Analyzing energy consumption while heating one-layer building envelopes in conditions of intermittent heating

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Abstract. This paper focuses on energy consumption for heating single layer building envelopes, used in conditions of intermittent heating in different physical and mechanical and thermophysical parameters of construction materials. The authors investigated several variants of single-layer building envelopes, used frequently in building practice, with different density and coefficients of building materials thermal conductivity. For each variant of a building envelope heat leakage and time spent on heating were calculated. Heating time was calculated by both exact and approximate analytical method. Then the researchers draw a graphic dependence of energy consumption on the density of the material taking this computational data as a basis. Further analysis showed that building envelopes made of lightweight aggregate concrete and porous concrete were the most energy efficient.

1 Introduction

At present, there are various construction and thermal insulation materials with differing physical and mechanical and thermophysical parameters used in the construction of country cottages [1-2]. For the construction of single-layered exterior walls of buildings and structures of individual buildings with bearing walls the following building materials are used: sand-lime brick, lightweight aggregate concrete [3], ceramic bricks[4], porous concrete, timber beams and no-fine lightweight aggregate concrete.

As a rule, country houses are rarely used in the cold period of the year for energy cost savings. That's why dynamic characteristics of building envelopes should be taken into account when designing such buildings. Frequency-response analysis is referred to a task of nonstationary heat transfer through outer walls and floor structures.

Methods for solving tasks of nonstationary thermal conductivity in solid bodies are set out in Papers [5-17].

Calculation methodology of heating time and units cost of heat energy for heating building envelopes are described in detail in Papers [18-19].

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This study focuses on the energy consumption for heating of one layer of the building envelopes used in the conditions of intermittent heating in different physico-mechanical and thermophysical parameters of building materials.

2 Materials and Methods

The task described above can be achieved while using an exact and an approximate analytical methods. When solving the task by the approximate analytical method, heating time is calculated according to the formula provided in the work of B.A. Semenov:

$$\tau_н = 2\frac{Q_н}{q_{от}}\frac{1+2\varphi}{1+\varphi}\text{, sec,} \tag{1}$$

where $Q_н$ is the amount of heat necessary to heat a square meter of the wall, kJ/m^2; $q_{from}$is the specific heat capacity of heating system W/m^2; φ is dimensionless criterion of boundary conditions.

When solving the task by the exact method, heating time is calculated according to the formula

$$\tau_н = -\frac{\delta^2}{\mu_1^2 \cdot a}\ln\frac{1+Ki+\dfrac{Ki}{Bi}-1-\dfrac{(R_0\cdot\alpha_в-1)(t_в-t_н)}{t_н\cdot R_0\cdot\alpha_в}\Theta_в}{Ki\cdot D_1}\text{, sec,} \tag{2}$$

where D_1 is the dimensionless coefficient; μ_1 is the root of transcendental equations $ctg\mu_1 = \frac{\mu_1}{Bi}$; Ki is Kipitchev's criterion; Bi - Bio criterion; a - temperature conductivity coefficient, m ²/sec; δ - structural thickness, m; $t_в$ - internal air temperature,° C; $t_н$ - external air temperature, °C; $\alpha_в$ - heat transfer coefficient on the inner surface of the building envelope, W/(m^2 °C); R_0 - thermal resistance of exterior walls, (m^2 ·° c)/W; $\Theta_в$ - dimensionless temperature of the inner surface of the wall.

Unit costs of thermal energy for heating a single-layer exterior wall when there is basic heating at hand is defined by the define formula

$$Q_н = c\cdot\rho\cdot\delta\cdot\Delta\tau\text{, kJ/m}^2\text{,} \tag{3}$$

where c is specific heat of the wall, kJ/kg ·° c; ρ_i - outer wall density, kg/m^3; δ - thickness of the outer wall, m; $\Delta\tau$ - wall temperature change, °C.

$$\Delta\tau_i = 0{,}5(t_{в2}-t_{в1}) - \frac{t_{в2}-t_{в1}}{2R_0}\left(\frac{1}{\alpha_в}-\frac{1}{\alpha_н}\right), \tag{4}$$

where $t_{в1}$, $t_{в2}$ are the internal air temperature when there is basic heating working in a current mode, °C; $\alpha_н$ - heat transfer coefficient by the open air, W/(m ² ·°C).

3 Results

The authors performed thermal calculations for different variants of single layer outer walls when there is basic heating at hand for the city of Samara by an approximate analytical method.

Calculation results are given in Table 1.

Table 1. The results of calculations of single-layer outer walls when there is basic heating at hand

No	The construction of the outer wall	Heat transfer resistance R_o, (m^2 ·°C)/W	Unit energy consumption Q_n, kJ/m^2	The outer wall heating time τ_n, h
1	Silicate brickwork on a sand-cement mortar of 0.640m thickness	1.00	4670.55	52.26
2	Expanded-clay concrete blocks on a sand-cement mortar of 0.4m thickness	1.50	1397.11	23.12
3	Ceramic brickwork on a sand-cement mortar of 0.640m thickness and 1800 kg/m^3 density	1.07	4697.35	56.17
4	Gas-concrete blocks on adhesive solution of 0.4m thickness and 600 kg/m^3 density	2.66	978.19	28.25
5	Outer wall of pine lumber with 0.3 m thickness and 500 kg/m^3 density	2.30	1666.07	41.76
6	Lightweight aggregate concrete stones of no-fine lightweight aggregate concrete on warm solution of 0.4m thickness and 600 kg/m^3 density	2.94	956.56	30.54

We also calculated various single-layer outer walls when there is no basic heating at hand. Calculation results are given in Table 2.

Table 2 The results of calculations of single-layer outer walls when there is no basic heating at hand

No	The construction of the outer wall	Heat transfer resistance R_o, (m^2 ·°C)/W	Unit energy consumption Q_n, kJ/m^2	The outer wall heating time τ_n, h		Fractional error, %
				Exact solution	Approximate analytical method	
1	Silicate brickwork on a sand-cement mortar of 0.640m thickness	1.00	24438.91	298.11	273.46	8.3
2	Expanded-clay concrete blocks on a sand-cement mortar of 0.4m thickness	1.50	7294.40	137.77	120.71	12.4

3	Ceramic brickwork on a sand-cement mortar of 0.640m thickness and 1800 kg/m^3 density	1.07	24568.02	324.56	293.79	9.5
4	Gas-concrete blocks on adhesive solution of 0.4m thickness and 600 kg/m^3 density	2.66	5097.98	164.75	147.23	10.6
5	Outer wall of pine lumber with 0.3 m thickness and 500 kg/m^3 density	2.30	8686.09	241.17	217.72	9.7
6	Lightweight aggregate concrete stones of no-fine lightweight aggregate concrete on warm solution of 0.4m thickness and 600 kg/m^3 density	2.94	4984.12	179.21	159.15	11.2

Then the researchers draw a graphic dependence of energy consumption on the density of the material taking this computational data as a basis. The dependence is illustrated by Figure 1.

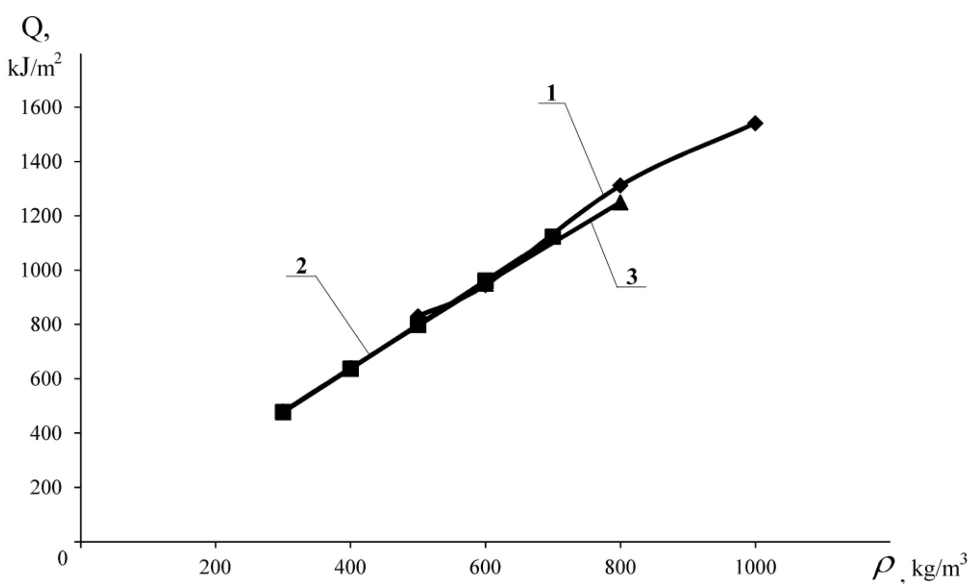

Fig.1. Energy consumption dependence of the density of the material: 1 – lightweight aggregate concrete; 2 – no-fine lightweight aggregate concrete; 3 – porous concrete

4 Discussion

The obtained results make clear the importance of dynamic characteristics of construction materials for building envelopes used in conditions of intermittent heating. It is due to heating energy saving and toachievement of comfort level during country cottage exploitation. Thus, building envelopes design must takein toaccount not only heatingti mebut also an operation mode of cottage power generator. Under remote control the owner of cottagehasthe opportunity to change operation mode: from stand-by mode to work mode. Under manual control it is necessary minimum time for envelope heating.

The results of the calculations presented in Tables 1 and 2, show that if we reduce the density of building materials it will reduce heat losses and time spent on heating building envelopes.

Conclusions

The paper presents calculation results of dynamic characteristics of various single-layer walls done by an exact and an approximate analytical methods of solving tasks of no stationary thermal conductivity. Analysis of these characteristics showed that the following structures proved to be the most effective: Expanded-clay concrete blocks on a sand-cement mortar of 0.4m thickness; gas-concrete blocks on adhesive solution of 0.4m thickness and 600 kg/m^3 density; lightweight aggregate concrete stones of no-fine lightweight aggregate concrete on warm solution of 0.4m thickness and 600 kg/m^3 density.

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