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SHEE «Prydneprovska State Academy of Civil engineering and Architecture»

MONOGRAPH

INSPIRING MATERIALS FOR TRIPLE ZERO BUILDINGS DESIGN

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Ministry of Education and Science of Ukraine
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FOR TRIPLE ZERO BUILDINGS DESIGN

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Authors:
M. M. Babenko – Cand. Sc. (Tech.);
M. V. Savytskyi – Prof. Doctor of Sceince (Engineering);
S. Y. Shekhorkina – Cand. Sc. (Tech.);
O. M. Kuzmenko – Cand. Sc. (Tech.);
M. V. Bordun – PhD student;
M. A. Kotov – Cand. Sc. (Tech.).

Reviewers:
V. V. Danishevskyi, Prof., Doctor of Science (Engineering), Vice-rector for Science and Research, SHEI «Prydneprovska State Academy of Civil engineering and Architecture»;
T. D. Nikiforova, Prof., Doctor of Science (Engineering), завідувач кафедри залізобетонних і кам'яних конструкцій SHEI «Prydneprovska State Academy of Civil engineering and Architecture»

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This edition is dedicated to spread the idea of sustainable design for individual buildings. There are accumulated the developments, for which the authors were inspired during the third stage of the "Triple Zero Building" project realization. Some general principles, construction materials, structural solutions, energy balance analysis and collection of reference norms are presented in this book.

This book is created in the frame of the project "Autonomous Ecological Building «Triple Zero»» financed by the Ministry of Education and Science of Ukraine..

Це видання присвячене поширенню ідеї сталого проектування і будівництва для індивідуальних житлових будівель. Представлено розробки авторів під час реалізації третього етапу наукового проекту «Науково-практичні засади проектування автономних екобудівель за концепцією «Потрійний нуль»». У монографії представлені деякі загальні принципи проектування, використання будівельних матеріалів і конструктивних рішень для автономної екобудівлі за концепцією «Потрійний нуль», а також аналіз енергетичного балансу та збірка відповідних нормативно-технічних стандартів.

Монографія створена в рамках проекту «Науково-практичні засади проектування автономних екобудівель за концепцією «Потрійний нуль»», який фінансується Міністерством освіти і науки України.

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1. THE CONCEPT OF ECO-BUILDING "TRIPLE ZERO"

The traditional economic model of consumption and use of natural resources is characterized by a linear approach, also known as "take-make-dispose". The materials are supplied, used and, are recycled as waste at the end of the life cycle. The long-term use of this model was due to the availability and low cost of natural resources. It is well-known that this approach creates negative external effects that include increased carbon emissions, unstable water extraction levels, and extensive ecosystem pollution. In addition, an increase in the population and the reduction of natural resources reserves also causes many of social and environmental problems.

The construction industry is the main consumer of natural resources. About half of all non-renewable resources consumed by mankind are used in construction. The construction industry has a significant impact on most environmental factors. The main feature of the traditional construction industry is the excessive use of energy that affects the process of global warming and climate change. Energy is spent in the extraction of raw materials, production and transportation of materials, in the process of construction, operation, repair and eradication of buildings. Per many studies, up to 50% of carbon dioxide emissions come from the construction industry. In addition, at the disposal phase of the building damage to the environment may be equivalent to its impact throughout its life cycle. These factors make construction one of the least sustainable industries in the world, but at the same time it is the most promising for the introduction of sustainable technologies and achieving the most visible result in reducing environmental impacts.

The main modern philosophy called to reduce the harmful effects of the industry on the environment - is the philosophy of sustainable development. To date, there are many terms for designing buildings that meet the needs of environmental conservation, designed with one purpose, all of them offer different solutions. To better understand this difference, let's look at the proposed classification in Fig. 1.

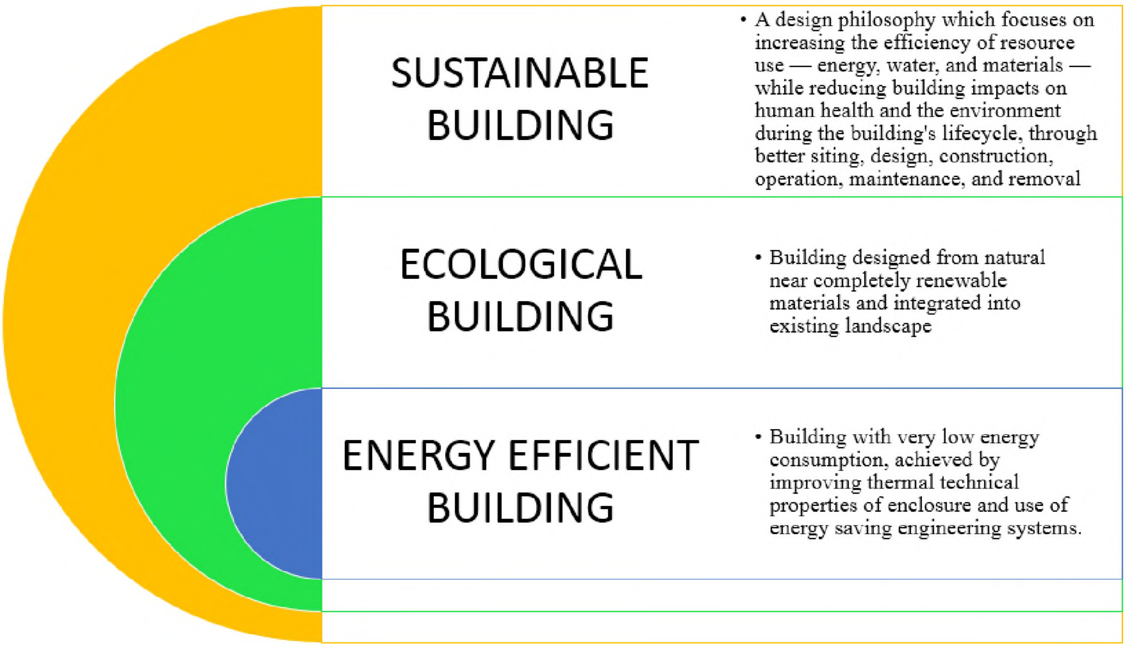


Fig.1. Constituents of the concept of sustainable construction

Based on the proposed classification, it can be concluded that only sustainable buildings include indicators of both energy efficiency and indicators of environmental efficiency or friendly attitude to the environment.

The concept of sustainable development is based on a combination of three components: economic, social and environmental. In recent years, it has been offered additional component - principle of preserving cultural heritage, as a separate, and not part of the social principle, as it was before.

The economic approach to sustainable development implies optimal use of raw resources and the use of environmental, energy, and material conservation technologies, including extraction and processing of raw materials, the creation of environmentally friendly products, minimization, recycling and disposal of waste.

The social component of sustainable development is oriented towards a person and aims at preserving the stability of social and cultural systems, including reducing the number of destructive conflicts between people. An important aspect of this approach is the fair sharing of benefits.

From an environmental point of view, sustainable development must ensure the integrity of biological and physical natural systems. Of importance is the viability of ecosystems, on which the global stability of the entire biosphere depends. The concept of natural systems and habitats includes artificially created human environment, such as, for example, cities.

The building, territory, and the effects of the human impact on the environment today should be considered from the point of view of sustainable development, the components of which are environmental requirements for the construction site.

As a tool for implementing the principles of sustainable development in production by the European Commission, on December 2, 2015, a working program on the circular economy was adopted, which created an important incentive to support the transition to a resource-intensive economy in the EU. This package includes legislative proposals, with long-term goals aimed at reducing waste placement and increasing the amount of recycling and reuse.

The concept of the circular economy envisages the transition from a linear model to a model where natural capital is stored and developed, efficiently used energy resources, preventing the creation of untreated waste and reducing the amount of harmful emissions. Materials and products are made with the maximum possible use of renewable resources, and the exploitation of products is carried out in repetitive cycles.

Given the current state of the construction industry, one can be concluded that for a noticeable result in reducing the environmental impact, the implementation of the basic provisions of the theory of circular economy is necessary. To ensure the life cycle of the building, appropriate design is required considering the origin, production, transportation of materials and elements, as well as construction, operation, disassembly, processing or utilization.

Preventing or minimizing negative impacts at each individual stage is critical to ensuring energy independence and environmental friendliness of the building.

In the general sense, this concept in simplification for the construction industry can be presented as an algorithm for switching from waste to resources, minimizing the use of raw materials (Fig. 3) depicts the conceptual model of interaction of measures on the transition to a circular economic system in construction.

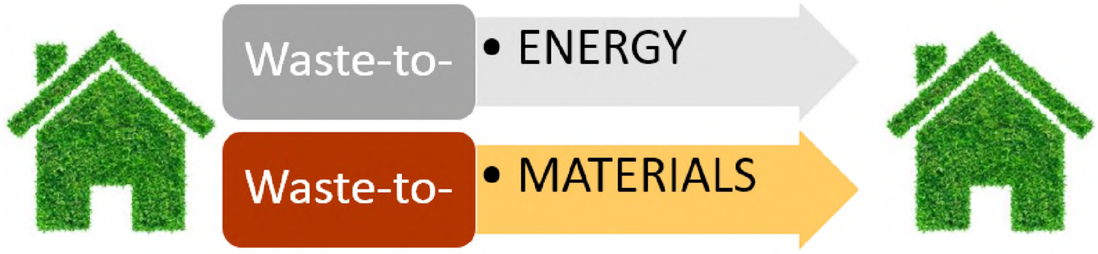


Fig.2. Circular economy in the construction sector

The first step towards the implementation of the principles of circular economy in the construction industry could be the development and implementation of energy autonomous ecological buildings with efficient waste management per the following criteria (Fig. 3):

1) **Zero energy** – is to provide a balance of energy consumption, which will ensure the autonomy of the building throughout the lifetime of using rational design solutions, energy saving technologies (including renewable energy sources – sun, wind, biofuels, etc.), high-quality thermal insulation of premises.

2) **Zero emission** – is to minimize harmful emissions to humans and the environment (carbon dioxide, volatile organic substances, etc.),

3**) Zero waste** – includes measures to minimize the pathogenic effects of the building during its life cycle, including the use during the construction of only those materials that can be recycled or reused as raw materials, rationalization of waste management at the exploitation stage, the provision of light dismantling of building structures at the end of operation.

The concept of "Triple Zero" can be considered as a system of introduction of the circular economy into construction, and the circular economy itself as the main instrument for the implementation of sustainable development in the industry, including construction. Zero here is considered **not in the absolute, but in the conventional sense**, per this concept, it is a question of **compensation on a global scale** (for the preservation of the ecology of the planet) and in the **local application** (concrete steps) of the principles of sustainable development (Fig. 3). At the same time, the global effect can only be achieved through an integrated approach that combines the principles of environmental and energy efficiency both in the reconstruction of buildings and in new construction.

Many principles that are associated with sustainable development and the circular economy are not new to Ukraine. Our construction industry supports, reuses, rebuilds or reorients infrastructure and buildings over the centuries. New approaches to design, new technologies already exist and apply.

However, there is a lack of a specific structure of target design that links all existing and new principles and design approaches, considering the sustainable circular nature of the functionality of the building, including design, construction, operation, maintenance, repurpose and recycling. This requires a step-by-step transition to system approach to design, development and application of innovative technologies.

Thus, the implementation of the principles of sustainable development, considering the theory of the circular economy for a specific building, consists primarily in the design for effective functioning throughout the life cycle, and not simply end-use. The proposed concept of the Triple Zero building to implement the principles of sustainable development and the circular economy offers an alternative approach to design, construction, operation and utilization. This approach is an opportunity to optimize the complex and multidimensional nature of the building as an artificially created environment.

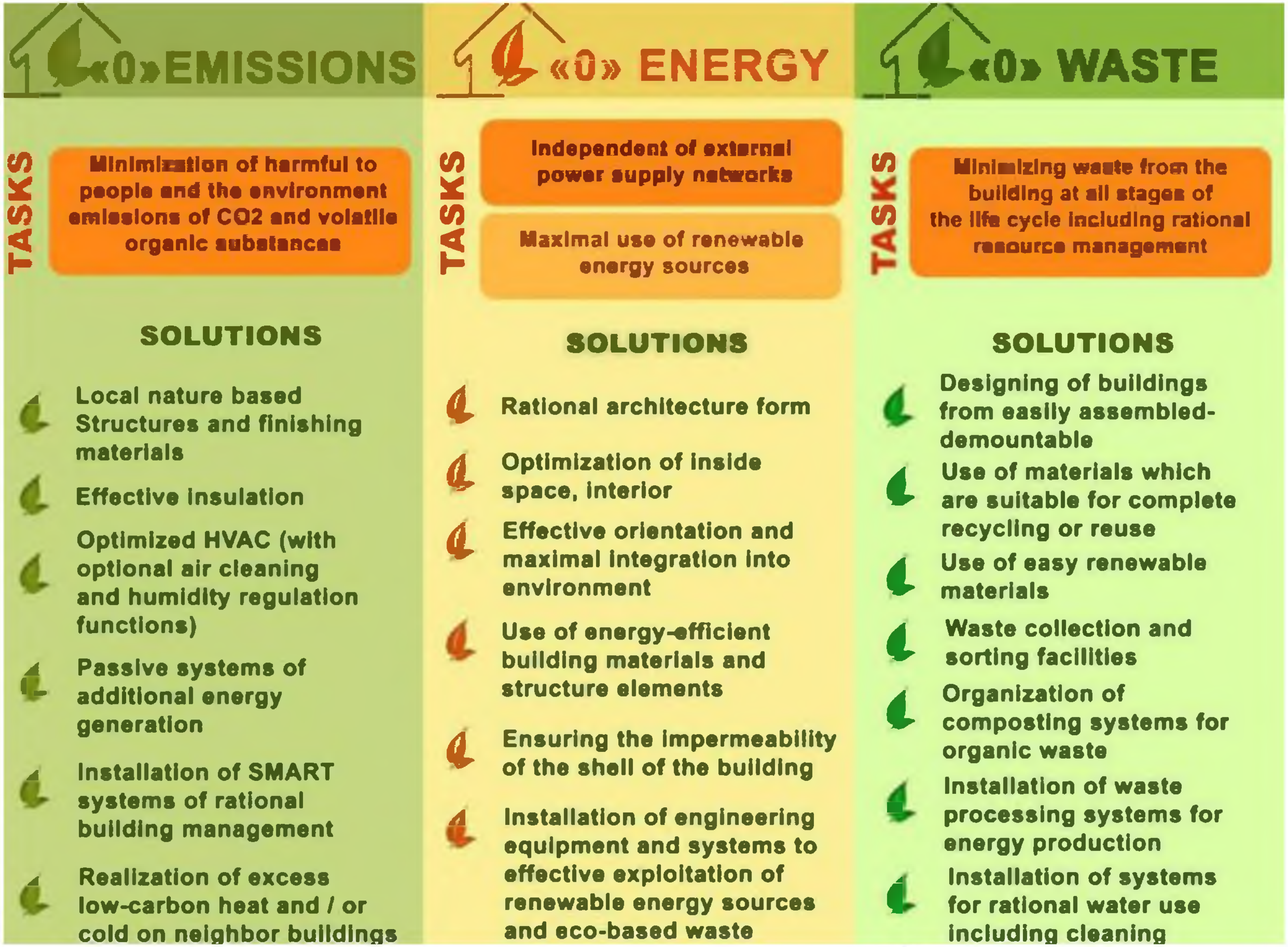


Fig. 3. Conception of building “Triple Zero”

Table 1. Matrix of "Triple Zero" building realization

		Principles of circular economy					
		Restoration	**Distribution**	**Optimization**	**Cycle**	**Virtualization**	**Alternative**
Components of the building	**Land plot (building site)**	Detoxification and restoration of the fertile layer (restoration of the local biosphere)	Systems for the cultivation of natural products, energy production, composting systems, etc.	Use of local renewable energy sources for own production	Restoration of site for reuse	Development of open source design through open, online platforms	Restoration in order to change the purpose of the plot
	Bearing elements	Structural solutions, structures and materials with a low impact on the ecosystem.	Reuse or recycling to change the scope of use	Durability and adaptability	Ability to recover or renovate. Change of purpose	Internet or BIM tracking system for technical state	Sustainable Building Approaches and Green Architecture
	Shell	Integration of green elements (facades, walls, roofs). Recycling for fertilization of green elements by composting	Easy disassembly	Sale of surplus production (fertilizers)	Modular elements of factory production	Internet or BIM tracking system for technical state	Sustainable Building Approaches and Green Architecture
	Interior space	Use of materials suitable for biorefining	Maximum use of useful space	Maximum use of natural light and ventilation	Restoration of elements using reused, repaired and new components	Interactive smart systems for monitoring the internal microclimate	Use of natural light and ventilation
	Engineering systems	Processing of food waste to low-carbon renewable energy	Reuse of components	Sale of excess energy	Collection of rain or melt water, recycling of used water	Smart sensors for monitoring and maintenance management remotely	Use of alternative natural renewable sources

Based on the performed work on systematization and analysis the general principles of design of buildings "Triple Zero" are proposed. The implementation of the Triple Zero conception is a way to implement the principles of sustainable development and the circular economy into design of construction. The systematic use of this concept in terms of neighborhoods, cities, regions or the country will help to use less natural resources, reduce environmental impacts, reduce dependence on unstable markets, ensure transition to more sustainable forms of economic growth, urban living and value creation.

2. NUMIRICAL AND LABORATORY THERMAL ANALYSIS OF WALL STRUCTURE OF TRIPLE ZERO BUILDING

Natural conditions and local building materials had a great influence on the formation of folk architecture, the types of residential buildings, their placement. The use of local materials, such as straw, reeds, etc., has been practiced in housing construction in Ukraine since ancient times.

Each natural landscape forms its own modes of dwelling. In forests, ancient buildings have been built from wood, in the forest steppe - from clay, straw and wood, in the steppe - from clay and stone. By the nature of natural building materials, the territory of Ukraine can be divided into three lanes. The forest zone occupies the north of Ukraine to the Volodymyr-Volynsky, Lutsk, Rivne, Zhytomyr, Kyiv, Nizhyn, and Glukhiv lines. The main building material here it was wood. Clay had an auxiliary value; the cover was made of straw. The Forest-Steppe belt harbors the central part of Ukraine to the Balta, Kremenchug, Poltava, and Kharkiv lines. In the building, here, there were used wood, clay, cane and straw; straw or cane cover (Fig. 4).

Along with the well-known advantages of such dwelling (ecology, economy, accessibility), the traditional constructive solutions are inherent in the shortcomings, in the first place, the failure to ensure the implementation of modern standards for energy efficiency in constructions.

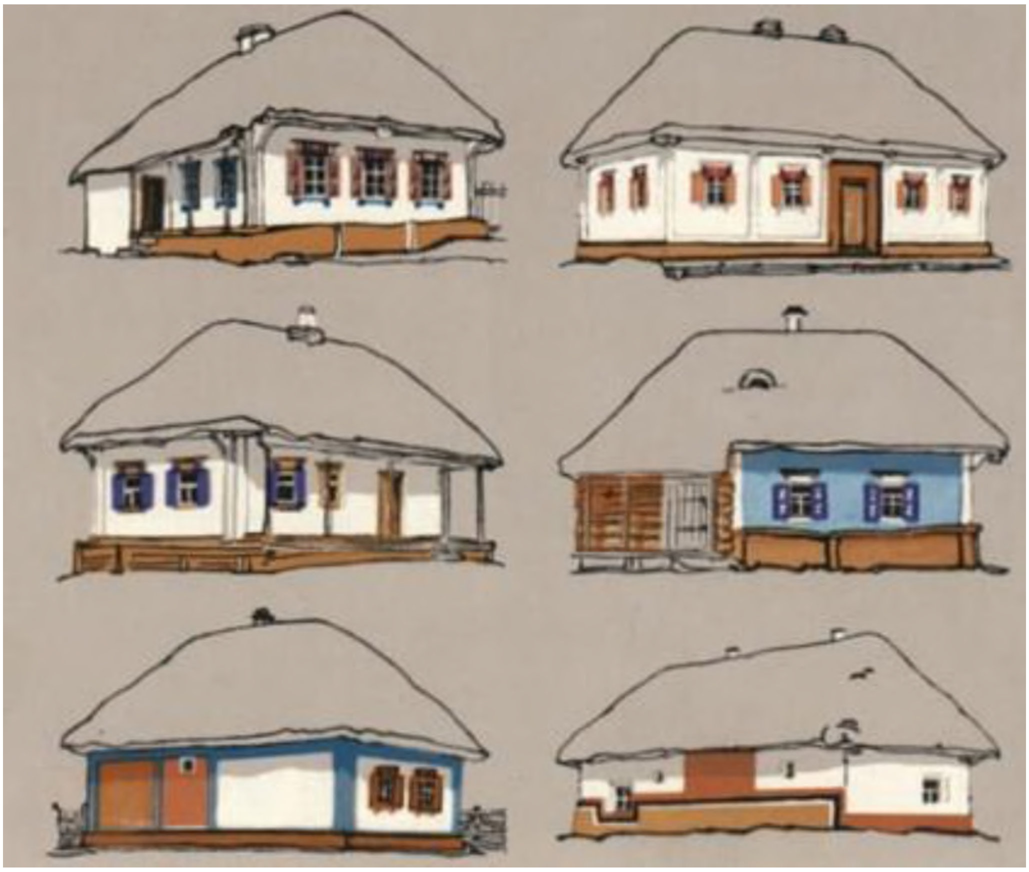


Fig. 4. Types of Ukrainian Dwelling (Poltava region, end of the XIX century)

Under the conditions of the global environmental, social and economic crisis, widespread use of local materials and energy-saving technologies in the construction industry can solve many of urgent social problems in providing the population with quality affordable housing that meets the criteria of the sustainable development policy.

For the introduction of mass ecological construction in design practice, it is necessary to adapt existing effective, unique technologies in the conditions of modern standards and norms.

For the existing material and cultural base of Ukraine, a promising construction technology is the technology of low-rise construction with the use of a wooden frame and local organic materials such as straw of cereals, hemp, reeds as insulation. Ukraine has especially considerable potential for the use of straw cereals in construction. Annually its available volume for use is about 5 million tons.

Today, in the world, a wooden frame is widely used in the construction of low-rise ecological housing. The construction of the wall from local organic materials and the choice of structural details depend on the type of frame chosen - the racks are in the center of the organic insulation, either on the outside or on the inside - and on the type of racks - simple or double ladder type or I-section (Fig. 5, Fig.6, Fig. 7).

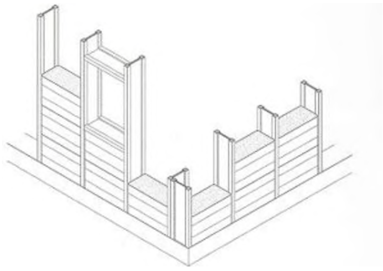


Fig. 5. I-section rack

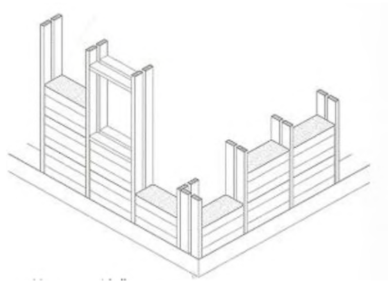


Fig. 6. Rack made of solid wood

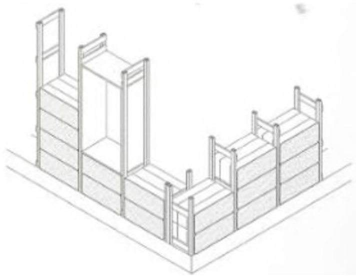


Fig.7. "Ladder" type rack

The most versatile of these technologies, suitable for any type of organic insulation (both in straw pressed blocs and in bulk packed) - is a "ladder" type frame. The main elements of external enclosing structures of this type used in the design of low-rise buildings from ecological local materials are shown in Fig. 8.

As the insulation material, it can be used any ecological plant origin local material. Meanwhile, the theoretic calculation of the presented model on energy-efficiency in the different architectural-planning context application per the existing Ukrainian standards showed, that the most effective local ecological material from the point of view of energy saving is the pressed straw of cereal crops, although a lightweight concrete of hemp and lightweight adobe make it possible to reach the level that corresponds to the highest energy conservation class A.

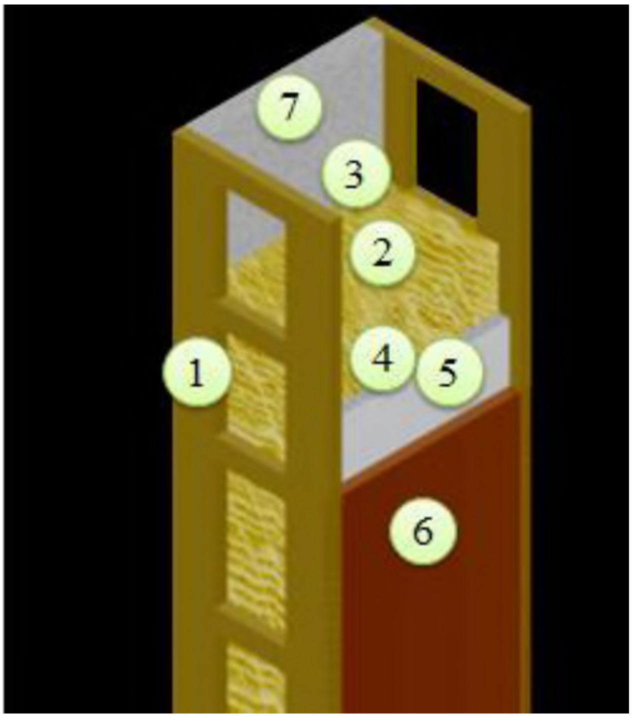


Fig.8. The main elements of external enclosing structures used in the design of low-rise buildings from environmental local materials
1 - "ladder" type rack; 2 - insulation from ecological local materials (straw cereals, light or traditional adobe, hemp or cane), 400 mm; 3 - vapor barrier; 4 - wind protection; 5 – grid; 6 - outer layer of clay plaster, 50 mm; 7 - moisture resistant gypsum board, 12.5 mm

For the research, we have chosen the wall structure for a sustainable building containing a wooden frame, a thermal insulation layer from materials of straw origin, an internal massive heat accumulation layer and an outer protective layer.The considered element is the fragment of pre-fabricate straw-wooden panel of 250 mm of width and the overall dimensions - 1000x1000 mm (thermal insulation layer); info red heating film (heating layer) and brick accumulation layer of width of 120 mm. Characteristics of materials are summarized in the Table 1.

The analysis is carried out in two general stages:

1. First stage – test of prefabricated straw-wooden panel without accumulation layer and heating under the conditions precise in the Table 2 (temperature in external camera).

2. Second stage – test of composed wall with insulation, heating and accumulation layers under the conditions precise in the Table 2 (temperature in external camera).

Table 2. Characteristics of materials

Material	Thickness, m	Thermal conductivity λ ,W/m·K	Thermal capacity, J/(kg·K)	Density, kg/m^3
1.External clay plaster layer	0,02	0,15	880	1600
2. Straw panel	0,25	0,062	600	220
3.Heat-reflecting material (e.g. Izolon, Penofol, etc.)	0,005	0,037	1950	33
4.Electric heating film	0,00034	0,42	1800	1000
5.Masonry of ceramic brick	0,120	0,17	2070000	1800

The obtained data will be compared with the next investigations concerning the detailed structure with wooden frame and expected thermal bridges; and with results of described samples testing under mentioned conditions in climate chamber. Experiment of the thermo-technical properties study of the proposed structure element is planned to realize in the big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). The disposition and numbers of measurement points are represented on the Fig. 9 and 10.

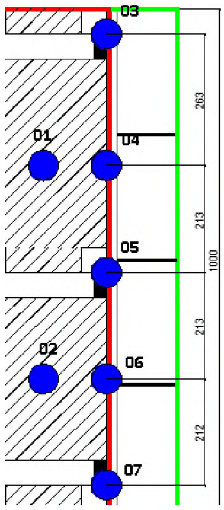


Fig.9. Disposition of measurement elements for the first stage of experiment

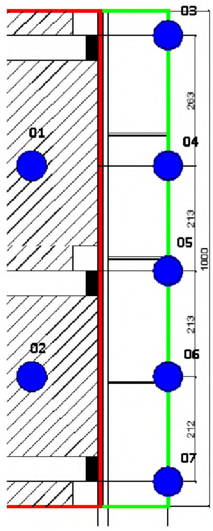


Fig.10. Disposition of measurement elements for the second stage of experiment

The numerical analysis was carried out by ANSYS workbench, a program to calculate the three-dimensional steady-state temperature distribution and heat transfer. The numerical approach permitted also to verify required dimensions of the samples in order to avoid distortion of the temperature field caused by edge effects during the experiment. The thermal conductivities of the materials are summarized in Table 3. Heat transfer coefficient of the interior surface is αint=8,7 W/m^2·K and for exterior surface αint=23 W/m^2·K. The calculations were done by choosing an appropriate grid resulting in 5853 nodes for the first stage of experiment and 11055 nodes for the second stage. The power capacity of the electric heating film is 10 W/m^2.

The exterior temperature is varying from -15 to +10°C. The figure 8 represents prefabricated straw panel without accumulation layer and heating. The figure 11 represents composed wall with insulation of straw, heating and accumulation layers. For the illustrated example for the both variants we imposed -15 °C on the cold side and 20 °C on the hot side with the purpose to obtain a maximal temperature difference of 45 °C.

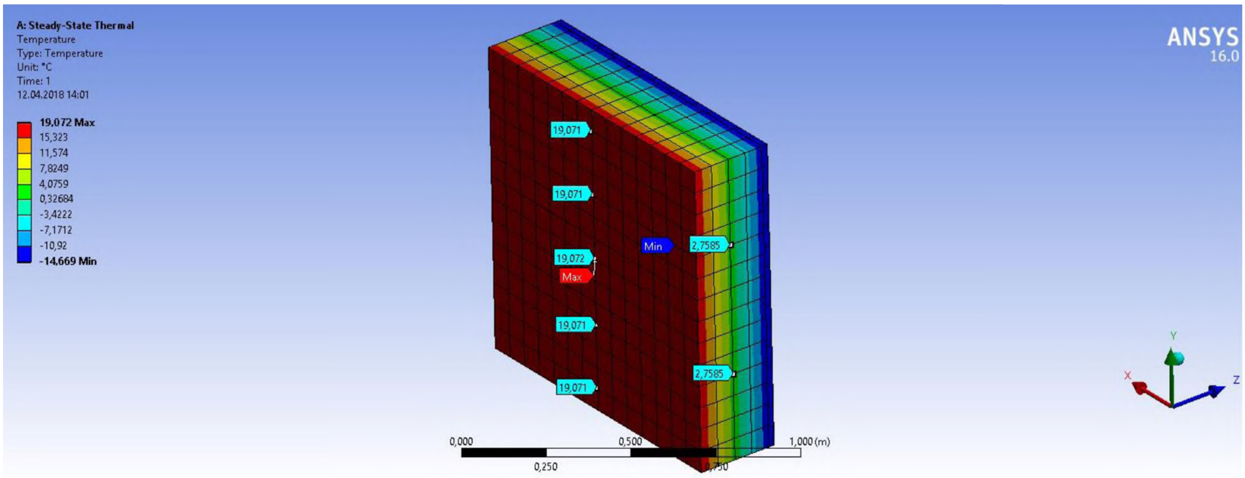


Fig. 11. Prefabricated straw panel without accumulation layer and heating.

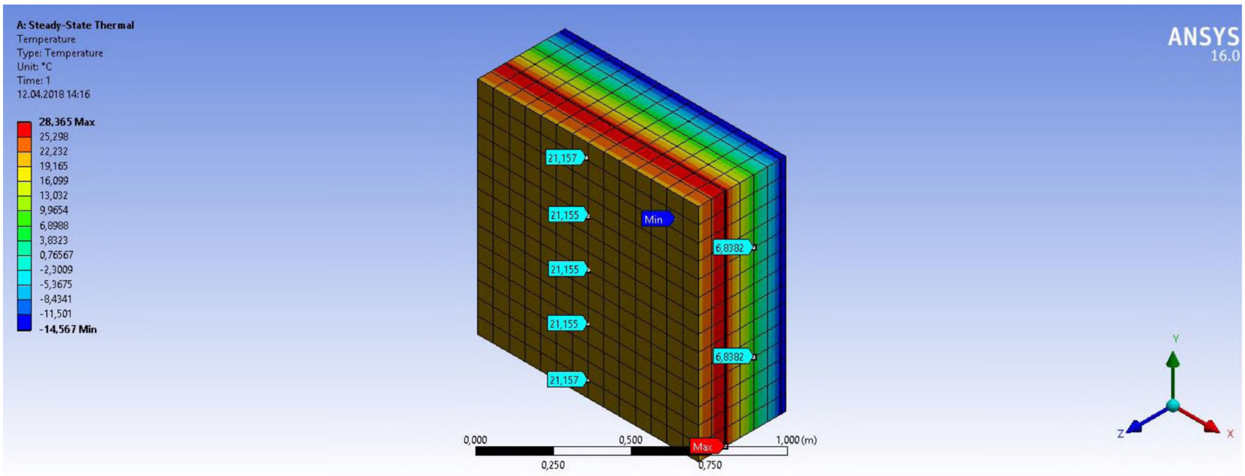


Fig. 12. Composed wall with insulation of straw, heating and accumulation layers.

The results of modelling for all variants of temperature conditions are represented in the Table 3.

The temperature difference between values for the first and for the second stage of point № 05 (under -15°C in external camera) located in the middle of the straw insulation layer reaches 2,083 °C. In other words the presence of heating film and an accumulation layer assure higher temperature on the hot side of the wall and protect it additional heat losses.

There have been proceeded the study of two variants of the wall structure for a sustainable building containing: for the first stage - a wooden frame, a thermal insulation layer from materials of straw origin and an outer protective layer; for the second stage – mentioned components plus a heat-reflecting material, an electric heating film and a masonry of ceramic brick as an accumulating layer. This research represents the numerical analysis of simplified fragments without elements of wooden frame in order to examine the main thermal field of the structure. The presence of heating film and an accumulation layer assure higher temperature on the hot side of the wall and protect it from additional heat losses.

Table 3. Results of numerical thermal analysis

Stage (type of sample)	Temperature in external camera*, t_{ex}, °C	Temperature values, °C						
		01	02	03	04	05	06	07
First stage prefabricated straw-wooden panel	-15	2,769	2,76	19,071	19,071	19,072	19,071	19,071
	-10	5,222	5,22	19,204	19,204	19,205	19,204	19,204
	-5	7,685	7,68	19,336	19,336	19,337	19,336	19,336
	0	10,148	10,148	19,469	19,469	19,467	19,469	19,469
	+5	12,611	12,611	19,602	19,602	19,602	19,602	19,602
	+10	15,074	15,074	19,735	19,735	19,735	19,735	19,735
Second stage composed eco wall with insulation, heating and accumulation layers	-15	6,8382	6,8382	21,157	21,155	21,155	21,155	21,157
	-10	9,7151	9,7151	21,268	21,266	21,266	21,266	21,268
	-5	12,593	12,593	21,379	21,377	21,377	21,377	21,379
	0	15,47	15,47	21,49	21,489	21,489	21,489	21,49
	+5	18,347	18,347	21,602	21,6	21,6	21,6	21,602
	+10	21,224	21,224	21,713	21,711	21,711	21,711	21,713

According to the UNEP, building sector consumes about 40% of global energy, 25% of water and creates 1/3 of greenhouse gas (GHG) emissions. At the same time, buildings offer the greatest potential for achieving significant GHG emission reduction. The European Parliament and the Council reasonably accepted Energy Performance Buildings Directive (EPBD), which shall ensure that by the end of 2020 all new buildings must be Nearly Zero-Energy Buildings (NZEB). However, a progress is slower than expected because of lack affordable solutions in innovative building design, especially taking into account different initial conditions, social and economic situation in EU countries.

The realized research focuses on a maximizing the integration of renewable materials in design of modern sustainable buildings taking into account the energy efficiency requires together with ecological and social aspects in the context of adaptation and availability of the proposed solutions.

The action plan for the Circular Economy has been accepted by EC in 2015. The circular economy refers to an industrial economy that is restorative by purpose, where components are kept in the economy at their highest utility and value in the long-term run. The construction sector of the industry primarily needs to provide these principles in wide application.

There are several gaps not permitting to wider implementation of the sustainable policies in building sector area have been defined: complex technical solutions requiring the informatic support, expensive materials and equipment providing energy-efficiency, lack of understanding and familiarity with green products, systems, and the development process.

The key feature of the upcoming research is a focus on environmentally pure and renewable local materials such as straw, flax, reed, hemp, soil-concrete and others. The core idea of this research work is to develop the most efficient industrial "easy-do" low cost combined solutions of sustainable low-rise building. This approach is based on combination elements with different functions to the autonomous unite. The cost minimization is considered in line coordinated with economical, ecological and comfort quality, e.g. building sustainability what could theoretically ensure its popularity and overall success.

The important "easy-do" principle of the considered conception requires finding the balance between complicated but effective "high-tech" and affordable but non-industrialized "low-tech" for design of multifunctional (housing and industrial purposes) buildings for rural area.

It is proposed an industrial wall structure for a sustainable building containing a wooden frame, **a thermal insulation layer** from materials of vegetable origin, **an internal massive heat accumulation layer** and **an outer**

protective layer - which is characterized by the formation of an energy-efficient environmental wall structure, where the bearing wooden elements are executed with metal detachable mounting elements, and work in a complex with insulation, protective and accumulating layers; Internal accumulation layer from soil concrete blocks, assembled dry and has **installation constructive holes for communications**, protective outer layer of lime-limestone compositions of carbonization hardening, heat insulation layer from a light heat-insulating material based on raw materials of vegetable origin (Fig.13).

The wooden frame 1 is formed by connecting the vertical wooden racks to the two-girder column by connecting the horizontal bar 2 and the diagonal slits on the removable mounting elements 3 to ensure geometric unchanging. The step of the columns of the step is determined by calculation depending on the chosen architectural decision. The insulating layer 4 is provided by filling the spaces between the columns with a light insulation material based on raw materials of straw origin (straw of cereal crops, flax, hemp, etc.). The thickness of the thermal insulation layer is determined by the design of the energy efficiency class of the building. The protection of wooden constructions and insulation of organic origin is carried out by a moisture-resistant parboiler 5, separating the main structure from the internal accumulation layer. The internal accumulated thermal energy of the massive layer is formed by the concrete blocks 6, which are formed dry without a solution and have technological openings 7 for the arrangement of communications. Painting layer 8 provides the tightness of the accumulation ball and the structure. From the outside of the wall, the frame elements and insulation isolate the wind barrier 9. The outer protective layer 10 consists of solid blocks of limy-limestone carbonization hardening compositions.

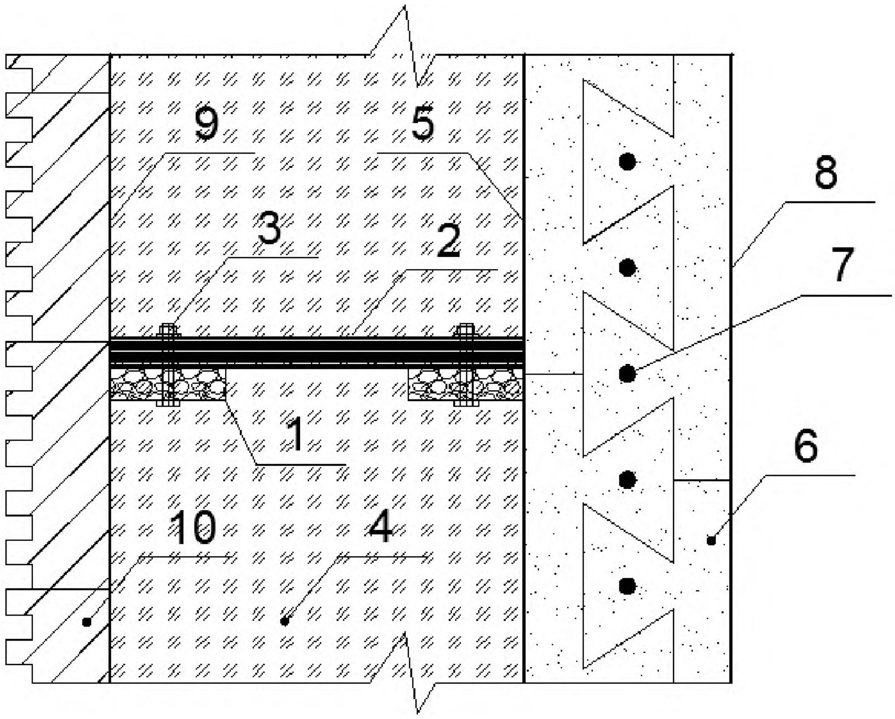


Fig.13. Detailed model of the proposed straw wall element.

Laboratory study has been preceded on the simplified model of the proposed straw wall element. The heating layer has been ensured by info-red heating film and the accumulated one by the standard silicate brick. Experiment of the thermo-technical properties study of the proposed structure element has been released in the big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). The test element is the fragment of pre-fabricate straw-wooden panel of 250 mm of width and the overall dimensions - 1000x1000 mm (thermal insulation layer); info red electric heating film, infro film Eco Term of width 1 m (thickness 0,34 mm) 140W/m2б 1x1 m (heating layer) and brick accumulation layer of width of 120 mm. (Fig. 14).

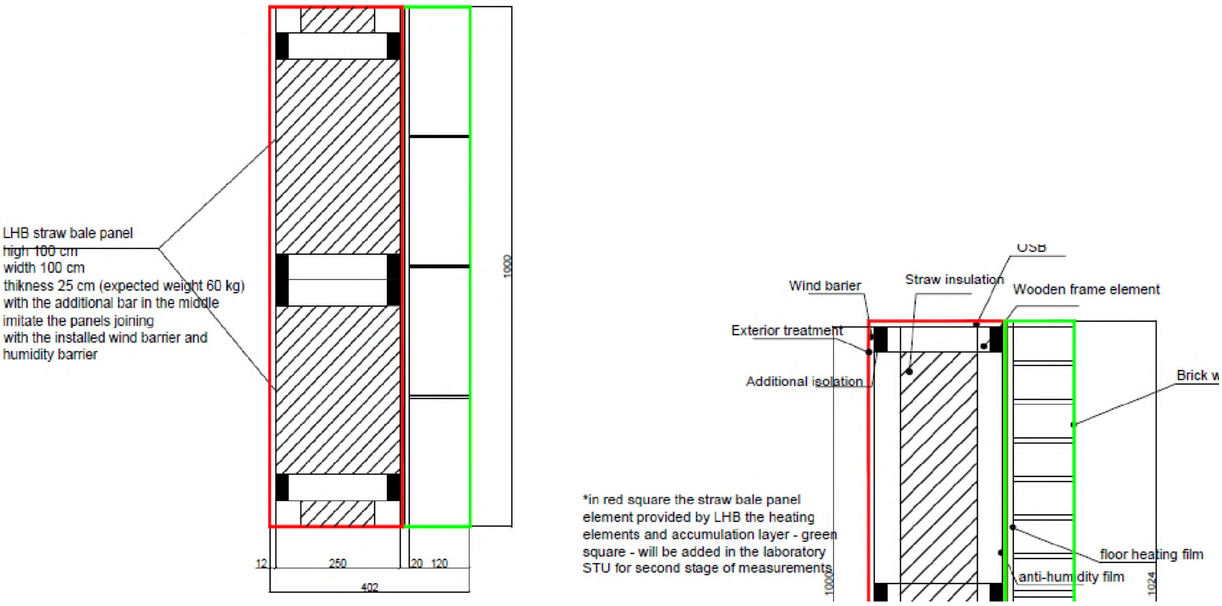


Fig. 14. The composition and parameters of the test sample.

The test was realized in two general stages:

1. **First stage** – test of prefabricated straw-wooden panel without accumulation layer and heating under the conditions precise in the Table 4.
2. **Second stage** – test of composed wall with insulation, heating and accumulation layers under the conditions precise in the Table 4.

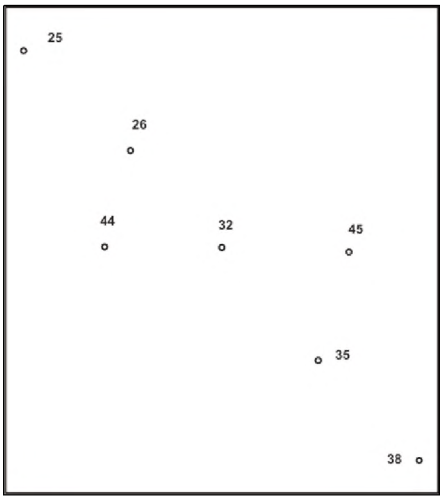
The parameters of the test are presented in the Table 4.

Table 4. The parameters of the stages of the experiment.

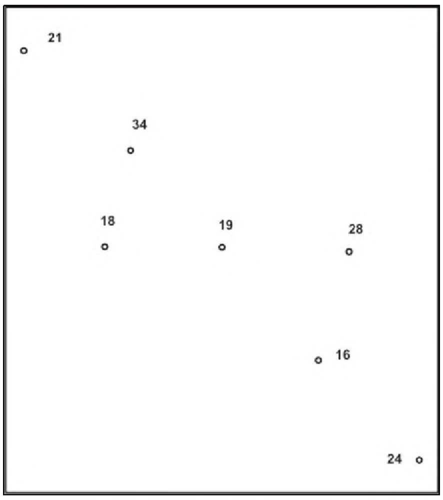
Stage (type of sample)	Temperature in external camera*, t_{ex}, °C	Temperature in internal camera, t_{in}, °C	Level of heating, temperature of heating film, t_h, °C	Relative humidity in external camera, W_{ex}, %	Relative humidity in internal camera, W_{in}, %
First stage	-15	20	0	50	50
prefabricated	-5		0	50	50
straw-wooden panel	+5		0	50	50
Second stage	-15	20	28	50	50
	-5		28	50	50
composed eco wall with insulation, heating and accumulation layers	+5		28	50	50

*Temperature-humidity regime has been supported certain period of time at least 24 hours

The disposition of measurement elements for the both stages of the experiment are shown on the Fig. 15 and Fig. 16.

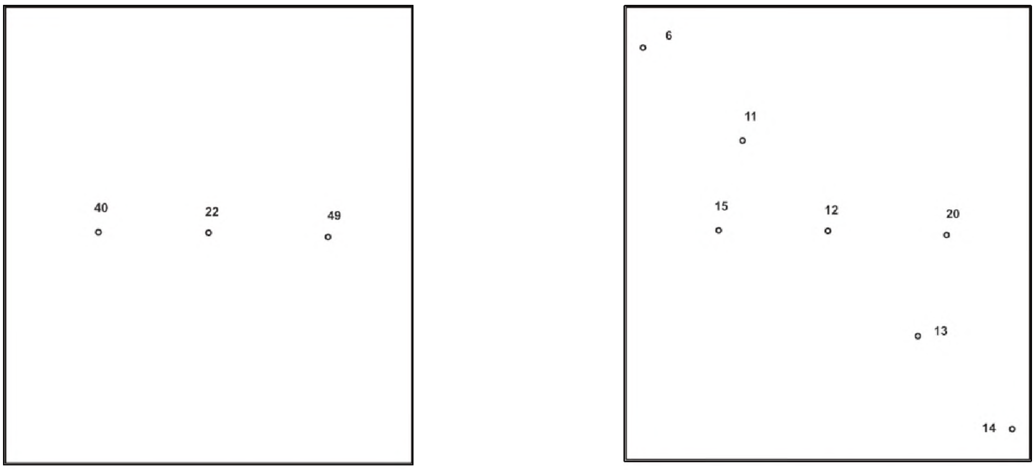


Exterior room



Interior room

Fig. 15. Disposition of measurement elements for the first stage of experiment.



Exterior room Interior room

Fig.16. Disposition of measurement elements for the second stage of experiment.

The expected test parameters for evaluation in the frame of the presented laboratory study are: the temperatures in the external and internal surface of the test element in several points including on the joints (wood frame elements), where the thermal bridges are expected; overall thermal image of the external and internal wall in the extreme negative temperatures; thermal flow to the interior (during the first stage) – to define the coefficient of thermal conductibility of straw-wooden panel itself; heating periods and energy consumption to ensure temperature stability within thermic barrier integrated in the wall element.

The temperature measurements results are shown in Tables 5–6. The received results describe the differences of temperatures on the surfaces in interior and external rooms of climate chamber. According to the received differences transmission of heat through a building wall has been calculated.

Table 5. First stage of measurements.

Position	ex	in	ex	in	ex	in	ex	in	ex	in	ex	in	ex	in
Meas. point	25	21	26	34	44	18	32	19	45	28	35	16	38	24
-15	-14.5	16.6	-12.2	18.1	-13.4	16.5	-14.2	17.13	-14.4	17.9	-14.8	15.7	-14.8	13.9
-5	-4.7	17.5	-3.4	19.1	-4.1	18.1	-4.8	18.01	-4.7	18.7	-4.9	17.7	-4.8	16.1
+5	5.1	18.4	5.7	19.6	5.3	19.1	5.4	18.77	5.1	19.3	5.1	19.0	5.2	18.2

Table 6. Second stage of measurements.

Position	ex	in(brick)	ex	in(brick)	ex	mid	in(brick)	ex	mid	in(brick)	ex	mid	in(brick)	ex	in(brick)	ex	in(brick)
Meas. point	25	6	26	11	44	40	15	32	22	12	45	49	20	35	13	38	14
-15	-14.5	19.9	-13.2	20.3	-14.4	15.8	19.4	-14.4	17.1	20.0	-14.7	17.4	19.9	-14.9	19.1	-14.9	17.86
-5	-4.8	19.7	-4.0	20.2	-4.6	17.5	19.7	-4.5	18.1	20.0	-4.8	18.3	19.9	-4.9	19.5	-4.9	18.67
+5	5.1	19.8	5.4	20.2	5.2	19.3	20.1	5.37	19.6	20.2	5.1	19.6	20.1	5.1	19.9	5.2	19.42

Table 7. Coefficient of thermal conductibility of straw wall under different thermal conditions.

Temperature regime, °C	U, W/m2K	Coefficient of thermos-transmission in different temperature regimes, W/m*K
-15	0.38	0.095
-5	0.32	0.08
+5	0.27	0.068

The analyze of the regime of work of heating layer to ensure the required interior regime is presented in the diagrams on the Fig. 17 – Fig.18.

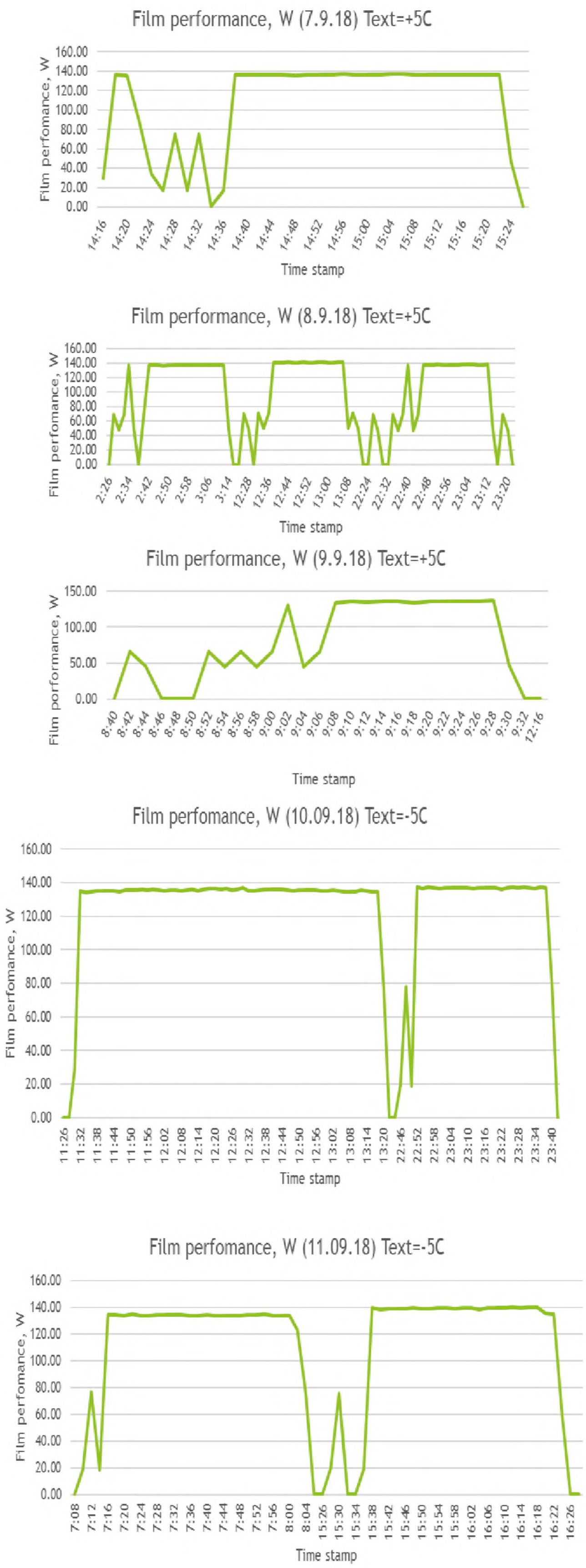


Fig. 17. Heating periods under the external temperature regime +5°C and -5°C.

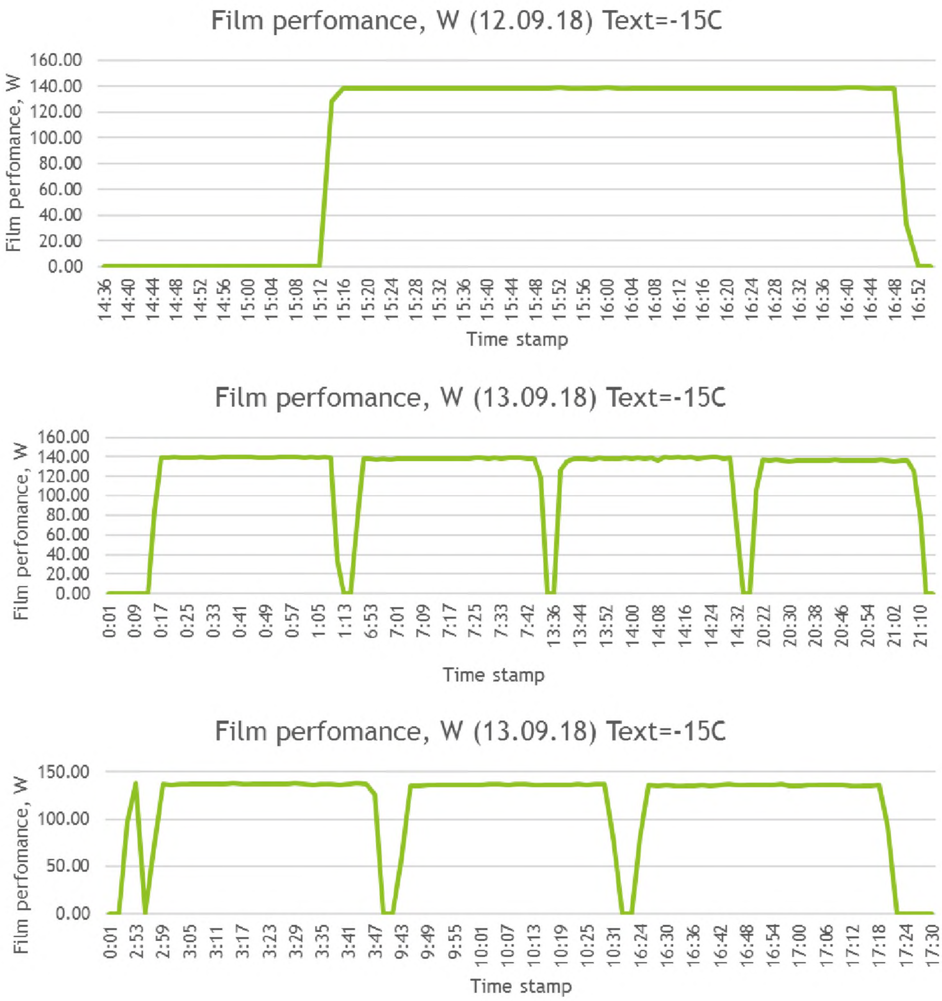


Fig.18. Heating periods under the external temperature regime -15°C.

The composite structure solution of straw wall for sustainable buildings has been developed. The structure is containing a wooden frame, a thermal insulation layer from materials of vegetable origin, an internal massive heat accumulation layer and an outer protective layer.

The complex study of thermal properties of the proposed structure has been preceded in big climate chamber TiR32 in the laboratory of building physics of Civil Engineering Faculty (Slovak University of Technology in Bratislava). Coefficient of thermos-transmission in different temperature regimes for the studied wall structure varies 0.095 - 0.068 W/m*K per the external temperature conditions.

The enfro-red heating film performance has been analyzed according to the supporting the temperature regime in interior room ($\geq +20°C$) and provide required temperature barrier. In average to support the required interior temperature regime during 10 hours under the external temperature +5 °C, the heating layer should work on the maximum regime (140 W) for 1 hour; to support the required interior temperature regime during 7-10 hours under the external temperature - 5 °C, the heating layer should work on the maximum regime (140 W) for 1-2 hours; to support the required interior temperature regime during 4-6 hours under the external temperature - 15 °C, the heating layer should work on the maximum regime (140 W) for 1 hour.

3. ENERGY SECURITY OF A LOW-RISE RESIDENTIAL ECOBUILDING "ZERO ENERGY" ON THE BASIS OF SOLAR ENERGY

1. *Initial data.* The location of the house is a mid-European zone with the intensity of solar radiation - 1223 kWh / (m^2 year) (Ukraine, Dnipro). Residential house with the area of 130 m^2 is designed for a family consisting of 3...4 people. Dimensions of the building - 6 x 10 m, the longitudinal axis of the building is orientated east-west. The house is two-story with an attic floor. The first floor is semi-basement. On it are located: kitchen-dining room, pantry, toilet, bathroom and room for sports activities. On the second floor are located: entrance hall, living room, bedroom, toilet, bathroom and study. On the attic floor, there are: a hall, a room for utilities, a dressing room. The useful area of one floor is 50 m^2, the attic floor is 30 m^2. The height of the rooms on the floors is 2.5 m, the mansard floor is 2.2 m. The house has a thermal insulation with an estimated heat loss of 25 W/m^3. All household appliances in the house is designed to be powered by a single-phase electric current of 220 V, 50 Hz. As a prototype, a building with walls made of straw panels «Life House Building» was chosen (see Fig.19, Fig. 20). The contract price is $ 350 per m^2 of the total area of the building.

2. *Consumption of heat and electricity in the building*. For the normal functioning of the projected house and the provision of comfortable living conditions for the people living in it, it is necessary to expend thermal and electric energy for the following functions:

- cooking and storage;
- heating (cooling) of air in the house to ensure comfortable living conditions for people;
- supply of cold water to the house and sewerage;

- heating of water for heating and hot water supply;
- functioning of household appliances;
- the functioning of the auxiliary objects of the manor (economic block, greenhouse, etc.);
- work of tools and devices of management.

Fig.19. The design of the house using straw panels

Fig. 20. Straw panel

The authors based on the statistical data, the experience of other specialists performed an analysis of the use of each consumer of energy during each month of the year, considering the duration of its operation and the power expended at the same time. The results of such an analysis are given in Table 8.

Table 8. Average power consumption by periods, kWh

Device	Power, W	Month												
		1	2	3	4	5	6	7	8	9	10	11	12	1-12
Basic regular consumers														
1	250	23	21	31	37	39	45	46	46	38	39	22	19	406
2	1200	112	101	112	108	112	72	74	74	144	112	90	93	1204
3	60	9	8	7	5	6	5	6	6	7	7	9	11	86
4	20	15	13	15	14	15	14	15	15	14	15	14	15	174
5	5	4	3	4	4	4	4	4	4	4	4	4	4	47
6	30	3	3	2	1	1	2	2	2	2	3	3	3	27
7	800	25	22	25	29	37	60	62	62	48	37	24	25	456
8	2500	194	175	116	30	30	20	20	20	25	124	188	194	1136
9	2500	47	42	46	45	31	22	16	16	22	31	45	43	406
10	150	9	8	9	9	14	18	19	19	14	12	9	7	147
	1x20	1	1	1	1	1	-	-	-	1	1	1	2	
	1x20	4	3	3	3	1	-	-	-	1	1	1	2	
	2x20	10	9	9	7	5	2	2	2	2	5	7	10	
	4x20	15	13	15	12	7	5	5	5	5	10	14	20	
	total	30	26	28	23	14	7	7	7	9	17	23	34	225
total		471	422	395	305	303	269	271	271	327	401	431	448	4314
Auxiliary regular consumers														
12	2000	10	12	12	8	8	10	10	10	10	10	12	12	124
13	1500	4	6	6	6	8	9	9	9	8	6	6	6	83
14	1500	9	12	12	12	12	12	12	12	12	9	9	9	132
15	1800	4	5	5	5	7	9	9	9	7	5	4	4	73
16	50	1	1	1	1	1	1	1	1	1	1	1	1	12
total		**28**	**36**	**36**	**32**	**36**	**41**	41	41	**38**	**31**	**32**	**32**	**424**
Irregular consumers														
17	1500	-	-	2	3	4	6	8	8	4	-	-	-	35
18	1500	-	-	3	4	4	6	8	8	4	-	1	-	38
19	3200	-	-	3	5	6	10	10	6	3	-	3	-	46
20	1500	-	-	2	4	-	-	3	9	6	2	-	-	26
21	1000	-	-	-	1	4	4	4	4	4	2	-	-	23
22	320	-	-	15	19	1								34
total		-	-	25	36	19	26	33	35	21	4	4	-	202
total		499	458	456	373	358	336	345	347	386	436	467	480	4941

Note: 1 - refrigerator, 2 - kitchen stove, 3 - TV, 4 - inverter, 5 - charge controller, 6 - laptop, 7

- cold water pump, 8 - heat generator, 9 - electric kettle, 10 - air recuperator, 11 - lighting lamps, 12 - electric oven, 13 - washing machine, 14 - iron, 15 - vacuum cleaner, 16 - kitchen extractor, 17 - cutting machine, 18 - electric drill, 19 - welding machine, 20 - plant crusher, 21 - lawn mower, 22 - pump greenhouses

3. Calculation of solar panels based on the determination of solar activity. The city of Dnipro has the following geographical coordinates in the world coordinate system WGS: 48 deg 27 min northern latitude, 34 degrees 59 min eastern longitude. The duration of daylight hours in civil twilight is equal to: the shortest is 9 hours 36 minutes, the longest - 17 hours 26 min. The minimum design time for active solar radiation is 9 hours 36 min - 2 hours. = 7 hours 36 min (7.6 hours).

Solar insolation in Dnipro according to NASA data is equal to: annual - 1223 kWh / m^2 / year, average monthly - 3,3516 kWh/m^2/day. The values of daily insolation by months are shown in Table 9.

Table 9. The average monthly level of solar radiation (solar constant) in the city of Dnipro, kWh / m2 / day

Month	1	2	3	4	5	6	7	8	9	10	11	12
Irradiation	1,21	1,99	2,98	4,05	5,55	5,57	5,70	5,08	3,66	2,27	1,2	0,96

To electrically supply the building, we select an autonomous solar power plant whose scheme is shown in Fig. 21.

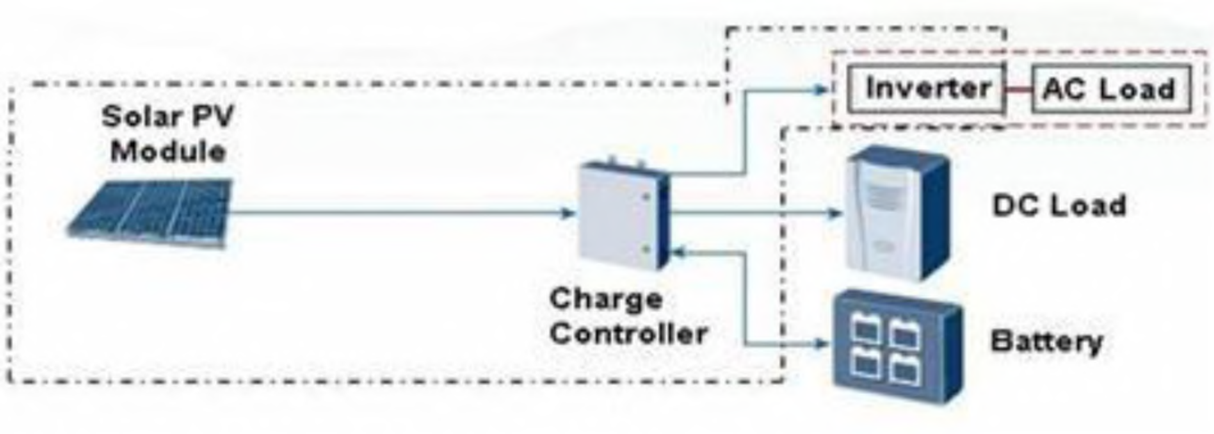


Fig. 21. Scheme of an autonomous solar power station.

As a working we choose polycrystalline panel ABISolar PS-P60250 with a power of 250 W, voltage 24 V. The panel size is 1650x992x35 mm, weight -20 kg, the active area of the panel is 1.6368 sq.m. The cost of the panel is 250 dollars USA.

The panels are fixed on the southern roof slope of the designed house. The size of the roof slope is 3.7 m x 10 m. The angle of slope of the ramp is approximately 37 degrees to the horizon. According to the recommendations, solar panels should be placed at an angle to the horizon at an angle of 15 degrees more than the geographical latitude of the installation site, i.e. 48 + 15 = 63 deg.

The number of panels is dictated by the amount of electricity demand for the most unfavorable months of the year - in January and December. The required number of panels for electricity consumption in January: 497.5 / 1.21x1.6368 = 8.1. The same for December consumption: 477.9 / 0.96x1.6368 = 9.8. We accept for operation 10 panels in a solar battery. Table 10 shows data on generation volumes and requirements by months of the year for all 10 panels.

Table 10. Consumption and generation of electrical energy, kWh

Parameter	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
generation	613	912	1512	1989	2816	2735	2892	2577	1797	1152	589	487	20080
consumption	499	458	456	373	358	336	345	347	386	436	467	480	4941
difference	114	454	1056	1616	2458	2399	2547	2230	1411	716	122	7	15139

4. Calculation of auxiliary equipment. Inverter. The power of the inverter is calculated by the most intense month-January. Consumption in this month is 497 kWh, i.e. for the day 497/31 = 16 kWh. The duration of active solar radiation in January is 7.6 hours. The power of the inverter should be at least 16 / 7.6 = 2 kW, and taking into account the reserve 1.4 × 2 = 2.8 kW. We accept the power of the inverter 3 kW. Since the house is fully provided with electricity from solar panels, we choose a hybrid inverter for single-phase current of 220 V, 50 Hz and with a clean sinusoid.

It is recommended to use a hybrid inverter PH3000-3K (Taiwan). Its brief technical characteristics: nominal power - 3000 W, voltage: input - 24.48 volts, output -230 V, charge current - 80 A, weight 29.5 kg. The cost is $1003.

The backup electric system can be an industrial power grid, and where it does not exist - an autonomous unit of an internal combustion engine - a generator with a capacity of about 4 kW.

Rechargeable batteries. The total battery capacity is chosen for the largest monthly consumption. Daily consumption in January is 16048 Wh. We take the following distribution of this consumption: in the afternoon from solar batteries - 40% and at night from accumulators - 60%. Then the daily consumption of batteries is 16048x0.6 = 9629 Wh. The required battery capacity is: 9629/24 = 401 Ah. To ensure the longevity of batteries, their discharge should be no more than 80%. Therefore, you need a battery with a capacity of 401 / 0.8 = 501 Ah.

We accept a 6 OpzV 600 battery with 600 Ah capacity and 2 V voltage. For a 24 V battery, 12 such batteries are needed. The Kharkov accumulator factory "Vladar" produces such batteries. These batteries are a new generation of gel, with panzer electrodes, with a service life of up to 18 years.

Charge Controller. We select the effective charge controller MPRT type - MORNINGSTAR TRISTAR-MPPT60 with the following technical characteristics: maximum continuous current of battery charge - 60 A, nominal voltage - 12, 24, 48 V, cost - 886 US dollars.

Based on the solar power plant calculator, indicative calculations of the parameters and cost of SES are given when choosing different power stations.

5. Variants of power supply of the building according to the scheme and without a "green tariff" scheme. The Ukrainian legislation allows for the transfer of surplus electricity generated by solar power stations of individuals to the country's industrial network. The order of such transfer is regulated by the Resolution of the National Council of Ukraine on February 27, 2014 No. 170. This resolution determines the requirements for a counter of such energy that it should be bidirectional. As a recommendation, you can offer, for example, a single-phase, bidirectional, multi-tariff meter MTX1A10.DF.2ZO-CO4 (Odessa). Its price is 41 US dollars. The use of a "green tariff" requires mandatory legal registration.

Table 11. Approximate calculations of parameters and cost of SES when choosing different power stations

Parameter of autonomous SES	Power station, kW		
	3	5	10
number of photomodules, pcs	12	20	40
area of photomodules, m^2	19	32	65
angle of incline, degree	63	63	63
autonomy, hours	24	24	24
Battery Type	not served Ventura AGM GPL-200		
winter consumption per month kWh	500	500	500
consumption in summer in a month, kWh	350	350	350
generation of solar power plant per year, kWh	3298	5496	10996
annual consumption of the facility, kWh	5212	5212	5212
not compensated by the electric power station, kWh	2 221	1411	534
compensated electricity by the station, kWh	2 991	3801	4 678
capacity of storage batteries, kWh	33.6	33,6	33.6
number of batteries, pcs	14	14	14
estimated cost of the power plant, USD	9750	12150	18150

The economic efficiency of the use of solar batteries and the "green tariff" is determined not only by the gain from the sale of surplus energy, but also by the absence of payment for the consumed energy. Using the currently known tariff for consumed electricity (from 01.03.2017), which determines the cost of a monthly payment in the amount of 0.035 USD / kWh (up to 100 kWh / month) and 0.065 USD / kWh (more than 100 kWh / month), as well as the approved "green tariff" from 01.01.2017 to 31.12.2019 in the amount of 0,205USD/kWh one can determine the annual economic efficiency: Э = 12x100x0,035 + (4941-12x100) x0.065 + 15139x0.205 = 3388 USD.

If for any reason it will not the possibility of selling excess electricity, and then develop it fully would be no point. In this case, it is necessary in each specific period to use a limited number of solar panels, which will be dictated by the amount of energy consumed. This option of using panels can significantly extend their durability. Table 12 shows the calculation of generation and consumption by period, considering the rational number of used panels.

Table 12. Generation and consumption of electricity in the absence of a "green tariff" scheme, kWh.

Parameter	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
generation	552	547	454	398	563	547	578	516	539	461	471	487	6113
consumption	499	458	456	373	358	336	345	347	386	436	467	480	4941
difference	53	89	0	25	205	211	233	169	153	25	4	7	1172
number of panels	9	6	3	2	2	2	2	2	3	4	8	10	

6. Ventilation and heat recovery system. When complete the residential buildings with plastic sealed window blocks, a good thermal insulation is provided, but there is a problem of air exchange in the premises. It is necessary to ventilate them periodically. However, in cold weather it is necessary to supply cold air to the rooms, which significantly breaks the thermal temperature regime in the rooms. Calculations and practice proved that through ventilation in winter, up to 50% of the heat energy is lost. There is a need to conserve this heat and at the same time to ensure ventilation. Systems of this designation are called recuperative.

An example of a successful implementation of such a system is the installation of VENTS MICRA 150E in the Poltava Ventilation Plant, which provides both ventilation and heat recovery. The advantage of this installation is also the availability of the function of heating the outside air. The unit has two fans with a total capacity of 15.5 W and a capacity of up to 150 m^3 / min. The weight of the installation is 20 kg; the cost is 1062 USD.

The second successful example is the recuperators of the company "PRANA", Lviv. These are recuperators for point use and must be installed in each room. Their brief characteristics: air flow - 125 m^3/h, air extraction - 115 m^3/hour, power consumption -32 Wh, room area - up to 60 m^2.

7. Water heating system for heating and hot water supply. The basis of such a system is an electric heat generator. The best technical solution at present is a heat generator with electromagnetic induction heating. It has the following advantages over other types of electric heating:

absolutely fireproof, because flameless heating;

the system does not form a scale;

great durability (up to 30 years);

silent operation;

high profitability;

the system can work on antifreeze.

Let us determine the thermal power of the heat generator. For a residential building with a heat consumption of 25 W/m^3, the required heat output is: (100 x 2.5 + 30 x 2.2) x 25 = 7900 W.

Based on the characteristics of the VENTS MICRA 150E and PRANA-150 recuperators, where it is indicated that these heat exchangers return 80 ... 93% of heat (assuming 70% for calculations), it can be concluded that to provide normal heating it is necessary to refill 7900 x (1 - 0.7) = 2370 W of thermal power.

Thus, the total power of the heat generator should be: 7900 + 2370 = 10270 W. We select for use induction boiler VIN-10 (Zaporozhye), which has the parameters:

thermal power -10 kW,

efficiency - 99%;

weight - 40 kg;

cost - 577 USD.

It should also be mentioned that hot summer water can easily be obtained using a solar collector installed, for example, on the roof and a large capacity storage tank installed and insulated on the attic floor. Table 13 shows the cost of building construction including engineering systems.

Table 13. The cost of building construction including engineering systems

No.	Element of the architectural,constructive and engineering system of the building	Cost, USD/m^2
1	Building box with a rough finish	350
2	Autonomous solar power plant with a power of 3 kW	75
3	Heat generator for heating and hot water supply	5
4	Thermal barrier system	50
5	Ventilation and heat recovery system	10
6	Water supply and sewerage system with appliances	20
	Total:	510

The results of the studies show that in the Central European zone of Ukraine, where Dnipro is located, it is possible to provide an autonomous power supply for a low-rise residential building. The proposed electric power supply system allows generating an excess amount of electricity, which can be realized according to the "green tariff" scheme. If the building is located in the area lack of the industrial power network, a system of selective use of solar panels is proposed to generate the amount of electricity that would be enough to cover the demand in each period of the year. This technique contributes to a significant extension of the life of solar panels and batteries. Currently, the Ukrainian market has all the necessary devices for the proposed construction system. There is an opportunity to organize own manufacture of separate elements and components of engineering systems. The cost of basic constructive and technological systems of eco-building "zero-energy" is determined, which indicates the competitiveness of the proposed solution.

4. ENERGY BELANCE OF TRIPLE ZERO BUILDING

Nowadays, there is no national standard for zero energy buildings in Ukraine. The in this studies are constitute part of the project wich aims at creating scientific bases for designing autonomous eco-buildings in Ukraine under the concept of "Triple Net Zero", i.e. “net zero energy-waste-emissions”. Mentionned project is supported by the Ministry of Education and Science of Ukraine.

Main target of this work is to assess energy consumption of the autonomous eco-building under the concept of "Triple Zero" in comparison with existing foreign analogues..

The European 20-20-20 strategy sets three main goals: to increase energy efficiency by 20%, reduce greenhouse gas emissions into the atmosphere by 20% (from 1990 levels) and cover 20% of Europe's energy consumption using renewable energy sources (RES) by 2020. The EU construction sector is going to achieve these ambitious targets through the Energy Performance of Buildings Directive [Directive 2010/31/EU] which states that all new buildings should be nearly zero-energy from 2021. According to this document, each country draws up a national standard for zero energy buildings, taking into account its specific climate conditions, primary energy factors, ambition levels, calculation methodologies and building traditions.

The national plans should define: a numerical indicator in primary energy expressed in kWh/m^2/year; policy, financial and any other type of measures that will support the implementation of nZEB and including national measures and requirements concerning the use of RES. The general approach to the design of NZEB buildings is based on the high level of the insulation and RES-based engineering system to meet all functional needs of the home. Most often, the numerical indicator of the standard it is a maximum annual total amount of primary energy (wholly or partially obtained from RES) to serve the needs of heating, air conditioning, ventilation, electricity, hot water production, etc . This indicator ranges from 0 kW / m^2 per year to 270 kW / m^2 (the last for public buildings, hospitals). For example, for Croatia, the value is 33 kWh / m^2 per year, for Denmark – 20 kWh / m^2, for Lithuania – 95 kWh / m^2, for Belgium, France, Slovakia, Bulgaria, Malta, United Kingdom, Ireland and Estonia it varies from 45 to 50 kWh / m^2

The National Institute of Standards and Technology (NIST) has summarized ten basic design principles for NZEB buildings, which were applicated in construction of 250 m^2 NZERTF (Net Zero Energy Residential Test Facility) for 4 residents in Gaithersburg (USA). The building is fully electrified, an air pump with a split system of 7 kW provides it with heating and cooling with recuperation. The thermal resistance of the outer walls reaches 7.9 $m^2 \cdot K / W$. Total energy consumption for all needs (heating, cooling, lighting, hot water supply, domestic electricity, ventilation) is 12405 kWh, thus specific energy consumption was 49.62 kWh / m2

The LUCIA building with a nearly zero energy and zero carbon footprint was built at the Valadolid campus in Spain. The publication presents an analysis of the building energy balance. The building is fully electrified, equipped with photovoltaic panels, an air-to-ground heat pump received a high LEED rating. Primary energy consumption has been found to reach 67 kWh / m2 per year when generating energy from renewable sources is 121 kWh / m2.

Italian scientists have noted that the cost of NZEB buildings ranges from 212 to 313 euros / m^2 and it is higher than the cost of conventional buildings. At the same time, the case study NZEB building allowed to reduce carbon emissions by 40% compared to the standard version of a typical building.

Finnish scientists prove the importance of the lean production for zero-energy buildings based on case monitoring of a modular wooden house in Vantaa. The obtained specific energy consumption of 92 kWh/m^2 is 40% lower than the permissible maximum of the standard for this class of buildings. The authors note that the construction of the case study building will result in an increase in investment value of 115 euros per 1 m^2 compared to the standard house. It is 15 euros cheaper than in the case of conventional nZEB construction, with energy savings of up to 8 euros per 1 m^2.

The Eco Silver House apartment building (Ljubljana, Slovenia) has been chosen by scientists in order to compare calculated and operational energy consumption. The results show the differences between the analytical and empirical methods which are ranged from 2.8% (for January) to 10.5% (for February). First of all, the error in February was caused by unusually warm weather conditions. In general, the calculation method used is quite reliable.

Research carried out by Italian scientists is about upgrading of an individual public building to nZEB level. The results of this research indicate a prospective reduction in energy consumption of the building by up to 40%.

It is well known that there is a problem of nZEBs integrating into existing city networks. This question was revealed in a publication using the example of five buildings built in different EU countries.

A team of scientists from seven EU Member States carried out a detailed analysis of barriers that have been preventing the active implementation of the nZEB standard in construction practice. The analysis presented in the publication demonstrates the superiority of technical, social and organizational barriers over financial. EU countries lack experienced specialists and adopted city infrastructure to the new nZEB. The authors are concerned about the risk of 20-20-20 strategy failure. In addition, the results indicate that almost all EU countries are unable to apply the directive to the construction of all new buildings according to the nZEB standard in the near future.

Therefore, the experience of European scientists can be used to develop an autonomous eco-building concept "Triple Zero" which should be adopted to the conditions of Ukraine with the maximum use of local materials and equipment to make proposed solutions affodable for the general public.

Methods. The following methods of theoretical research were used: abstraction, analysis and synthesis, idealization, induction and deduction, mental modeling, ascent from abstract to concrete.

Architectural concept and structural solutions for Triple Net Zero Building. The projected residential building has two floors. There are entrance hall, living room, kitchen, bathroom, wardrobe on the ground floor (Fig.22). Hall, bedrooms, bathroom are situated on the attic floor. The height of the premises of the first and attic floors is 2,7 m. The residential areas are oriented towards the southern horizon, glazed. Auxiliary rooms are north oriented, deaf or with minimal glazing.

The structural scheme of the building is framed. The load-bearing elements of the walls has complex cross-section of two timber 89x38 mm posts with a step of 600 mm. The bearing structures of ceiling and roof are timber trusses from elements with a section of 89x38 mm and step of 0.6 m. The spatial rigidity of the building is provided by diagonal braces between the posts, as well as the monolithic slab of soil-concrete in the upper chord of the trusses.

Cereal straw is used for insulation. The walls are covered with OSB sheets; on the inside soil-concrete blocks that act as a heat accumulator are laid. The ceilings are lined with plywood or other wood-based finishing material. The floor is covered with ceramic tiles (for kitchens and bathrooms) or plank flooring (for other rooms). Roof is covered with reed slabs.

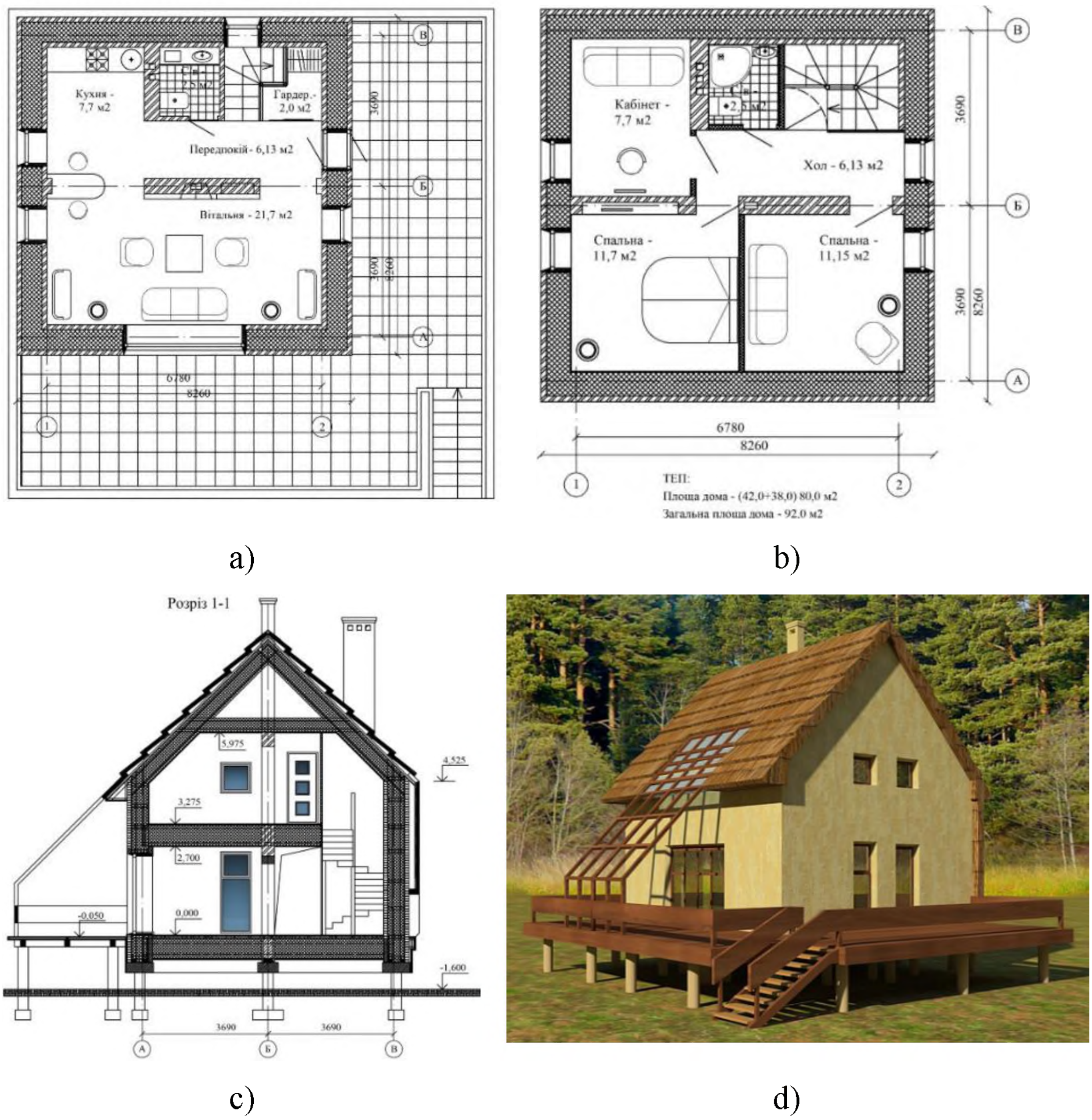


Fig. 22. Triple Net Zero Building: a) first floor layout; b) attic floor layout; c) cross-section; d) 3d visualization

The coefficient of heat transfer of the enclosure Uk for each external building structure is determined at the preliminary stage of the building design in accordance with ukrainian building code DBN B.2.5-31: 2016 "Thermal insulation of buildings". The calculated values of the thermal resistance Rk and the heat transfer coefficient Uk are presented in Table 14.

Table 14. Calculated values of the thermal resistance Rk and the heat transfer coefficient U_k

Type of construction	Surface, m^2	R_k, m^2·K/W	U_k, W/ m^2·K
Floor slab	54,33	6,7	0,15
External wall	141	6,8	0,147
Roof slab	42,7	11,1	0,09
Window systems Saint Gobain Glass Nord East South West	 2,29 14,63 6,1 7,86	 1,67	 0,6
Entrance door	1,88	2	0,5

Air-conditioned space area of case study building is ***Af*** = 80 m^2.

According to building standart, energy efficiency indicators for buildings are:

specific energy demand for heating, cooling, hot water supply;

specific energy consumption for heating;

specific energy consumption for cooling;

specific energy consumption for hot water production;

specific energy consumption of ventilation systems;

specific energy consumption for lighting;

specific energy consumption of primary energy;

specific energy consumption of greenhouse gas emissions.

Energy demands for heating, cooling and hot water supply. Specific energy demand for heating, cooling and hot water production for residential building are determined by the following formula:

$$EN = \left(Q_{H,nd} + Q_{C,nd} + Q_{DHW,nd}\right) / A_f \,,$$

$Q_{H,nd}$ – annual energy demand of the building for heating, kWh, determined in accordance with paragraphs 7, 8, 9, 10, 11, 12, 13 and 14 of DSTU B A.2.2-12;

$Q_{C,nd}$ – annual energy consumption of the building for cooling, kW · h, determined in accordance with paragraphs 7, 8, 9, 10, 11, 12, 13 and 14 of DSTU B A.2.2-12;

$Q_{DHW,nd}$ – the annual energy demand of the building for hot water supply, kWh, is calculated by the formula;

A_f – air-conditioned space area, 80 m^2.

Energy demands for heating and cooling. Internal conditions.

The needed temperature of building for heating period $\theta_{int,Hset}$ was calculated by formula, and it was based on the set of design temperatures of internal premises. The internal design temperature of premises was taken according to national building standard DBN V.2.2-15 and it was +21 °C for living rooms, + 22 °C for bathroom, and +19,5 °C for other premises.

The needed temperature of cooling was taken according to table 16 and it was $\theta_{int,Cset}$ =25 °C. The energy demand for heating - Q_{Hnd}, kWh was calculated for every month by formula and presented in the table 16. All additional parameters, calculated to obtain energy demand for heating, were also presented in the tables 2 and 3. Annual energy demands for heating and cooling of building $Q_{H,nd,an}$, kWh were calculated by formula and each parameter respectively consist of total amount of energy demands for all months of heating season and cooling season.

Table 15. Calculation of energy demands for heating

Month	Parameter						
	$Q_{H,tr}$, kWh	$Q_{H,ve}$, kWh	$Q_{H,sol}$, kWh	$Q_{H,int}$, kWh	$Q_{H,gn}$, kWh	$Q_{H,ht}$, kWh	$Q_{H,nd}$, kWh
October	154,13	18,56	109,29	17,47	125,01	172,70	66,19
November	652,38	82,36	154,12	17,47	169,84	734,74	564,51
December	839,15	106,71	119,12	17,47	134,85	945,86	809,45
January	911,94	116,82	175,29	17,47	191,01	1028,76	836,66
February	882,16	112,68	266,33	17,47	282,05	994,84	714,93
March	720,04	90,16	380,14	17,47	395,87	810,20	437,98
April	138,49	16,48	150,19	17,47	165,91	154,97	34,42
Annual energy requirements for heating, $Q_{H,nd,an}$, kWh							3464

Table 16. Calculation of energy demands for cooling

Month	Parameter						
	$Q_{c,tr}$, kWh	$Q_{c,ve}$, kWh	$Q_{c,ht}$, kWh	$Q_{c,sol}$, kWh	$Q_{c,int}$, kWh	$Q_{c,gn}$, kWh	$Q_{C,nd}$, kWh
May	120,23	31,69	151,92	300,88	17,472	176,43	34,48
June	120,23	31,69	151,92	301,02	17,472	177,43	32,12
July	120,23	31,69	151,92	318,26	17,472	185,97	32,07
August	120,23	31,69	151,92	298,42	17,472	174,78	36,08
September	120,23	31,69	151,92	267,73	17,472	157,75	43,31
Annual energy demands for cooling, $Q_{H,nd,an}$, kWh							178,06

The meaning of the parameters in the Table 15 and Table 16 are presented below.

$Q_{H(C),tr}$ – the total heat transfer by transmission, kWh.

$Q_{H(C),\ ve}$ – the total heat transfer by ventilation (mechanical ventilation), kWh.

$Q_{H(C),sol}$ – the solar heat inputs to the side of building under consideration for each month, kWh.

$Q_{H(C),int}$ – the total amount of the heat gain from internal sources during a calculation period, kWh.

$Q_{H(C),gn}$ – the total heat gains in heating (cooling) mode, kWh.

$Q_{H(C),ht}$ – the total heat transfer in heating (cooling) mode, kWh.

Energy consumption for heating. The duration of the heating period was determined according to the national standard, and it make 4184 hours for I temperature zone of Ukraine. The duration of the cooling period was defined according to the paragraph 15.3.4 based on the data of the Table 6 annex A for city Dnipro and it makes 1156 hours.

Annual energy consumption for heating, kWh, is defined as the sum of every month energy consumptions $Q_{H,use,I}$, kWh, and it is calculated by the formula:

$$Q_{H,use,an} = \sum_i Q_{H,use,i} / 1000.$$

Thermal energy consumption during heating of premises is determined by the formula:

$$Q_{H,use,i} = Q_{H,gen,out,i} + Q_{H,gen,ls,i},$$

$Q_{H,gen,out,i}$ – output energy from the production / generation and heat accumulation subsystem during i-month, kWh, that is determined according to 15.6.1;

$Q_{H,gen,ls,i}$ – the total heat losses of the production / generation and heat accumulation subsystems during the i-month, kWh, that are determined according to 15.6.2.

Output energy from the production and heat accumulation subsystem. For the purposes of the standard, it is accepted that the total energy output from the production / generation and heat accumulation subsystem is equal to the input energy into the distribution subsystem:

$$Q_{H,gen,out,i} = Q_{H,dis,in,i},$$

$Q_{H,gen,out,i}$ – output energy from the production / generation and heat accumulation subsystem during i-month, kWh

$Q_{H,dis,in,i}$ – input energy into the distribution subsystem during the i-month, kWh, that is determined according to 15.5.6.

The input energy that is needed for the distribution subsystem, kWh, is determined by the formula:

$$Q_{H,dis,in,i} = Q_{H,dis,out,i} + Q_{H,dis,ls,nrvd,i},$$

$Q_{H,dis,out,i}$ – the output energy from the distribution subsystem during the i-month is equal the input energy into the heat transfer subsystem for a certain combination of zones which are operated by the same distribution subsystem, and is determined according to 15.4.4, kWh;

$Q_{H,dis,ls,nrvd,i}$ – non-utilized heat losses of the distribution subsystem during the i- month, kWh, are determined according to 15.5.3.

The total heat losses of the production / generation and heat accumulation subsystems during the i-month, kWh, are calculated by the formula:

$$Q_{H,gen,ls,i} = Q_{H,gen,out,i}\left(1-\eta_{H,gen}\right)/\eta_{H,gen},$$

$\eta_{H,gen}$ – the efficiency of heat production / generation and accumulation subsystems;

$Q_{H,gen,out,,i}$ – the output energy from the heat production / generation and accumulation subsystems during the i-month, kWh, is determined according to 15.6.1.

The cottage with 80 m^2 area is equipped with the underground heat pump NIBE F1255PC type "brine / water" with a capacity of 6 kW (according to the calculation of the maximum peak heating capacity and hot water supply demand of 5,3 kW). The "brine / water" heat pump is provided with the inverter control of the compressor and the automatic control of circulation pumps with variable power. It has energy efficiency class "A". The heat pump can be connected to the hot water boiler with required volume. It can also be combined with other heat generating devices, such as: any type third-party boiler or a solar collector. The heat pump has energy efficiency class A+++ and Coefficient of Performance (COP) 4,7, which was defined as $\eta_{H,gen}$.

The results of the energy consumption calculation for heating are shown in Table 20.

The energy consumption for heating is 9.64 kWh/m^2 and it doesn't exceed the value 15 kWh/m^2, which is the maximum permissible value of the Passive House Institute standard. In average the received value corresponds to the European analogues of buildings with zero energy consumption.

Table 17. The calculation of energy consumption for heating

Month	Parameter					
	$Q_{H,nd,}$, kWh	$Q_{H,dis,ls,nrvd}$, kWh	$Q_{H,em,in} = Q_{H,dis,out}$, kWh	$Q_{H,dis,in} = Q_{H,gen,out}$, kWh	$Q_{H,gen,ls}$, kWh	$Q_{H,use}$, kWh
October	66,19	5,503	66,812	72,315	-56,929	15,386
November	564,51	20,347	569,814	590,161	-464,595	125,566
December	809,45	24,341	817,056	841,396	-662,376	179,02
January	836,66	25,893	844,523	870416	-685,221	185,195
February	714,93	25,258	721,653	746,911	-587,994	158,917
March	437,98	21,801	442,093	463,894	-365,194	98,7
April	34,42	5,099	347,46	39,844	-31,367	8,477
Annual energy consumptions for heating, $Q_{H,nd,an}$, kWh						771,264
Specific energy consumption for heating, kWh/m^2						9,64

Total energy consumption for cooling. Cooling system of considered residential building consists of the underground heat pump, which is combined with a fan coil type air-conditioning system.

The total energy output from the cooling system is determined according to the formula, taking into account the formula and the fact that the distribution subsystem for cooling system is absent ($Q_{c,dis,in} = Q_{c,nd}$):

$$Q_{C,gen,out} = Q_{C,dis,in} / \eta_{C,ac} = 96{,}18 / 0{,}93 = 103{,}43 \text{ kWh}$$

The total heat losses of the production / generation subsystem are calculated by the formula. The efficiency of the production / generation subsystem is taken according to the table 31 and it is $\eta_{C,\,gen}$ =2,25:

$$Q_{C,gis,in} = Q_{C,gen,out}\left(1-\eta_{C,gen}\right)/\eta_{C,gen} = 103{,}43\left(1-2{,}25\right)/2{,}25 = -71{,}3 \text{ kWh}$$

The total cooling energy consumption is determined according to formula:

$$Q_{C,use} = Q_{C,gen,out} + Q_{C,gis,in} = 103{,}43 - 71{,}3 = 32{,}13 \text{ kWh}$$

The additional energy for the heat transfer / emission subsystem is determined according to formula:

$$W_{C,em,aux} = f_{C,em,aux} \cdot Q_{C,gen,out} \cdot t_{C,op} / 1000 = 0{,}06 \cdot 103{,}42 \cdot 5 / 10000 = 0{,}031 \text{ kWh}$$

The annual amount of additional energy during cooling is calculated by the formula, taking into account the fact that there is no distribution subsystem:

$$W_{C,aux,an} = W_{C,em,aux} + W_{C,dis,aux,an} = 0{,}031 + 0 = 0{,}031 \text{ kWh}$$

Total energy consumption of ventilation systems. The volume flow rate of air in the mechanical ventilation system is determined by the air exchange multiplicity and the volume of internal premises, which is accepted according to the project data Vs = 296,5 m^3.

$$V_L = V_S \cdot n_S = 296{,}5 \cdot 1 = 296{,}5 \text{ m}^3$$

$$P_{el} = SFP \cdot V_L / 3600 = 2 \cdot 296{,}5 / 3600 = 0{,}16 \text{ kWh}$$

SFP – specific ventilation capacity of mechanical ventilation system, kWh/(m^3/s).

The fan energy consumption is calculated by the formula, taking into account the operating time of the ventilation system, which according to the schedule of use of the building will be:

$$Q_{V,SYS,fan} = P_{el} \cdot t_V = 0{,}16 \cdot 600 = 96 \text{ kWh}$$

Energy demands for hot water system. Specific annual energy demands are determined are 15 kWh / m^2 for a single-family residential building.

The total energy demands for hot water system are:

$$Q_{DHW,need} = 20кВт \cdot год / м^2 \cdot A_f = 15 \cdot 80 = 1200кВт \cdot год,$$

Energy consumptions for hot water system. The hot water system of the cottage is provided with two-pipe system without the circulating circuit. Pipelines with a diameter of 20 mm are heat-insulated according to the standard. The water temperature in the hot water system is 60 °C.

The heat losses of the distribution subsystem for the hot water system of the concerned residential building are negligible and not taken into account.

Annual energy consumption for the hot water system is determined by the formula. The efficiency of the heat production / generation was accepted according to the table 27 for use the heat pump in winter and solar collector in summer, $\eta_{gen} = 3,6$.

$$Q_{DHW,use} = Q_{DHW,nd} / \eta_{gen} = 1200/3,6 = 333,33кВт \cdot год,$$

The additional energy for the hot water system is the energy for the circulating pumps with a capacity of 0.1 kW each unit and is determined by the formula.

$$W_{W,dis,aux} = P_{pmp} \cdot t_{pmp} \cdot N = 0,1 \cdot 2 \cdot 5 \cdot 365 = 365кВт \cdot год,$$

P_{pmp} – the pump power, kW;

t_{pmp} – the pump operating time, hour / day;

N – the number of days when the pump works during the year.

The total amount of energy consumption for hot water system is determined by the formula:

$$DHW_{totaluse} = Q_{DHW,use} + W_{W,dis,aux} = 333,33 + 365 = 698,33кВт \cdot год,$$

The specific energy consumption of the building for the hot water system is 8,73 kWh / m^2.

Energy consumption for lighting. 12 watts LED lamps will be installed in the case study building. The lighting in the building is equipped by cte system -

constant illumination control / adjustment. This system has the photovoltaic cells with natural light sensors, which reduce the light intensity. For calculation we established that 60% of lighting has such regulation.

The annual amount of energy consumption for lighting, kWh, is calculated by the formula:

$$W = W_L + W_P,$$

W_L – the needed energy for artificial lighting in the building, kWh;

Wp – the parasitic energy required to charge the batteries of the luminaires emergency lighting and energy to control / adjust the lighting in the building, kWh.

W_L values are calculated by the formula:

$$W_L = (P_N \cdot F_c) \cdot ((t_D \cdot F_o \cdot F_D) + (t_N \cdot F_O)) \cdot A_f / 1000,$$

P_N – the specific power of the artificial lighting in the building, 2 W / m^2;

Fc – the constant brightness factor. This factor related to the using of the lighting load in the building with the functional constant control of illumination in zones. The factor is determined and is 0,9.

F_0 – the lighting utilization factor is the ratio between the total artificial lighting capacity use to the period of the zone using. It is accepted and is 0,9.

FD – the natural light factor is the ratio between the using of the total artificial lighting capacity to the available natural lighting. It is accepted 0,9;

t_D – the use of the natural lighting during the year - 2250 h;

t_N – the use of the artificial lighting during the year - 250 h;

A_f – air-conditioned building area, 80 m^2.

Wp values are calculated by the formula:

$$W_P = (P_{em} + P_{pc}) \cdot A_f,$$

P_{em} – the specific total capacity of the batteries for the luminaires in the emergency lighting in the building, 1 kW · h / m^2 ;

Ppc – the total capacity of all lighting control systems in zones when lamps are not in use, 5 kWh / m^2.

The calculation results are given in the Table. 18.

Table 18. Energy consumption for lighting

W, kWh	W_L, kWh	*Wp*, kWh
774,84	294,84	480

The specific energy consumption of the building for lighting is 9.69 kWh / m^2.

In previous stages of investigation a 6 kW power NIBE F1255PC ground source heat pump was selected for heating (according to 5.3 kW – the maximum peak heating capacity and hot water supply demand). The obtained data reveals that the specific energy consumption of 9.64 kWh / m^2 does not exceed the standard of the Passive House Institute of 15 kWh / m^2 . This equals an average for the European analogues of buildings with zero energy consumption. The cooling of the premises is carried out by the heat pump in reverse mode. Specific energy consumption for cooling is only 0.4 kWh / m^2 thanks to the use of the ventilation system with local heat recovery equipment in each room. This leads to the energy consumption by the ventilation system in the amount of 1.2 kWh / m^2. The specific energy consumption of the building for DHW production is 8,73 kWh / m^2. The house is provided with LED lamps of 12 watts. The specific energy consumption of the building for lighting is 9.69 kWh / m^2. Therefore, the total energy consumption of the building will be 29,66 kWh / m^2. The indicated result is approximately twice less than the maximum according to the Passive House Institute standard - 65 kWh / m^2 and significantly lower than the national average of the EU countries concerned in a literature survey. The present result is very promising and offers possibilities to carry out in the future more detailed calculations of the energy balance of

"Triple Net Zero" building taking into account the energy production input thanks to the equipment based on renewable energy sources.

5. DEVELOPMENT OF INFORMATION MODEL OF TRIPLE ZERO BUILDING

The review of functional possibilities of information modeling of Triple Zero Building using Autodesk

Autodesk Green Building Studio (abbreviated, GBS) - is a flexible cloud service that allows simulation fo the performance of a building in order to achieve the required level of energy efficiency and reduce greenhouse gas emissions during the design phase. The starting point for modeling in GBS is a three-dimensional building model created in the Revit environment that contains information about the geometric, physical and technical parameters of the building elements, as well as geographical coordinates.

A distinctive feature of GBS is the integration of the DOE-2.2 software module and ASHRAE Standard140 "Standard Testing Method for Computer Programming for Building Energy Efficiency Simulation" verification to provide reliable data. DOE-2.2 is a simulator program certified by U.S. Department of Energy Certified Energy Indicator. It is used to estimate building energy and operating costs based on the effects and interactions of building form, materials and structures, interior systems, occupancy schedules, etc. All required parameters are entered by the designer, and meteorological data are obtained from the weather station database for specific geographical coordinates.

The energy efficiency and emissions of a building depend on the optimum combination of geometric shape, materials for the fabrication of structures and elements, heating, ventilation and air conditioning (HVAC) systems that meet the functional purpose and climatic conditions of the location of the building.

Geometric parameters (shape, size, orientation of the building, the presence of surrounding buildings, etc.) are one of the main factors affecting energy consumption. These parameters are taken into account when forming the Energy

Analytical Model (EAM), which is a discrete space and surface, each reflecting the main sources and paths of heat exchange inside the building and with the environment. All sources of heat gain and loss, possible ways of heat transfer and the dynamics of their change over time are calculated using the finite element method.

The climatic conditions are another factor that directly affects the following parameters: energy consumption, the choice of thermal insulation materials, and the decision of building envelope. In GBS, the climate influence is accounted for up-to-date weather station data or meteorological observations for a given region (air temperature, relative humidity, direct and diffuse solar radiation, direction and speed wind).

The thermal performance and combination of materials, which are used for building supporting and enclosing structures, affect the building microclimate parameters and energy consumption of heating and cooling systems. In modeling, the data of thermal performance materials are considered when the building's geometry is formed by creating material library. The library includes the basic physical properties data of materials (thermal conductivity, specific heat and density) and also the sequence in the formation of constructive elements of walls, roof, and windows. Equipment for heating, cooling, ventilation and lighting systems can be installed from the Autodesk library, or appointed in detail when a building model is being created.

The intensity of operation building (residence hours, activity schedule of residents, etc.) is considered in GBS modeling by standard methods (for example, ASHRAE 90.1). Moreover, the purpose of the building and the number of residents also are considered. In spite of the fact that the buildings operation parameters can be different with standard ones in reality, these data can be enough for comparative analysis.

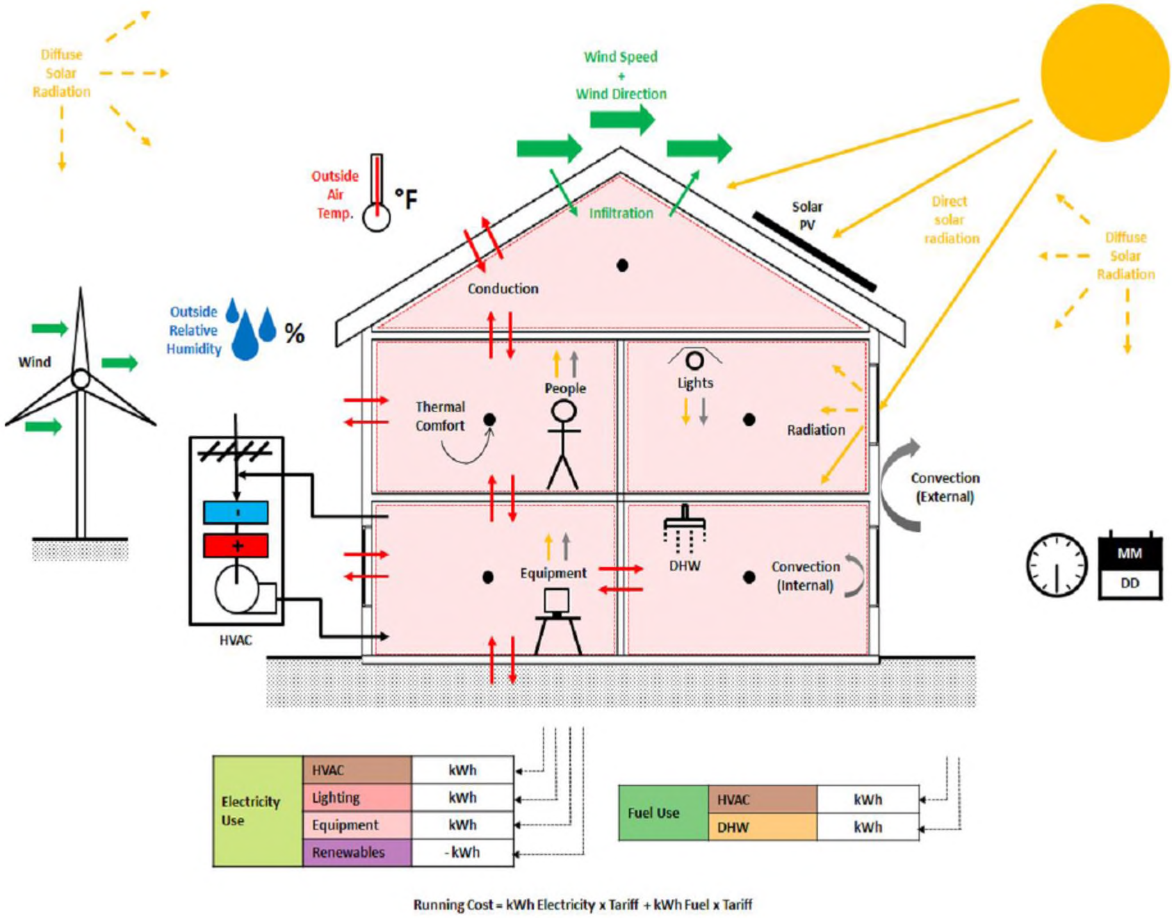


Fig. 23. The concept of the Autodesk Green Building Studio information model

Autodesk Revit and Green Building Studio allow to evaluate and optimize the building by criteria the "Triple Zero" building (zero-energy, zero-emissions and zero-waste), namely, in terms of minimizing energy consumption and CO_2 emissions. We can't directly estimate of the household waste volume by GBS. However, Revit allows creating the most detailed building model with which we can make specifications for the types of materials that use. We also can make estimating the building potential for recycling (reuse) or effective disposal by these specifications.

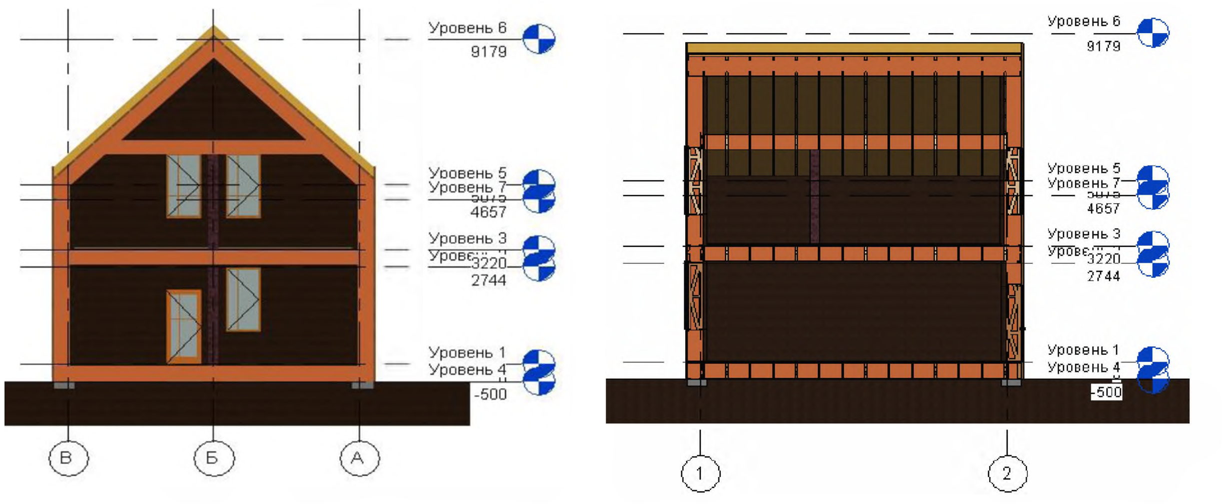
Information modeling for the project of the individual residential building "Triple zero"

The information model conception and testing for the project of the individual residential building "Triple Zero" was carried out by means of Autodesk Revit and Autodesk Green Building Studio (*license for students and teachers*).

At the initial stage, we defined the geometric model of the building with parameters of structural materials and decoration. The architectural idea and design of the building were described in the report for stage 2 of the project. The material characteristics were specified through the Revit dialogs (Fig. 24).

Building windows have the next caracteristics: the size 1830 mm x 900 mm or 1500 mm, the heat transfer coefficient – 3,69 W/(m^2K) and their solar thermal emission factor is 0,78. Exterior doors of buildings are 2100 mm x 900 mm and their heat transfer coefficient is 3,8 W/(m^2K).

Autodesk Revit generated information concerning the cost of basic materials for the next zero-waste building potential analysis in terms of reuse and recycling at the end of its life cycle.



a) b)

Fig. 24. Cross sections of the geometric model of the Triple Zero building:transverse; b) longitudinal

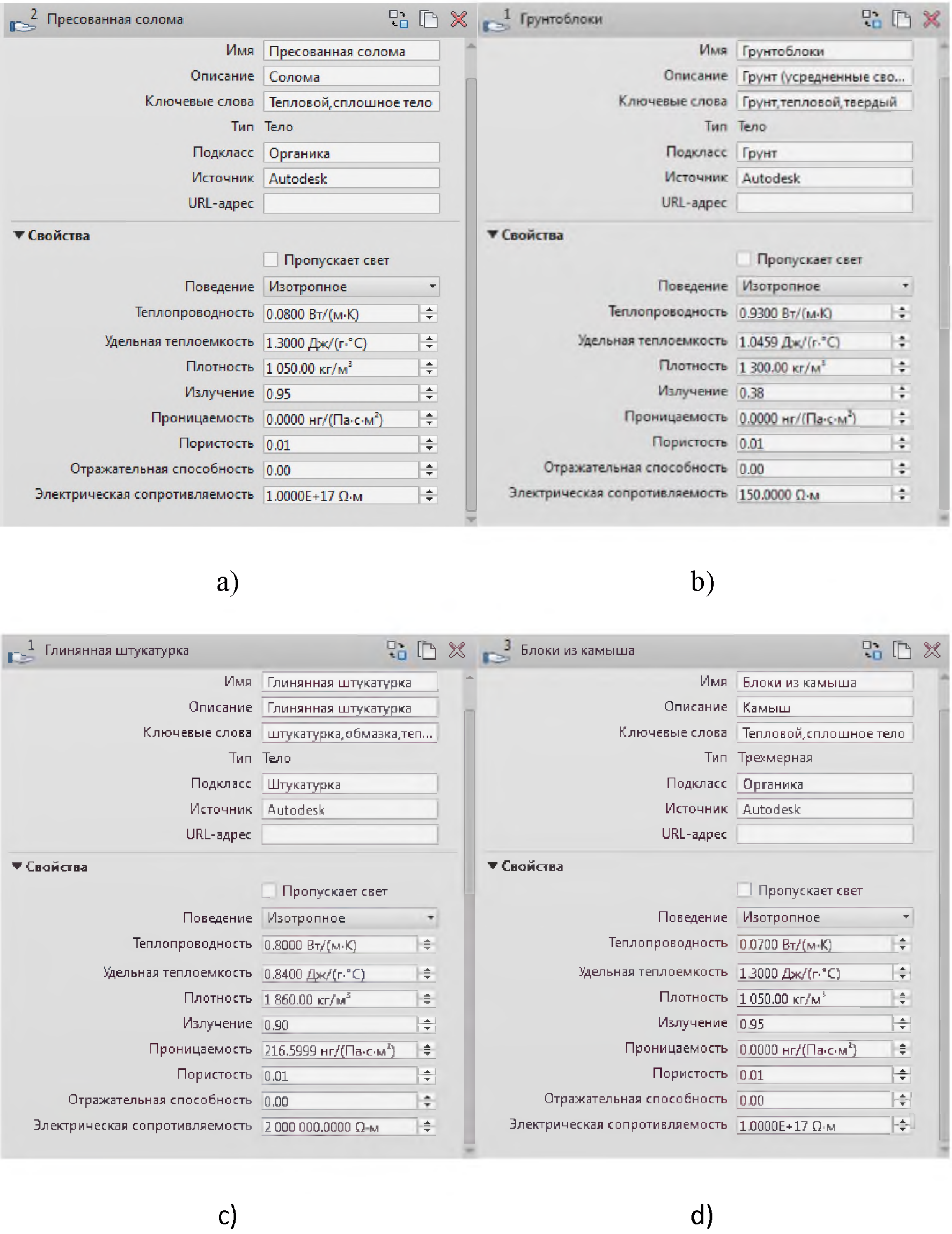


Fig. 25. Characteristics of materials for information modeling of the building "Triple zero": a) pressed straw; b) soil blocks; c) clay plaster on the chips; d) reed block.

The consumption of materials for roofing, walls and floors (Tables 19 - 21) was determined by Revit means.

Fig. 26. 3D view of the building

Table 19. Specification of the roof materials

Material	Volume, m^3	Surface, m^2	Specific weight, kN/m^3	Heat capacity, kJ/K	Thermal resistance, $(m^2 \cdot K)/W$
Reed blocks	19,64	98	10	25,36	2,8571
Pressed straw	39,28	98	10	50,73	5,7143
Plywood cladding	1,18	196	5,4		

Table 20. Specification of the wall materials

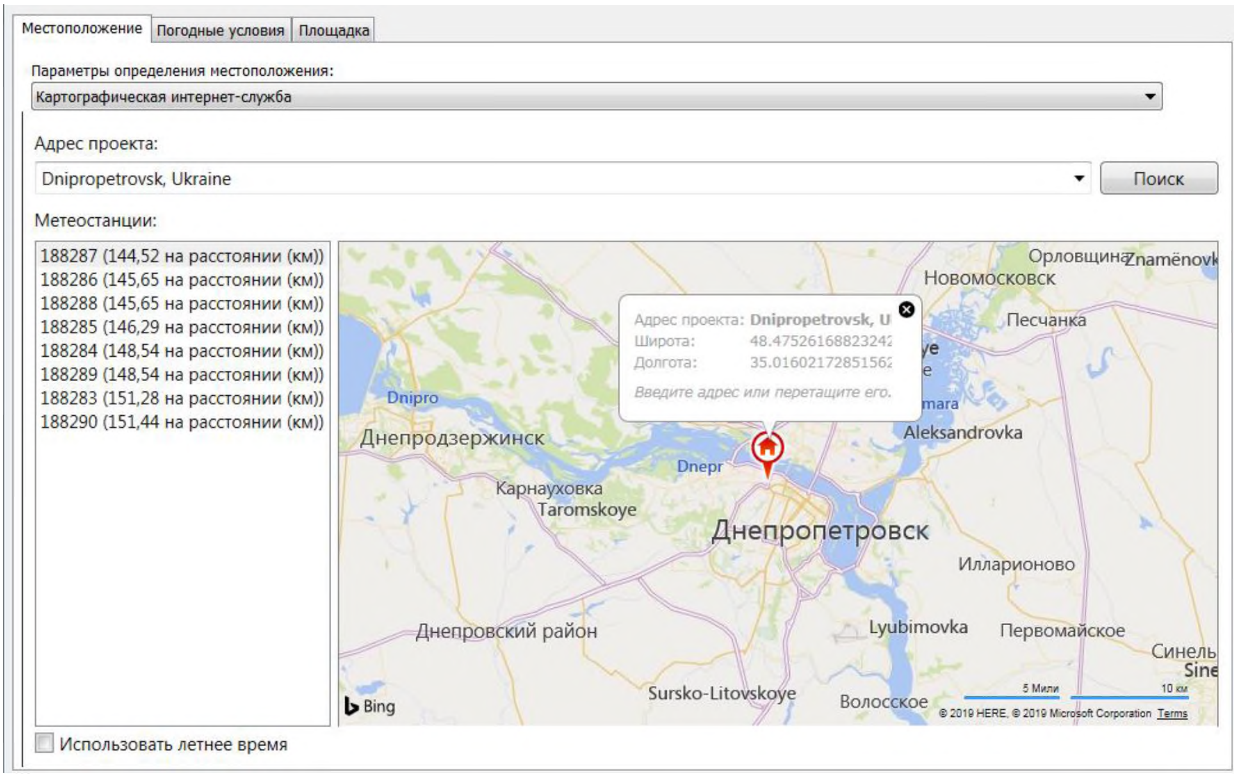
Material	Volume, m^3	Surface, m^2	Heat capacity, kJ/K	Coefficient of heat transmittance, $W/(m^2 \cdot K)$
Clay plaster	11,04	221	7,26	16,000
Soil blocks	18,17	151	15,16	7,7483
Brick	12,90	52	30,24	2,1600
Pressed straw	74,48	186	50,73	0,2000

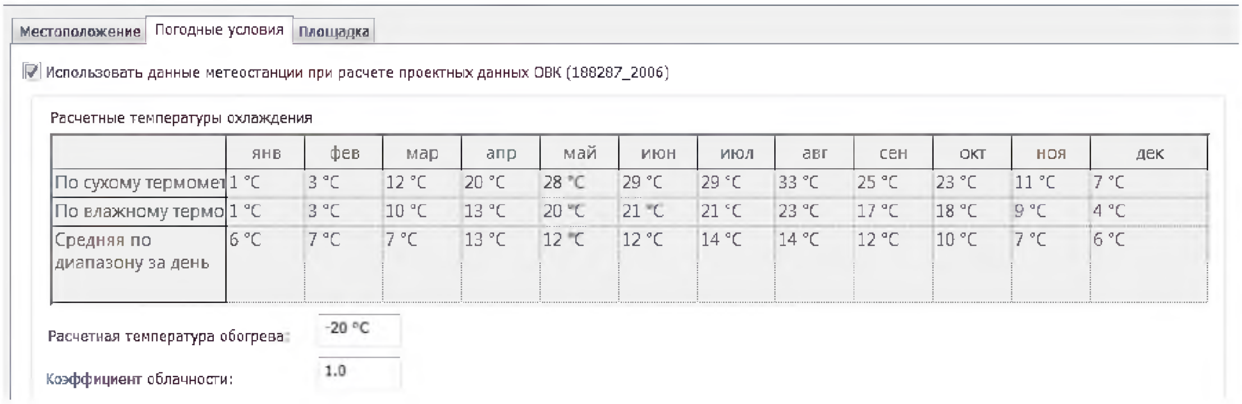
Table 21. Specification of the floor slab materials

Material	Volume, m^3	Surface, m^2
Soil blocks	5,23	105
Ceramic tile	1,57	105
Pressed straw	57,06	143
Plywood	0,43	108

Determination of climate data.

The construction site is supposed to be situated in the neiborghood of Dnipro. After entering the corresponding coordinates, Revit uses the Standard Annual Meteorological Data from the nearest meteorological station from the Green Building Studio database (Fig. 27). The meteorological data used in the simulation is summarized in Fig. 28.



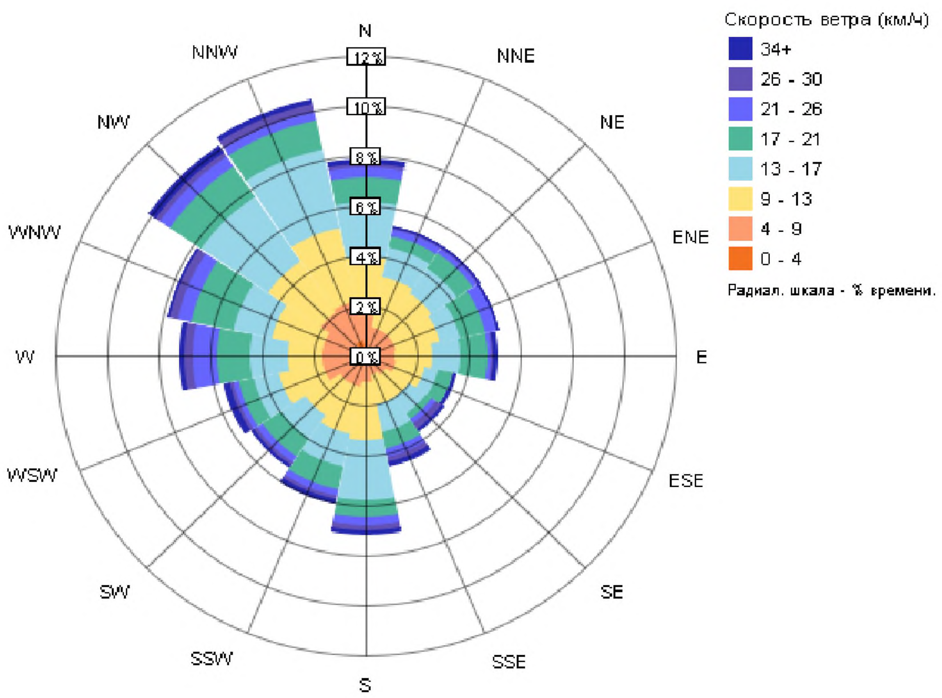


	янв	фев	мар	апр	май	июн	июл	авг	сен	окт	ноя	дек
По сухому термомет	1 °C	3 °C	12 °C	20 °C	28 °C	29 °C	29 °C	33 °C	25 °C	23 °C	11 °C	7 °C
По влажному термо	1 °C	3 °C	10 °C	13 °C	20 °C	21 °C	21 °C	23 °C	17 °C	18 °C	9 °C	4 °C
Средняя по диапазону за день	6 °C	7 °C	7 °C	13 °C	12 °C	12 °C	14 °C	14 °C	12 °C	10 °C	7 °C	6 °C

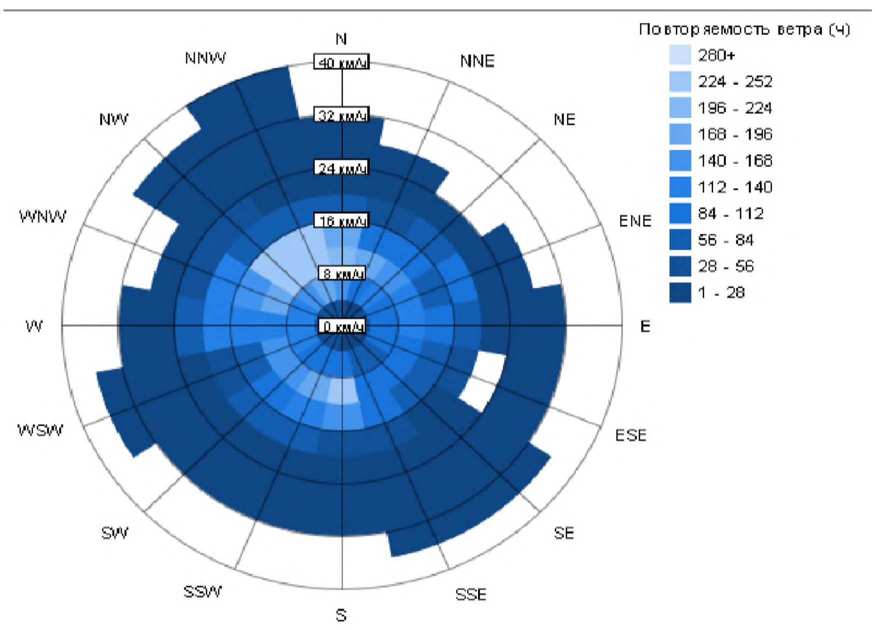
Расчетная температура обогрева: -20 °C

Коэффициент облачности: 1.0

Fig. 27. Weather station location and weather conditions for the city of Dnipro from the Green Building Studio database



a)



b)

Fig. 28. Meteorological data used in the modeling by Green Building Studio (abbreviated): a) annual wind rose (velocity distribution); b) annual wind rose (recurrence)

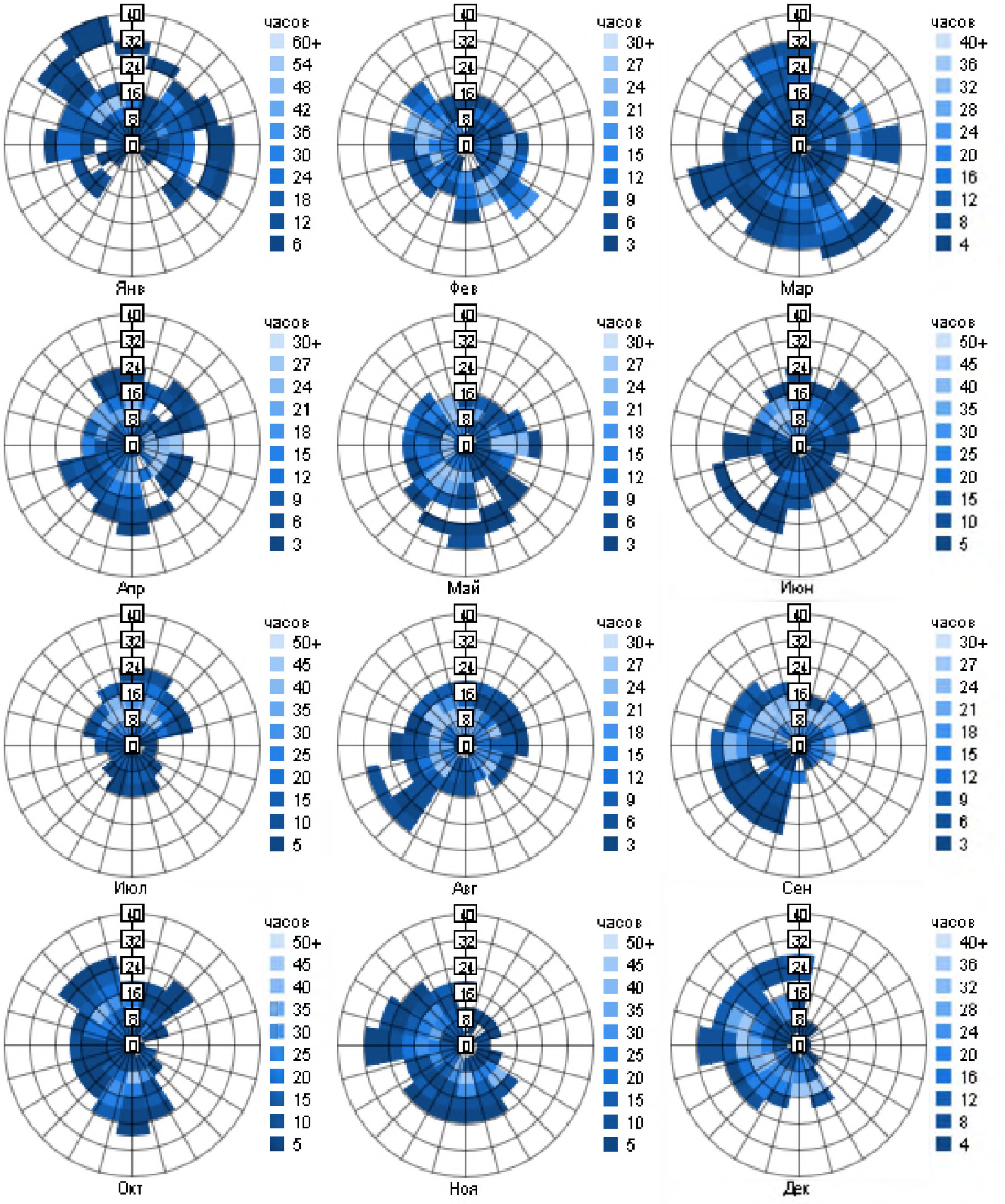


Fig. 29. Wind roses for each month

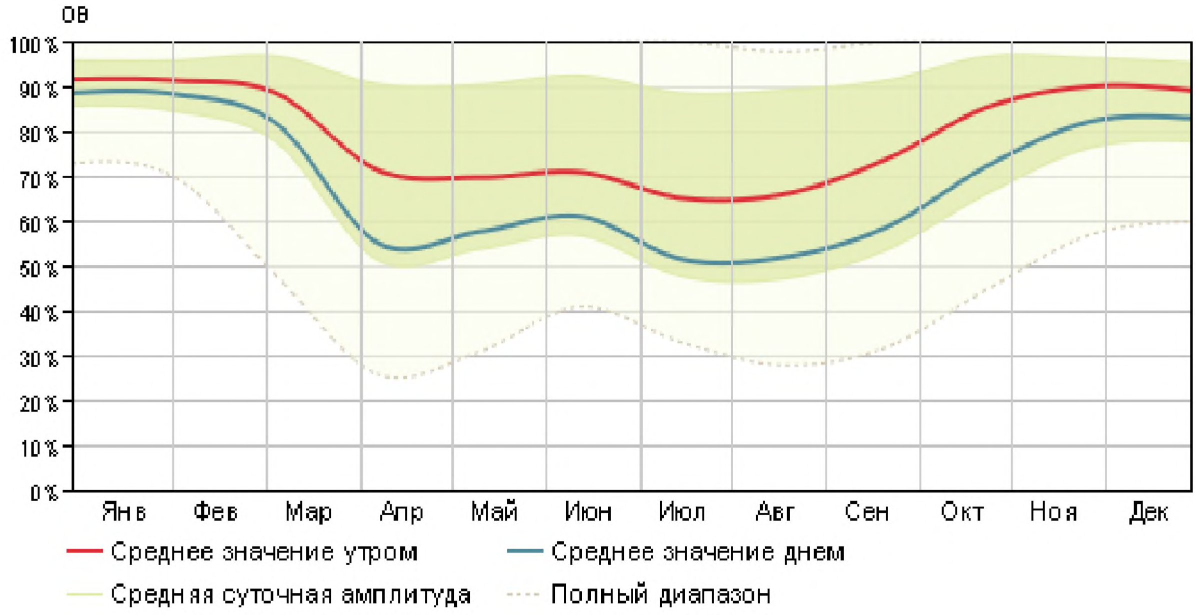


Fig. 30. Annual distribution of relative humidity

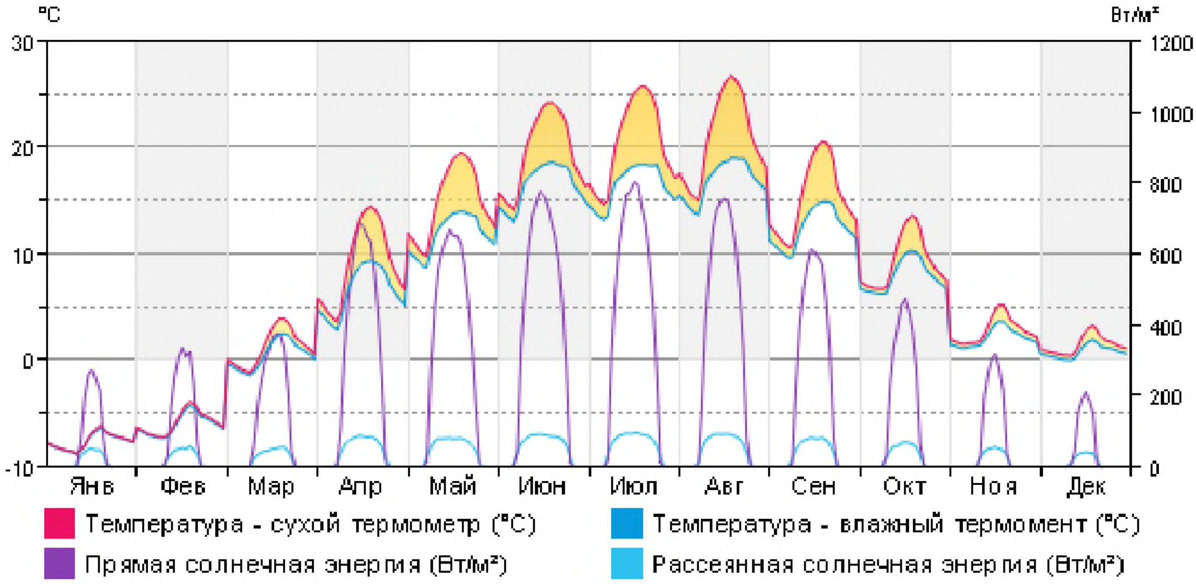


Fig. 31. Annual distribution of daily temperature

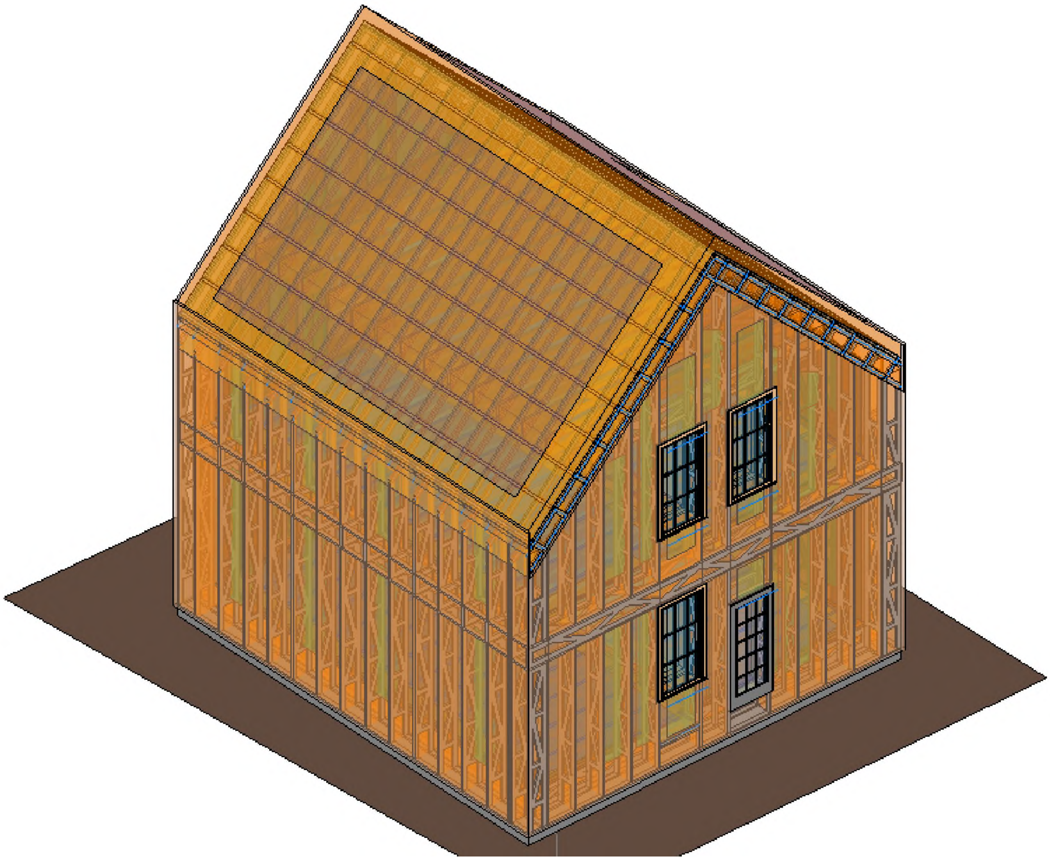


Fig. 32. Energy model of the Triple Zero Building

Simulation results.

As a result of the calculations in the cloud service we obtained the conceptual parameters of energy consumption and CO_2 emissions from the equipment, which are presented in the form of tables, graphs and diagrams. The results include the intensity of the energy consumption indicators, calculation of annual electricity and fuel consumption, energy recovery/energy saving potential, average carbon emissions, monthly air conditioning load, etc.

As an illustration, the monthly load distribution on the heating and air-conditioning system are presented in Fig. 33, as well as a diagram of the annual consumption distribution (Fig. 34). The findings provide information for the developing possible ways to improve productivity and bring the project to the target.

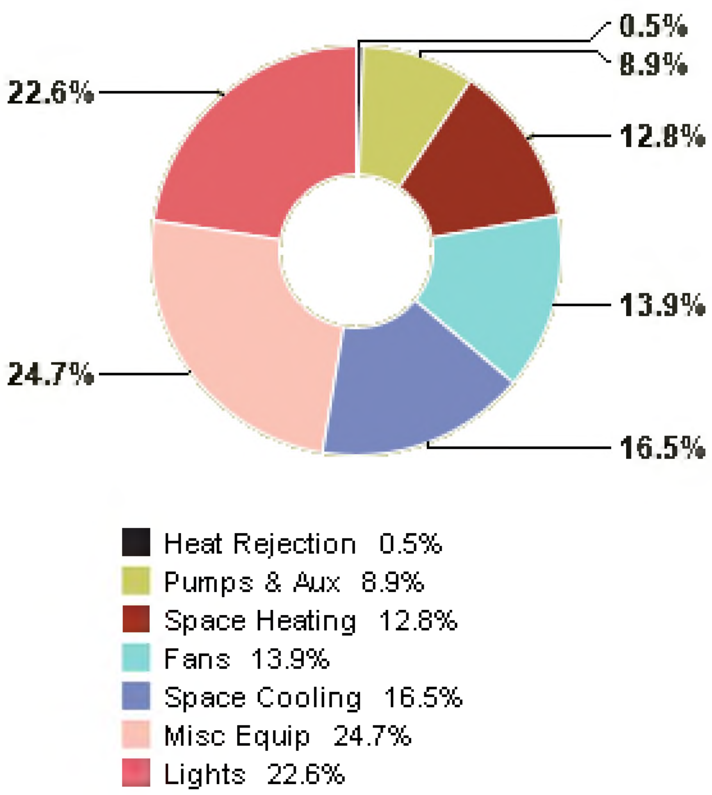


Fig. 33. Diagram of the annual distribution of the electricity consumption

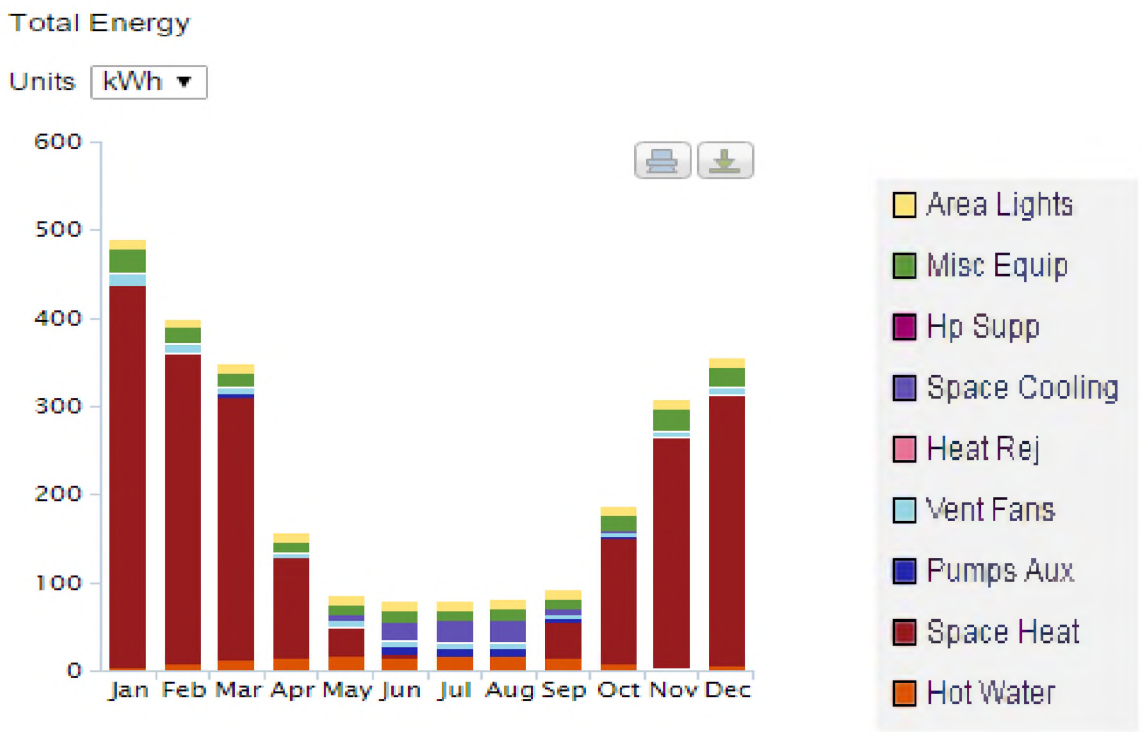


Fig. 34. Monthly energy consumption diagrams

6. UKRAINIAN CONSTRUCTION STANDARDS TO APPLY IN SUSTAINABLE BUILDING DESIGN

Today the building is considered as a complex system of elements, which is present by **input value** (materials, sources, energy, etc.) asses by **output value** (emission, waste, etc.) and by **outcome one** (quality of people use the building). Each element is taken into account according to the general principles of sustainable development. Every year there are a lot of new normative and standards appear to ensure the implementation of energy efficiency and ecology in daily practice of building engineers. There are numerous of standards which are being under development currently in EU in the international legitimate level and in the world in the commercial level.

For Ukraine adaptation, such new standards are the strategic issue in several meanings: to provide energy independence in the building sector (development of energy autonomic, energy effective green buildings) and to approach to the well developed international community of sustainable (responsible) engineering, create attractive investment base.

Complex studying of existing national Ukrainian normative in the field of ensuring energy efficiency in constructions and its comparative analysis will simplify the understanding of gaps between national legitimate and acting in EU one; develop the working basic instrument for engineers to design in sustainable way by existing norms.

The literature study and comparative analyze were used as the base of the present research. All the studied standards in the field of green building were divided in two general groups: normative and voluntary, each of which listed other sub-groups (Fig. 35).

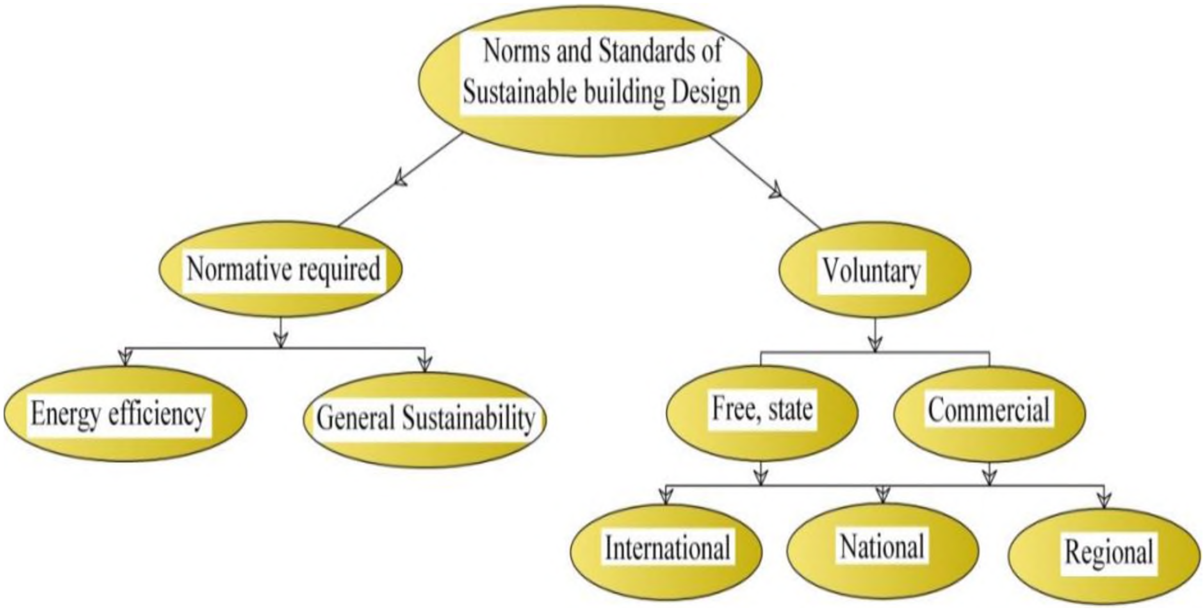


Fig. 35. Hierarchy for effective acting norms analysis

There were defined current Ukrainian standards in the field of energy efficiency and environmental housing design for compliance with European analogues and standards of sustainable. Those European standards that today have no analogues in Ukrainian norms, but which are important in the development of sustainable buildings projects are highlighted as N/A.

The voluntary standards applying around the world in construction sector were studied. The criteria which are in priority in the context of actual situation in the construction sector of Ukraine were determinated and on their base the assessment of environmental parameters of building objects.

Normative required construction standards in the field of energy efficiency and sustainability requirements Ukraine and EU.

Adopted in 2005, Directive 2005/32 / EC sets requirements for the environmental and energy components of products. In accordance with this Directive, manufacturers of products are required to take measures to reduce energy consumption and other negative environmental impacts throughout the life cycle of products. This approach was called "eco-design"- from resources to utilization within the chain: natural resources - production - transportation -

exploitation - utilization. In order to expand the scope of the aforementioned directive in 2009, Directive 2009/125 / EC on eco-design was enacted, which included the inclusion of not only energy-intensive, but also some products that affect energy consumption (e.g. plumbing). The following stages of the product life cycle are formed: the definition of raw materials and materials, design, production, packaging, transportation, implementation, installation, use, maintenance, utilization. For each stage of the product life cycle, environmental aspects are assessed according to the following parameters set by the Directive: expected costs of raw materials, materials, energy and other resources; Expected emissions into the atmosphere, water or soil; pollution due to physical factors of the environment; the ability to recycle, recycle and dispose of materials and / or energy.

The EU has the most significant experience in the application of methods for technical regulation of energy efficiency. The main types of regulatory legal documents used in the EU are as follows:

- regulations (fully binding and applicable in all Member States);

- directives (binding on Member States in terms of results to be achieved and to be reflected in the national legal framework);

- decisions (required only for the entities to which they are addressed);

- recommendations and conclusions (not binding and are declarative documents);- standards (applied on a voluntary basis, but various measures are taken in the EU to stimulate their application).

To date, the EU has a large number of regulations and directives aimed at implementing energy efficiency. The main instrument for regulating energy efficiency issues in the EU is regulations, directives and standards. In the practice of technical regulation of energy efficiency in the EU there are two main methods - marking energy efficiency and setting requirements for eco-design products (environmentally-oriented design).

In 2010, Ukraine joined the Energy Community Treaty, which required the enactment of the laws, regulations, and administrative provisions necessary to comply with the requirements of the Directive 2009/28 / EC of the European Parliament and of the Council of 23 April 2009 on the promotion of to the use of energy from renewable sources.

In accordance with the decisions of the Energy Community, the following Directives of the European Parliament and the Council on Energy Efficiency are required: Directive 2006/32 / EC on energy end-use efficiency of energy and energy services; Directive 2010/31 / EC on energy efficiency in buildings; Directive 2010/30/ EC on labeling and standard product information, energy consumption and other resources by energy products. In view of the need to ensure the effective implementation of international energy efficiency criteria and the detection of gaps in the national regulatory and technical base, it is necessary to carry out an analysis of existing EU regulatory documents and compare them with existing ones in Ukraine or to establish the absence of such.

Absolutely correct comparison is difficult for a number of reasons, namely:

1. There is no possibility to compare energy efficiency classes, because the main condition though is the same for Ukrainian and European energy efficiency standards, but they are calculated in different ways. Since the results are given in different units of measurement, and take into account different factors.

2. European regulatory framework in the field of energy efficiency, with initially higher requirements for the construction site, began to form much earlier than in the Ukrainian SSR and independent Ukraine. In addition, it is comprehensive, taking into account not only the amount of heat loss and the costs associated with providing a comfortable temperature, but also takes into account the amount of carbon dioxide emissions, not only when operating a ready building, but also during extraction, production and transportation of

materials, i.e. throughout the life cycle, affecting the principles of the non-circular economy, considering buildings as a complex structure with subsequent processing and full disposal at the end of its life of all without exception Ia structural elements.

3. Ukrainian regulatory documents in the field of energy efficiency have been published and supplemented, with higher requirements for heat loss since the beginning of the 2000th year. However, their number is insufficient, some are superficial, and they do not cover a significant range of parameters that must be taken into account and normalized for the possibility of designing reliable, durable, energy-efficient and eco-friendly housing. As can be seen from Table 1.1, Ukrainian norms can be compared with European norms, at best only partially, and for frequent Ukrainian analogs simply are absent.

Table 22. Comparative analysis of energy efficiency standards in the EU and Ukraine

Title	Content	Nearest Ukrainian counterpart
Energy performance of building		
Directive EPBD (On Energy Performance of Buildings) - the basis of all EU energy efficiency standards.	The purpose of this directive is to achieve a comprehensive energy efficiency improvement for all EU buildings	"Law of Ukraine "On Energy Efficiency of Buildings
EN 15217 Energy performance of buildings - Methods for expressing energy performance and for energy certification of buildings	This standard is devoted to methods for determining the energy performance of buildings, as well as drawing up a certificate of energy efficiency.	DBN V.2.6-31:2016 (partially)
EN 15603 Energy performance of buildings. Overall energy use and definition of energy ratings	The purpose of the standard is: a) compare the results of other standards that calculate the use of energy for one or another service within the building; b) take into account the energy produced in the building, a certain part of which may be transferred for use elsewhere; c) provide a summary of the energy use of the building in tabular form; d) provide energy assessment based on primary energy, carbon dioxide emissions or other parameters specified by the national energy policy; e) Establish general principles for calculating primary energy factors	DBN B.2.6-31:2016 (partially) DSTU B V.2.2-39:2016 (partially) DSTU B V.2.2-21:2008 (partially)

	and carbon emission factors. This standard defines energy services that need to be taken into account for rating energy performance for projected and existing buildings. f) method for calculating the standard calculated energy rating (passport), standard energy usage, which does not depend on the behavior of residents, actual weather and other actual (surrounding or internal) conditions; g) method for estimating the energy rating (passport) on the basis of supplied and used energy; h) methodology for increasing the reliability of the calculation model of a building compared with actual energy use; i) a method for assessing the energy efficiency of possible improvements.	
BS EN ISO 13790 Energy performance of buildings. Calculation of energy use for space heating and cooling	These norms include the calculation: a) heat transfer when ventilation of the building area when heated or cooled to a constant internal temperature; b) the contribution of internal and solar heat to the thermal balance of the building; c) annual energy requirements for heating and cooling, as well as for maintaining the set room temperature; d) annual energy consumption for	DBN V.2.6-31:2016 (partially); DSTU B V.2.2-21:2008 (partially); DSTU B. A. .2.2-12:2015

	heating and cooling of the building using the relevant system standards specified in this standard.	
EN 15316-1 Energy performance of buildings. Method for calculation of system energy requirements and system efficiencies. General and Energy performance expression, Module M3-1, M3-4, M3-9, M8-1, M8-4	These norms include calculation: heat, mathematical calculations, efficiency, energy consumption, thermal power, thermal protection systems, heating equipment, buildings, systems of spatial heating, heat transfer, heat loss, hot water supply systems.	N/A
EN 15316-2 Energy performance of buildings. Method for calculation of system energy requirements and system efficiencies. Space emission systems (heating and cooling), Module M3-5, M4-5.	These norms include calculation: heat losses, hot water supply systems, energy saving, thermal protection systems, heating equipment, heat power, buildings, heat exchangers, heaters.	N/A
EN 15243 Ventilation for buildings. Calculation of room temperatures and of load and energy for buildings with room conditioning systems.	These standards include: a) Determination of the calculation procedure, calculation methods for temperature determination, reasonable loads and energy requirements for the premises to be used in the design process; b) Description of calculation methods for determining the hidden cooling and heat load for building heating, cooling, humidification, drainage and loading on these systems;	N/A

	c) Determination of the general approach for calculating the total energy efficiency of buildings with air conditioning systems; d) Determination of one or more simplified methods for calculating the energy needs of the system for specific types of systems based on demand and energy consumption of a building derived from EN ISO 13790 and determining their scope.	
EN 15316-3 Energy performance of buildings. Method for calculation of system energy requirements and system efficiencies. Space distribution systems (DHW, heating and cooling), Module M3-6, M4-6, M8-6.	These standards include: heat losses, heating equipment, spatial heating systems, thermal calculation of buildings, thermal efficiency, energy consumption, mathematical calculations, central heating, heat exchange, thermal protection systems, hot water supply systems, efficiency, buildings.	DBN V.2.6-31:2016 (partially)
EN 15265 Energy performance of buildings. Calculation of energy needs for space heating and cooling using dynamic methods. General criteria and validation procedures.	These standards include: a) Evaluate the energy characteristics of each room in the house; b) Supply of energy data to be used as an interface for analyzing system performance (heating, cooling, ventilation, lighting, domestic hot water, etc.). The procedure is used to check the energy requirements for heating and cooling of premises based on the model of transitional sound thermal balance taking into account: - external thermal balance of the surface;	DSTU B V.2.6-37: 2008 (partially) DSTU B V.2.6-101: 2010 (partially) DSTU B V.2.6-189: 2013 (partially) DSTU B V.2.2-21: 2008 (partially)

	- conductivity through the shell of the building; - thermal power of external and internal structures; - internal heat balance; - air heat balance; - methods for determining the thermal balance.	
EN 15193 Energy performance of buildings. Energy requirements for lighting.	These standards include: electrical measurements, performance, lighting systems, design, electrical power systems, energy consumption, lighting equipment, mathematical calculations, fixtures, power measurement (electric), electric lamps, buildings, electricity consumption, energy saving, indoor lighting.	DSTU B V.2.2-21: 2008 (partially)
EN 15241 Ventilation for buildings. Calculation methods for energy losses due to ventilation and infiltration in buildings.	This standard describes a method for calculating the energy impact of ventilation systems (including ventilation) in buildings, which will be used to calculate the thermal and cooling load. His goal is to determine how to calculate the characteristics (temperature, humidity) of air entering the building, and the corresponding energy required for its processing, as well as the required amount of electrical energy for the auxiliary devices.	DSTU B A.2.2-12: 2015 (partially) DSTU B V.2.6-37: 2008 (partially)
EN 15232 Energy performance of buildings. Impact of Building Automation, Controls and Building	These standards include: control systems, efficiency, lighting systems, heat engineering, ventilation, thermal protection systems, air conditioning systems,	N/A

Management.	automatic control systems, buildings, mathematical calculations, spatial heating systems, energy saving, productivity, energy consumption, heat calculation of buildings.	
EN ISO 6946 Building components and building elements. Thermal resistance and thermal transmittance. Calculation methods.	These norms include: heat transfer, thermal conductivity, mathematical calculations, thermal balance of buildings, buildings, thermal insulation, thermal stability, details of building systems.	DSTU B V.2.6-100: 2010 (partially) DSTU B V.2.6-101: 2010 DSTU B V.2.6-189: 2013
EN ISO 13370 Thermal performance of buildings. Heat transfer via the ground. Calculation methods.	These norms include: physical properties of soils, temperature, soil, equation, floor, floor boards, formulas (maths), thermal insulation, cellars, thermal properties of materials, heat measurements, thermal behavior of structures, thermal resistance, heated floors, heat transfer , climate, hanging floors, thickness, ventilation, heat transfer coefficient, refrigerating chambers, groundwater, dimensions, mathematical calculations, thermal conductivity, thermal bridges.	N/A
EN ISO 10077-1 Thermal performance of windows, doors and shutters. Calculation of thermal transmittance.	These standards include: double-glazed windows, doors, thermal design of buildings, mathematical calculations, window frames, windows, blinds (buildings), details	DSTU B.2.6-XX: 200X (partially) DSTU B

General.	of building structures, thermal insulation, glazing, doors, window glass, thermal conductivity.	V.2.7-107: 2008 (partially)
EN 13947 Thermal performance of curtain walling. Calculation of thermal transmittance.	These standards include: buildings, curtains, lining (buildings), building components, thermal conductivity, glazing, glass, heat transfer, mathematical calculations, thermal bridges, thermal calculation of buildings, thermal insulation.	N/A
ISO 10077-2 Thermal performance of windows, doors and shutters. Calculation of thermal transmittance. Numerical method for frames.	These standards include: frame for slots, door frames, glazing, windows, mathematical calculations, roller shutters, specific heat conductivity, parts of building systems, doors, door block (door with door box), thermal measurements, window frame, heat transfer, thermal conductivity .	N/A
EN ISO 14683 Thermal bridges in building construction. Linear thermal transmittance. Simplified methods and default values.	These standards include: classification of systems, constraints, heat transfer, parts of building structures, thermal conductivity, buildings, heat transfer, mathematical calculations, heat calculation of buildings, definitions, thermal bridges, linearity, construction work.	DSTU B EN 13187: 2011 (partially)
EN ISO 10456 Building materials and products. Hygrothermal properties. Tabulated design values and procedures for determining declared and design thermal values.	These standards include: building materials, buildings, thermal calculation of buildings, thermal properties of materials, specific thermal conductivity, heat resistance, homogeneity, change, temperature, material aging, humidity, thickness, test conditions, calculations, statistical methods of	N/A

	analysis.	
EN 15242 Ventilation for buildings. Calculation methods for the determination of air flow rates in buildings including infiltration .	These standards include: air flow, ventilation equipment, buildings, air flow measurements, mathematical calculations, heat shrinkage systems, ventilation, air conditioning systems, mechanical ventilation, air, and productivity.	DBN V.2.6-31: 2006 (partially) DSTU B V.2.2-19: 2007 (partially)
EN 13779 Ventilation for non-residential buildings. Performance requirements for ventilation and room-conditioning systems.	These standards include: heat shrinkage systems, air, system classification, thermal design of the building, thermal comfort, quality, air conditioning systems, ventilation, air conditioning equipment, ventilation equipment, efficiency (productivity), buildings, operating conditions, energy consumption .	N/A
EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.	This standard specifies indoor environmental conditions in buildings that affect the energy efficiency of buildings: - How to set the internal input parameters of the environment to calculate building design and energy efficiency. - Methods for the long-term assessment of the internal environment, obtained as a result of calculations or measurements. - measurement criteria that can be used if a compliance check is required. - determines the parameters that will be used to monitor and display the internal environment in existing	N/A

	buildings. This standard is applicable mainly to non-industrial buildings, where the criteria for the internal environment are established by the person and the production process does not significantly affect the internal environment. The standard can thus be applied to the following types of buildings: single-family houses, apartment buildings, offices, educational institutions, hospitals, hotels and restaurants. The standard specifies how to use different categories of criteria for the internal environment. But their use is not unconditional and depends on national rules or specifications of individual projects. The recommended criteria in this standard may also be used in national calculation methods that may differ from the methods described herein. The standard does not design methods, but gives the water parameters for designing buildings, heating, cooling, ventilation and lighting. The standard does not include criteria for local discomfort factors such as sediment, asymmetry of the radiant temperature, vertical air temperature difference and surface temperature	
EN ISO 15927-5+A1	These standards include:	N/A

Hygrothermal performance of buildings. Calculation and presentation of climatic data. Data for design heat load for space heating.	maintenance of buildings, equipment of thermal systems, systems of spatial heating, climatic loading, humidity, windows, speed, methodology of determination and measurement, design of heat communications, thermal protection, heat calculation of a building.	
EN ISO 7345 Thermal insulation. Physical quantities and definitions.	These norms include: units of measurement, definitions, symbols, terminology, thermal properties of materials, thermal insulation, thermal conductivity.	ДБН В.2.6-31:2016 ДСТУ Б В.2.6-34:2008 (частково)
EN ISO 9288 Thermal insulation. Heat transfer by radiation. Physical quantities and definitions.	These norms include: units of measurement, definitions, symbols, terminology, thermal properties of materials, thermal insulation, thermal conductivity.	N/A
EN 12792 Ventilation for buildings. Symbols, terminology and graphical symbols	These standards include: ventilation, terminology, symbols, graphic symbols, buildings, air conditioning systems, air conditioning equipment, ventilation equipment.	N/A
EN 15378 Heating systems in buildings. Inspection of boilers and heating systems.	These standards specify the procedures and additional measurement methods that will be used to check and assess the energy performance of boilers and heating systems.	N/A
EN 15240 Ventilation for buildings. Energy performance of buildings. Guidelines for inspection of air-	These standards include: thermal protection systems, ventilation equipment, maintenance, energy consumption, air conditioning systems, cooling, air conditioning	N/A

conditioning systems.	equipment, inspection, buildings, heating, productivity, ventilation.	
EN 15239 Ventilation for buildings. Energy performance of buildings. Guidelines for inspection of ventilation systems.	These standards include: ventilation, ventilation equipment, ventilation ducts, air, energy saving, power consumption, mechanical ventilation, buildings, control systems.	N/A
Sustainability of building		
ISO 15392:2008 Sustainability in building construction -- General principles	This standard identifies and establishes general principles for sustainability in building construction. It is based on the concept of sustainable development as it applies to the life cycle of buildings and other construction works, from their inception to the end of life.	N/A
ISO 21929-1:2011 Sustainability in building construction -- Sustainability indicators -- Part 1: Framework for the development of indicators and a core set of indicators for buildings	This standard establishes a core set of indicators to take into account in the use and development of sustainability indicators for assessing the sustainability performance of new or existing buildings, related to their design, construction, operation, maintenance, refurbishment and end of life. Together, the core set of indicators provides measures to express the contribution of a building(s) to sustainability and sustainable development. These indicators represent aspects of buildings that impact on areas of protection related to sustainability and sustainable development.	N/A
ISO/TS 21929-2:2015	This standard establishes a list of	N/A

Sustainability in building construction -- Sustainability indicators -- Part 2: Framework for the development of indicators for civil engineering works	aspects and impacts which should be taken as the basis for the development of sustainability indicators for assessing the sustainability performance of new or existing civil engineering works, related to their design, construction, operation, maintenance, refurbishment and end-of-life. Together, the indicators developed from this list of aspects and impacts provide measures to express the contribution of a civil engineering works to sustainability and sustainable development. The developed indicators should represent aspects of civil engineering works that impact on issues of concern related to sustainability and sustainable development.	
ISO 16745-1:2017 Sustainability in buildings and civil engineering works -- Carbon metric of an existing building during use stage -- Part 1: Calculation, reporting and communication; Part 2: Verification	This standard provides requirements for determining and reporting a carbon metric of an existing building, associated with the operation of the building. It sets out methods for the calculation, reporting and communication of a set of carbon metrics for GHG emissions arising from the measured energy use during the operation of an existing building, the measured user-related energy use, and other relevant GHG emissions and removals. These carbon metrics are separated into three measures designated CM1,	N/A

	CM2, and CM3	
ISO 21930:2017 Sustainability in buildings and civil engineering works -- Core rules for environmental product declarations of construction products and services	This standard provides the principles, specifications and requirements to develop an environmental product declaration (EPD) for construction products and services, construction elements and integrated technical systems used in any type of construction works.	N/A

Voluntary standards of environmental assessment of buildings according to the sustainability principles.

The principles of "green" construction presuppose the application of a certification system developed based on the concept of sustainable development, considering national particularities. For most of the countries of the post-Soviet space, support for the global trend in the development of the construction industry in accordance with "green" standards is becoming more urgent due to the need to address such actual problems as high dependence on fuel and energy resources, irrational use of land resources, shortage of affordable quality housing, low energy efficiency of the existing housing stock.

Among the problems and peculiarities of certification of construction objects for compliance with the standards of sustainable development were scientists such as Granev V.V., Zhurba A.O., Kozharinov A.V., Matrosov Yu. A., Naumov A.L., Primak L.V., Sukhinina E.A., Tabunshchikov Yu.A., Rob Watson, etc. In different countries of the world Eco-certification has become so popular that environmental standards are considered mandatory for many types of buildings.

At the same time, in Ukraine, construction that meets the standards of sustainable development has been extended so far only at the level of individual developers. Despite the creation of the Council for Green Building and the development of a number of government programs aimed at improving energy efficiency in the housing and communal sector, Ukraine does not have a national system for the environmental certification of construction sites, and the development and implementation of such standards in the country have not been received necessary dynamics. As a result, the principles of "sustainable development" and "green building" have not been integrated into the national construction practice for now.

From the perspective of a modern understanding of sustainable development, environmental requirements should be met by all the components of the construction site, including the building, territory and the consequences of human impact on the environment.

The ecological characteristics of the building can be assessed by the criteria of "green" standards designed to ensure the transition from traditional design and construction to a balanced (sustainable, "clean"), which implies the following principles: safety and favorable healthy conditions for human life, limiting the negative impact on the environment, consideration of the interests of future generations.

On the one hand, the variety of systems for the environmental certification of construction sites is justified by the differences in the conditions under which they are implemented - geographic location, climatic conditions, the level of development of construction technologies, the market of materials and services, etc. However, rating systems with a different set of criteria create certain difficulties for stakeholders, including investors who buy buildings in different countries.

All existing systems of environmental certification of the building, taking into account the number of certified facilities and their geography, can be conditionally divided into global distribution systems and the systems of national importance.

The group of global rating systems include the LEED standard (USA) and the BREEAM standard (UK), which have the following features:

• these standards were adopted as national standards in many countries or formed the basis of national rating systems;

• according to these standards, more objects are certified than other rating systems;

• these standards have become widespread and popular.

The national rating system includes all national standards, for example, German standard DGNB, French HQE, Danish EcoProfile, Japanese CASBEE, Canadian GBI, Russian Green Standards.

In recent years, based on the standards of sustainable development in construction, they have started to create software packages for the assessment of the environmental parameters of the project (BEES - Building for Environmental and Economic Sustainability).

Voluntary assessment of buildings according to the sustainability standards in Ukraine

In Ukraine, at the state level, numerous laws have been adopted and draft laws have been drafted aimed at energy saving in construction. However, up to now, there has not been developed a national voluntary system for assessing buildings in accordance with the standards of sustainable development, taking into account the life cycle - from the project of the construction site to the utilization of building materials.

The "green" standards are based on the Life Cycle Assessment (LCA) method, which includes the following stages: extraction of raw materials, natural materials, processing of materials, production of goods, transportation and distribution, use, maintenance, processing, reuse and disposal waste.

Based on the analysis of foreign experience of the LCA method, the Ukrainian system of voluntary environmental certification of construction objects is proposed, which is harmonized with the world standards of sustainable development. Its tasks are:

• Minimization of the negative impact of the property on the environment;

• minimization of environmental pollution by real estate objects - both during construction and operation;

• rational use of natural resources necessary for the construction and operation of real estate;

• Introduction of advanced energy-efficient technologies into the practice of construction and operation of buildings and structures;

• Promotion and promotion of the development of green building in Ukraine;

• Assistance to buyers in the competent choice of real estate objects that do not have a negative impact on the environment.

The following construction sites are subject to certification:

• land plots - a part of the earth's surface (including the soil layer), the boundaries of which are described and fixed in the established order;

• new buildings and structures - capital construction facilities that have load-bearing and enclosing or combined structures forming a closed volume;

• objects of construction in progress - a building or structure for which documents on the commissioning of the facility have not been issued in accordance with the established procedure;

• operated buildings and structures - capital construction facilities in operation;

• social complexes and settlements - an administrative-territorial unit, united by one territory, infrastructure, social orientation;

• internal premises - objects that are part of buildings and structures.

Formation of environmental requirements for construction sites is the rational use of natural resources, minimizing the negative impact of economic activities on the environment, providing favorable conditions for human life and its self-realization.

In existing systems, one of the priority criteria is energy efficiency, which is mainly achieved and evaluated through the use of high-tech energy-saving equipment, which increases the cost of initial investment in construction. In the conditions of Ukraine, the use of such equipment is difficult because of its high cost.

Since the indicator of the energy efficiency class is one of the most important criteria for compliance with the standards of sustainable development, it was suggested that the developed system assess it with indicators of the effective use of local renewable materials of organic origin with high thermal characteristics and the use of rational architectural and constructive solutions. The energy efficiency class is assessed in accordance with the current Ukrainian standards, whose requirements and method of classification are generally comparable with world standards.

In the proposed system of certification of construction objects, the criteria for sustainable development are determined by the combination of the following indicators: innovative management, site selection, efficient use of natural resources, integration architecture, materials and structures, organization of internal space, operational waste, energy efficiency, economic efficiency and socio-cultural organization.

Innovative management is assessed both at the design stage, and during the implementation of the project, operation and disposal of the construction site. At the design stage, the thermophysical and energy characteristics of the facility, the environmental friendliness of materials, and the optimization of the economic performance of the facility, taking into account the life cycle, are taken into account. For the analysis of these indicators, the project documentation and data received from the developer are studied.

At the stage of the construction project, the following parameters are taken into account: construction of a building site in accordance with environmental requirements for the construction process, minimization of waste during construction work (secondary processing or use of waste); informing citizens about the main indicators of the property, carrying out measures to protect and restore the environment in the process of construction (conservation of the soil layer, recycled water supply, dust suppression, regulation current storm water collection in a single place, wastewater treatment, protection of stem and root system of trees and shrubs, portion reduction with fertile soil).

To assess the environmental impact of the facility during its operation, visual monitoring is used, which includes the analysis of a certain set of indicators, including the use of environmentally friendly fertilizers for gardening, cleaning products, anti-icing agents, the refusal to use mercury-containing lamps, the availability of environmental certificates for engineering equipment object. In addition, at all stages of the building's life cycle, qualified environmental monitoring is carried out, which allows to increase the environmental performance of the building due to timely professional analysis and adjustment.

When **choosing the site** of the construction, the environmental quality is assessed, including the degree of pollution of soil, air, water sources, the effects of electromagnetic radiation, the risks of man-caused impacts and hazardous natural phenomena, the degree of planting of the territory, insolation of the adjacent territory, the protection of the territory from noise, vibration, infrasound, other indicators in accordance with current standards and norms of Ukraine. It also assesses the possible impact of urban development on the existing ecosystem - indicators of the effective use of natural resources and the integration architecture.

Analysis of the **efficiency of the use of natural resources** in such parameters as the reduction of the water consumption per person per year in relation to the standard, the separation of water supply into technological and drinking water, the availability of wastewater reuse systems for toilets and urinals, the collection of rainwater, their purification and use in system of technological water supply, collection of rain water for irrigation of the adjacent territory, accounting of water consumption at the end user, availability of water-saving drain tanks, shower grids, mix Lei, the use of secondary and renewable energy. The given criterion allows to estimate all systems of the building object aimed at energy saving and rational use of available natural resources on the site.

The level of **architecture integration** is evaluated expertly, including the analysis of the quality indicators of the architectural appearance of the facility, its correspondence to the surrounding buildings, functional purpose, originality, architectural perfection, aesthetics. In addition, at the design stage, an assessment should be made of the optimality of the chosen architectural form of the object and its orientation, which are designed to provide the best energy performance, comfort of space-planning solutions (overall indoor indices), natural lighting possibilities, planting of greenery ("winter garden" , vegetative roof, elements of vertical gardening).

The general level of environmental friendliness of the facility is fundamentally affected using **building materials** of natural origin, especially those that are certified as ecological. The quality of materials is assessed for compliance with one of the main criteria of sustainable development - waste minimization and the possibility of their complete reutilization.

Attention in assessing the ecological compatibility of the building is paid to the indicators of the organization of the **internal space**. Including air-thermal comfort can be controlled due to the planned measures to optimize the microclimate parameters - temperature, humidity, air exchange, air speed. No less important is light comfort, which is estimated by the degree of compliance with the standards for illumination, the presence of automatic control of artificial lighting or complex LED lighting. Special measures to reduce noise ensure the organization of acoustic comfort in the room, which is especially important in urban development and in the design of apartment buildings and public buildings. Olfactory comfort should be provided both by ventilation systems and by the use of non-toxic materials without sharp odors. An important indicator of the environmental security of a room for a person is the security of the premises from the accumulation of radon.

The next criterion for assessing the environmental friendliness of the facility is the level of **operational waste -** the quality of the organization of collection / disposal of waste and sanitary protection of the facility. It should be noted that to date, the organization of the primary sorting of waste, which is specified in government regulations, has not yet been integrated into the practice of public services for the residential sector. The proposed project provides an indicator of the level of utilization of operational waste, which significantly enhances the environmental friendliness of the facility. The quality of sanitary protection is ensured by the tightness of the garbage chutes and compartments with autonomous mechanical ventilation, the presence of an automated system of antibacterial treatment and an automated system of protection against the rodents and insects of garbage chutes, pantries, cellars, etc.

In the energy and economic realities of Ukraine, one of the key indicators of the environmental friendliness of the facility should be to ensure the **energy efficiency** of construction projects. Energy efficiency is understood as the rational use of energy resources, i.e. use the minimum possible amount of energy to provide the same level of energy supply to buildings or technological processes. The criterion proposes to estimate the cost of heat energy for heating and ventilation in accordance with the energy efficiency class in accordance with current standards; Expenses of thermal energy for hot water supply; electricity costs for lighting, engineering support systems, air conditioning systems, application of LED lighting sources, installation of electrical equipment with a high energy consumption class with the appropriate marking. The presence of a centralized control system of the facility with the possibilities of zonal regulation of the local engineering support system allows monitoring energy efficiency indicators, which improves the overall environmental performance of the facility.

An important indicator of the environmental friendliness of the facility is its **economic efficiency**. This indicator is estimated by the ratio of the investment value of the object to the cost of a similar facility that meets the minimum established requirements, and the ratio of the average annual cost of operating the facility to similar costs for a traditional analogue facility.

The **socio-cultural organization** is assessed from the point of view of the reach of the objects of the social and domestic infrastructure necessary for the normal provision of vital functions for people (health care institutions, trade points, passenger transport, banking and postal services, catering, household and communal services, etc.). Particular attention in assessing this criterion should be given to guarantees of accessibility of services for the low-mobility population groups. Estimation of the property's compliance with environmental requirements is carried out by direct comparison of project indicators (or a finished building) with existing standards and standards.

Per the proposed methodology, each score indicator is put a score, which is then summed per the criterion and by group of criteria. The resulting amount is multiplied by 100% and is divided into the highest possible total score. As a result, the estimated score for the object is calculated.

As a result of certification one of the four types of certificates can be assigned, provided all the necessary requirements have been fulfilled and the total points obtained from the maximum possible score have been achieved (see Table 23).

Table 23. Proposed certificates for compliance with the level of environmental friendliness of construction sites

Certificate	**Somme of points, %**
Certified for sustainability requirements	40 – 49
Silver	50 – 59
Gold	60 – 80
Platine	More 80

An analytical review of more than 25 current Ukrainian standards in the field of energy efficiency and environmental housing design for compliance with European analogues and standards of sustainable development has been carried out. Those European standards that today have no analogues in Ukrainian norms, but are important in the development of sustainable buildings projects are highlighted.

Based on foreign experience and in accordance with Ukrainian national norms, a system for assessing the environmental performance of construction sites was proposed and registered as the corporative standard at SHEI “Prydneprovska State Academy of Civil Engineering and Architecture”.

7. THE BEST EUROPEAN PRACTICES OF ENERGY EFFICIENT BUILDINGS AND THE ASSESSMENT OF ITS ADAPTABILITY IN UKRAINE

The European 20-20-20 strategy aims to increase the energy efficiency of national economies by 20%, reduce gas emissions into the atmosphere by 20% (from 1990 levels) and reach 20% of Europe's energy consumption through renewable energy by 2020. In 2014, about 30% of greenhouse gases were generated by the construction sector in Europe, which corresponds to 40% of the total energy consumption of the European Community.

According to the European Directive on the Energy Efficiency of Buildings, all new residential buildings starting December 31, 2020 must meet the standard of zero energy buildings or be "positive". In order to meet these requirements, a strategy was established to define common principles for implementing the Directive. This document includes various existing definitions of zero energy buildings that have been formulated by EU countries and set at the legislative level, as well as national plans to increase the number of these buildings for some EU and US countries. Over the last two decades, about 330 homes have been built according to different national standards for zero energy buildings in the world.

The specifications for the standards for zero energy buildings differ due to different climatic conditions and standards for energy consumption. The numerical indicator of the standard in most cases is the maximum annual total requirement of primary energy (wholly or partially obtained from alternative renewable sources) to meet the needs for heating, air conditioning, ventilation, electricity, hot water, etc. This parameter ranges from 0 kW / m^2 per year to 270 kW / m2 (the latter for public buildings, hospitals). For example, for Croatia, this parameter is 33 kWh / m^2 per year, for Denmark 20 kWh / m^2, for Lithuania 95 kWh / m^2, for Belgium, France, Slovakia, Bulgaria, Malta, United Kingdom, Ireland and Estonia ranges from 45 to 50 kWh / m^2. Other countries have chosen the building class as an indicator (for example, for Lithuania, the A ++ class building is a zero energy building). Some countries have not yet enshrined the definition of zero energy buildings legally. National regulations classify buildings by energy efficiency, but official definitions of zero or energy-plus buildings are not yet available in Ukraine.

For the analysis of specific examples, open bases of certified buildings of the world were used in accordance with the standards of the Passive House Institute, including energy-positive houses (Germany) and the Observatory of houses with low energy consumption (France).

We have also taken into account the official criteria of the Passive House Design Package (PHPP), a climate-active standard developed by the Passive House Institute in Darmstadt, according to which:

- an indicator of total annual primary energy demand ≤ 65 kW / m^2 per year;
- heating costs ≤ 15 kW / m^2 per year;
- leakage rate n50 ≤ 0,6 h-1;
- mechanical forced-air ventilation with heat recovery.

Analysis of implemented energy efficient projects is important to accelerate progress toward the promotion of zero energy buildings (nZEBs) and energy-plus.

Since these projects illustrate practice experience, potential future residents considering them can learn more about the types of energy efficient buildings, the equipment needed, the basic operating parameters, and to realize that energy independence is possible here and now.

Among several hundred samples, the examples were selected by the following criteria:

- Type - individual low-rise building (up to 3 floors) for one family (the number of occupants to 5 persons);

- The level of energy efficiency - nZEB, Passive House new build*, Passive House Premium new build* and Bepos Effinergie *;
- Heating space up to 300 m^2;
- The energy balance of the building is positive or near to zero (the level of energy production exceeds the amount of needs);
- Use of the predominant amount of primary energy of renewable energy resources to meet all the needs of the home in autonomic exploitation mode;
- Ecology of building materials and possibility of their full utilization or recycling;
- Energy-saving engineering systems with waste heat recovery function, preferably equipped with modern control and monitoring systems;
- Integration of the building into the environment (functional and design solutions), availability of landscaping, landscaped adjoining territory;
- Application of independent system of the water supply network, rainwater collectors and wastewater recycling (treatment).

Table 24. The best european practices of energy efficient buildings.

<table>
<tr><th colspan="3">#1Characteristics</th><th colspan="5">Energy</th></tr>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td rowspan="2">The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td rowspan="2">Use of renewable energy resources</td></tr>
<tr><td>Energy supply</td><td>Energy demand</td><td>Surplus</td></tr>
<tr><td>96.98</td><td>-49.38</td><td>+47.6</td><td rowspan="3">R_{wall} = 9.09
(textile facade, 16 mm Cospan board, wooden frame + 160mm mineral insulation, 38mm vacuum insulated panel, 40mm internal insulation + 16 mm Particleboard and 10 mm gypsum board)
R_{roof} = 4.26
R_{floor} = 7.52
Windows area is 38.34 m2: three-chamber vacuum windows,
U = 0.83, W / (m^2K)</td><td rowspan="3">Mechanical ventilation system with heat recovery and humidity control. Full electrification. Heating and air conditioning are provided by an air-to-air heat pump. Electricity requirements (household + charging of 2 cars) are provided with photovoltaic panels on the roof. Hot water supply is carried out by flat solar collectors.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country, city, standard</td><td rowspan="2">Building type</td><td colspan="3">Heating area, m^2</td></tr>
<tr><td colspan="3">86 m^2</td></tr>
<tr><td rowspan="6">House B10, 2014, Werner Sobek Group (architects)</td><td rowspan="6">Germany, Stuttgart</td><td rowspan="6">The first Triple Zero single-family house</td><td colspan="5">Emission</td></tr>
<tr><td colspan="3">Existing green area; integrating the built environment with nature, +/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td colspan="3">+</td><td>Wood, gypsum board, textiles, mineral insulation</td><td>Internal heat recovery</td></tr>
<tr><td colspan="5">Waste</td></tr>
<tr><td colspan="3">Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td colspan="3">+</td><td>+</td><td>+, alphaEOS AG</td></tr>
</table>

#2Characteristics

Project name (year of construction, architect)	Country, city, standard	Building type
Habitat Audois, 2013, Cécile Escourrou (architect)	France, Castelnodary, Bepos Effinergie 2013 *	Single Family Home

Energy

Building energy balance (HVAC, electricity), kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Energy Supply	Energy demand	Surplus		
142.5	**-48**	**+94.5**	**R_{wall} = 3.73** (brick cavity wall consists of brick 50mm + 70mm extruded polystyrene foam + 80mm finishing brick) **Rroof = 6.49** **R_{floor} = 6.62** **Window S = 22,33 m2:** double-glazed window filled with argon, **U = 1.06, W / (m2K)**	Mechanical ventilation system with heat recovery and humidity control. Solid fuel boiler on granular wood. (6kW power) Electricity (household) demands are covered by photovoltaic panels on the roof. (4.5 kW power) The flat solar collectors provide hot water (S = 3.94m2).
Heating area, m^2				
100 m2				

Emission

Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	Wood, brick	Internal heat recovery

Waste

Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	-

*http://www.observatoirebbc.org/construction/1379

#3Characteristics		
		
Project name (year of construction, architect)	Country, city, standard	Building type
Temperance Street Passive House, 2016, Michael Nemeth (building system designer), Robin Adair (architect)	Canada, Saskatchewan **Passive House Plus new build ***	Single Family Home

Energy				
Building energy balance (HVAC, electricity), kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Energy Supply	Energy demand	Surplus		
55,8	**-56**	**-0.2**	**Rwall = 11.63** (Larsen truss wall: wooden frame filled with cellulose insulation 356 mm + vapor barrier + fiberboard facing) **Rfloor = 8.84**EPS Type II (036) **Rroof = 19.23**(cellulose insulation 637 mm) **Windows:** double-glazed window filled with argon **U = 0.58, W / (m2K)**	Full electrification. The electric energy consumption is provided by photovoltaic panels (6.2 kW capacity) on the roof.
Heating area, m2	Heating demand, kWh / m2 per year	Heating load, W / m2		
202	**14**	**11**		

Emission		
Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	Wood, cellulose	Heat recovery of used water
Waste		
Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	-

* http: //passivhausprojekte.de/index.php? lang = en # d_5086

<table>
<tr><th colspan="3">#4 Characteristics</th><th colspan="5">Energy</th></tr>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td rowspan="2">The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td rowspan="2">Use of renewable energy resources</td></tr>
<tr><td>Energy Supply</td><td>Energy demand</td><td>Surplus</td></tr>
<tr><td>89</td><td>-59</td><td>+30</td><td rowspan="3">Rwall = 7.69
(Rwall: wooden frame filled with min. cotton wool 190mm + vapor barrier + facing with light concrete blocks 100mm)
Rfloor = 8.13(extruded expanded polystyrene 300mm)
Rroof = 12,048(mineral wool 306 mm)
Windows: double-glazed windows,
U = 0.56, W / (m2K)</td><td rowspan="3">Full electrification. The electric energy consumption is covered by photovoltaic panels on the roof.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country, city, standard</td><td rowspan="2">Building type</td><td>Heating area, m^2</td><td>Heating demand, kWh / m2 per year</td><td>Heating load, W / m2</td></tr>
<tr><td>186</td><td>14</td><td>10</td></tr>
<tr><td rowspan="6">Fulford passivhaus, 2015, Adam Dadeby (building system designer), Phil Bixby of Constructive individuals (architect)</td><td rowspan="6">United Kingdom, York Passive House Plus new build *</td><td rowspan="6">Single Family Home</td><th colspan="5">Emission</th></tr>
<tr><td colspan="3">Existing green area; integrating the built environment with nature, +/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td colspan="3">+</td><td>Wood, mineral insulation</td><td>-</td></tr>
<tr><th colspan="5">Waste</th></tr>
<tr><td colspan="3">Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td colspan="3">-</td><td>-</td><td>-</td></tr>
</table>

* http: //passivhausprojekte.de/index.php? lang = en # d_4762

<table>
<tr><th colspan="3">#5 Characteristics</th><th colspan="3">Energy</th></tr>
<tr><td colspan="3" rowspan="2"></td><td>Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td>The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td>Use of renewable energy resources</td></tr>
<tr><td>-6 kW year / m2</td><td rowspan="3">Rwall = 6.67
(load-bearing reinforced concrete walls + concrete-filled cavity wall + 16cm rock-wool panel)
Rfloor = 5.26
Rroof = 6.67
Windows: a three-chamber window filled with argon
U = 0.96, W / (m2K)</td><td rowspan="3">Mechanical ventilation with heat recovery and humidity control systems. Heating: floor heating + radiators in the bathroom. Heating, hot water and air conditioning are provided by a water-to-water heat pump. The Electric energy demand is covered by photovoltaic panels (7kW) on the roof.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country</td><td rowspan="2">Building type</td><td>Heating area, m^2</td></tr>
<tr><td>130 m2</td></tr>
<tr><td rowspan="6">CorTau House, 2015, SP Corgnati (building system designer), M. Luciano (architect)</td><td rowspan="6">Italy Italian Climate Zone E, 2549 Degree Days</td><td rowspan="6">Single-family home (refurbishing of a traditional rural building)</td><th colspan="3">Emission</th></tr>
<tr><td>Existing green area; integrating the built environment with nature, +/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td>+</td><td>wood</td><td>Internal heat recovery</td></tr>
<tr><th colspan="3">Waste</th></tr>
<tr><td>Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td>-</td><td>-</td><td>+</td></tr>
</table>

#6Characteristics

Project name (year of construction, architect)	Country, city, standard	Building type
"off-grid life in a Nordic design style house"., 2013, Ohtori Constructio Co. Ltd (architect)	Japan, Gifu **Passive House Plus new build** *	Single Family Home

Energy

Building energy balance (HVAC, electricity), kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Energy Supply	Energy demand	Surplus		
139	**-58**	**+81**	**Rwall = 5.52** (wall: wooden frame filled with polyurethane foam insulation 100mm + fiberboard + expanded polystyrene 104mm)) **Rfloor = 8.13** **Rroof = 6.45** **Windows:** two-chamber double glazed, **U = 0.5, W / (m2K)**	Heating: solid wood boiler. The electric energy consumption is covered by photovoltaic panels on the roof. The hot water is produced by solar collectors (S = 6m2)
Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2		
103	**10**	**9**		

Emission

Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	wood	Internal heat recovery

Waste

Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	+

* http: //passivhausprojekte.de/index.php? lang = en # d_5165

<table>
<tr><th colspan="3">#7Characteristics</th><th colspan="5">Energy</th></tr>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td rowspan="2">The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td rowspan="2">Use of renewable energy resources</td></tr>
<tr><td>Energy Supply</td><td>Energy demand</td><td>Surplus</td></tr>
<tr><td>35</td><td>-50</td><td>-15</td><td rowspan="3">Rwall = 6.25 (S = 240 m2) (250 mm brick walls with foam glass insulation (240mm), no balconies, terrace (with 280mm foam glass insulation) is situated on a separate foundation)
R basement wall = 5.56(220 mm Foam Glass)
R basement floor = 5.56 (100mm foam insulation under 270mm concrete slab)
Rroof = 7.7(200 + 50mm of expanded polystyrene on rafters)
Windows (S = 65 m2 or 23% of effective area):two-chambered double-glazed window with argon
U = 0.83, W / (m2K)</td><td rowspan="3">Heating (radiating wall and floor surfaces) is provided by geothermal inverter heat pump with deep vertical system (86 m x 4 boreholes). The hot water is produced by solar collectors located on the south side of the roof (S = 22m2). Water tank of 1000l. Mechanical system of ventilation includes a ground heat exchanger + recuperator.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country, city, standard</td><td rowspan="2">Buildi ng type</td><td>Heating area, m^2</td><td>Heating demand, kWh / m2 per year</td><td>Load on the heating system, W / m2</td></tr>
<tr><td>281,1</td><td>15</td><td>11</td></tr>
<tr><td rowspan="7">"Sun House" (the first passive eco-house in Ukraine), 2008, Tatiana Ernst (architect)</td><td rowspan="7">Ukraine , Kyiv, Passive House new build *</td><td rowspan="7">Single Family Home</td><td colspan="5">Emission</td></tr>
<tr><td colspan="3">Existing green area; integrating the built environment with nature, +/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td colspan="3">+ (translucent south-facing structures, orangery ensures sun-protection)</td><td>Internal plaster (30 mm) - clay (indoor humidity - 50%), natural linoleum and parquet</td><td>Internal heat recovery. Geothermal ventilation</td></tr>
<tr><td colspan="5">Waste</td></tr>
<tr><td colspan="3">Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td colspan="3">-</td><td>-</td><td>-</td></tr>
</table>

* http: //passivhausprojekte.de/index.php? lang = en # d_1539

#8Characteristics

Project name (year of construction, architect)	Country, city, standard	Building type
Red Bluff,2015, Constructive Individuals (London) Ltd, (architect), Williams Energy Design, (building system designer)	UK, Andover, **Passive House Plus new build ***	Single Family Home

Energy

Building energy balance (HVAC, electricity), kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Energy Supply	Energy demand	Surplus		
84	**-27**	**+57**	**Rwall = 6.67** (wooden frame of walls is filled with cellulose thermal insulation 300mm) **Rfloor = 11.63**(100mm concrete slab, 400mm polystyrene foam) **Rroof = 7.81**(wooden roof frame is filled with 350mm cellulose insulation) **Windows:** **U = 0.53, W / (m2K)**	Heating (FanCOIL floor convector) and hot water supply are provided by air-to-water heat pump. The Electric energy consumption is covered by photovoltaic panels on the roof. Mechanical supply and exhaust ventilation system includes heat recovery.
Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2		
197	**13**	**9**		

Emission

Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	wood, cellulose (insulation)	Internal heat recovery

Waste

Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	-

* http: //passivhausprojekte.de/index.php? lang = en # d_5283

<table>
<tr><th colspan="3">#9Characteristics</th><th colspan="5">Energy</th></tr>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td rowspan="2">The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td rowspan="2">Use of renewable energy resources</td></tr>
<tr><td>Energy Supply</td><td>Energy demand</td><td>Surplus</td></tr>
<tr><td>82</td><td>-48</td><td>+34</td><td rowspan="3">Rwall = 10.64
(250mm sandwich panels filled with polyisocyanurate (kind of polyurethane foam) covered with 9mm magnesium plates)
Rfloor = 2.89(extruded polystyrene foam + reinforced concrete slabe)
Rroof = 5.78(polyisocyanurate, 250mm)
Two-chamber windows:
U = 1.06, W / (m2K)</td><td rowspan="3">The building is completely autonomous and energy self-sufficient. The Heating load is low and is ensure by air-to-air heat pump. Photovoltaic panels cover with excess electric energy consumption and hot water supply. Mechanical supply and exhaust ventilation system includes heat recovery.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country, city, standard</td><td rowspan="2">Building type</td><td>Heating area, m^2</td><td>Heating demand, kWh / m2 per year</td><td>Heating load, W / m2</td></tr>
<tr><td>180</td><td>2</td><td>4</td></tr>
<tr><td rowspan="6">Springdale,2017, David Halford 5c Sustainable Building Design, (architect), Luc Plowman Detail Green, (building system designer)</td><td rowspan="6">Australia, Queensland, Passive House Plus new build *</td><td rowspan="6">Single Family Home</td><td colspan="5">Emission</td></tr>
<tr><td colspan="3">Existing green area; integrating the built environment with nature, +/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td colspan="3">+</td><td>-</td><td>Internal heat recovery</td></tr>
<tr><td colspan="5">Waste</td></tr>
<tr><td colspan="3">Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td colspan="3">-</td><td>-</td><td>+</td></tr>
</table>

http://passivhausprojekte.de/index.php?lang=en#d_5309

#10Characteristics		
		
Project name (year of construction, architect)	Country, city, standard	Building type
SCI PRESTIGE,2015, Maison Econature, (architect)	France, E-li-bin, **Bepos Effinergie 2013***	Single Family Home

Energy

Building energy balance (HVAC, electricity), kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Energy Supply	Energy demand	Surplus		
96.1	**-54.9**	**41,2**	**Rwall = 5.88** (wooden frame of walls is filled with mineral insulation - 150mm and internal insulation - 60mm + wooden facing) **Rfloor = 8.33**(extruded polystyrene foam + reinforced concrete slab) **Rroof = 10**(mineral insulation 450mm) **Windows (S = 66.53 m2 or 37.18% of living area) double-glazed two-chamber windows filled with argon and protected by shutters: U = 1.29, W / (m2K)**	Solid fuel heating system burns pelleted wood. The heat spreads by an air exchanger. There is a mechanical thermodynamic dual flow ventilation system based on the use of an air-to-air heat pump. Photovoltaic panels (25.63 m2) cover electric energy consumption. Hot water supply is provided by an external air-water heat pump.

Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2
176	**9**	-

Emission

Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	wood	Internal heat recovery

Waste

Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	-

*http://www.observatoirebbc.org/construction/1510

#11Characteristics

Project name (year of construction, architect)	Country, city, standard	Building type
Family house in Agios Nikolaos-Crete,2016, Stefan Chatzoulis, (architect)	Greece, Agios Nikolaos, **Passive House Premium new build***	Single Family Home

Energy

Building energy balance (HVAC, electricity), kWh / m^2 per year		
Energy Supply	Energy demand	Surplus
132	**-30**	**+102**
Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2
170	**4**	**8**

The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
Rwall = 6.1 (100 mm brick walls + 200 mm extruded polystyrene foam) **Rfloor = 1.79**(pre-stressed concrete slab 100 mm + polystyrene foam 50 mm + pre-stressed concrete slab 400 mm) **Rroof = 6.06**(pre-stressed concrete slab 100 mm + polystyrene foam 200mm + pre-stressed concrete slab 180mm) **One chamber windows 4/16/4 + shutters: U = 0.5, W / (m2K)**	Heating is provided by an air-to-air heat pump COP = 5. Ventilation system includes heat recovery (COE=82%) and ground heat exchanger. Hot water is produced by a solar collector of 4m2. Electric energy demand is covered by photovoltaic panels of 25m2.

Emission

Existing green area; integrating the built environment with nature, +/-	Use of materials of natural origin	Use of secondary energy resources
+	-	Internal heat recovery

Waste

Rainwater harvesting and greywater reuse systems, +/-	Waste management and recycling, +/-	Building automation and monitoring, +/-
-	-	-

* http: //passivhausprojekte.de/index.php? lang = en # d_5214

#12Characteristics			Energy				
			**Building energy balance (HVAC, electricity)**, kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
			Energy Supply	Energy demand	Surplu s		
			54	**-54**	**0**	**Rwall = 6.71** (exterior finish-Siberian larch, 40mm of non-ventilated air layer, 100mm mineral wool of high density, 60mm laminated wooden panel) **Rfloor = 5.15**(stone floor 15 mm, structural wooden panel 19 mm, non-ventilated air layer 40 mm, mineral wool 80 mm, 19 mm wooden panel) **Rroof = 5.05**(19 mm wooden panel, 180 mm mineral wool, 19 mm wooden panel, ventilated layer) **Windows (three-chamber double-glazed window with argon):** **U = 0.8, W / (m2K)**	The autonomous house is not connected to the city grid. All electric energy demands are provided by photovoltaic panels situated in the surrounding area. Groundwater from the well is extracted for household needs and irrigation. Heating and hot water are provided by a solid fuel pellet boiler and excess energy from photovoltaic panels (hot water). Water circulating in radiators represents transfer medium. Ventilation ensures heat recovery with 84% efficiency.
Project name (year of construction, architect)	Country, city, standard	Building type	Heating area, m^2	Heating demand, kWh / m2 per year	Heatin g load, W / m2		
			149	**9**	**10**		
Passive house off grid,2016, Marcos Baptista, Patricia Rodríguez., (Architect)	Spain, Lianera, (Asturias) , **Passive House Plus new build***	Single Family Home	**Emission**				
			Existing green area; integrating the built environment with nature, +/-			Use of materials of natural origin	Use of secondary energy resources
			+			wood	Heat recovery
			Waste				
			Rainwater harvesting and greywater reuse systems, +/-			Waste management and recycling, +/-	Building automation and monitoring, +/-
			+			-	-

*http://passivhausprojekte.de/index.php?lang=en#d_4832

#13Characteristics			Energy				
			**Building energy balance (HVAC, electricity)**, kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
			Energy Supply	Energy demand	Surplus		
			41	**-41**	**0**	**Rwall = 5.46**(300mm compressed soil brick, Proclima Intello vapor barrier membrane, Gutex 180mm thermal insulation, 70mm lightweight brick, external lime plaster) **Rfloor = 2.22**(100 mm concrete slab, 80 cork insulation, 80 mm pressed soil, 70 mm cap) **Rroof = 4.4**(roofing material, pre-stressed slab of 50 mm concrete, Gutex 160 mm wooden insulation, Proclima Intello vapor barrier membrane, 15 mm plasterboard) **Window (two chamber window with argon filling): U = 1.15, W / (m2K)**	The autonomous house is not connected to the city grid. All electric energy demands are provided by photovoltaic panels. Rainwater (collected and stored in traditional tanks) is used for household purposes. 4 solar collectors (10.4 m2) cover 92% hot water energy demands. The other 8% is covered by an electric boiler. A solid fuel oven (7.7 kW) generates heat for heating through a pipe system. There are 3 infrared heaters for additional heating. Ventilation system is combined with ground heat exchanger.
Project name (year of construction, architect)	Country, city, standard	Building type	Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2		
			143	**8**	**12**		
Proyecto Tierra (Project Earth),2014, Neus García Iñesta (architect), Instal 3 PuntoCero (Building services)	Spain, Lukymeior, Balearic Islands, (Asturias), **Passive House Premium new build***	Single Family Home	**Emission**				
			Existing green area; integrating the built environment with nature, +/-			Use of materials of natural origin	Use of secondary energy resources
			+			Brick, wood, lime	Heat recovery
			Waste				
			Rainwater harvesting and greywater reuse systems, +/-			Waste management and recycling, +/-	Building automation and monitoring, +/-
			+			-	-

*http://passivhausprojekte.de/index.php#d_4717

<table>
<tr><th colspan="3">#14Characteristics</th><th colspan="5">Energy</th></tr>
<tr><td colspan="3" rowspan="3"></td><td colspan="3">Building energy balance (HVAC, electricity), kWh / m^2 per year</td><td rowspan="2">The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$</td><td rowspan="2">Use of renewable energy resources</td></tr>
<tr><td>Energy Supply</td><td>Energy demand</td><td>Surplus</td></tr>
<tr><td>59</td><td>-29</td><td>+30</td><td rowspan="3">Rwall = 9.8(brick masonry 175mm, extruded polystyrene foam 300 mm)
Rfloor = 9.09(300mm of polystyrene thermal insulation, 300mm concrete slab, 30mm extruded polystyrene foam, 20mm sound insulation, 50mm cap)
Rroof = 11.63(roofing material 10 mm, 200 mm concrete slab, 200 mm polyurethane foam, 95 mm extruded polystyrene foam)
Windows (two chamber windows):
U = 0.53, W / (m2K)</td><td rowspan="3">The THZ 304 air-to-water heat pump provides heating, hot water production and ventilation with recovery up to 90% of exhaust air. Electric energy demands are fully covered by photovoltaic panels.</td></tr>
<tr><td rowspan="2">Project name (year of construction, architect)</td><td rowspan="2">Country, city, standard</td><td rowspan="2">Building type</td><td>Heating area, m^2</td><td>Heating demand, kWh / m2 per year</td><td>Heating load, W / m2</td></tr>
<tr><td>216</td><td>15</td><td>10</td></tr>
<tr><td rowspan="6">Freistehendes Einfamilienhaus,2017, Massivbau (architect),</td><td rowspan="6">Germany, Nidderau, Passive House Plus new build*</td><td rowspan="6">Single Family Home</td><th colspan="5">Emission</th></tr>
<tr><td colspan="3">Existing green area; integrating the built environment with nature,
+/-</td><td>Use of materials of natural origin</td><td>Use of secondary energy resources</td></tr>
<tr><td colspan="3">+</td><td>Brick</td><td>Heat recovery</td></tr>
<tr><th colspan="5">Waste</th></tr>
<tr><td colspan="3">Rainwater harvesting and greywater reuse systems, +/-</td><td>Waste management and recycling, +/-</td><td>Building automation and monitoring, +/-</td></tr>
<tr><td colspan="3">+</td><td>-</td><td>-</td></tr>
</table>

*http://passivhausprojekte.de/index.php#d_5461

#15 Characteristics			**Energy**				
			**Building energy balance (HVAC, electricity)**, kWh / m^2 per year			The thermal resistance of building envelope (Composition), $\frac{m^2 \cdot K}{W}$	Use of renewable energy resources
			Energy Supply	Energy demand	Surplus	**R bearing wall = 6.67**(1.0 cm internal plaster [λ = 0.11 W / (mK)], thermal insulation brick 42,5 cm [λ = 0,07 W / (MK)], thermal insulation 2,5 cm [λ = 0,10 W / (MK)]) **R enclosure wall = 7.69**(8.5 cm wooden panel, 30 cm blown loose-fill thermal insulation of Steicozell wooden fiber, 3 cm wooden frame, 0.8 cm facade panel) **Rfloor = 9.09**(200 mm thermal insulation λ = 0.038 W / (MK)], reinforced concrete slabe 25.0 cm [λ = 2.10 W / (MK)], insulation 12.0 cm [λ = 0.034 W / (MK)] , cap 5,0 cm, parquet 2,0 cm) **Rroof = 10.87**(14.7 cm wooden panel, Steicozell insulation 40.0 cm [λ = 0.040 W / (MK)], fiberboard 1.6 cm [λ = 0.09 W / (MK)]) **Windows (two chamber windows):** **U = 0.53, W / (m2K)**	The heat pump and solar collectors (12m2) cover the energy demands for heating and hot water supply. Ventilation is performed by Paul, Novus 300 equipment with a soil heat exchanger and humidity control system. Electricity Energy demands are fully covered by photovoltaic panels.
			72	**-21**	**+51**		
Project name (year of construction, architect)	Country, city, standard	Building type	Heating area, m^2	Heating demand, kWh / m2 per year	Heating load, W / m2		
			168	7	7		
Zweifamilienhaus als Plusenergie-Passivhaus,2011, ArchiUmPlan (architect),	Germany, Niederkirchen, **Passive House Plus new build***	Single Family Home	**Emission**				
			Existing green area; integrating the built environment with nature, +/-			Use of materials of natural origin	Use of secondary energy resources
			+			Brick, wood	Heat recovery
			Waste				
			Rainwater harvesting and greywater reuse systems, +/-			Waste management and recycling, +/-	Building automation and monitoring, +/-
			+			-	+

*http://passivhausprojekte.de/index.php#d_2169

Analysis of expected objects

We studied 15 projects that have an energy performance level in the range of NZEB (or approaching NZEB level) in the different EU Member States (MSs). Selected buildings are characterized by an optimal volume-planning solution: compactness, the orientation of the main part of the translucent structures to the south, the use of passive heat storage systems, the roof is suitable to place photovoltaic panels and solar collectors. Almost all buildings are geographically located in similar climatic conditions with Ukraine. Only two examples are situated in the subtropical zone (2 examples). Eleven houses represent 10 EU countries (Germany - 3, Spain - 2, France - 2, Greece - 1, UK - 2, Italy - 1) and the other countries of the world (Canada - 1, Japan - 1, Australia - 1, Ukraine - 1). All buildings are implemented and occupied permanently. The new construction is represented by 14 specimens and one is a renovation of a traditional rural home to the nZEB level (CorTau House, 2015, Italy). The heating area varies from 86 to 281 m2. All buildings considered meet the PHPP energy efficiency requirement in terms of total energy demand parameter (≤65 kW / m2 per year): maximum value is 59(# 4), minimum 21 kW / m2 per year (# 15). Indicators of own energy supply range from 35 (# 7) to 142.5 kW / m2 (# 2) per year.

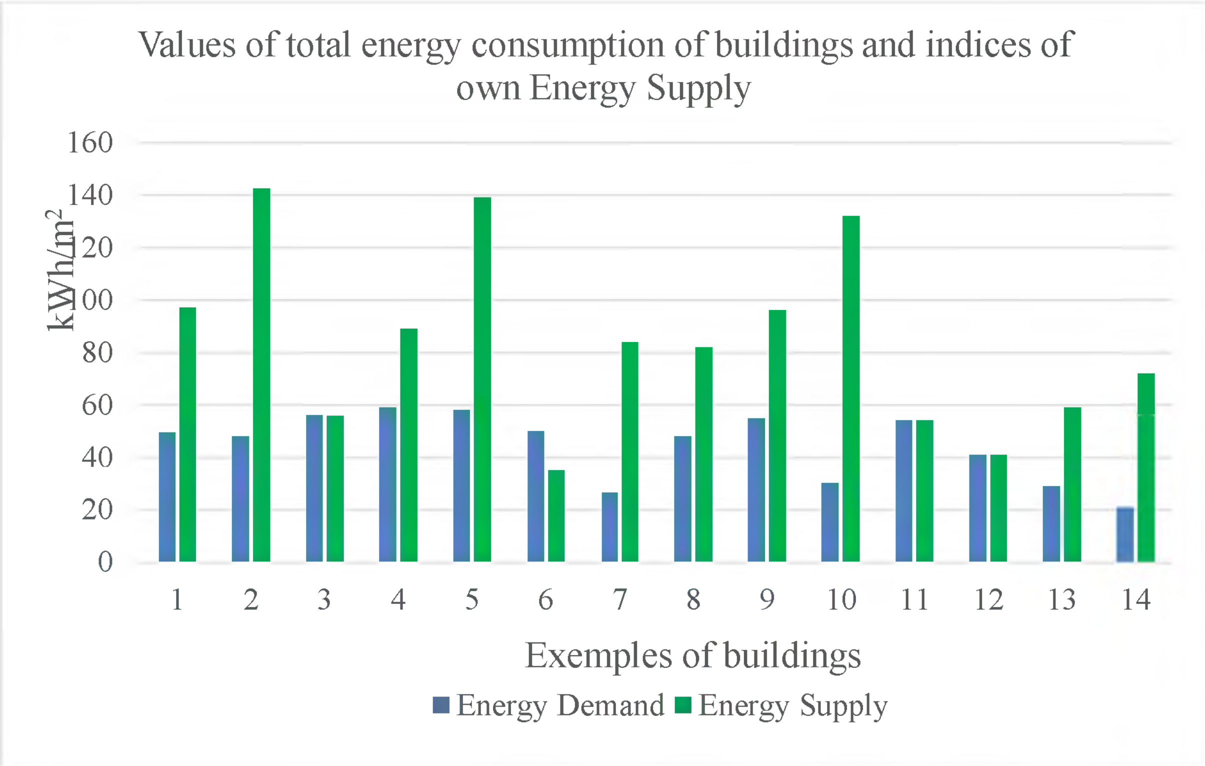


Fig. 36. Value of total energy consumption of buildings and indices of own energy Energy Supply.

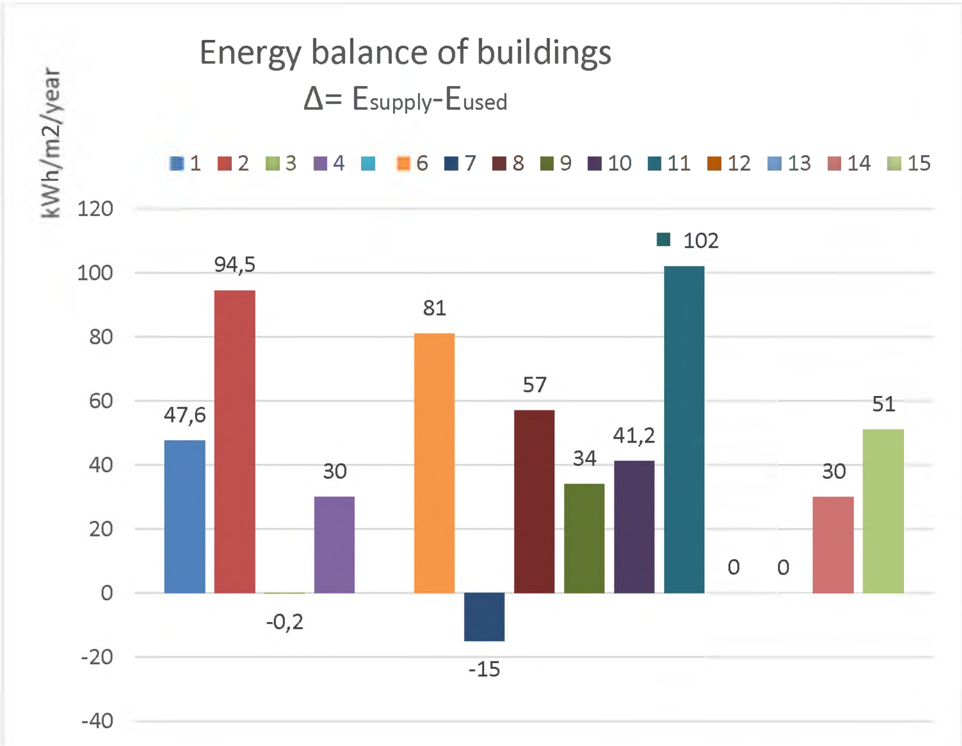


Fig. 36. Energy balance of buildings.

Most of the windows are double-glazed and filled with argon. Only one example provided with single-glazed windows and three cases have three-chamber windows.

Type of wall protection structures

- brick masonry with external insulation (2 exemples - extruded polystyrene foam, 2 - fibreboards, foam glass, mineral wool) or brick cavity wal1 (filled with extruded polystyrene foam) is used in 7 examples of houses,
- wooden frame of exterior walls, used in 7 houses, was filled with cellulose insulation (2) or mineral wool (4) or polyurethane foam insulation (1).

One house has sandwich panels (# 9) filled with a variety of polyurethane foam. Mineral wool (1), expanded polystyrene extruded (2) or expanded polystyrene are chosen as the exterior insulation for classic brick walls. Gutex wooden insulation was used for house # 13.

Table 25. Analysis of the thermal resistance for the buildings under consideration

Type of enclosure	Thermal resistance R, $\frac{m^2 \cdot K}{W}$		
	Average value	The lowest value	Highest value
Exterior wall	7.23	3.73	11,63
Ceilings	8.3	4.26	19,23
Floor (ground slab or ceiling over an unheated basement)	6.68	1,79	11,63
U Windows, $\frac{Bm}{м^2 \cdot K}$	0.78	0.5	1.29

Building # 3 was the most insulated because of its more severe winters in Canada. The least insulated floors of buildings # 11 and # 13. This fact can be connected to the location of these projects in the Mediterranean (south of Greece and Spain).

Type of engineering equipment

All examples of homes are equipped with engineering systems based on **renewable energy sources.**

10 examples of homes demonstrate complete electrification of the building (absence of raw material incineration processes) to meet all the Energy demands. All the investigated houses obtain **electricity** from photovoltaic panels installed on the roof or in the house. 3 projects are completely autonomous from the city grids (including water supply).

For most of the projects (7) different heat pumps were selected to provide **heating**:

- "air-water" - 1 house;
- "air-air" - 3;
- "water-water" - 2;
- "ground-to-air" - 1.

Traditional solid fuel stoves or solid fuel pellet boilers serve 5 homes.

Three homes are heated by FanCOILs or radiators connected to an electric boiler.

There are three variants of **hot water supply**: using a heat pump, a photovoltaic-powered electric heater, or solar collectors. The combination of the equipment can be different due to the variable local conditions (maximum power of the equipment). For example, for # 13, solar collectors (10.4 m2) provide 92% of hot water energy demands. The other 8% is covered by an electric boiler. Among the studied objects, only 3 independently satisfy the Energy demand for drinking and technical water. Four homes have a wastewater treatment and reuse system in place. Inhabitants of project # 13 collect distilled rainwater in a traditional tank for domestic use. For this purpose, underground water is extracted from the well in projects # 12 and # 9.

13 homes are provided with a **mechanical ventilation system and heat recovery** (82 to 95% efficiency). Three buildings use a more optimized system with a ground heat exchanger. Only one building has equipment for heat recovery from the used domestic water.

Building automation and monitoring systems are not well spread among considered buildings. There were only 5 of them with the mentioned facilities. Similarly, only house # 1 has a system of waste management and recycling, for sure.

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Babenko M. M.
Savytskyi M. V.
Shechorkina S. Y.
Kuzmenko O. M.
Bordun M. V.
Kotov M. A.

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