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PROMPT CFD SIMULATION OF AIR IONS DISPERSION IN THE ROOMS

Представлена CFD модель для моделювання розсіювання аероіонів в приміщеннях. Модель заснована на використанні рівняння переносу домішки і моделі потенційного течії. Представлені результати обчислювального експерименту, проведеного на базі розробленої моделі.

Ключові слова: аероіони, CFD моделювання, мікроклімат приміщень.

Представлена CFD модель для моделирования рассеивания аэроионов в помещениях. Модель основана на использовании уравнения переноса примеси и модели потенциального течения. Представлены результаты вычислительного эксперимента, проведенного на базе разработанной модели.

Ключевые слова: аэроионы, CFD моделирование, микроклимат помещений.

A CFD model to simulate the air ions concentration in rooms was developed. This model is based on the equations of the admixture dispersion and the model of potential flow. The implicit schemes are used for the numerical simulation. The results of the numerical experiment are presented.

Key words: air ions, CFD simulation, rooms microclimate

Introduction. The prediction of the air ions concentration in industrial rooms, office rooms is now the problem of great interest. It is well known that the concentration of negative and positive air ions influence on the health of people. To provide the normal air ions conditions in industrial rooms it is necessary to predict the air ions concentration at the work places when the special equipment of air ions emission are proposed to be used. To solve this problem the researches need special mathematical models.

Literature review. Now in Ukraine to predict the air ions regimes in rooms only the analytical models are used [2 - 5]. These models allow to calculate rapidly the air ions concentration but the models can’t take into account the influence of the furniture deposition in rooms or the air flow induced by ventilation system on the air ions dispersion. CFD models developed abroad are based on Navier – Stokes equations [1] and need a lot of computational time. It is not very convenient at practical use especially when many variants of have to be solved. So it is necessary to have CFD models to provide researches with the more power tools of air ions prediction in industrial rooms.

The objective. The main objective of this paper is the development of the effective CFD model to predict the air ions concentration in rooms.

Governing equations. To simulate the process of the negative and positive air ions dispersion in the room the transport equations 1 and 2 are used [1]

$$\frac{\partial C}{\partial t}+\frac{\partial uC}{\partial x}+\frac{\partial vC}{\partial y}=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial C}{\partial y}\right)-\alpha CB-\beta CD+\sum Q_c(t)\delta(x-x_c)\delta(y-y_c) \quad (1)$$

$$\frac{\partial B}{\partial t}+\frac{\partial uB}{\partial x}+\frac{\partial vB}{\partial y}=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial B}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial B}{\partial y}\right)-\alpha CB-\beta BD+\sum Q_B(t)\delta(x-x_B)\delta(y-y_B) \quad (2)$$

where C is the concentration of the negative air ions; u, v, are the velocity components in x, y direction respectively; σ is the parameter taking into account the process of flocculation and decay; μ_x , μ_y , are the coefficients of turbulent diffusion in x, y direction respectively; B is the concentration of the positive air ions; x_i , y_i , are the Cartesian coordinates; α is parameter taking into account the interaction of negative and positive air ions; β is the parameter taking into account the interaction of the air ions with dust particles; Q_{Ci} is the negative air ions emission rate; Q_{Bi} is the positive air ions emission rate; x_c,y_c , etc. are the coordinates of emission; $\delta(x-x_i)\delta(y-y_i)$, etc. is Delta function.

The transport equation 1 or 2 is used with the following boundary conditions [6,7] (we describe these conditions only for equation 1):

– *at the inlet boundary*: $C|_{inlet}=C_E$, where C_E is the known concentration of the air ions;

– *at the outlet boundary:* in numerical model the following condition $C(i+1,j)=C(i,j)$ is used. Here C(i+1,j) is the concentration at the outlet boundary cell.

At the '*solid*' surfaces of the computational region (on the floor of the room, at the surfaces of the furniture, etc.) the following boundary condition is used

$$\frac{\partial C}{\partial n}=0,$$

where n is the vector of the normal to the corresponding surface.

In the model 1, 2 the process of the air ions interaction with the dust is taken into account. It means that it is necessary to simulate the dust dispersion in the room. To simulate the dust dispersion in the room he following equation is used

$$\frac{\partial D}{\partial t}+\frac{\partial uD}{\partial x}+\frac{\partial vD}{\partial y}=\frac{\partial}{\partial x}\left(\mu_x\frac{\partial D}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_y\frac{\partial D}{\partial y}\right)+\sum Q_{Di}(t)\delta(x-x_D)\delta(y-y_D) \quad (3)$$

where D is the dust concentration; Q_{Di} is the emission rate of dust.

Fluid Dynamic Model. The ventilation of the room forms the comprehensive flow pattern in the room which influence the air ions and dust dispersion. To predict this flow field is very difficult because of the different obstacles (furniture, etc.) which influence on it**.** To simulate the air flow in the room the model of the potential flow is used. In this case the governing equation is [7,8]

$$\frac{\partial^2 P}{\partial x^2}+\frac{\partial^2 P}{\partial y^2}=0, \quad (4)$$

where P is the potential of flow.

Velocity components are computed using the following formulae [8]

$$u = \frac{\partial P}{\partial x}, \quad v = \frac{\partial P}{\partial y},$$

Numerical integration of the equations. To solve equation (4) it is transformed into the 'evolution' equation

$$\frac{\partial P}{\partial \eta} = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} \qquad (5)$$

where η *is a fictive time*.

To solve equation 5 the difference scheme of the conditional approximation is used [9]. The change triangle difference scheme of the splitting is used for the numerical integration of equations 1-3 [6,7]. On the basis of the developed CFD model the code '*AIRPRED*' was created using FORTRAN language.

Results. The proposed CFD model was used to predict the negative air ions concentration in the office (Fig.1). The special equipment of air ions emission is used in the room (Fig.1., position 1). Also in this office the different obstacles are situated (Fig.1). Emission of negative air ions is Qc=10^{11} particles/s. Another parameters of the study case are as following: dimension of the calculation region: 6.25m*4.20m; Q_B=4000 particles/s; Q_D= $4*10^6$ particles/s (area where the dust emission takes place is schematically shown in Fig.1 by wave arrows); $\alpha=1{,}5\times10^{-12}$ m^3/s, $\beta=1\times10^{-12}$ m^3/s [1]; both coefficients of the turbulent diffusion are equal to 0.4$м^2$/c; the velocity of the air flow at the inlet opening is 1m/s. The numerical experiment was carried out for two scenarios: the height of the equipment producing negative air ions is 2.5m and this height is 3.3m.

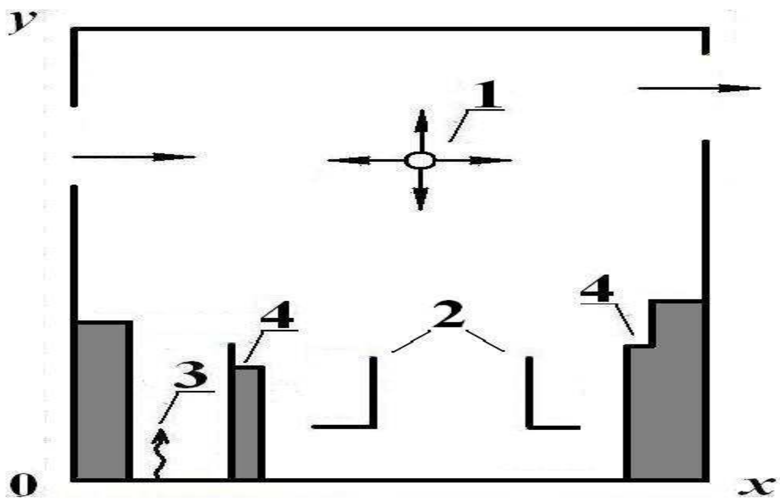

Fig. 1. Sketch of the computational domain:
1 – equipment producing negative air ions; 2 – chairs;
3 – place of dust emission; 4 – place of positive ions emission

The results of the numerical experiment are shown in Fig.2 and Fig.3. The position of the equipment producing negative air ions is shown in these figures by '*round*'.

One can see from Fig. 2, 3 that the position of the equipment producing air ions influences the concentration of ions in different points of the room. To see it's clear the concentration of the negative air ions above the chairs at the work places is shown in Table.1. Worthy of note that the air flow speed above the first chair is 0.26m/s, and above the second chair is 0.25m/s.

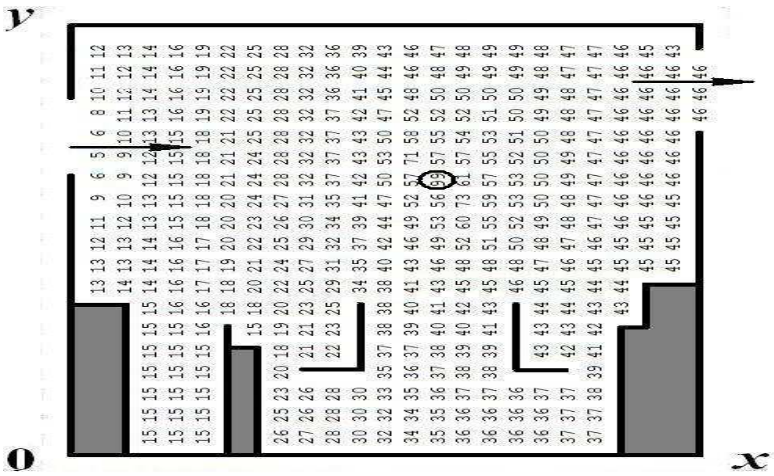

Fig. 2. Concentration of negative air ions
(first scenario, Cmax=0.21*10^{11} particles/m3)

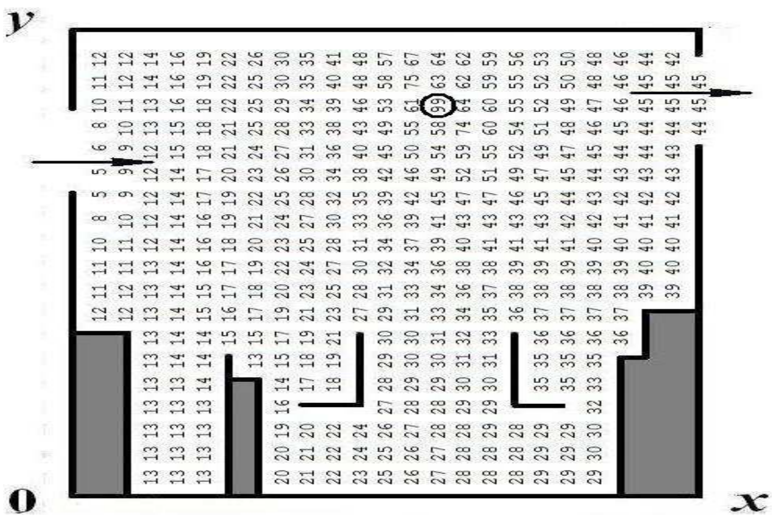

Fig. 3. Concentration of negative air ions
(second scenario, Cmax=0.23*10^{11} particles/m3)

As we see from Tabl.1 the concentration above the first chair is less than above the second chair. This is explained by the air flow 'pushing' of air ions from left side of the room to the right side of it.

Table 1

Concentration of negative air ions above the chair

Scenario	First work place	Second work place
First scenario	0.76*10^{10} *particles/m3*	0.10*10^{11} *particles/m3*
Second scenario	0.66*10^{10} *particles/m3*	0.89*10^{10} *particles/m3*

The computational time to solve the problem was about 5 *sec*. So the developed model can be used for prompt computing of air ions concentration in rooms.

The next step in this field will be the development of 3-D numerical model for prediction of air ions concentration in rooms.

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