Feasibility study of building envelopes selection for low-rise construction

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Abstract. Optimal selection of different types of building envelopes for low-rise construction is a key issue in effective implementation of Regional Programs of Low-rise Housing. When studying this issue the area of construction and ways of transportation should be taken into consideration. In the present paper calculation of minimum thickness and cost per square meter of different variants of load bearing building envelopes was performed at the same thickness of insulant and minimum heat transfer resistance. Comparative analysis was performed providing data on choice of materials for different types of construction.

1. Introduction

In 2011 Ministry of Regional Development of Russian Federation approved the Development Strategy for building materials industry and industrial housing up to 2020. The development and implementation of the Strategy is determined by the necessity of better quality and wider range of products of construction industry at the local market [1].

Low-rise construction is currently spreading over the territory of Tomsk Region. In 2013 85.3 thousand square meters of low-rise housing has been launched. In 2014 60 Ha of land area will be tendered for individual housing.

According to construction codes 50.13330.2012 “Heat protection of buildings” (the updated edition of construction codes SNIP 23-02-2003) the construction of buildings should be performed in accordance with the requirements to heat protection of buildings to provide the necessary microclimate inside the building, the necessary reliability and durability of structures, climatic conditions for operation of technical facilities under minimal energy consumption for heating and ventilation during heating season [2].

Currently the designed building should meet the energy efficiency class A, B^{++}, B^{+}, B and C.

The low-rise building can be considered energy-efficient when while design stage they use building materials enabling to reduce heat losses through exterior walls during operation and resulting in lower energy consumption. In conditions of Tomsk region the problem of optimal choice of materials for the exterior wall is relevant [3].

Modern solutions make it possible to use building materials in different combinations. Therefore the thickness of exterior wall can be decreased up until minimum carrying capacity while keeping thermal and physical properties of the house and also reducing the time of construction [4].

Building materials for building envelopes should meet the following requirements:
1. Energy efficiency;
2. Eco-friendliness and safety for people;
3. Cost-effectiveness;
4. Durability;
5. Fire safety;
6. Aesthetic view.

2. Materials and methods

Thermal-technical calculation of the exterior wall will be held in accordance with Russian construction codes SNIP 23-02-2003 "Heat protection of buildings".

The exterior envelope is calculated as a flat wall that divides the air environment with different temperature and humidity; it is bordered by parallel surfaces and is perpendicular to heat flow. The required heat transfer resistance of building envelopes meeting the sanitary and comfort requirements is calculated by construction codes SNIP 23-02-2003.

Degree day of the heating season:

$$D_d = (t_{\text{int}} - t_{ht}) \cdot z_{ht} = (21 - (-8{,}4) \cdot 236 = 6938{,}4^0 C \cdot \tilde{n}\acute{o}\grave{o}\ , \tag{1}$$

where $t_{\text{int}} = 21$ ^{0}C – design temperature of inside air; t_{ht}=-8,4 – the average temperature of heating season; z_{ht} – duration of heating season, equals to 236 days.

Standard value of heat-transmission resistance of building envelopes (walls) is given in Table 4 Construction codes SNIP 23-02-2003.

$$R_{reg} = a \cdot D_d + b = 0{,}00035 \cdot 6938{,}4 + 1{,}4 = 3{,}83\grave{\imath}\ ^{2} \cdot {}^{0}\tilde{N} / \hat{A}\grave{o}\ . \tag{2}$$

The reduced resistance of building envelope:

$$R_0 = R_{si} + R_k + R_{se}, \tag{3}$$

where:

R_{κ} – thermal resistance of building envelope, m^2·°C/W;

$R_{si} = 1/\alpha_{\text{int}}, \alpha_{\text{int}}-$ heat transfer coefficient of the internal surface of building envelope, W / (m^2·°C), is accepted as in Table 7 SNIP 23-02;

$R_{se} = 1/\alpha_{ext}, \alpha_{ext}-$ heat transfer coefficient of the external surface of building envelope for cold climate conditions, W / (m^2·°C), is accepted as in Table 8 SNIP 23-101-2004.

Thermal resistance R, m^2·°C/W, of homogeneous layer of multi-layered building envelope should be defined by the formula:

$$\mathrm{R} = \delta / \lambda, \tag{4}$$

where:

δ - thickness of layer, m;

λ - designed coefficient of heat transfer of layer, $\hat{A}\grave{o}\ /\ \grave{\imath}\ ^{2} \cdot {}^{0}\tilde{N}$.

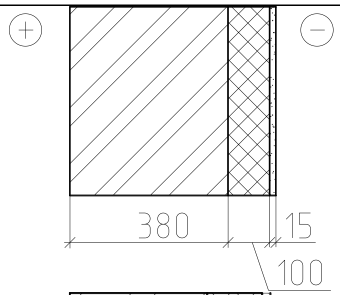
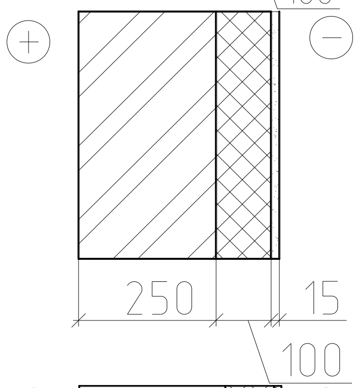
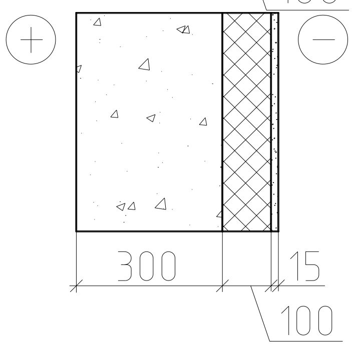
Heat transmission resistance:

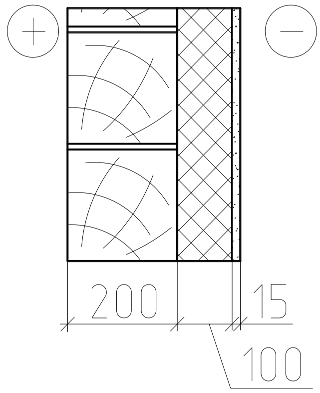
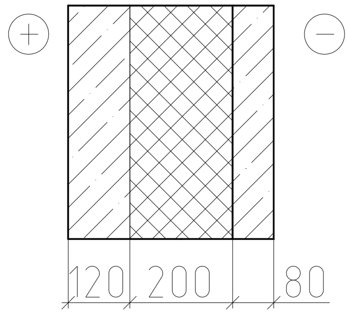
$$R_o = \frac{1}{\alpha_{\hat{a}}} + \frac{\delta_1}{\gamma_1} + \frac{\delta_2}{\gamma_2} + \frac{\delta_3}{\gamma_3} + \frac{\delta_4}{\gamma_4} + \frac{1}{\alpha_{\acute{\imath}}}. \qquad (5)$$

Note that:

1. The thickness of insulant is accepted as 100 mm for all of the variants of building envelope;
2. For all the structures of building envelope it is accepted that R_0^{min}= 3,83 $m^2{\cdot}°C/W$;
3. The thickness of the bearing layer of building envelope is accepted from the condition of providing the carrying capacity.

Table 1. Calculation of heat transfer coefficient of building envelope.

Structure of building envelope	Calculation of the thickness of bearing layer of building envelope	R_o^{actual}, $m^2{\cdot}°C/W$	Design of building envelope
Ceramic brick Foam polystyrene PENO-PLEX-35 Plaster mortar	$\delta_3 = \left(3{,}83 - \left(\frac{1}{8{,}7} + \frac{0{,}1}{0{,}03} + \frac{0{,}015}{0{,}76} + \frac{1}{23}\right)\right)\cdot 0{,}64 = 0{,}21\text{ì}$ δ=380 mm	4,26	
Large-size conventional brick PORO-THERM 25 Foam-polystyrene PENO-PLEX-35 Plaster mortar	$\delta_3 = \left(3{,}83 - \left(\frac{1}{8{,}7} + \frac{0{,}1}{0{,}03} + \frac{0{,}015}{0{,}76} + \frac{1}{23}\right)\right)\cdot 0{,}24 = 0{,}08\text{ì}$ δ=250 mm	4,43	
Gas-concrete block Foam polystyrene PENO-PLEX-35 Plaster mortar	$\delta_3 = \left(3{,}83 - \left(\frac{1}{8{,}7} + \frac{0{,}1}{0{,}03} + \frac{0{,}015}{0{,}76} + \frac{1}{23}\right)\right)\cdot 0{,}4 = 0{,}169\text{ì}$ δ=300 mm	4,41	

Bar of square section (pine-tree) Foam polystyrene PENO-PLEX-35 Plaster mortar	$\delta_3 = \left(3,83-\left(\frac{1}{8,7}+\frac{0,1}{0,03}+\frac{0,015}{0,76}+\frac{1}{23}\right)\right)\cdot 0,18 = 0,058\text{ì}$ δ=200 mm	4,62	
Wall panel	$R_{\hat{o}} = \frac{1}{8,7}+\frac{0,12}{0,67}+\frac{0,2}{0,03}+\frac{0,08}{0,67}+\frac{1}{23} = 7,13\text{ì}^{2}\cdot^{\circ}\tilde{N}/\hat{A}\text{ò} \succ R^{o}_{\min}$ δ=400 mm	7,13	

All the variants under consideration correspond with the accepted minimum heat transfer coefficient of building envelopes R_0^{min}= 3,83 $m^2\cdot°C/W$. This in its regard will allow construction of low-rise buildings in Tomsk region with the highest energy-efficiency class A.

To select the optimal material of the bearing building envelope for low-rise construction we will perform cost calculation for 1 square meter of living floor area (Table 2).

Table 2. Total cost of building envelope counting 100 m^2 of residential floor area.

Material of building envelope	Amount	Cost of material per cubic meter, roubles	Cost of material, roubles	Cost of insulant + finishing, roubles	Total cost, roubles	Cost of material per square meter, roubles
Ceramic brick, m^3	31,92	3200	102144	37800+2898	142842	1428
Large-size conventional brick PORO-THERM 25, m^3	21,0	4100	86100	37800+2898	126798	1267
Gas-concrete block, m^3	25,2	3600	90720	37800+2898	131418	1314
Bar of square section (pine-tree), m^3	16,8	6300	105840	37800+2898	146538	1465
Wall panel	33,6	8000*	-	-	268800	2688

Note: Total cost includes 1 m^3 of reinforced concrete and the chosen insulant.

All the data provided can be applied for construction of different types of low-rise settlements. Variability of choice is defined by the area for construction and the way of materials transportation.

Taking for instance industry or field-based villages the most appropriate is construction of fast erected structures on a lightweight foundation. For construction in the countryside where there are companies-manufacturers of ceramic brick, ceramic large-scale conventional brick or gas concrete block, the construction of these materials will be more reasonable. In case the countryside lacking such companies the choice of materials for building envelopes should be selected regarding the minimal cost.

Table 3. Variability of materials selection for different types of construction.

Type of construction / Material of building envelope	Construction within the city line	Marginal development	Countryside construction	Industry-based villages (agricultural, gas or oil-industry-based villages)
Ceramic brick	+	+	–	–
Large-size conventional brick	+	+	+	–
Gas concrete block	+	+	–	–
Bar of square section (pine-tree)	+	+	+	+
Wall panel	+	+	–	–

3. Conclusions

Building materials under study are reliable and durable; they correspond to the climate conditions of Tomsk Region, while having minimum energy consumption for heating and ventilation of buildings during heating season.

The optimum choice of material use for the load bearing building envelope was performed for low-rise construction in Tomsk and Tomsk Region. The minimum thickness of building envelope and its cost per square meter was estimated for Tomsk and Tomsk region. The table of materials choice variability was offered for different types of construction.

The given data can be used in Development Programs of low-rise construction providing the economical feasibility of investment projects.

References

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