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АНАЛІЗ ТЕПЛОМАСООБМІНУ В ПРИМІЩЕННІ БУДІВЛІ

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Запропоновано інформаційну технологію аналізу конвективного теплообміну в приміщенні будівлі в наближенні нестаціонарного тривимірного турбулентного потоку двокомпонентної пароповітряної суміші за наявності внутрішніх джерел і стоків енергії.

Ключові слова: *інформаційна технологія, модель, нестаціонарній тривимірний турбулентний рух, пароповітряна суміш.*

HEAT AND MASS EXCHANGE ANALYSIS INDOORS

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The information technology of convective heat exchange analysis indoors within the limits of a non-stationary three-dimensional turbulent flow of two-component steam-air mixture in the presence of internal sources and sinks of energy is proposed. Turbulence modeling is based on a Menter's SST-model, which is a combination of known k-ε and k-ω models. In this case we use several types of boundary conditions, including permeable boundary conditions within the calculated area (input and output), boundary conditions on a solid impermeable wall, boundary conditions of symmetry, periodic boundary conditions. For numerical implementation of convective heat and mass exchange indoors we use the finite volumes method.

Keywords: *model, non-stationary three-dimensional turbulent flow, steam-air mixture.*

Today, to satisfy customer requirements in different fields of application the information and automated (application program packages) systems are created. This approach can significantly extend the functionality of the system and reduce costs both for the development of the system and if necessary, for its subsequent upgrading.

The package language as well as system and content functionality are the constituent elements of application program packages. Functional content includes models and methods of the effect analysis, processes and objects of the area for which the package is intended.

Nowadays there is an urgent need for the development of the application program package to optimize heat loss in non-productive buildings.

This work deals with development of the model and methods of analysis and optimization of heat loss in buildings as a part of the functional content of the specialized application program package.

Analysis of studies and publications. Nowadays in scientific books great attention to modeling of heat processes in buildings with the use of information technology is paid to. A number of foreign computer programs for calculating heat consumption of buildings are available, including the most popular:

– DOE-2 (DOE-2.3), developed by Lawrence Berkley National Laboratory, USA [1];

– EnergyPlus (EnergyPlus 8.1.0), worked out by Lawrence Berkley National Laboratory, USA CERL, University of Illinois, USA [2];

– BSim, developed by Danish Building Research Institute, Denmark [3];

– ESP-r, developed by University of Strathclyde, Great Britain [4].

As a rule, these programs depend on the national normative documents and hidden mathematical models on which their calculative algorithm are based. This fact complicates their correct application in building industry of Ukraine.

In addition [5–7], these programs created to assess the validity of the foreign computer programs, give the calculation results that can vary significantly depending on the selected computer program.

In the CIS heat conditions modeling in buildings is in its initial stage. In [8–10] attention is paid to developing software package oriented to numerical solving of Navier–Stokes' equations in space with arbitrary geometry. The code has options to solve the problem of free and mixed convection of steam and gas mixture taking into account the surface steam condensation in the presence of non-condensable gas. With this code in two-dimensional and three-dimensional statements the numerical modeling of convective heat exchange tasks indoors is carried out.

Concerning this there is a necessity of further research in this area.

The purpose of the study, problem statement – to develop an effective model of non-stationary three-dimensional turbulent flow analysis of continuum of two-component steam-air mixture in the presence of internal energy sources and drains.

Research materials. Non-stationary turbulent three-dimensional flow of two-component steam-air mixture is described by such a system of equations [11]:

$$\frac{\partial\rho}{\partial t}+\nabla(\rho\overline{U})=0\,,\ \frac{\partial\rho\overline{U}}{\partial t}+\nabla(\rho\overline{U}\overline{U})=-\nabla P^{*}+\nabla\sigma+g(\rho-\rho_h)\,,$$

$$c_p\left[\frac{\partial\rho T}{\partial t}+\nabla(\rho\overline{U}T)\right]=\frac{\partial P_a}{\partial t}-\nabla\overline{q}-(c_{pg}\overline{m}_g+c_{pV}\overline{m}_V)\nabla T\,,$$

$$\frac{\partial\rho y_V}{\partial t}+\nabla(\rho\overline{U}y_V)=\nabla\overline{m}_V\,,\ y_g+y_V=1\,. \tag{1}$$

Here ρ, P, $\overline{U}=(U_x,U_y,U_z)$ and T – density, pressure, velocity vector and temperature of the mixture; P^* – modified pressure; P_a – average pressure of the mixture; c_p – specific heat capacity of the mixture; $y_i=\rho_i/\rho$ – mass concentrations of summands (ρ_i – partial density, i = V, g). Subscripts $(...)_V$ and $(...)_g$ mark appropriate values for non-condensed steam and air.

The total diffusion transfer is given in system (1) with a stress tensor σ and density vectors of heat $\overline{q}$ and mass $\overline{m}_i$ flux, which use gradient approximations in the form of Newton, Fourier and Fick's laws [11].

The density of the mixture is determined by the equation of state (M_i – molecular weight of the components):

$$\rho=\frac{1}{\dfrac{y_g}{M_g}+\dfrac{y_V}{M_V}}\frac{P_a}{RT}\,.$$

Specific heat capacity of the mixture consists of specific heats of its multipliers with account of their mass particles:

$$c_p=c_{pg}M_g+c_{pv}M_v\,.$$

Dynamic viscosity coefficient is determined similarly:

$$\mu=\mu_g M_g+\mu_v M_v\,.$$

Turbulence modeling is based on a Menter's SST-model [12]. Menter's model (SST-model) by the set of its properties is one of the best (perhaps the best) among existing RANS turbulence models (within the averaged equations by Reynolds). The SST-model is a combination of known k–ε and k–ω models, providing a combination of the best qualities of these models. In terms of k (turbulence kinetic energy) and ω (specific rate of its dissipation), this model looks like [12]:

$$\frac{D(\rho k)}{Dt} = \nabla\left[\left(\mu + \sigma_k \mu_T\right)\nabla k\right] + P_k - \beta^* \rho\omega k\ , \tag{2}$$

$$\frac{D(\rho\omega)}{Dt} = \nabla\left[\left(\mu + \sigma_\omega \mu_T\right)\nabla\omega\right] + \gamma\frac{\rho}{\mu_T}P_k - \beta\rho\omega^2 + \left(1 - F_1\right)D_{k\omega}\,. \tag{3}$$

When solving convective heat exchange indoors several types of boundary conditions, including permeable boundary conditions within the calculated area (input and output), boundary conditions on a solid impermeable wall, boundary conditions of symmetry, periodic boundary conditions are used.

Heat and mass exchange equation (1) is written in the integral form:

$$\int_V \frac{\partial\rho}{\partial t}dV + \oint_S \rho\overline{U}d\overline{S} = 0\,,$$

$$\int_V \frac{\partial\left(\rho\overline{U}\right)_x}{\partial t}dV + \oint_S \rho U_x \overline{U}d\overline{S} = -\oint_S \frac{P^*}{\rho}dS_x + \int_V g(\rho - \rho_h)dV + \oint_S \sigma_{xj}dS_j\ ,$$

$$\int_V \frac{\partial\left(\rho\overline{U}\right)_y}{\partial t}dV + \oint_S \rho U_y \overline{U}d\overline{S} = -\oint_S \frac{P^*}{\rho}dS_y + \int_V g(\rho - \rho_h)dV + \oint_S \sigma_{yj}dS_j\ ,$$

$$\int_V \frac{\partial\left(\rho\overline{U}\right)_z}{\partial t}dV + \oint_S \rho U_z \overline{U}d\overline{S} = -\oint_S \frac{P^*}{\rho}dS_z + \int_V g(\rho - \rho_h)dV + \oint_S \sigma_{zj}dS_j\ ,$$

$$\int_V c_p\frac{\partial\rho T}{\partial t}dV + \oint_S c_p\rho\overline{U}Td\overline{S} = \int_V \frac{\partial P_a}{\partial t}dV - \oint_S \overline{q}d\overline{S} - \oint_S\left(c_{pg}\overline{m}_g + c_{pV}\overline{m}_V\right)Td\overline{S}\ ,$$

$$\int_V \frac{\partial\rho y_V}{\partial t}dV + \oint_S \rho\overline{U}y_V d\overline{S} = \oint_S \overline{m}_V d\overline{S}\,. \tag{4}$$

Turbulence Menter's model, recorded in terms of k (turbulence kinetic energy) and ω (specific velocity of dissipation), has such an integral form:

$$\int_V \frac{\partial\rho k}{\partial t}dV + \oint_S\left[\overline{U}\overline{n}(\rho k) - (\mu + \sigma_k\mu_t)\frac{\partial k}{\partial n}\right]dS = \int_V \rho(P_k - \beta^* k\omega)dV\ ,$$

$$\int_V \frac{\partial\rho\omega}{\partial t}dV + \oint_S\left[\overline{U}\overline{n}(\rho\omega) - (\mu + \sigma_\omega\mu_t)\frac{\partial\omega}{\partial n}\right]dS =$$

$$= \int_V \rho\left(P_k - \beta\omega^2 + 2(1 - F_1)\sigma_\omega\frac{1}{\varpi}\frac{\partial k}{\partial x_i}\frac{\partial\omega}{\partial x_i}\right)dV\ ;$$

$$\mu_t = \frac{\rho k}{\omega},\ \ \tau_{ij} = 2\mu_t S_{ij} - 2\overline{I}\,\frac{\mu_t\nabla\nabla + \rho k}{3},\ \ P_k = \tau_{ij}\frac{\partial u_i}{\partial x_j},\ \ P_\omega = \frac{\gamma}{\mu_t}\tau_{ij}\frac{\partial u_i}{\partial x_j}\,. \tag{5}$$

For numerical implementation of the problem of convective heat and mass exchange indoors we use the finite volumes method [13], and the basic equations are written in the integral form (4)–(5).

In this paper, the integral over a closed circuit is shown as a sum of integrals along the circuit of each face of the control volume. Making a discrete analog of gas dynamics and heat and mass exchange equations, pay attention to how the velocity vector is directed relatively to the examining of the control volume. This integral approximation is based on the assumption of constancy of *f* over the entire surface of examining face:

$$\int_{S_e} f dS = f_e \int_{S_e} dS = f_e S_e . \tag{6}$$

This approximation has another order of accuracy.

Time in physics is considered as a kind of the fourth coordinate with the only difference that the past and future vary clearly. What has happened in the last moment, can affect future events only, but not those that have already occurred (principle of causality).

Consequently, when solving the task numerically the process time can be divided into some steps, creating a time grid along with the spatial one.

Partial derivatives of time are presented as a final difference forward:

$$\frac{\theta_i^n - \theta_i^{n-1}}{dt} .$$

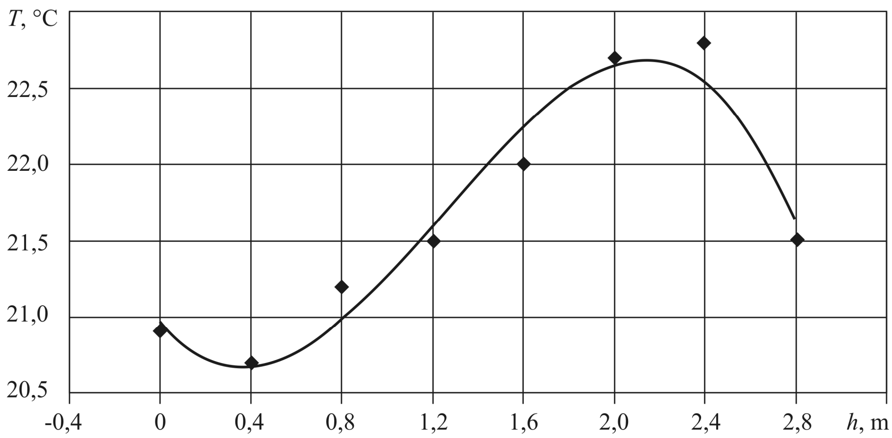
As a result we get a clear difference scheme which is stable under the condition of Courant

$$dt < \frac{\min(dx, dy, dz)}{\max(U_x, U_y, U_z)} .$$

Heating appliances are realized in the model as distributed heat sources in space with geometry, location and other characteristics that meet the real heating appliances.

Numerical research, in particular, showed that the density of the air in the considered room does not change, despite the fact that it increased substantially the temperature of the heating device was. Therefore, in modeling the thermal regime it can be considered that the density is constant. At the same time the system of equations describing convective heat exchange within the considered model becomes simpler.

Figure presents temperature distribution across the room height.



Temperature distribution across the room height.

In the figure the temperature calculated by the proposed model is represented by a solid line, and experimental – by dots [14]. Room size: height – 3 m, length – 6 m and width – 3 m. Heating device dimensions – 80×60 cm, and the temperature is 85°C. Ambient temperature is –20°C.

CONCLUSION

Under this research, using the modern information technologies, where the methods of mathematical modeling are very important, the method of calculation of three-dimensional non-stationary turbulent convective heat exchange in the non-production building is proposed.

The results of numerical experiment agree well with the results obtained experimental data.

Convective heat exchange indoors should be coordinated with the conduction through the walling.

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