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SANITARY ESTIMATION OF VORTEX AIR CIRCULATION FOR WORK-ROOM VENTILATION

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Over a couple of recent decades, world science and technology literature has featured reports on using vortex air circulation by way of improving workroom environments. The vortex effect is achieved due to some peculiar properties of whirling air currents, which are as follows: high turbulence, significant diffusion, heat and mass coefficients, which contribute to process intensification and shorten its duration. This study showed the possibility to considerably reduce air consumption required to ensure desired indoor environment parameters, such as air temperature, velocity and gas and dust levels. At the same time, however, the study contains no particular design data for the above-mentioned air exchange arrangement.

We, in the industrial ventilation laboratory of the Moscow Research Institute for Occupational Safety and Health (VCNIIOT), have for several years now conducted investigations aimed at identifying the conditions for the arrangement (emergence) of steady indoor air circulation with a vertical axis of revolution and possibilities of ensuring desired workplace air environment parameters.

The process of vortex air circulation within limited indoor space is very complex a phenomenon and to describe it mathematically presents rather difficult a task. This is partially the reason why to solve the above-stated problems we used physical (three-dimensional) modelling, a method rather commonly employed in ventilation engineering. We used mathematical methods of experiment planning. A second order polynomial was assumed as equation describing the parameters being studied, namely maximum and mean air movement velocities in occupied areas, maximum to minimum air temperature gradient across the workplace floor-space area and maximum and mean concentrations of harmful substances in workplace air.

Vortex air circulation within the space (room) being ventilated was arranged by a tangential supply of clean air using 2 or 4 air distribution units, placed equidistantly from the floor level, to ensure a unidirectional air outflow along the space outline (perimeter), air distribution being most efficient as the air is supplied in flat jets; the exhaust air was removed via a unit, placed right in the vertical axis of air revolution (whirling) at different heights, as dictated by concrete design specifications. This study was particularly concerned with investigating the efficiency of vortex ventilation with the air removal unit being placed in the vertical axis of air flow revolution at the roofing level.

An industrial building (structural space limited by four columns) mock-up was used to determine the conditions under which a tangential supply of fresh air with exhaust air being removed via a unit placed in the vertical air flow revolution axis at the roofing level was conducive to the formation of vortex air circulation. The quantity of energy introduced by inlet air per 1m^3 of space being ventilated, as well as the ratio between the geometrical dimensions of the room (space) and ventilation units were found to be the most powerful determinants.

In order to study the hygiene efficiency of vortex air circulation and the possibility of utilising it by way of industrial premise ventilation we investigated workplace air environment parameters, determined the principles governing their changes and main contributing factors. Such investigations could in practice be caried out only on an industrial building model (mock-up), equipped with plenum and exhaust systems.

With a view to finding solutions to the above-stated problems, we made two building mock-ups of different size, whereof the smaller one was assumed to be the building model proper (model conditions) while the smaller one was assumed to be the actual space being ventilated (field conditions).

Such investigations were necessitated by the fact that we failed to find any literary reports ascertaining the possibility of extrapolating model air environment parameter findings to field conditions. Workplace air parameter findings were presented in the form of relative dimensionless quantities, relating: workplace air velocity to the velocities at the outlets of air distribution systems; harmful substance concentration in workplace air to that in the air being removed via the roofing; and the difference between the temperatures of air at some measurement point and supplied air to that between supplied and removed air temperatures.

The obtained experimental data led us to believe that the process of indoor vortex air circulation was self-similar with respect to Raynolds number, which indicated the possibility of designing vortex effect-based ventilation systems using the proposed equations whatever air flow rate.

As far as we can judge, before this study there seemed to have been no literary mention of harmful substance temperature distribution over the cross-section of whirling air streams.

The experimental study of harmful substance concentration and air temperature distribution patterns across the workplace area (wherefor the experimental model was furnished with mock-ups of heat and gas emitting equipment with electric heaters, operated off mains, and toluene vapour supply, carried in with air flow) showed three air current zones to actually form within model space, which were as follows: in the vicinity of the guarding devices air particles followed concentrical paths (potential or clean flow, velocity varying (spreading) in inverse proportion to the radius); in the model centre the air flow revolved round its own axis (vortex core, revolving similarly to a solid body); in the transition zone air particles (elements) moved along spiral paths from guards to the axis.

Toluene vapour concentrations increased steeply from the guards towards the model centre, reaching their maximum nearest the whirling axis. No toluene vapour levels whatsoever were observed over a rather large portion of the model area (some 30%), - the outer zone; in about 68% of the model surface area toluene vapour concentrations were within current exposure limits; and only 2% of the area (in the immediate proximity of the whirling axis) had toluene vapour concentrations twice the maximum level.

As certain dimensional ratios within the "room-ventilation" system are achieved, the excess concentration zone could be eliminated altogether.

We can cite as an example some air flow rate values sufficient to ensure the required level of workplace air cleanliness, which, at three different "room-ventilation" system versions, constituted, respectively, 52%, 64% and 78% of those normally required in more traditional air exchange arrangements.

The fact that highest harmful substance levels (or excess heat) concentrated in one rather limited location made it possible to arrange for their efficient removal and considerably reduce air consumption for general (dilution) ventilation. It would be apposite to note that concentration field formation depends on some aerodynamic process parameters, namely, on air flow structure, which, in its turn, is determined by the ratio between the revolving, axial and radial components of velocity, depending on the geometrical dimensions and location of ventilation units.

Presented below are examples of the equations enabling workplace or work zone (w.z.) air parameter values to be calculated under the conditions when vortex air circulation is achieved by air being introduced in 4 compact jets with harmful emission source located in the centre and allowing for the effects of the following factors: room height, air distribution unit location height above the floor level, the height and surface area of gas and heat emitting manufacturing equipment, specific quantity of heat emissions; air removal outlet located in the roofing:

- calculating mean excess temperature value:

$$\Delta\bar{t}^{mean}_{w.z.} = (t^{mean}_{w.z.} - t_0)/(t_{out} - t_0) =$$

$$= 0.358+0.048X_1+0.0141X_3-0.052X_5+0.063X_6+0.086X_1X_2-$$
$$-0.052X_2X_4+0.048X_3X_6+0.083X_4X_5-0.138X_3X_5-0.076X_3X_4;$$

- calculating mean concentration value:

$$\bar{C}^{mean}_{w.z.} = C^{mean}_{w.z.}/C^{mean}_{out} =$$

$$= 0.256+0.046X_1+0.077X_2-0.132X_5-0.051X_6+0.041X_1X_2-$$
$$-0.021X_1X_6-0.02X_3X_6+0.027X_4X_5+0.025X_3X_5;$$

- calculating mean air flow velocity value:

$$\bar{V}^{mean}_{w.z.} = V^{mean}_{w.z.}/V_0 =$$

$$= 0.106-0.021X_1+0.037X_2-0.002X_3+0.016X_4-$$
$$-0.011X_1X_6+0.007X_2X_4-0.0075X_3X_5-0.011X_3X_4$$

In the above equations X_1 through X_6 represent coded designations of the following factors:

$$X_1 = \frac{\bar{h}_1^{adu} - 0.375}{0.375}; \quad X_2 = \frac{\bar{F}_0 - 0.00264}{0.00158}; \quad X_3 = \frac{\bar{H} - 0.375}{0.125};$$

$$X_4 = \frac{\bar{h}_{eq} - 1.2}{0.4}; \quad X_5 = \frac{\bar{F}_{eq} - 0.245}{0.12}; \quad X_6 = \frac{0.91\, q \sqrt{F_{fl}} - 78}{78};$$

where

$\bar{h}_1^{adu} = (h_1^{adu} - h_{w.z.})/(H - h_{w.z.})$ is the relative height of air distribution unit (adu) location (1)', $h_{w.z.}$ is work zone height, H is the height of room (space) being ventilated; $\bar{F}_0 = F_0/F_{fl}$ is total relative area of air distribution units, F_{fl} is floor surface area of the room being ventilated; $\bar{H} = H/ F_{fl}$ is relative room height; $\bar{h}_{eq} = h_{eq}/h_{w.z.}$ and $\bar{F}_{eq} = F_{eq}/F_{fl}$ are heat and gas emitting manufacturing equipment height and area, respectively; $q = Q_{eq}/V$ is specific excess heat emission quantity (W/m^3), Q_{eq} is excess indoor heat flux (W), V is the size (volume) of room being ventilated (m^3).

CONCLUSIONS

We, in the Moscow Research Institute for Occupational Safety and Health', used industrial building mock-ups to find whether it is possible to utilise vortex air circulation for work room ventilation.

The study demonstrated the expediency and efficiency of vortex air circulation arrangement, which contributed to the reduction of air consumption, required for work room ventilation, and helped ensure the desired workplace air environment parameters.

Equations are proposed enabling one to calculate workplace air parameters with aptly chosen air distribution unit area and location height above the floor level.