Insulation system of low-rise buildings on a wooden frame

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Abstract. Residential development of agricultural territories involves the use of low-cost construction solutions to provide housing for emerging new farms or implemented during the development of gardening plots. In this case, it is advisable to construct frame buildings with effective insulation systems.

The article presents the results of studies of the properties and application features for warming wooden structures of rolled foam polyethylene with or without a metallized coating. The tensile strength tests in the longitudinal direction were carried out in accordance with the standard. It was found that the tensile strength in the longitudinal direction for products with a metallized coating is 80–92 kPa, without a metallized coating – 80–87 kPa, and for a weld - 29-32 kPa.

As a result of the studies, insulation systems were developed (which have found wide practical application) and a full-scale thermophysical assessment of the thermal characteristics of these systems and the condition of the wooden frame in the building was carried out.

The results of experimental determinations of the resistance of the outer wall of a wooden frame with a warming sheet of foamed polyethylene amounted to: thermal resistance 2.96 m²°C / W, heat transfer resistance 3.12 m²°C / W. The specific humidity of the pine timber was 7.7–7.8% - at the level of equilibrium humidity values. No putrefactive manifestations of the wooden frame were found, which confirms the advisability of using these insulation systems for the construction of rural residential buildings.

1. Introduction

Wooden frame buildings are widely used in rural and low-rise construction for a number of objective reasons, one of which is their relatively low cost compared to brick structures or buildings based on blocks of cellular concrete, expanded clay concrete or their analogues. In favor of frame structures can be attributed a relatively low mass of walls, which makes it possible to use tape foundations with a low depth or pile, which also increases the economic attractiveness of such solutions [1–3].

On the other hand, the use of the listed massive wall materials does not allow reaching the normative indicators for the thermal resistance of building envelopes, which suggests the additional use of insulation systems, facade heat-insulating, composite or hinged ventilated facades [4–6]. The need for additional insulation further increases the cost and material consumption of building envelopes. For complex insulated residential facilities, seeking minimal or even zero heat consumption for heating, the need to use such solutions significantly increases the cost of design solutions [7, 8].

In real constructions and implemented building systems, an inherent feature for them all begins to appear: cold bridges, through which heat from an isolated room goes into the environment. This
reduces the heat engineering uniformity of the structure. The use of frame systems with insulation allows one to increase the heat engineering uniformity of the insulation shell under certain conditions [9–11].

2. Materials and Methods

If you are using a wooden frame are the traditional insulation system using insulation boards of mineral wool (Fig. 1a), or an alternative to it - with the use of rolled foam (Fig. 1b). According to the calculations of direct costs for the implementation of the systems (Table 1), the use of insulating shells based on rolled polyethylene foam (with or without a reflective coating) implies lower financial (including material) costs compared to mineral wool slab insulation [12–14].

Additional advantages are manifested during the operation of systems in construction conditions. Insulation systems of frame structures differ from plaster systems and ventilated facades in that the heat-insulating elements do not perceive mechanical stress. This makes it possible to use materials of low and medium density with a minimum base load and low thermal conductivity. The density of mineral wool products for frame walls is 50–70 kg / m³. The strength of these products is low, which implies protection of the insulating layers not only from air and vapor-air mixture flows, but also from mechanical stresses. Otherwise, shrinkage and deformation of mineral wool slabs, i.e. violation of the continuity of the insulation coating, are possible. The heat engineering uniformity of the insulating sheath also reduces possible heat loss at the joints of the plates and in the places of their contact with the supporting frame of the building [6–8].

![Figure 1](image_url)

**Figure 1.** Design schemes of facades with a frame wall: a-insulation made of unstitched polyethylene foam; b-mineral wool insulation; 1-wood frame element; 2-thermal insulation; 3-external cladding; 4-internal cladding; 5-vapor barrier

| Frame type of the system                  | Cost, Euro / m² |
|------------------------------------------|-----------------|
|                                          | By materials    | By work | Total    |
| With mineral wool insulation             | 10–13           | 13–15   | 23–28    |
| With insulation based on rolled polyethylene foam | 10–12           | 9–12    | 19–24    |

**Table 1.** The comparative cost of various frame systems
Insulation systems of frame buildings with the use of slab products suggest (Fig. 1a) mandatory vapor barrier from the inside and wind protection from the outside. This allows you to reduce the movement of the vapor-air mixture through the wall, and the use of additional insulating layers complicates the design and increases its cost (see table 1). Seamless insulation shell based on rolled polyethylene foam is made in one layer, which allows to optimize the costs of installation and operation, and also increases the durability of the insulation system.

Rolled foamed polyethylene is placed on the outside of the frame (Fig. 1b), fixed mechanically and welded with hot air. Further mounted cladding from siding or other facade materials. Given the small (compared with concrete or brick walls) loads on the foundation, shallow strip foundations are recommended, which also allows you to optimize the cost of construction.

3. Results

Experimental studies on the possibility of using rolled foamed polyethylene in the insulation systems of frame rural buildings were carried out in the following areas: testing of the thermophysical properties of the material and products; testing the mechanical characteristics of products, including the strength of the weld; determination of the properties of insulation systems in building conditions, including the assessment of humidity and possible putrefactive damage to a wooden frame.

The creation of a seamless insulating sheath is achieved by connecting rolls of polyethylene foam (20 to 150 mm thick) with a lock joint, followed by welding with a building hair dryer. Welding two rolls at a temperature of 110–120 °C results in a single seamless web [15]. A similar technology is used to insulate frame cottages.

As already noted, the elastic insulating shell is deformed along with the base (with a wooden frame). Products in operation experience tensile loads due to their temperature deformations. For the integrity of the insulating sheath, the reliability of the welded joint between the individual insulating panels (sheets, rolls) is also important.

![Figure 2. Experimental determination of the tensile strength in the longitudinal direction of foamed polyethylene](image-url)

The tensile strength tests in the longitudinal direction were carried out in accordance with the standard "Heat-insulating products used in construction. A method for determining tensile strength parallel to front surfaces" (Fig. 2). It was found that tensile strength in the longitudinal direction for products with a metallized coating is 80–92 kPa, without a metallized coating 80–87 kPa, and for a weld 29–32 kPa.
To assess the heat-shielding qualities of the outer wall of a wooden frame with insulation by a foam polyethylene web on a selected section of the wall, an experimental determination of the heat transfer resistance was carried out in accordance with the standards “Buildings and constructions. Methods for determining the heat transfer resistance of building envelopes” and “Buildings and structures. A method for measuring the density of heat fluxes passing through building envelopes”. Sensors were installed both on the inner surface and on the outer surface of the wall (Fig. 3).

![Figure 3. Installation of temperature and heat flow sensors](image)

The results of experimental determinations of the resistance of the outer wall of a wooden frame with a warming sheet of foamed polyethylene amounted to: thermal resistance 2.96 m² °C / W, heat transfer resistance 3.12 m² °C / W. The specific humidity of the pine timber was 7.7–7.8% – at the level of equilibrium humidity values. No putrefactive manifestations of the wooden frame were found, which confirms the advisability of using these insulation systems for the construction of rural residential buildings.

To maintain the microclimate in a room that meets the requirements of the standard “Residential and public buildings. The microclimate parameters in the rooms”, it is recommended to warm only the external polyethylene cloth of the calculated thickness without filling the frame with normative air exchange and compliance with air conditioning conditions.

4. Discussion

Studies have shown that insulation based on rolled polyethylene foam is a durable material that does not deform during the operation of buildings and structures, and is also heat, vapor and waterproofing. The service life of thermal insulation made of foamed polyethylene is at least 50 years without additional repairs to restore or replace materials that form the insulation shell.

As a result of the studies, constructive solutions for frame buildings and system solutions for their complex insulation with one material were developed, which have found wide practical application (Fig. 4). Developed and implemented recommendations for construction and installation works.
Figure 4. Thermal insulation of the cottage: a - deployment of a roll of polyethylene foam; b - mechanical fixing of thermal insulation and stitching of the roll; c - formation of an insulating contour and window openings; d - cottage after five years of continuous operation.

The overall energy efficiency of the solutions implemented in the construction of insulation systems for wooden frame cottages consists of the following elements. Firstly, it is the cost of materials and construction. When implementing classical systems, the use of energy-saving solutions increases the cost of building facilities. In this case, this does not happen, since the formation of a seamless insulating sheath practically minimizes heat loss along the surface of the wall.

Secondly, it is ensuring long operational cycles without major repairs. Monitoring of the state of objects on a wooden frame showed that all structures are in normal operating condition without manifestations of excess moisture and the accompanying appearance of fungal lesions. Blue or mildew.

Thirdly, it reduces operating costs for hot water and heating. It should be noted here that effective reduction of heat loss is achieved by the use of recuperators installed in window openings. This eliminates the negative effect of heat “open window” while providing an influx of fresh air for natural ventilation of the premises.

It is necessary to conduct an economic efficiency assessment and determine the economic effect of the application for the entire life of the facilities, taking into account changes in energy prices. The cost of operating the facilities under consideration will be less than the cost of ordinary housing, given the constant increase in prices for heating, hot water and electricity.

5. Conclusions

Studies have shown that insulation based on rolled polyethylene foam is a durable material that does not deform during the operation of buildings and structures, and is also heat, vapor and waterproofing. The service life of thermal insulation made of foamed polyethylene is at least 50 years without additional repairs to restore or replace materials that form the insulation shell.

The on-site thermophysical assessment of the thermal characteristics of complex insulation systems and the condition of the wooden frame in the building showed that the humidity of the pine timber was 7.7–7.8% – at the level of equilibrium humidity. No putrefactive manifestations of the wooden frame were found, which confirms the advisability of using these insulation systems for the construction of rural residential buildings. As a result of the studies, insulation systems (which have found wide practical application) and recommendations for construction and installation work have been developed.
## References

[1] Kuchumov A V, Vorobyova E S 2018 *Development of peasant (farm) farms within the framework of achieving the doctrine of food security* (Moscow economic journal no. 4) pp 266-277

[2] Zhuk P M, Zhukov A D 2018 *The regulatory framework for the environmental assessment of building materials: prospects for improvement* (Ecology and Industry of Russia Vol 22, no. 4) pp 52–57. DOI: 10.184 12 / 1816-0395-2018-4-52-57

[3] Umnyakova N P, Tsygankov V M, Kuzmin V A 2018 *Experimental thermal engineering studies for rational design of wall structures with reflective insulation* (Housing construction no. 1-2) pp 38-42

[4] Ivanova N A 2018 *Main directions of the prospects for the development of housing construction at the local level* (Moscow economic journal no. 4) pp 65-74

[5] Aleksey Zhukov, Andrey Medvedev, Alexey Poserenin and Boris Efimov 2019 *Ecological and energy efficiency of insulating systems* (E3S Web of Conferences. Volume 135 (ITESE-2019) Published online: 04 December 2019 DOI: https://doi.org/10.1051/e3sconf/201913503070)

[6] Fedyuk R S, Mochalov A V, Simonov V A 2012 *Trends in the development of standards for the thermal protection of buildings in Russia* (Bulletin of the Engineering School of FEFU no. 2 (11)) pp 39–44

[7] Lorenzo Belussi, Benedetta Barozzi, Alice Bellazzi, Ludovico Danza, Anna Devitofrancesco, Carlo Fanciulli, Matteo Ghellere, Giulia Guazzi, Italo Meroni, Francesco Salamone, Fabio Scamoni, Chiara Scrosati. 2019 *A review of performance of zero energy buildings and energy efficiency solutions* (Journal of Building Engineering, Vol 25, DOI: 10.1016/j.jobe.2019.100772) pp 100172

[8] Almusaed A, Almassad A, Alasadi A 2019 *Analytical interpretation of energy efficiency concepts in the housing design process from hot climate* (Journal of Building Engineering Vol. 21. DOI: 10.1016/j.jobe.2018.10.026) pp 254-266

[9] Shen X, Li L, Cui W, Feng Y 2018 *Coupled heat and moisture transfer in building material with freezing and thawing process* (Journal of Building Engineering T. 20, DOI: 10.1016/j.jobe.2018.07.026 ) pp 609–615

[10] Nardi L, Perilli S, De Rubeis T, Sfarra S, Ambrosini D 2019 *Influence of insulation defects on the thermal performance of walls an experimental and numerical investigation* (Journal of Building Engineering Vol 21, DOI: 10.1016/j.jobe.2018.10.029) pp 355-365

[11] Bauer E, Pavon E, De Castro E K, Barreira E 2016 *Analysis of building façade defects using infrared thermography: laboratory studies* (Journal of Building Engineering T. 6, DOI: 10.1016/j.jobe.2016.02.012) pp 93–104

[12] Wang Y, Huang Z, Heng L 2007 *Cost-effectiveness assessment of insulated exterior wall of residential buildings in cold climate.* (International Journal of Project Management, no. 25(2)), pp 143–149

[13] Gnip I Ya, Kerchulis V I, Vaitkus S Ya 2012 *Confidence intervals predicting creep strain of expanded polystyrene* (Building Materials no. 12 C), pp 40–44

[14] Gnip I J, Keršulis V J, Vaitkus S J 2005 *Analytical description of the creep of expanded polystyrene under compressive loading.* (Mechanics of Composite materials 41(4)), pp 357–364

[15] Zhukov A D, Ter-Zakaryan K A, Semenov V S 2018 *Insulation systems with the expanded polyethylene application.* (Science Direct IFAC Paper On Line Volume 51, Issue 30, DOI: 10.1016/j.ifacol.2018.11.191) pp 803-807