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Implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia

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Abstract. Special climate conditions and out-of-date energy system at the urban territories of the Arctic zone of Russia reinforce the need for the development of a new concept for the implementation of energy efficient smart technologies at these territories. In this regard, the article is focused on identifying the prospects for the development of the energy sector of the urban territories of the Arctic zone of Russia with the involvement of smart technologies. Methods of the study include system analysis and modeling, which allow authors to consider the prospects of implementing energy efficient smart technologies in a comprehensive manner. Article suggests the interpretation of the **concept** of "energy efficient smart technologies" determines the priorities and introduces the models for the implementation of these technologies at the urban territories of the Arctic zone of Russia. The proposed concept and models were developed taking into account the modern information and communication infrastructure of the given territories. Particular attention was paid to the complex of characteristics influence the implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia.
Keywords: energy efficiency, smart technologies, Arctic zone of Russia, biofuel, renewable energy source

1. Introduction

Russia can become the first country where energy efficient smart technologies will be implemented by the order of the government, and not at the initiative of municipalities or IT companies. According to Otis O., Ponamareva L., Isahi A., legislative and technological prerequisites for this have been created [1].

At the same time, the process of ubiquitous implementation of energy efficient smart technologies, using common tools, may not be effective, taking into account the climatic and environmental specifics of the urban territories of the Arctic zone of Russia. This zone includes 8 subjects of Federation: Murmansk and Arkhangelsk regions; Republic of Komi and Yakutia; Krasnoyarsk region; Nenets and Yamalo-Nenets Autonomous Districts, Chukotka Autonomous District.

All cities of the Arctic zone has harsh climate. The average summer temperature is about 0 ºC, and average annual temperature is negative. Most of these cities are located on the coast of the Arctic seas or in the immediate vicinity of it, as well as in the lower part of the rivers flowing into the Arctic Ocean.

Authors consider some cities as the most prospective for the implementation of energy efficient smart technologies. Among them Murmansk (325,000 inhabitants), Norilsk (205,000 inhabitants), Vorkuta (85,000 inhabitants), cities of Yakutia and the Krasnoyarsk region, mono-cities of the Arkhangelsk region (Severodvinsk, Novodvinsk, Onega), and the city of Monchegorsk, Murmansk region.

Currently, these cities are the objects of research of many scientists from the prospective for the sustainable development, and some projects are already under implementation.

One of the large scale projects is "Arctic Partnership for International Research and Education: Promoting Urban Sustainability in the Arctic" (2015–2021), funded by the National Research Foundation of the United States.

Research in this project is already being provided by a number of US universities (The George Washington University, University of Northern Iowa, Cedar Falls, University of Alaska, MIT, University of Virginia) with the participation of many partners around the world, including the University of Helsinki, University of Saskatchewan, Norwegian Institute of International Relations, University of Tromse, St. Petersburg State University, Kola Scientific Center of the Russian Academy of Sciences, Institute of Geography of Moscow State University, SOPS, State Hydrological Institute of the Russian Federation.

In the next two years Russian scientific center "Skolkovo" together with the Department of Urban Planning and Research of the MIT International Science and Technology Initiative will implement a project focused on the Urban Sustainable Development Index of the Arctic.

This Index will provide an opportunity to assess different aspects of the development of the cities of the Far North in a uniform way, such as the effects of climate warming, the cyclical nature of the resource economy development, the level of social tension, and others; compare the Arctic cities among themselves on a single scale and make recommendations on the application of city policies.

Many of the existing studies consider the possibility of implementation of energy efficient smart technologies for the development of Arctic cities, but the concept of this process remains virtually undeveloped.

Authors of this paper developed new definition of the category "energy efficient smart technologies" as a set of technical decisions and methods aimed at:
- optimization of energy consumption;
- automation of an intelligent energy network;
- formation of a flexible energy distribution system;
- intellectualization of the control and regulation of demand;
- integration of renewable energy sources.

Also, term "energy efficient smart technologies" includes the software and hardware for managing an intelligent power grid or energy efficient buildings and structures.

2. Priorities for the implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia

The research company Frost & Sullivan for 15 years has been analyzing the practice of creating the smart cities around the world. In 2016 Frost & Sullivan formed the list of the main city improvements reached through smart technologies implementation. These list includes reducing harmful emissions, creating a scalable and flexible urban environment, increasing security level and level of resource saving and energy efficiency, providing social support and universal access to the information, improving logistics and transportation, formation of rational supply chain management, etc. [1].

The analysis of the provisions of the Federal "Strategy for the development of the Arctic zone of the Russian Federation and ensuring national security for the period until 2020" suggests that the urban infrastructure of the Arctic regions is in need of smart technologies in the sphere of:

- ensuring environmental safety (this aspect also included in the National Public Standard, a public agreement of the population of cities, businesses and authorities on preserving the ecological structure of territories [2]);
- ensuring the safety of the population, including the development of a system for monitoring the geophysical situation in Arctic cities;
- monitoring the use of renewable and alternative energy sources (taking into consideration local recourses);
- power supply management;
- management of energy distribution, including nuclear power plants energy (for example, the Kola NPP with VVER-440 units in the Murmansk region [3]);
- advancing telecommunications;
- formation of information intelligence centers in the cities.

The strategy for the development of the Arctic zone implies a transition from centralized power supply systems to a distributed networked intellectual energy systems, which is impossible without implementation of smart technologies at the energy sector.

Nowadays the most promising for the urban territories of the Arctic zone of Russia looks the implementation of energy efficient smart technologies at multi-apartment buildings.

3. Characteristics of energy infrastructure of the urban territories of the Arctic zone of Russia

The Arctic region of Russia as a whole could be described with the following characteristics:

- high energy intensity and low efficiency of extraction of natural resources, high cost of manufacturing, and lack of effective compensation mechanisms, low labor productivity;
- underdevelopment of the energy system, as well as irrational structure of generating capacities, high production costs of generation and transportation of electricity.

At the same time, according to the estimates of the Ministry of Energy of the Russian Federation, the Murmansk region is one of the leaders in the energy efficiency rating of the Subjects of Federation. Basically, such results have been achieved through extra budgetary sources, using the mechanism of the energy service contracts. Now the cities of the Murmansk region develop bioenergy sector, focused on using local biofuels (wood waste and peat) [4].

The rating of energy efficiency in the regions of the Arctic zone is presented in Figure 1.

The city of Monchegorsk will perform as a pilot territory for the implementation of bioenergy sector development projects in the Murmansk region.

At the same time, another related projects are under implementation in Kodinsk, Krasnoyarsk Region. The city heating infrastructure predominantly using electricity, one of the most costly and scarce energy sources in the Arctic zone. At the moment, an electric boiler-house with a total heat capacity of more than 110 GCal per hour is operating in Kodinsk at a peak load of not more than 55 GCal per hour. This project allowed a partial replacement of the existing electric boiler house with a bio-boiler that operates on wood waste, secondary unclaimed product of sawmilling and timber processing.

New project with total investments of 354 500 thousand rubles is aimed at the construction of a biofuel water-heating boiler with capacity of 20.0 MW. Expected useful heat supply (from collectors) is 105 055 GCal per year. The cost of raw materials (chips) is 63.5 rubles per cubic meters, including VAT. This is an example of successful financing of an energy efficient project at the expense of credit resources.

According to researches of Russian scientists, development of renewable energy sources at the urban territories of the Arctic zone of Russia has big prospective. First of all, we are talking about solar and wind energy. Considering the remoteness of cities in the Arctic zone, from each other, autonomous energy generation infrastructure, including alternative energy sources, becomes especially important. These can be autonomous combined power plants, urban nuclear power-technological complexes, etc. For these objects implementation of smart technologies for the automation of data collection from alternative energy systems becomes urgent.

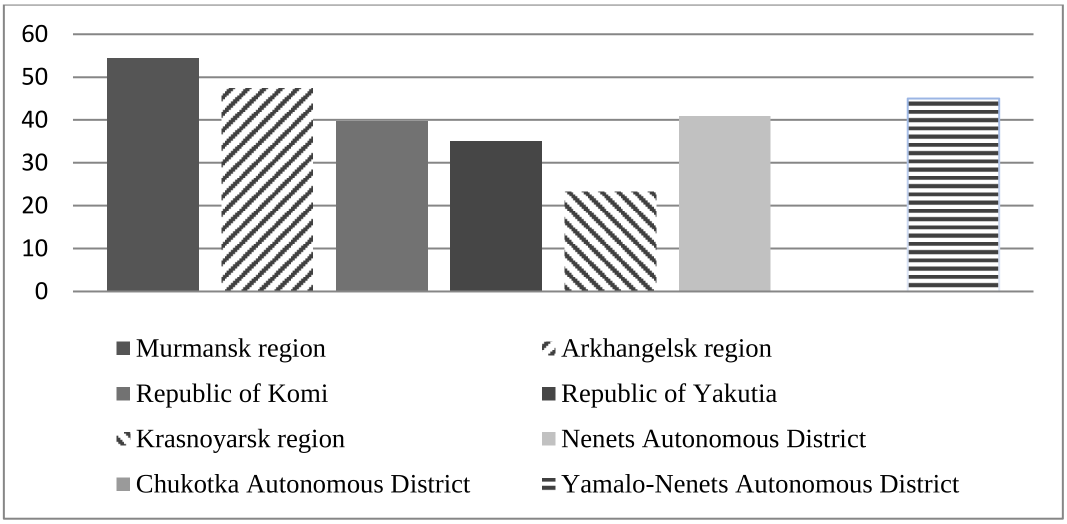

Figure 1. Rating of energy efficiency in the regions of the Arctic zone as of January 1, 2017
Source: compiled by authors based on the official data at www.energy.s-kon.ru

Belugin A.V., Lagunov A.Y. and Pozdeev V.A. emphasize the need to introduce a smart monitoring system of alternative energy sources in the Arctic [5].

Currently, Russia has developed a system of intelligent control with advanced adaptation and diagnostic functions. This system implements elements of artificial intelligence in the form of blocks for predicting the states of jointly operating subsystems, and has been recommended by experts for the urban territories of the Arctic zone of Russia [6].

The experience of implementation of energy efficient smart technologies in multi-apartment buildings has already been obtained in Yakutia. Three-storey "smart homes" have increased insulation; energy-efficient windows are installed everywhere. Six of these homes use heat from three autonomous block-modular gas boiler houses, the rest of them get heat centrally, but they have automatic electronic units that clearly react to temperature changes and support it in the set parameters inside the house. Hot water is heated through solar collectors, and the emergency power system operates on solar panels, all houses also have a ventilation system. Another important detail is that the tenants themselves can regulate the microclimate in the apartment.

Residents of "smart homes" pay only for cold water, saving on hot water about 50 %, and 25 % on heating. The payment goes according to the actual consumption of resources, not to average norms as in the city of Yakutsk or in Yakutia in general [7].

4. Models of implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia

The analysis of market of energy efficient smart technologies based on theoretical and methodological sources allowed the authors to develop two models of implementation of those technologies at the urban territories of the Arctic zone of Russia:

1. A basic model, when energy efficient smart technologies are implemented locally to solve a specific problem. In this case, there is a traditional way of planning and financing at the level of energy sector enterprises or multi-apartment buildings. Smart projects are carried out independently. The purpose

of the model is to prove the value of smart solutions, to show the benefits of investing in pilot energy efficient smart projects.
2. The growth model, when the state set up standards for the development of the energy efficient smart systems are approaches to data processing and management. The purpose of the model is to improve the results of the implementation of smart initiatives in the energy sector and to coordinate them at the city level.

Today, we can say that the basic model is implemented in Yakutsk, at the level of apartment buildings.

As part of the analysis, the authors developed complex of characteristics influence the implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia (Table 1).

Table 1. Characteristics influence the implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia

Characteristics	Suggested groups	Notes and examples
Localization level	Apartment building	Measuring instruments and devices (first of all, smart meters and smart sensors)
	City section	The experience was gained in Yakutsk, using alternative energy sources (solar energy)
	City	Provided at a single autonomous energy supply facility
Model of implementation	Basic model	Recommended by the authors for implementation at the level of apartment building or a city section
	Growth model	Recommended by the authors for implementation at the city level
Core of Energy concept	Renewable energy sources Small Nuclear Power Engineering Optimization of the use of traditional fuels	

Source: compiled by authors

Traditional devices, unlike smart meters and traditional counters with connected smart sensors, measure only the total amount of energy consumed and do not provide information of schedule of consumption. Using intelligent meters we can easily get such information. It allows responsible agencies to introduce groups of tariffs for consumption depending on the time of the day and season, and to organize monitoring of consumption. This leads to the reduction of unnecessary consumption of resources by end-users. It is known that a decrease in consumption for 1 kWh by the consumer saves up to 4–5 kWh of energy from the manufacturer. In the residential sector of Russia, the consumption of hot water and heating energy is up to 80–90 % of the total energy consumption. Therefore, smart meters and systems for monitoring consumption and saving water and heat are most relevant in smart homes and public buildings [8–10].

Practically in all Arctic cities, which are the objects of research, the tariff for energy is much higher than average in Russia. Climatic conditions, the need for fuel delivery lead to a natural rise in price, and most of the energy tariffs are subsidized. The introduction of smart meters and smart sensors will partly help to reduce the corresponding tariffs.

Based on analysis of the Russian market the best technical characteristics for implementation at the urban territories of the Arctic zone of Russia have the following devices: Counters "Matrix", AIIS KUE "Smart IMS", "Compact V", Automated Smart Metering System "Alpha smart AS1440", Counter "Light S" and others. Their difference lies in the fact that they fix and normalize significant differences in the supply of energy, operate at low temperatures, do not require a high-speed connection.

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An example of an engineering solution that can be implemented in the cities of the Arctic zone is smart energy technology, the implementation of which is justified by Kolosov R.V., Titov V.V., Titov V.G. [11].

As part of the state order, scientists analyzed smart technologies that allow to generate energy in parallel on the basis of wind turbines and solar batteries and from small-scale power systems.

This approach allows to obtain constant energy, regardless of the climatic conditions of a particular period. The intellectual energy system in this case predicts the energy consumption in the network, estimates the economic benefit from the use of a particular source in a certain period of time, and automatically decides on the choice of that one.

This smart technology is based on the use of the algorithm of the increment of conductivity. The main advantage of the method of additional conductivity over the random perturbation algorithm is that it can calculate the direction to change "working point" for absorbing solar energy. This change could be short-term or long-term. Therefore, with a sharp change in illumination, the operation of such an algorithm will not lead to an erroneous choice of the direction of the changes.

The scheme of operation of the conduction incremental algorithm used in the analyzed smart technology is shown in Figure 2.

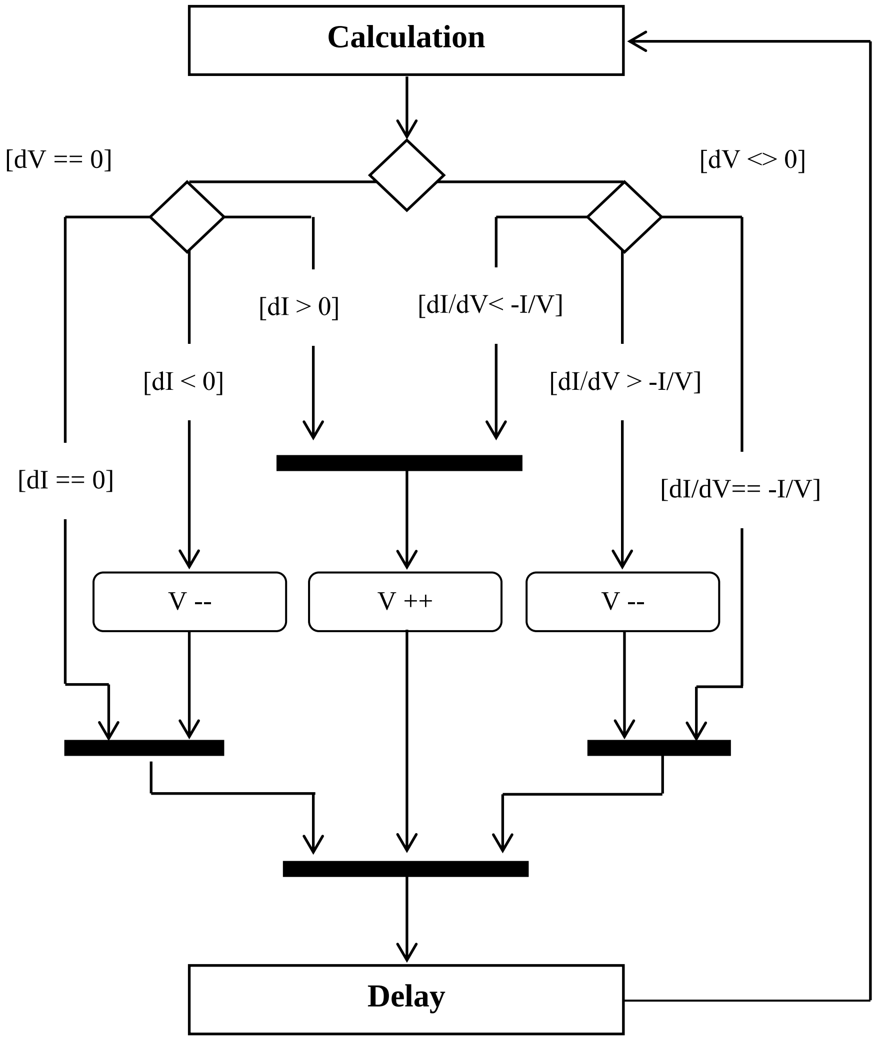

Figure 2. The scheme of operation of the conduction incremental algorithm
Source: compiled by authors based on the [11]

It should be noted that in the Arctic zone the daily intake of direct solar energy according to NASA SEE data varies from 3 to 5 kWh per sq. m per day or 0.7 to 1.8 kWh per sq. m per day (from 60 to 150 kg of fuel equivalent per sq. m per year). For comparison, we note that the average daily supply of solar energy in southern Germany, where solar installations are widely used, is only about 3.4 kWh per sq. m per day.

5. Efficiency of the use of the proposed energy efficient smart technologies for sustainable development of the urban territories of the Arctic zone of Russia

Under the concept of sustainable development of the cities, considered technologies assume either the effective use of traditional energy resources (resource-saving, energy efficiency) or the use of renewable energy sources, instead of traditional ones. This aspect allows us to speak about very positive environmental characteristics of energy efficient smart technologies, and about the observance of main principles of sustainable development.

In addition, the introduction of these technologies can contribute to the economic growth of cities, as their use will free up part of the budget funds spent on electricity and heat supply of public facilities.

To calculate the budgetary efficiency of the considered energy efficient smart technologies (E_B), the following formula was proposed and used:

$$E_B = \frac{\sum_{i=1}^{t}\left(BR_i + BS_i - BE_i\right)}{BI \cdot (1+\frac{r}{100})^t}, \quad (1)$$

where BR_i – expected budget revenues for the urban territories of the Arctic zone of Russia from the implementation of energy efficient smart technologies for year “*i*” of the considered period, thousand RUR;
BS_i – budget savings for the urban territories of the Arctic zone of Russia from the implementation of energy efficient smart technologies for year “*i*” of the considered period, thousand RUR;
BE_i − expenses of the city budget for the implementation of energy efficient smart technologies for year “*i*” of the considered period, thousand RUR;
BI − initial budget investments in launching technology in a particular city, thousand RUR;
r – the refinancing rate established by the Central Bank of the Russian Federation for the time frame of expenses, %;
t – considered period for budget efficiency, from t_{min} = 1 year to t_{max} = planned period of use of energy efficient smart technologies in the territory of a particular city.

The use of energy efficient smart technologies at the Arctic Territories of Russia should be considered effective if, as a result of calculating the budgetary effectiveness, the result is ≥ 0.

The technical efficiency in the framework of the given study is understood as the property of an energy efficient smart technology to convert costs into effects, taking into account the compliance of a technical solution with its goal.

Summary results of the evaluation of the effectiveness of the energy efficient smart technologies considered or effects assessed in the context of the concept of sustainable urban development are presented in Table 2.

6. Concept of implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia

At the current stage of development of the information and communication infrastructure of Russian Arctic cities, it is possible to propose a concept for the implementation of energy efficient smart technologies (Figure 3).

Table 2. Assessment of the effectiveness of the implementation of energy efficient technologies at the Arctic Territories of Russia

Name of energy efficient smart technologies	Budgetary efficiency for the city (the aspect of economic growth)	Improving the quality of life of urban population	Environmental characteristics	Technical efficiency
Biofuel water heating boiler house	+ (1,23), calculated on the example of the city of Kodinsk	+ uninterrupted supply of heat energy and hot water, regardless of the supply of traditional fuels	+ "zero waste"	+ expected useful heat output is 105,055 Gcal/year
Management of intra-urban energy distribution, including those allocated by nuclear power plants	+ (≥ 1)	+	+ preserving clean air and water	+ reduction of energy use: ≥ 10%, but ≤ 17%
Smart-meters and Smart-sensors	+ (от 2-5), calculated for electricity meters "Matrix", AIIS KUE "Smart IMS", "Compact V", automated Smart Metering System "Alpha smart AS1440", electricity meters "Light S"	–	–	+ reduction of energy use: ≥5 %, but ≤ 47%
Low-power power systems that combine wind turbines and solar panels	+ (≥ 1)	+	+ "zero waste", preserving clean air and water	+ reduction of energy use ≥ 5 GW, но ≤ 22,5 GW

Source: compiled by authors

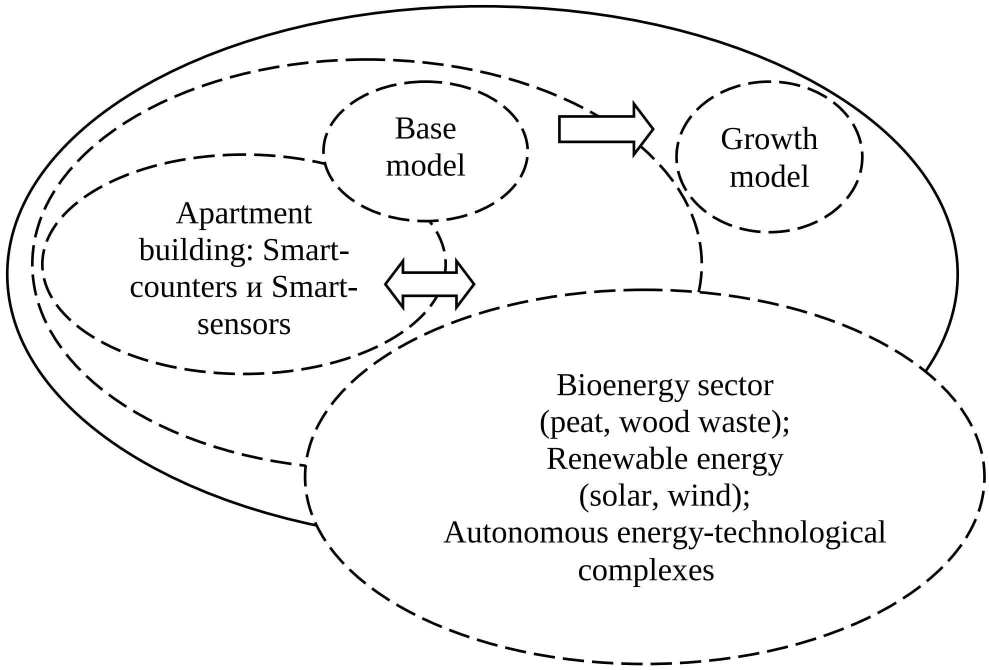

Figure 3. Concept of implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia
Source: compiled by authors

7. Conclusion

The study allows authors to conclude that the implementation of energy efficient smart technologies at the urban territories of the Arctic zone of Russia is most effective through creation of autonomous energy-technological complexes, involving biofuels and renewable energy.

At the level of apartment buildings using traditional sources of energy could be optimized by implementation of smart meters and smart sensors.

For Murmansk, Norilsk, Vorkuta, Severodvinsk, Novodvinsk, Onega, Monchegorsk, the cities of Yakutia and Krasnoyarsk Region it is rational to gradually increase the use of energy-saving technologies in decisions to ensure the safety of communal infrastructure. Some experience of using energy efficient smart technologies, bioenergetics, wind and solar energy already gets the city of Murmansk, Yakutia and Krasnoyarsk Region. It can be adapted for other cities in the Arctic zone.

Nowadays at the Russian market we can find a lot of "products" to help rational generation, accumulation and consumption of energy suitable for the urban territories of the Arctic zone of Russia, but this process requires the political will of regional and local authority bodies.

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