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A study of thermal conductivity in multilayer building materials and products

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Abstract: At this time, the solution to the problem of energy use, namely: energy conservation and energy efficiency is extremely important. Saving energy in buildings by solving the practical problems of reducing the total consumption of energy resources, is implemented through the use of effective thermal insulation materials, energy-efficient structures of external walls and a significant increase in thermal protection of the operated Fund. The actual solution to these problems is the development of new approaches to the calculation, design and manufacturing of insulation materials in wall constructions and how they are implemented. Therefore, it is necessary to improve the theoretical and scientific basis in order to make a more thorough study of the distribution of temperature within the material from which the design is made. Different methods of researching the thermal conductivity of multilayer structures and methods for calculating the temperature field of single- and multi-layered building structures have been proposed in studies of temperature distribution and energy efficiency improvements of building materials and products.

Keywords: thermal conductivity, energy efficiency, multi-layered building constructions, numerical methods

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Introduction

At this time, solving energy consumption problems, namely energy saving and energy efficiency, is extremely important.

Saving energy in buildings by solving the practical problem of reducing the total cost of non-renewable energy resources is realized through the use of effective insulation materials, energy-saving structures in external walls and a significant increase in the thermal protection of the exploited fund. The main source of heat loss in a building are: walls, floors, windows and doors.

The actual solution to these problems is in the development of new approaches to the calculation, design and manufacturing of insulation materials in wall constructions and how they are used.

Therefore, it is necessary to improve the theoretical and scientific basis in order to make a more thorough study of the distribution of temperature within the material from which a design is made. Calculations of thermal conductivity in structures are carried out according to the standard method used in design. It is believed that inside the layer, which consists of one material, the temperature change will be linear. As a result, it is impossible to establish what is really going on within each specific building material. If the temperature is known only at the beginning and end of a certain layer of the wall, it is impossible to conclude that it is spreading.

Thus, the relevance of the work is due to the need for a theoretical study of heat conductivity in building materials and products in order to increase energy efficiency.

1. Analysis of the processes of heat transfer and energy saving in construction

The calculation of heat loss in buildings is the most important stage in the design of a house. It can be calculated without knowing the heat-shielding properties of the enclosing structures, the coefficients of heat exchange on the surfaces or the calculated external and internal conditions. There are different approaches to choosing the calculated values of the heat conductivity coefficients in building materials. At the same time diligence in selecting the value of this factor is extremely important, taking into account the fact that manufacturers of heat-insulating materials often indicate thermal conductivity that does not reflect normal operating conditions, but only dry conditions. It is also necessary to correctly evaluate the values of the coefficients of heat transfer on the surfaces of the enclosing structures, especially the coefficient of heat transfer on the inner surface. If its value is overestimated, the calculated temperature on the inner surface will be overestimated.

In determining the heat loss of the building, proper assessment of the coefficients of heat transfer in the enclosing structures is important. Heat loss in buildings occur in the form of heat dispersion by external enclosing structures, which arises and increases, not only, as the temperature difference of air from the inside and outside of the building increases, but also as a result of increased infiltration of external air under the pressure of wind.

The following outstanding scientists engaged in the study of the thermal conductivity of enclosing design and the study of temperature fields: A. Likov,

G. Karslow, V. Bogoslovsky, V. Machinsky, G. Fahrenyuk, E. Kartashov, N. Nikitenko, L. Kozdoba, B. Rvachev, N. Belyaev and others.

However, these studies are used for the stationary operational mode of the enclosing multilayer structures and do not allow for the analysis of the dynamics in the process of heat transfer components in walls when related to the passing of time and the outdoor air temperature.

When performing heat-engineering calculations (related to the definition of thermal resistance in structures used for fencing) for the thickness of the heater layer to be solved, the thickness of the other materials in the design also need to be known.

In many cases, the elements of the construction are multilayered. Each of the elements included in the system, has its thermophysical, mechanical and other properties that are fully consistent with the designation of the layers. If there is equality in the temperature of heat fluxes occurring at the boundary of the body, this indicates that there is an ideal thermal contact. If, due to micronivity, the actual area of collision is considerably less geometric, then the thermal resistance of the contacting surfaces occurs at the point of the body junction. At the same time, the temperature at the joints of the structures will not be the same.

Theoretical methods provide the opportunity to explore a limited range of issues. The exact relationships obtained on their basis are expressed by functional dependencies, which are difficult to use in calculation, together with precise analytical methods for the study of heat transfer in multilayer structures used in numerical methods.

These days, the basis of mathematical modelling used to study the process of heat and mass transfer processes, both in theoretical and practical studies, is theoretically based on the Fourier law for heat propagation.

Among the methods used to solve nonstationary heat conductivity, the best known are the classic variable separation method, grid method, variational and projection methods, the method of R-functions and the finite element method.

A study of publications on the determination of thermal conductivity found that the distribution of temperature in structural elements is determined for each layer as a whole and the calculation of the temperature field in single and multilayer wall structures indicates the absence of more accurate information related to the temperature distribution in each layer of the structure.

2. Methods used in studying the thermal conductivity of multilayer construction products

In order to determine the thermal conductivity of building materials and products, the basis of the research was on the analytical, graphical and practical methods of calculation.

As a result of the research, the most accurate of the considered methods was found to be the practical method of calculating thermal conductivity. The distribution of temperature at all nodes of the studied material was found by dividing the subject into squares (grid method): pre-defining some arbitrary values of temperature in all grid nodes, and then sequentially calculating the values of the temperature, replacing the previous values obtained if they do not resolve themselves within the relevant equations for given air temperatures on either side of the structure. The calculation process can be considered complete only when, within the given margin of error, the temperature remains constant in all grid nodes.

In the analytical method, the calculation of the temperature field is based on the classical theory of temperature fields. That is, the study of thermal conductivity is reduced to the study of spatial-time variations of the temperatures within all layers of the design. The coefficients of thermal conductivity of materials does not depend on temperature and change of temperature as depicted by a straight line.

To determine the temperature in multilayer structures graphically, lay a horizontal axis, which corresponds to zero temperature and mark all of the thermal resistance values. Through the resulting points, vertical lines are drawn that correspond to the temperature of the internal and external air and are connected to the straight line. The points of intersection of this line with the corresponding vertical lines give the boundaries of the segments, which express the values of temperatures at the boundaries of the layers of the design.

3. The problem of non-stationary heat conductivity in a multilayer environment

For a theoretical study of thermal conductivity, the solution to the problem of non-stationary heat conductivity by means of the integral direct method is shown. Where the region consists of three parts with different coefficients of thermal conductivity (Fig. 1).

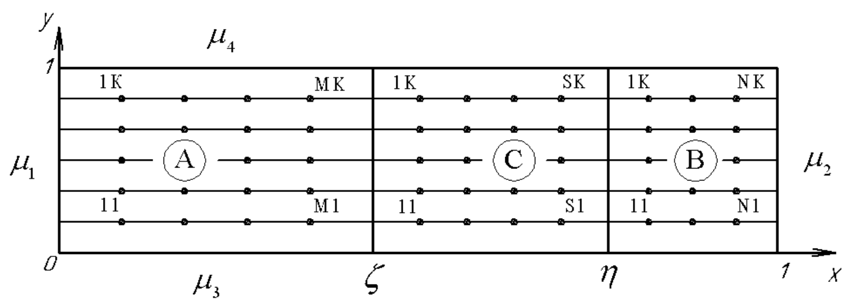

Fig. 1. Scheme of thermal conductivity

In order to determine the temperature in each layer of construction and the place of their connection, the recurrence formulas obtained for the approximation coefficients of the system of non-stationary thermal conductivity equations are used. By integrating the heat equation in the vicinity of each node, taking into account the approximate solution, we obtain a system of differential equations of the first order with respect to the temperature values at the nodal points of the corresponding layer of construction. Changing the domain of integration leads to the solution of the problem by the method of direct, improved by the method of direct and method with the choice of the domain of integration due to the initial conditions.

The main task is to solve this equation:

$$\frac{\partial u}{\partial t}=\frac{\partial}{\partial x}\left[a(x)\frac{\partial u}{\partial x}\right]+f(x,t) \tag{1}$$

where the coefficient of thermal conductivity $a(x,y)$ is significant:

$$a(x)=\begin{Bmatrix} a_1, x<\xi_1; \\ a_2, \xi_1<x<\xi_2; \\ a_3, \xi_2<\xi_3; \\ a_4, \xi_3<x \end{Bmatrix} \tag{2}$$

in the region which satisfies $\{(x,t),\ 0<x<1,\ x\neq\xi_1,\xi_2,\xi_3;\ t>0\}$, the initial condition (3),

$$u(x,0)=\phi(x) \tag{3}$$

conditions on boundaries (4):

$$\begin{cases} [\beta_1 u_x+\gamma_1 u]_{x=0}=\psi_1(t), \\ [\beta_2 u_x+\gamma_2 u]_{x=1}=\psi_2(t) \end{cases} \tag{4}$$

and conditions for the connection (5), (6):

$$\begin{aligned} u\Big|_{x=\xi_1-0}&=u\Big|_{x=\xi_1+0} \\ u\Big|_{x=\xi_2-0}&=u\Big|_{x=\xi_2+0} \\ u\Big|_{x=\xi_3-0}&=u\Big|_{x=\xi_3+0} \end{aligned} \tag{5}$$

$$\begin{aligned} a_1\frac{\partial u}{\partial x}\Big|_{x=\xi_1-0}&=a_2\frac{\partial u}{\partial x}\Big|_{x=\xi_1+0} \\ a_2\frac{\partial u}{\partial x}\Big|_{x=\xi_2-0}&=a_3\frac{\partial u}{\partial x}\Big|_{x=\xi_2+0} \end{aligned} \tag{6}$$

Each layer of material in the thickness is divided by the corresponding step which is given and contains nodal points.

For a numerical solution of the problem (1)-(6) along the x-axis, a grid is introduced in accordance with the step:

$$h_{Ax} = \frac{\zeta}{M+1},\ h_{Cx} = \frac{\eta - \zeta}{S+1},\ h_{Bx} = \frac{1-\eta}{N+1}$$

Relative to the axis in the interval (0, 1), the net with a step:

$$h_{Ay} = h_{Cy} = h_{By} = \frac{1}{K+1}.$$

The solution to the heat conduction equations in the vicinity of the nodal points of each layer is in the form of a quadratic polynomial:

$$P(x, x_k, t) = \sum_{i=0}^{2} A_i^k(t)(x - x_k) \tag{7}$$

where:

x_k - coordinate of the point,

A_i^k (t) - coefficients of a polynomial.

Integrating equations (1) at the intervals $(x_k - \alpha_x h,\ x_k + \alpha_k h)$ we obtain the system of algebraic equations M × K + S × K + N × K of linear differential equations with respect to $A_{00}^{mk}, C_{00}^{sk}, B_{00}^{nk}$

$$\dot{A}_{00}^{mk} + \frac{\alpha_{mk}^2 h_{Ax}^2}{3}\dot{A}_{20}^{mk} + \frac{\alpha_{mk}^2 h_{Ay}^2}{3}\dot{A}_{02}^{mk} = 2a_A A_{20}^{mk} + 2a_A A_{02}^{mk} + \Phi_A^{mk};$$

$$\dot{C}_{00}^{sk} + \frac{\alpha_{sk}^2 h_{Cx}^2}{3}\dot{C}_{20}^{sk} + \frac{\alpha_{sk}^2 h_{Cy}^2}{3}\dot{C}_{02}^{sk} = 2a_C C_{20}^{sk} + 2a_C C_{02}^{sk} + \Phi_C^{sk};$$

$$\dot{B}_{00}^{nk} + \frac{\alpha_{nk}^2 h_{Bx}^2}{3}\dot{D}_{20}^{nk} + \frac{\alpha_{nk}^2 h_{Dy}^2}{3}\dot{B}_{02}^{nk} = 2a_D D_{20}^{nk} + 2a_D D_{02}^{nk} + \Phi_D^{nk},$$

where:

Φ - double integral of $f(x,y)$ at each interval of integration;

$$k = \overline{1,K}, m = \overline{1,M}, n = \overline{1,N}.$$

Given the initial conditions, this system can be expressed in matrix form

$$\dot{R}_{00} = \alpha R_{00} + \beta\psi + \Phi, \tag{8}$$

where:

$\dot{R}_{00}=\{\dot{A}_{00},\dot{B}_{00},\dot{C}_{00}\}^T$; $R_{00}=\{A_{00},B_{00},C_{00}\}^T$;

α,β - corresponding matrices with numerical coefficients for the columns R_{00} and ψ;

Φ - matrix-column of double integrals from $f(x, t)$.

By solving the system and using (1) various coefficients for thermal conductivity of materials, one can investigate the temperature fields of multilayer media of different nature.

For $x = x_k$ the temperature value $A_0^k(\mathrm{t})$ in the k-th node is obtained. This allows the temperature to be determined, not only in the nodes in the vicinity of certain points, but also within the contact material, which is very important.

By changing the limits of integration in the equalization of heat conductivity, the calculation is made by the straight-line method and by the improved straight-line method.

Conclusions

To increase the energy efficiency of building materials and products, existing methods for studying the thermal conductivity of multilayered structures and methods for calculating the temperature field of single- and multi-layered building structures have been proposed and studied. The analysis showed that the most accurate is the practical method for calculating heat conductivity in multilayer structures, which shows the study of temperature distribution in all nodes of the partition into squares of the test material. Due to the results obtained with different difference schemes, you can choose a more reliable solution for a particular material arrangement.

Changing the thickness of the layers and the coefficients for the thermal conductivity of the materials, you can acquire the necessary layout of materials to achieve the appropriate purpose. And this, as a result, will allow the opportunity to obtain new thermal insulation materials.

Bibliography

Lykov, A. (1961) *Theoretical Foundations of Building Thermophysics*. Minsk, Academy of Sciences of the BSSR, 526 p.

Fokin, K. (1973) *Construction Heat Engineering of Fencing Parts of Buildings*. Moscow, Stroyizdat, 288 p.

Ryndiuk, V., Ryndiuk, S. & Mishchuk, T. (2008) *Simulation of the thermal conductivity of a two-dimensional three-layer environment*. Vinnitsa, Modern Technologies, Materials and Constructions in Building: Scientific and Technical Collection, 5, 96-98.

Ryndiuk, S. (2018) *Method for Determining the Thermal Conductivity of Building Materials and Products*. Vinnytsia, 154 p.

Badanie przewodności cieplnej w wielowarstwowych materiałach i produktach budowlanych

Streszczenie: Obecnie rozwiązanie problemu zużycia energii, a mianowicie: oszczędzanie energii i efektywność energetyczna, jest niezwykle ważne. Oszczędzanie energii w budynkach poprzez rozwiązywanie praktycznych problemów zmniejszenia całkowitego zużycia zasobów energetycznych realizowane jest poprzez zastosowanie efektywnych materiałów termoizolacyjnych, energooszczędnych konstrukcji ścian zewnętrznych oraz znaczny wzrost ochrony cieplnej. Rzeczywistym rozwiązaniem tych problemów jest opracowanie nowych podejść do obliczania, projektowania i produkcji materiałów izolacyjnych wykorzystywanych w konstrukcjach ścian oraz sposobu ich zastosowania. Dlatego konieczne jest ulepszenie podstaw teoretycznych i naukowych w celu dokładniejszego zbadania rozkładu temperatury w materiale, z którego wykonany jest dany element konstrukcji. Do analizy rozkładu temperatury i poprawy efektywności energetycznej materiałów i produktów budowlanych zaproponowano różne metody badania przewodności cieplnej konstrukcji wielowarstwowych oraz obliczania pola temperatur jedno- i wielowarstwowych konstrukcji budowlanych.

Słowa kluczowe: przewodzenie ciepła, efektywność energetyczna, wielowarstwowe konstrukcje budowlane, metody numeryczne