Energy Efficient Architecture for “High Latitudes”

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Abstract. The purpose of this paper is to get acquainted readers with rich experience of Russian architects in the field of designing residential buildings in extremely cold areas. To approve effectiveness of proposed solution we compared energy consumption of residential houses with two different shapes of shell – typical building and innovative energy-efficient building designed especially for the Russian North. Research method is based on simulation process in eQUEST software that provided detailed reports on all aspects of building energy-efficiency and allowed to determine amount of consumed energy.

1. Introduction

According to the recommendation of the Geneva conference, areas higher 66° of North latitude should be referred as “high latitudes”. Therefore, the architectural activity in the Russian “Far North” is called by general term “Architecture of High Latitudes”. The “Far North” of Russia includes Arctic desert of the Islands, the Northern part of Taimyr Peninsula, tundra and coniferous forests zone, which goes beyond the Polar Circle in the central part of Yakutia. These territories constitute about half of the Russian territory by area in square kilometers. Architecture of High Latitudes, as one of the components of the northern theory and practice of construction in the areas of new development, occupies an important place in the Russian urban planning. The circumpolar cities (Murmansk, Arkhangelsk, Norilsk and more than 50 settlements close to the Northern sea route) enriched world practice of construction and operation of large settlements in harsh climatic conditions. It is exactly this unique experience that can serve as an invaluable source of information for cities with extremely cold climatic conditions anywhere in the world. In cold climatic zones main energy consumption accounts for heating.

Despite the fact that Russia has climatic zones from Subtropical to Arctic, biggest part of the country area is located in the Subarctic zone. Therefore, energy-efficient solutions of the external envelopes of residential buildings are a key branch of passive technologies and require a deep analysis and a rational approach in the design process of such solutions. Undoubtedly, energy-efficient solutions lead to a rise of construction cost. This is a key factor, which is able to influence the choice of structure solutions of the exterior wall of the building.

The purpose of this article is to get acquainted readers with experience in northern housing design of Russia. Next goal is to calculate and compare energy consumption of energy efficient and standard buildings in a given climatic zone, based on the simulation performed in the eQUEST. Positive result of simulation can prove that further operation of the building with an effective passive solution of the
outer shell can significantly reduce energy consumption, which is certainly a vital factor for sustainable environmental development in the modern world.

2. Historical background

Russia, in contrast to other continuous countries, is on two-thirds Northern country. Surprisingly, but in the Russian “Far North” also live and work people who need to have strong, warm and comfortable homes. Three constant threats hamper the development of modern Northern homes: extreme cold, winter snow blizzards and summer fires. This is a serious problem that affects not only the professional interests of a narrow group of specialists – architects and builders. For many reasons Russia needs a specialized bioclimatic building for the North, developed according to principles of doctor of architecture Klim Turalysov.

Klim Georgievich Turalysov (03.06.1941 – 13.06.2012) doctor of architecture, outstanding Yakut artist, Dean of the architectural faculty of the Yakut State Engineering Institute. Professor Turalysov considered the succession in architecture of Northern dwelling of Europe, Asia and America as the foundation of the dwelling of the indigenous population, which consist in the following principles:

- maximum heat preservation;
- minimum windage of structures;
- usage of combustible materials.

According to Turalysov, North needs succession of dwellings of indigenous peoples and the Russian settlers in the architecture and technology of construction of modern homes. Special attention Turalysov drew on the traditional housing of the nomadic Yurt. The Yurt is an invention of nomads, made in the very region of Inner Mongolia from which Yakuts (Sakha people) in the early 13th century were driven out by tribes led by Genghis Khan.

2.1. What is a Yurt?

The word “Yurt” (yurt, jurt, jurd) is of Turkic origin. For the Turks the word “Yurt” originally meant some territory, possession. Gradually this name spread to the dwelling, namely the home on the basis of a cylindrical wicker frame, covered with felt cats to protect against rain, wind and cold, with a rounded or conical top. At the top is usually left round hole for smoke.

According to the Mongolian scientists, Yurt is the most stable antiseismic building on the land. The Yurt has a number of advantages of all-weather dwelling – in winter it is warm, and in summer it is...
cool. A strong wind cannot overturn the Yurt, because the outer structure of the walls is approaching the circle. Natural building material (felt koshma) not only has low thermal conductivity, but also under certain treatment is practically not exposed to fire. The Yakut people of Sakha, in the process of migration to the North, brought with them the traditions of building a “Yurt”.

Figure 2. Traditional Yurt house.

The first Russian settlers of the XVI century in The Russian Ustie adopted the external form of the dwelling, close to the hexagon. According to its structure and physical parameters, the priority function of such a home is the maximum energy conservation. From school physics course everyone knows that if building has more amount of sharp corners, then greater the loss of energy occurs. The wind blows out the heat from sharp corners of the building, i.e. the sharper the angle, the more heat the house loses, becoming either colder or consuming more energy for heating.

2.2. Monosota house
Regardless from Turalysov, in 1989, engineer Vladimir Shumovsky, during his research on “the behavior of materials in conditions of the Far North”, came to the conclusion about the optimal hexagonal shape of the building for extreme conditions. Communicating with locals, Shumovsky defined a problem — there are no good qualitative houses which would keep heat in the conditions of severe climate of the far North. This is how the idea of creating an ideal home that would be able to withstand the temperature of -80 degrees Celsius and at the same time would perform its functions on one hundred percent appeared.

According to Shumovsky, the composite solution for maximum heat saving is the “monosote” (mono-honeycomb) structure of the house, therefore, the most energy-efficient solution for the North is the “monosota” house. “Monosota” is the hexagonal shape of the building close to the form of a circle, which has no sharp corners, so the wind flows around the building, not “clinging” to the corners, and not “taking away” heat with it. Another important factor is the speed of construction. Since the summer in the Far North is very short, it is necessary to complete the construction process quickly. “Monosota house” is placed on screw piles in a few days. It should be noted that one can work with screw piles in the winter. On a construction site, walls together with windows and doorways are putted on a frame (wooden or metal), leaning against a grillage of screw piles. Between the house and the ground there is the so-called “podpol”, the design of which will not allow to thaw the permafrost.
For the construction of the outer shell of the building are used plates of wood-laminated plastic with a plate insulation inside (extruded expanded polystyrene “penopleks”), pre-lined on the inside with two layers of gypsum fiber sheets, and on the outside – with a special fire-resistant cement slab. Thanks to special impregnation such panels are water-resistant and fireproof. In addition, the houses made with these panels are not afraid of cold up to -60 degrees Celsius. “Monosota house” is perfect for the far North in all aspects, including not only speed of construction, but also retain of the heat.

2.3. **Features of the architecture of the Northern house**

In the opinion of the architect Usov, features of the Northern home architecture include the following factors:

2.3.1. **Compactness** – a capacity property of a spatial form, which is determined by the volume-to-surface ratio. The consequence of increasing the compactness of the spatial shape of the home is a decrease in the surface of the external envelope and the reduction of the territory of development. From these values the cost of building construction and engineering landscaping are in direct proportion. To an even greater extent, the operating costs of heating, snow cleaning, maintenance of roads and communications depend on the compactness of the building and the volume of buildings. American architect Ralph Knowles points out that the exposure of the structure to the effects of severe climate affects not only the orientation of the home, but also the shape of its spatial shell. Knowles found that the area-to-volume ratio (S/V) or exposure ratio correlated with the level of impacts of a particular construction site, in other words, the larger the area-to-volume ratio, the more the building is exposed to climate impacts.

2.3.2. **Orientation** – a property of flexibility of the spatial form, its ability to reflect the conditions of the outside world. If the compactness of the shape comes out from the need of insulation of the dwelling from the external environment, the orientation of the shape, on the contrary, is caused by the necessity of its connection with the external environment. Direction of the housing form primarily means its orientation in the prevailing wind direction and the flow of solar radiation. The purpose of this orientation are the opposite: according to the wind – proof of envelope, the streamlined surfaces of buildings and protection of residential areas from penetration of wind and snow; according to the sun – perceiving the flux of solar radiation, reflection and focusing it on the wind-protected sections of the residential area.
2.3.3. **Integrity** – a property of spatial form, which characterizes the organic unity of all its parts and details. If compactness is a special measure of volume, if the orientation establishes a connection of this volume with its environment, the integrity of the spatial form expresses the unity of the internal spatial organization.

2.4. **Compound “Polar” house**

Based on the above principles and the principles of “Monosota home” architect Shipkov has developed promising type of an arctic building-complex named “Polar”, which is a comprehensive organization of the home, comprehensive service and a winter garden, combined in a coherent spatial composition. In other words, it is a variant of bioclimatic building in high latitudes. The bioclimatic house, built with sustainable construction technologies, takes into account friendly attitude to nature, when the functionality and aesthetics of the house are in a dialogue with the environment; it takes into account the peculiarities of the climate of the region and is designed to provide the most comfortable conditions for life, combined with minimal energy consumption. To achieve this goal, the house is given a multi-faceted (rounded) shape, inside the building allocated buffer thermal zones, and effectively used landscape protects the building from cold winds. Theoretically, thanks to such simple measures it will be possible to significantly reduce energy consumption. In order to confirm this hypothesis, we will calculate electricity consumption using specialized software in the next section of this paper.

![Figure 4. “Polar” house.](image-url)

3. **Methodology**

Research method of this paper is based on simulation of building energy efficiency and its energy consumption with help of eQUEST software. Preparation to simulation process starts with building models of chosen houses and specifying list of parameters that can be critical in the energy consumption field. After completion of simulation process eQUEST provides comprehensive reports that show detailed energy consumption prediction for the chosen interval.

3.1. **Simulation software introduction**

eQUEST is a sophisticated, easy to use and freeware building energy use analysis tool that provides professional-level results with an affordable level of effort. eQUEST was designed to allow to perform detailed comparative analysis of building designs and technologies by applying sophisticated building energy use simulation techniques but without requiring extensive experience in the "art" of building performance modelling. This is accomplished by combining schematic and design...
development building creation wizards, an energy efficiency measure (EEM) wizard and a graphical results display module with a complete up-to-date DOE-2 (version 2.2) building energy use simulation program. To get a more complete summary of the features and capabilities of this excellent program users can read the eQUEST Overview.

3.2. Sequence of work in eQUEST

eQUEST allows to construct either schematic building envelop or full comprehensive complex model within the program. There are three input wizards in eQUEST that all have different levels of complexity: Schematic Design Wizard (simple inputs), Design Development Wizard (detailed input) and Energy Efficiency Wizard. Each wizard has extensive default inputs that are based on California Title 24 building energy code. One more option is detailed DOE-2 interface, that can be used in special cases if highest level of detailing is needed. Long-term average weather data (TMY, TMY2, TMY3, etc.) for more than one thousand North American locations are available via automatic download within eQUEST.

The eQUEST Schematic Design Wizard firstly requires general information about building design and then progressively delves deeply into details. Building description process consists of 53 data entering steps - each represented by a wizard screen that provides easy-to-understand choices of components and system options. It also offers advice in the form of "intelligent defaults" for each choice. These defaults are marked with green colour and based on information gathered earlier during description process. Although the building description process can get quite detailed there is no need to complete every single step in the wizard. There is possibility to skip unnecessary steps if user is already satisfied with detailing level of model. At that point the wizard fills in missing information using eQUEST intelligent default process. In addition, eQUEST automatically skips steps that do not apply to chosen design.

After compiling description, eQUEST produces detailed simulation of created building model, as well as estimation of energy consumption. Although these results are generated quickly, they are quite accurate because eQUEST utilizes the full capabilities of DOE-2 (the latest version of a well-respected and popular building energy simulation program developed by the US DOE).

3.3. Simulation process in eQUEST

3.3.1. Starting point. Process starts from choosing wizard in main window of eQUEST. In our case we have chosen Schematic Design Wizard.

3.3.2. Parameter input. Sequence of following floating windows are used to input all parameters related to the building design: location in climatic zone, geometrical size and orientation of the house, structure of envelope and its material with different options for insulation, openings percentage, HVAC systems and etc.

Novosibirsk of Russia was chosen as a city for the calculations. The climate of Novosibirsk is continental, much more continental than the climate of the European regions of Russia (in particular Moscow region), that are located at the same latitude. Winter in Novosibirsk is severe and long, with a steady snow cover, strong winds and blizzards. Canadian Red Deer was chosen as the location for the subsequent simulation in eQUEST, because database of this software includes only North American cities, and the climatic conditions of Red Deer and Novosibirsk are very similar. The climate conditions of Russia and Canada are largely similar, as determined by the same geographical latitudes.

The purpose of simulation is to compare amount of consumed energy by two buildings with different shape of shell but with exactly same area of 660 m² each. As an initial variant was chosen standard residential house and as a more energy-efficient alternative – “Polar” hexagonal house by architect Shipkov (Figure 5). The main parameter of comparing is different compositional design of buildings, but all other parameters must be unchanged and strictly fixed for the purity of the experiment.
The model detailing process consists of fifty-three steps detailing each aspect of the building being prepared for the simulation. However, thanks to the intelligent algorithm of eQUEST there is no need to fill in each parameter manually. User only needs to choose the most critical parameters and all the rest will be completed with “intelligent default” process by wizard.

3.3.3. Specification of model. After completing the building description process in the dialog boxes, eQUEST generates a simplified model. Despite the fact that the visual appearance of generated model is quite primitive (for example in comparison with REVIT models), it has an extra broad range of physical parameters as well as a full set of engineering systems that are required for further simulation. Area of each house 660 m². Envelope: walls – wood advanced frame, exterior finish with wood and plywood, polyurethane insulation (R 19); roof surface – wood advanced frame with polyurethane insulation (R 38). Openings: windows – wood or vinyl windows with quadruple Low-E glazing; doors – standard doors. HVAC systems: heating equipment – hot water coils.

As we are satisfied with all characteristics of generated model we can get calculation of energy consumption by simulating building performance in eQUEST. Simulation can be started using the command Simulating Building Performance to achieve this. After a short-term calculation process, we can get a comprehensive report with all the sophisticated parameters.
4. Results and discussion
This section is devoted to the analysis of calculations obtained as a result of the simulation. Completed eQUEST simulation allow to consider quantitative information and compare the values for the two types of houses.

4.1. Monthly Energy Consumption
Electricity consumption peak of typical house in January: 7310 KWh. Gas consumption peak of typical house in January: 178100000 Btu.

Electricity consumption peak of “Polar” house in January: 6990 KWh. Gas consumption peak of “Polar” house in January: 157090000 Btu. Main uses of “Polar” house are miscellaneous equipment with ventilation fans and space heating.

![Figure 7. Monthly energy consumption of typical house.](image1)

Electricity annual consumption of typical house: 82270 KWh. Gas annual consumption of typical house: 1047 MBtu.

Electricity annual consumption of “Polar” house: 79050 KWh. Gas annual consumption of “Polar” house: 931 MBtu.

![Figure 8. Monthly energy consumption of “Polar” house.](image2)
4.3. Comparison of Monthly Energy Consumption

Comparison of the consumed amount of electricity and gas demonstrates the effectiveness of hexagon “Polar” house structure. Usage of a more efficient design can reduce electricity consumption by 3220 kW and 116 MBtu (4 and 12% respectively) per year, which is a substantial benefit in monetary terms. A significant difference in the percentage of energy savings and gas savings occurs because of the fact that external wall design has most serious impact on savings of the heat that is provided by the gas, while most percentage of electricity is used for ventilation and miscellaneous equipment.

5. Conclusion

The aim of this work is to demonstrate how eco-friendly approach to design can affect the choice of design, which in turn can lead to significant energy savings and also savings of finance. The result of the simulation shows that usage of energy-efficient hexagonal structure in Far North conditions can reduce energy consumption by 4%, and gas by 12%. With usage of energy-efficient roof and foundation structures these percentages can increase significantly. Improved modern thermal insulation will also give a significant increase to the overall efficiency of the building envelope. A positive effect on energy saving can be achieved by the selection of energy-efficient equipment for heating and ventilation. With application of any combination of the abovementioned additional investments the expenses would not be ineffective. Any investment in solutions of green character (whether active or passive) will be paid back, only payback period can slightly increase.

In conclusion, it is important to remind that the relevance of usage of energy-efficient and environmentally friendly structures is not only conditioned by financial savings and personal benefits, but also by the responsibility towards society and future generations of our planet. Reducing the consumption of any resources is a highest priority in all developed countries. Therefore, proven financial feasibility of seemingly more expensive solutions and the awareness of the wider society is vital for future prosperity of humankind.

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