The possibility of building a living environment in the Arctic zone of Russia based on artificial ecosystems

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Abstract. The article proposes to use artificial ecosystems to create comfortable and safe living conditions in the Arctic region. The principles of the organization of artificial ecosystems – bioregenerative systems of human life support – are formulated. A brief information about the history of the development of experimental installations and the experiments to find people in isolation from the external environment is given. The scheme of an artificial ecosystem is described, which includes equipment and technologies that make it possible to provide isolation in terms of respiration, water circulation, and human nutrition. The concept of an autonomous non-volatile and environmentally independent module for creating a favourable living environment in the Arctic is described. An example of the implementation of a similar project for the construction of an autonomous module designed to support the livelihoods of the inhabitants of the ecovillage Syuderbin (Gotland Island, Sweden) is given.

1. Introduction
“Fundamentals of the State Policy of the Russian Federation in the Arctic” notes the difficulties of the development of the northern territories, consisting in the extreme climate, the absence of productive ecosystems, remoteness from the resource, medical, educational, and cultural centres of civilization.

For sustainable development of arctic and arid deserts, Mark Nelson and others [1] proposed the use of new life support technologies based on the creation of artificial ecosystems (AE). When creating a human habitat in the form of AE, the main thing is to organize closed internal material flows and ensure the cyclic reproduction of necessary resources and disposal of the resulting waste, just as it happens in the global ecosystem of the Earth – the biosphere.

Therefore, it is relevant to develop a residential module that allows people to live on the basis of their own energy supply and the isolation of internal material flows. Such a residential module will provide:
– safe and comfortable living of people in a favourable environment, which will preserve the psyche, health, and work capacity of workers and military personnel in the Arctic;
– long-term autonomous existence of the living environment, which guarantees the survival of people when supplies from the «mainland» are cut off in case of emergencies at transport and resource-supplying infrastructure;
– reducing the supply of resources intended to maintain the functioning of the habitat, which will reduce the cost of purchasing and transporting food and energy resources to ensure the life of people in the Arctic.
2. Methods

According to A.S. Kerzhentsev, an artificial ecosystem is a closed autonomous bioregenerative life support system (BLSS), the closing link of which in all physicochemical and biological processes is a person [2]. Bioregeneration means that, unlike life support systems based on simple physical and chemical processes, the production of resources necessary for a person—oxygen, fresh water, food, and the disposal of the resulting waste occurs with the participation of the functions of “living matter”, that is, organisms of various biological species—plants, animals, and microbes.

The creation of BLSS began in 1964 at the Krasnoyarsk Institute of Biophysics, Siberian Branch of the Academy of Sciences. In 1972, work was launched on the «Bios-3» installation, which included experiments to completely isolate people from the external environment. Experiments have proved the possibility of obtaining the nutrition, oxygen, and fresh water necessary for a person from biological species located inside the test complex [3].

Since then, artificial ecosystems have been built in America, Japan, and China. The experiment “Biosphere-2” was carried out in the USA in 1984-1993 in a sealed complex located on an area of 1.27 hectares and having a volume of more than 200 thousand cubic metres, inside which aquatic and terrestrial ecosystems of the biosphere were artificially recreated: a mini-ocean with an artificial reef made of coral, tropical rainforest—jungle, savanna, woodland of thorny plants, desert, freshwater, and salt swamps [4]. From 1998 to 2001, studies were carried out in Japan at the Closed Ecological Experimental Facility (CEEF), in which the possibility of creating closed cycles of gas exchange, water circulation, growing plants, and breeding domestic animals was studied [5]. In 2014, tests began at the Chinese complex “Yuegong-1” (Lunar Palace), where experiments are being conducted on the long-term stay of people in conditions of 99% closeness of internal flows of matter [6].

At the present time, it is possible to formulate the basic principles of creating closed AE, which allow ensuring human life within the BLSS. The maintenance of gas exchange is provided by the presence of microalgae and a phototrophic link, which includes higher plants. Water circulation is ensured by the presence of a biological anaerobic pollution control system. Nutrition is provided by the constant reproduction of edible plant biomass in phytotrons and by aquaculture. Waste disposal takes place by composting the formed organic matter to obtain nutrients for the grown plants.

Based on the achievements in the field of creating IE, a scheme was drawn up of a closed circulation of matter inside an autonomous residential module, designed to create a living environment in the Arctic (Fig. 1). The system includes a phytotron for growing higher plants that provide the plant part of the diet of the inhabitants of the module, a system for utilizing organic waste with the formation of a soil-like substrate, an anaerobic biological wastewater treatment system, as well as a microalgal cultivator that produces oxygen necessary for breathing and desalinates water. Also, the AE provides for the possibility of aquaculture cultivation by using recycled water and food waste, growing mushrooms on a soil-like substrate, and planting halophytic flora in purified water—edible saltwort plants to remove excess salt and return sodium chloride to the human food chain [7].

For the functioning of AE, energy supply from the outside is required. The power supply of an autonomous residential module can be organized using solar, wind, geothermal, tidal, and biochemical energy. Currently, new types of devices have been developed for more efficient use of the energy of the Sun, air, water, and biomass. The choice of a specific type of natural energy resource and the type of electric generator used is determined by the characteristics of the territory of the planned module location.

Microbial fuel cells [8], in which electricity is generated by microorganisms, capable of carrying electrons during their metabolism, can become a universal source of energy supply for AE. The biochemical processes occurring in this case are similar to those that occur under anaerobic conditions during wastewater treatment, which in the future allows combining the functions of generating electricity and utilizing organic waste in one device.
3. Results
At the Bauman Moscow State Technical University (BMSTU) in 2016, the concept of an autonomous residential module was developed for use in the Arctic zone of Russia [9]. For modules located in the polar zone, wind generators are most suitable, since strong, often repeated winds are characteristic of the arctic deserts. It is most advisable to use flying wind generators such as Buoyant Airborne Turbine (BAT) and the “flying wing” Wing 7 [10].

As food plants of the phototrophic link, it is necessary to use species that do not require “night rest”, i.e. capable of photosynthesis of biomass under 24-hour lighting. In experimental greenhouses, the following varieties have already been studied quite well: dwarf spring wheat of the selection line 232, lettuce “Mizuna”, green onions, tomatoes “Minibel”, sweet pepper “Sweetie”, and the oilseed culture of chufa. Plants can be grown in a phytotron using a conveyor belt of different ages under artificial lighting conditions. It is advisable to use white Bridgelux LED arrays as a light source. As the lower plants of the phototrophic link, to ensure closed gas exchange in photobioreactors, green microalgae – chlorella can be cultivated.

To organize a closed water circulation, you can use the anaerobic method of biological wastewater treatment from organic matter. In the process of multistage microbial methane fermentation, complex organic substances are converted into simpler components, a significant part of which then goes into biogas (a mixture of CH₄ and CO₂), a solution of mineral salts and activated sludge. The generated methane can be used for back-up energy and heat supply to the module using microturbine installations with the function of heat recovery by heating water, which will provide hot water supply.
It is advisable to use the dome-shaped structure developed by R. Buckminster Fuller as the construction of the module for placing the IE. Fuller’s dome consists of a symmetrical grid of flat elements (triangular, quadrangular, and hexagonal) superimposed on a spherical surface.

The calculations have shown that to ensure the life of 20 people, 200 kW of electrical power is required, obtained, for example, from a wind generator. For backup power supply and hot water supply of the module, two microturbine units with a capacity of 100 kW each can be used. Accumulator battery, consisting of 50 thousand pieces, will support the autonomous power supply of the module (including phytotrons) for a week.

Using 900 pcs. LED arrays with a power of 200 W each for illumination of phytotron will provide the inhabitants with plant food, which, together with the additions of canned beef, fish, and lard, will make a diet with a nutritional value (ratio of proteins, fats, and carbohydrates) of 1.3: 1: 3.7 close to optimal (1: 1: 4). Utilization of inedible plant parts can be done by the microbiota of the forming soil-like substrate. Spherical methane tank is capable of completely purifying 350 litres of water per day. To ensure the provision of oxygen to the inhabitants and the removal of carbon dioxide, 15 cavity photobioreactors, with a volume of 250 litres each, in which Chlorella vulgaris is cultivated, can be used.

A hemispherical dome with a radius of 6.87 m will make it possible to place inside it a cylindrical phytotron 5 m in height and with a base radius of 3.25 m. The base of the dome is fixed to the ground using screw piles. It is necessary to use cold-resistant steel as a material for the dome structure, and for the dome lining – polyethylene foam (“foam lone”) – a strong and elastic, foamed multilayer, physically cross-linked material with very high thermal insulation.

A similar project is already being implemented in Sweden, in the ecovillage Suderbin, located on the island of Gotland. The plant is called Closed Loop Baltic (CLB) and is a self-contained closed module that eliminates the flow of agricultural and household organic pollutants in the Baltic coastal areas, which will improve the ecological state of the sea and prevent further destruction of aquatic ecosystems [11].

For the construction of an autonomous module that ensures the livelihoods of eco-settlers on the island of Gotland, all proposals of the project of the BMSTU 2016, except for the cultivation of chlorella and aquaculture. The CLB project uses a wind turbine to generate power, which was independently manufactured by the residents. To produce plant nutrition, several tubular aeroponic towers were installed with a height of 4 to 7.5 m, which made it possible to organize a spiral conveyor of different ages for various types of edible plants.

To organize a closed water circulation in the CLB, an anaerobic method of purifying wastewater from a wide range of organic substances is used using methane fermentation in digesters. Biocomposting processes are used to utilize organic waste and form a soil-like substrate.

As a structure for placing the module equipment in the CLB project, a Fuller dome structure was made, consisting of a symmetrical mesh of flat triangular elements. The entire dome consists of five types of elements; therefore, such a structure, shown in Figure 2 is called “Pentad”.

![Figure 2. Dome structure of the module: (a) the project of the BMSTU; (b) CLB project.](image-url)
4. Conclusion

To understand the principles that make it possible to create a living environment based on IE, it is necessary to introduce universal environmental education and upbringing. Therefore, participation in the implementation of projects similar to the development of the autonomous module described in the article can become an important element in the training of not only ecologists, but also students of other directions, both technical and humanitarian.

The practice of the successful construction of a prototype of an autonomous non-volatile and environmentally-independent module to support the life of the community of the settlement of Syuderbin by the residents themselves and volunteers involved in educational projects by the community of several universities shows that it is quite possible to create a prototype of an autonomous residential module at the expense of its own scientific and educational organizations.

When placed on the ground, the module can be connected by transitional vestibules with other residential, household, social, administrative, technical, and storage modules, which allows assembling large enough settlements from separate modules. In such ecovillages, in addition to ensuring the isolation of internal material flows, it is also necessary to create a sphere of employment for the population and organize a social environment to maintain the normal psychological state of residents.

Building a living environment based on AE will allow not only ensuring comfortable living of people in areas with extreme climates, but also achieving zero emission of pollutants and reducing anthropogenic impact on the natural environment. It will save the unique ecological systems of the Arctic and minimize the impact on the global climate and the biosphere of the planet generally.

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