Architectural and engineering solutions for high-rise residential buildings with nearly zero energy balance

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Architectural and engineering solutions for high-rise residential buildings with nearly zero energy balance

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Abstract. Optimization of consumption and distribution of resources, as well as power management efficiency improvement, are the top priority tasks for economy of most countries. Problems of world energy require innovative solutions in the area of constructing highly energy efficient buildings, based on alternative fuels. The article develops a concept of a high-rise nearly zero energy building. Due to architectural and engineering decisions, the building may autonomously produce the amount of energy which is necessary for its proper functioning.

1. Introduction
Efficient energy management is one of vital issues in modern world. According to annual Global Energy & CO₂ Status Report by IEA (International Energy Agency), consumption of fossil fuels throughout the world has increased by 2.3% in 2018 (almost two times higher than the average growth rate in 2010), which is 70% of the total amount of consumed energy. As a result, CO₂ emissions increased by 1.7% in 2018 and set a new record. At the same time renewable sources using grew at double–digit pace, but still not fast enough. Architectural and constructional solution of this problem is developing a concept of «Net Zero Energy Building» [1, 2]. During its large-scale implementation the main drawback – high power consumption, – will be eliminated. This idea is especially relevant for high-rise buildings. According to the Council on Tall Buildings and Urban Habitat (CTBUH), overall amount of high-rises with a height of over 100 m makes up the majority of objects in the world. Such facts evidence the demand for this type of projects, because it is more economically expedient, due to the high cost of land and the growing population. Still, its main disadvantage have always been enormous energy consumption costs.

The suggested project represents the concept of highly-efficient multistorey residential building with energy consumption tending to zero (in this research “high-rise” includes buildings not higher than 75 m (standard of organization OJSC Central Research Institute of Experimental Home Design 01422789-001B). Achieving zero energy balance of a building is based on a concept the building being able to satisfy most of its needs in energy due to geographically available, environmentally friendly, renewable energy sources. It should be taken in account, that the lower the building is, the more extra-produced energy may be sold to a local electricity grid (for example).

It should be noted that there is no such an energy source, which is considered as “fully renewable”. More or less, all of the sources consume irreplaceable natural resources. According to the EROI (Energy return on investment), energy sources are divided into decreasing and increasing, and are calculated as the ratio of the energy received to the one consumed [3] It is important that non-renewable sources get exhausted and their index falls. Technologies of photovoltaics (PV)
and geothermal heating develop constantly, which is evidenced by, for example, the constant decline in the price of solar watt production, as well as the price of 1 watt of heat produced by geothermal drops. Consequently, their EROI increases. Thus, in condition of world environmental degradation and rapid growth of tariffs for gas and electricity, the practice of constructing sustainable buildings is gaining momentum.

2. Concept of the energy efficiency improvement of the nearly zero energy building

The purpose of the project is to create a multi-energy high-rise residential building, which will independently produce the necessary amount of energy for full operation. It can be achieved only as a result of joint work of an architect and engineer, based on the optimization of urban planning, climatic, engineering, structural factors. The main task is to create a comfortable internal microclimate with maximum using renewable sources of heat and electricity.

The main sources of the presented concept of the building produce at least as much energy as the house consumes during the year and the amount of energy consumed depends on a particular combination of architectural and engineering solutions that affect the maintenance of the ecological balance during building, lifetime use and decommissioning. Throughout these stages, the three-fold objective has to be efficient in using resources and reducing the negative impacts on the environment. Since it is impossible to create an object with zero energy efficiency only by increasing the level of thermal protection and improving heating and ventilation systems.

In this project of the residential building, heat supplying air conditioning and heating of water are due to geothermal heating using a heat pump, and electricity supply due to the operation of three generators driven by steam, also a hydro generator operating due to the increased flow of domestic water. And additional electrical energy will be produced by means of photovoltaic panels. As the main engineering directions, it is possible to set actions for heat and water supplying, heating, ventilation, conditioning (cooling), power supply.

If the building energy produced does not satisfy necessary consumption needs in a certain period then traditional energy sources are used. And when its own energy production can exceed the needs of the building, the surplus is exported to the external power system and organized its local storage, which makes it possible to provide energy to nearest objects. Energy surplus is defined broadly as the amount of energy left over after the costs of obtaining the energy has been accounted for.

3. Space planning solutions

The type of high buildings with a several renewable sources of energy as the kind of sustainable architecture allows to create space planning solutions which purposefully enhances the efficiency of installations working due to an alternative power supply.

Thus, there is projecting single-section civic house has a 75 meters tall ground part and the underground part is recessed by 8 meters, in the basement there is necessary engineering equipment. It also significantly affects on the form of a building, reflects on developed stylobate part and planning structure. As a result, this object has a wide span and square shaped plan with a side of 33 meters. The wide span of the building reduces heat loss and creates a steady microclimate and there is the smallest surface area of the envelope that require minimum building maintenance costs and increase the degree of energy efficiency. There is the cylindric shaped glass atrium with the diameter of 16 meters that occupy the core of the house from the basement to the top floor. It is the self-contained volume with a complex of engineering units. Also it is the source of additional lighting and ventilation. Total living area of one floor is 886 m² (Figure 1)

Combination of these decisions allows accommodating more apartments (subject to the conditions of all six apartments) without lengthening non-residential communications. Also it reduces the perimeter of exterior walls per unit of living space, internal engineering communications decrease and the temperature regime improves (especially radiation). Besides, the indicator of natural illumination is quite high. In the amount, it gives economical use of resources.
4. Engineering solutions

4.1. Heating and air conditioning systems

Generation of energy from renewable sources, using equipment located in the building, provides the greatest stability of the engineering systems. One of the most reliable ways to generate energy in an interchangeable way is heat of specific air and a geothermal heat pump, since the soil surface layers of the earth are actually a heat accumulator of unlimited capacity, the mode of which is formed under the influence of two main factors: solar radiation and the radiogenic heat flow coming from the earth’s bowels [4, 5]. The operation of the heat pump presents the possibilities of heating, water heating, and air conditioning in the summer. The heat carrier comes from the soil at $t^\circ + 8$, and leaves at $t^\circ + 2$ on averages, but it also depends on the outside temperature and the heat needs of the house. The drilling depth varies from 60 m to 100 m. One should also note that the high-rise buildings are often arranged on piles, so the location of geothermal wells one must take into account. Thus, in the basement of the central cylindrical volume there is a complex of equipment for hot water preparing, which includes the following basic elements: heat pump installations, hot water storage tanks, a system for collecting low-grade thermal energy of the soil and removed ventilating air heat, waste heat utilizor, hydro-generator, circulating pumps, measuring devices. The Main tower is an example of a high-rise building with this type of heating. It is a 56-storey skyscraper in the Innenstadt district of Frankfurt, Germany [6]. Currently in Russia there are no high-rise buildings using low-
potential geothermal sources, but there is such an example in a multi-storey construction. That is a seventeen-story residential building in the Nikulino-2 urban settlement [7].

The heat pump works in conjunction with the utilizer. Recycling and reusing most of the wastewater energy will save heat energy. Since the heat pumps operation mode that uses earth heat is constant, and the hot water consumption is variable, the hot water system is equipped with an accumulator tank.

4.2. The electrical system

4.2.1. Steam-driven generators. In a heat pump, water is heated, then converted into steam and by means of traction its upward directed heat flow forces the blades of three turbines to move, which, through a special drive, cause the rotor to rotate. The stronger the air flow, the faster the blades spin, producing the greatest amount of electricity. Steam turbines use high-pressure steam to drive the rotor of the generator, so they faster than wind turbines. And the greater the temperature difference between external air and air in the tube, the greater the energy efficiency.

The location of the rotation axis relative to the earth surface is an important parameter. The generator has a vertical rotation axis. The rotor axis turns parallel to the earth surface; therefore it has a higher power of converting the energy of the air flow into alternating current. Prior to each turbine, the pipe slightly converges and smoothly rounded. S-shaped flow, perpendicular to the turbines will increase their capacity for electricity generating, as air flows with greater force, contributing to increase of the turbine blades rotation and generation of MW-energy appropriately. As an approximate example, one may consider the structure of the Bahrain World Trade Center building. It is a 240-meter-high twin tower complex located in Manama, Bahrain. The two towers are connected through three bridges, each holding a wind turbine, which generate 1300 MW of electricity per year. The same figure is for 2 million tons of coal and 6 million tons of oil barrels. Wind turbines are designed to produce 11–15% of the energy required by the towers, or 1.1–1.3 GW per hour approximately.

And the second example is Strata Tower. It is a central London’s tallest residential building at 147.9 m high. The three 9m diameter wind turbines are rated at 19kW each and are expected to produce 50 MWh of electricity per year. This will provide approximately 8% of Strata SE1’s estimated energy consumption. Independent analysis by Integrated Environmental Solutions (IES) has found that Strata should achieve a 73.5% reduction in CO2 emissions relative to the Building Regulations benchmark.

4.2.2. Hydraulic turbine. The revolution will happen when we start to use full energy received and regenerate its surplus. To maximize the reuse of domestic water, in conjunction with the battery bank (which used as an uninterruptible power) an additional hydropower equipment work. It is a hydraulic turbine which converts the energy of domestic sewage water into electricity.

At the beginning domestic wastewater have to split into “black” (foul) and “gray” (waste) water. The discharge from sanitary appliances such as kitchens, baths, showers and wash hand basins, bidets, etc. connected to wastewater system and discharge from wc’s connected to foul water system.

Then gray water will be filtered in a common pipe, recycled and at the last stage of energy conversion, a powerful pressure is created which will convert water into electricity with the help of a hydraulic turbine, as well as some of the generated electricity can go to recharge the battery bank, which directly works with the pumping system.

4.2.3. Using of photovoltaic panels (PV). One of the most available and economically viable sources of energy are photovoltaic panels. It gives a possibility use to the fullest generated electric and heat energy. Getting of this energy happens by splitting water into oxygen and hydrogen by electrolysis method. After that the hydrogen recycled in fuel cell.
Using of solar power is expedient not only in the areas with the prevailing number of sunny days but also in areas with the average of the previously mentioned days. Modern panels can recycle energy both in clear and in cloudy weather, and even at night, but with lower efficiency. As an example, a residential house “Twenty River Terrace” in New York. Total height of the building is 76 meters. Photovoltaic panels able to compensate 5 percent of the total building electricity consumption. It should be taken in account that in most regions of Russia there is a problem of icing panels because of long period of freezing temperatures. But nowadays the new developments are being implemented. These developments allow to melt the ice by heating the surface or the contour of the panel. It makes it possible to receive energy in full, even in winter.

5. Ventilation system
To improve the energy efficiency of the building, along with all of this system of energy consumption and heating, the following methods are used:

The building includes mechanical ventilation with heat recovery from extract air, convectors for space heating. For natural ventilation, double glazing with high heat and sun protection characteristics is provided. Dry hot air will come from channels arranged between double glazed facades. Such ventilation of glass will also reduce the overall heating of the building and, as a consequence, the cost of its air conditioning. As an example of two-layer ventilated facade is the Main Tower in Frankfurt, Germany [8, 9].

6. Conclusion
A high-rise building, as a rule, is an exceptional object. Constructive, engineering, power, and other systems are developed for each separate case. It stimulates the development of scientific and technical progress. Essential synergetic approach is important in the design of modern high-rise buildings. Synergy is the benefit that results when the sum effect of the interaction of two or more factors characterized by the fact that their action significantly exceeds the effect of each individual part. The whole is greater than the sum of its parts.

So the combination of several renewable energy sources and the collaborative approach of the architect and engineer to the experiment in relation to buildings with net zero energy balance will represent the highest level of skill in the compilation of a unique combination of existing devices and systems to achieve the main goals— energy saving and energy efficiency.

References
[1] Crawley D, Pless S and Torcellini P 2009 Getting to Net Zero Ashrae Journal 51 (9) 18–25
[2] Directive 2010/31/EU on the energy performance of buildings (recast)
[3] Hall C, Balogh S and Murphy D 2009 What is the Minimum EROI that a Sustainable Society Must Have? Energies 2 26–47 https://doi.org/10.3390/en20100025
[4] Sustainable buildings 2012
[5] National Laboratories Department of Energy https://www.energy.gov/energysaver/heat-and-cool/heat-pump-systems
[6] Tabunschikov Yu, Brodach M and Shilkin N 2015 Energy efficient buildings AVOK 1 (Moscow: AVOK-press) Chapter II pp 94–99
[7] Tabunschikov Yu and Shilkin N 2004 Aerodynamics of high-rise buildings ABOK 8 (Electronic Materials) https://www.abok.ru/for_spec/articles.php?nid=2662
[8] Shilkin N 2005 Natural ventilation for high-rise buildings ABOK 1 (Electronic Materials) https://www.abok.ru/for_spec/articles.php?nid=2721
[9] Semikin P 2014 Principles of formation of architecture of high-rise buildings with renewable energy sources (Electronic Materials) https://marhi.ru/referats/2014/semakin_diser.pdf

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