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The building extension with energy efficiency light-weight building walls

Надстройка существующих зданий с применением легких стен по каркасной технологии

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Abstract. The effective use of plan area is more crucial in high-rise buildings, since they are mostly narrow compared to the conventional buildings. The measurement of the overall thermal transmittance of lightweight steel-framed walls, including the effect of thermal bridges due to metal structure, is a challenge for designers, engineers and energy audits. In this paper the energy efficiency light-weight wall technology for over story of buildings was considered. In this work was developed a mathematical model of non-stationary heat transfer through the enclosing wall using the lightweight wall technology and evaluated the efficiency of various designs of lightweight wall. In this model, the profile perforation is taken into account due to the results of the solution of the test problem while maintaining the possibility of using structured grids with the number of elements not exceeding 1 million, which allowed to obtain more accurate results.

Аннотация. Вопрос об увеличении площади зданий становится все более актуальным. В данной статье рассмотрено решение по устройству легких стен по каркасной технологии. Сделан вывод об экономической и энергетической эффективности использования данной технологии для жилого и общественного строительства. Были построены математические модели фрагментов тонкостенного профиля и термокаркаса. Сделан вывод об эффективности работы термопрофиля только в совокупности с утеплителем. Исследовано влияние анизотропных включений в конструкцию, посредством построения математической модели в ПК ANSYS для фрагментов термопрофиля и легких стен по каркасной технологии. В рассматриваемой модели перфорация профиля учтена за счет результатов решения тестовой задачи при сохранении возможности использования структурированных сеток с числом элементов не превышающих 1 млн, что позволило получить более точные результаты.

1. Introduction

Construction becomes dependent on climatic parameters, seasons, transport accessibility. Low temperatures, high wind speed and heavy rainfall make us care not about the architectural appearance of buildings, but about their energy and economic component.

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In recent decades, the issue of increasing the buildings area due to overstory is becoming increasingly important. The desire of investors to use the already built-up area more effectively is justified [1–5].

The purpose of this work is to determine the effectiveness of the use of energy efficiency lightweight building walls for high-rise construction.

Work tasks that need to be solved to achieve the goal:

1) Development of a mathematical model of non-stationary heat transfer through the enclosing wall using the lightweight wall technology.

2) Evaluation of efficiency of various designs of lightweight wall.

The purpose of the simulation is to determine the presence and location of cold bridges, in the presence of which, expensive heat out of the room; such a building can not be called energy efficient. Heat loss can also occur because of heterogeneity of enclosing structures, including the presence of heat-stressed elements.

With the development of computer technology it became possible to create mathematical models of various types of structures, including enclosing, using all kinds of domestic and foreign software systems. The use of the software allows for rapid thermal diagnostics of external heterogeneous multilayer enclosing structures with different geometric characteristics and thermal properties of the materials used in real operating conditions [6–10].

In work [11-18] because of the conducted research of mathematical model of the protecting design in the ANSYS PC recommendations on creation of a humidity mode indoors are given.

Thus, in this paper, for the construction of a mathematical model of the enclosing structure and the study of the heat transfer process, we will use the ANSYS software package based on the finite element method [19–27].

2. Materials and Methods

The rectangular region of the enclosure structure excluding cladding is selected for research of the nonstationary heat transfer lightweight wall. However, the most interesting is the steady-state operation of lightweight wall at specified climatic parameters and temperature at the inner boundary of the frame.

The structure of the wall consists of the main frame: rack and guide lsts profiles of galvanized steel with perforation. The width of the guide profile is 154 mm, the width of the rack profile is 150 mm. inside the profile is a mineral wool insulation based on basalt fiber with a thickness of 150 mm, a density not more than 35 kg/m3. Outside, the insulation is closed with a layer of hydro-windproof membrane, installed overlap, which eliminates moisture from the outside on the surface of the insulation, and prevents weathering of low density insulation fibers. On the opposite side of the frame are installed guides of Z-profile, between which is placed a layer of insulation thickness of 50 mm, a density not less than 90 kg/m^3. From the room side is arranged the base for the interior finish of two layers of plasterboard, insulation between layers. All materials are fastened together by exhaust rivets or stainless steel screws. The lightweight wall is fixed on the floor slabs through the bearing brackets. A paronite gasket is installed between the bracket and the floor slab.

The light-weight wall structure is presented at Figure 1. Value of heat transfer resistance of enclosing walls is 5.06 [m^2·C/W]

The enclosing structure consist of: ceramic granite 10 mm; air gap 40 mm, windscreens, insulation in the thermal profile 150 mm; insulation 50 mm; gypsum wallboard 25 mm.

The following conditions were accepted as assumptions in the construction of a mathematical model:

1) thermal characteristics of the materials in the lightweight wall do not depend on the humidity and temperature of the material and are taken under normal conditions;

2) heat transfer is carried out only due to the thermal conductivity of the material;

3) do not take into account in the design of such elements as: slopes, tides, fire cut-offs, elements of ventilated facade;

4) take account of the perforation of the walls of the thermal profile is carried out using the input correction coefficient obtained when comparing the fragment profiles with and without perforation.

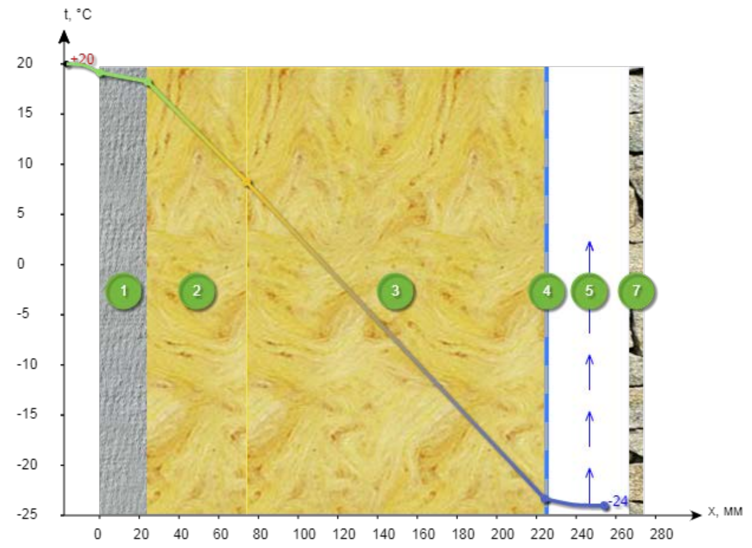

Figure 1. The light-weight wall structure.

For the mathematical formulation of the problem are given the geometric parameters of structures and thermal characteristics. Heat transfer in a multilayer enclosing structure is reduced to the solution of the direct heat transfer problem, in which it is required to obtain a temperature field under specified boundary conditions.

The solution of the direct heat transfer problem is reduced to the solution of the differential equation of thermal conductivity at the given thermal conductivity coefficients λ (1).

$$\frac{\partial t}{\partial \tau}=\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right), \tag{1}$$

where T – temperature, τ – time, x, y, z – coordinates of the temperature function, λ – coefficient of thermal conductivity.

To calculate the problem of conjugate heat transfer at the interface of two materials, the conditions of equality of temperatures and heat fluxes are set.

Boundary conditions of the first kind, in which the temperature distribution on the surface of the body for each moment of time is given: $Tm = f(y)$, the special case $Tm = \text{const}$;

Boundary conditions of the second kind, in which the heat flux for each point of the surface of the body and for any point in time $q_c = f(y, \tau)$, the special case $q_c = \text{const}$;

Boundary conditions of the third kind, in which the ambient temperature is set TSR and the law of heat transfer between the surface of the body and the environment in the cooling and heating process, which is described by Newton-Richman's law: the heat flux density q is proportional to the temperature difference between the surface of the body and the environment.

$$q=\alpha\left(T_{cp}-T_m\right), \tag{3}$$

where is the heat transfer coefficient.

In our case, there are boundary conditions of the third kind, as we have information about the ambient temperature outside the structure (indoor temperature of the building and outdoor temperature). However, since the value of the heat transfer coefficient (3) is unknown for the solution search, the boundary conditions of the first kind shifted for the walls (boundaries) by 1 m from the calculated region of the solid structure were applied.

On the walls of the calculated areas are given boundary conditions of constant temperature (conditions of the first kind): the temperature of the hot wall T_h = 293 K (20 °C); the temperature of the cold wall T_C = 233 K (-40 °C). Symmetry conditions are set for the walls: $dV/d_y = 0$. The temperature on the surface of the solid is obtained convective, and the center of the heat conduction.

For a solid according to Fourier law: the amount of heat transferred is proportional to temperature, time and cross-sectional area.

The amount of heat transferred to the unit area and the unit of time pattern is as follows:

$$q = -\lambda gradT, \tag{4}$$

Fourier law for the case of heat transfer through a homogeneous layer (wall):

$$q = -\lambda \frac{dT}{dx}, \tag{5}$$

When solving the temperature problem for a wall consisting of several homogeneous layers with different properties, it is necessary to take into account the conditions at the boundaries of the regions: according to the law of energy conservation, the heat flow must be constant and for all layers the same. Therefore, for each layer we have:

$$\frac{\lambda_i}{\delta_i}\frac{dT_i(x)}{dx} = \frac{\lambda_{i+1}}{\delta_{i+1}}\frac{dT_{i+1}(x)}{dx}, \tag{6}$$

where λ_i, λ_{i+1} – thermal conductivity coefficients, δ_i, δ_{i+1} – thicknesses.

It is assumed that the boundaries of the regions are close to each other and have a common temperature, i.e. $T_{(x\text{-}0)} = T_{(x+0)}$.

The temperature difference between the cold and hot walls is 44 K. Mathematically, natural convection is described by a system of equations (7)–(9), the process of heat transfer in a solid roof structure consisting of homogeneous layers is represented by equations (1)–(6).

3. Results

First of all, it is necessary to analyze the results of modeling the temperature field for the profile fragments without leaks, and thermal profile with leaks. The boundary conditions of the 1st kind related to the distance of 1 m from the structure on both sides were used in the construction. The simulation results are shown in Figure 2 for continuous profile (1, a) and for thermal profile (2, b).

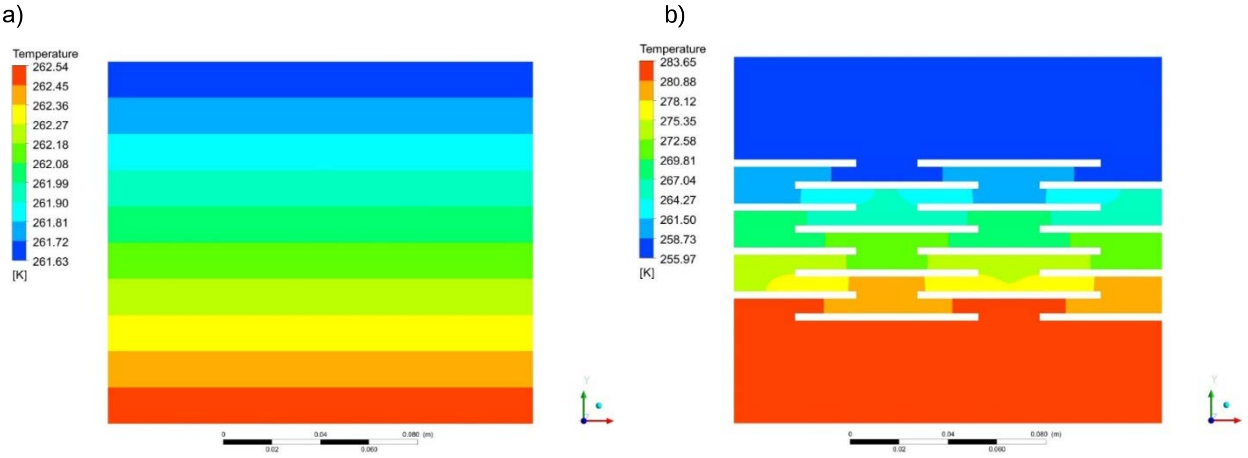

Figure 2. Temperature fields of a) continuous profile, b) thermal profile.

It is also worth noting that all results are obtained on structured grids that provide grid independence of the obtained solutions.

According to the obtained data of temperature fields, it is obvious that the thermal profile with gaps does not give a significant gain in thermal conductivity. Because of the lightweight wall works as a whole, and the insulation in the cavities has a margin of 100 mm on each side, it is obvious that the thermal profile with the gaps works only in conjunction with the mineral wool insulation, which fills the gaps. So the consideration of an independent thermal profile is an incorrect solution. Thus it is necessary to research an additional model with thermal insulation in the cavities (Figure 3).

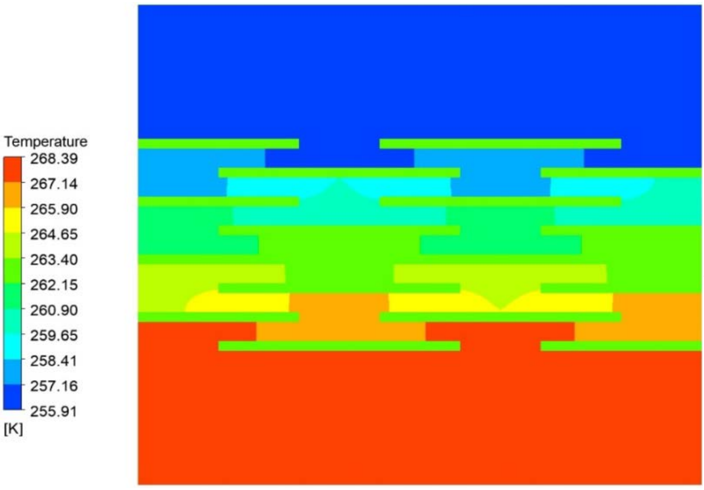

Figure 3. Temperature fields in the thermal profile with insulation in the gaps

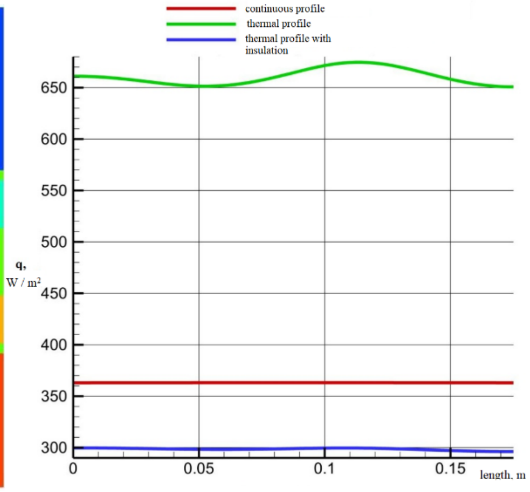

Figure 4. The distribution of the thermal flow q along the length of the structure

On the schedule (Figure 4) the heat flow on the surface of the metal profile and thermal profile with different filling of the gaps is presented. The heat flow through the thermal profile without filling is much larger than the same solid profile (Figure 4). For a uniform profile, the value of the thermal averaged over the length is 363 W/m^2. The value for the average heat flux through the thermal profile with mineral wool insulation filling is 18 % less. Thus it is possible to formulate the main conclusion about the effectiveness of the thermal profile only in conjunction with the insulation.

The next step is to analyze the results of mathematical modeling of the lightweight wall construction fragment.

The problem was solved in 3D formulation for a continuous profile. From the temperature distribution can be seen (Figure 5), that the greatest heat losses occur through the profile due to its high heat capacity.

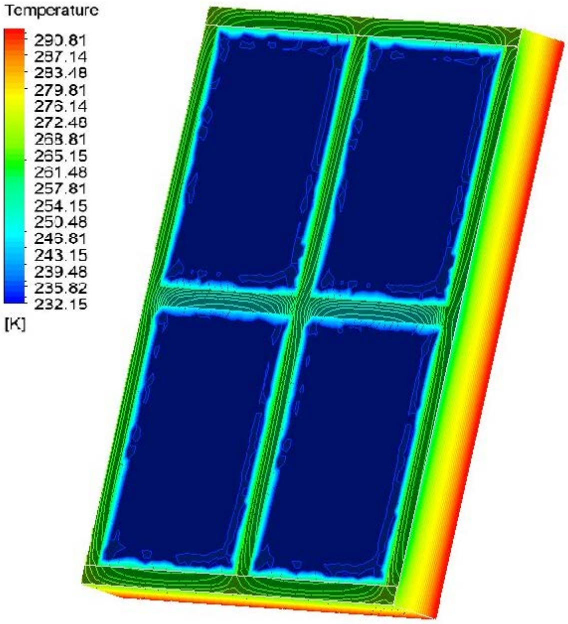

Figure 5. Temperature field of three-dimensional fragment lightweight wall.

Figure 6 presents the simulation results of the same fragment in a 2D configuration (horizontal slit insulation and mullion profile).

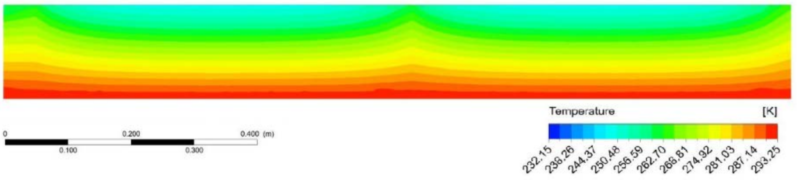

Figure 6. The temperature field of a two-dimensional fragment of the thermal frame structure.

Thus when used in this model thermal profile in tandem with mineral wool insulation, which fills the cavity leaks, local heat loss can be reduced by 18 %, thereby improving the quality of the entire structure.

Many researchers have approached the experimental calculation of the Uoverall for lightweight walls in laboratory conditions [28–33]. The authors [28] combined experimental measurements and numerical simulations in order to calculate the Uoverall of a LSF wall. Another resechers [29] calculated the Uoverall of a LSF wall based on the Zone Method of ASHRAE [31], which is a simplified and accurate numerical method [32]. The difference between the theoretical and experimental values of Uoverall was approximately 9 %.

4. Conclusion

The mathematical models of fragments of thin-walled profile and lightweight wall were constructed. The mathematical model of the profile was made in three configurations: solid steel profile, profile with perforation, and profile with perforation and filling with mineral wool insulation.

The main conclusion on the analysis of the results of the temperature fields of the profile is the efficiency of the thermal profile with perforation only in conjunction with the insulation. Thermal profile without insulation is the least effective of the three selected profile configurations. A profile with filling is 18% more efficient than a solid profile.

Analysis of the results of the temperature fields of the lightweight wall fragment showed obvious results that the greatest heat losses are in areas with the inclusion of a continuous profile. Thus, when using an effective thermal profile in tandem with the insulation, an excellent thermal insulation ability of the entire enclosing structure will be achieved.

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