Development Strategy of the Energy Supply System for MPEI Campus Blocks Based on Green Building

Ildar A. Sultanguzin[1], Ekaterina V. Zhigulina[1], Yury V. Yavorovsky[1], Ivan D. Kalyakin[1], Alexandr V. Govorin[1], Alexandre A. Krolin[2], Sergey V. Guzhov[2]
1 Department of Industrial Thermal Engineering Systems, National Research University "MPEI", Moscow, Russia
2 Department of Energy Management, National Research University "MPEI", Moscow, Russia
E-mail: ZhigulinaYV@mpei.ru

Abstract — The article presents the development strategy of the energy supply system for National Research University "Moscow Power Engineering Institute" (MPEI) buildings based on green building. The designing mathematical model of one of MPEI academic buildings connected with the Scientific and technical library of the University has been created in Passive House Planning Package and designPH software. The parameters of the building energy supply system with the lowest energy consumption are presented.

Keywords — green building, passive house, zero energy building, energy consumption

Energy-efficient buildings construction with minimum energy consumption in Russia is one of the basic tasks in solving of energy saving problems. Here optimum solutions are to be estimated for north, moderate and south climate zones taking into account their specific characteristics.

The solution for the optimization task through a mathematical model allows to determine optimum parameters of energy supply system at which power independence of the considered object would be reached. It will allow to use the renewable energy and to preserve fossil fuels that is urgent because of existing reserves exhaustion

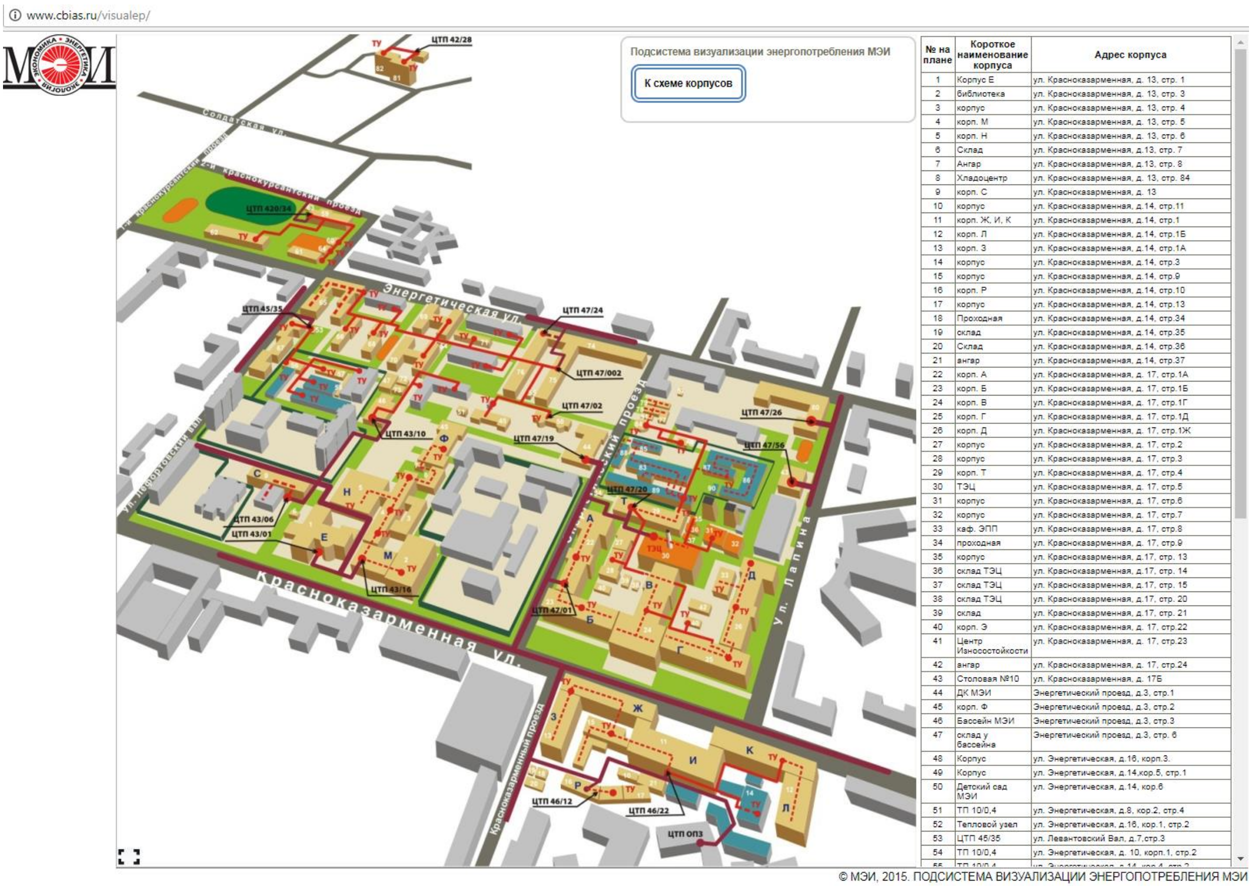
In accordance with Federal Law № 261-FZ from 23.11.2009 "On energy saving and increasing energy efficiency and on amendments to certain legislative acts of the Russian Federation" starting from 01.01.2010 the state (municipal) institutions should ensure the reduction under comparable conditions the uptake of water, diesel and other fuels, natural gas, heat and electricity, coal for five years, not less than 15% of the volume actually consumed by them in 2009 each of these resources with the annual decrease this amount by at least 3%.

National Research University "Moscow Power Engineering Institute" is one of the largest technical universities of Russia. MPEI infrastructure consists of nine educational buildings that contain hundreds of academic and scientific laboratories, a training-experimental heat and power plant, five buildings of students hostel, pilot-production plant, health center, culture house, dining-hall, sports complex "Energia", swimming pool.

Being the main power engineering university in Russia National research university of MPEI realizes its responsibility for students and for society to represent itself an example of the most energy efficient organization and to develop the energy-saving technologies. Despite the fact that MPEI regularly hosts energy survey (Fig. 1) [1,2] and there were implemented many of the energy efficiency measures, the conditions of all buildings of the campus are quite far from passive house or nearly zero energy building standards.

The author collective has developed and suggested the following strategy of the energy supply system for MPEI buildings based on green building.

Similar projects are being realized in Europe in the recent years. For example, the administrative building of Vienna Technical University [3,4], renovated in 2015 – the first high-rise building in Europe, which produces more energy than this consumes. This building operated as a public building which is visited by approximately 800 employees and up to 1,800 students every day. In October 2015, Vienna Technical University, in whose ownership there is the building, awarded by the Austrian state prize for outstanding achievements in the field of technologies of environmental protection and energy efficiency (category "Research and innovation"). There are also the similar examples among multi-storey residential buildings, such as Aktiv-StadtHaus in Frankfurt am Main, with total living area of 10714 square meters, that was constructed in 2015 [5].



№ на плане	Короткое наименование корпуса	Адрес корпуса
1	Корпус Е	ул. Красноказарменная, д. 13, стр. 1
2	библиотека	ул. Красноказарменная, д. 13, стр. 3
3	корпус	ул. Красноказарменная, д. 13, стр. 4
4	корп. М	ул. Красноказарменная, д. 13, стр. 5
5	корп. Н	ул. Красноказарменная, д. 13, стр. 6
6	Склад	ул. Красноказарменная, д.13, стр. 7
7	Ангар	ул. Красноказарменная, д.13, стр. 8
8	Хладоцентр	ул. Красноказарменная, д. 13, стр. 84
9	корп. С	ул. Красноказарменная, д. 13
10	корпус	ул. Красноказарменная, д.14, стр.11
11	корп. Ж, И, К	ул. Красноказарменная, д.14, стр.1
12	корп. Л	ул. Красноказарменная, д.14, стр.1Б
13	корп. З	ул. Красноказарменная, д.14, стр.1А
14	корпус	ул. Красноказарменная, д.14, стр.3
15	корпус	ул. Красноказарменная, д.14, стр.9
16	корп. Р	ул. Красноказарменная, д.14, стр.10
17	корпус	ул. Красноказарменная, д.14, стр.13
18	Проходная	ул. Красноказарменная, д.14, стр.34
19	склад	ул. Красноказарменная, д.14, стр.35
20	Склад	ул. Красноказарменная, д.14, стр.36
21	ангар	ул. Красноказарменная, д.14, стр.37
22	корп. А	ул. Красноказарменная, д. 17, стр.1А
23	корп. Б	ул. Красноказарменная, д. 17, стр.1Б
24	корп. В	ул. Красноказарменная, д. 17, стр.1Г
25	корп. Г	ул. Красноказарменная, д. 17, стр.1Д
26	корп. Д	ул. Красноказарменная, д. 17, стр.1Ж
27	корпус	ул. Красноказарменная, д. 17, стр.2
28	корпус	ул. Красноказарменная, д. 17, стр.3
29	корп. Т	ул. Красноказарменная, д. 17, стр.4
30	ТЭЦ	ул. Красноказарменная, д. 17, стр.5
31	корпус	ул. Красноказарменная, д. 17, стр.6
32	корпус	ул. Красноказарменная, д. 17, стр.7
33	каф. ЭПП	ул. Красноказарменная, д. 17, стр.8
34	проходная	ул. Красноказарменная, д. 17, стр.9
35	корпус	ул. Красноказарменная, д.17, стр. 13
36	склад ТЭЦ	ул. Красноказарменная, д.17, стр. 14
37	склад ТЭЦ	ул. Красноказарменная, д.17, стр. 15
38	склад ТЭЦ	ул. Красноказарменная, д.17, стр. 20
39	склад	ул. Красноказарменная, д.17, стр. 21
40	корп. Э	ул. Красноказарменная, д. 17, стр.22
41	Центр Износостойкости	ул. Красноказарменная, д. 17, стр.23
42	ангар	ул. Красноказарменная, д. 17, стр.24
43	Столовая №10	ул. Красноказарменная, д. 17Б
44	ДК МЭИ	Энергетический проезд, д.3, стр.1
45	корп. Ф	Энергетический проезд, д.3, стр.2
46	Бассейн МЭИ	Энергетический проезд, д.3, стр.3
47	склад у бассейна	Энергетический проезд, д.3, стр. 6
48	Корпус	ул. Энергетическая, д.16, корп.3.
49	Корпус	ул. Энергетическая, д.14,кор.5, стр.1
50	Детский сад МЭИ	ул. Энергетическая, д.14, кор.6
51	ТП 10/0,4	ул. Энергетическая, д.8, кор.2, стр.4
52	Тепловой узел	ул. Энергетическая, д.16, кор.1, стр.2
53	ЦТП 45/35	ул. Левантовский Вал, д.7,стр.3
54	ТП 10/0,4	ул. Энергетическая, д. 10, корп.1, стр.2

Figure 1. Energy distribution and consumption of MPEI visualization subsystem.

The main stages of the forthcoming work at MPEI are:

I. Reconstruction of the following MPEI blocks: E, M and Scientific and Technical Library (STL) of MPEI on the basis of the implementation of green building strategy Passive House Planning Package (PHPP)

1. Determination of the existing energy consumption and setup of mathematical models for buildings E, M and STL in the three-dimensional modeling software package, designPH and passive house design PHPP based on energy audit results.

2. Development and implementation of the buildings thermal protection programme through application of modern and advanced building materials and technologies

- Thermal protection of external walls
- Energy-saving windows and doors installation
- Insulation of the roof and technical floor
- Insulation of basements
- The use of phase change materials (PCM)

3. Development of the energy supply system for buildings based on modern and advanced energy-saving technologies

- Heating system
- Hot water system
- Ventilation system
- Air Conditioning system
- Lighting system
- Power supply system
- The automation system of the individual subsystems

- The system of monitoring and integrated management of the entire energy supply system

4. Implementation strategy of green technology through renewable energy sources usage:
    - Solar collectors
    - Solar panels
    - The combined production of electric and thermal energy technology based on BIPV and BIPVT (Building Integrated PhotoVoltaic Thermal) solar batteries and collectors integration in the roof and the facades
    - Trigeneration of electricity, heat and cold with the use of PVT technology and absorption chillers to provide air conditioning systems in summer
    - Wind turbines
    - Inverters and electric accumulators
    - System daily, weekly and seasonal thermal energy storage
5. Economic evaluation of green building projects implementation
6. Analysis and choice of energy saving projects with minimal funding
7. Analysis and selection of green building projects with the necessary funding leading to nearly zero energy building

II. Reconstruction of other blocks of MPEI campus based on the implementation strategy for green building:

1. Academic and administrative buildings;
2. Residential buildings and dormitories;
3. Institutions of culture and medicine, buildings of public catering and shops.

By now the first point is being done. The mathematical models of buildings M and STL have been developed in the three-dimensional modeling software package, designPH and passive house design PHPP [6,7] based on energy audit results [1,2].

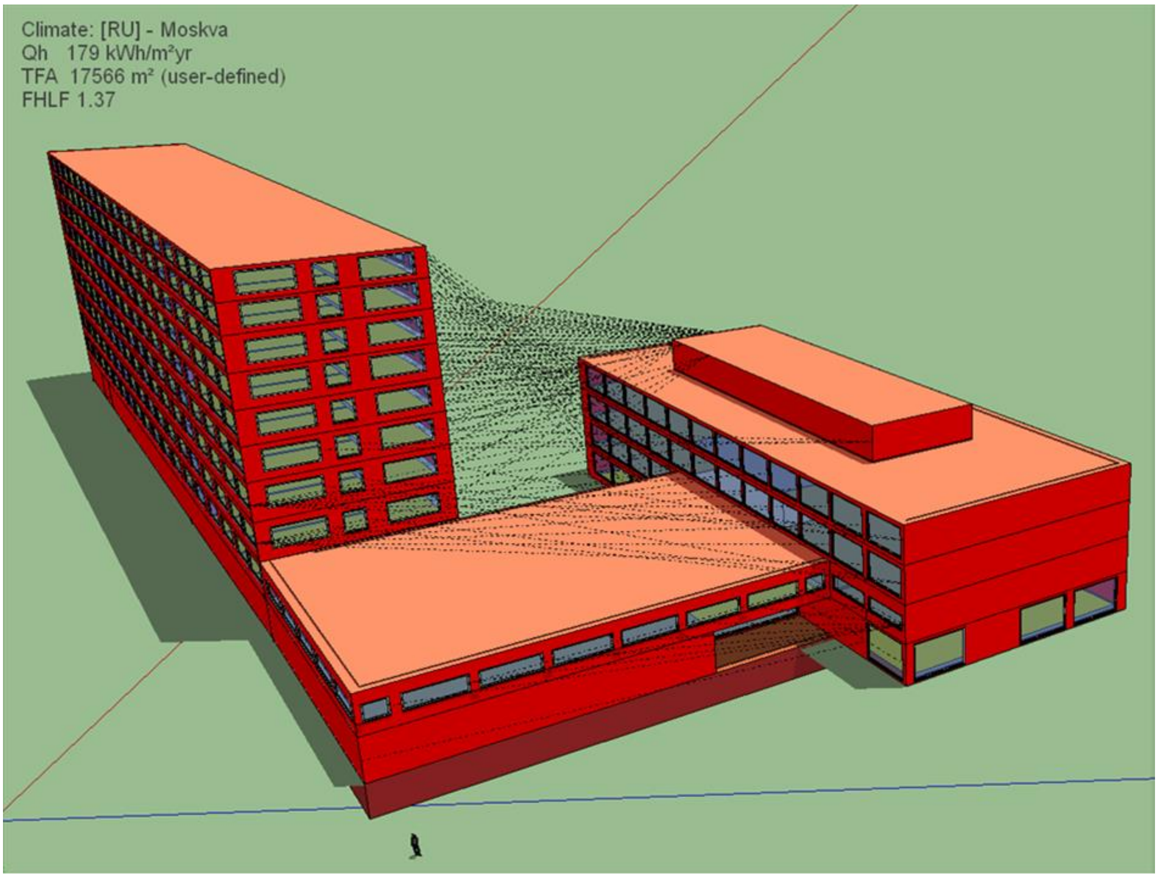


Figure 2. Buildings of M -block and the Scientific and Technical Library

The model of M-block and of the Scientific and technical library is presented in Fig.2. The results of modeling the buildings before the reconstruction are shown in table 1.

Table 1. The results of modeling the buildings at present

▼ Annual Heat Demand

Total heat losses (kWh/a)	Total free heat gains (kWh/a)	Utilisation factor	Treated Floor Area (m²)	Ann. Heat Demand (kWh/a)	Specific Ann. Heat Demand, Q_h (kWh/m²a)
3663513.34	527381.10	1.00	17566.41	3136160.15	178.53

▼ Transmission heat losses

Total Heat Loss Area (m²)	Area Weighted U-value (W/m²K)	Av. Temp. Factor	Ann. Htg. Degree Hours (kKh)	Transmission Heat Loss (kWh/a)	Q_t (kWh/m²a)
24111.59	1.34	0.89	116.00	3431520.82	195.35

▼ Ventilation heat loss

Treated Floor Area (m²)	Ventilation volume (m³)	Eff. air exchange rate	Heat capacity of air	Ann. Htg. Degree Hours (kKh)	Ventilation heat loss (kWh/a)	Q_v (kWh/m²a)
17566.41	43916.02	0.14	0.33	116.00	231992.52	13.21

▼ Solar heat gains

Group nr.	Area Group	Win. area (m²)	Glazing area (m²)	g-value	Reduction factor	Radiation, G_s	Solar heat gain (kWh/a)	Q_s (kWh/m²a)
2	North Windows	219.10	176.06	0.50	0.49	148.15	7898.35	0.45
3	East Windows	2108.01	1734.09	0.50	0.50	322.18	169187.71	9.63
4	South Windows	338.83	277.24	0.50	0.50	448.60	37659.61	2.14
5	West Windows	2116.02	1737.66	0.50	0.50	219.29	115380.12	6.57
6	Horizontal Windows	0.00	0.00				0.00	0.00
		4781.95	**3925.05**				**330125.80**	**18.79**

▼ Internal heat gain

Treated Floor Area (m²)	Internal heat gain rate (W/m²)	Heating period (days/a)	Heating period (kh/a)	Internal heat gain (kWh/a)	Q_i (kWh/m²a)
17566.41	2.10	222.80	5.35	197255.30	11.23

Energy audit showed that the buildings M and STL have big heat losses. Thermovision inspection has been carried out outside of building. The temperature defect of the building guarding construction (walls and windows) is watched on Fig. 3. It means that necessary to increase of wall insulation and change of some windows to energy saving windows.

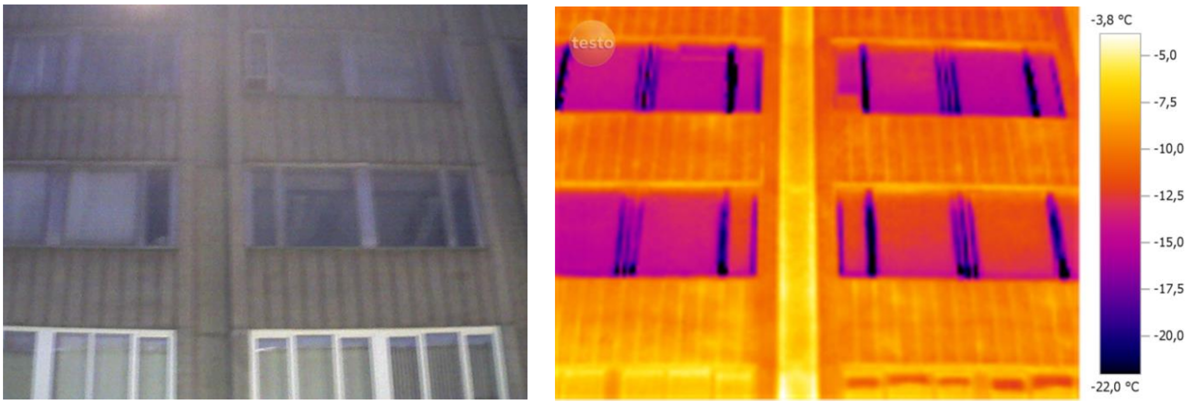


Figure 3. Thermovision inspection of outside of building M.

Also, energy audit showed that inside temperature in building M was 22,5 – 25,2 °C in December 2016 – January 2017 when outside temperature was in range +1,5 - -26 °C. Indoor temperature is significantly higher than norm temperature 20 - 22 °C. It means that it is necessary to develop the heating automation system, that will allow to get the essential energy saving for heating.

Just time ventilation system for building M and STL is used without recuperation of waste air.

Installation of ventilation units with 80 – 90 % heat recovery efficiency and 50 – 80 % humidity recovery efficiency allows decrease loss of heat with exhaust air. According to Passive House Institute recommendations [8] the building envelope must be built in a very airtight way, $n_{50} < 0.6\ h^{-1}$ is required and < 0.3 is recommended. Also, in the interest of justifiable operational costs, the ventilation systems in University buildings must be operated periodically or according to demand. Regulation of the air quantities according to demand should be strived for the CO_2 content of the air and depend on the occupancy density.

For decision problem of air conditioning system in summer it is necessary to select energy effective equipment for specific conditions. Here different schemes, including heat pumps could be analyzed and chosen.

Realization of energy saving program on building M and STL reconstruction allows to decrease specific energy consumption for heating from 179 kW·h/(m^2·year) to 25 kW·h/(m^2·year) approximately. The results of preliminary modeling the buildings after reconstruction are shown in table 2.

Table 2. The results of modeling the buildings after reconstruction

▼ Annual Heat Demand

Total heat losses (kWh/a)	Total free heat gains (kWh/a)	Utilisation factor	Treated Floor Area (m²)	Ann. Heat Demand (kWh/a)	Specific Ann. Heat Demand, Q_h (kWh/m²a)
954294.72	533305.57	0.98	17566.41	434216.34	24.72

▼ Transmission heat losses

Total Heat Loss Area (m²)	Area Weighted U-value (W/m²K)	Av. Temp. Factor	Ann. Htg. Degree Hours (kKh)	Transmission Heat Loss (kWh/a)	Q_t (kWh/m²a)
24111.59	0.27	0.89	116.00	722302.20	41.12

▼ Ventilation heat loss

Treated Floor Area (m²)	Ventilation volume (m³)	Eff. air exchange rate	Heat capacity of air	Ann. Htg. Degree Hours (kKh)	Ventilation heat loss (kWh/a)	Q_v (kWh/m²a)
17566.41	43916.02	0.14	0.33	116.00	231992.52	13.21

▼ Solar heat gains

Group nr.	Area Group	Win. area (m²)	Glazing area (m²)	g-value	Reduction factor	Radiation, G_s	Solar heat gain (kWh/a)	Q_s (kWh/m²a)
2	North Windows	219.10	179.58	0.50	0.50	148.15	8056.39	0.46
3	East Windows	2108.01	1764.93	0.50	0.51	322.18	172194.94	9.80
4	South Windows	338.83	282.30	0.50	0.50	448.60	38346.77	2.18
5	West Windows	2116.02	1768.85	0.50	0.51	219.29	117452.17	6.69
6	Horizontal Windows	0.00	0.00				0.00	0.00
		4781.95	**3995.66**				**336050.27**	**19.13**

▼ Internal heat gain

Treated Floor Area (m²)	Internal heat gain rate (W/m²)	Heating period (days/a)	Heating period (kh/a)	Internal heat gain (kWh/a)	Q_i (kWh/m²a)
17566.41	2.10	222.80	5.35	197255.30	11.23

Building M and STL are situated on Krasnokazarmennaya street, and from south side there are no buildings which cover facades and roofs for solar radiation. It means that it is possible to install building integrated photovoltaic panels on ventilated facades and BIPVT panels [9-11] on roofs of building M and STL.

Calculation with PHPP software [6,8] showed that it is possible to rebuild M block and STL with nearly zero energy balance like buildings in [3-5] cases with using BIPV and BIPVT technologies for good insulating energy saving buildings.

We hope that this will be a demonstrative project of energy saving green building in MPEI.

All other buildings of MPEI Campus could be reconstructed as green nearly zero energy buildings realized on the base of M block building and STL experience.

Conclusion

The present work proposes the development strategy of the energy supply system for MPEI campus blocks based on green building.

Realization of this strategy is considered on the example of M block and Scientific and Technical Library modeling and further reconstruction.

The research will be prolonged in the future together with NESEFF partners.

References

1. Krolin A. A. Guzhov, S. V., MPEI — modern platform for the promotion of energy-saving technologies // Regional energy and energy efficiency, 2015, special issue, Pp. 4 – 5.
2. Dragunov V. K., A. A. Krolin, Guzhov, S. V., et.al. The energy consumption, monitoring and energy saving measures in the University with the use of information systems // Scientific and methodological problems and new educational technologies, 2014, №6, Pp. 32 – 38.
3. Prize-winning energy-plus building in Vienna TU // SAUTER Facts, 2015, No. 33, pp. 22-23.
4. Bismarck M. Reconstruction of the Vienna technical University // Building high technology, 2016, no. 4, Pp. 18 – 21.
5. Elokhov A. E. an Example implementation in Germany residential buildings with positive energy balance // EuroStroyProfi, 2016, special issue on "Energy efficiency. Energy saving. Environment", Pp. 28 – 33.
6. Feist V. Basic provisions on design of passive houses. M.: OOO «KONTIPRINT», 2015. 144 p.
7. Sultanguzin I., Kalyakin I., Govorin A., Khristenko B., Yavorovsky Yu. Optimization of the energy efficient active house // 3. INGENIUERTAG 2016. Der Fakultat Maschinenbau, Electro- und Energiesysteme Gus- und Osteuropatag. NESEFF-NETZWERKTREFFEN 2016. Tagunsband. Brandenburgische Technische Universitat. Cottbus-Senftenberg. 14-15 November 2016. Pp. 8 - 12.
8. Passive House schools – Requirements // https://passipedia.org/planning/non-residential_passive_house_buildings/passive_house_schools/passive_house_schools_requirements
9. Debbarma M., Sudhakar K., Baredar P. Thermal modeling, exergy analysis, performance of BIPV and BIPVT: A review // Renewable and Sustainable Energy Reviews, 2017, Vol. 73, Pp. 1276-1288.
10. Biyik E., Araz M., Hepbasli A., et.al. A key review of building integrated photovoltaic (BIPV) systems // Engineering Science and Technology, an International Journal, 2017, Vol.20, Pp. 833-858.
11. Lamnatou Ch., Mondol J.D., Chemisana D., Maurer C. Modelling and simulation of Building-Integrated solar thermal systems: Behavior of the system // Renewable and Sustainable Energy Reviews, 2015, Vol. 45, Pp. 36-51.