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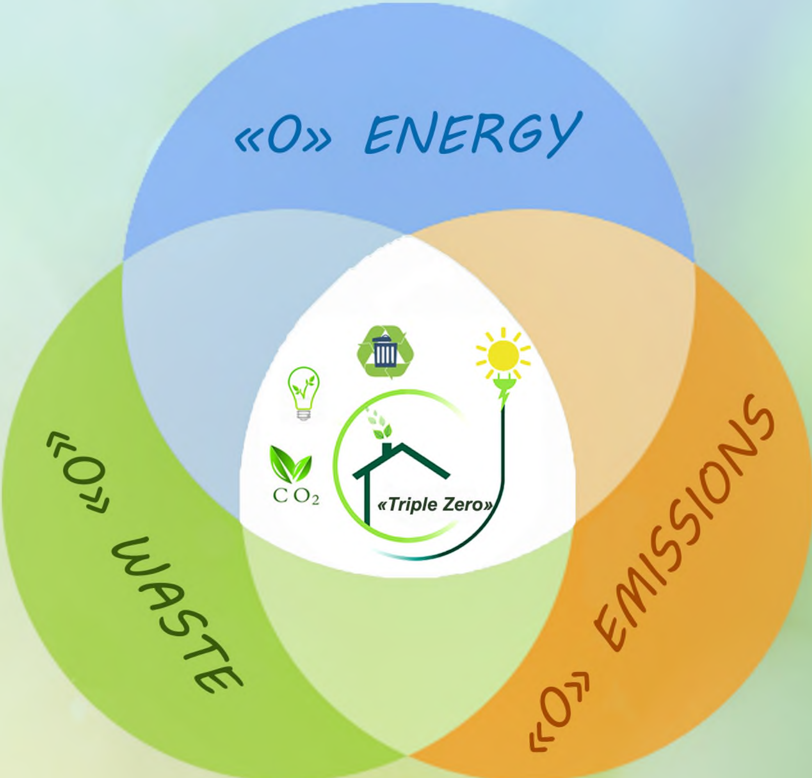
GREEN TECHNOLOGIES AND 3D-PRINTING FOR A TRIPLE-ZERO CONCEPT IN CONSTRUCTION



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Mykola SAVYTSKYI, Maryna BABENKO,·Maryna BORDUN,·
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Green Technologies and 3D-Printing for a Triple-Zero Concept in Construction

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Sustainable building is available to everyone and affordable for anyone

Monograph

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G 78

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This book explores the issue of global construction industry challenge in the context of sustainability, based on environmentally friendly building design; important check lists for each implementation stage of ecological and energy-efficient autonomous structures; and propose the strategy for Triple Zero ecological buildings development. Architects and engineers, university lecturers, researchers, students and other individuals will find this monograph useful to raise their awareness and improve knowledge in the field of sustainability in construction and real-life implementation of its principles in building design.

Ця книга досліджує проблему глобального виклику будівельній галузі в контексті сталого розвитку на основі створення проектів екологічних будівель; важливі контрольні списки для кожного етапу впровадження екологічних та енергоефективних автономних конструкцій; та запропонувати стратегію розвитку екологічних будівель Triple Zero. Архітектори та інженери, викладачі університетів, дослідники, студенти та інші особи знайдуть цю монографію корисною для підвищення їх обізнаності та вдосконалення знань у галузі стійкості в будівництві та реалізації її принципів у проектуванні будівель у реальному житті.

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CHAPTER 1

INTRODUCTION INTO THE TRIPLE-ZERO ECO-BUILDING APPROACH

1.1. Sustainable development in construction

1.1.1. Sustainable development

Not so long ago, at the UN summit, which was dedicated to sustainable development and took place in New York on September 25, 2015, the UN member states adopted a plan for sustainable development until 2030. This plan consists of 17 goals, namely: poverty eradication; elimination of hunger; good health and wellness; quality education; gender equality; clean water and sanitation; cheap and clean energy; decent work and economic growth; industrialization innovation and infrastructure; reduction of inequality; sustainable development of cities and towns; responsible consumption and production; combating climate change; conservation of marine ecosystems; conservation of terrestrial ecosystems; peace, justice and effective institutions; partnership for sustainable development. All the goals have a number of their own phased indicators to be achieved within 15 years. Within the framework of this work, the “Eleventh Goal” is of particular interest, which provides for the creation of cities and towns open, safe, resilient and sustainable. [1]

The projects being developed should demonstrate the rational use of natural resources and their management throughout the entire life cycle of their use. Environmental issues, especially those related to the supply and movement of materials, water and energy, should take a dominant role in design approaches. It is also necessary to increase the positive impact of the projected facility on the environment by reducing harmful emissions and introducing low-carbon construction.

Conservation of the existing landscape, land use policies, reclamation and water management should be a part of environmentally friendly strategies. The main emphasis in construction should be put on the use of renewable energy, the use of recycled materials to significantly reduce CO_2 and other greenhouse gas emissions while minimizing toxic side effects. New approaches to the use of material resources in construction, focusing on cycles from "cradle to cradle", rational use of existing building stocks, minimization of water consumption and reduction of waste. The use of flexible, durable and non-toxic products, reliable structural parts, an emphasis on the optimal interaction of building systems, and the promotion of environmentally friendly technologies. [2]

1.1.2. Concept of sustainable development in the construction sector

"Sustainability" is one of the popular but the least understandable term. Its basic meaning is often distorted by various interpretations, exacerbated by a tendency to be superficial about the subject, be it "eco", "green" or "smart" topic. However, for those in public and private sectors who take this issue seriously, sustainability encompasses the environment, interacting with it in a harmless way and its long-term resilience. Likewise, an integral part of sustainability are critical development issues related to the responsible use of resources in a circular (circular) economy and ensuring social equity through equitable distribution of benefits.

Considering a huge amount of material and energy costs required to produce and maintain a built environment, as well as a significant amount of emissions and waste generated by this environment throughout its existence, the construction sector can make one of the main contributions to the achievement of sustainable development goals. Considering the growth rate of urbanization and the trend towards its growth in the future, it becomes more and more important that newly built and already existing construction projects are sustainable on all registers - in the environmental, economic and social terms.

1.1.3. Sustainable future of construction

Sustainable construction, with appropriate conditions for its development, was set out in the Brundtland Commission's report "Our Common Future" back in 1987, and aims to meet today's needs for housing, working environment and infrastructure without compromising for future generations to meet the same needs. By meeting these needs now and over time, sustainable building, in other words, can become more socially beneficial in the long term by reducing its overall ecological footprint.

Due to a significant impact of the building sector on the environment, sustainable construction includes the following aspects: design and implementation of building structures, regardless of the scale of buildings, infrastructure or urban agglomerations; production of durable, sustainable and recyclable materials at all stages and throughout the entire cycle of their use; use of renewable energy sources, as well as related technologies in construction, operation and maintenance to reduce global greenhouse gas emissions.

In view of its economic impact, sustainable construction involves the following aspects: transition from a linear to a circular (circular) economy of renewable energy production, recycling of materials and waste, water collection and storage, portable technologies and adaptability of structures to changes in use; innovative financing models based on smart cost savings that deliver more for less.

Because of its social impact, sustainable construction involves the following aspects: adhering to the highest ethical standards in business and industry practice at all stages of the project; promoting socially good living and working conditions, including occupational health and safety standards for workers and users; improvement of all processes associated with the production and use of the built environment as a common wealth.

Fulfilling these simultaneous tasks, sustainable construction includes the aesthetic, external and internal appeal of architectural forms, construction site and the built environment in general, taking into account local cultural characteristics. [3]

1.1.4. Assessment criteria in sustainable construction

In 2002, the World Green Building Council has been established to promote the design and construction of sustainable buildings and to promote construction around the world.

This council specifically deals with the change and transformation of the construction sector of the economy in three areas: negative impact on the climate; health and well-being of residents; saving resources and their circulation. The organization has an extensive network of councils around the world, about 70. Through an approach to systemic change, this network is leading the construction industry towards a clean, green, equitable and sustainable zero carbon environment.

Today, the global market is dominated by two well-known leaders in green certification BREEAM (UK) and LEED (USA). There are also other standards, such as: HQE (France), EcoProfile (Denmark), CASBEE (Japan), GBI (Canada), Green Star (Austria), but they are regional.

The **US LEED** [4] (Leadership in Energy and Environmental Desighn - LEED) system is a green building board, which is a voluntary rating system for the certification of sustainable buildings and neighborhoods. LEED was established in 1998 and is highly popular not only in the United States but also abroad, such as Mexico, Canada, China, India, Brazil and others.

LEED's goal is to restore and maintain the environment and positively impact the well-being of the residents, throughout the entire life cycle of the facility. LEED's mission is to transform the way buildings and communities are designed, built and operated, creating environmentally and socially responsible, healthy and prosperous environments that improve the quality of life.

Fig.1.1. How LEED works [5]

The certification process is to determine the number of points earned by the project in the context of various aspects of sustainable construction. Depending on the degree of environmental friendliness, projects of buildings and structures can be issued “platinum” (more than 80 points), “gold” (from 60 to 79 points), “silver” (from 50 to 59 points) certificates, or they can simply be certified (from 40 to 49 points). Here is a brief structure of the elements of the LEED system: Sustainable construction sites (total points available - 7); Water efficiency (total points available - 2); Energy and atmosphere (total points available - 14); Materials and resources (total points available - 14); The quality of the internal environment (total points available - 15); Innovations and previously accredited projects (total points available - 5) [1].

British system **BREEAM** (Building Research Establishment Environmental Assessment Method). BREEAM is an independent, comprehensive, international certification and sustainability assessment system for individual buildings, communities and infrastructure projects that can be carried out at several stages of the life cycle, as well as at all stages of design, construction, operation and repair.

In the case of BREEAM, third-party certification involves reviewing - by impartial experts - the appraisal of a building or project by a qualified and licensed BREEAM evaluator against the scheme's quality and performance standards.

Fig.1.2. How BREEAM works [8]

At the heart of this process are certification bodies - organizations that have government approval (through national accreditation bodies) to certify products, systems, and services. [6] The BREEAM system, when certified, covers a wide range of categories from pollution to management and determines their sustainability. Each of these categories is among the most influential factors, including low impact design and carbon reduction; durability and stability of the structure; adaptation to climate change; ecological value and protection of biodiversity.

The certification of construction objects in the BREEAM system is based on the rating. Each project is awarded some stars for each category and ranges from Acceptable to Pass, Good, Very Good, Excellent, and Outstanding as reflected in the number of stars awarded on the certificate (maximum six stars).

Each category is subdivided into a number of assessment questions, each with a target and benchmarks. When a target or benchmark is achieved, a BREEAM assessor determines asset scores called credits or category score, which is calculated according to the number of credits received and the weight of its category. After the design has been fully assessed, the final performance rating is determined by the sum of the scores of the weighted category. [6]

1.2 Energy-saving in building sector

1.2.1. Energy efficiency in construction (EU)

Residential and civil buildings take up a significant part of our daily life, as we spend most of it being inside, at home or at work. However, regardless of the type and configuration of the building, the built environment is the main and largest consumer of energy in the EU, CIS, USA, PRC, and other countries and territorial entities. In addition, buildings emit a significant amount of CO_2 emissions (construction process, material transportation, renovation, reconstruction, demolition, disposal).

For example, in the EU, housing and public funds are responsible for 40% of all energy consumed and 36% of total carbon dioxide emissions. In this regard, the EU has adopted an ambitious goal by 2050 to achieve the neutralization of CO_2 emissions from all buildings, within the framework of the European Environmental Agreement.

Currently, about 75% of the EU building stock is not energy efficient. And in this view, a significant part of the energy consumed is simply lost and ends up in waste. These losses can be minimized by improving existing buildings, through the introduction of “smart solutions” and energy efficient materials. These solutions can be used for repair and reconstruction.

In 2018, within the Clean Energy for All Europeans program, the main energy efficiency directives (EPBD) 2010/31 / EU, EED) 2012/27 / EU were revised upwards. In addition, each EU country must present its strategy for solving energy problems in buildings for the period 2021-2030. Through its Integrated National Energy and Climate Plans (NECP). The combined impact of these efforts at the national level will contribute to the overall target of reaching the EU target of 32,5% by 2030. [8]

The directives are mainly focused on enhanced long-term renewal strategies for the EU countries; buildings with almost zero energy consumption; energy performance certificates; health and wellness assessment (air pollution), e-mobility (electronic chargers) and smart technologies (smart meters, self-regulating equipment) in new buildings.

1.2.2. Energy efficiency in construction (USA)

In the US, the construction sector accounts for approximately 76% of electricity consumed and 43,8% of all CO_2 emissions from ventilation, heating, lighting, and cooling. The construction fund also occupies 40% of the entire US territory. Based on this, the goal was set to reduce greenhouse gas emissions by 50% by 2030, through measures to improve the energy efficiency of newly built and existing facilities.

In addition, to achieve this goal, it is planned to adopt a number of standards, the main of which are the Commercial Building Energy Consumption Survey (CBECS) and the Residential Energy Consumption Survey (RECS), which are still being developed. Only a series of recommendations was made, the Challenge 2030, however they strengthen the requirements of existing norms, codes, ratings, and rules already existing in the construction industry. Basically, it refers to certain standards, indicating to what extent this or that value should be increased. At the moment, the most effective American energy efficiency standard is ASHRAE Energy Standard 90.1-2007.

According to the above norms, the overall efficiency of a building should be considered as an integrated system with an improvement in the performance of all its subsystems and designed to provide residents with a comfortable, safe, and attractive living environment. This requires superior architecture and engineering designs, quality construction methods, and careful maintenance of structures. Also in buildings, more and more often, more complex electronic control, distribution and accounting systems are located. The main areas of energy consumption in buildings are heating, ventilation and air conditioning - 35% of all energy in a building; lighting - 11%; basic appliances (water heaters, refrigerators and freezers, dryers) - 18% with the remaining 36% go to various needs, including electronics. In each case, there is a scope for both improving the performance of system components (for example, increasing the efficiency of lighting fixtures) and improving the way they are controlled as part of an integrated building system (for example, sensors that adjust light levels based on occupancy and daylight). [9]

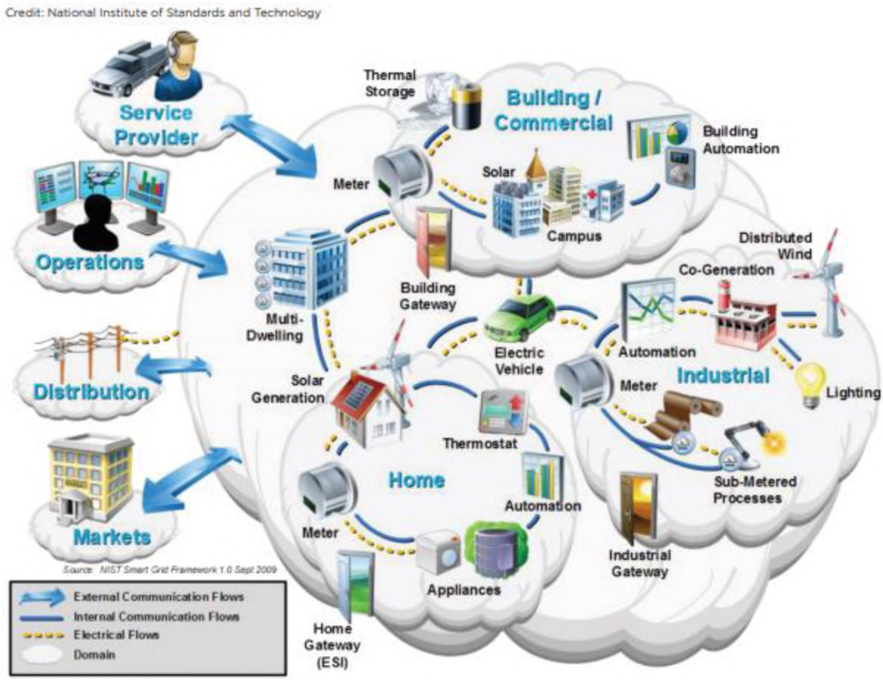

Fig. 1.3. Interconnection diagram of system components [9]

1.2.3. Energy efficiency in construction (Ukraine)

The household sector in Ukraine accounts for 52,5% of the population living in detached privately owned houses. The remaining 47,5% of the population, the vast majority (93%) live in owner-occupied apartments in 240,000 apartment blocks, 70% of which date back to the Soviet period. (*See* Annex A for basic data on the housing situation in Ukraine and cost estimates of energy-saving investments).

Energy-saving investment in apartment blocks requires group decision-making. There is a form of legal entity established in Ukrainian law since 2001, namely the “Law of Ukraine on Associations of Co-owners of Multifamily Buildings”. However, only about 17,000 out of 240,000 apartment blocks have adopted this practice, and the numbers do not grow fast. It can be explained, in part, due to a large number of very poor people who could not afford investment expenditures and well-off people who do not want to take the risks of financial responsibility for their neighbors unable to perform obligations. [10]

The reporting period of NEEAP for Ukraine to achieve the estimated goal, according to the Directive, is from 2012 to 2020. The main objective is to ensure that all Contracting Parties have planned energy savings in the amount of 9% of the average domestic energy consumption over the last statistically available period (2005-2009), the for the 9th year of the Directive application. The first NEEAP sets an interim and indicative target within three years of the implementation period in the amount of 2% of domestic target of energy consumption. The above mentioned purpose does not apply to energy consumers covered by the Directive 2003/87/ EU, which sets greenhouse gases quotes in the Community (hereinafter referred to as the ETD), as well as end consumers in the areas of air and inland waterway transportation. In order to achieve the goal, aggregated and individual data on energy consumption were used. These data were provided by the State Statistics Service of Ukraine.

Energy balance indicators do not differ from the data provided by the Eurostat. In the course of Plan implementation, Ukraine should also introduce efficient regulatory, taxation, financial, and organizational measures for the overall implementation the Directive. In order to achieve the indicative objectives, it is necessary to provide mobilization of significant financial resources, enhancement of energy efficiency actions planned by the State, and further liberalization of the energy market, particularly in terms energy service delivery, as well as development of public-private partnerships in the field of energy efficiency.[10]

Over the last years some improvements in the energy saving policy of the building sector in Ukraine have been observed. There is a trend to adapt current standards and norms to the global tendencies and energy saving goals in the context of sustainable development. The prerequisite for the successful implementation of the updated standards and norms is their promotion among developers and end-users, state policy with the benefits for all target groups. The best practices of the leading countries in this field could be implemented at local and national levels.

1.2.4. Measures to improve energy efficiency and reduce CO_2 emissions

The main design concepts to be considered in buildings to improve their energy efficiency include the following elements:

- *The shape of the building and its orientation in space.* The orientation of a building must be chosen in order to maximize solar supply, especially infrared and visible components of the spectrum, in the winter and reduce the supply in the summer due to the appropriate technology and form.
- *Air conditioning and ventilation*. For building design, it is necessary to consider structural measures for possible natural ventilation, for example, the difference between inlet and outlet ventilation holes in order to create natural draught. Since air conditioning (cooling) and forced ventilation lead to significant energy costs, more is spent only on lighting. The quality of the distribution system design is also important, since the performance of even the best devices can drop because of losses.
- *Heating.* Heating costs during the cold season can be extremely significant and account for more than half of the life cycle cost of a building. To reduce these costs, it is necessary to insulate the external enclosing structures. Preference should be given to non-polymeric insulating materials, such as mineral wool (with a minimum degree of impregnation), foam glass, aerated concrete and other similar materials. Combination of different materials to reduce thickness and thermal conductivity can give the best insulation performance. Also, it is necessary to remember about the quality of windows, insulation of openings,

basements and roofs, through which from 10% to 40% can be lost, depending on a building configuration.

- *Building Materials.* Materials should be environmentally friendly, preferably of natural origin, so that after the facility life span, they can be reused, or recycled into something else.
- *Landscaping.* The choice of vegetation native to a given area can greatly affect water consumption in civil engineering. Landscaping can also be used as part of a passive energy strategy, planting trees that shade the roof and windows during the hottest part of the day can reduce solar gain inside the building, or by drowning the building partially into the ground, passive ground heating can be achieved [11].
- *Rainwater use.* The introduction of rainwater drainage systems and its accumulation with subsequent use as technical, for flushing or irrigation, allows people to achieve significant savings.
- *Renewable energy systems.* Such systems include wind turbines (power generation and mechanical work); solar panels (power generation); solar collectors (water heating); heat pump (heat generation); the use of biomass (heat and electricity production); the use of piezoelectric elements (power generation). By using one or a combination of several systems, it is possible to achieve the sawing energy autonomy of a building without using fossil fuels and without emissions of greenhouse gases.

The following chapters will represent in detail a step-by-step strategy how to design energy efficient ecological buildings to meet the requirements of “Triple Zero” concept and general principles of sustainable construction.

1.3 Heritage and eco-building development

Natural conditions and local building materials had a great influence on the formation of vernicular 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 provided its own types of dwellings. In forests, ancient buildings were built from wood, in a forest steppe - from clay, straw and wood, in a steppe - from clay and stone. By the characteristics of natural building materials, the territory of Ukraine can be divided into three zones. The forest zone occupies the north of Ukraine to Volodymyr-Volynsky, Lutsk, Rivne, Zhytomyr, Kyiv, Nizhyn, and Glukhiv. The main building material there was wood. Clay had an auxiliary value; the cover (roof) was made of straw. The Forest-Steppe area is the central part of Ukraine to Balta, Kremenchug, Poltava, and Kharkiv. For building purposes wood, clay, cane, and straw were used; straw or cane for roofing. (Fig.1.4.) [12].

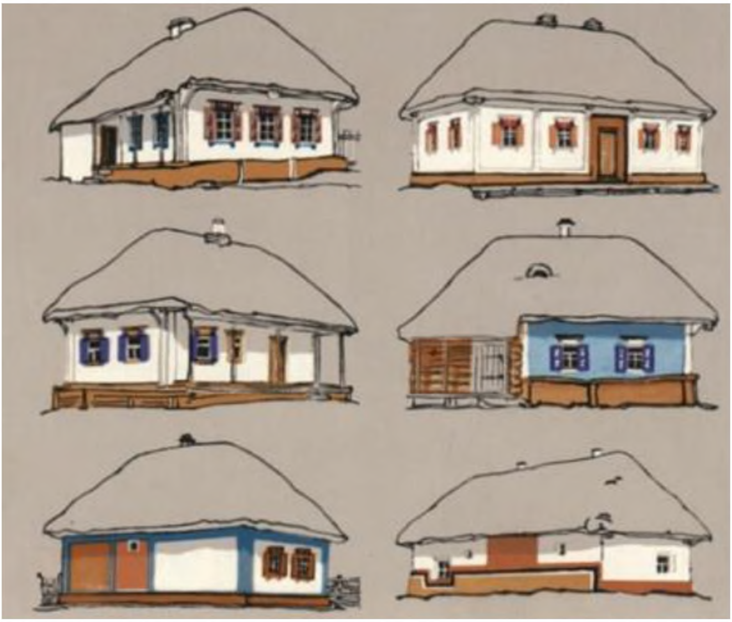

Fig. 1.4. Types of Ukrainian Dwellings (Poltava region, end of the XIX century) [14]

Along with the well-known advantages of such dwellings (ecology, economy, accessibility), traditional structural concepts have a number of drawbacks. In the first place, it is a failure to ensure the implementation of modern standards for energy efficiency in construction [13].

Ukraine has significant experience in application of widespread modern natural building materials, therefore there is a great potential for them to be adapted for sustainable standards and wide industrialization in a large scale construction projects.

1.4 Triple zero eco- building approach – definition

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, which is based on environmental requirements for the construction site. The concept of the circular economy envisages the transition from a linear model to a model where natural capital is stored and developed. Energy resources are used efficiently, preventing 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.

The first step towards the implementation of circular economy principles in the construction industry could be the development and implementation of energy autonomous ecological buildings with efficient waste management according to the following criteria (Fig. 1.5.):

1) Zero energy – is to provide a balance of energy consumption, which will ensure the autonomy of the building throughout the lifetime, 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 of only those materials during the construction 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.

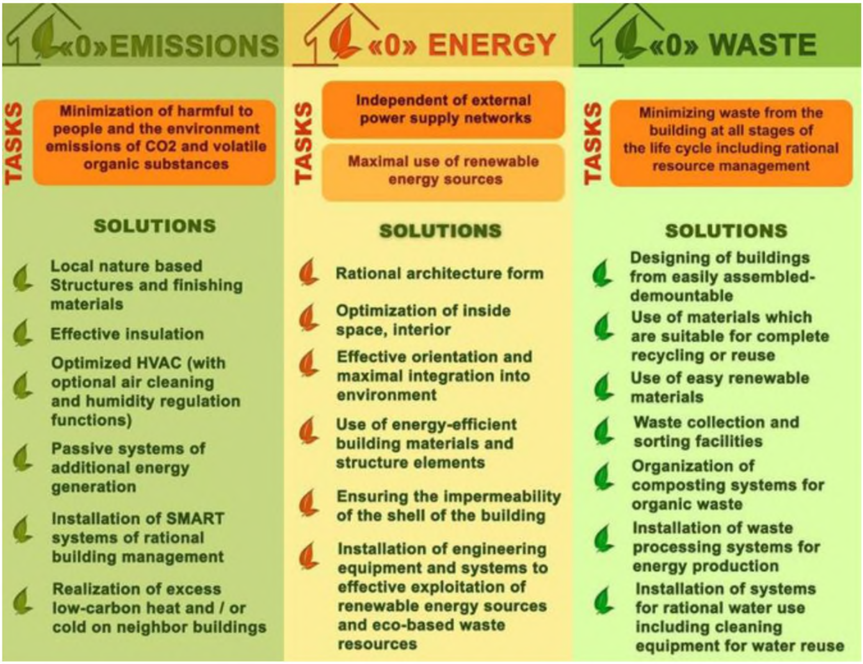

Fig. 1.5. The first step criteria for "Triple Zero"

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 is considered here not in the absolute, but in the conventional sense. According to 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. 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.

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CHAPTER 2
ARCHITECTURAL PRINCIPLES FOR SUSTAINABILITY APPLICATION IN CONSTRUCTION

2.1. Definition of sustainable architecture and design in the context of triple-zero eco-buildings

There has been a significant change in the ideology of design and construction over the last half century. The adoption of the Concept of Sustainable Development by the world community in 1987 determined the desire of mankind to turn to the search for opportunities to implement its principles in all spheres of human activity, which was reflected in architecture.

At the World Congress of Architects in 1993, the Declaration of Interdependence for a Sustainable Future, it was recognized that the architectural environment in general and buildings in particular, play an important role in the negative human impact on the natural environment. Consequently, architects can have a significant impact on restoring ecological balance and ensuring a high quality of life for mankind, creating an architectural environment that meets human needs, and at the same time preserves or even improves the natural environment. This architectural environment, as well as the process of its creation, has been called "**sustainable architecture**".

In the XXI century a lot of life processes underwent significant transformation. At the moment, the world community is trying to form a universal architectural concept to develop new strategies and methods for various climatic, political, social and cultural conditions. At the same time, architecture is viewed as a kind of flexible "interface" between a man and the environment.

Sustainable architecture is not a trend or direction in architecture, it is more of a reference point for the design process than the architecture itself. In its stylistic name it is a vector of development, a system of principles or a design paradigm.

The concept of "sustainable architecture" can be deciphered as a set of architectural and engineering solutions that ensure high performance of the human environment and the preservation of ecological balance [1].

Following the "Concept of Sustainable Development", sustainable architecture is designed to meet the needs of living generations of people at a high quality level, without depriving future generations of the same opportunities.

Along with the term “sustainable architecture”, such concepts as “green architecture”, “ecological architecture”, “low-cost architecture”, “high-tech architecture”, “bioclimatic architecture” are often used. All these areas are based on a reduction in the consumption of material resources while improving the quality of buildings and the comfort of the internal environment of design objects, reducing the consumption of energy resources (renewable and non-renewable) and improving the technology of construction and operation of buildings.

Today the main principles of the formation of sustainable architecture are: harmonization of social, economic, ecological, territorial and spatial factors of the development of settlements; identification of the optimal combination of stable and variable objects in the design program; adaptability to challenges and risks of natural, climatic and technogenic nature; spatial and mathematical modeling of the shape of the building depending on the factors that determine the life cycle; increasing the physical and mental comfort of people by improving the functional, microclimatic and aesthetic parameters of the living environment. The principles listed above are not intended to be exhaustive, since a sustainable architectural environment covers a wider range of concepts and objectives [2].

One of the conceptual challenges of modern architecture is the design and creation of "new generation" which satisfy human needs while preserving the environment throughout the building's life cycle.

https://www.stefanoboeriarchitetti.net/en/news/the-second-vertical-forest-will-be-born-in-lausanne-ch/

Fig. 2.1. "Cedar Tower" - building with vertical landscaping (architect Stefano Boeri, Lausanne, Switzerland)

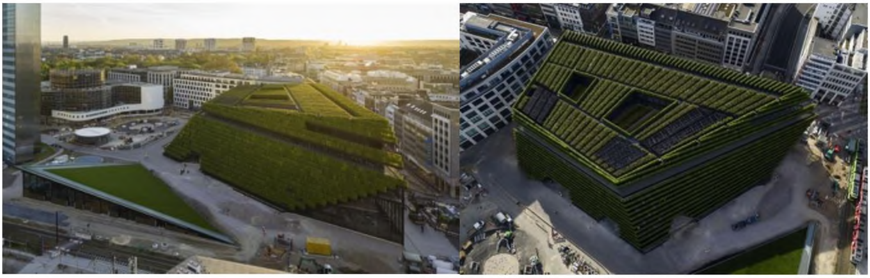


Photo © ingenhoven architects / HGEsch

Fig. 2.2. Multifunctional complex Kö-Bogen II (architect Christoph Ingenhofen, Dusseldorf, Germany)

Practical implementation of the basic principles of sustainable architecture was applied by the authors in the development of the concept of design and construction of autonomous buildings "Triple Zero".

2.2. Building as a living body

Today, a building is no longer just seen as a shelter from adverse environmental factors or a human habitat but serves as an external «macroshell» of a human being with his vital and spiritual needs. A building, whether it be one-storey residential buildings or multi-storey urban development, is no longer just a constructive shell, but a rather complex technically equipped object, filled with energy arteries - electrical wiring and a gas pipeline; life-support and metabolism systems - water supply and sewerage, ventilation equipment, air conditioners, refrigerators, lamps; and a kind of "nervous system" - audio and video equipment, telephone, receivers, video surveillance systems, burglar alarms, computer equipment, and the Internet. Like an artificial organism, building functions, receives light and heat, consumes water and energy, breathes, excretes metabolic products, and produces waste.

Receiving oxygen from the atmospheric air, a functioning building emits carbon dioxide into the environment. The average cottage produces several tons of greenhouse gases every year. By multiplying these figures by the total number of apartments and cottages, global indicators of the problem emerge. The problem of air exchange and air pollution seems to be even more urgent against the additional background of an annual increase in the number of cars and an increase in the size of landfills and waste.

The ecological approach to the design of autonomous buildings, according to the concept of "Triple Zero", considers the building as an organism initially closely interconnected with the external environment. At the same time, the tasks of organizing effective natural ‘metabolic processes’ within the building volume and the external environment (including the use of natural energy) at all stages of its life cycle are a priority [4].

2.3. Interaction of the building with the environment

The design of Triple Zero buildings initiates a creative search for technical solutions that minimize the negative and optimize the positive impact of energy, environmental and technological factors at all stages of the life cycle that define a building as a human environment.

The main goal of designing ecological independent buildings is to create the most environmentally friendly, comfortable and safe artificial human environment, provided that all possible natural conditions and renewable resources are used to achieve autonomy.

The main tasks that arise in the design of such buildings are: optimal orientation of the building to the cardinal points, the location of the building in the development, the choice of the shape of the building envelope, the choice of glazing and materials for external fences, the consideration of the building as a single energy system, taking into account the directional effect of the external climate. For example, buildings with natural ventilation should have such an orientation and location of the inflow and outflow channels so that air exchange in the premises is uniformly provided in all wind directions. The convection factor makes it possible to provide upward air currents even in calm conditions. The high albedo of the reflective surfaces of walls and roofs protects both the building itself and the surrounding air envelope from overheating. Often, flat roofs of buildings are recommended to be planted with plants appropriate for a given climate in order to reduce overheating of the roof in summer and heat loss in winter and to ensure a positive humidity regime around the building.

https://ecotechnica.com.ua/images/-foto4/388-dom-iz-konopli-ecotechnicacomua-2.jpg

Fig. 2.3. Eco-building - SUNIMPLANT (architect Monica Brummer, Morroko)

An important task in the design of buildings that uses ecological types of energy is to find ways and means of converting, accumulating and distributing air, heat, light fluxes in order to maintain optimal microclimatic parameters of premises in conditions of cyclical (daily, seasonal) and periodic (cloudiness, precipitation) changing parameters of the external environment. At the same time, the solution of the following main tasks is of key importance:

- to collect energy, to obtain the required amount of energy, taking into account its certain diffusion in the external environment, i.e. compensate for the insufficient power of natural energy flows;

- to preserve, accumulate the collected energy (how to compensate for the characteristic mismatch in time of periods and daily-seasonal irregularities in the supply and consumption of energy);

- to distribute energy, to provide a regulated distribution of energy in the building to ensure the required at the moment and at this time, functional, technological and microclimatic parameters of parts and elements of the building.

To solve this problem, passive and active solar heating systems are used, for example, the Trombus wall, various solar panels and solar collector systems, as well as the use of building structural elements as heat accumulators. For example, in the heating system of a solar house in Kappelrodek (Ortenau County, Baden-Württemberg, Germany), a seasonal capacitive heat accumulator is used, which is integrated in the interior of the building in the shape of a central column (Fig. 2.4) [3].

https://sol-dom.com.ua/solnechnye-doma/germany

Fig. 2.4. Solar house in Kappelrodek, Ortenau County, Baden-Württemberg, Germany

2.4. The influence of climatic and geographical factors on the formation of eco-buildings

Being in a natural environment, the building is exposed to sunlight and its thermal (infrared) component, various climatic factors - winds and precipitation, the influence of the Earth's energy, some peculiar factors of geology and hydrology. Geographic latitude affects the angle of slope of the sun's gush of light and its intensity, the length of daylight hours and seasonal temperature fluctuations.

In the northern hemisphere, in the morning the rays, which are now warm, illuminate the eastern facade, at noon the most active solar phase illuminates and warms up the building from the south, and in the afternoon the sunlight and afternoon heat passes to the western facade. The northern facades are the darkest, coldest and dampest. The sunlight rays emerge there either reflected or only during the summer solstice in northern latitudes. Insolation conditions vary significantly at different geographic latitudes, which determines a wide difference between traditional forms of buildings and the features of their design in different climatic zones.

In addition to solar exposure, the building is influenced by the dominant winds direction and intensity: air masses from the north can significantly cool the northern parts of the buildings, especially in winter. Air masses from the south heat up the building and can bring significant discomfort in summer. Therefore, the northern and southern facades of energy-efficient buildings can differ significantly in geometric configuration, the nature of glazing and cladding, the use of certain heat-insulating or heat-absorbing materials and technologies, in accordance with the difference in climatic problems. If the southern facade has to be protected from overheating, then the northern one has to be insulated and sheltered from cold northern winds; if the sun protection of the southern facade has horizontal slats, then the sun protection of the eastern and western ones are vertical (in the temperate latitudes of the northern hemisphere). Therefore, it is quite justified to provide alternative engineering and architectural solutions with a general compositional and stylistic unity to the facades of the same building, but which are differently oriented and exposed to external influences.

https://infmir.ru/articles/germany_freiburg_rotate/

Fig. 2.5. Revolving House (architect Rolf Disch, Freiburg, Germany)

The general shape of the building and the shape, slope and structure of roofs are directly influenced by the frequency and rate of precipitation. The primary purpose of the roof is protection from rain rate, cold in winter and excessive overheating in summer. Therefore, traditional preferences in the shape, slope curve and materials vary depending on the climatic zones [5].

https://www.figueras.com/ru/projects/corporate/455_the-sandcrawler-lucasfilm-hq.html

Fig. 2.6. The Sandcrawler Building - Lucasfilm HQ (architect AEDAS, Singapore)

Actively interacting with the environment, buildings adapt for the physical characteristics of their location. The connection between architecture and nature is more subtle and deeply essential, which is proven by the whole history of architecture. Therefore, the use of the patterns of constructing the forms of nature in architecture gives a modern architect ample opportunity to reach the required solutions and forms for creating energy-independent eco-buildings.

2.5. Aspects of Comfort in the Design of Eco-Buildings

With all the relative diversity of geographical and climatic factors, a person is characterized by practically uniform and stable preferences in the microclimate of a home, which include functionality, safety, comfort, efficiency and environmental friendliness. All these factors are decisive in the design and construction of eco-buildings [6].

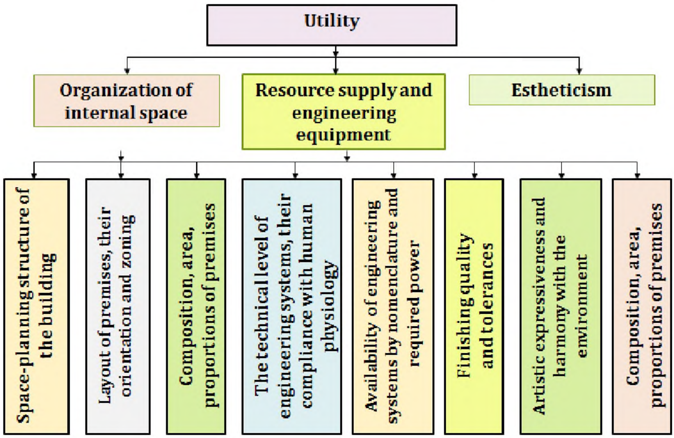


Fig. 2.7. Scheme of requirements and restrictions imposed on buildings to ensure functionality parameters (*Author – Dr. Sc. (Tech), Prof. M.V. Savitskyi, PSACEA, Dnipro, Ukraine*) [7]

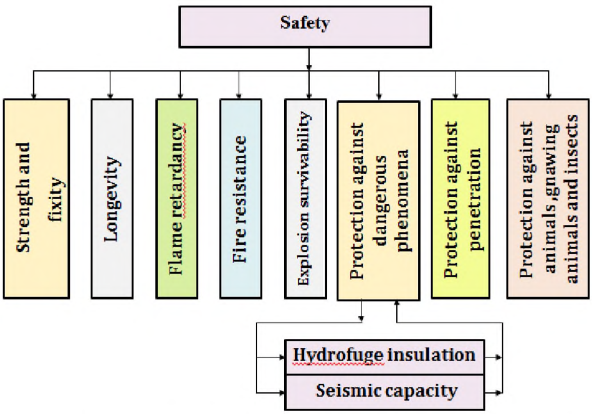


Fig. 2.8. Scheme of requirements and restrictions imposed on residential buildings to ensure safety parameters (*Author – Dr. Sc. (Tech.), Prof. M.V. Savitskyi, PSACEA, Dnipro, Ukraine)* [7]

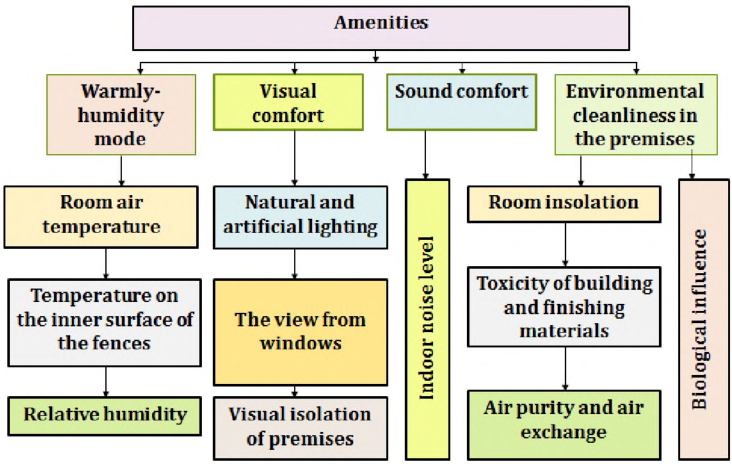


Fig. 2.9. Scheme of requirements and restrictions for residential buildings to ensure comfort parameters (*Author – Dr.Sc. (Tech.), Prof. M.V. Savitskyi, PSACEA, Dnipro, Ukraine*) [7]

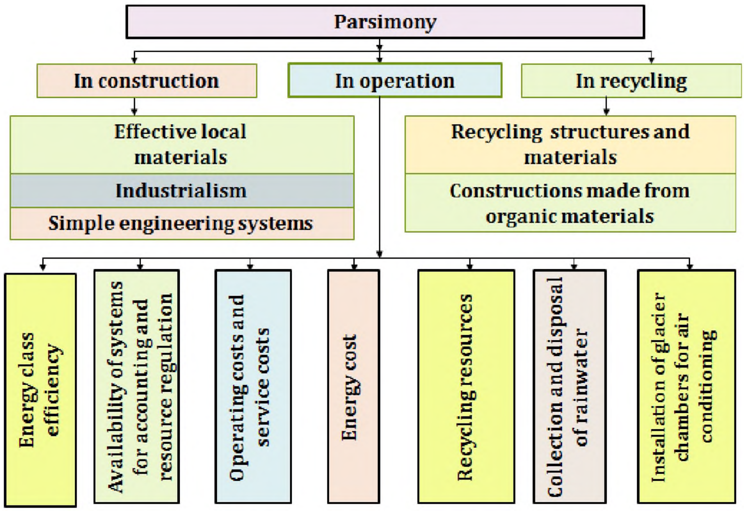


Fig. 2.10. Scheme of requirements and restrictions for residential buildings to ensure efficiency parameters (*Author – Dr.Sc. (Tech.), Prof. M.V. Savitskyi, PSACEA, Dnipro, Ukraine*) [7]

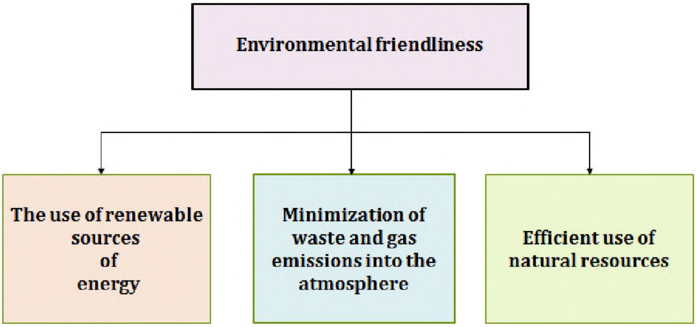


Fig. 2.11. Scheme of requirements and restrictions for residential buildings to ensure environmental parameters (*Author – Dr.Sc. (Tech.), Prof. M.V. Savitskyi, PSACEA, Dnipro, Ukraine)* [7]

High standards of life support and comfortable atmosphere in eco-buildings are achieved due to an integrated approach to the design, construction and operation of such buildings, as well as application of various engineering systems and technical equipment of the building: regulation of insolation intensity, the use of passive heat exchange systems (heating or cooling), natural ventilation, the use of ecological materials, renewable natural resources, effective building management system [7].

2.6. Sun and light as the foundation of eco-architecture

The sun is one of the fundamental factors in the design of non-volatile eco-buildings. These buildings have a number of functions related to the maximum use of natural light and heat.

In modern practice, architects achieve an equal distribution of light fluxes by modeling the appropriate geometry of facades, taking into account the geographical latitude of the construction site and the corresponding angles of incidence of sunlight at different times of the year. Thus, with the right approach to design, you can significantly reduce, or even completely, reduce the amount of energy required for heating or cooling a building [8].

2.6.1. Solar energy as an affordable source of heat

Solar energy can be used not only to illuminate a building, but also as an additional alternative source of energy in the heating system.

Solar heat is the most affordable renewable source of thermal energy [9]. For its effective use, first of all, it is necessary to determine the optimal location and orientation of the building. That means that the building should be oriented in such a way that it would be able to ensure maximum penetration of sunlight and heat during the day in cold winter period, but at the same time ensure the supply of the minimum amount of heat to the premises in warm summer period [10].

Solar energy in the world is associated with the use of active solar heat supply systems. However, the experience in the development, construction and operation of objects with solar heat supply, analysis and generalization of world achievements in this area show that passive solar heating systems are also quite effective. Such systems are distinguished primarily by the fact that they have simple design solutions and efficiency, ease of use, do not require specially trained service personnel, or special solar equipment that requires its industrial production. Thus, there is an objective opportunity for the rapid implementation of passive systems in design and construction practice.

A passive solar heating system (PSHS) is an energy system in which the processes of receiving, accumulating and using solar energy for heating needs occur naturally in the architectural and construction systems of a building with minimal use of additional energy and special solar equipment.

The design of facilities with PSHS should be carried out at three levels:

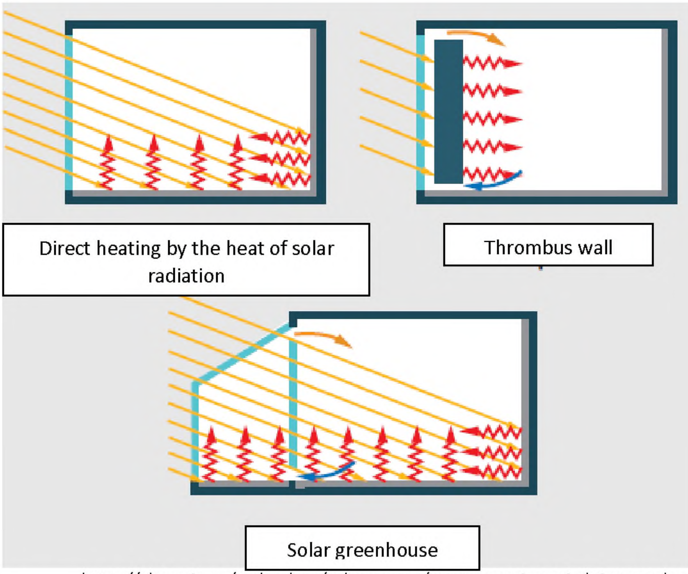
- urban planning (selection of a development site, appropriate type and orientation of development or individual buildings, taking into account natural and climatic factors; landscaping solution);

- architectural (appropriate architectural and planning structure of the building (shape, size, number of storeys, type of external walls, orientation and size of openings, necessary types of PSHS and means integrated in the structure of the building);

- constructive (best design solutions, choice of materials, solar and thermal protection).

The following basic principles to provide proper architectural and planning solutions for buildings with PSHS are recommended:

- The principle of orientation - construction of the structure and its elements with a southern orientation (deviation of 15-20 degrees is allowed).



https://alteco.in.ua/technology/solar-energy/pervye-passivnye-i-aktivnye-solnechnye-doma

Fig. 2.12. Architectural solutions for passive solar heating of a building

- The principle of functionality is the organization of functional processes in glazed spaces.

- The principle of temperature zoning is the layout of rooms with a higher standard temperature on the southern facade, and rooms that are not heated or with low temperatures - on the northern one.

- The principle of climate formation is the creation of a transitional heat zone between the external and internal environment.

Due to the discrepancy in time and in terms of quantitative indicators of the receipt of solar radiation and heat consumption, for effective robots of solar heating systems, it is necessary to use heat accumulators [9].

2.6.2. Heat accumulators

The solar energy flux varies during the day from zero at night to its maximum value at solar noon. Since the heat load of heating is maximum in winter months, and the supply of solar energy during this period is minimal, to ensure heat consumption, it is necessary to capture more solar energy than it is required at the moment, and accumulate its excess in the heat accumulator.

The energy reserve in the battery can be calculated for several hours or days in case of short-term storage and for several months in case of seasonal storage.

Batteries can be classified according to the nature of physicochemical processes occurring in heat-accumulating materials [9, 11]:

- capacitive-type batteries, in which the heat capacity of the heated (cooled) storage material is used without changing its state of aggregation (natural - stone, pebbles, - water, aqueous solutions of salts, etc.);

- accumulators of the phase transition of a substance, in which the heat of fusion (solidification) of a substance is used;

- energy accumulators based on the release and absorption of heat during reversible chemical and photochemical reactions.

In capacitive batteries, the processes of heating and cooling of the heat storage material occur sequentially or simultaneously, either directly due to solar energy, or through a heat exchanger. The main disadvantage of batteries of this type is their large mass and, as a consequence, the need for large areas and building volumes per 1 GJ of accumulated heat.

Requirements for heat storage materials: high heat capacity and phase transition enthalpy with a sufficiently high thermal conductivity; high density of the material and its chemical stability; safety and non-toxicity; low cost.

An accumulator based on the phase transition is more efficient than an accumulator of the capacitive type, since for many substances the values of the enthalpy of the phase transition are much higher than the heat content due to the heat capacity [9, 11, 12]. However, the complexity and high cost of such batteries make it necessary to calculate the economic feasibility of their use.

2.6.3. Sun protection systems

For non-volatile eco-buildings, it is important to balance the incoming sunlight, along with regulating the penetrating heat from sun rays. It is necessary to illuminate the room with natural daylight to preserve the possibility of premises ventilation through windows and skylights, making the external space from premises visible, but at the same time overheating of premises should not be allowed.

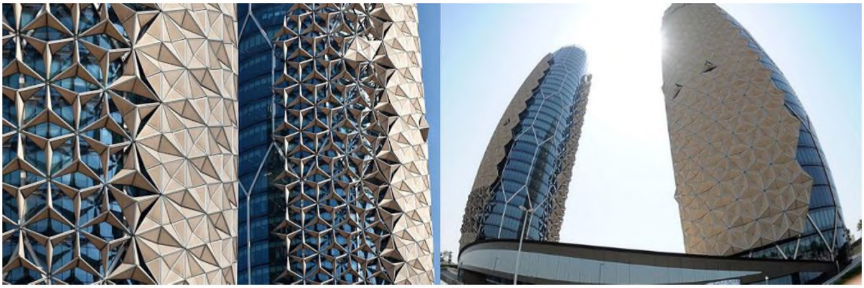
Sun protection systems are essential to ensure the required level of illumination and the maximum possible uniform distribution of natural light, to limit overheating of the air in rooms, and to ensure energy savings.

The ways to provide sun protection are as follows:

- shade-forming elements of facades - belts, loggias, canopies, niches;
- awnings, pergolas;
- external blinds, sun blinds, front lamellas, mesh aerated shells, thermal protective glazing made of special glass (filtering the infrared part of the spectrum).

https://stroy-trading.ru/information/article/610-Zachem-nuzhny-dinamicheskie-fasady

Fig. 2.13. Dynamic building facades of the Kiefer Technic Showroom (Austria)



https://stroy-trading.ru/information/article/610-Zachem-nuzhny-dinamicheskie-fasady

Fig. 2.14. Architectural solutions for sun protection in Al Bahar Towers in Abu Dhabi (UAE)

Architectural space-planning tasks for solar protection (to protect against overheating in hot season and from the blinding effect of sunlight) of buildings contain:

- rational orientation of facades and parts of buildings, rational zoning of premises, their window openings and skylights against the position of the sun in terms of daylight hours with regard to the latitude of the region;

- facades exposed to the sun, arrangement of shade-forming structures - active vertical planes on the east and west sides and horizontal ones in the south, arrangement of galleries and deep loggias;

- heat-reflecting, heat-absorbing and light-scattering glass as materials providing skylight in buildings;

- heat-insulating materials and air gaps in the structures of external walls, ventilated facades;

- "green roofs", facade landscaping;

- facade coatings (primarily southern ones) and roofing elements with high albedo materials (light with high reflectivity) and finishing of the interior surfaces of premises oriented to the south in cool tones;

- landscaping of adjacent areas with the longest and most intense insolation;

- covering of roads and sidewalks with non-heat-consuming materials.

Constructive sun protection tools are divided into stationary and adjustable.

Internal sun protection treatments (curtains, curtains, blinds, roller blinds) installed directly in the room are ineffective, since they absorb the solar radiation that has already entered the room and, as a result, become a secondary source of heating.

External sun protection systems are the most effective means of ensuring light and thermal balance. Their rational use diffuse sunlight to create light comfort and reduce the load on indoor air cooling systems, often making air conditioning unnecessary.

Passing through the glazing, solar energy is distributed into the components: reflected radiation, absorbed radiation and transmitted radiation. Most often, to reduce the transmitted radiation, various types of sunscreen systems are used, which will allow controlling the process of transmitting the flow of solar energy without violating the lighting standards of the working room. The best sun-protection effect is achieved by limiting the insolation of the premises through the skylights by the complex use of heat-reflecting glass in the outer frame of the window and external adjustable blinds.

ARCHITECTURE – CHECK LIST

Marker	***Description***
The quality of the architectural view of the object	Architecture is judged from criteria which include opinions, values, ideals and impressions of desirable characteristics. In the frame of the conception of sustainable design the core characteristic of architectural solution is the rate of its integration into the natural environment.
Optimal shape and orientation of the object	At the design stage it is necessary to assess the optimality of the chosen architectural form of the object and its orientation, which should be designed to provide the highest possible thermal performance. The compering analysis is required on the stage of project.
Comfort of planning solutions	Sustainable planning is considered as the main architecture approach of the providing of comfort of all meaning in the interior of the building. Usable spaces should be integrated, the compact solutions are desirable. The coefficient of compact of the building is to check.
Providing the object with natural light	Natural lighting, also known as daylighting, is a technique that efficiently brings natural light into your home using exterior glazing (windows, skylights, etc.). Natural light plays on the comfort, health and mood of the human, but it varies depending on

	where we are. In architecture, it is integral to the design of a building, it brings added value. The rate of providing the sufficient natural ventilation through the chosen architectural-planning solution is critical, especially due to the high focus in the energy saving in the modern sustainable buildings.
Providing the object with natural ventilation	Natural ventilation systems rely on pressure differences to move fresh air through buildings. Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or differences in humidity. Natural ventilation promotes a healthier lifestyle. For instance, the oxygen from fresh air can enhance your heart rate, blood pressure, and energy levels. It strengthens your immune system. The rate of providing the sufficient natural ventilation through the chosen architectural-planning solution is critical, especially due to the high focus in the energy saving in the modern sustainable buildings.
Greening of the object	Application as much as possible natural origin materials in the architectural design concept, as well as the appropriate to the environment green façade solutions.

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CHAPTER 3

SMART BUILDING MATERIALS FOR TRIPLE-ZERO ECO-BUILDING

Choice of building materials is a critical point of triple-zero eco-building design. It has significant influence on the sustainability of the construction at all stages of a lifecycle. Appropriate materials for triple-zero design should conform to the list of essential criteria to ensure not only energy efficiency but also healthy indoor climate, reasonable operational use and recycling.

Ecological aspect of building design has a complex structure based on the evaluation of environmental impact globally and of human activity locally. In the design process, it is very important to consider the building material not as a final product, but to take into account all stages of building material application. Over the last years with the worldwide tendency to the sustainability in all sectors of industry, the key transformation has been required from the sustainable buildings design. The ideal picture of building materials application should be represented as a circular one (Fig.3.1).

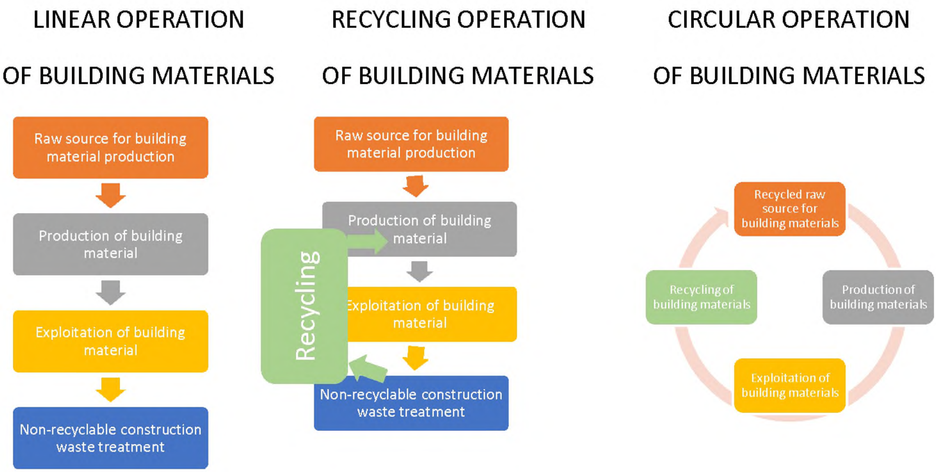

Fig.3.1. Transformation of building materials operation from linear to circular [developed by authors]

3.1 Functionality of building elements to provide the standards for triple-zero eco-buildings

The functionality of building elements specifies the requirements to ensure the design of Triple Zero eco-building. Any layout and engineering techniques in general are based on physical properties. Having provided necessary physical and technical parameters, the environmental assessment of possible solutions could be realized. Considering a great amount of time spent on the building process – the esthetic requirements for materials selection in the triple-zero eco-building design are on the top of the pyramid, which we have proposed (Fig. 3.2).

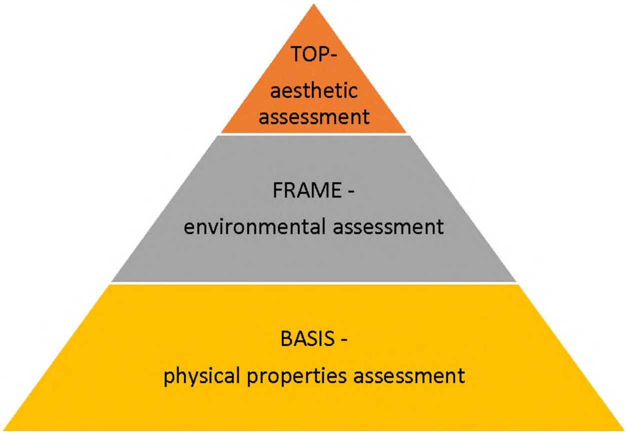

Fig.3.2. Self-assessment pyramid for materials selection during triple-zero eco-building design [developed by the authors]

Considering building structure elements as the elements of human body, it is necessary to demonstrate the balance between all the systems to ensure the triple-zero objective. The energy, air and humidity balance, flexibility and stability are the basis of the sustainable building (Fig.3.3).

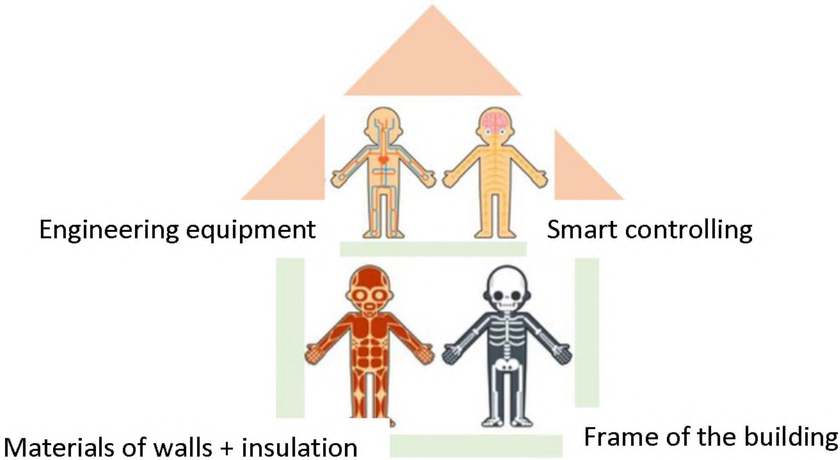

Fig.3.3. Visual analogy of a building and human anatomy [developed by the authors with the use of images] [1]

All the requirements for the Triple Zero eco-building design should be focused primarily on the criterion of low energy, building ecology and biology, and the generally valid principles of the design of building structures.

Environmental and climate factors influence the required parameters of the building and the selection of building materials. The main external natural factors are shown in Fig. 3.4.

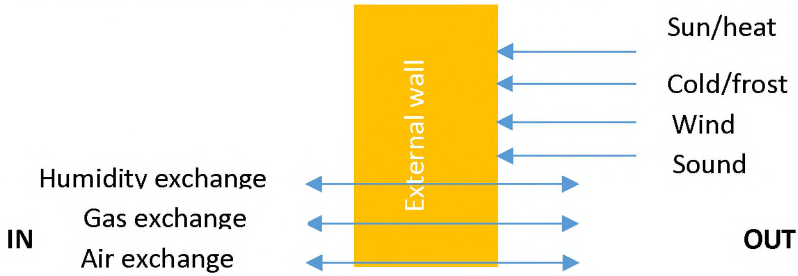

Fig. 3.4 Effect of environmental and climate factors on the building [developed by the authors]

Building structures should not only be a means of protecting living spaces but should increasingly promote human health and well-being. Building physics mainly deals with events in building structures related to the movement of air and humidity, which are defined by four basic concepts:

- convection of air (air permeability of the structure);
- water vapor diffusion (passage of water vapor through structures);
- sorption (receiving and delivering gaseous substances by structures);
- ventilation (air and humidity exchange through openings). [2]

Building structures and elements are generally assessed according to five basic building and physical criteria: *thermal protection, air permeability, fire protection, sound protection.*

In addition, the following aspects of building structures and elements should be considered in building ecological design: *health and hygiene parameters; primary energy demand; durability and longevity; removal requirements; implementation costs.* [3].

Triple Zero ecological buildings are about more than just materials. Filling the frame with straw rather than fiberglass is only a small part of the challenge to standard construction. Ecological building implies a completely different attitude towards space, the building site, the environment, work on a construction site and the way of life in a building. Natural construction allows paying attention to the details suggested by nature itself to embody the idea of Triple Zero Eco-building in its best possible way. [4].

Functions of building components are significant through the whole lifetime of building construction projects but most importantl in the early project phases (a new building or renovation of an existing building), where requirements are identified and specified – function modelling [5]. This approach is critical for the complex Triple Zero design, where all the functions of elements should be taken into consideration for the appropriate selection of materials to apply in the project.

Construction components have many functions but, when they are initially identified, they are often justified by only one or a few functions. A window, for instance, has normally at least two primary functions, to draw natural light into a room and to give view from the room. However, a window has also an insulation function, an acoustic function and a ventilation function (if it can be opened). Basically, a building component may be identified and created solely on the basis of its primary function and before its geometry is determined. [6]

In this chapter we focus on the thermal-isolation materials for a Triple Zero ecological building.

The main role of insulation is to limit, due to its ability to trap air, heat transfers in the walls of the building. But it can also have other technical properties: fire resistance, mechanical resistance, sound insulation, etc. The requirements for the thermal insulation depend on the air, where the insulation is used (Fig. 3.5.):

- in case of horizontal thermal insulation, a certain load-bearing capacity of the layer is required;
- in case of insulation with the additional function of sound insulation from footsteps, a certain degree of elasticity (dynamic stiffness) is required;
- when insulating walls and ceilings, it is necessary to distinguish between external, internal and core insulation.

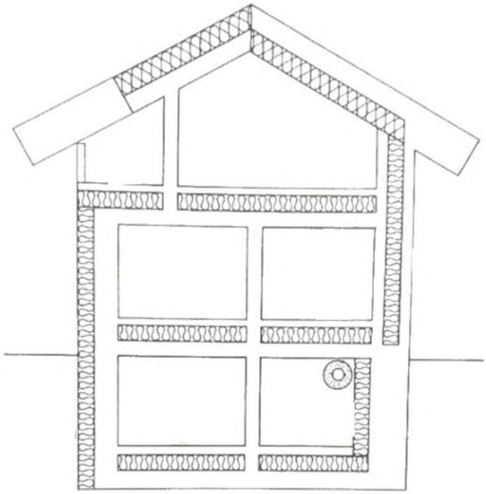

Fig. 3.5. Functional areas of insulation application [7]

There are currently three main groups of thermal insulation for walls:

- glass wool, rock wool and slag wool;
- alveolar plastics: expanded polystyrene foam (milled or extrude), polyurethane and phenolic foam;
- insulation materials of animal or plant origin: based on cellulose, cork, wood fibers, wood wool, sheep, etc.

In addition, there are cellular glass, perlite, and expanded clay.

Mineral wool and cellular plastics used in new construction provide more than 80% of insulation. Some building materials, such as cellular concrete and multi-cell bricks, act both as structural and insulating materials.

Depending on the type of wall and insulation, a vapor barrier may be required. This is a screen which limits the transfer of steam and which, in general, when placed on the interior side, prevents the formation of condensation in the walls. [8]

The effective application of materials of natural origin is based on the initial analysis of complex functionality, climate conditions, locally available raw resources, heritage practice of traditional construction.

Humidity regimes of the future building are to be taken into consideration, since natural materials could be significantly affected due to its organic nature.

3.2 Effective insulation of the eco-building: principles and criteria

The concept of a Triple-Zero ecological building is based on a wide application of natural eco-friendly materials in construction. Natural materials – are the materials that have not been processed industrially. But the realization of full building design within the 100% organic-based materials, without industrial treatment, is not real in practice. It should be taken into account that every process of industrial influence on any initially natural material, such as wood or straw, for example, will remove it from nature.

Thus, *the designing a building from ecological materials - is a search for the most effective techniques for the selection and processing of natural raw materials, considering the need to minimize industrial impact on them and maximize the use of their original positive properties.*

The list of possible materials to apply in truly ecological structures is quite short. There is an internal classification of natural materials – *biological and geological* origin. Biological materials are plant-based and animals-based ones – straw, hemp, junk, wool etc. Geological materials are soil-based ones - clay, loam, stone, sand, etc.

All the criteria of materials to be evaluated during the design of the Triple Zero ecological building may be divided according to a relatively acceptable scale shown in Fig. 3.6.

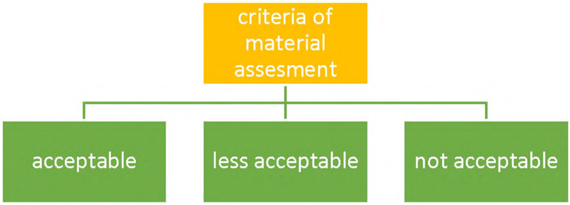

Fig.3.6. Classification of criteria to evaluate material or solution for Triple-Zero ecological building [developed by the authors]

The rate of acceptability depends on existing technical and environmental norms and standards, general focus of the project – energy saving, maximum natural materials application or the complex of measures.

BASE - Physical background to consider

According to the presented self-assessment pyramid for materials selection (Fig. 3.2) – BASE physical properties evaluation of all the materials to be used in a Triple Zero ecological building project must be proceeded at the first stage of every project development.

Some thermo-technical parameters for effective design and exploitation of Triple-Zero ecological buildings are presented below. These are basic physical characteristics for every thermal and technical calculation of the building insulation.

The amount of heat required to heat 1 kg of 1 ˚C material is called *specific heat* (c). The thermal capacity of a material is expressed by the value S, proportional to the specific heat c and to the density:

$$S = c \times \rho \qquad \text{(Eq. 1)}$$

The *thermal capacity* corresponds to the quantity of heat necessary to heat 1 m^3 of material by 1˚C. The thermal resistance R of a building element is determined by its thermal capacity S and its thickness d:

$$R = c \times \rho \times d \quad \text{(Eq.2)}$$

The thermal conductivity of a material is expressed by the value λ. It corresponds to the amount of heat through a 1 m wall presenting a temperature difference of 1 ˚C.

The rate at which a wall loses, or stores heat is indicated by the *coefficient of thermal efficiency* E, which depends on the specific heat, density and thermal conductivity:

$$E = \sqrt{c \times \rho \times \lambda} \quad \text{(Eq.3)}$$

The higher the E-value of a material, the faster heat penetrates inside, rapidly cooling the surface of the hand holding it.

The expression "thermal bridge" designates points on a wall or roof which resistance to heat diffusion is lower than that of surrounding surfaces. At these points, the heat loss to the outside is much greater than elsewhere. These bridges not only increase the thermal losses of the building, but they can also cause humidity problems, because the water condenses there in the absence of a vapor barrier. The penetration of moisture at their level further reduces the thermal resistance of the wall. [9]

It is possible to minimize the influence of "thermal briges" by providing thermal insulation of the outer surface of walls throughout the house. To achieve the maximum effect of energy saving, it is necessary to observe the principle of a closed thermal circuit, excluding the presence of non-insulated areas. This rule seems very simple, but in practice it is not always possible to follow it. The most unreliable in this regard are the places where the walls joint with ceilings and roofs, window openings, places under windowsills, balcony or veranda openings. In addition to a loose fit of the material, the reason for "thermal bridges" may be in insufficient thickness of the heat-insulating layer. Increased heat transfer through the "cold bridges" leads to a number of negative consequences: energy consumption for heating the building increases on the lateral surface of building elements, surface temperatures become lower, which leads to condensation, accumulation of moisture followed by mold. [10]

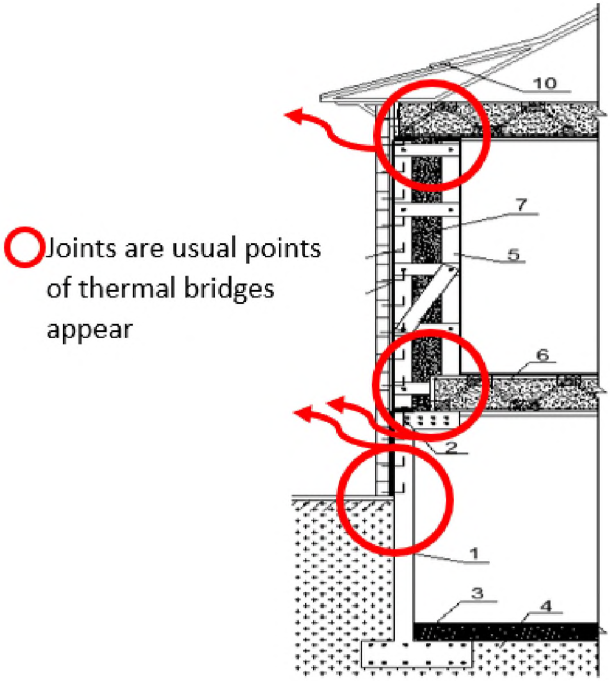

Fig.3.7 Typical wall structure of ecological low-rise building with the points where thermal bridges appear

1 - foundation, 2 - anchor for attaching the foundation with the frame, 3 - floors of technical underground, 4 - hydro-insulation and anti-radon protection, 5 - wooden frame, 6 - closing, 7 - thermal insulation of straw materials, 8, 9 - frame elements, 10 -roofing;
[11]

The main problem in application of natural materials is to avoid the thermal bridge effect in the continuous layer and to find out the *balance between the "respirating envelope" and "thermal resistant compact envelope".*

The basic characteristics of common building materials, which are considered natural, are presented in Table 3.1.

Table 3.1. General characteristics of basic natural building materials [12]

Material	Volume mass, kg/m^3	Coefficient of conductivity, Wt/(m*K)	Compressive Strength, MPa
Junk	400	0,12	-
	300	0,09	-
	260	0.078	-
	220	0,06	-
Pressed straw	150-250	0,09	-
	90-110	0,045	-
	73-85	0,04-0,05	-
	100	0,054-0,065	-
Hemp	70-90	0,048-0,06	-
Pressed adobe	1600	0,6	1,8
Traditional adobe	1500	0,5	0,9
Lightweight adobe	1000	0,13	0,8
	900	0,114	0,7
	580	0,073	0,6
	420	0,071	0,5
Hemp adobe	260	0,075	0,23
	360	0,079	0,41
	400	0,084	0,5

FRAME - environmental aspects to consider

The classification of building materials into ecological and non-ecological is not realistic or justified. It is appropriate to select materials that meet the widest possible range of building ecological requirements and if they cannot be applied due to some reasons, it is necessary to look for solutions.

The environmental assessment of the materials to be applied in the buildings is based on the following stages:

- extraction of raw materials, their demand and impact on the landscape;
- energy demand for the manufacture of end product;
- transportation energy expenses and CO_2 impact;
- ecological safety during the assembling procees at the building facility;
- fire safety of the product;
- exploitation safety and sustainability of the building material;
- recycling impact.

The simplified matrix of FRAME - environmental aspects to consider are represented in Fig. 3.8.

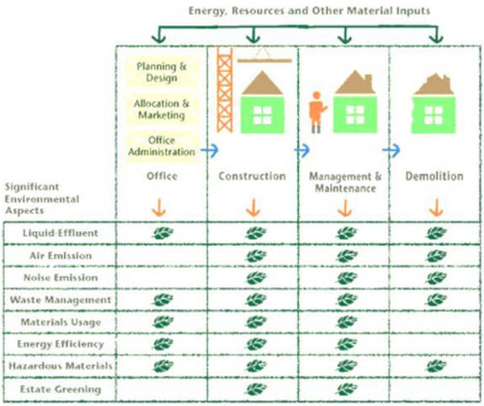

Fig. 3.8. Simplified matrix of FRAME - environmental aspects to consider [13]

The impact of any building material can be *direct* – visibly harmful effect on humans during production, assembly, use or recycling and *indirect* – post-recycling harmful effect of the environment or waste on humans.

To reach a compromise on energy-efficiency, economy and ecology, considering all direct and indirect effects during the whole life cycle is a very complex and multi-criteria task based on the multidisciplinary approach.

TOP - aesthetic assessment

In the context of aesthetic assessment of building materials, flexibility is a criterion to be evaluated and used as a parameter to implement into the design of Triple Zero ecological buildings.

The bio-based materials are aesthetic by their nature, because they are taken from nature. The challenge for the developers of new eco-friendly materials is to apply the materials with their initial aesthetic characteristics as much as possible to create the products with the minimal industrial treatment but within the industrialized systems and constructive solutions for extensive use.

In its aesthetic meaning material (stone, wood, metal, concrete) is a medium with visual and sensory form, which is created by artists. According to its criteria, material is an essential component of artistic creation. In terms of aesthetic analysis of the material there are two fundamental factors from the aspect of construction:

- particulars (inner structure, color, texture, etc);
- decision over the structure (strength, physical characteristics).

In general, a form is good and aesthetic if it is in perfect harmony with the inner regularities of the material, discloses the natural beauty of the material, and shows its strengthes and reactions.

Materials for engineering structures are known as structural or building materials. Building materials markedly influence how engineering structures look, they are fundamental for the shape of engineering structures. Durability, mouldability, texture, color and load capacity of the materials are important factors of aesthetic quality. High-strength materials permit to reduce cross sections, make thinner and light-weight structures with finer connections, as well as to reduce structural mass to make the impression that they are light.

Knowledge of the aesthetic aspects of material selection is indispensable for the creative work of structural designers, a precondition of creating aesthetic engineering structures.

Thus, structural design endeavours to find a logic. Maximally functional structural solution taking the material, the demand and the man into consideration, such that it does not counteract material laws, and to find an aesthetic formal solution for it - raising thereby the beauty of logic to the logic of beauty [14].

The important aspect of eco-materials application is to provide unlimited design opportunities, which shows that bio-based eco-materials are acceptable not only in rural dwelling design.

3.3 Green standards and certification systems for sustainable building materials

A lot of standards as well as certification systems have been developed over the last decades in order to assess the ecological quality of building materials in terms of sustainable development in general, and as the *instrument of the circular economy implementation* in particular.

Every system is based on a fundamental approach to the assessment of materials influence on human health and environmental conditions. On a large scale, it could be presented as in Fig. 3.9.

The product should meet clearly defined criteria or the most optimal combination of minimum requirements (mainly the impact on man and nature in the manufacture, use and disposal of the product or its components).

Apart from global complex systems of green certification for building projects in general, there is a long list of existing voluntary and mandatory, global and local certification tools and ecolabels developed for building materials and products. The most visible and widely applicable ones for the eco-building materials are as follows: [15].

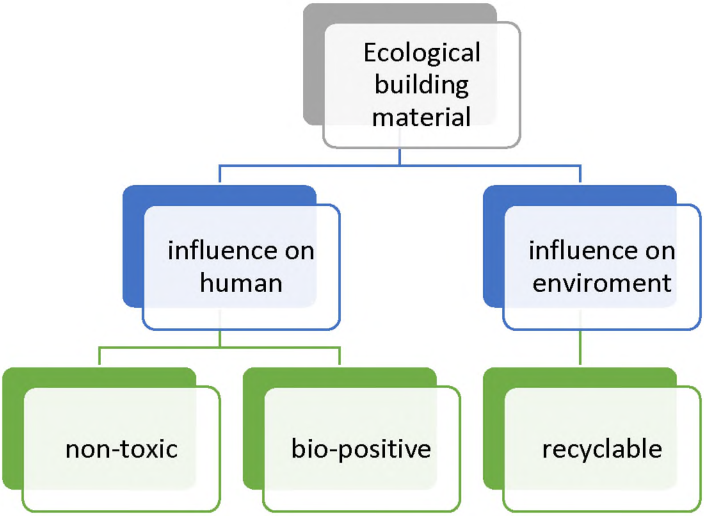

Fig.3.9. General approach as the basis for ecological assessment of building materials [developed by the authors]

EU Ecolabel A voluntary scheme designed to encourage businesses to market products and services that are kind to the environment and for European consumers - including public and private purchasers - to easily identify them.

BASTA system focuses on hazardous substances in construction and building products. Products are assessed according to their chemical ingredients.

CarbonFree® Certified label is aimed at increasing awareness of product emissions and recognizing companies that are compensating for their carbon footprint. The label was created in response to the growing market for eco-friendly products and consumer demand for transparent, credible and readily accessible information at the point of purchase.

Cradle to Cradle Certified (CM). Products Program provides a company with a means to demonstrate efforts in eco-intelligent design. Cradle to Cradle Certification is a third-party sustainability label that requires achievement across multiple attributes: materials that are safe for human health and the environment through all stages of application; product and system design for material reutilization, such as recycling or composting; use of renewable energy; efficient use of water; water quality associated with production; company strategies for social responsibility.

Eco-INSTITUT-Label. With substantial emission and toxicological testing living up to more than just the legal specifications, eco-Institut supplies clients with a reliable and significant label for building products and textiles without any health hazards.

Global Green Tag® is a third party, green product rating and certification system, underpinned by scientific and Life Cycle Assessment (LCA) processes. The program assesses products against worst case business as usual products in the same functional category and with the same functional purpose, based on the following impacts / benefits: product synergy; greenhouse emission point (ISO 14067); human health & eco-toxicity (REACH and US EPA); life cycle assessment (ISO 14040-44), biodiversity and resource consumption corporate social responsibility (Ethics, ILO, ISO 8000 & Devel Programs).

Green Crane (Ukraine) is a voluntary, multiple specifications-based environmental labelling program that operates according to international standards and principles. It is awarded to products with relatively less environmental impact compared to similar products during their entire life cycle, from extracting and collecting the product materials to the manufacturing, distribution, use and consumption, disposal, and recycling.

Greener Product Certification Seal demonstrates that a product has been evaluated against the LEED, LEED for Homes and NAHB green building standards using internationally recognized third-party certification organizations, laboratory test results and/or other supporting documentation. Products in twenty four building products categories are evaluated using seven environmental qualifiers, namely energy (conservation and renewable), regionally produced materials, air quality, certified wood, recycled content, reused and renewable materials. Significant environmental impacts are considered, and products are evaluated from raw materials extraction through manufacturing to use and disposal.

IBU Type III Environmental Declaration (IBU Environmental Product Declaration).This is a Type III declaration for building products. It is based on ISO 14025 as well as ISO 21930 and EN 15804 and declares environmental information on a pass/fail basis. It is meant to identify properties of building products that are relevant to the environmental performance of buildings, and it is based on a Life Cycle Assessment.

U.S. EPA Safer Choice program (previously U.S. EPA Design for the Environment Program) advances EPA's mission to protect human health and the environment. The program uses EPA's chemical knowledge and resources to carefully evaluate products and to label only those that have met the program's leadership standard.

GREENGUARD is now provided by UL Environment, a divison of UL (Underwriters Laboratories), helps manufacturers create -- and helps buyers identify -- interior products and materials that have low chemical emissions into indoor air during product usage.

There are a lot of other standards and systems, but, in general, they could all be classified as it is shown in Fig.3.10.

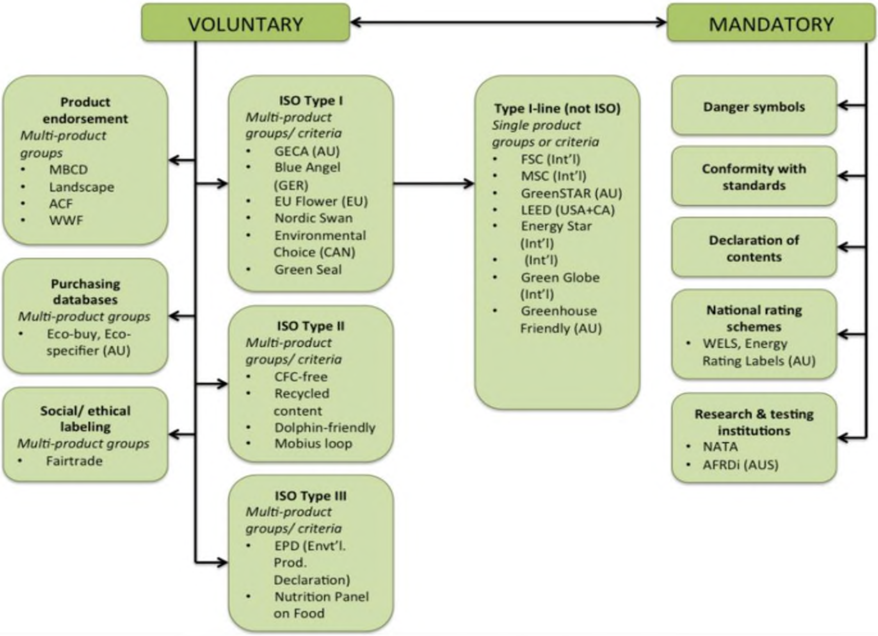

Fig.3.10.Classification of eco-labels [16]

MATERIALS – CHECK LIST

Marker	*Description*
BASE - physical properties assessment	
Volume mass, kg/m^3	Volume mass (density) of a material is its mass per unit volume. The lower mass volume is, the higher thermal resistance of the material is (can vary by the structure, quantity of pores etc.)
Coefficient of Conductivity, Wt/(m*K)	Thermal conductivity is the ability of a material to conduct heat. Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. The lower thermal conductivity is, the lower heat loss through the construction is.
Compressive Strength, MPa	Compressive strength or compression strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to a material or structure which withstands loads tending to elongate. In other words, compressive strength resists being pushed together, whereas tensile strength resists tension (being pulled apart).
Breathability	Breathability is a property that prevents or limits harmful moisture within the building fabric. Breathable structures are most effective when the amount of moisture penetrating the building fabric is regulated.

Moisture sorption isotherm	At equilibrium, the relationship between water content and equilibrium relative humidity of a material can be displayed graphically by a curve, the so-called moisture sorption isotherm. For each humidity value, a sorption isotherm indicates the corresponding water content value at a given, constant temperature. If the composition or quality of the material changes, its sorption behavior also changes.
Fireproofing	Fireproofing is rendering something (structures, materials, etc.) resistant to fire, or incombustible; or material for use in making anything fire-proof. To check the certification of the material.
FRAME - environmental assessment (Ecolabels to check)	
Extraction of raw materials, demand and impact on the landscape	All the mentioned markers should be integrated in the environmental certification of the building material. The eco-labeling is used to check each product for the building construction. If the natural
Energy consumed for the manufacture of end products	
Energy transportation expenses and CO_2 impact	
Ecological safety during the assembling	

of the materials at the building facility;	bio-based material has no appropriate certificate, it is difficult to ensure general assessment according to the mentioned markers.
Fire safety of the product	
Operating safety and sustainability of building materials	
Impact from recycling.	
TOP-aesthetic assessment	
Rate of industrial treatment	The lower rate of industrial treatment of natural material, the higher level of its bio-originality.
Flexibility of forms and areas of application	The wider application area of the material – functional and visual, the higher level of its aesthetic sustainability.
Heritage	Application of heritage principles of natural material use in construction sector is raising the rate of social-esthetic sustainability of material and structure as a whole.

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CHAPTER 4.

STRUCTURAL DESIGN IN THE FRAME OF TRIPLE-ZERO ECO-BUILDING CONCEPT

4.1. Basic structural components of a building

Every sustainable eco-building has to meet the strength and serviceability requirements, i.e. be strong, stable, durable, safe and reliable for its residents.

The main structural elements of civil buildings are foundations, walls, ceilings, individual supports, roofs, stairs, windows, doors and partitions. All of these elements serve the purpose of supporting, enclosing and protecting the building structure.

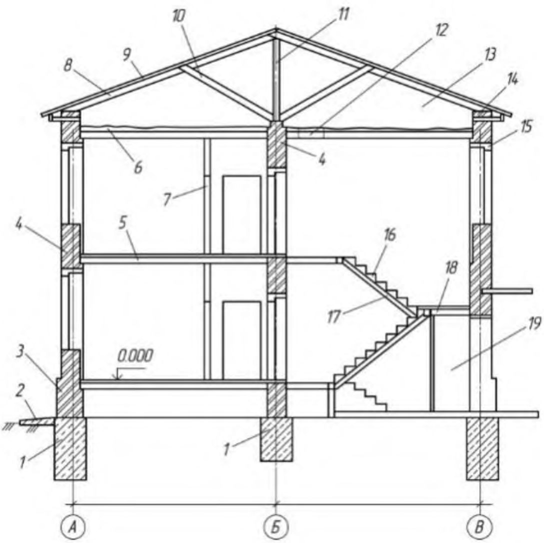


Fig. 4.1.Basic Structural Components of a Building [1]
1. Foundation. 2. Blind area. 3.Plinth. 4. Load-bearing walls. 5. Floor. 6. Attic floor. 7. Partition. 8. Roof. 9.Roof lathing. 11.Pillar. 13.Attic. 15. Lintel. 16.Stairs

Foundation is an underground structure that takes the entire load from the building and transfers it to the ground.

Blind area is a waterproof covering around the building (a strip running along the perimeter of the building), with a slope away from the building.

The blind area around the house is installed regardless of the type of foundation; the arrangement of the blind area is included in the list of mandatory measures to prevent the soil from getting wet at the base of the building.

The main purpose of the blind area is to protect the soil from wetting, which partially loses its bearing properties when saturated with moisture. Also, the blind area serves as an element of landscape design and is a part of appearance of a building.

Concrete, small-piece or crushed stone is usually used as a material for arranging the blind area. The width of the blind area must be at least 100 cm.

Plinth is a part of the foundation above the ground level. The main purpose of the plinth is to transmit the weight of the building to the ground for greater stability and a longer service life.

***Walls* are vertical elements of the building that make an enclosure of internal space. According to their purpose and location in the building, walls are divided into external and internal.** Depending on **load-bearing functions**, they are divided into bearing and non-bearing.

Load-bearing walls sustain the loads from floors and roof. Both external and internal walls can be load-bearing.

*Curtain walls are usually partitions.*They serve for dividing large rooms bounded by capital walls into smaller ones within a floor, and no foundation is required to support the partitions.

External walls can be *self-supporting* and rest on foundations. They bear the load only from their own mass and are non-bearing (hinged), which are only fences and rest on other elements of the building on each floor.

Partitions are walls designed to divide a building within floors into separate rooms. Most often they are stationary structures, but they can be collapsible and transformable (sliding, folding). Partitions can be made of wood, stone, ceramics, plasterboard, glass, etc.

Columns and pillars are load-bearing vertical elements that transmit the load from floors and other building elements to foundations.

Floors are horizontal load-bearing structures resting on load-bearing walls or pillars and sustain permanent and temporary loads transmitted to them. The slabs connect the walls to each other, increase their stability and increase the spatial rigidity of the building on the whole.

Depending on the location in the building, the floors can be dividing adjacent floors: between the upper floor and the attic, between the first floor and the basement, and between the first floor and the underground.

Attic is a space located between the ceiling and the roof of a building. It can be a space equipped between the roof and ceiling of the house, but it can be left unfurnished. In such unequipped state, the attic most often plays the role of a warehouse. In that case, if the attic is finished, it performs the function of the working and living space.

Roof is a structural element that protects the premises and building structures from precipitation. It consists of load-bearing elements and enclosure part.

Lintel is a horizontal support of timber, stone, concrete, or steel across the top of a door or window, which sustains the load from the above structure.

Stairs are used to bridge large distance between floors, as well as for evacuating people from the building. The construction of stairs mainly consists of flights (inclined elements with steps) and platforms. For the safety of movement on stairs, marches are fenced with handrails.

4.2. Wall structures

The vast majority of newly-built houses are built with a timber frame. There are many benefits of timber frame buildings. They are quick and relatively inexpensive to build. Timber frame buildings are stable, reliable, and aesthetically pleasing, because they can be clad in almost any facade material.

But the main advantage of timber frame buildings is that they are much more eco-friendly than other building types.

A timber frame house will cause lower CO_2 emissions in comparison with, for example, a traditional brick or concrete building.

If the wood is ethically managed and sourced, with all trees replanted, the environmental credentials are even better.

The framing system is the structure of the building holding up the walls, floors, and roof. The main purpose of a structural frame is to transmit all vertical and horizontal loads to the foundations [2]. Framing systems use structural elements and dimensional lumber to support the walls and sheathing materials to cover them. The benefit of this method is that it requires less material to create structures. [3]

Post and beam construction comprises vertical structural posts and horizontal beams, jointed to form a structural frame. Post and beam construction uses large structural members to resolve loads; horizontal beams transmit the load to vertical posts. The number of interior walls can be reduced, making it suitable for creating open plan spaces. This relatively intuitive and simplistic building system is based on lumber that is strong enough to carry these larger loads.

Balloon framing consists of wood elements with small cross-sections (called "dimension lumber") configured in the wall as plates (horizontal) and studs (vertical); and in the floors, roofs, joists, and rafters respectively. This method starts with studs running from bottom to top and then the floors are added to the desired height.

A subsequent modification of balloon framing was so-called "**platform framing**," which is the prevalent mode of a light wood framing today. The main difference between the two systems is that in balloon framing, the vertical studs are continuous from foundation to roof, whereas in platform framing, the studs are interrupted at each floor level by the floor construction.

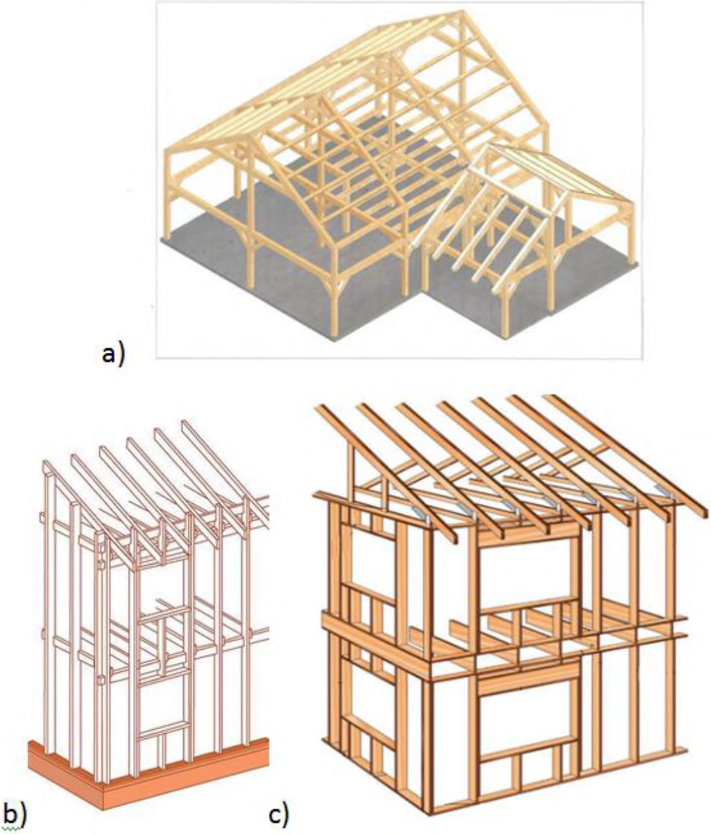


Fig. 4.2.Timber Framing Systems *[4, 5, 6]:*
a) post and beam; b) balloon; c) platform

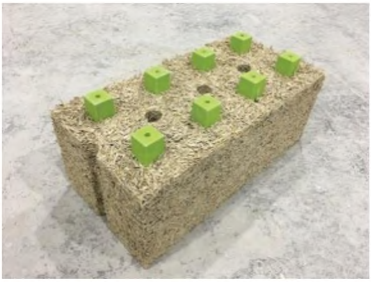
Eco-friendly mass walls are made using **hemp-blocks**, which are abiocomposite mixture of hemp hurds and lime, sand or pozzolans.

The natural insulating hurd material from the industrial hemp plant is used to build a healthy, warm, low energy shelter for your home that will last for several generations. The hemp lime blocks use a binder that reclaims CO_2 released in its production. These combined materials have a negative CO_2 emission rating [7].

It is usually used in the form of prefabricated building blocks for the construction of self-supporting walls or internal partitions of buildings, as well as heat and sound insulation material.

The technology of construction from ***monolithic wood-concrete*** has also become widespread.

Isocrete blocks[8]



Hempcrete lego-block [9]

Wall ofHempcrete lego-block [10]

Monolithic wood concrete wall[11]

Fig. 4.3.Eco-friendly mass walls with hemp

Straw house is a method of eco-construction using compressed straw building blocks [12]. The straw is pressed by a special mechanism or by hand. The compressed block is tied with metal wire or nylon cord.

The blocks are 90 cm long, 45 cm wide and 35 cm high. The weight of the block is about 23 kg with a density of 100 kg / m³. Usually straws of rye, flax or wheat are used. It is also possible to use hay.

Straw houses are built of two types: frame and without frame.

Load-bearing walls without frame are laid out just from straw blocks. The blocks are fastened together with vertical stakes or mortar. The lower end of the stake is attached to the foundation and a nut is attached to the upper end of the rod to tie the straw blocks. The advantages of this construction method are low cost and ease of construction. But this method imposes additional requirements on the structure of the roof and its weight, as well as on the density of the blocks.

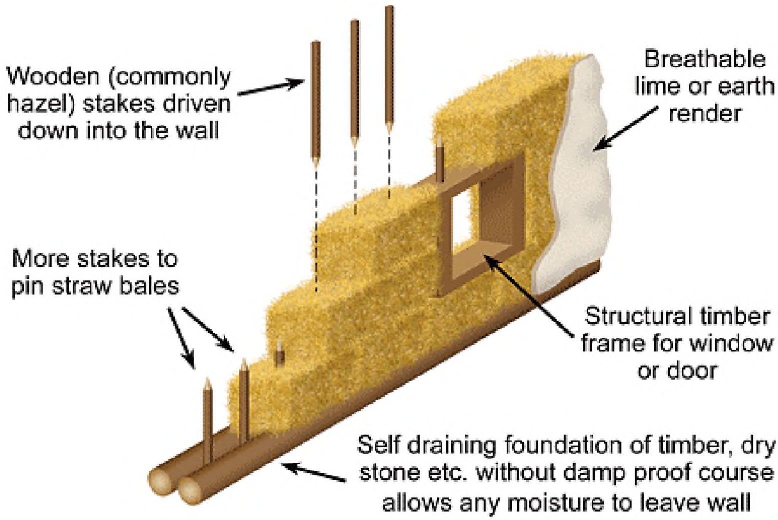


Fig. 4.4. Load-bearing straw walls without frame [13]

In the framed type a wooden supporting frame is built, with straw blocks inside. The blocks are tightly packed into the frame. It is also possible to use bonding methods similar to those used without any frame.

Stacked straw blocks are placed at a slight elevation above the floor to protect against moisture penetration.

The frame is similar to that used in the construction of frame houses. A double frame is also possible (with two rows of vertical posts, between which the blocks are stacked).

A metal or polymer mesh is attached to the sides of the straw blocks and several layers of plaster up to 75 mm thick are applied. Plaster protects the straw blocks from water, fire, rodents, and other pests.

Straw blocks can be used both dry and pretreated with clay mortar. In the latter case, the block is dipped for a short time in a thin clay solution before laying. This technology offers advantages in wall geometry accuracy, strength and fire safety, but it is more time-consuming. The walls are harder, they dry for a long time and in damp weather they can become moldy during drying. Also, they keep heat worse.

Fig. 4.5.Straw blocks building [14]

In addition, there is another frame construction method - assembling a house from straw panels.

Prefabricated straw bale wall panels combine the performance and low environmental impact of traditional straw bale with reduced labor costs and more consistent results. These structural insulated panels (SIPs) are built offsite and transported to the job site, or built onsite and "tipped up" into position.

Fig. 4.6.Prefabricated straw bale wall panels [15]

4.3. Floor structures

Floors in buildings with timber frame typically consist of several beams which are installed at a prescribed spacing.

Beams can be made of sawn lumber or a variety of prefabricated engineered elements. Beams are sheathed with boards or panels attached to the top surface and finish materials, such as gypsum board, to the bottom surface. Blocking between beams is used at the ends of the floor beams or a continuous joist header can be used at the ends. Nogging is necessary to prevent beams of lateral buckling.

For large spans and loads it is necessary to use ***engineered wood products***. Such products are combinations of wooden or glued elements with different materials, such as metal elements. The theoretical maximum size of products is limited only by the possibilities of production, processing and transportation.

In addition, there are products in the form of ***reconstituted board products***, which consists of wood fibers or shavings formed into panel products.

Structural products include traditional glued wooden structures made of lumber that have been properly treated: ***glued laminated timber (glulam)*** and ***crosslaminated timber (CLT).***

Dried lumber with removed defective areas are spliced lengthwise and glued in layers under pressure. The technology of splicing on length and pasting allows receiving large-size elements (dimensions are limited by the possibilities of transportation). Glued laminated timber is used for beams, columns, arches, etc. CLT-panels are used for erection of load-bearing walls, ceilings, and partitions of buildings.

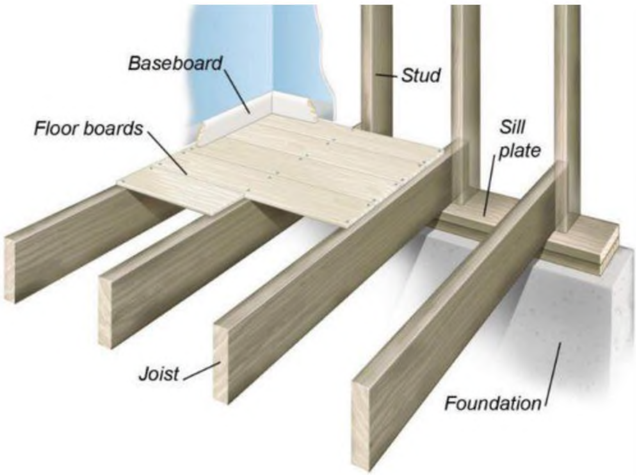


Fig. 4.7.Balloon frame floor

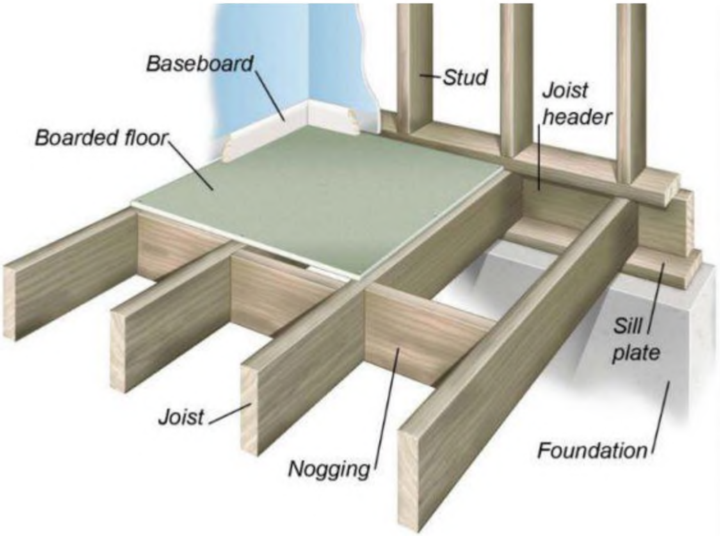


Fig. 4.8.Platform frame floor

Examples of floor arrangement for wood-frame house [16]

In addition to wood-glued materials, in which lumber is used as the main elements, there is a ***structural composite lumber (SCL)***. The products of this group are LVL, PSL, LSL, OSL. These are very homogeneous and stable materials made from deeply processed raw materials.

LVL, (*laminated veneer lumber*) is made from glued sheets of unidirectional veneer (with a parallel arrangement of fibers in adjacent layers). LVL is produced in the form of plates, bars, boards. LVL is used in flat and spatial structures, including long-span structures - beams, trusses, frames, components of ceiling, floor and wall elements.

PSL (*parallel strand lumber***)** is made from glued long strips of veneer (length of 1000 mm), stacked in layers in parallel (on one axis). It is the strongest material in the SCL family.

LSL (*laminated strand lumber***)** is made from long flat shavings stacked in parallel.

OSL *(oriented strand lumber)* is made from long flat shavings, but twice as short as LSL.

In terms of strength and rigidity, both materials are inferior to PSL and LVL. However, in the process of their production, the maximum wood processing is achieved and low-grade wood can be used. LSL and OSL materials are used for columns and beams of framed houses.

One of the promising areas in modern construction is the use of ***I-joists***. The shelves of such I-beams are made of wooden elements of solid cross-section, and the wall is made from board composite materials (for example, oriented strand board, plywood, etc.).

sawn lumber

glued laminated timber

laminated veneer lumber

parallelstrandlumber

laminatedstrandlumber

orientedstrandlumber

Fig. 4.9.Engineered wood products

solid wood beams

I-joist

light weight trusses

cross-laminated panel

Fig. 4.10. Floors with different types of beams

Timber-Concrete Composite (TCC) is a technology which uses structural connection between timber and concrete elements. Structural efficiency is achieved due to composite action between these materials. This hybridization allows reducing cross sections and increasing spans.

A concrete slab can be made on-site or precast at the plant. On-site installation is generally preferred, since a structural diaphragm without additional concrete topping or additional connections between prefabricated panels is created.

Solid timber CLT-panels or engineered wood beams (glulam, LVL, PSL) can be used as the support for the concrete topping.

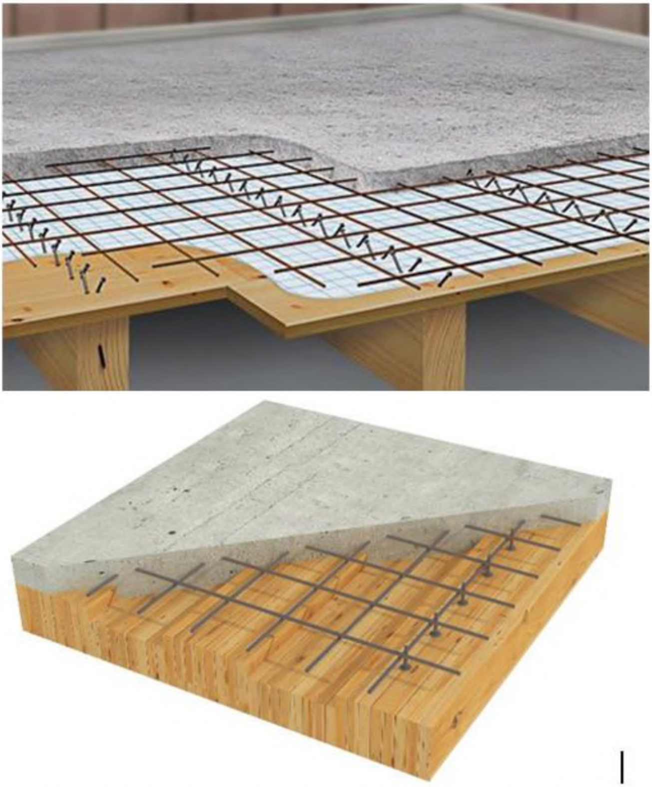


Fig. 4.11.Timber-Concrete Composite Floor[17]

Traditional concrete can be partially replaced with eco-friendly material such as soil concrete.

Soil concrete is a material that has a high compressive strength, which allows it to withstand significant loads without deformation.

Soil concrete consists of soil for at least 95% of the total mass, as well as Portland cement, the amount of which depends on the required characteristics. In addition, water is used, which is necessary to hydrate the cement in the mix, as well as to achieve maximum soil compaction.

When mixed, soil, cement and water form a dense mixture ready for the construction of the structural layer and its compaction. After mixing, the resulting mixture hardens, gains strength and turns into soil concrete, resistant to moisture.

Fig. 4.12. Soil concrete buildings [18, 19]

4.4. Eco-friendly reinforcement materials

Unfortunately, the building has structures in which it is almost impossible to completely avoid using traditional materials (steel and concrete). These elements include, for example, foundations, which must be very strong and durable.

To provide bending strength, instead of conventional steel reinforcement, you can use ***eco-friendly reinforcement materials***, which can be found in forms of fibers and rods.

Eco-Friendly Reinforcement Fibers are strong threads which are mixed with concrete and prevent its cracking due to loading. These fibers can be classified as:

- Natural fibers, for example, bamboo or jute fiber.
- Artificial fibers, e.g. plastic fiber made of waste plastics.
- Inorganic fibers: asbestos fiber, carbon fiber, synthetic fiber, polypropylene fiber.
- Metallic fibers obtained by reprocessing of steel or aluminum waste products.

Eco-Friendly Reinforcement Rods have the same design, mix proportions and construction techniques as for steel reinforcement. But steel reinforcement is replaced with bamboo, jute or reed reinforcement.

jute fiber

banana fiber

coconut fiber

hemp fiber

Fig. 4.13. Eco-Friendly Reinforcement Fibers

Jute

Reed

Bamboo

Fig. 4.14. Eco-Friendly Reinforcement Rods

Fig. 4.15. Foundation reinforcement with bamboo rods [20]

4.5. Roof structure

There two main types of roofs: flat roofs and pitched roofs.

Flat roofs are the simplest type. The inclination angle of such structure is 3–15° and in the autumn-winter period, it is not always enough for the snow to slide off on its own.

Flat roofs are preferred for garages, technical or outbuildings. Sometimes such structures are chosen when the goal is to equip a recreation area on the roof - a terrace, a mini-garden or a sports ground.

Pitched roofs have the surface slope sufficient for self-removal of precipitation: it usually exceeds 10-15°**.** The slope also resists winds and the degree of heating of the roofing material under the influence of sunlight, heating strongly the attic space. Pitched roofs have a number of advantages over flat roofs: rainwater flows from them without delay and snow slides off, they provide better thermal insulation, additional useful room, such as an attic, can be equipped under them. The ***rafter system*** is used as a skeleton of the roof.

Rafters perform a load-bearing function in the roof system. The weight from the roof is transferred through the rafter system to the load-bearing walls of the building.

Depending on the roof structure type, the rafter system may include rafters, horizontal girders, beams, as well as struts and other elements.

By the type of structure, roof systems are divided as following:

- rafters;
- hanging rafters;
- metal plate connected trusses.

Roof rafters are systems in which the rafter legs rest (have supports) in several points. So, the lower ends of the rafters rest on the inferior purlins, and in the upper part - on the pillars, girders or struts.

It is a good practice to install a ***hanging system*** in buildings that do not have internal load-bearing walls. Such structures are supported mainly on the walls of a building without a central support.

Single-slope roof

Located with a slope of 15-30 °.

The front and rear walls of the building are of different heights, the overlap is laid on them.

Double-slope roof

Has two planes (slopes), inclined in opposite directions (the optimal slope is 45 °).

Slopes can be symmetrical or asymmetrical.

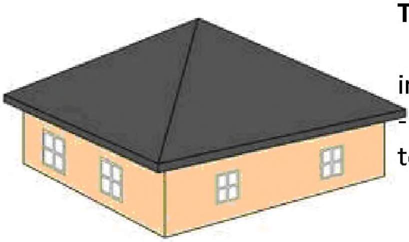
Hip roof

A four-pitched structure with different-shaped upper planes: two triangular (hips) and two trapezoidal.

The slopes of the same shape are located on opposite sides; from top view the roof resembles an envelope.

Half hip

One of the types of hip roof, when the triangular slopes occupy a small part of the pediment and hang over it.

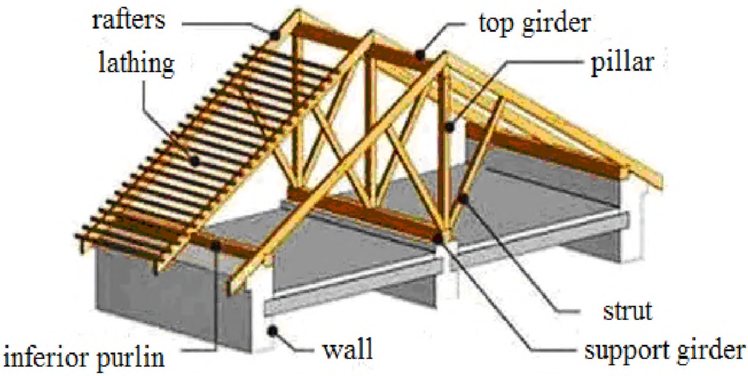


Tented roof

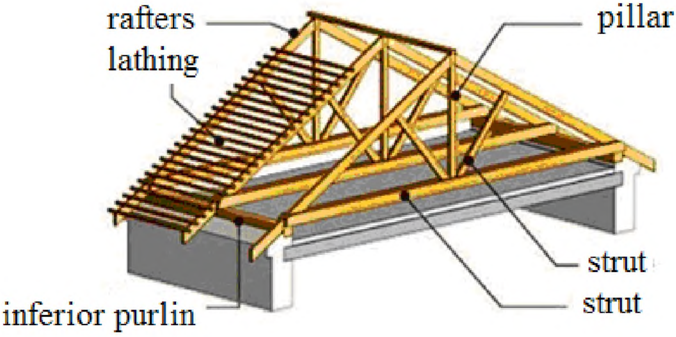
This is another type of hip roof, in which all four slopes are the same - triangular in shape and resemble a tent.

Multi-pitched roof

Used for the house with a complex shape, combined from several geometric shapes.



Rafter roof elements



Hanging rafter roof elements

Fig. 4.16. Structural elements of roof rafter systems [21]

Fig. 4.17. Examples of traditional roof rafter system

A fast and easy way to install a roof on a low-rise building of any type under construction is to use ***prefabricated trusses on metal toothed plates***.

Metal toothed plates are rectangular parts with a thickness of about 1.2 mm; the teeth curved in one direction are pressed into the tree when assembling the rafter system. Connecting prefabricated wooden trusses with metal toothed plates makes possible to simplify the procedure of the roof installation a lot. After their installation, there is a surface for laying the roofing lathing, as well as a surface for installing a ceiling covering and thermal insulation materials.

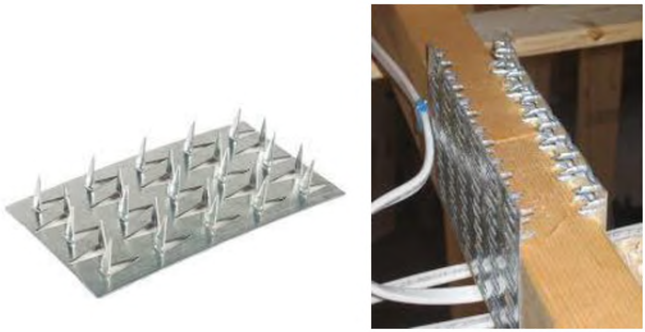


Fig. 4.18. Metal toothed plate connectors [22]

Fig. 4.19. Examples of roof system with metal plate connected trusses

STRUCTURE – CHECK LIST

Marker	Description
Strength	The element can sufficiently sustain the loads applied without any damage.
Stability	The element remains in equilibrium under the loads applied.
Durability	The materials of an element have no corrosion or ageing effects during the service life of a building.
Serviceability	The element is designed to withstand unexpected deflections, rotations, vibrations, cracking.
Renewable source	Sources of raw material are rapidly renewable, e.g. wood and bamboo.
Reuse of waste product	Use of waste that can be reused or recycled, e.g. agriculture or industrial waste. Use of materials with less waste production.
Local availability	It is preferred to search for and to use suitable local alternatives to save cost.
Low pollution	Use of materials with low emissions and leaching. Reuse of waste that would otherwise have resulted in landfill.

Energy efficiency	Use of materials and products that require less energy during construction, operation and maintenance.
Durability and life span	Use of structural materials that are durable or require minor repairs. The longer the life of an element is, the less frequently it should be replaced. Thus, the quantity required to be produced is reduced.
Reuse / recycle	Reuse or recycle of materials from demolished building elements or different products, e.g. furniture, packaging, etc.
Biodegradability	Use of materials that can be decomposed in a natural way, e.g. wood, organic or earthen materials.
Embodied energy	It is the total energy consumed by all processes associated with the service life of the building (from raw material extraction to demolishing). E.g. steel has much more embodied energy than timber or hempcrete and even concrete due to its high production energy needs.

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CHAPTER 5

ENGINEERING SYSTEMS FOR AUTONOMOUS HEALTHY ENVIRONMENT

5.1 Water-saving principles

5.1.1. World “Water issue”

Over the last 100 years, fresh water consumption in the world has doubled. The growth of water resources consumption was going faster than population growth on the planet. According to scientists’ predictions, 5.2 billion of human beings will live in cities by 2025. Such level of urbanization will require a wel-developed infrastructure of water distribution, its collection and treatment.

Furthermore, today one person consumes on twice more water than in 1900. The growth of fresh water consumption by the mid of the XXI century will be 55%, which can cut on the supply availability for the whole population of the earth.

Many experts call "water issue" one of the most serious challenges for humanity in the future. In the 21st century, water will become more important than oil and gas. The growing global water crisis threatens security, stability and environmental sustainability of developing nations. Millions die ach year from water-borne diseases, while water pollution and ecosystem destruction grow, particularly in the developing world. In 1998, the Sixth Session of the Commission on Sustainable Development stated that there was a need for regular, global assessments on the status of freshwater resources. In response to this recommendation, the member organizations of UN-Water (known then as the ACC Subcommittee on Water Resources) decided to undertake a collective UN system-wide continuing assessment process. Founded in 2000, the flagship program of UN-Water, the World Water Assessment Programme coordinates the production of the triennial UN World Water Development Report (WWDR), with an aim to report on the status of global freshwater resources and the progress achieved in reaching the Millennium Development Goals related to water [1].

All over the world government, civil society and businesses have started to solve current problems, since in the future they may only increase in connection with the use of global water resources. There is also a strong necessity to develop measures for the proper management of these resources. The availability of fresh water on the earth and daily residential use of potable water in litres is presented in Fig. 1.

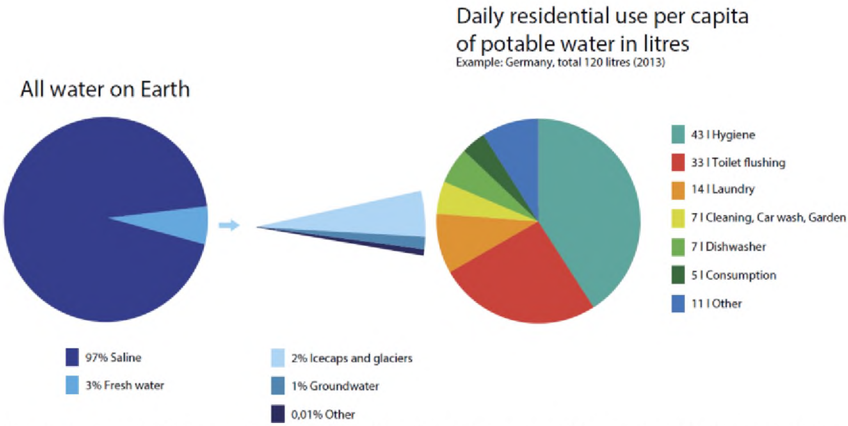

Fig.5.1. Availability of water on Earth. (Source: Water in Crisis: A Guide to the World`s Fresh Water Resources (Oxford University Press, New York).

"The 2030 water resources group" was created in order to help countries close the gap between water demand and supply by 2030 [2]. 2030 WRG is helping countries developing water security and resilience planning capabilities through different approaches and methodologies.

5.1.2. Collection and use of rainwater for domestic purposes

The composition of rainwater directly depends on the degree of air pollution over the area. In the best case, it contains 4 times less harmful substances than tap water, and its hardness is about 18-20 times lower than that of the well, so the scale doesn’t build up on the surfaces.

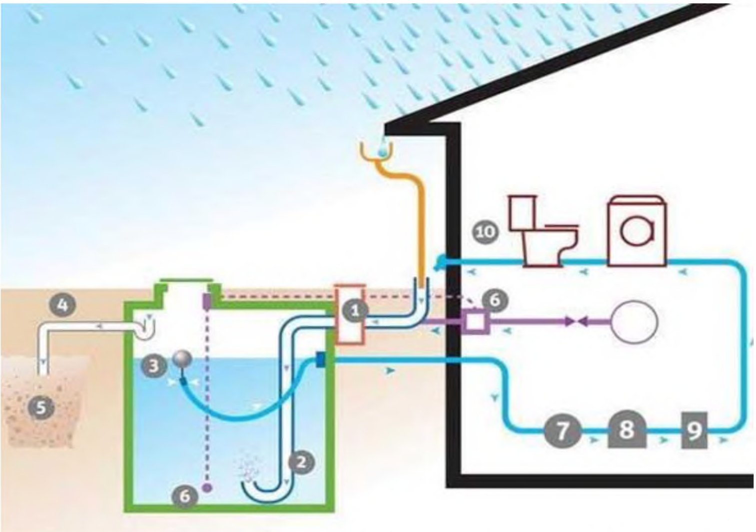

Fig.5.2. Rainwater collector operation scheme: 1-filter, 2-water supply to the tank, 3-float pump switch 7, 4-drainage overflow, 5-drainage pit, 6-water level meter, 8.9-household appliances, 10 - "Grey" water directed to the bioreactor.

Most often, rainwater is used as technical. It's storing in ground insulated tanks made of polyethylene with a volume of 750 to 2000 liters or underground tanks of 3000 liters, which are located below the freezing depth for building the area. The tanks are in a stable thermal regime. The viability of microorganisms in the water is reduced. In case of the long absence of precipitation, the tank is filled with tap water, so you should provide an automated system for filling it to maintain autonomy from the centralized water supply. Rainwater is also used to irrigate the surrounding land [3,4].

Water from wells can be used as drinking water. To ensure this type of water supply, you must first carry out a geological study of soils, identify the chemical composition of water (suitability for consumption, the need to install a filter) and the required depth and number of wells.

Fig. 5.3. Faucet aerator.

Showers and bathrooms consume up to 70% of domestic water, the rest is used for washing, cleaning, cooking.

The family house should be equipped with water-saving devices and preferably waterless (biologically active) toilets. For example, faucet aerators (Fig.3) can reduce water consumption by up to 40%.

5.2 Energy-saving solutions

5.2.1. Energy-saving potential of ventilation systems

Today, in Ukraine energy efficiency is recognized as one of the priorities of the country's energy policy. Despite the overwhelming need to address these challenges, particularly under the volatile oil and gas market prices, the improvements have been fragmented over the past decade, whereas the use of energy resources remains excessive.To ensure the low energy consumption in the energy efficient houses of new generation, the technology of a ground heat exchanger with a heat recovery system is used almost everywhere. However, this technology has not been widely disseminated in Ukraine or enshrined at the statutory level. Leading national and foreign scientists have proved that natural ventilation leads to significant heat leakage. Thus, the introduction of supply air heating practice in ventilation systems, especially through renewable energy sources and heat recovery systems, is a very relevant question.

Therefore, energy efficiency is a priority in situations of energy crisis in the country. In Ukraine, as in most EU countries, more than 30% of final energy is consumed by buildings. The use of geothermal ventilation can improve energy efficiency in the construction industry. This technology involves the use of a soil heat exchanger in a mechanical supply and exhaust ventilation system. In such a system, the supply air can be heated from -24C to + 3C depending on manufacturers. This energy-saving effect can be increased by the use of a heat recovery solution in the ventilation system, which makes it possible to take some heat from the exhausted air and return it to a house with the supply air with a temperature up to +18 at -24C outside. The introduction of such systems in Ukraine requires extensive parametric studies, development of engineering methods and a comprehensive study of the possibility of their efficient operation.

5.2.1.1. Geothermal ventilation system with heat recovery

The design of the sealed external walls of modern energy-efficient houses makes it possible to prevent the uncontrolled flow of outdoor air into the premises. In order to provide passive houses with fresh air and to remove polluted air from them, it is necessary to use mechanical ventilation, which allows maintaining the necessary parameters of microclimate in the premises. To save thermal energy in ventilating systems, used for heating of the external air, it is appropriate to apply the «air-air» heat exchangers and ground heat exchangers. The «air-air» heat exchangers are intended for heating the external intake air by heating the exhaust air. In passive houses, it is a good practice to install heat recovery systems with a recovery rate of more than 75% [5]. Ventilation systems where the ground heat exchangers are used for the first heating of the external intake air are called geothermal (Fig 4.).

The principle of geothermal ventilation during the cold period of the year is as follows: the air with a temperature of t_{ext},, is fed to the input of the ground heat exchanger and takes the soil heat through the wall of the heat exchanger; as a result, the external intake air is heated to $t_s$and fed into the room. If necessary, the air with a temperature of t_s is heated in the heat recovery system by the heat of the exhaust air up to the necessary temperature of the inside air t_{ins}[6].

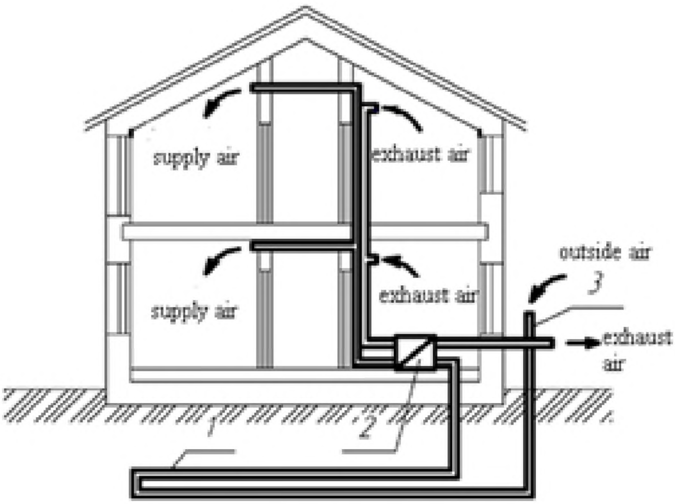

Fig. 5.4. Structural scheme of geothermal ventilation of a passive (active) house: 1 - horizontal ground heat exchangers, 2 - recoverer, 3 - intake ventilation shaft.

The underground heat exchangers for ventilation are divided into three main groups: gravel (ductless), tubular (duct) and membraneless. In any scheme, the main air supply channel will be connected to ventilation, and a mechanism is provided for switching from the use of the heat exchanger to the use of the direct air flow from the street [7]. The soil duct heat exchanger is a system of pipes laid in the ground below the freezing point, which act as heat exchangers between the soil and the air passing through these pipelines. The diameter of the pipes is from 200 to 400 mm (sometimes larger, depending on the volume of a building).

The pipelines provide heating of the intake air into the house in winter and cooling during the hot season of the year. Such system makes possible not only to save considerable amount of thermal energy, but also to improve comfort in the house. Heat recovery is a process of heat return. In our case, heat recovery means the heating process with warm exhaust air of the cold incoming air taken into the house for its airing and ventilation. It is necessary to return the heat we collect from all the premises to the house [8].

The main element of the supply and exhaust ventilation unit with heat recovery is a surface-type plate recuperative heat exchanger. It makes possible to use the heat of the exhaust air, which is removed from the premises by the exhaust fan, to heat the outdoor air fed into the room by an air supply fan. Since the efficiency of heat transfer depends directly on the surface condition of the transmitting heat in order to protect it against the pollution, intake and exhaust air filters shown in Fig. 5 must be used [9].

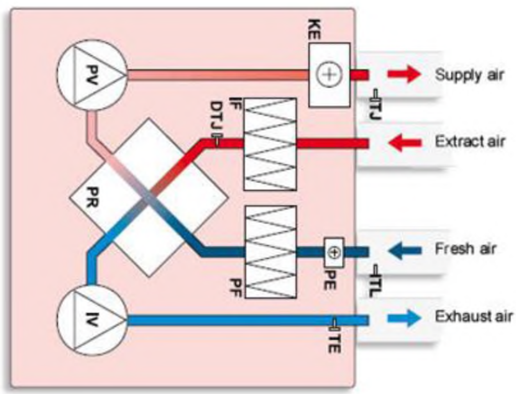

Fig. 5.5. Scheme of supply and exhaust ventilation unit with heat recovery with a surface-type plate recuperative heat exchanger.

Also, there is an indoor heat recovery unit (mountedon the wall), designed to ensure year-round ventilation in premises without energy losses. The system works as follows: two airflows pass through the copper heat exchanger, located inside the working module; two “input-output” airways are separated from each other, both are located inside the working module. The system allows air to travel to each direction simultaneously. For example, in the Prana ventilation system (Fig.6) the warm exhaust air, which is removed from premises, heats the fresh cold air from the outside [10]. On the contrary, in summer, the heat recovery unit cools the air down. The installation of filters is possible; however, the copper heat exchanger ensures disinfected air without any filters.

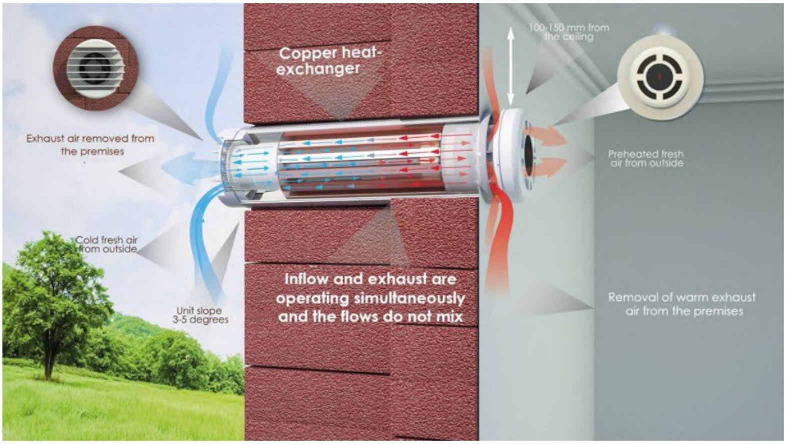

Fig.5.6. Operating principle of “Prana” recuperator.

Geothermal ventilation is more effective with a heat recovery system, but often these two technologies are used separately.

5.2.1.2. Installation technology of horizontal ground heat exchangers

The assembling of horizontal ground heat exchangers is carried out in pre-designed trenches. The choice of mechanisms depends on soil conditions. The technology of horizontal heat exchanger is based on the following sequence of actions. First, the heat exchanger route is marked and the home entry point is planned. During the development of the trenches, the ground is removed and a pipeline is placed on the bottom of the trenches. The pipeline is banked up with soil every few metres. Then, the pipe is inserted into a specially made hole in the basement and grounded. A pressure test of the pipeline and the backfilling of the trench shall be carried out after full completion. Moreover, the first 15 sm shall be manually filled in. The further backfilling is done by a bulldozer or other mechanisms. The safety during the installation of service equipment in buildings (structures) must be provided with compliance with the rules contained in the material and engineering documentation.

The pipe laying is usually done according to the Tihelman scheme (Fig. 7) presented below.

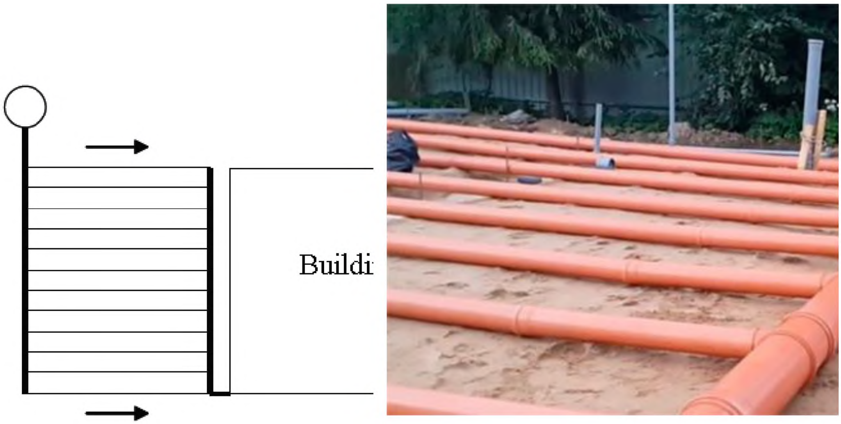

Fig. 5.7. Tigelman Pipe Laying Scheme and in-situ photo

The construction operations are as follows:

1. Site planning.
2. Excavation of a pit.
3. Sand blanket placement and compaction.
4. Handling of the mechanical core by a crane into the excavation pit.
5. Pipelaying in the designed position.
6. Building-in of PP pipes through the walls of the building.

7. Padding.
8. Manual layer-by-layer tamping.
9. Hydraulic pressure test of pipelines.
10. Excavation backfill.
11. Soil compaction with electrical rammers

Further on Air-Cooled Heat Pump (ACHP) can be coupled with a Horizontal Air-Ground Heat Exchanger (HAGHE) to preheat outside temperature before involving by the heat pump. This scheme improves heat pump performance (Fig.8) [11].

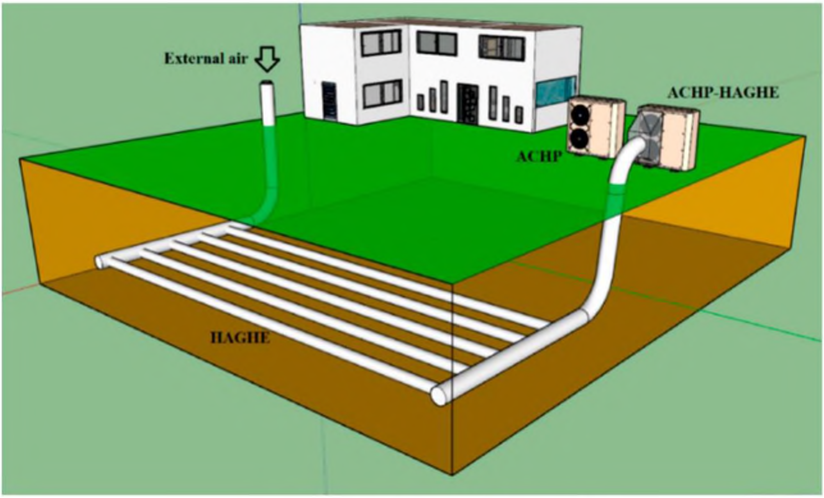

Fig. 5.8. ACHP-HAGHE plant

5.2.2. What Is a Heat Pump and How Does It Work?

A heat pump is an electrical device that extracts the heat from the source of low heat, increases its temperature, and transfers it to the consumer. The mentioned solution is not a new technology; the heat pump has been used world-round for decades.

Thanks to the sun's rays, which continuously enter the atmosphere and to the surface of the earth, there is a constant release of heat. This is how the surface of the earth receives heat energy all year round.

Air partially absorbs heat from the energy of the sun's rays. The remaining solar thermal energy is almost completely absorbed by the earth.

In addition, geothermal heat from the bowels of the earth constantly provides a soil temperature of + 8 ° C (starting from a depth of 1.5-2 meters and below). Even in cold winters, the temperature at the depth of the water courses and seas remains in the range of + 4- 6 ° C.

Therefore, heat pump absorbs low-potential heat of soil/water or air (Fig. 9) and transfers it from the environment to the heating circuit of a private house, having previously increased the temperature level of the transfer medium to the required + 35-80 ° C.

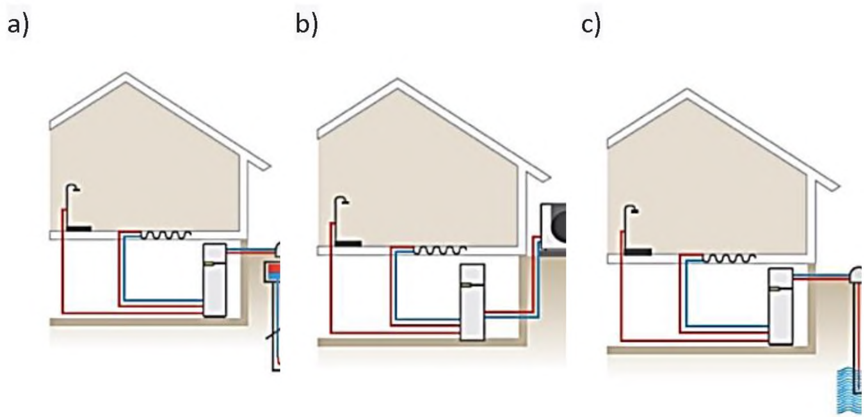

Fig. 5.9. Different types of heat pumps depending on heat source: a) ground - source; b) air- source; c) water- source.

There are three closed circuits in the system of the heat pump. The circuit filled with the transfer medium substance called a refrigerant is situated inside the heat pump unit. A heat pump functions using the circulation of a refrigerant through a cycle of evaporation and condensation. This refrigerant is characterized by the low boiling temperature. There is also an external circuit going from the heat pump unit to the air/ground/water source with the purpose of heat extraction from the environment. It is filled with a non-frizzed substance capable to absorb the low heat and transmit it to the circuit filled with refrigerant. This way the heat of the ambient air (1st step in Fig. 10) makes the refrigerant boil at the temperature of 6ºC (2nd step) and turns it into gas. Then a heat transfer medium is exposed to the high pressure in the compressor (3) - its temperature is increased and the heat is transmitted to the third internal circuit of the domestic heating system. In transit the heat refrigerant becomes liquid in the condenser (4, Fig. 10). This condensed refrigerant is still under high pressure, so it passes through the expansion valve (5, Fig. 10) in order to decrease pressure and repeat the process.

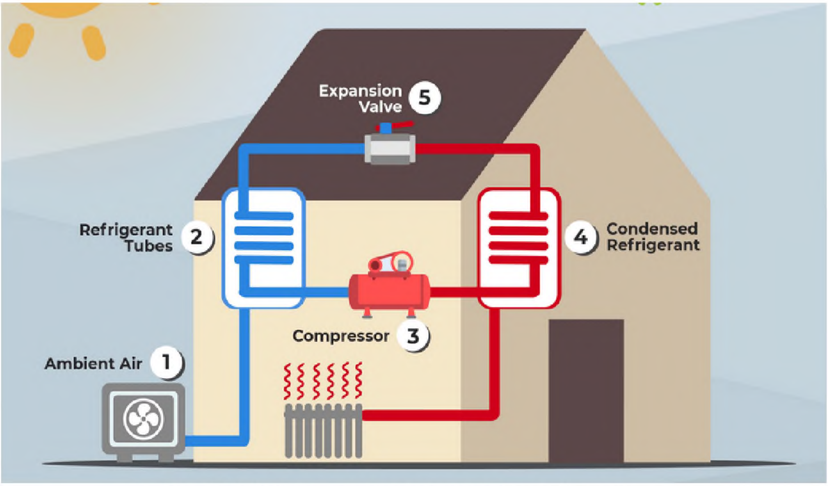

Fig. 5.10. Heat pump operation scheme

The compressor does not work to generate heat, but to move it from the environment to room. Therefore, spending only 1 kW of electrical energy to rotate the compressor shaft, we get 3,5 – 5,0 kW of heat on the condenser. For example, an Air Source Heat Pump (ASHP) will generate around 3kW of thermal energy for every 1kW of electrical energy consumed, providing an “efficiency” of 300 %. It is thermodynamically incorrect to have an efficiency of more than 100%, as this means that more energy is produced than used. Thus, the performance is expressed as a Coefficient of Performance (COP) rather than efficiency. The above mentioned case can be characterized as the one having a COP of 3. The reason, why more energy is produced than used, is that the electricity consumed to drive the compressor and pumps is the only energy input. The rest of the obtained energy is just transferred from a heat source that is not involved (such as ambient air, soil, lake, river), thus, is not considered as the energy input [12].

5.3. Solar power for a self-sufficient home

5.3.1. The principles of operation and use of photovoltaic panels

Back in 1839, Alexander Edmond Becquerel discovered the photovoltaic effect. 44 years later, Charles Fritts managed to design the first module using solar energy, and the basis for it was selenium, covered with a thin layer of gold. The scientist found that this combination of elements allows, in a minimal amount (about 1%), converting solar energy into electricity. 1883 is considered to be the year of birth of the solar energy era. However, not everyone thinks the same. In the scientific world, there is an opinion that the "father" of the solar energy era is none other than Albert Einstein himself. In 1921, Einstein was awarded the Nobel Prize for his explanation of the laws of the external photoelectric effect.

For a hundred years, the development of the industry, stimulated by scientists, investments of private and public structures, has experienced ups and downs. This fragile success forced society to forget about "solar technology" for years.

Today, almost every developed country is encouraging the use of photovoltaic panels through the adoption of laws on tax benefits. Furthermore, there is a mechanism for selling excess electricity to the grid at a favorable «green tariff». This approach attracts investors to the renewable energy sector. In this way, you can produce DC electricity using photovoltaic panels, convert it to AC form and sell it to the grid (Fig.11).

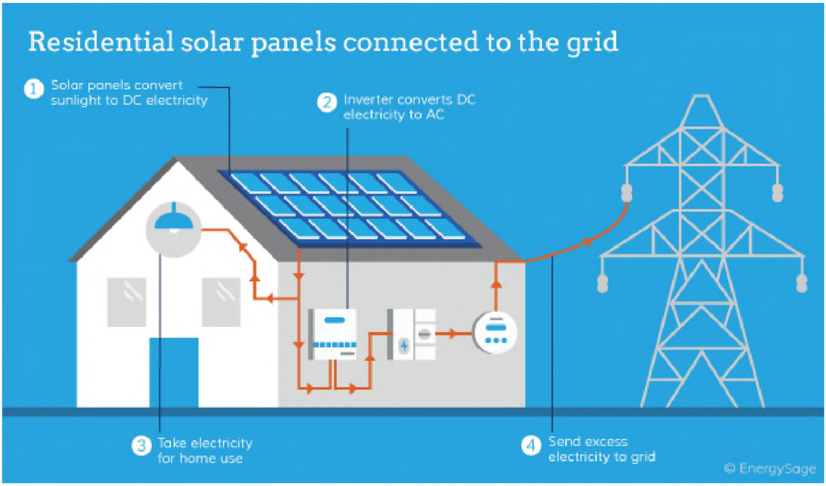

Fig. 5.11. Residential solar panels connected to the grid

BENEFITS

First, "raw material" is sunlight that never runs out.

Second, solar energy is widely available, because the sun shines in the south and west, in Africa and Europe.

DRAWBACKS

The question of absolute safety of these technologies for the environment is controversial. Of course, this is not nuclear energy or oil and gas production. But at this stage of development of "solar" technologies, harmful substances are used in the manufacture of batteries, which can harm the nature anyway. Ready-made samples (photocells) contain toxic substances such as lead, cadmium, gallium, arsenic.

There are two ways to convert solar energy: photothermal and photoelectric. In the first case, the heat transfer medium is heated in a solar collector to a high temperature and this thermal energy is used for hot water supply or space heating. In the second case, there is a direct conversion of solar radiation into electricity with the help of semiconductor photovoltaic cells - solar panels.

The principle of their operation resembles the operation of a transistor. The main and key element that can provide this effect - is a semiconductor material. The most common material for solar panels is silicon. For the production of solar panels, silicon can be monocrystalline or polycrystalline. Monocrystalline silicon can be distinguished by a uniform black-gray color of the surface of the photocell. This type of material is grown in industrial conditions and cut into thin plates with a special thread. The second type is a more modern generation of elements made of more affordable polycrystalline silicon. Manufacturing is proceeded by casting. The material looks like a surface with an uneven blue sheen.

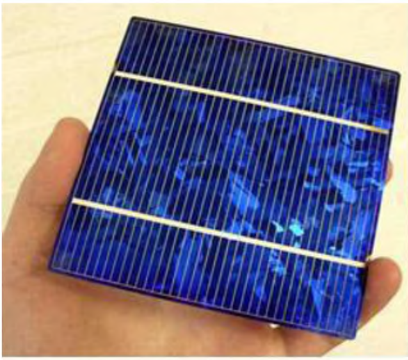

Fig. 5.12. Photocell made of polycrystalline silicon

Fig. 5.13. Photocell from monocrystalline silicon

Therefore, to obtain electricity from a solar battery, it is necessary to make a photo effect. This process is associated with the physical phenomenon of the p-n junction. Structurally, the photocell consists of two silicon wafers. One of the plates contains boron atoms and the other arsenic atoms. The upper layer is characterized by an excess of electrons, and the lower - their lack. In this case, an electron-hole transition (p-n junction) is supported at the boundary of these plates.

As a result of sunlight (photons) hitting the photocell, the plates are illuminated and both layers interact like the electrodes of a conventional battery - there is an electromotive force.

The sun's rays activate electrons that begin to move from one plate to another. Thin layers of the conductor are weld and connected to the load to remove electrical energy on both surfaces. The production of this energy is not associated with chemical reactions, so this solar battery can last quite a long time.

Today, scientists are studying issues that could improve the generation of electricity in the photocell by increasing the efficiency of installations. To do this, the thin-film cells of the element may contain not only silicon but also gallium, arsenide, cadmium, copper, selenium and many other materials. An significant problem in the efficiency improvement of solar panels is the excess heat that occurs when heating the plates of photovoltaic cells. After all, the efficiency of panels in rare cases exceeds 30%.

CHARACTERISTICS OF SOLAR PANELS

Solar panels are built from modules made from silicon crystals. Depending on the field of application, solar modules can have different design solutions and different output powers. Solar panels are used to provide autonomous electricity.

Solar panels are classified by the organization of silicon atoms in the crystal of the solar cell: monocrystalline, polycrystalline and amorphous.

Monocrystalline batteries are equipped with extremely pure silicon, which is quite well spread in the production of semiconductors. The monocrystal grows from the seeds extracted from the silicon melt. The rods obtained in this way are cut into pieces 0.2-0.4 mm thick, forming cells. The optimal number of used cells is 36. Batteries made of silicon single crystals are the most popular. The efficiency of monocrystalline batteries is 14-17%.

Polycrystalline solar cells are made of silicon, which comes from a slowly cooled silicon melt. This method is less energy-intensive and cheaper. Silicon obtained for polycrystalline solar cells is bright blue. The efficiency of polycrystalline batteries is 10-12%.

Amorphous silicon batteries are obtained by the "evaporation phase technique". A thin film of silicon settles on the carrier material and it is protected by a coating, so such batteries are also called thin-film. This method of manufacture is the simplest and cheapest, but the efficiency of the battery is much lower than in crystalline batteries. Besides, elements of amorphous silicon are prone to degradation. Thin-film batteries work at scattered radiation. They can be installed on the walls of buildings. The efficiency of amorphous silicon batteries is 5-6%.

5.3.2. Benefits of solar water heating

A solar collector is the equipment designed to absorb solar radiation and convert it into thermal energy, which is used to heat domestic water (hot water supply system).

Solar water heating systems are based on solar panels, called collectors, fixed to your roof. This equipment collects thermal energy from the sun and uses it to heat water which is stored in a hot water tank (Fig. 14). A boiler or immersion heater can be included in the system as a back-up to heat the water further to reach the required temperature or to cover risks of the lack of insolation.

The operation principle of all collectors is almost the same. Structurally, only the type of surface that receives solar radiation and its material differs. This surface (or its elements) transmits thermal energy to the liquid of the heat transfer medium in the heat exchanger. The heated coolant enters the storage tank filled with water through thin tubes. The tubes of the heat transfer medium pass through the whole tank, providing uniform heating of liquid. As it flows through the tank, the heated coolant cools and it is fed back into the collector in a cold state, where it is heated again. This ensures the constant circulation of the hot coolant through the water storage tank. Water from the tank can be used for bathing, washing the dishes, and other household needs or supplied to heating radiators.

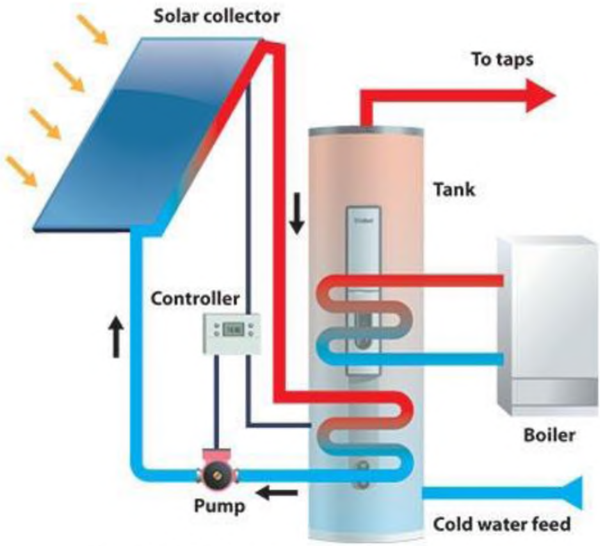

Fig. 5.14. Solar water heating system

There are two main types of solar collectors:

1. Flat plate solar collectors.
2. Evacuated tube solar collectors.

The flat solar collector consists of the following main elements:

- the body of structure (insulated metal box);
- absorber plate and flow tubes;
- transparent protective coating (usually glass cover);
- heat-insulating coating (usually mineral wool in combination with reflective aluminum foil);
- equipment fasteners.

Flat solar collectors attract consumers by a reasonable price and high efficiency (98%). The main element of such a collector is a flat absorber (heat absorber) with a serpentine tube for the coolant flow. The absorber has the form of a metal plate, the upper part of which must be painted black (for maximum absorption of sunlight). A thin metal serpentine tube is welded to the lower part of the plate. The coolant (usually water, rarely - antifreeze) circulates through this tube. Welds run along the entire length of the tube to ensure full thermal contact.

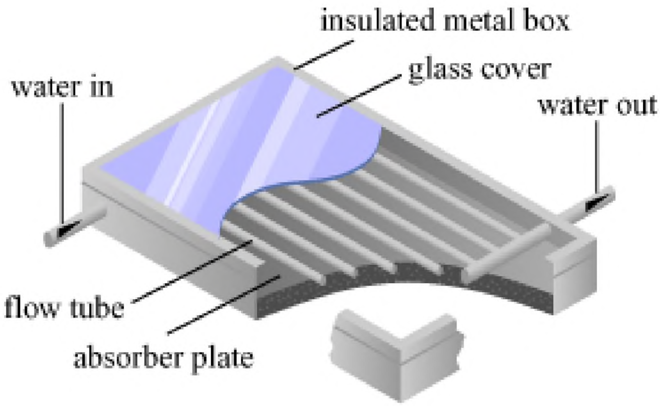

Fig. 5.15. Flat plate solar collector

The vacuum flat collector (Fig. 5.16) differs from the usual flat collector by the presence of a vacuum in the middle of the system to reduce heat loss. A flat vacuum collector has high performance compared to other flat collectors. However, its distribution is limited, because it is very expensive. Besides, a vacuum flat collector is very difficult to install and operate.

Fig. 5.16. Vacuum flat collector

In Ukraine, the maximum productivity of a flat solar collector per $1m^2$ for a day in summer is 50 l (temperature 50 ... 60 ° C).

Table 5.1

Pros and cons of flat solar collectors

Advantages	Disadvantages
• High productivity (efficiency of more than 50%). • Simple and reliable design. • High durability of the equipment (more than 50 years; a guarantee for 10 years of operation is usually provided by the manufacturer). • Ability to work all year round. • They work effectively when it is necessary to heat the water by 20 ... 40°C higher than the ambient temperature.	• Low productivity in winter and during unfavorable weather conditions (compared to a vacuum collector). • Maximum efficiency of a flat collector is reached only when sunlight hits at right angles (at noon). • Requires periodic cleaning from dust, dirt, snow. • If the collector is damaged, it is necessary to replace the whole device but not a separate element, as in case of tubular vacuum collectors.

The vacuum thermotube collector (Fig. 5.17.) is equipped (instead of usual vacuum tubes) with more advanced thermotubes which represent a tube from thin-walled copper filled with easily boiling liquid. The collector consists of a set of thermotubes - when sunlight hits the tubes, the boiling liquid (for example, inorgatik) boils to a temperature of 250 ... 380 ° C, its vapor rising to the top of the tube, which is a condenser, gives energy to the heat transfer medium and cools turning up into the liquid and then re-enters the lower part of the thermotubes.

Fig. 5.17. Vacuum thermotube collector

The advantages and disadvantages of the vacuum thermotube solar collectors are presented in Table 5.2.

Table 5.2

Pros and cons of vacuum thermotube solar collectors

Advantages	Disadvantages
• High efficiency system throughout the year and even in winter. Compared to other types of collectors, the tubular vacuum collector produces 30 ... 40% more heat throughout the year; • ability to work at negative temperatures (not all types); • some manufacturers produce tubular collectors with a surface made of impact-resistant glass that can withstand the impact of hail or a slight fall; • low windage design allows fixing the equipment more reliably with smaller efforts and expenses. • more serviceable system. If one tube is damaged, it is relatively easy to replace, which is impossible in flat collectors; • the ability to heat water to a temperature of 130 ... 200 ° C.	• Higher cost; according to the manufacturers, the payback of the collector system is 1-5 years; • large size and heavy weight; • in Ukraine, the productivity of the vacuum collector in winter may decrease due to precipitations (snow or frost); • low service life, the system suffers from hail (more typical of products from China); • one of the main breakdowns of the system - the leakage of the vacuum in the system (more typical of products from China).

5.4 Waste management in residential buildings

5.4.1. Wastewater reuse for technical (non-potable) purposes

The most popular technology today is the so-called binary systems. Next to the regular drinking water supply network, a second network for the delivery of treated wastewater is organized.

This water can be used for the following purposes:

- domestic industrial water for toilets in cases that do not involve direct contact of water with a person (i.e. mainly for flushing toilet bowls);
- watering of green spaces of garden and park areas, sports fields, golf courses, etc;
- cleaning of streets, sidewalks, pedestrian crossings, etc;
- water supply for decorative fountains;
- car wash.

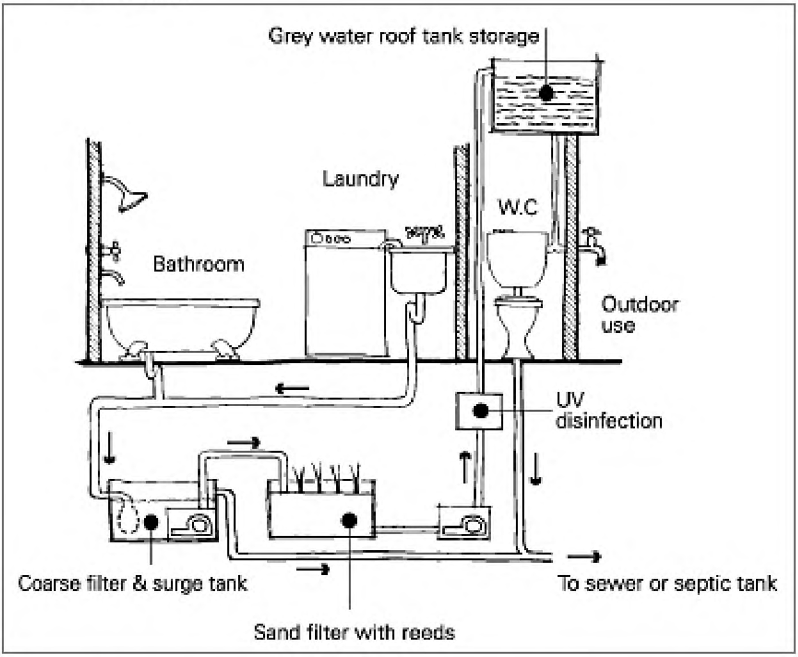

Fig.5.18. Typical home wastewater reuse system

Purification of water for technical use involves sequential passage through flocculation clarification, filtration and disinfection. Household wastewater is sent for such treatment, most often, the so-called "gray" drain, excluding fecal water containing urine and feces.

At the same time, apart from common double systems today, there are effective technologies for purifying water that has already been used in individual units of bathrooms for subsequent secondary use. For example, wastewater from washbasins, bathtubs and shower stalls is filtered, soap and impurities are removed from it, and it is sent to toilet cistern or for other technical needs, for example, for washing a car or watering a garden. Such systems are suitable for individual houses, individual apartments, small hotels, clubs, etc. The results of the experiments showed that such systems provide savings up to 50% in ordinary residential buildings and up to 40% in the hotel business and trade. The main advantages are complete autonomy of the water supply system without any cross-contamination of drinking and industrial water, absence of chemicals and harmful by-products, significant energy efficiency (a 12 W direct current source is used to power the electric pump), possibility of using solar energy, fully automatic cleaning cycle.

5.4.2. Composting at home

Food waste can make up 45% of ordinary rubbish bin. At the same time, separation is now almost impossible, and organic matter is becoming dangerous in landfills. Composting is a safe way to process organic waste. How harmful can be an organic waste in landfills? Organic waste on landfills, along with other garbage, is compressed and buried; therefore, organic waste is processed in anaerobic (airless) conditions. Anaerobic bacteria release methane, a corrosive greenhouse gas, as a result of this process. Landfills provide about 11% of methane emissions into the atmosphere. The process of methane formation actively takes 30-50 years, and then it passes into the decay phase, but does not stop. So far in Ukraine, there is no infrastructure for the collection and processing of organic matter.

What is compost? It is the fertilizer that is formed as a result of the decomposition of organic matter by microorganisms. By making a compost heap, a person simply accelerates and intensifies natural processes. Since composting mainly involves aerobic bacteria, this process is safe for the environment and reduces methane emissions by decreasing the amount of organic matter on landfills. The finished compost contains the nutrients that plants need, and besides, it improves the structure of the soil, making it looser. Moisture and air penetrate better into such soil; it is easier for the root system to develop in it. Most of all, compost is needed in sandy and clay soils.

How to compost correctly in a private house without technical solutions? To make composting faster and more efficient, it is necessary to create a favorable environment for microorganisms - warm, humid, with sufficient nutrients and air access. There are two types of composting: cold and hot. Cold composting is effortless - you just need to stack leaves, weeds, vegetable peels and skins in a compost heap, but it takes months to a year (sometimes even longer). In hot composting, the pile should be turned over every time it is heated inside and kept moist (but not wet). This method allows you to get ready-made compost in a few weeks, sometimes in 1-3 months, depending on the weather, the contents of the heap, and the frequency of overturning. It is necessary to throw in a pile nitrogen-rich "green" organics (fresh grass, remnants of vegetables and fruits, tea leaves, flowers) and carbon-rich "brown" organics (dry leaves, hay, sawdust). Diseased plants can make the fertilizer unusable.

What solutions are there for a more effective composting? Composting is practically the only universal way of processing organic matter in a city apartment or private house. The disposer is a food waste shredder that is installed under the sink and is suitable only for residents of those settlements where treatment facilities are equipped with special biogas plants.

There are several ways to compost food waste in a city apartment or house. Vermicomposter is a container with California worms that quickly and efficiently recycle organic matter. The price of vermicompost depends on its volume and design, as well as on the number of worms inside.

Fig. 5.19. Vermicomposter

The second variant is a container with microbial biological products. A biological product (for example, "Bokashi") is a mixture of effective microorganisms grown on wheat bran. Containers with such a mixture are airtight, so there will be no flies and no smell. They are also usually equipped with a tap to drain the liquid.

There is also an electric composter - a sealed container that plugs into a power outlet and recycles any organic waste. The temperature inside is maintained at which the processing progress is faster - the finished compost can be collected in 10 days. A significant disadvantage of an electric composter is its price [13].

5.4.3. Waste sorting at home

First, we should understand why it is important to sort waste. Separate waste collection is a useful habit that allows you to reduce the amount of garbage sent to landfills, create a comfortable environment for life, and take care of your health. Most industrialized countries have long been sorting waste and saving their resources on it. It's time to join in and implement a good habit! Our tips will help you with this.

1. Before you start sorting waste, you need to explore the possibilities for separate disposing of garbage in your area or city.

For this, use the online map, which already contains containers and collection points for recyclable materials in your country and city. Once you have chosen the locality and the type of waste you need, you can easily find a collection point for sorted waste near your home, office, or on the way to your frequent shops and cafes.

2. Determine the types of waste that you will dispose for recycling.

Now you need to read carefully the rules for the separate collection of waste, published on the website of the company that collects recyclable materials, on containers in the yard, etc.

Find out what types of recyclable materials can be taken to the nearest container or collection point; how far will you have to carry what you cannot hand over within walking distance. You should also understand how much space you have at home to organize a separate collection.

The next step is to determine what is easier for you to sort. Our advice: don't set yourself unsoluble problems. Start with something small, such as collecting paper, metal, or glass. There are a lot types of plastics - it will take a little more time and effort to understand the rules for putting each type into recycling.

Choose simple solutions: if metal and waste paper is accepted near the house, then it will be easier for you to collect and hand over them separately. In this case, the glass can be collected and returned periodically.

Without a car, it is complicated to take boxes or bags with cans and other containers to a collection point that is far away. But you can negotiate with neighbors who have a car and take out the waste together on a specific day.

Collecting hazardous waste (batteries, mercury lamps and thermometers) does not require a lot of space, but it will make an important contribution to keeping the environment free from toxic substances. Hazardous waste collection points are often located in large stores and retail chains such as IKEA, METRO C&C etc. Many libraries and post offices collect household batteries for recycling.

3. Find convenient containers.

If there is a two-line separate collection system near your home, it is not at all necessary to use a separate container for each type of waste. It is enough to add a box, container, or recycling bag to the existing trash can.

If you have the more complex infrastructure, it makes sense to use several containers or bags that can be taken out altogether or in turn. To organize a place for separate collection, you need to analyze the rate of accumulation of each type of waste and the location of the points where you will donate waste. If the container or collection point is far away, you can store recyclables under the sink, bed, on the balcony, in the closet in the hallway or in a box in the common vestibule, if there is one, and hand over it for recycling periodically.

It is not necessary to buy special containers. You can use old bags, boxes, or disposable containers that can be recycled. A separate container should be set up to collect hazardous waste. It is important that it has a tight-fitting lid and is kept out of the reach of children and pets.

4. Prepare recyclable materials for processing.

Preparation of materials and their rational storage allow not only to effectively using the space at home but also your time. In order to prevent unsanitary conditions, all materials need to be rinsed - this does not take much time and will eliminate the unpleasant odor.

In addition, the packaging should be reduced in volume: fold cardboard boxes, press aluminum, tin, and plastic cans and bottles, remove the lids, insert one glass of yogurt, sour cream, or cottage cheese into another, crumple multilayer packaging for milk and juices. This not only saves space at home but also makes it possible to increase the efficiency of separate collection of recyclables: procurers will be able to transport more recyclable materials and spend fewer resources on sorting them [14].

EQUIPMENT – CHECK LIST

EQUIPMENT	Criteria for checking
Rainwater collector	1. The height of the covering should be deeper than the frost depth in winter. 2. The strength, frost resistance and equipment assembly must meet the project requirements. 3. The viability of microorganisms in the water should be reduced by a special solution. 4. The service life period must be at least 60 years. 5. 70 % of materials should be recyclable.
Horizontal ground heat exchangers	1. The height of the covering should be deeper than the frost depth in winter. 2. The viability of microorganisms in the exchanger should be reduced by a special solution. 3. 70 % of materials should be recyclable. 4. The service life period for exchangers must be at least 50 years.
Heat recovery system	1. A recovery rate must be higher than 75%. 2. The service life period must be at least 20 years.
Heat Pump	1. Refrigerant should be safe (Freon R-134A, R-134A, R-134A, R-407C, R-404A, R-404A, R-410A). 2. The compressor warranty must be at least for 15 years. 3. The heat pump warranty must be at least for 5 years.
Photovoltaic panels	1. The efficiency of monocrystalline batteries should be at least 14-17%.

	2. Ideally, the installation angle of a fixed, roof-mounted solar energy system should be equal to the latitude of the location. However, pitch angles between 30 and 45 degrees will work well in most situations. 3. In the northern hemisphere, solar panels should face true south (in the southern hemisphere – true north). 4. You need to ensure that your charge controller or inverter can handle the highest possible voltage and current.
Solar collector	1. High productivity (efficiency of more than 50%). 2. High durability of the equipment (more than 50 years). 3. A guarantee of operation for 10 years. 4. You'll need from five to ten square metres of roof space. 5. Collectors should be faced East to West through South and get direct sunlight most part of the day. 6. The panels don't have to be mounted on a roof. They can hang on a wall.
Wastewater reuse	1. Cross-contamination of drinking and industrial water is impossible. 2. Absence of chemicals and harmful by-products. 3. Significant energy efficiency (a 12 W direct current source is used to power the electric pump). 4. It is possible to use solar energy. 5. Fully automatic cleaning cycle.

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CHAPTER 6
3D-PRINTING IN CONSTRUCTION

6.1 3D-Printing technology

3D-printing (3D-Printing) is the process of reproduction of a real object based on the original 3D model [1, 2] (Fig. 1.1). Unlike a conventional printer, which outputs information onto a sheet of paper, a 3D printer allows you to output three-dimensional information, that is to create certain physical objects. The technology of 3D printing is based on the principle of layer-by-layer creation of a solid model. 3D printing can be done in different ways and use different materials, but at the heart of any of them is the principle of layer-by-layer creation of a solid object.

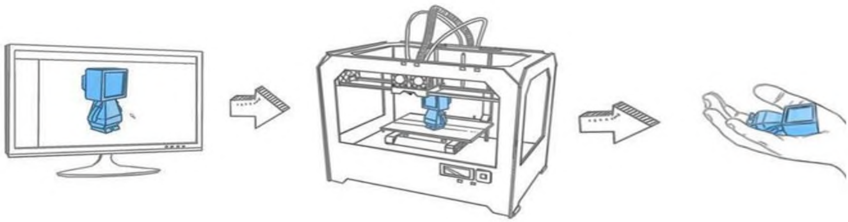


Fig. 6.1. Stages of 3D printing of a physical object

In 2019, J'son & Partners Consulting completed an analysis of the current situation and prospects for the use of 3D printing in construction in the world [3]. 3D printing in construction or construction 3D printing, also known as "additive manufacturing for construction" or 3DCP, is a group of technologies that use the method of 3D printing for the manufacture of buildings and building components, namely: sequential fabrication of objects layer by layer by digital (computer, CAD) 3D model using various materials, including concrete. This opens up broad prospects for changing the standard architecture and geometric shapes.

Housing construction is projected to be the fastest growing segment of the 3D printing market. The main factors of market growth are the demand for affordable cost of printed houses and the ability to create complex architectural structures at a low price.

Today the following materials are used for 3D printing: concrete, plastic, metal, ceramics, etc. According to the types of 3D printing products, the market can be divided into: walls, roofs, floors, stairs, etc. 3D-printed concrete walls are one of the most important designs that are made in advance on site or at the factory.

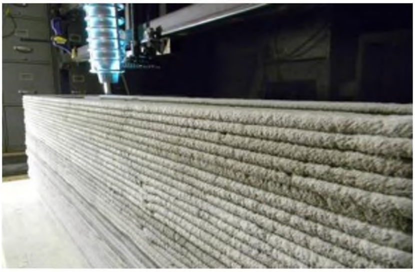
Construction 3D printer uses extrusion technology, in which each new layer of building material is extruded from the printer on top of the previous one.

The following technological schemes of 3D-printing are used in construction:

- print the building in full (Fig. 6.2, a, b);
- print some structural elements (Fig. 6.2, c), as well as models of buildings made of real building materials and elements of landscape design (Fig. 6.2, e, f).

It is possible to use a combined 3D-printing scheme when building a house, and part of the structures are made separately and transported to the construction site.

a)



b)

c)

d)

e)

f)

Fig. 6.2. 3D printing of construction objects:

a, b - construction of the building; c - printing of designs; d - installation of printed building structures; e - models of buildings; f - elements of landscape design

6.2 Materials for 3D-Printing

Concrete is the main material for 3D printing, as it is already widely used in construction, and there are a sufficient number of highly developed technologies for this material.

Impurities. Impurities are considered as additional components in the composition of the mixture to be combined with cement, water and aggregates, as they are important components. The only reason for adding these impurities is to modify specific properties. Impurities can change the curing time, compressive strength, construction capacity, facilitate the operation of the pump for the manufacture of structures, change the curing temperature and even color.

Accelerators. There are two types of accelerators:

1. Accelerators of curing conditions. Acceleration occurs due to the creation of certain curing conditions: steam heating at atmospheric pressure, steam heating at elevated pressure (autoclave), electric heating, etc.
2. Hardening accelerators. The use of concrete hardening accelerators - special additives for concrete, allows you to accelerate the set of strength in natural ("field") conditions and without the use of heating.

Inhibitors. This type of impurities is opposite to the effect of impurities – accelerators because it is used to delay the curing time of concrete mixtures by temporarily preventing hydration reactions that occur in the concrete mixture.

Superplasticizers. The inclusion of this impurity in the concrete mix allows you to use less water without changing the performance or power of a particular pump. This has obvious advantages for the 3D printing process, as it allows the use of a lower water-cement ratio w / s (0.26 and 0.35), which, in turn, provides a shorter preparation time and ensures that the process takes less time and this way printing can be done quickly.

Silicate dust. This fine powder is obtained as a by-product in the production of silicon alloys (Fig. 6.3) and can be found in most HPC (High Performance Concrete). This additive is widely used in HPC because it includes the ability to obtain not only concrete with increased compressive strength (more than 100 MPa), but also with less curing time.

Fig. 6.3.Silicon dioxide

Kaolin white clay (Fig. 6.4). White cement is Portland cement made from specially selected raw materials, usually pure chalk and white clay (kaolin), which contains a very small amount of iron oxides and manganese oxides. White cement is often chosen by architects to use in the production of white or colored concrete.

Fig. 6.4. Kaolin

Today it is a recognized impurity that provides a number of benefits:

- Increased compressive strength and flexural strength.
- Increased durability.
- Production of concrete with ecological characteristics of sustainable development.
- Reduction of greenhouse gas emissions compared to concrete made entirely of Portland cement.
- Reduced permeability (including permeability to chloride ions), which provides additional protection against corrosion of reinforcing steel.
- Improved ductility and ease of installation.
- Improving solar reflection characteristics and promoting more energy efficient buildings and structures.

Polypropylene fibers. Polypropylene fibers with a nominal length of 6, 12 or 18 mm are an ideal admixture in concrete mixtures in order to reduce plastic shrinkage, increase crack resistance and properties of the concrete surface (Fig. 6.5).

Fibers do not replace traditional steel structural reinforcement or the usual amount of cement used. The addition of propylene fibers in the recommended dose of 0.6 - 0.9 kg / m^3 increases the adhesion and reduces the stratification of the concrete mixture.

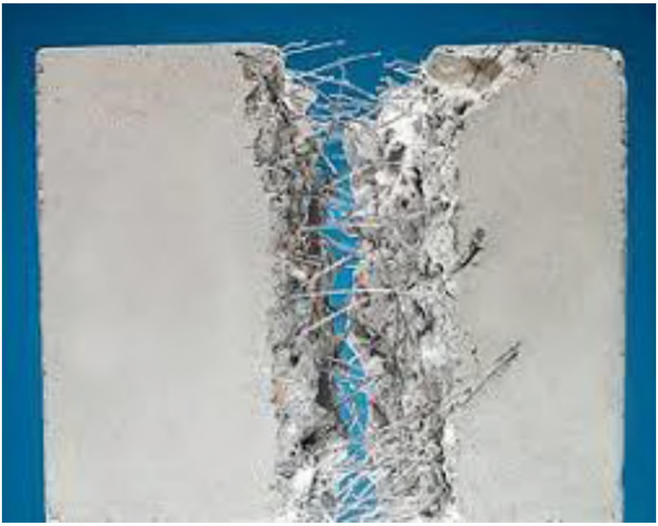


Fig. 6.5. Concrete sample containing polypropylene fibers

6.3. Architecture of houses for 3D-Printing

Today there is a considerable experience in printing a variety of buildings: single-storey and with one room; two-storey with several rooms, in the construction of which reinforcement elements are used; from ecological materials and energy saving ones; multi-storey; diverse exterior architecture that takes into account the purpose of the building, national traditions and cost indicators.

Fig. 6.6. China, Shanghai, 2015 (Fiberglass-reinforced concrete products)

Fig. 6.7. UAE, Dubai, 2016, Dubai Future Foundation

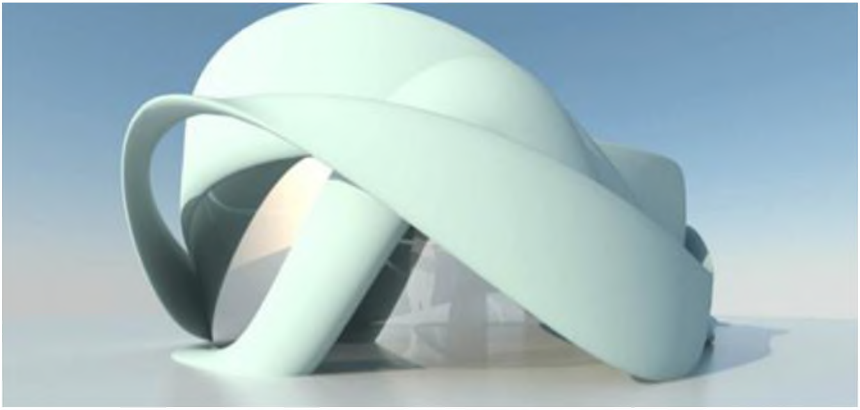


Fig. 6.8. Netherlands, 2017, Conference center, 90 m2 (Constructions of any shape from a special concrete mortar CyBe MORTAR)

Fig. 6.9. Italy, Gaia House, 2018, Dwelling house (natural mixtures from the soil of the adjacent territory, waste from rice production, crushed straw)

Fig 6.10. UAE, Dubai, Two-storey office building, 640 m^2

Analysis of the world experience of building houses by 3D printing in the world, which is only gaining momentum, already allows us to draw certain conclusions about the classification of houses on such grounds as: functional purpose of the house, storeys, area and dimensions of the house, architectural planning characteristics construction of the building, building materials, type of 3D printer.

Classification of houses erected by 3D printing by characteristic features:

- ***functional purpose of the house*** – residential buildings (one-apartment (cottage, mansion, villa), apartment), hotel, office, conference center; two-storey administrative building; SolarPark Innovation Center;
- ***type of house*** – stationary, mobile;
- ***storeys of the house*** – one-storey (mostly), two-storey, multi-storey (five floors);
- ***square*** – from 30 m2 to 1100 m2;
- ***dimensions of the house*** – width - 10.0 m, 12.0 m, 20.0 m; height - from 3.0 m to 6.0 m; diameter - 15.0 m;
- ***planning*** – simple scheme - square, rectangle, circle; complex scheme - a rectangle with arched walls, a rectangle with rounded corners; free planning;
- ***shaping*** - building-cube, building-parallelepiped, building-dome, building-cylinder, building-module, building-capsule, complex

architectural form, bionic form, free form, constructions of arbitrary form;

- ***building construction technology:***
  - printing of the whole building;
  - printing of building elements, assembly of elements;
  - printing of the building in parts;
  - printing of separate blocks;
  - printing of individual panels of complex shape, assembly;
  - printing of modules, assembly of modules;
  - printing by Batiprint3D method - 3D printing "from within";
- ***building materials:***

- cement mortar with additives;

- formwork of foam material that insulates the layer and structures the layer;

- special concrete mix;

- natural mixtures from soil taken from the surrounding area, as well as wastes from rice production, such as shredded straw and rice husks;

- cement mortar reinforced with fiberglass;

- a mixture of construction waste, including glass, steel, cement;

- a mixture of cement and construction waste with the addition of hardener;

- printing materials: soil, polyurethane foam, sand, cement, gypsum.

6.5. Building structures for 3D-Printing

Features of construction 3D-printers create wide opportunities for shaping and configuration of building structures, by varying:

• thickness of walls, floor slabs, jumpers and other structural elements;

• thickness, height, material of the printed layer of concrete;

• multi-chamber structure and cross-sectional shapes.

Construction 3D-printer is able to form the walls of the future building of a curvilinear shape, with sharp and obtuse angles, curves and curves of any radius, which greatly expands the range of architectural solutions.

Foundations. The design of foundations for load-bearing walls, formed by the method of 3D printing, should be performed in accordance with the requirements of regulations on the design of foundations and foundations of buildings and structures. No specific requirements for the construction of foundations in the design of houses by 3D printing were found.

Walls. When designing buildings by 3D-printing,it is necessary to provide planning solutions with a uniform and symmetrical arrangement of elements relative to the central axes. It is not desirable to accept asymmetric schemes that allow torsional forces. It is recommended to design houses with longitudinal and transverse load-bearing walls. Walls erected with the help of construction 3D printers can be external and internal, load-bearing, self-load-bearing and non-load-bearing, single-chamber and multi-chamber. The proposed design solutions for load-bearing walls for 3D printing are shown in Fig. 6.11.

The example of load-bearing walls presents the main cross-sectional options that are used for most structures made by 3D printing. They can differ in cross-sectional width, thickness of the concrete layer, number of internal partitions, thermal insulation material, the presence of sound insulation materials, the presence of flexible connections and air inclusions filled with insulating materials or concrete. A prerequisite for determining the thickness and structure of the wall structure is its compliance with the requirements for load-bearing capacity and stability, as well as thermal and sound insulation conditions.

Both traditional steel and composite reinforcement is used for reinforcement of wall structures, from which a spatial reinforcing frame is formed by installing vertical and horizontal rods (Fig. 6.12). In addition, reinforcement with different types of fiber is widely used in 3D printing structures. Comparison of the characteristics of different types of fiber for reinforcing structures on the technology of 3D printing is given in table. 4.1 [4, 5].

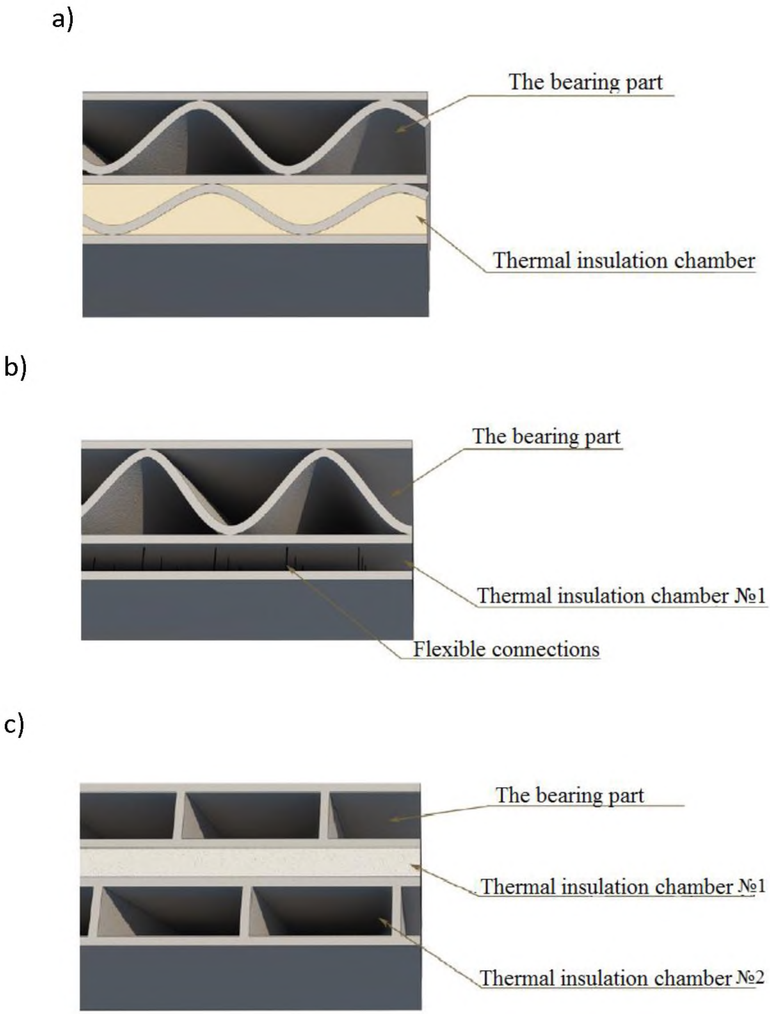


Fig. 6.11. Structural solutions for load-bearing walls for 3D printing [6]: load-bearing wall with thermal insulation; b) load-bearing wall with air connection and flexible connections; c) load-bearing wall with two heat-insulating chambers

Overlapping. Slabs and coverings can be prefabricated (traditional or printed using a 3D printer), as well as monolithic.

The depth of support of prefabricated reinforced concrete slabs on load-bearing walls must be at least 120 mm. Reinforcement plates should be provided in the floor slabs for connection to the anti-seismic belt. To evenly redistribute the load on the wall, it is recommended to support the slabs through a concrete cushion - 60 mm thick, which, if necessary, is formed by a 3D printer using a continuous multi-row layer of concrete and reinforced between the layers with composite reinforcement mesh.

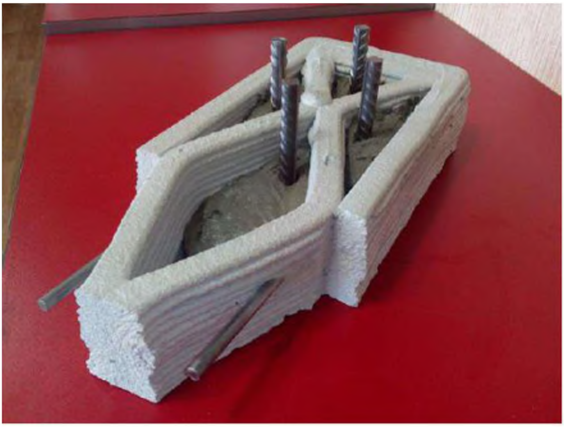


Fig. 6.12. Fragment of a 3D printing structure with vertical and horizontal reinforcement with steel reinforcement [7]

When installing a monolithic floor at the junction with the walls, it is necessary to arrange substrates that prevent concrete from entering the wall cavity.

Roofing. Roofs of buildings should be designed from light materials and structures. Load-bearing structures of pitched roofs must have the necessary spatial rigidity and exclude the possibility of transmitting to the walls of the expansion forces, for which it is recommended to use expansion structures. The use of flat roofs with internal and external gutters is allowed. The base of the roof with necessary slopes for gutters can be made by 3D-printing as a separate structural element.

Window and door openings. Supporting surfaces of window and door openings are formed by the 3D printer by means of a continuous multirow layer of concrete on a substrate from a composite or metal grid. To do this, when creating a 3D model of the object, you must additionally specify these layers. The side faces of the holes are formed in the process of printing the next layer.

It is recommended to use jumpers over window and door openings using a 3D printer, but you can use ready-made reinforced concrete jumpers. To print ready-made reinforced concrete bridges, the location of the bridges should be specified in advance in the 3D model of the object, and the depth of support in the holes of the inner and outer walls should be at least 100 mm. The design parameters of the jumpers are assigned based on the results of calculations, depending on the size of the hole and the actual loads.

Utility system. When designing a building in a 3D model, technological vertical niches and openings for the installation of water supply and sewerage should be provided, and in places of their horizontal laying, installation should be carried out on the surface of walls or ceilings. Wiring is mounted in the cavities of the wall chambers. To do this, when forming a 3D model of the building in the last inner layer, technological channels and holes for wiring must be provided. To install ventilating mines, it is recommended to use cavities in structure of walls.

Exterior and interior wall decoration. Wall structures must be protected from moisture in places of intense moisture and in horizontal areas (window sills, parapets, areas adjacent to the coverings of the visors, supporting balcony slabs and architectural elements). The untreated surface of the walls may be painted or treated with hydrophobic solutions. Operation of an untreated surface of walls, but with impregnation with a hydrophobic solution - is allowed for buildings of any purpose of all degrees of durability. Plastering of walls, painting on plaster, plastering and painting on a layer of insulator, facing or installation of hinged front systems are also allowed.

3D-PRINTING – CHECK LIST

Marker	*Description*
Additive technologies	is the form of production technologies, where a three-dimensional object is created during a computer controlled process by depositing materials, usually in layers.
3D printing	is a method of creating a three dimensional object layer-by-layer using a computer created design.

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GLOSSARY OF DESIGN TERMS FOR TRIPLE-ZERO ECO-BUILDINGS

Sustainable development in construction	- ensuring the safety and favorable conditions of human life in the implementation of urban planning, limiting the negative impact of economic and other activities on the environment and ensuring the protection and rational use of natural resources in the interests of present and future generations.
Energy-saving	-implementation of legal, organizational, scientific, technical and economic measures aimed at efficient (rational) use (and economical consumption) of fuel and energy resources and the involvement in the economic turnover of renewable energy sources.
Energy-efficiency	- efficient (rational) use of energy resources. Use less energy to provide the same level of energy supply to buildings or processes.
Energy efficiency class	- the level of energy efficiency of the house in the range of values of the specific consumption of thermal energy for heating the house during the heating period.

Energy passport of the building	- a document containing the geometric, energy and thermal characteristics of the house, designed or operated, the thermal insulation of the house, and establishes their compliance with the requirements of regulatory documents.
Environmental efficiency	-results of management of ecological aspects of the organization.
Environment	-a set of components of the natural environment, natural and natural-anthropogenic objects, as well as anthropogenic objects.
Impact on the environment	-any change in the environment of a negative or positive nature, in whole or in part resulting from the environmental aspects of human activities.
Natural lighting	- lighting of premises by the daylight (direct or reflected) penetrating through light apertures in external enclosing designs.
Investment value	-the cost of capital expenditures on a construction project.
Operating cost	- annual operating costs for the maintenance of the building.

Use of natural resources	-involvement of natural resources in economic turnover throughout the life cycle of the object.
Insolation	-irradiation of surfaces and spaces with direct sunlight.
Indoor microclimate	-the state of the internal environment of the room, which has an impact on a person, characterized by indicators of air temperature and enclosing structures, humidity and air mobility.
Minimum environmental requirements	-environmental requirements established in legislative and regulatory documents.
Sanitary protection	-a set of measures to preserve sanitary and sanitary-epidemiological safety in the area.
Operation waste	- residues of substances, materials, objects, products, and goods partially or completely lost their primary consumer properties for direct or indirect use due to physical or moral wear and tear in the processes of social or personal use (life), operation.
Waste separation	-mechanized treatment of inhomogeneous waste, which aims to separate them into homogeneous components.

Utilization	- types of work to ensure resource conservation (taking into account the requirements of ecology and safety), in which processing and / or reuse of expired and / or rejected products, materials, packaging, etc., as well as technological waste and secondary materials is carried out.
Waste utilization	- activities related to the use of waste at the stages of their technological cycle, and / or ensuring the re (secondary) use or processing of decommissioned products.
Wastewater	- any atmospheric water or precipitation and irrigation water diverted to reservoirs from industrial enterprises and inhabited locations through the sewerage system or by gravity used in this field.
Thermal energy efficiency indicator	- the ratio of the estimated specific consumption of thermal energy for heating and ventilation of the building to the minimum standard specific consumption of thermal energy for heating and ventilation of the building.
Meter	-technical means intended for measurements which meets the obligatory metrological requirements.

Adjacent territory	- land within the established limits and the residential building located on it, other real estate objects, where separate parts intended for residential or other purposes (premises) are in private, state, municipal and other forms of ownership, and other parts (joint property) are in joint ownership.
Natural resources	- components of the natural environment, natural objects and natural-anthropogenic objects that are used or can be used in economic and other activities as sources of production and consumer goods and have consumer value.
Renewable energy resources	-energy from sources that are inexhaustible on a human scale. The basic principle of using renewable energy is to extract it from constantly occurring environmental processes and provide it for technical use. Renewable energy is obtained from natural resources, such as sunlight, wind, rain, tides and geothermal heat, which are renewable (replenished naturally).
Secondary energy resources	- wastes from production and consumption reused with the release of heat and / or electricity.
Building engineering systems	-heating, ventilation, air conditioning, hot water and electricity supply systems.

Environmental sustainability	- an integrated category that characterizes the maximum satisfaction of human needs in the building as an environment for his life with minimal impact on the environment and consumption of non-renewable resources throughout the life cycle of the property.
The cost of the life cycle of a building or structure	-the total cost of the period during which engineering surveys, design, construction (including conservation), operation (including current repairs), reconstruction, overhaul, demolition of a building or structure are carried out.
Specific annual consumption of thermal energy for the hot water supply system	-the amount of thermal energy for hot water supply per square meter of apartment area or usable area of a public building.
Specific annual energy consumption for the air conditioning system	-the amount of energy per year consumed by the air conditioning system, per square meter of apartment area or usable area of a public building.
Specific consumption of thermal energy for heating and ventilation of the building during the heating period	- the amount of useful thermal energy for the heating period spent on compensation of heat losses of the building, taking into account air exchange and additional heat emissions at normalized parameters of

	microclimate of premises in it, referred to the unit area of apartments of the house (or heating area of one-apartment houses) and degree - days of heating.
Specific annual consumption of electricity for lighting	- the amount of electricity per year consumed by the building for lighting, referred to the floor area of the apartments of the building or the usable area of the public building.
Specific annual electricity consumption for power supply of engineering systems	- the amount of electricity per year consumed by the building for the power supply of engineering systems, attributed to the floor area of the apartments of the building or the usable area of the premises of the public building.
Environmental requirements	-requirements aimed at ensuring the rational use of nature, environmental protection, protection of human health and genetic resources.
Ecological certification	- activities to confirm the compliance of the object, which is certified, to the proposed environmental requirements.
Ecological certificate	- a document issued in accordance with the rules of the environmental certification system, certifying compliance with certain environmental standards and requirements of finished products, production technology and life cycle in general.

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Green technologies and 3D-printing for a triple-zero concept in construction

Monograph

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This book explores the issue of global construction industry challenge in the context of sustainability, based on environmentally friendly building design; important check lists for each implementation stage of ecological and energy-efficient autonomous structures; and propose the strategy for Triple Zero ecological buildings development Architects and engineers, university lecturers, researchers, students and other individuals will find this monograph useful to raise their awareness and improve knowledge in the field of sustainability in construction and real-life implementation of its principles in building design.

The BOOK was prepared by a team of young scientists SHEI "Prydniprovska State Academy of Civil Engineering and Architecture":

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