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Modeling of air flow in industrial rooms

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Abstract

The article is devoted to the air distribution in a room by swirl and laying air jets. Dynamic parameters of air flow that is created due to swirl and laying air jets at their leakage in a room has been determined. The mathematical model of air supply with swirl and laying air jets in the industrial rooms is improved. Simulation of air flow is performed due to CFD FLUENT (Ansys FLUENT). Solution of the equation by using k-ε model of turbulence is presented. Dynamic parameters of air flow that is created due to swirl and laying air jets at their leakage at variable regime and creation of dynamic microclimate in a room has been determined. Results of experimental investigations of air supply into the room by air distribution device which creates swirl air jets for creation more intensive turbulence air flow in the room are presented. The results of theoretical researches of influence of dynamic microclimate to the human organism are presented.

Key words: air distribution, swirl jet, laying jet, variable regime, air velocity, flow rate.

1 Introduction

For maintenance of the normalized parameters of air environment in a working area of rooms [1, 2] it is necessary that distribution of incoming air would be effective [3], as a result the ways and air distribution devices essentially influence on technical and economic parameters of a microclimate maintenance system as a whole.

There are a number of air distribution devices, where the effect of air jet swirling or air jet laying is used [4, 5].

2 Aim of work

Determining of air flow characteristics, that is created both swirl and spread air jets and obtaining of the analytic equations for determination of the necessary parameters of air jets and air distribution devices at the rated demands.

3 The analysis of existing research

One of the most rational ways of air distribution is submission of coming air directly into a room serviced area [6]. For this purpose, air distribution devices with high intensity of falling of parameters (velocity *V* and temperature *t*) of incoming air are used. As characteristic property of such incoming air jet there is its higher turbulence in comparison with common air jets [7, 8, 9]. Both swirl and laying air jets using is an effective way of increasing its turbulence [10, 11].

In this work opportunity of achievement of falling high intensity of parameters is considered at distribution of air supply by air distribution device with creation both swirl and spread air jets. The question has been solved due to using of air distribution device with creation both swirl and laying air jets, that leakage from the nozzle at the same conditions [12, 13, 14, 15].

4 Analytical studies

Simulation of air flow is carried out due to CFD FLUENT program (Ansys FLUENT) [7]. At this simulation some conditions and simplifications have been adopted:

- internal air is non pressed and air flow is constant;
- air jets are isothermal;
- initial air velocities in nozzle were: $V = 5 – 15$ m/s;
- air flow rates were: $L = 200 – 500$ m^3/h;
- incoming air supplied by air device with creation of swirl and spread air jets;
- air distribution device was situated on height 3 m.

Let us consider $k-\varepsilon$ model of turbulence. Equation of inseparability: text.

$$\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \tag{1}$$

X, Y and Z – directions (U, Y and W – impacts) accordingly:

$$\frac{\partial}{\partial t}(\rho u)+\frac{\partial}{\partial x}(\rho uu)+\frac{\partial}{\partial y}(\rho uv)+\frac{\partial}{\partial z}(\rho uw)=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\mu_e\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\mu_e\frac{\partial u}{\partial y})+\frac{\partial}{\partial z}(\mu_e\frac{\partial u}{\partial z})+ \\ +\frac{\partial}{\partial x}(\mu_e\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\mu_e\frac{\partial v}{\partial x})+\frac{\partial}{\partial z}(\mu_e\frac{\partial w}{\partial z}) \tag{2}$$

$$\frac{\partial}{\partial t}(\rho v)+\frac{\partial}{\partial x}(\rho uv)+\frac{\partial}{\partial y}(\rho vv)+\frac{\partial}{\partial z}(\rho vw)=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\mu_e\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}(\mu_e\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\mu_e\frac{\partial v}{\partial z})+ \\ +\frac{\partial}{\partial x}(\mu_e\frac{\partial u}{\partial y})+\frac{\partial}{\partial y}(\mu_e\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\mu_e\frac{\partial w}{\partial y})-g(\rho-\rho_0) \tag{3}$$

$$\frac{\partial}{\partial t}(\rho w)+\frac{\partial}{\partial x}(\rho uw)+\frac{\partial}{\partial y}(\rho vw)+\frac{\partial}{\partial z}(\rho ww)=-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}(\mu_e\frac{\partial w}{\partial x})+\frac{\partial}{\partial y}(\mu_e\frac{\partial w}{\partial y})+\frac{\partial}{\partial z}(\mu_e\frac{\partial w}{\partial z})+ \\ +\frac{\partial}{\partial x}(\mu_e\frac{\partial u}{\partial z})+\frac{\partial}{\partial y}(\mu_e\frac{\partial v}{\partial z})+\frac{\partial}{\partial z}(\mu_e\frac{\partial w}{\partial z}) \tag{4}$$

Relationship between stresses by Reynolds and parameters of averaged air flow due to different turbulence models has been determined.
In Ansys FLUENT equations of $k-\varepsilon$ model are accordingly:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k U_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon U_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+\rho C_1 S_\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \tag{6}$$

In this equations G_k is turbulent kinetic energy [J], that is created from average gradients of velocity. On base of Bussinesc's hypothesis:

$$G_k=\mu_t\cdot S^2 \tag{7}$$

where:

$\mu_t=\rho\cdot C_\mu\frac{k^2}{\varepsilon}$, (m)

$C_\mu=const$;

S - invariant of deformations tensor, (m^2/s)

$$S=\sqrt{2S_{ij}S_{ij}} \tag{8}$$

G_b - kinetic energy of pushing force, (J):

$$G_b=\beta g_i\frac{\mu_t}{\Pr_t}\frac{\partial T}{\partial x_i} \tag{9}$$

where:

$\Pr_t$ - turbulent Prandtl's constant for energy, (-);

g_i - component of gravity vector in *i*- direction, (m/s^2);

β - coefficient of temperature widening, (1/K):

$$\beta=-\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p \tag{10}$$

where:

T - temperature, (K);

$C_{3\varepsilon}$ - constant (-), that determines influence degree of pushing force on ε:

$$C_{3\varepsilon}=\tanh\left|\frac{v'}{u'}\right| \tag{11}$$

where:

v',u' - components of air velocity, (m/s), that accordingly are parallel and normal to gravity velocity;

Y_M - contribution of variable widening at press turbulence into common velocity of dissipation:

$$Y_M=2\rho\varepsilon M_t^2 \tag{12}$$

where:

M_t - Makh's number for turbulent liquid,

$$M_t = \sqrt{\frac{k}{a^2}} \tag{13}$$

where:

a - speed of the sound, (m/s), $a = \sqrt{\gamma RT}$.

Constants else: $C_{1\varepsilon} = 1{,}44$, $C_2 = 1{,}9$, $\sigma_k = 1{,}0$, $\sigma_\varepsilon = 1{,}2$.

Calculating of equations has been carried out due to Ansys FLUENT program:

$$\frac{\partial}{\partial t}(\rho\tilde{v}) + \frac{\partial}{\partial x_j}(\rho\tilde{v}u_i) = G_v + \frac{1}{\sigma_{\tilde{v}}}\left[\frac{\partial}{\partial x_j}\left\{(\mu + \rho\tilde{v})\frac{\partial \tilde{v}}{\partial x_j}\right\} + C_{b2}\rho\left(\frac{\partial \tilde{v}}{\partial x_j}\right)^2\right] - Y_v + S_{\tilde{v}} \tag{14}$$

where:

G_v - turbulent viscosity, (m^2/s);

Y_v - destroying of turbulent viscosity, (m^2/s);

$\sigma_{\tilde{v}}$, C_{b2} - constants,

v - molecular kinetic viscosity.

Turbulent viscosity is determined:

$$\mu_t = \rho\tilde{v}f_{v1} \tag{15}$$

$$f_{v1} = \frac{\chi^3}{\chi^3 + C_{v1}^3} \tag{16}$$

where: $\chi \equiv \frac{\tilde{v}}{v}$

$$G_v = C_{b1}\rho \cdot \tilde{S}\tilde{v} \tag{17}$$

where: $\tilde{S} \equiv S + \frac{\tilde{v}}{k^2 d^2} f_{v2}$, $f_{v2} = 1 - \frac{\chi}{1 + \chi \cdot f_{v1}}$,

but:

C_{b1} , k - constants.

S - invariant of deformations tensor:

$$S \equiv \sqrt{2\Omega_{ij}\Omega_{ij}} \tag{18}$$

where: $\Omega_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right)$

$$Y_v = C_{w1}\rho \cdot f_w \left(\frac{\tilde{v}}{d}\right)^2 \tag{19}$$

where: $f_w = g\left[\frac{1 + C_{w3}^6}{g^6 + C_{w3}^6}\right]^{1/6}$, $g = r + C_{w2}(r^6 - r)$, $r \equiv \frac{\tilde{v}}{\tilde{S}k^2 d^2}$

C_{w1} , C_{w2} i C_{w3} - constants: $C_{b1} = 0{,}1335$, $C_{b2} = 0{,}622$, $\sigma_{\tilde{v}} = \frac{2}{3}$, $C_{v1} = 7{,}1$, $C_{w1} = \frac{C_{b1}}{k^2} + \frac{(1 + C_{b2})}{\sigma_{\tilde{v}}}$, $C_{w2} = 0{,}3$, $C_{w3} = 2{,}0$, $k = 0{,}419$.

As we see from fig.1, incoming swirl air jet at the angle of swirling plates 90° is similar to direct-flowed air jet by its characteristics. The laying air jet is flows independently from swirl air jet. At relative distance $\overline{X}=0{,}2$ from air device $\overline{v}=0{,}75$, but at $\overline{X}=0{,}4$ - $\overline{v}=0{,}5$.

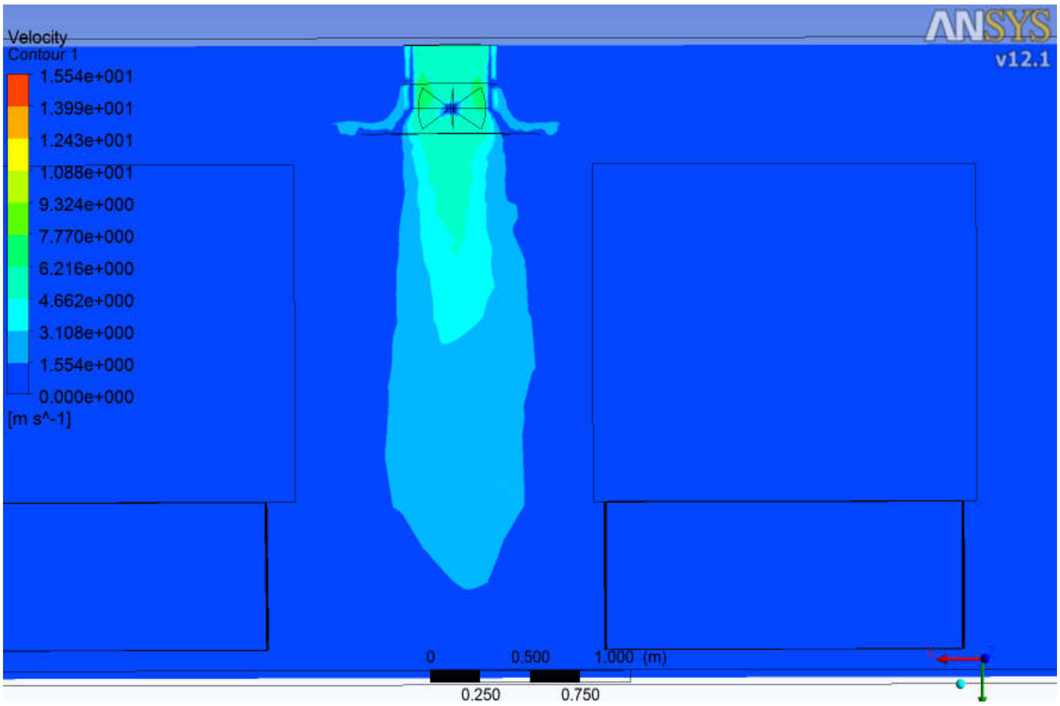

Figure 1: Velocity epure of incoming air flow in nozzle section at air supply by swirl and laying air jets and angle of swirling plates 90°

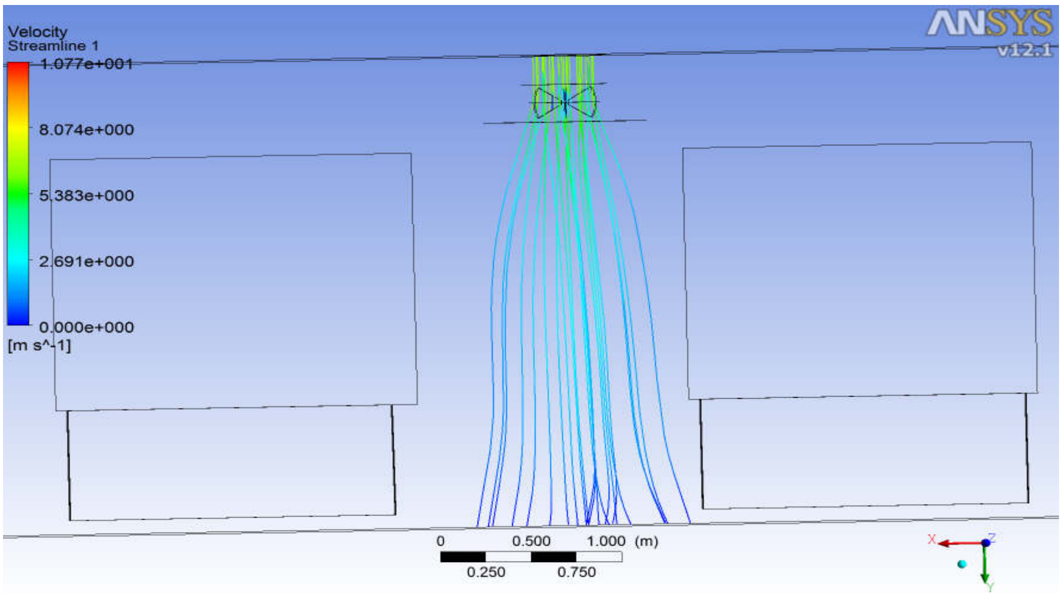

Figure 2: Lines of flow at air supply by swirl and laying air jets and angle of swirling plates 90°

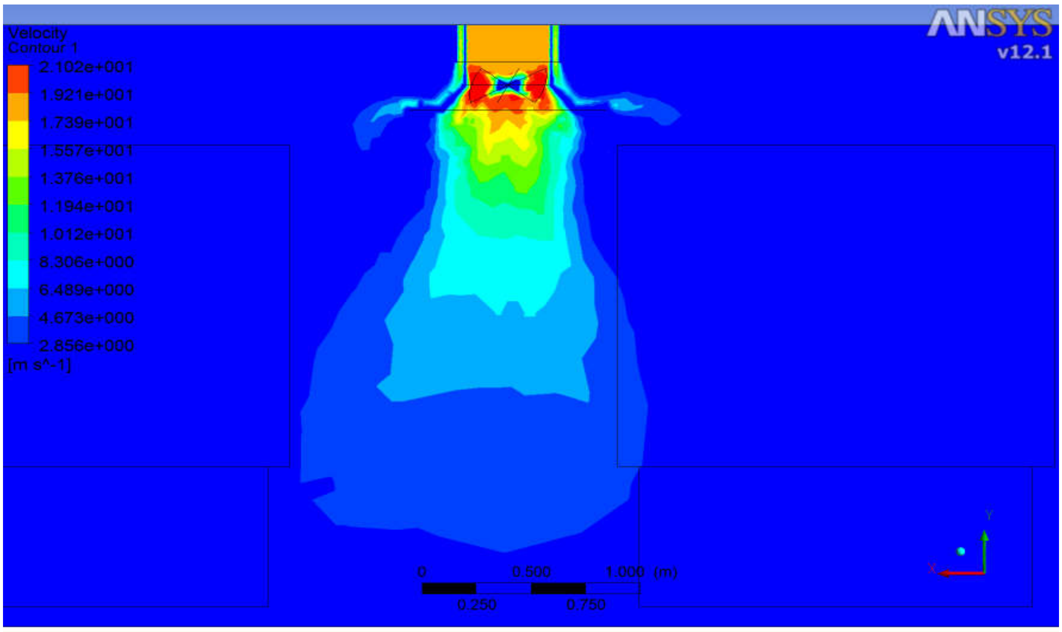

Figure 3: Velocity epure of incoming air flow in nozzle section at air supply by swirl and laying air jets and angle of swirling plates 60°

As we see from fig.3, at angle of swirling plates 60° incoming laying air jet also flows independently from swirl air jet. At relatively distance $\overline{X}=0{,}11$ value $\overline{v}=0{,}7$, at $\overline{X}=0{,}2$ - $\overline{v}=0{,}5$, but at $\overline{X}=0{,}4$ - $\overline{v}=0{,}3$. At angle 30° interaction between both air jets take place. Intensive velocity falling for incoming air flow takes place in section $\overline{X}=0{,}2$.

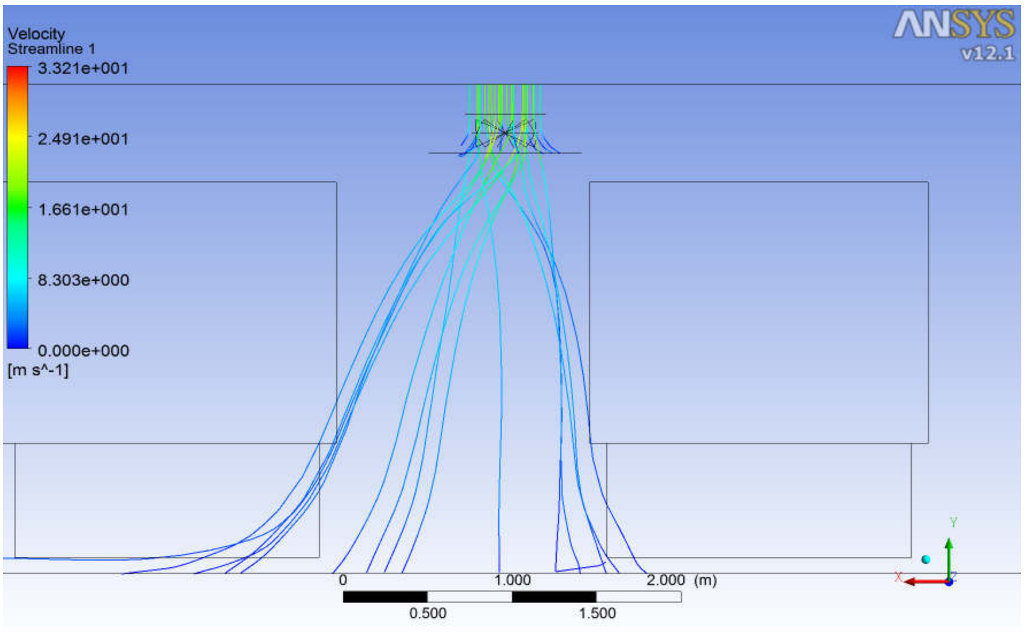

Figure 4: Lines of flow at air supply by swirl and laying air jets and angle 60°

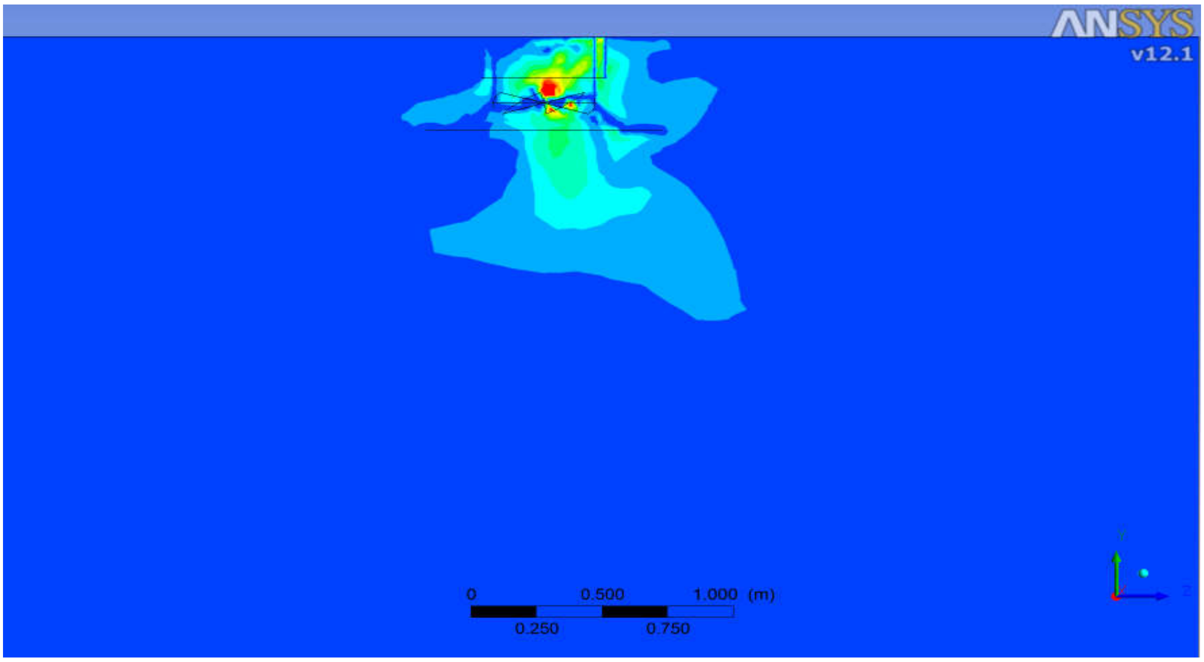

Figure 5: Velocity epure of incoming air flow in nozzle section at air supply by swirl and laying air jets and angle of swirling plates 30^0.

5 Conclusion

On base obtained results we assert:

- geometric and flow rate characteristics of air distribution device with creation of swirl and spread air jets have been determined and optimized;
- there is determined, that it will be effective to increase an angle of swirling plates and to use an effect of jet spreading;
- using of air distribution devices with creation of swirl and spread air jets will allow to increase ADPI (Air Distribution Performance Index) index at air supply into a room.

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