-discharging lead-acid batteries are used. The total capacity of batteries in the system amounts to 700 A × hour. *Ventura GPL12-100* storages are installed in order to ensure uninterrupted power supply (see the parameters in Table 8).

For storages in batteries are connected to increase both capacity and storage voltage.

The annual production of electricity by the wind generator and photoelectric modules totals 14 874 kW × hour, the average daily production reaches 40.751 kW × hour. The shares of *solar-wind* hybrid system components in the production are showed in Fig. 15 (see the color inset). The minimum daily production amounts to 19.067 kW × hour, the maximum daily production reaches 62.935 kW × hour.

Hence, during the most favorable months, it is possible to get about 2000 kW×hour electricity generated by the solar plant and the wind generator, which is enough for the operation of prototype building.

CONCLUSIONS

- The necessary and most effective equipment to be used for power supply of zero-energy passive building has been selected; the power supply system of the prototype building has been designed on the basis of renewable and alternative energy sources;

- A 3D numerical model for determining optimal conditions of wind turbines arrangement within the building has been developed.

Having computed the 3D fields of wind flux parameters, the researchers proposed ways for effective arrangement of the wind generator in urban area, within the Institute's territory. When choosing the optimal power supply system for the prototype, several options were considered, with the solar-wind hybrid system selected as the most appropriate one. The combination of various renewable sources enables creating the power supply system for the prototype, which meets the requirements for output, time of uninterrupted operation, and costs.

The calculations have showed that the electricity generated by photo modules (the total output of solar plant is 10.7 kW) and wind generator (the nominal output is 5 kW) is enough for 266.6 m^2 area building.

The electricity generated by the hybrid system (solar plant and 5 kW Fortis wind turbine) in the most favorable periods reaches 2000 kW × hour monthly or even more. The average daily production totals about 45 kW × hour that is enough for the common building, moreover, for the energy efficient one.

REFERENCES

1. *Atlas energetichnogo potencialu netradicijnih ta vidnovljuvanih dzherel energii.* Kyiv: Institut vidnovljuvanoi energetiki NANU, 2008 [in Russian].
2. Dolins'kij A.A., Basok B.I., Nedbajlo O.M. ta in. Konceptual'ni osnovi stvorennja eksperimental'nogo budinku tipu «nul' energii». *Зb. nauk. pr. «Budivel'ni konstrukcii»*. Kyiv, Vip.77 (2013). S. 222—227 [in Russian].
3. Basok B.I., Bozhko I.K., Beljaeva T.G. ta in. Polivalentna sistema teplozabezpechennja eksperimental'nogo budinku pasivnogo tipu (ploshheju 300 m^2) na osnovi vikoristannja vidnovljuvanih ta al'ternativnih dzherel energii. *Nauka ta innovacii*. 2014, 10(6): 34—51 [in Russian].
4. Basok B.I., Hibina M.A., Beljaeva T.G. Jenergojeffektivnye doma tipa «nol' jenergii». Principy sozdanija i puti razvitija. *Promyshlennaja teplotehnika*. 2013, 35(6): 57—66 [in Russian].
5. Basok B.I., Nedbajlo A.N., Hibina M.A., Beljaeva T.G. Dom «nol' jenergii» na osnove ispol'zovanija al'ternativnyh i vozobnovljaemyh istochnikov jenergii. *Materialy Mezhdunarodnoj konferencii «Ukraina—Rossija—Skolkovo. Edinoe innovacionnoe prostranstvo»*, 2013, Kyiv [in Russian].

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СИСТЕМА ЕЛЕКТРОЗАБЕЗПЕЧЕННЯ ЕКСПЕРИМЕНТАЛЬНОГО БУДИНКУ ТИПУ «0-ЕНЕРГІЇ» (ПЛОЩЕЮ 300 м^2) НА ОСНОВІ ВИКОРИСТАННЯ ВІДНОВЛЮВАНИХ І АЛЬТЕРНАТИВНИХ ДЖЕРЕЛ ЕНЕРГІЇ

Наведено результати розробки та впровадження системи електрозабезпечення експериментального будинку типу «0-енергії» на основі використання відновлюваних та альтернативних джерел енергії. Розроблено CDF-модель, за допомогою якої визначенні оптимальні умови для розміщення вітрових енергетичних установок в межах забудови.

Ключові слова: пасивний будинок, будинок 0-енергії, енергоефективний будинок, вітроенергетична установка, сонячна електрична панель.

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СИСТЕМА ЭЛЕКТРООБЕСПЕЧЕНИЯ ЭКСПЕРИМЕНТАЛЬНОГО ДОМА ТИПА «0-ЭНЕРГИИ» (ПЛОЩАДЬЮ 300 м^2) НА ОСНОВЕ ИСПОЛЬЗОВАНИЯ ВОЗОБНОВЛЯЕМЫХ И АЛЬТЕРНАТИВНЫХ ИСТОЧНИКОВ ЭНЕРГИИ

Представлены результаты разработки и реализации системы электроснабжения экспериментального дома типа 0-энергии на основе возобновляемых и альтернативных источников энергии. Разработана CDF-модель для определения оптимальных условий для размещения ветровых энергетических установок в пределах застройки.

Ключевые слова: пассивный дом, дом 0-энергии, энергоэффективный дом, ветроэнергетическая установка, солнечная электрическая панель.

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