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NUMERICAL SIMULATION OF HEAT TRANSFER IN A HOLLOW CONCRETE BLOCK

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ТЕПЛОПЕРЕНОСА В ПУСТОТЕЛОМ БЕТОННОМ БЛОКЕ

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Аннотация. *Рассматривается задача сложного теплообмена в замкнутой полости с твердыми теплопроводными стенками. Область решения, в некотором приближении, соответствует пустотелому бетонному блоку. Решение представленной задачи проведено на основе разработанной вычислительной модели, включающей уравнения неразрывности, движения и энергии в воздушной среде, а также уравнение теплопроводности в твердых стенках. Проведена верификация разработанных математических моделей и разработанных численных алгоритмов на известных экспериментальных данных и модельных задачах. Проведен анализ влияния сеточных параметров на структуру течения и теплообмен в области решения. В результате получены распределения термогидродинамических характеристик внутри анализируемого объекта, установлены значения интегральных параметров на характерных границах.*

Introduction. The problem of heat and energy conservation is highly relevant in the world. In the energy balance of Russia, the construction industry consumes more than 55% of all extracted energy resources [1]. Improving the energy efficiency of buildings saves enormous amounts of money and makes housing better and more comfortable. The study of heat transfer characteristics in buildings and structures based on mathematical modeling is relevant, due to the need to develop models that reflect the dependence of the internal temperature of the object from the external climatic conditions and different building characteristics. The interest in this problem has led to numerous experimental and numerical studies [2-4]. Thermal performance of hollow autoclaved aerated concrete blocks in wall constructions of buildings under hot summer conditions has been investigated by Mahmoud et al. [5]. They determined the size and distribution of cavities (within building blocks) that reduce heat flow through the walls and thereby lead to energy savings in air conditioning. Their findings indicated that several small cavities in a block may lead to small reductions in heat flux, but the best configuration found is a large cavity with a fine divider mesh in which case heat flux reductions of 50% are achievable.

Published works on this issue contain analysis of fairly simple formulations (the temperature of the source is constant and Dirichlet boundary condition is considered at the external boundaries), which does not allow using the results obtained in the study of physical processes and phenomena occurring in real hollow concrete blocks. The goal of this study is to investigate thermogravitational convection with surface radiation inside the enclosure (within a building block).

Research methods. The problem under consideration is shown in Figure 1. It is a square enclosure bounded by concrete walls of finite thickness *h*. The medium inside the enclosure is air, which is incompressible and radiatively transparent. The change in air density with temperature is introduced through the Boussinesq approximation. The external surfaces of top and bottom walls are maintained adiabatic. On left and right external borders of solid walls, convective heat exchange with an environment is simulated. It should be noted that the thermal properties of both the solid walls material and the air are the temperature independent.

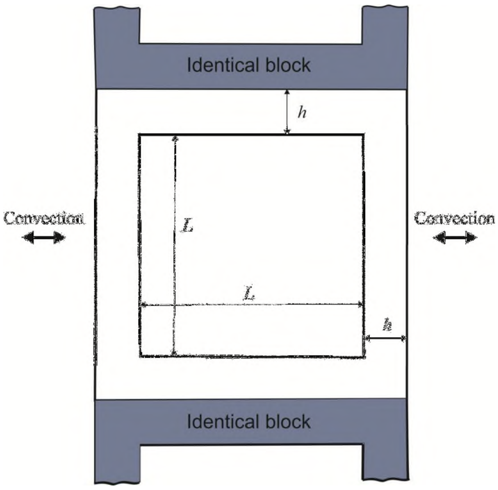

Fig. 1. Schematic diagram for a hollow block

Bearing in mind the above assumptions, the Reynolds-averaged Navier-Stokes equations can be written in the following form:

$$\frac{\partial G}{\partial t}+\frac{\partial S_1}{\partial x_1}+\frac{\partial S_2}{\partial x_2}=R \tag{1}$$

$$G=\begin{pmatrix} 0 \\ u_1 \\ u_2 \\ T \\ k \\ \varepsilon \\ T \end{pmatrix} \tag{2}$$

$$S_i=\begin{pmatrix} u_i \\ p\delta_{i1}-(\nu+\nu_t)\sigma_{i1}+u_iu_1 \\ p\delta_{i2}-(\nu+\nu_t)\sigma_{i2}+u_iu_2 \\ -(\alpha+\alpha_t)\partial T/\partial x_i+u_iT \\ -(\nu+\nu_t/\sigma_k)\partial k/\partial x_i+u_ik \\ -(\nu+\nu_t/\sigma_\varepsilon)\partial \varepsilon/\partial x_i+u_i\varepsilon \\ \alpha_w\,\partial T/\partial x_i \end{pmatrix},\ \forall\ i=1,2 \tag{3}$$

$$R=\begin{pmatrix} 0 \\ 0 \\ g\beta\Delta T \\ 0 \\ P_k+G_k-\varepsilon \\ \left(c_{1\varepsilon}\left(P_k+c_{3\varepsilon}G_k\right)-c_{2\varepsilon}\varepsilon\right)\dfrac{\varepsilon}{k} \\ 0 \end{pmatrix} \quad (4)$$

$$\sigma_{ij}=\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i} \quad (5)$$

Here x_1, x_2 are the physical coordinates; T is the temperature; u_1, u_2 are the velocity components in the projection on the x_1 and x_2 axes, respectively; ε is the dissipation rate of the kinetic energy of turbulence; α_w is the coefficient of thermal diffusivity of the solid wall material; ν is the coefficient of kinematic viscosity; ν_t is the coefficient of turbulent viscosity; g is the gravitational acceleration; k is the kinetic energy of turbulence; α_t is the coefficient of turbulent thermal diffusivity; β is the temperature coefficient of volume expansion; t is the time; L is the characteristic size of the enclosure (Figure 1). The Kolmogorov–Prandtl formula $\nu_t=c_\mu k^2/\varepsilon$ was used to calculate turbulent viscosity. To solve the set of governing equations (1)–(5) the finite-difference method is used. To change a non-uniform grid in physical domain to a uniform grid in computational domain, a special algebraic coordinate transformation is applied.

Conclusion. In this study, we have provided a complex overview of the available results concerning the heat transfer and fluid flow inside a hollow concrete block. The effect of dimensionless time and surface emissivity of internal surfaces has been investigated. The total heat transfer, which includes both the convective and radiative heat transfer, was also studied. A role of the free convection in the total energy transport is decreased with the walls surface emissivities. At the same time, reducing the effects of convection is compensated by the contribution of radiative mechanism.

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