The influence of enclosing structures of walls on the energy efficiency of a wooden building (on the example of the international project KO 1089 "Green Arctic Building")

S Yu Buryachenko¹, I M Karachentseva¹, Z A Voronin² and A A Kuzmenkov²

¹ Murmansk State Technical University, Murmansk, Russia
² Petrozavodsk State University, Petrozavodsk, Russia

¹ karachentsevam@mstu.edu.ru

Abstract. As part of the implementation of the international project “Green Construction in the Arctic” (KO 1089 - GrAB) of the Kolarctic 2014-2020 cross-border cooperation program, it is planned to construct experimental buildings (“model objects”). To implement the measures included in the GrAB project, it is planned to build two identical buildings on the territory of Murmansk and Petrozavodsk. The buildings are designed for research in the field of “green” technologies and energy-efficient construction, as well as approbation of research results. Objects in Murmansk and Petrozavodsk should be identical in external architectural appearance, design solutions and materials used, which will allow us to study the effectiveness of the use of the same building materials and structures in different climatic conditions. The model object is a one-story wooden house, its size in the plan is 13x6 m. It is envisaged to use modern technologies of wooden housing construction and equipping the house with energy-efficient engineering equipment, as well as a special temperature and humidity monitoring system for research. The facility is intended for conducting research in the field of green building technologies, testing new technologies and evaluating the effectiveness of their work in the Far North (Murmansk) and adjacent territories (Petrozavodsk). Purpose of work: a comprehensive assessment of the influence of the structure of the walls of a wooden house on its energy supply.

1. Materials and methods
The choice of materials and research methods is determined by the purpose of the work: a comprehensive assessment of the influence of the structure of the walls of a wooden house on its energy supply. The purpose of the work corresponds to the objectives of the project KO 1089 – GrAB. The main objectives of this work can be formulated in the following thesis points:

- comparison of calculated and experimental values of specific losses of thermal energy. The calculated values are determined by standard methods, and the experimental ones as a result of actual monitoring of the state of the experimental building during the heating period;
- determination of the energy efficiency class of the building according to the calculated and experimental values;
- determination of the degree of influence of options for constructive solutions of enclosing structures and options of heat-insulating materials of the experimental building in the structure of heat loss of the building on the energy efficiency class;
- development of criteria for the application of various options for building envelopes in the construction of an energy-efficient ("passive") building in the Arctic region.
Table 1 [5] presents the results of the assessment of losses of thermal energy and heat sources in the building, which can be taken as the working hypothesis of the study.

| Leaks (loss) of heat | Heat sources            |
|---------------------|-------------------------|
| Drains              | 4 %                     |
| Roof                | 8 %                     |
| Foundation          | 18 %                    |
| Walls               | 21 %                    |
| Windows and doors   | 20 %                    |
| Ventilation (window leafs, exhaust ventilation) | 29 % |
|                     | Lighting                |
|                     | Man (own heat)          |
|                     | Solar power             |
|                     | Hot water               |
|                     | Home Appliances and Cooking |
|                     | Heating system          |

At the current stage of the study, the solution of problems associated with the calculation of specific thermal characteristics and with the prediction of the energy efficiency class from the calculated values of the heat transfer resistance of building envelopes is considered. Next, an assessment is made of the influence of design options for wall cladding in the structure of thermal energy losses on the building's energy efficiency class.

In the implementation of this part of the study, analytical, calculation and modeling methods were used. To solve the problems posed in this part of the study, methods of calculating the characteristics of the consumption of thermal energy were applied in accordance with the rules of the thermal protection of buildings.

2. Objects and research methods

The model object is a one-story building with dimensions in plan in the axes of 12.45x5.5 m. The height of the building along the ridge of the highest part is 4.3 m. The building consists of two volumes connected by a vestibule-corridor. The right and left parts of the building have the same area of premises and the same internal volume. The main applied structural material is wood [9]. The south facade and floor plan are shown in Figure 1.

2.1. Constructive solutions for covering structures

For both parts of the building, the structures of the roof, lower floor and foundations are the same. Foundations are columnar. Lower floor - beam, insulated. The total thickness of the lower floor is 465 mm, including the thickness of the insulating layer - 300 mm. Mineral insulation based on quartz “ISOVER Frame-M37” in two layers of 150 mm is adopted as a heat-insulating material. The roof covering material is metal tile. The total thickness of the roof structure is 450 mm, including the thickness of the insulating layer - 350 mm. Mineral insulation based on quartz “ISOVER Pitched Roof” in two layers of 200 and 150 mm was adopted as a heat-insulating material.

The structures of the external walls and the technology of their construction are different for the parts of the building. The walls of the parts of the building are constructed using two different technologies: one part using the frame technology, the second using the double-log technology. The total thickness of the frame structure of the wall is 350 mm. The thickness of the insulating layer is 250 mm. Mineral wool insulation “ISOROC Super Warm” has been adopted as the main insulation material for the frame wall. The composition of the structural layers of the frame structure of the wall is shown in Figure 2.

The average thickness of the wall structure made using the double-log technology is 472 mm. The thickness of the insulating layer is 126 mm. Chips and sawdust, which are a waste in the production of log cabin elements, are accepted as the main heat-insulating material. The composition of the structural layers of the wall structure, made on the principle of a double log house, is shown in Figure 3.
One of the conditions for comparability of research results in different climatic zones is the same orientation of the experimental buildings on the ground. The blank wall of the building should be oriented north. In each part of the building, the northern wall is divided into three sections. At each site, a separate type of thermal insulation material is used. For the frame part of the building, additional thermal insulation materials are: natural insulation Flaxan Mix, ecowool and linen mats (Figure 1). An additional heat-insulating material for a double-log wall is linen mat. The third section of the double log wall is represented by an air gap without additional insulation (Figure 1).

2.2. Engineering support
Engineering systems of the model facility include a heating, ventilation, power supply system, as well as lighting.

The main heating system of the experimental house is electric heating with convectors located on the walls inside the premises. GLAMOX heaters are used as electric heaters. The number of electric heaters and their location are determined on the basis of heat engineering calculations. The total heat load is 8 kW.

The ventilation system for the experimental house is forced-air and exhaust ventilation with mechanical motivation with recovery. The building ventilation system is represented by two independent systems for each part of the building. For each system, a NOVA-300 air handling unit with recovery is provided. The main characteristics of the ventilation installation: air consumption - 100-200 m³/h, consumed electric power for heating - 3.6 kW.

The power supply system includes lighting networks, grounding, an electrical network for measuring equipment, uninterrupted guaranteed power supply of an integrated fire safety system, emergency lighting. The total electric power is 20 kW. The main consumers are 220V socket network, lighting (working and emergency), measuring equipment, supply and exhaust ventilation equipment, heating system equipment, AFS systems equipment.

2.3. The initial data for the calculation

The calculated climatic and heat energy parameters of the experimental building are adopted for the conditions of the city of Murmansk in accordance with Set of rules 131.13330.2012 “Construction Climatology”, updated version of Construction rules and regulations 23-01-99* [10], and are presented in Table 2. Of the two territories considered, are accepted conditions for the city of Murmansk, as the most climatically unfavorable.

Table 2. Climatic and heat power parameters.

| Name of design parameters                              | Parameter designation | Unit of measurement | Calculated value |
|--------------------------------------------------------|-----------------------|---------------------|------------------|
| The estimated temperature of the internal air          | \( t_{\text{int}} \)  | °C                  | 22               |
| The estimated outdoor temperature                      | \( t_{\text{ext}} \)  | °C                  | -30              |
| Duration of the heating period                         | \( z_{\text{ht}} \)   | day                 | 275              |
| Average outdoor temperature for the heating period     | \( t_{\text{ht}} \)   | °C                  | -3.4             |
| Degree-day of the heating period                       | \( D_{d} \)          | °C·day               | 6985             |

Table 3 provides a summary of the thermal insulation materials used in the building's enclosing structures, as well as the required and calculated heat transfer resistances of the enclosing structures.

Table 3. Applied thermal insulation materials and resulting characteristics.

| Insulation material     | Thermal conductivity, W/(m²·°C) | Heat transfer resistance of enclosing structures, m²·°C/W |
|-------------------------|---------------------------------|---------------------------------------------------------|
|                         | Frame walls                     | Double log walls | Roof | Overlapping |
|                         | 250                             | 126             | 350  | 300         |
| Thickness of the insulation layer, mm            | 3.30                            | 3.30            | 4.39  | 3.74        |
| Required, standardized heat transfer resistance   | Est. Heat Transfer Resistance   |                 |       |
| Isoroc Super Warm     | 0.037                           | 4.577           |
| Flaxan Mix            | 0.043                           | 4.198           |
2.4. Method of calculation

To calculate the specific characteristics of the facility, Set of rules 50.13330.2012 “Thermal protection of buildings”, updated version of Construction rules and regulations 23-02-2003 (with amendments and additions from 12/14/2018, date of introduction 06/15/2019) [11] was used. According to [11], the calculated value of the specific characteristic of the heat energy consumption for heating and ventilation of the building $q_{\text{heat}}^{\text{est}}$ is determined taking into account the climatic conditions of the construction area, the selected space-planning solutions, the heat-shielding properties of the building envelope, the orientation of the building, the building's ventilation system, as well as the use of energy-saving technologies, $W/(m^3 \cdot ^{\circ}C)$:

$$q_{\text{heat}}^{\text{est}} = k_{\text{gen}} + k_{\text{vent}} - \beta_{\text{UR}} \cdot (k_{\text{house}} + k_{\text{solar}}),$$

(1)

Where:
- $k_{\text{gen}}$ - specific heat-shielding characteristic of the building, $W/(m^3 \cdot ^{\circ}C)$;
- $k_{\text{vent}}$ - specific ventilation characteristic of the building, $W/(m^3 \cdot ^{\circ}C)$;
- $k_{\text{solar}}$ - specific characteristic of heat receipts in the building from solar radiation, $W/(m^3 \cdot ^{\circ}C)$;
- $\beta_{\text{UR}} = K_{\text{reg}}/(1+0.5n_{\text{air}})$ - the coefficient of useful heat gain;
- $K_{\text{reg}} = 0.8$ - coefficient of efficiency of heat supply regulation in heating systems;
- $n_{\text{air}} = \frac{\text{vent} \cdot n_{\text{vent}} + G_{\text{inf}} \cdot n_{\text{inf}}}{168 \cdot \beta V_{\text{heat}} V_{\text{heat}}}$ - the average multiplicity of air exchange of a building during the heating period - $h^{-1}$ (determined by the total air exchange due to ventilation and infiltration).

Specific heat-shielding characteristic of the building, $k_{\text{gen}}, W/(m^3 \cdot ^{\circ}C)$, is calculated by the formula §1.1, Appendix §, [11] according to the reduced heat transfer resistances of individual building envelope enclosing structures and their areas:

$$k_{\text{gen}} = \frac{1}{V_{\text{heat}}} \cdot \sum \left( n_{t,i} \frac{A_{f,i}}{R_{\text{red},i}} \right),$$

(2)

Where:
- $R_{\text{red},i}$ - reduced heat transfer resistance of the i-th fragment of the building's heat shield, $(m^2 \cdot ^{\circ}C)/W$;
- $A_{f,i}$ - the area of the corresponding fragment of the building's heat shield, $m^2$;
- $V_{\text{heat}}$ - heated volume of the building, 175 m$^3$;
- $n_{t,i}$ - coefficient that takes into account the difference between the internal or external temperature of the structure and the degree-day calculation of the heating period.

Data on the areas and the given heat transfer resistances of fragments of the building's enclosing structure are given in table 4.
Table 4. The given resistance to heat transfer of a fragment of the building's shield and their area.

| Name of the fragment of the enclosing structure | Area $A_{li}$, m$^2$ | Reduced heat transfer resistance $R_{0li,red}$, m$^2$·°C/W | $n_{kli}$ | $A_{li}$ | $R_{0li,red}$ | %  |
|------------------------------------------------|----------------------|----------------------------------------------------------|----------|--------|----------------|----|
| Exterior walls of the facade                    |                      |                                                          |          |        |                |    |
| Frame (Mineral wool)                            | 1                    | 27.53                                                     | 4.119    | 6.68   | 11.94         |    |
| Frame (Flaxan Mix)                             | 1                    | 3.69                                                     | 3.778    | 0.98   | 1.75          |    |
| Frame (Ecowool)                                | 1                    | 4.74                                                     | 3.998    | 1.19   | 2.12          |    |
| Frame (Linen mats)                             | 1                    | 4.04                                                     | 4.058    | 1.00   | 1.78          |    |
| Double log (Sawdust and shavings)             | 1                    | 26.56                                                     | 3.049    | 8.71   | 15.56         |    |
| Double log (Linen mats)                        | 1                    | 3.83                                                     | 4.056    | 0.94   | 1.69          |    |
| Double log (Air)                               | 1                    | 3.83                                                     | 1.745    | 2.19   | 3.92          |    |
| Windows and stained-glass windows in exterior walls | 1                  | 5.80                                                     | 0.584    | 9.93   | 17.73         |    |
| Entrance doors                                 | 1                    | 2.15                                                     | 0.717    | 3.00   | 5.36          |    |
| Roof                                          | 1                    | 55.85                                                    | 5.160    | 10.82  | 19.34         |    |
| Floor                                         | 1                    | 53.52                                                    | 5.081    | 10.53  | 18.82         |    |
| Sum                                           | -                    | 191.541                                                   | -        | 55.97  | 100.00        |    |

The specific ventilation characteristic of the building $k_{vent}$, W/(m$^3$·°C), is calculated by the formula Γ.6, Appendix Γ, [11]:

$$k_{vent} = 0.28c \cdot \frac{L_{vent} \rho_{air} n_{vent} (1 - k_{ef}) + G_{inf} n_{inf}}{16 \beta \gamma_{heat}}$$  \hspace{1cm} (3)

Where: $c$ - specific heat capacity of the air, $c = 1$ kJ/(kg·°C);
$n_{vent}$ - the average multiplicity of the air exchange of the building for the heating period, $n_{vent} = 8.5$;
$k_{ef}$ - recuperator efficiency coefficient, $k_{ef} = 0$;
$\rho_{air}$ - average supply air density for the heating period, $\rho_{vent} = 1.31$ kg/m$^3$;
$G_{inf} = 0.1 \beta \gamma \gamma_{heat} = 14.875$ m$^3$ - the amount of infiltrating air into the building through the covering constructions;
$\beta \gamma = 0.85$ - air volume reduction coefficient in the building, taking into account the presence of internal covering constructions;
$n_{inf}$ - the number of hours of accounting for infiltration during the week, $n_{inf} = 159.5$ h;
$L_{vent} = 188$ m$^2$ (with multiplier $A = 4$).

The specific characteristic of household and radiation emissions of the building, $k_{house}$, W/(m$^3$·°C), is calculated by the formula Γ.6, Appendix Γ, [11]:

$$k_{house} = \frac{q_{house} \delta_{liv(est)}}{\gamma_{heat}(t_{int} - t_{ht})}$$  \hspace{1cm} (4)

Where: $q_{house} = 17$ W/m$^2$ - the amount of domestic heat per 1 m$^2$ of the residential part of the building.

The specific characteristic of heat receipts in the building from solar radiation, $k_{solar}$, W/(m$^3$·°C), is calculated by the formula Γ.7, Appendix Γ, [11]:

$$k_{solar} = \frac{11.6 q_{solar} \delta_{year}}{\gamma_{heat} D_{d}}$$  \hspace{1cm} (5)
Where: \( Q_{\text{year}}^{\text{solar}} = 1000 \text{ MJ/year} \) - total heat input through windows located on facades oriented in directions, and lights from solar radiation during the heating period.

The normalized specific characteristic of the consumption of thermal energy for heating and ventilation of buildings \( q_{\text{req heat}}^{\text{FP}} \) is determined for a one-story public building on [11, table 14] and is 0.487 W/(m\(^3\)·ºС).

### 2.5. Calculation results

Table 5 shows the results of the calculation of the specific characteristics of the object and the calculated value of the energy efficiency class.

| The specific characteristic                                      | Value   | Unit of measurement | Impact assessment, % |
|-----------------------------------------------------------------|---------|---------------------|----------------------|
| The normalized specific characteristic of the consumption of thermal energy for heating and ventilation of buildings, \( q_{\text{req heat}}^{\text{FP}} \) | 0.487   | W/(m\(^3\)·ºС)     | -                    |
| The calculated value of the specific characteristic of the heat energy consumption for heating and ventilation of the building, \( q_{\text{est heat}} \) | 0.213   | W/(m\(^3\)·ºС)     | -                    |
| The specific heat-shielding characteristic of the building, \( k_{\text{gen}} \) | 0.32    | W/(m\(^3\)·ºС)     | 63                   |
| The specific ventilation characteristic of the building, \( k_{\text{vent}} \) | 0.043   | W/(m\(^3\)·ºС)     | 8                    |
| The coefficient of useful heat gain, \( \beta_{\text{UR}} \) | -       | 0.749               |                      |
| The specific characteristic of household emissions of the building | -       | 0.191   | 28                   |
| The specific characteristics of heat input to the building from solar radiation during the heating period | -       | 0.009   | 1                    |
| Energy efficiency                                             | 56%     | A+, very high       |                      |

When comparing the basic specific characteristics of the consumption of thermal energy for heating and ventilation with the actual characteristic, the divergence was 56% (included in the range from 50 to 60%), which corresponds to the energy saving class of the public building A+ (very high) [11, tab. 15].

### 3. Conclusion

At the design stage a comprehensive assessment of the influence of the structure of the external walls of a single-story wooden house on its energy supply was made. The project envisages the construction of two identical houses in Murmansk and Petrozavodsk, which will allow us to study the effectiveness of the use of the same building materials, structures and technologies in different climatic conditions of the northern regions.

One of the conditions for the correct comparability of calculation results in different climatic zones was the same orientation of the experimental buildings on the ground. In the calculations, it was assumed, that the blank wall of the building is oriented to the north.

In addition to geographical diversification, it was provided that the structures of the external walls and the technology of their construction are different for the parts of the building. The walls of the parts of the building were constructed using two different technologies: one part - using the frame technology, the second - using the double-log technology.

In this work, the distribution of the specific heat-shielding characteristics of the object was performed on different types of building envelope structures designed using various technologies (table 6, figure 4).
Table 6. Assessment of the impact of options for structural solutions of walling

| The specific characteristic                                         | Value  | Unit of measurement | Impact assessment, % |
|---------------------------------------------------------------------|--------|---------------------|----------------------|
| The specific heat-shielding characteristic of the building,         |        |                     |                      |
| Including:                                                          |        |                     |                      |
| External walls - frame construction                                 | 0.32   | W/(m^3·°C)          | 63                   |
| External walls - double log construction                            | 0.056  | W/(m^3·°C)          | 11                   |
| Windows and entrance doors                                          | 0.068  | W/(m^3·°C)          | 13                   |
| Roof                                                                | 0.074  | W/(m^3·°C)          | 15                   |
| Floor                                                               | 0.061  | W/(m^3·°C)          | 12                   |

The specific ventilation characteristic of the building – 8%
The specific characteristic of household emissions of the building – 28%
The specific characteristics of heat input to the building from solar radiation during the heating period – 1%
The specific thermal-protective characteristics of floor structures – 12%
The specific thermal-protective characteristics of roof structures – 12%

Figure 4. Assessment of the impact of structural solutions of wall envelopes on the energy efficiency class of a building.

Analyzing the data of the table and diagram, we can draw the following conclusions:
- The initially accepted working hypothesis was confirmed by calculations with an error of up to 3%;
- Using the existing rules and design standards, it was found that, according to the criterion of building energy supply, the construction of frame walls is more effective than the “double log house” version of the walls.

The degree of influence of constructive solutions of wall envelopes on the building's energy saving class for the experimental building under consideration is estimated at 39% based on the results of an analytical study.

Given the steady interest of researchers [1, 2, 3, 4, 6, 7, 8, 12] in the subject of work, the results presented in the article, obtained in the framework of the international project KO 1089 - GrAB, are relevant, practically significant and have the prospect for further development. The calculated data obtained will be additionally evaluated as part of field studies based on the monitoring results of the experimental buildings presented above, followed by a comparative analysis.

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