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Influence of Visitors' Flows on Indoor Air Quality of Museum Premises.

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Abstract.

The article considers the influence of visitors' flows on indoor air quality of museum premises and work of ventilation and air conditioning systems. The article provides the analysis of the heat input from visitors, the results of mathematical simulation of visitors flow influence on indoor air quality. Several advice options are provided on application of variable air volume systems for provision of constant indoor air quality.

Key words: indoor air quality, mathematical simulation, visitors' flows, museum premises.

1 Introduction

Modern museums are designed for conservation and creation of a set of monuments of material and spiritual culture, their study and exhibition. Every museum has individual architectural solution that is determined by its collection, form of operation and engineering systems, which have to provide optimal conditions for conservation of exhibits and take into account visitors' requirements. The capacity of ventilating systems is determined by pollutants' arrival features in the area.

Architectural and spatial structure of rooms, their dimensions, form and system of interconnection between them, other premises and surrounding space are determined by exhibit's determination and character and essentially has an effect on creating comfortable conditions for visitors.

During exploitation of old buildings exposition's structure has to be designed according to composition development of existing interiors. Considerable difficulties in establishment of engineering systems are created when museum is situated in an old building. Sometimes it is impossible to lay in the ducts for air supplying museum rooms, especially when it's located in a building that is a historical monument.

Museum premises are characterized by arrival periodicity of pollutants, that cause appearance of considerable temperature and relative humidity range and air-gas composition change.

The visitors are the most fundamental source of contamination of museum premises; more over heat and humidity arrivals have periodic character. The visitors' locations have stochastic character and in the first approach it can be presented as compact and dispersed. For simple evaluating of visiting influence on the state of museum rooms climatic parameters it's reasonable to substitute visitors by equal heat-exchange surfaces. [1]

The process of heat input and indoor air quality forming during the visitors' movements in the premises is an important and not studied yet [2]. One of the ways to provide required ventilation in museum premises in case of low capacity of air conditioning systems, is air supply by overflow through the openings that connect adjoining rooms.

2 Results of investigations

The heat exchange between visitors and ventilation air takes place by convection because air is almost transparent for radiation heat. But radiation from visitors cause warm of other surfaces (building constructions, furniture, exhibits etc) that cause's the appearance of secondary heat sources. Rules of spreading of convective and radiative heat are different, that's why it is reasonable to determine heat input in the work zone like that [3,4]:

$$Q_{wz} = \sum_1^n \frac{\lambda+\beta\varphi}{1+\varphi} Q_i, \tag{1}$$

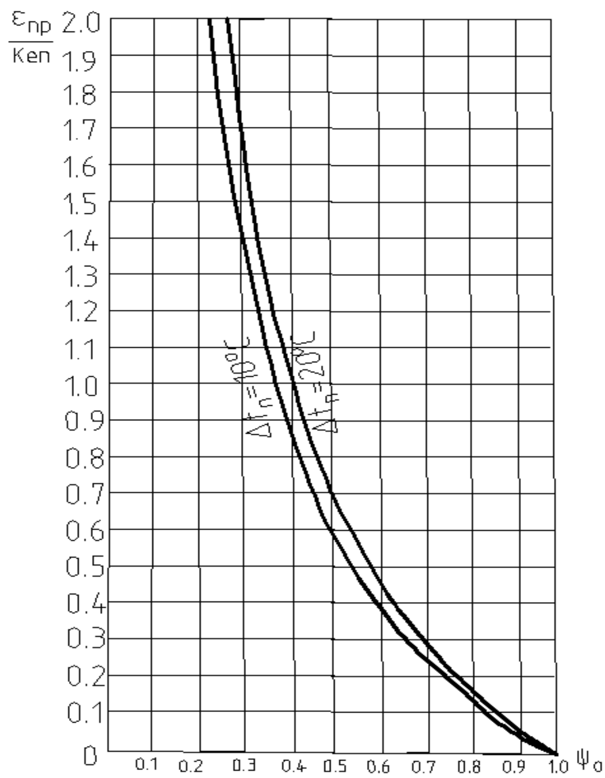

Figure 1: The dependence on the value $\varepsilon_{прив} / K_{en}$ from surface temperature and convective-to-full heat output ratio

where λ- radiative heat that is assimilated by supply air in the work zone to full radiative heat ratio. Rough value of λ can be accepted as $\lambda = \frac{1{,}4-0{,}1\left(\sqrt{H^{н}_{дж}}+\sqrt{H^{в}_{дж}}\right)}{2}$, where $H^{н}_{дж}$ and $H^{в}_{дж}$ – vertical distance from floor level to up (down) side of heating surface, m;
β- convective heat that is assimilated by supply air in the work zone to full convective heat ratio. There are two border values of coefficient β=0 – for heat sources located higher than work zone and β=1 – for heat sources located in the work zone but their capacity is low for creating of powerful thermal flow, so all convective heat is assimilated in the work zone;
φ- full convective heat to full radiative heat ratio; Q_i- full heat input fron the source. Coefficients β and φ in equation (1) are determined by experiment.

So the main task is determination of full heat input from chaotically moving visitors in the premise Q_i. and its influence on indoor climate. To make this task easier its worthwhile replace visitors by equal heat exchange surfaces. While calculating character dimensions of equal heat exchange surface is assumed odd temperature on surface of real and equal heat sources are the same $\Delta t_n^{заг} = \Delta t_n^{en}$. So for maintaining equal radiative heat to convective heat ratio determinative is volume $\frac{\varepsilon_{прив}}{K_{en}}$, that is similar $\frac{\varepsilon_{прив}}{K_{en}} = \frac{A_m \Delta t_n^{1/3}}{c_o b_{1-2}}\left(\frac{1}{\psi_o}-1\right)$, where $\varepsilon_{прив}$ - reduced blackness power of heating surface; K_{en} - real-to-virtual surface ratio; A_m – coefficient that includes physical features of air and orientation of heat exchange surface; b_{1-2} – the distance between heat sources; ψ_o – convective-to-radiative component ratio. By the plot (fig.1) at specified values of Δt and ψ_o we find the value $\frac{\varepsilon_{прив}}{K_{en}}$. In the equation $\frac{\varepsilon_{прив}}{K_{en}} = \frac{\varepsilon_{прив} F_{en}}{F_{дж}}$ the value $F_{дж}$ is known. Whether we know the value $\frac{\varepsilon_{прив} F_{en}}{F_{дж}} = D$, the value $\varepsilon_{прив}$ is assigned. Then the area of equal heat exchange surface could be calculated [5].

To estimate visiting influence on a character of climate forming in museum premise mathematical modeling was done using a program CosmosFloWorks 2008. Modeling was doing for two cases of visitors movement – organized and chaotic. By organized movement group of visitors was substituted by equal surface (parallelepiped for exsample). By chaotic movement every visitor is substituted by equal cylindrical surface. Initial parameters aceepted by modeling in calculating and border premises are t_{wz} =20°C, φ_{wz} = 40%, the pressure in border premises is equal to atmospheric. Exhaust air volume is 1000 m^3/h. Geometrical dimensions of premise in cut are 10x20 m, 4,5m height. Visitors movement speed is 0,5 m/s , number of visitors is 50 pers. Some results are on fig.2-3.

Modeling show significant influence of visitors movement on indoor air climate. By organized visitors movement increasing of temperature on 1,5-2 °C and relative humidity 20-35% is observed, maximal volumes are in heat flow area at that. By chaotic visitors movement in museum premise almost steady height diversity changing of temperature and relative humidity fields is observed (Δt=0.3-2.3°C; Δφ=10-12%). Maximal values of temperature (23°C) and relative humidity (50%) are observed in plan in areas with higher visitors number in the same moment. So modeling results show that the temperature gradient in different visiting modes is not higher than 0,5^{o}C/m. Thereof we can make a conclusion that the majority of pollutants is assimilated in the work zone. In addition the work of exhaust system causes negative pressure that led up to fresh air overflow from border premises.

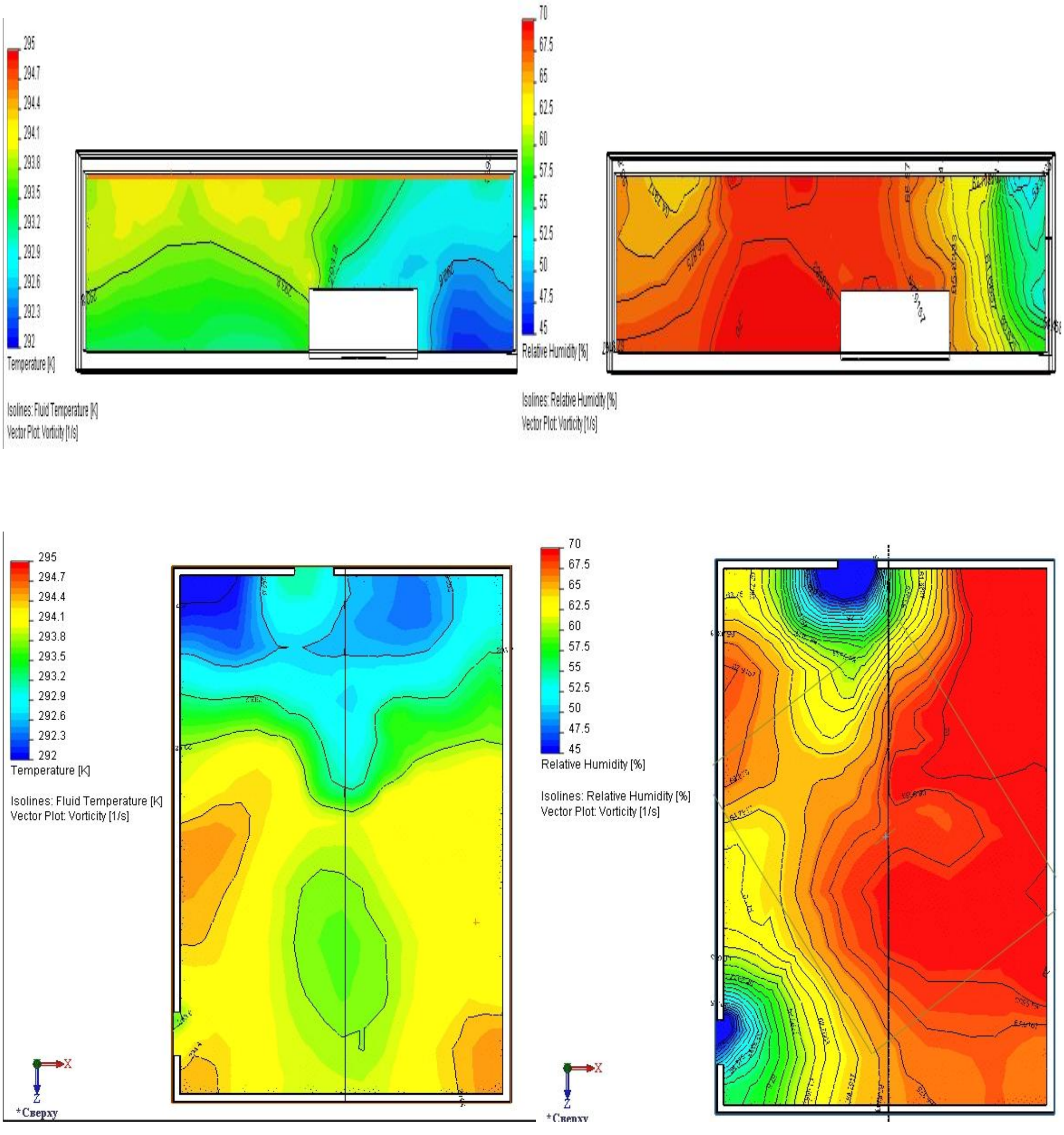

Figure 2: Temperature and relative humidity distribution at movement in premise a group of visitors with a motion rate of 0,5m/s at τ=300c.

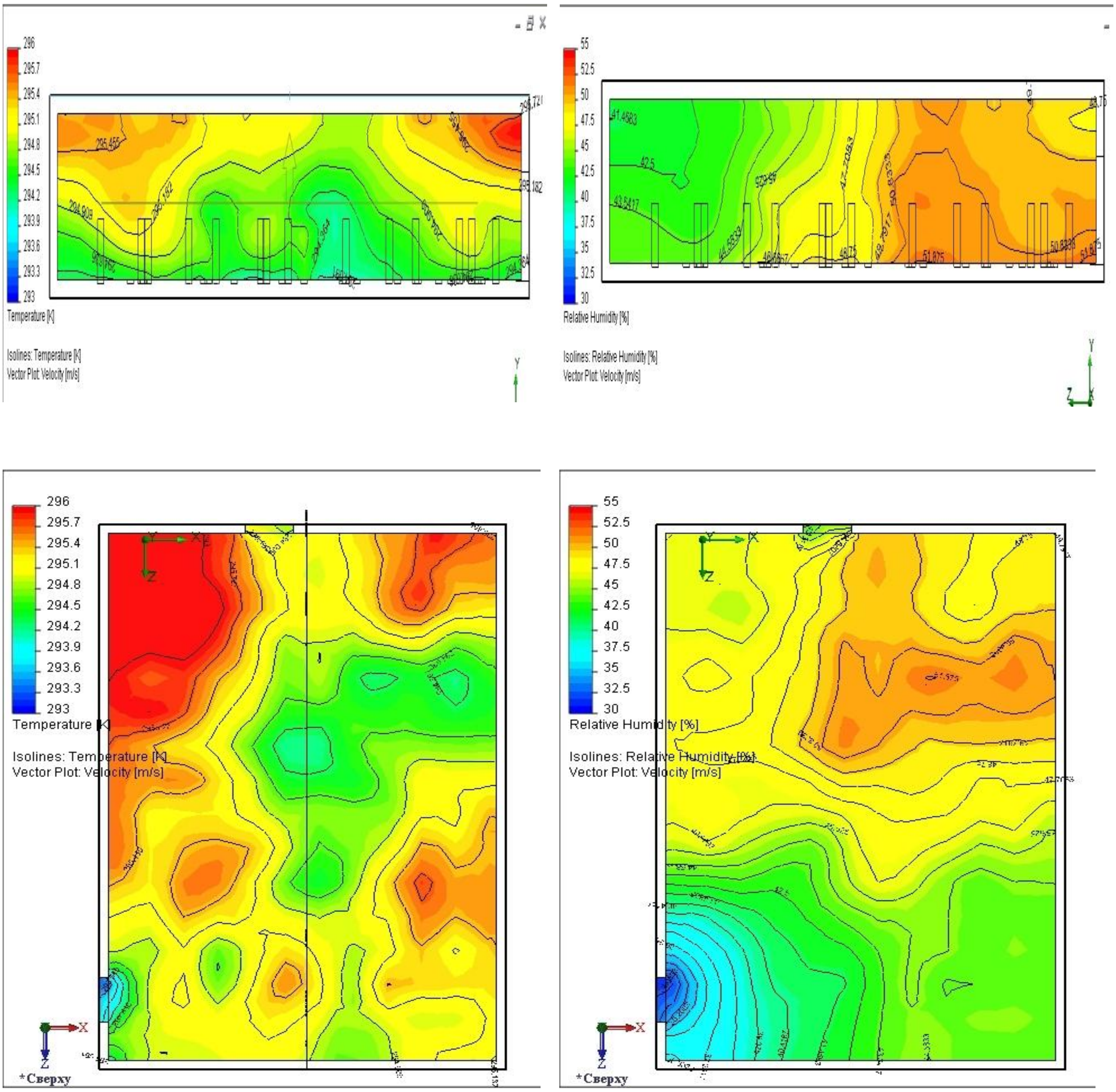

Figure 3: Temperature and relative humidity distribution at chaotic visitors movement in premise with a motion rate of 0,5m/s at τ=300c.

By balanced work of supply and exhaust ventilating systems the character of air overflow between rooms is determined by gravity forces.

The difference between density in border premises ($\rho_1 > \rho_2$) stipulates the exsisting of gravitational pressure $P_{1\text{-}2}$ in the openings area. Three specific modes of openings work are possible (fig.4):

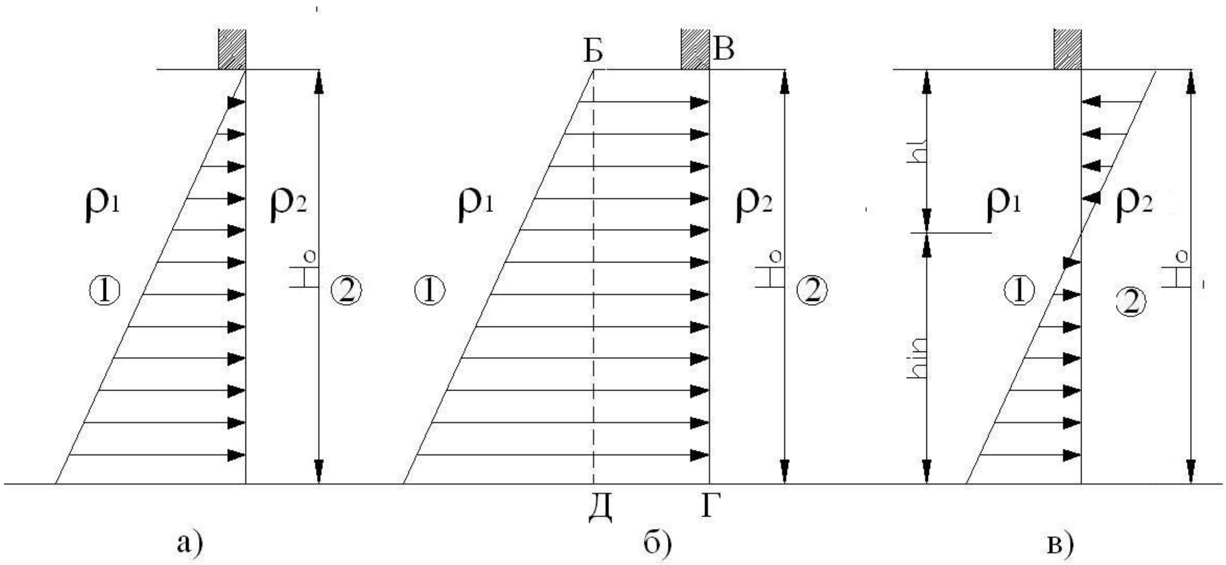

Figure 4: Pressure distribution in the opening connecting two premises area:
а, б – opening works in one side; в – opening works in two sides

If the pressure difference in the opening changes from zero to its maximal valye ΔP_{max} (fig. 4,a), then the air volume throw elementary area for which is possible to consider that ΔP=const is equal (on condition $\rho_1 > \rho_2$) [4]:

$$\mathrm{d}G = \mu\, b\, \mathrm{d}h \sqrt{2g\rho_1(\rho_1 - \rho_2)h}\,, \tag{5}$$

where μ – opening volume coefficient, b- opening width, h- moving high coordinate.
Integrating equation (5) we’ll have maximal possible air volume Gmax, that can be realized under effect of local odd pressure in the opening connecting border premises:

$$G_{\max} = \frac{2}{3}\mu b \sqrt{2g\rho_1(\rho_1 - \rho_2)}\sqrt{H_o^3}\,, \tag{6}$$

where Ho – opening height, m.

The recirculation in border opening absence is ensured when

$$G \geq \frac{2}{3}\mu b \sqrt{2g\rho_1(\rho_1 - \rho_2)}\sqrt{H_o^3}\,, \tag{7}$$

Whence it appears boundary permissible opening height on condition of recirculation absence in it:

$$H_o \leq \sqrt[3]{\frac{2{,}25G^2}{\mu^2 b^2 2g\rho_1(\rho_1 - \rho_2)}}\,. \tag{8}$$

When real air volume throw border opening G > Gmax, it answers to maximum air density difference between this premises and to maximum pressure (fig.4,б). Rectangle ДБВГ shows part of pressure that is caused by vacuum in the premise with a higher pressure.

When real air volume flow throw border opening G < Gmax, then the top of distribution diagram moves inside the premise with a higher temperature. (fig.4,в). The crosspoint between distribution diagram and vertical opening area divides it on two parts each characterizing pressure in bordering premises. In this case pressure in the premise with a higher temperature causes air overflow.

In calculation scheme with openings that part of their area works on air income, and other part works on exhaust (fig. 4,в), air volume throw lower openings part have to be:

$$G_{in} = \frac{2}{3}\mu b\sqrt{2g\rho_1}\,\sqrt{[h_{in}(\rho_1-\rho_2)]^3}\,/\,(\rho_1-\rho_2), \tag{9}$$

and the air flow throw higher part:

$$G_l = \frac{2}{3}\mu\, b\sqrt{2g\rho_2}\,\frac{\sqrt{[h_l(\rho_1-\rho_2)]^3}}{\rho_1-\rho_2}. \tag{10}$$

Dividing (9) on (10), we'll get :

$$\frac{G_{in}}{G_l} = \sqrt{\frac{\rho_1}{\rho_2}}\,\sqrt{\left(\frac{h_{in}}{h_l}\right)^3}, \tag{11}$$

whence:

$$\frac{h_{in}}{h_l} = \sqrt[3]{(G_{\mathrm{in}}/G_l)^2(\rho_2/\rho_1)}. \tag{12}$$

Air recilculating in the opening that connects border premises have negative effect on efficiency of air exchange in the premise.

3 Conclusions

The Major portion of museums are located in old buildings, that have small ducts to give enough for pollutants assimilation air volume. In addition the change of planning decision is possible in some premises, that brigs changes of ventilation system algorithm work. Data analysis show that visitors movement have to be discounted during air exchange organizing In view of being impossible to change traces and cuts of ventilating systems is essentially to use a possibility of ventilating border premises throw openings. Overflow character is determined by disbalance of income and exhaust air in birder premises and by pressure in the opening. The maximal air volume is limited by standard air flow rate in the work zone. To regulate air distribution between premises is possible by using variable air volume air condition system.

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