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Modelling of air flow supply in a room at variable regime by using both K - E and spalart – allmaras turbulent model

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Abstract

The abstract is to The article is devoted to the decision of actual task of air distribution efficiency increasing with the help of swirl and spread air jets to provide normative parameters of air in the production apartments. The mathematical model of air supply with swirl and spread air jets in that type of apartments is improved. It is shown that for reachin of air distribution maximal efficiency it is necessary to supply air by air jets, that intensively extinct before entering into a working area. Simulation of air flow performed with the help of CFD FLUENT (Ansys FLUENT). Calculations of the equation by using one-parameter model of turbulence Spalart-Allmaras are presented. The graphical and the analytical dependences on the basis of the conducted experimental researches, which can be used in subsequent engineering calculations, are shown out. Dynamic parameters of air flow that is created due to swirl and spread 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 turbulization air flow in the room are presented. Obtained results of these investigations give possibility to realize engineer calculations of air distribution with swirl air jets. The results of theoretical researches of favourable influence of dynamic microclimate to the man are presented. When using dynamic microclimate, it's possible to decrease conditioning and ventilation system expenses. Human organism reacts favourably on short lasting deviations from the rationed parameters of air environment.

Key words: air distribution, swirl jet, spread jet, variable regime, air velocity.

1 Introduction

We can see that human working efficiency largely depends on how sanitary parameters of microclimate suitable to the physiological needs [1,2]. The physical condition of the aparment air space depends on temperature, moisture, air velocity, noise, dust, odors and others. For maintenance of the normalized parameters of air environment in a working zone of rooms it is necessary that distribution of incoming air would be effective, as a result the ways and air distribution devices essentially influence on technical and economic parameters of a microclimate maintenance system as a whole. To choose air distribution method we should take into account the features of apartment, it's setting, structural features, location and size of warmth, moisture, harmful gases sources.

One of the most rational way of air distribution in productive buildings is submission of coming air directly into a room serviced area with air distribution devices with high intensity of falling of parameters (velocity V and temperature t) of incoming air using swirl and spread air jets [3].

There are a number of air distribution devices, where the effect of air jet swirling or air jet spreading is used. One of the most rational ways of air distribution is submission of coming air directly into a room serviced area. 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. Both swirl and spread air jets using is an effective way of increasing its turbulence [4].

In this work the 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 is being solve due to using of air distribution device with creation both swirl and spread air jets, that leakage from the nozzle at the some conditions [5].
Purpose of work: is determining of air flow characteristics, that is created both swirl and spread air jets at its leakage at variable regime and obtaining of the analytic equations for determining of the necessary dynamic parameters of air jets. To present calculations of incoming air flow by using one-parameter model of turbulence Spalarta-Almarasa are presented.

2 Presentation of the main material

Consider air flow in unsteady regime in air conditioning systems with air jets developing in free space and define its parameters [6,7]. Axial velocity V_x in determined point A with coordinate X_A in case of constant motion (without using pulse mode) is determined from the formula of calculation of the axial velocity V_o is known:

$$V_x = V_o \cdot m \frac{\sqrt{F_o}}{x} \quad (1)$$

Using the pulsing mode supply (with the help of control device Belimo) due to appliance initial velocity V_0 of jet exit from the nozzle will oscillate according to the periodical order, namely it will change within the limits from V_{0min} to V_{0max}

$$V_0 = \overline{V}_0 + A \cdot \sin \omega t \qquad (2),$$

where $\overline{V_0}$ – average value V_0 at period of vibration, m/s;
A – amplitude of V_0 oscillation, m/s;
ω – cyclic frequency of oscillation, s^{-1};
t – time, s.

Values $\overline{V_0}$, A and ω can be determined from the formulas:

$$\overline{V}_0 = 0{,}5 \cdot \left(V_{0max} + V_{0min}\right) \qquad (3);$$

$$A = 0{,}5 \cdot \left(V_{0max} - V_{0min}\right) \qquad (4);$$

$$\omega = \frac{2\pi}{T} \qquad (5),$$

where T - period of oscillation, s.

We observe that during the initial moment of time the neutral position of partition was taken.

Similarly lets write the expression for the axial velocity oscillation when $\omega = \frac{2\pi}{T}$ is taken into consideration.

$$V_x = \overline{V}_x + B \cdot \sin\left(\frac{2\pi}{T} t - \varphi\right) \qquad (6)$$

Since axial velocity V_x is late at phase comparatively with V_0, so initial phase comes into expression (6) with negative sign.

Mean V_x and amplitude of its regression B are determined analogically ((7) and (8)) as the initial parameters ((3) and (4)):

$$\overline{V}_x = 0{,}5 \cdot \left(V_{x_{max}} + V_{x_{min}}\right) \qquad (7)$$

$$B = 0{,}5 \cdot \left(V_{x_{max}} - V_{x_{min}}\right) \qquad (8)$$

After that we obtain:

$$\overline{V}_x + B \cdot \sin(\omega t - \varphi) = \overline{V}_o \frac{m\sqrt{F_0}}{x} + A \frac{m\sqrt{F_0}}{x} \cdot \sin \omega t \qquad (9)$$

Since constant mode is the partial case of the pulse supply with the amplitudes of oscillation A = 0 and B = 0, so equation (9) changes into (10) and is analogical to (1)

$$\overline{V}_x = \overline{V}_0 \frac{m\sqrt{F_0}}{x} \qquad (10)$$

Taking into consideration (9), (10) we have:

$$B \cdot \sin\left(2\pi \frac{t}{T} - \varphi\right) = A \frac{m\sqrt{F_0}}{x} \cdot \sin 2\pi \frac{t}{T} \qquad (11),$$

from where we determine amplitude B:

$$B = A\frac{m\sqrt{F_0}}{x} \cdot \frac{\sin 2\pi t/T}{\sin(2\pi t/T - \varphi)} \tag{12}$$

Experimental investigations have been carried out at such conditions and simplifications:

- incoming air has been supplied by air device with creation of swirl and spread air jets;
- air jets are isothermal;
- initial air velocities in nozzle were: V = 5 – 15 m/s;
- period of velocity change at experimental investigations was constant: T = 16 min.;
- air flow rates were: L = 200 – 500 m3/ h.
- air distribution device was situated on height 3 m.

Air velocity have been measured by thermal electrical anemometr testo-405 at using coordinate device with net of points 5x5 sm.

Experimental results are presented on figure 1.

The amplitude B of regression of the axial velocity is variable in time, that corresponding to the dynamic microclimate. Let's determine the initial phase φ, and the initial time-point p. A. For that consider schematically the dependence of average axial velocity $\overline{V}_x$ depending on the running coordinate x $(\overline{V}_x = f_1(x))$ and depending on time t $(\overline{V}_x = f_2(t))$ in the initial and main areas of air jet.

Time t_A of air jet elementary volume from nozzle to calculating point p. A with coordinate xA will be the initial moment of time of axial oscillation velocity V_x, (13):

$$t_A = \frac{x_A}{V} \tag{13}$$

and the average velocity V – by integrating at intervals of primary main sections (14):

$$V = \frac{\overline{V}_0 x_{поч} + \int\limits_{x_{поч}}^{x_A} \frac{V_0 m\sqrt{F_0}}{x} \cdot dx}{x_A} \tag{14}$$

As a result of integrating we obtain an expression for the average velocity of air jet V:

$$V = \frac{\overline{V}_o}{x_A}\left(x_{поч} + m\sqrt{F_0} \cdot \ln\frac{x_A}{x_{поч}}\right) \tag{15}$$

So, taking into consideration (13) and (15) initial moment of time tA:

$$t_A = \frac{x^2{}_A}{\overline{V}_0\left(x_{поч} + m\sqrt{F_0} \cdot \ln\frac{x_A}{x_{поч}}\right)} \tag{16}$$

Value t_A, that is determined from (16), is the time of delay of axial oscillation velocity V_x, so the initial phase φ get from (3) and (16):

$$\varphi = \frac{2\pi \cdot x^2{}_A}{T \cdot \overline{V}_0\left(x_{поч} + m\sqrt{F_0} \cdot \ln\frac{x_A}{x_{поч}}\right)} \tag{17}$$

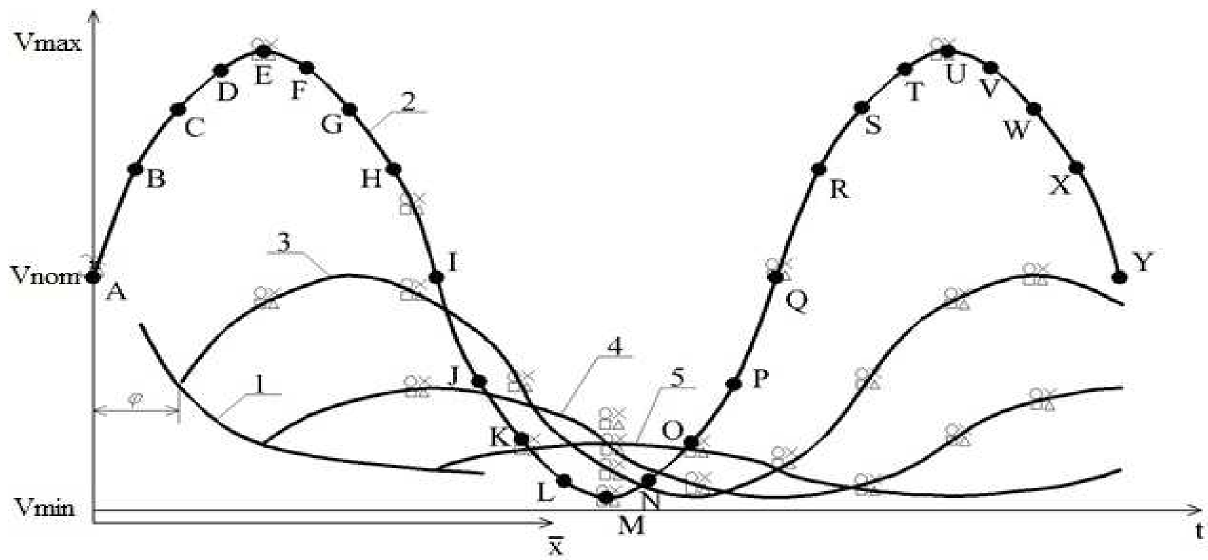

Figure 1: Experimental results: 1 – dependence of air velocity against coordinate at constant regime; 2, 3, 4, 5 – dependences of air velocity against time at different coordinates (variable regime)

All values that are necessary for calculating variable in time axial velocity Vx in point p. A are determined (6) as two-factor dependence $\overline{V}_x = f(x; t)$, namely: $\overline{V}_x$ - (10) , $\overline{V}_0$ - (3) , φ - (17) , B - (12).

Modelling of air flow have been carried out in accordance to CFD FLUENT program (Ansys FLUENT) at such conditions and simplifications:

- incoming air has been supplied by air device with creation of swirl and spread air jets;
- exhaust from the working area is provided by the exhaust hood, and from the upper zone of the room was out of coverage of supply air jets;
- air distribution device was situated on height 3 m.

Calculations of the equation by using one-parameter model of turbulence Spalarta-Almarasa are presented:

$$\frac{\partial}{\partial t}(\rho\tilde{v}) + \frac{\partial}{\partial x_j}(\rho\tilde{v}u_i) = G_v + \frac{1}{\sigma_{\tilde{v}}}\left[\frac{\partial}{\partial x_j}\left\{(\mu + \rho\tilde{v})\frac{\partial\tilde{v}}{\partial x_j}\right\} + C_{b2}\rho\left(\frac{\partial\tilde{v}}{\partial x_j}\right)^2\right] - Y_v + S_{\tilde{v}} \qquad (18)$$

where G_v - the production of turbulent viscosity,

Y_v - the destruction of turbulent viscosity that occurs in the near-wall region due to wall blocking and viscous damping,

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

v - the molecular kinematic viscosity.

The turbulent eddy viscosity is computed from:

$$\mu_t = \rho\tilde{v} f_{v1} \tag{19}$$

$$f_{v1} = \frac{\chi^3}{\chi^3 + C_{v1}^3} \tag{20}$$

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

$$G_v = C_{b1}\rho \cdot \tilde{S}\tilde{v} \tag{21}$$

where $\tilde{S} \equiv S + \frac{\tilde{v}}{k^2 d^2} f_{v2}$,

$f_{v2} = 1 - \frac{\chi}{1 + \chi \cdot f_{v1}}$,

and C_{b1}, k - the constants.

S - is the magnitude of the vorticity:

$$S \equiv \sqrt{2\Omega_{ij}\Omega_{ij}} \tag{22}$$

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

$$Y_v = C_{w1}\rho \cdot f_w \left(\frac{\tilde{v}}{d}\right)^2 \tag{23}$$

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} - the constants:

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

$C_{w3} = 2{,}0$, $k = 0{,}419$.

Results of modeling are presented on figures 2, 3.

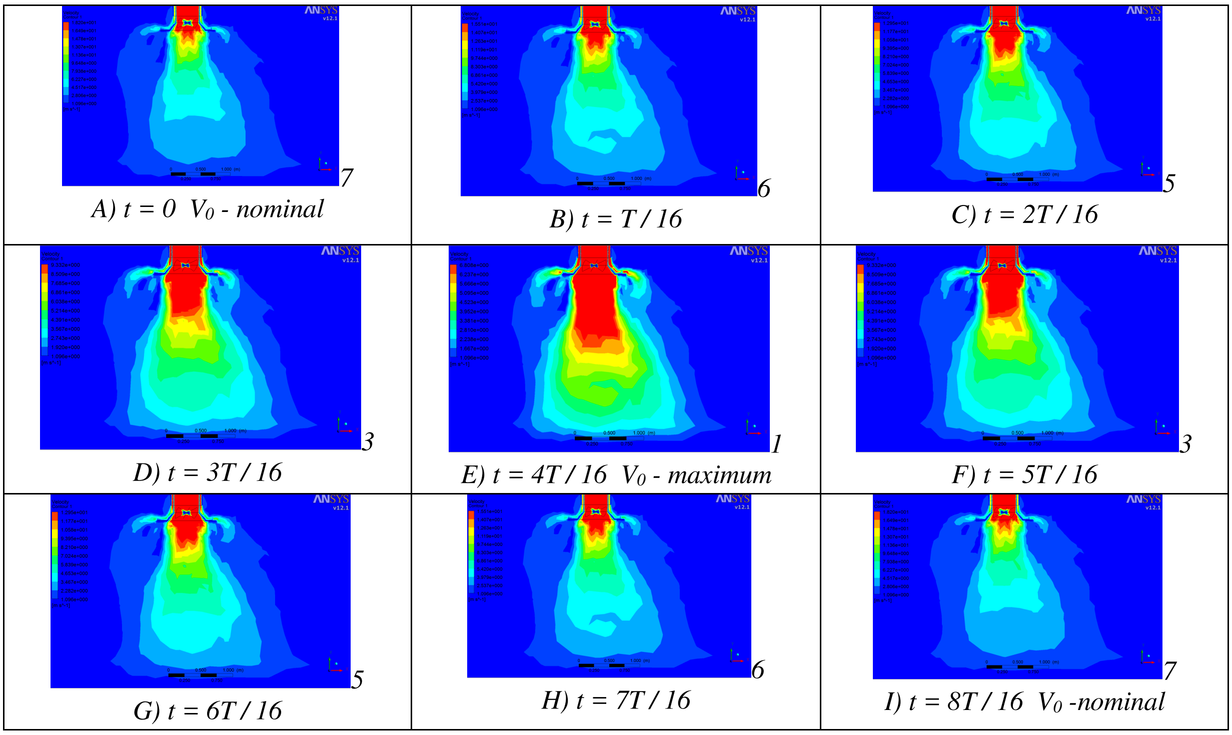

Figure 2: Velocity epure of incoming air flow in nozzle section at air supply by swirl and spread air jets at angle of swirling plates 60° and at time step t = T/16 (1 min) (Spalart-Allmaras model)

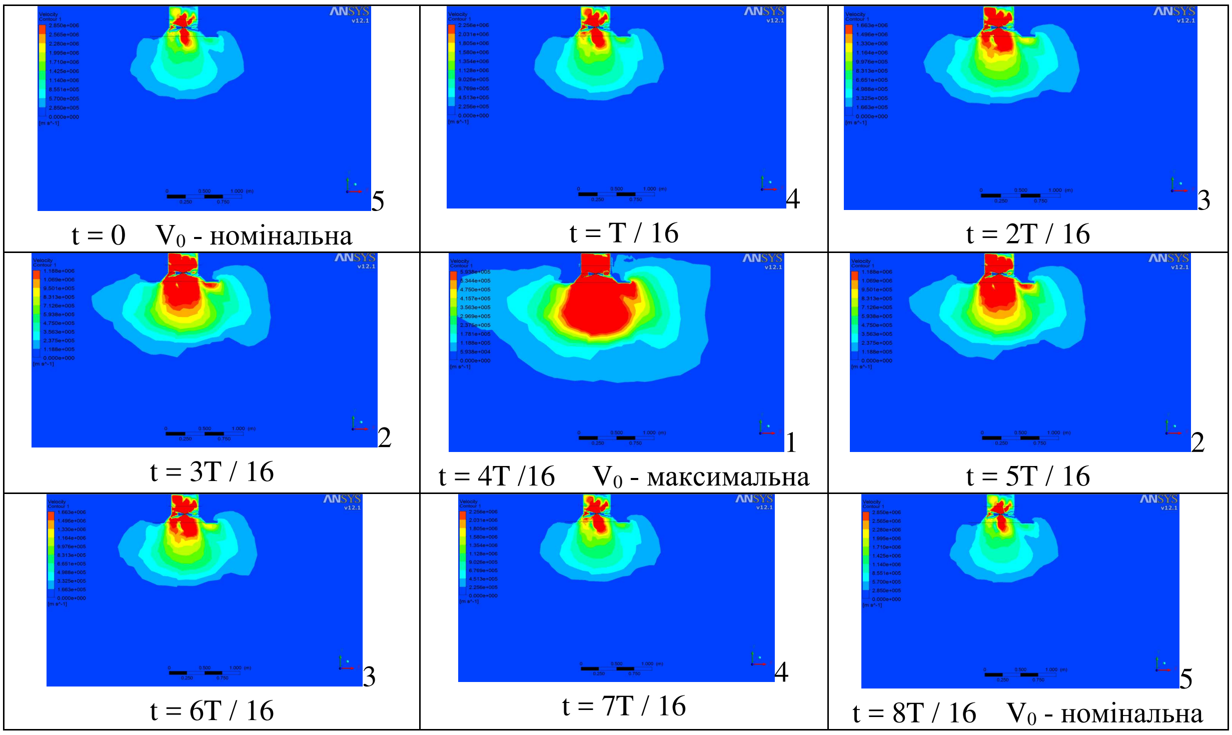

Figure 3: Velocity epure of incoming air flow in nozzle section at air supply by swirl and spread air jets at angle of swirling plates 30° and at time step t = T/16 (1 min) (k ε model)

3 Conclusion

There is a significant increase of velocity on swirling plates, indicating significant turbulence in the supply air flow, that is confirmed by both turbulent models.

There is determined that for decreasing of velocity $\overline{V}$ extinction coefficient it is needed to change angle of swirling plates from 600 to 300 and to use a spreading effect.

References

[1] O.Vozniak, O.Dovbush. Influence of indoor climate on a person heat exchange in a room. *Zeszyty naukowe Politechniki Rzeszowskiej "Aktualne problemy budownictwa i Inzynierii srodowiska"*; czesc 2 - inzynieria srodowiska", Rzeszow, 2000 r., - s.441 – 447.

[2] Voznyak, O., Sukholova, I., Myroniuk, Kh. (2012). The characteristics of air swirl supply device. *SSP – Journal of Civil Engineering, 7 (1), 95–102*. doi: 10.2478/v10299-012-0023-0

[3] Hrimitlin M.I. *Raspredelenie vozduha v pomeshcheniah*. – M., Stroiizdat 1982, – 163 s.

[4] Vozniak O.T., Sukholova I.Ye. Deklaratsiynuy patent Ukrayiny № 40185 vid 25.03.2009 r., Biul. № 6, 2009 r. "Povitrorozpodil'nyk".

[5] Возняк, О. Т.; Сухолова, І. Є.; Миронюк, Х. В. Дослідження пристрою для повітророзподілу закрученими і настильними струминами у змінному режимі. *Восточно-Европейский журнал передовых технологий*, 2015, 6 (7): 15-23.

[6] Malhin Yu. V. Sozdanie efektivnogo dinamicheskogo mikroklimata v pomeschenii. *Inzhenernye sistemy. AVOK-Severo-Zapad*, №3 (41), 2009. – s. 42 – 46.

[7] Voznyak, O., Myroniuk, K., Sukholova, I. Energy saving at creation of dynamic indoor climate in a room. *Current issues of Civil and Environmental Engineering in Kosice, Lviv and Rzeszow.* XIII international scientific conference. Kosice, 2011