Measuring the thermal resistance of typical multi-layer building walls using the accelerated measurement method

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Abstract. This paper considers the application of accelerated thermal resistance measurement to typical constructions of multi-layer walls of buildings with thermal insulation. It is shown that it is possible to reduce the measurement time considering the results of preliminary modelling. The required calculations for some typical constructions of building walls were made. The examples of simulation results shown in this paper allow to reduce the thermal resistance measurement time by 15-20%. There can be made calculations for other structures of building walls, following the presented method.

1 Introduction

The lack of thermal resistance of the main building structures is one of the main reasons for low energy efficiency of buildings built in the USSR in 1960-1990 years [1-4]. According to the research, in a traditional apartment house up to 40% of heat is lost through walls, 18% through windows, 10% through basement, 18% through roof and 14% through ventilation [5-8]. Heat loss is especially noticeable in the northern regions [9-11]. Usually buildings built before 1995 in central Russia have values of thermal resistance 2-3.5 times smaller than it should be according to the modern standards [12]. In 1995 in Russia the nation-wide regulatory requirements for thermal protection of buildings were established, increasing the resistance requirements for enclosing structures. Now it is regulated by SNiP 23-02-2003 "Thermal protection of buildings". Additional insulation on facades of buildings pays off in about 3.5 years [13-15], but it requires estimating of thermal resistance of the existing walls.

Methods for determination of thermal resistance, approved in Russia, require long-term measurements. For building walls, it takes more than 15 days, according to GOST [16]. Reduction of the measurement time will significantly simplify such work, reduce its cost and will make it easier to increase the energy efficiency of the buildings [17-19].

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2 Materials and methods

One method of measuring the thermal resistance of the wall is the thermal stabilization of its sides at different temperatures and measuring the heat flux through the wall. A noticeable drawback of it is that you must wait for the system to steady state, which can take up to 15 days.

A method of accelerated measurement of thermal resistance of homogeneous walls is considered in the patent [20]. It is shown that when considering homogeneous walls, the use of the half-sum of incoming and outgoing heat flows becomes constant much earlier than the whole system. That allows to take measurements significantly earlier than the system achieves a steady state. The essence of this method is clearly demonstrated in Figure 1.
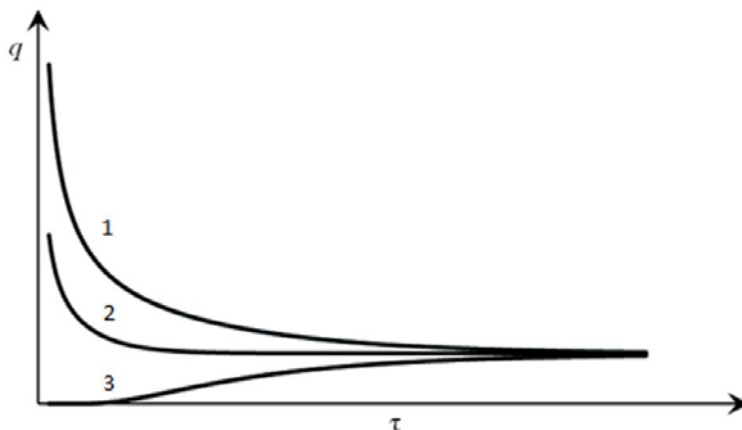

Figure 1. The essence of the original method. Time dependence of the incoming (1), outgoing (3) heat flows and their half-sum (2).

To determine the minimum measurement time with an error of less than 5% is used the following relationship:

$$a\tau/h^2 > 0.1 \tag{1}$$

where
a - thermal diffusivity of the wall;
h – its thickness;
τ – the measurement time.

As shown in [21], the use of this method for measuring the thermal resistance of multi-layer walls made of materials with significantly different thermal properties allows to reduce the measurement time by about 15%, but it is hard to estimate the minimum measurement time in advance with sufficient precision.

Since the structural elements the walls of buildings are built of (bricks, concrete blocks, sheets of insulation, etc.) have a number of standard dimensions, it is possible to produce a computer simulation of the measurement of thermal resistance for a number of typical constructions of walls [22]. Taking into account the results of the simulation, it is possible to make accelerated measurement of deviations of the expected thermal resistance values, taking the measurement time with some excess to take into account the possible influence of changed material properties.

3 Results and discussion

As was shown in [21], for the walls of brick and concrete without thermal insulation layers the relationship (1) works completely. In this paper are considered some models of building walls

consisting of brick, concrete, polystyrene and mineral wool in the form of blocks in various combinations.

Let us consider in detail the case of a brick wall with a layer of polystyrene foam insulation and gypsum layers on both sides. The simulation was performed in the program Heat 2. A two-dimensional model represents a part of a vertical wall with the temperature of t = 20 °C at the inner surface and t = 0 °C on an outer surface. Adiabatic conditions are applied to the horizontal surfaces [21]. The material properties are taken from the built-in library of the program. Figure 2 shows the structure of the model, Figure 3 - the temperature field in a steady state, and Figure 4 – the specific heat flux field.
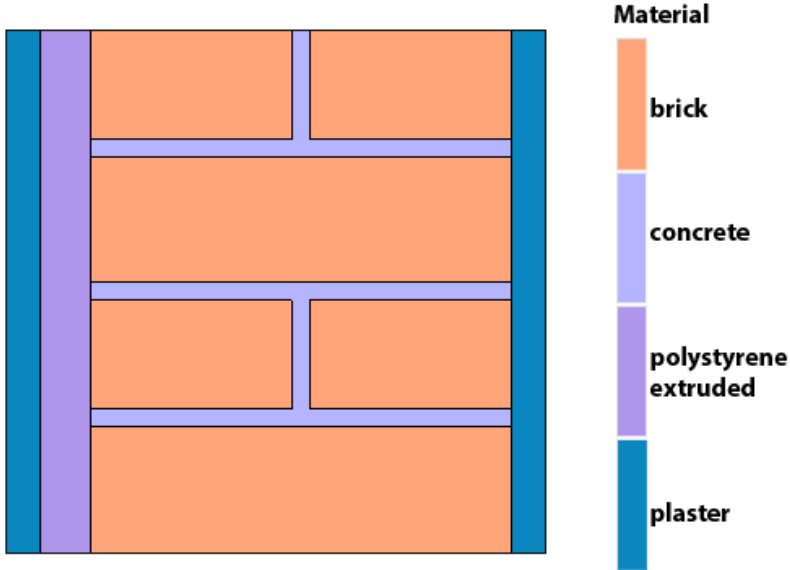

Figure 2. Structure of the model, brick wall with a layer of thermal insulation and two layers of plaster.
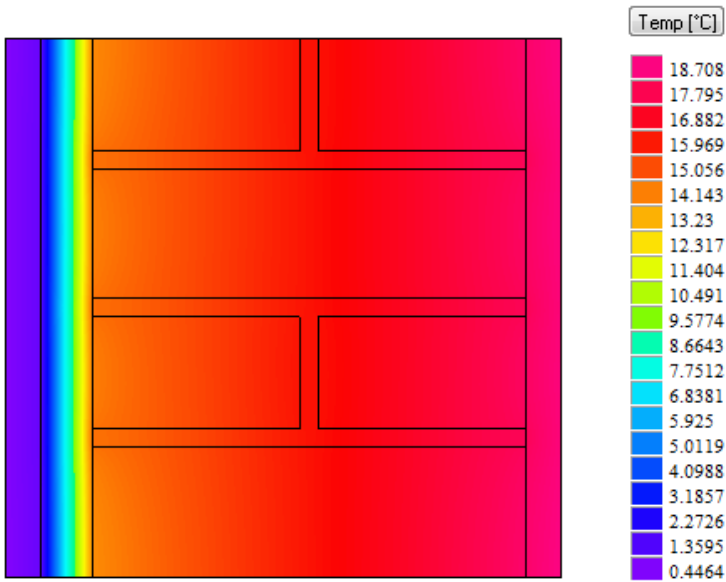

Figure 3. Results of the simulation. Temperature field in a steady state.

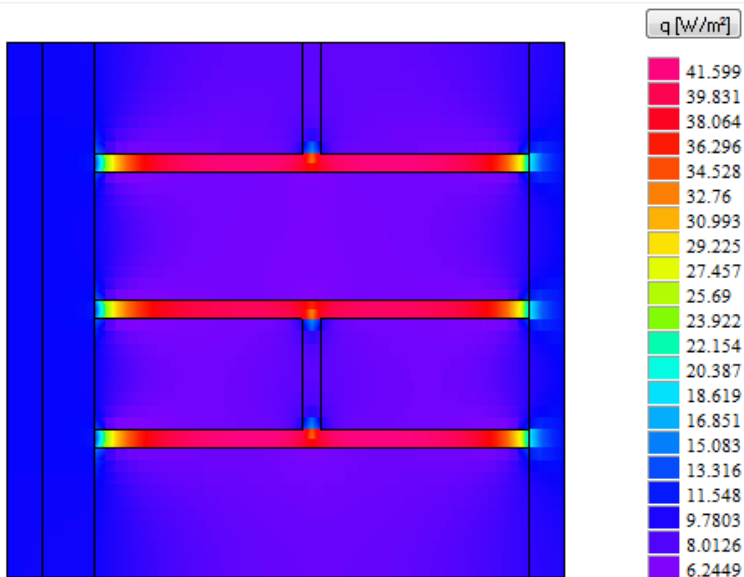|	q [W/m²]
	41.599
	39.831
	38.064
	36.296
	34.528
	32.76
	30.993
	29.225
	27.457
	25.69
	23.922
	22.154
	20.387
	18.619
	16.851
	15.083
	13.316
	11.548
	9.7803
	8.0126
	6.2449

Figure 4. Results of the simulation. Specific heat flux field in a steady state.

During the simulation the program tracked heat flux on both of the vertical surfaces within 15 days of virtual time in increments of 15 minutes. The results are presented in Figure 5.
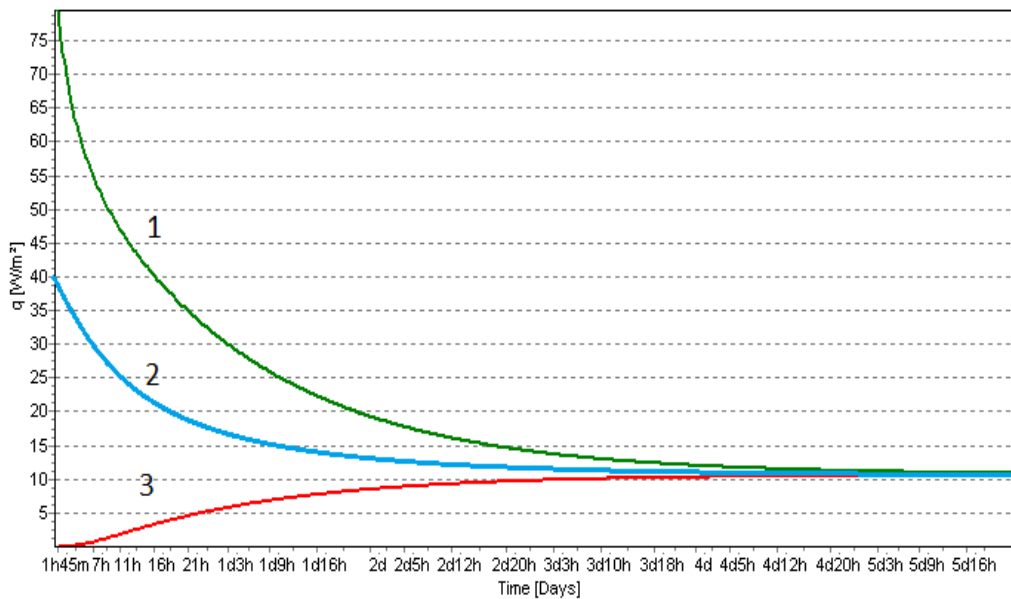

Figure 5. Results of the simulation. Time dependence of the incoming (1), outgoing (3) heat flows and their half-sum (2).

It was found that with a deviation of 5% the values of incoming and outgoing heat flows become equal to the flows obtained after 15 days in 5 days and 2 hours (τ_1), and half the sum of these flows becomes equal to the same flows in 3 days and 20 hours (τ_2). Thus, the reducing of measurement time is $\Delta=24,6\%$. Similarly, were considered some other types of building wall structures. The results are shown in Table 1.

Table 1. Simulation results for various wall designs.

Wall structure	τ_1, h	τ_2, h	Δ, %
One brick (250 mm), polystyrene foam (20 mm), plaster (2 x 20 mm)	77	62	19.5
One brick (250 mm), polystyrene foam (30 mm), plaster (2 x 20 mm)	122	92	24.6
One brick (250 mm), polystyrene foam (50 mm), plaster (2 x 20 mm)	142,5	117	17.9
One brick (250 mm), polystyrene foam (20 mm), plaster (2 x 20 mm)	172,5	140	18.8
One brick (250 mm), mineral wool (50 mm), plaster (2 x 20 mm)	93,5	80	14.4
One brick (250 mm), mineral wool (100 mm), plaster (2 x 20 mm)	128	112	12.5

Thus, the use of the presented simulation results allows to reduce the thermal resistance measurement time by 15-20% (18% on the average for the provided examples). The results for other combinations obtained by a similar method also can be used to simplify the renovation of old buildings to increase their energy efficiency.

4 Conclusions

1. The results obtained by the presented method can be used to simplify the process of renovation of old buildings.
2. For acceleration the measuring of thermal resistance of typical design multilayer insulated wall can be used the results of calculations presented in this paper, or obtained by the same method.
3. The use of the calculations presented in this paper allows to reduce measurement time by 15-20%.

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