Energy efficient building in the Arctic

Vitaly Arkhipov*, Darya Nemova, Daria Petrosova and Viktoria Morokhoeva
Peter the Great St. Petersburg Polytechnic University, 29, Polytechnicheskaya str., St. Petersburg, 195251, Russia

* E-mail: arx.vitaliy@gmail.com

Abstract. This article covers the topic of energy-efficient buildings belonging to the Far North and the design of such a house in these conditions. The analysis of existing energy-efficient technologies was carried out and the prospects of their application in the Arctic conditions were determined. New technical solutions have been developed to ensure the energy efficiency of buildings in the Arctic. Research methods included: theoretical study of existing energy-efficient buildings; software: Autodesk Revit to create a three-dimensional model of the building together with Autodesk Green Studio to calculate energy efficiency and Solar plugin to calculate the energy performance of solar panels. The scientific novelty of the work consists in obtaining practical recommendations for the design of an energy-efficient house located in the Republic of Sakha (Yakutia) 62 degrees North latitude and 129 degrees East longitude. The practical value of the work is to use the recommendations for the construction and reconstruction of energy-efficient buildings, geographically located in the Arctic zone. The theoretical significance of the developed model and the proposed technology for determining energy efficiency indicators will allow it to be used for further calculations.

1. Introduction

One of the priority directions of development of science and technology is energy efficiency and energy saving. In modern architecture and construction, this can be achieved by improving architectural and planning solutions, the use of external building envelope structures with the necessary level of thermal protection, the introduction of effective systems to ensure microclimate and energy saving in buildings, the use of renewable energy sources, improving the quality of building design.

Construction, being one of the most energy-intensive sectors of the economy, at the same time has great potential for the development and application of various energy-efficient solutions. From here such concepts as active and passive houses began to appear.

The relevance of this work lies primarily in the importance of this issue in the construction field. According to statistics, construction projects consume 40% of the world's energy. Industrial and residential buildings are becoming one of the main sources of thermal emissions of carbon dioxide into the atmosphere.

The need for the development of the Arctic is due to global economic development trends, climate change, advances in technology and regional development requirements. For more quality and productive potential of the Arctic plays an important role proper and adequate use of available resources, if it in practice has universal value, in extreme climates and remote areas where the infrastructure is poorly developed around it is paramount. To do this, it is necessary to pay attention to the accounting of the practice of energy-efficient construction and the promotion of all energy-efficient technologies. It will also be necessary to adapt and respond to the large-scale changes that will arise due to the
implementation of intensive production of raw materials, it is necessary to reduce the negative impact on the environment to a minimum.

The territory of the Arctic is a kind of platform for the development of innovative solutions for energy efficiency. Some countries already have well-established and proven innovative solutions (e.g. clean technologies and energy in the Tamper region, Finland). Territorial cooperation can support new and innovative solutions to improve efficiency by combining knowledge and research resources. The specificity and heterogeneity of Artika as a region as a whole is a certain development of alternative energy, for example, in places of high latitudes where regions can receive a significant amount of energy from solar stations, in other places biomass, wind turbines will be used. The Arctic climate is very different from the temperate climate. In the Arctic regions, the ambient temperature reaches extreme values and has a direct large impact on heat loss through the building fence and creates problems with the Foundation due to permafrost. Solar time is completely different due to the limitation of winter, but in summer the sun can also be above the horizon for 24 hours. Strong winds and storms have a great influence on the penetration of cold in buildings, and they strongly affect the heat loss passing through the fence of the building. Wind conditions have a great influence on the local microclimate around the building and create large drifts and problems with thawing, icing occurs and there is a high probability of condensation in the enclosing structure. Humidity in the interior in winter is forced through the fence of the building due to the pressure drop, strong winds and low coefficient of water in the open air. The Arctic region is determined by different conditions, such as what construction methods are used and what materials are available, and energy supply is more important.

2. Materials and methods
In this article, the design of an energy efficient house was carried out using the example of a two-story residential building, which is shown in Figure 1.

![Figure 1. 3D model of the calculated building.](image)

Certain solutions were used to optimize the energy efficiency of the house according to the "Passivhaus" standard.

The main purpose of the work was to design an energy-efficient, environmentally friendly, comfortable for living building, as well as its energy analysis for compliance with the "Passivhaus" standard, taking into account the climatic features of the proposed construction. The analysis of the building was performed using Autodesk Revit software and its extensions: Energy Analysis, Solar and Green Building Studio.

The study solves the following tasks:
- Application of various architectural and planning, spatial solutions and analysis of their impact on energy consumption
• Selection of enclosing structures and analysis of their effectiveness in accordance with the standard
• Selection of possible engineering equipment, as well as the concept of the most rational system of ventilation and heating
• Analysis of the building for compliance with the "Passivhaus" standard

![3D model of the calculated building](image1.png)

**Figure 2.** Another 3D model of the calculated building.

![Floor plan and legend of the premises](image2.png)

**Figure 3.** Floor plan and legend of the premises.

2.1. *Thermal performance*
Using the program "Teremok" has been defined thickness of insulation 50 mm. Adopted the layers of the wall structure is presented in figure 4.

2.2. Energy efficiency parameters
In our work, we calculated the energy efficiency of the building, Autodesk Green Building Studio was used as a tool

2.3. Orientation of the building
For the analysis of the solar load was carried out a few calculations with different orientations of the building. Initial position - the most glazed facade is directed to the South.

![Figure 4. Light-shadow analysis(clockwise: spring, autumn, winter, summer).](image)

2.4. Ventilation
The scheme of natural heat recovery was selected, which is shown in the Figure 5.
2.5. **Solar panel**
A number of measures related to photovoltaic panels have been calculated in the Autodesk Green Studio software for the calculation of energy efficiency indicators and the Solar plugin.

2.6. **Wind impact.**
In our calculation was taken into account the high-speed wind flow and its direction in the Figure 6.

---

**Figure 5.** Heat recovery scheme.

**Figure 6.** Wind direction and speed.
As protection against wind flows, measures have been taken in the form of green fences in the most blown facades shown in the Figure 7.

![Figure 7](image)

**Figure 7.** Measures to protect the building from wind flows.

2.7. *Heating*

The building was calculated the influence of heating and refrigeration loads in the Insight program. Figure 8 shows the energy efficient model of the building in the Insight program, where the "FRONT" view is the southern most glazed facade.

![Figure 8](image)

**Figure 8.** An overall image of an energy-efficient building model in Insight.

2.8. *Lightning*

Calculation is performed in the Lighting module of Revit program.
2.9. Thermal engineering calculation of reinforced brick wall
This section presents the calculation of the brick wall using reinforcing mesh of steel and basalt in the software package Simulia Abaqus 2017. Figure 10 shows the wall unit with the layout of the reinforcement mesh.

3. Results
During the calculation of energy efficiency indicators, the following energy parameters are obtained, shown in figure 11.
When choosing the orientation of the building, it was found that the most favorable orientation was the location to the SOUTH, the option was the most effective, this was confirmed by the Green Building Studio program. The calculation data is shown in the diagram of the Insight program in figure 12.

![Figure 12. Orientation of the building (triangle – this is our option, the rest – options for turning the building at different angles clockwise).](image)

It was considered that the rational use of natural ventilation allows to reduce some energy costs, which can be seen in figure 13, while reducing the value of electric energy by 2 kWh/m² per year.
The amount of heat that our building will receive from photovoltaic panels is 171 kWh/m² per year. This can be seen in figure 14.

**Figure 14.** Energy generation by solar panels on the roof.

Calculation results on the influence of heating and cooling loads in the Insight program. In the figures, all the rooms – spaces are painted in the color corresponding to the value of the heat load.

**Figure 15.** Plot heat load on the building.
The heating of building needs 95.1 V/m² of heat.

According to our calculation to the lighting of the building complies with all building codes even without artificial light with the exception of utility rooms and stairwells that during the daytime allows you to save electricity for lighting.

When calculating the thermal performance of the wall, the following results were obtained:

![Figure 16. Plot cooling load on the building.](image)

![Figure 17. The result of the calculation (the thermal conductivity brick is 0.6, 50.2 steel).](image)
The figures show that the size of the cold bridge in the inner corner of the wall reinforced with basalt mesh is smaller than that of the wall with steel mesh (figures 17, 18).

The use of composite reinforcement not only increases the strength of the reinforced structure, but also reduces the energy for heating, which is also positive for the energy efficiency of the designed house.

4. Conclusion

After a number of changes, based on the analysis of various energy efficiency indicators through the prism of Autodesk Green Building Studio, the following result is obtained: the Intensity of energy use (heating costs, hot water and electricity) – 691.4 MJ/m²/year, or (if you take 1 kWh = 3.6 MJ) 192 kWh/m²/year. We also used a number of measures that reduce the value obtained:

The use of photovoltaic panels - 171 kWh/m² per year, the use of natural ventilation – 2 kWh/m² per year. Total we obtain that the specific value of the annual energy consumption of 19 kWh/m², which corresponds to the required value of the standard "Passivhaus".

Also on the schemes obtained through the service Autodesk Green Building Studio, it is clear that the selection of structures of walls, roofs and infiltration system is rational. The diagrams are shown in figure 19.

Figure 18. The result of the calculation (the thermal conductivity brick is 0.6, and basalt – 1.5).

Figure 19. Rational use of wall, roof and infiltration structures.
References
[1] Matrosov Yu A, Butovsky I N, Norford L K, Opitz M W 1997 Standards for Heating Energy Use in Russian Buildings: A Review and a Report of Recent Progress *Energy and Buildings* **25(3)** 207-22.
[2] Friess W A, Rakhsan K, Hendawi T A, Tajerzadeh S 2012 Wall insulation measures for residential villas in Dubai: A case study in energy efficiency *Energy and Buildings* **44** 26-32.
[3] Wang W, Tian Zh, Ding Y 2013 Investigation on the influencing factors of energy consumption and thermal comfort for a passive solar house with water thermal storage wall *Energy and Buildings* **64** 218-23.
[4] Dodoo A, Gustavsson L, Sathre R. 2011 Building energy-efficiency standards in a life cycle primary energy perspective *Energy and Buildings* **43(7)** 1589-97.
[5] Cheng Y, Xin J, Gao N. Thermal comfort models: A review and numerical investigation 2012 *Building and Environment* **47** 13-22.
[6] Ott H, Wang J, Fetsch D, Dumont R 2013 Technical note: Airtightness of older-generation energy-efficient houses in Saskatoon *Journal of Building Physics* **36** 294-307.
[7] Kunzel H M, Kiessel K. 1997 Calculation of Heat and Moisture Transfer in Exposed Building Components *International Journal of Heat Mass Transfer* **40(1)** 159-67.
[8] Mlakar J, Strancar J 2013 Temperature and Humidity Profiles in Passive-house Building Blocks *Building and Environment* **60** 185-93.
[9] Dos Santos G H, Mendes N 2009 Heat, Air and Moisture Transfer through Hollow Porous Blocks *International Journal of Heat and Mass Transfer* **52(9-10)** 2390-8.
[10] Kiselev V G, Sergeev V V and Rouzich E N 2017 Influence of the electric double-layer capacitance at the rate of corrosion at the phase interface *Corros. Rev.* **35** 47-51.
[11] Teodosiu R 2013 Integrated Moisture (Including Condensation)—Energy—Airflow Model within Enclosures *Building and Environment* **61** 197-209.
[12] Schnieders J, Feist W, Røngen L 2015 Passive Houses for different climate zones *Energy and Buildings* **105** 71-87.
[13] Iordache V, Teodosiu C, Teodosiu R 2016 Permeability Measurements of a Passive House During Two Construction Stages *Energy Procedia* **85** 279-87.
[14] Zalejska–Jonsson A, Lind H, Hintze S 2013 Energy-efficient technologies and the building’s saleable floor area: bust or boost for highly-efficient green construction buildings **3** 570-87.
[15] Kiselev V G, Sergeev V V and Rouzich E N 2017 Influence of the electric double-layer capacitance at the rate of corrosion at the phase interface *Corros. Rev.* **35** 47-51.
[16] Rodriguez-Ubinas E, Montero C, Porteros M 2014 Passive design strategies and performance of Net Energy Plus Houses. *Energy and Buildings* **83** 10-22.
[17] Mitterer Chr, Hartwig M, Künzel, Herke S, Holm A 2012 Optimizing energy efficiency and occupant comfort with climate specific design of the building *Frontiers of Architectural Research* **9(25)** 229-35.
[18] Rodriguez S, Voss K, Todorovic M 2014 Energy efficiency evaluation of zero energy houses. *Energy and Buildings* **83** 23-35.
[19] Ionescu C, Baracu T, Vlad G E, Necula H, Badea A 2016 The historical evolution of the energy efficient buildings *Renewable and Sustainable Energy Reviews* **49** 243-53.
[20] Marszal A J, Heiselberg P, Bourrelle J S, Musall E, Voss K, Sartori I, Napolitano A 2011 Zero Energy Building – A review of definitions and calculation methodologies *Energy and Building* **43** 971-9.
[21] Mitterer C, Künzel H M, Herkel S, Holm A 2012 Optimizing energy efficiency and occupant comfort with climate specific design of the building *Frontiers of Architectural Research* **1(3)** 229-35.
[22] Borovkov V M, Zysin L V and Sergeev V V 2002 The totals and technological problems of usage of vegetative biomass and organic waste in power engineering *Izv. Akad. Nauk. Energ.* 13–24.
[23] Klingenberg K 2008 Passive House – a Positive Net Energy Home. ISTC **10** 37-46.
[24] Visa I, Moldovan M D, Comsit M, Duta A 2014 Improving the renewable energy mix in a building toward the nearly zero energy status *Energy and Buildings* **68 Part A** 72-8.
[25] Xiaolong Xue, Hengqin Wu 2015 Measuring energy consumption efficiency of the construction industry Journal of Cleaner Production 107 509-15.
[26] Rehab I, Andre Ph, Silva C. 2015 Verification of the Energy Balance of a Passive House by Combining Measurements and Dynamic Simulation Energy Procedia 78 2310-5.
[27] Barsi D, Perrone A, Yu Q, Ratto L, Ricci G, Sergeev V and Zunino P 2018 Compressor and Turbine Multidisciplinary Design for Highly Efficient Micro-gas Turbine J. Therm. Sci. 27 259–69
[28] Georges L, Berner M, Mathisen H. 2014 Air heating of passive houses in cold climates: Investigation using detailed dynamic simulations Building and Environment 74 1-12.
[29] Ovchinnikov P, Borodînces A and Millers R 2017 Utilization potential of low temperature hydronic space heating systems in Russia J. Build. Eng. 13 1–10
[30] Kalamees T, Lupíšek A, Sojková K, Mørck O C, Borodînces A, Almeida M, Rovers R, Op'Tveld P, Kuusk K and Silva S 2016 What kind of heat loss requirements NZEB and deep renovation sets for building envelope? ed L A H P Sojkova K. Tywonjak J. CESB 2016 - Cent. Eur. Towar. Sustain. Build. 2016 Innov. Sustain. Futur. 137–44
[31] Gorshkov A S and Vatin N I 2013 Properties of the wall structures made of autoclaved cellular concrete products on the polyurethane foam adhesive Mag. Civ. Eng. 40 5–19
[32] Borodînces A, Zemitis J and Prozuments A 2012 Passive use of solar energy in double skin facades for reduction of cooling loads World Renew. Energy Forum, WREF 2012, Incl. World Renew. Energy Congr. XII Color. Renew. Energy Soc. Annu. Conf. 6 4181–6
[33] Abanda F.H, Byers L 2016 An investigation of the impact of building orientation on energy consumption in a domaestaic building using emerging BIM Energy and Buildings 118 181-96.
[34] Figueiredo A, Kämpf J, Vicente R 2016 Passive house optimization for Portugal: Overheating evaluation and energy performance Energy and Buildings 50 7-18.
[35] Mohamed A, Hasan A, Sirén K 2014 Fulfillment of net-zero energy building (NZEB) with four metrics in a single family house with different heating alternatives Applied Energy 114 385-99.
[36] Kaklauskas A, Rute J, Zavadskas E.K, Daniunas A, Pruskus V 2012 Passive House model for quantitative and qualitative analyses and its intelligent system Energy and Buildings 50 7-18.
[37] Kaklauskas A, Rute J, Gudauskas R, Banaitis A 2012 Integrated model and system for passive houses multiple criteria International Journal of Strategic Property Management 15(1) 74-90.
[38] Bajc T,Todorović M, Svorcan J 2015 CFD analyses for passive house with Trombe wall and impact to energy demand. Energy and Buildings 98 39-44.
[39] LEED-The Leadership in Energy & Environmental Design. LEED 2009 for New Construction and Major Renovations Rating System US Green Building Council 2009. URL: http://www.usgbc.org