

Calculation air regime of a residential building with individual exhaust channels

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Abstract. Purpose. This article deals with the algorithm of the air renewal calculation of the building on the example of a residential building in order to determine correspondence of the incoming and removed air quantity to the characteristics of the current standards. The algorithm of calculation allows to determine the air consumption and direction of flow that are filtrated through the hole in the enclosing structures and removed by local vent systems natural ventilation. **Method.** This calculation can be performed on the electronic computing machine (computer) using one of the programming languages. **Result.** The calculation program will consist of two units: the unit of pre-calculations, and unit of iterations. The unit of preliminary calculations deals with the boundary conditions and the calculation of the resistance characteristics of air-penetrating building elements (windows, doors) and the characteristics of aerodynamic resistance of sections of the ventilation system. The iterative unit deals with the determination of internal pressure in rooms and air consumption, filtered through the air-penetrating holes and removed by local vent systems. The solution of the air renewal of a building is the description of its balance equations for each apartment, an elevator hall and a corridor. In this example we see a separate local vent from each ventilating grid that does not provide for a recalculation of characteristics of aerodynamic resistance of sections of ventilation systems depending on the change of the air consumption in them. **Conclusion.** The results of the calculation of the air renewal may show whether the air consumption (the incoming and removed air quantity) corresponds to the characteristics of the current standards. The resulting pattern of air renewal of the building will allow to determine whether there are some deficiencies in the ventilation system.

1. Introduction

The air streams which are formed by natural forces (gravity and wind pressure) and come into the building through leakages in fences, windows and doors, compensate the air removed by exhaust gravitational systems from kitchens, bathrooms and lavatories. All these processes are united by the notion of air renewal of the building. The methodology of calculating air renewal of the building is based on N.N. Razumova's [1] and S. V. Biryukov's [2,3,4] ideas and results.



2. Mathematical model

Solution of the air renewal of a building is the solution of the balance equations of each room: the amount of air consumption through all air penetrating elements within one room m must be zero [2]:

$$\sum_{n=1}^N G_{m,n} = 0 \quad (1)$$

where: $G_{m,n}$ is the air consumption through the air penetrating element, kg/h; $n=1,2,3,\dots$ is a number of air penetrating element in the room, $n=1,2,3,\dots$; m is a number of the room, $m=1,2,3,\dots$

The consumption of the air, kg/h:

-air penetrating element between the rooms [2]:

$$G_{m,k} = \left[\frac{|P_{in,m} - P_{in,k}|}{S_{h,m,k}} \right]^{1/r} \text{sign}(P_{in,m} - P_{in,k}) \quad (2)$$

-by means of filling the area light (windows, stained-glass windows, shop-windows) and entrance doors [2]:

$$G_{m,k} = \left[\frac{|P_{out,k} - P_{in,m}|}{S_{h,m,k}} \right]^{1/r} \text{sign}(P_{out,k} - P_{in,m}) \quad (3)$$

where: $P_{in,m}, P_{in,k}$ is the pressure inside and outside of the building in the center of the inner air-penetrating element, Pa; $P_{out,k}, P_{in,m}$ is the pressure inside and outside the room in the centre of the outer air penetrating element, Pa; $\text{sign}(P_{in,m} - P_{in,k})$, $\text{sign}(P_{out,k} - P_{in,m})$ is a function adopted in many language programs with a value (+1), if $\Delta P > 0$, and the value (-1) if $\Delta P < 0$. It can be replaced by:

$$\frac{P_{out} - P_{in}}{|P_{out} - P_{in}|} \quad (4)$$

The air consumption removed by exhaust ventilation from the room m , kg/h, [1,7]:

$$G_{rem,m} = \left(\frac{|P_{e,n} - P_{b,n}|}{S_n} \right)^{1/2} \text{sign}(P_{e,n} - P_{b,n}) \quad (5)$$

where: $P_{e,n}$ is the pressure at the end segment of the ventilation network, Pa; $P_{b,n}$ is the pressure at the beginning segment of the ventilation system, Pa; S_n is resistance characteristic of vent area network.

The calculation of the pressure is relative to the conventional zero, which is taken as the most remote element of the earth's surface, i.e. the top of the exhaust ventilating shafts is at a distance H_{est} . Taking into account the internal gravitational pressure, full excess pressure on the building, Pa, is equal to [2,5]:

$$P_{full}^{out} = g(H_{est} - h)(\rho_{out} - \rho_{in}) + (C_{aer} - C_{aer}^{leew}) \frac{v_{wind}^2}{2} \rho_{out} k \quad (6)$$

where: g is acceleration of gravity, m/s^2 ; h is height of air-penetrating element relatively to the ground level, m; ρ_{out} is the density of outdoor air, kg/m^3 ; ρ_{ins} is the density of inside air, kg/m^3 ; C_{aer}, C_{aer}^{leew} is the aerodynamic coefficients on the windward and leeward sides of facades [6]; k is a coefficient taking into account the change of wind pressure by height of the building [7]; v_{wind} is the wind speed at the facade [8], m/s.

Resistance characteristics of air penetrating holes is defined in [2]:

- for windows $S_{h,m,k}$, the $Pa/m \cdot (kg/h)^2$:

$$S_{h,m,k} = 10 \left(\frac{R_{i,m,k}}{F_{h,m,k}} \right)^{3/2} \quad (7)$$

- for a door $S_{h,m,k}$, the $\text{Pa/m} \cdot (\text{kg/h})^2$:

$$S_{h,m,k} = 10 \left(\frac{R_{i,m,k}}{F_{h,m,k}} \right)^2 \quad (8)$$

where: $R_{u,m,k}$ is resistance to air-permeability of air penetrating holes [9], $(\text{m}^2 \cdot \text{h})/\text{kg}$; $F_{h,m,k}$ is the area of air penetrating holes, m^2 ; 10 is the pressure difference for translucent leakages of the windows, which tests their air permeability, Pa.

The value of resistance to air permeability of walling (windows and porch doors), which depends on the value of air permeability is determined by the formula [9]:

$$R_i = \frac{1}{G_n} \cdot \left(\frac{\Delta P}{\Delta P_0} \right)^{2/3} \quad (9)$$

where: ΔP is the pressure difference of the air on the outer and inner surfaces of enclosing structures according to the equation (6), Pa; G_n is normalized transverse air permeability of building enclosing structures, $\text{kg}/(\text{m}^2 \cdot \text{h})$, taken according to the table 2 [9].

The description of the aerodynamic resistance of ventilation system elements S , $\text{Pa}/(\text{kg/h})^2$, is determined by the formula [2,5]:

$$S = \frac{\frac{\lambda}{d} l + \sum \zeta}{2 f^2 \rho 3600^2} \quad (10)$$

where: λ is the coefficient of friction; d is the equivalent diameter of air duct, m; l is the length of the air duct; ζ is the local resistance coefficient [10,11]; f is the clear section of the element, m^2 ; ρ is the density of the transported air, kg/m^3 .

Ventilation systems in residential buildings are designed in accordance with the regulations [7, 12, 13, 14]. Ventilation in residential buildings according to SP 54.13330.2016 "residential buildings" can be:

- with natural supply and removal of air. To improve the performance of the ventilation system: deflectors, heat impulse, the valves of the "AERECO" type are used [15, 16, 17];
- with mechanical supply and removal of air, including the combination with air heating;
- combined with natural inflow and removal of air with a partial use of mechanical impulses. They are called hybrid ventilation systems [18-20].

Typically, in residential buildings natural ventilation is provided, where air renewal occurs under the influence of natural forces (gravity and wind pressure), and gravity systems of ventilation. In this article the ventilation systems with individual exhaust ducts from each ventilation grid are studied (Fig.1).

3. The algorithm of the air renewal calculation

Let us consider the calculation algorithm on the example of a nineteen-storey residential building (Fig.2). The program will allow to perform calculation of the air renewal of a building equipped with gravitational or mechanical ventilation systems. Iterative calculation is performed under the assumption of the estimated consumption of the air in the areas of ventilation systems in order to determine the internal pressure in rooms and air flow through the air penetrating holes and the ventilation systems. Then, in subsequent iterations, the values of consumption are specified. The program consists of two parts, the algorithms are presented below:

1. Preliminary calculations:

The unit of preliminary calculations is meant to determine the boundary conditions, which include all the forces that influence the process of air renewal in the building. The unit of preliminary calculations includes:

- the input data source: climatic data of the area of construction; geometrical characteristics of buildings and ventilation systems; aerodynamic building characteristics and air permeability of leakages;
- the pressure calculations applied to the outside of the hole centers according to the equation (6).

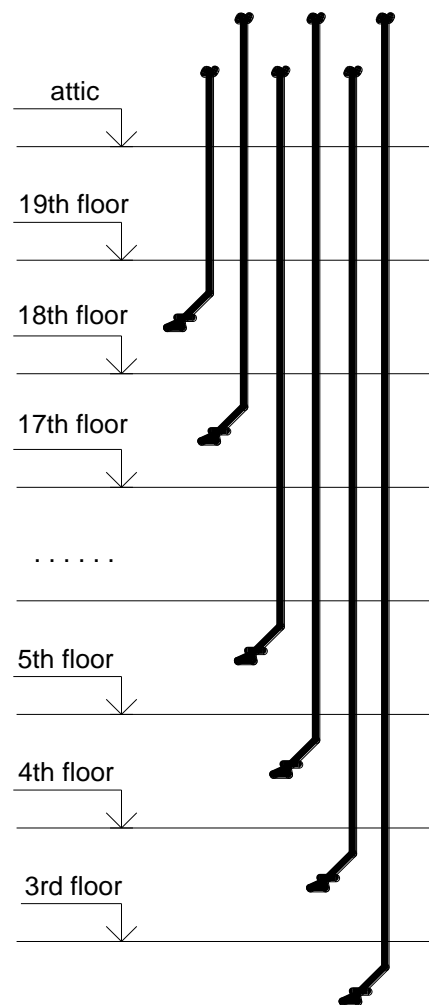


Figure 1. Diagram of the ventilation system with an individual local vent for each grid

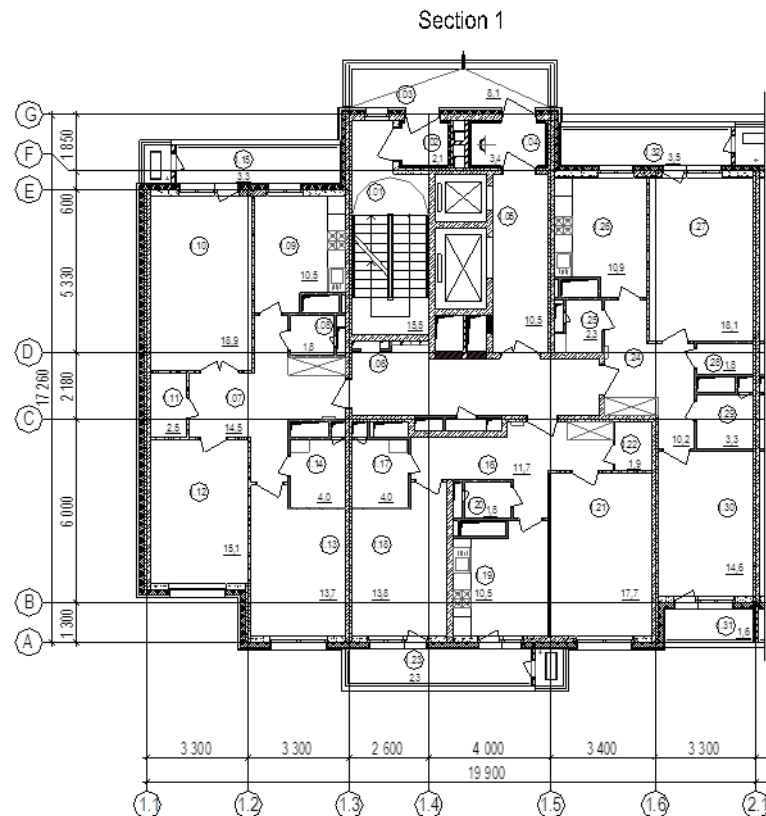


Figure 2. Typical floor plan of a section in a nineteen-storey residential building

In addition, in the unit the resistance characteristics of air penetrating holes according to the equations (7, 8) are calculated and the characteristics of the aerodynamic resistance of ventilation system elements according to the equation (10).

The ventilation system of one apartment is connected in parallel, as well as the outer holes, the resistance characteristics of which can be summed up. For the selected in this article residential building, full external pressure, which is formed in the outer air in the center of the hole of one apartment, is different because of different distances from the center of the hole to the conventional zero, unlike the vent systems where an external pressure is full excess pressure formed in the outer air in the shaft. Therefore it was decided in this example to sum up resistance characteristics only of ventilation systems. The addition of resistance characteristics in the calculation of the air renewal was first proposed by N. N. Razumov [1]. According to the addition of the resistance characteristics of parallel-connected holes it appears [1, 5]:

$$S_{\text{paral}} = \left(\frac{1}{\frac{1}{\sqrt{S_1}} + \frac{1}{\sqrt{S_2}} + \dots + \frac{1}{\sqrt{S_n}}} \right)^2 \quad (11)$$

The pre-calculation unit is over.

2. The iterative part.

Unknown in this calculation is the consumption of air filtered through air penetrating holes and removed by the local vent system and pressure areas of each floor. Each apartment is seen as a single volume without regard to the partitions between the rooms. Due to the fact that the internal aerostatic pressure was delivered to the outside one, the desired value of pressure inside the room will be constant in adjustment to the height of the apartment.

The calculation consists of several iterations. While solving the air renewal of the building the following techniques were introduced:

1. in the preliminary calculation we assume there are no doors leading out of apartments and the lift lobby to the corridor (no air-penetrating holes in the wall). Let us explain the above mentioned assumptions: within the first iteration the pressure inside the apartments, and the pressure in the corridors are unknown. To determine the airflow through the door according to the formula you need to know the pressure outside the air-penetrating hole, which is for the door to the corridor is the pressure in the apartment.

2. in the iterative part the algorithm is repeated, only the balance equation is supplemented by the air flow through the door leading to the corridor. The explanation for the above mentioned assumptions: after determining the first iteration of the pressures in the corridors it is possible to consider the flow of air through the doors facing the corridor, for which calculated in the previous iteration pressure in the corridors is taken as the outer pressure.

Within the preliminary calculation balance equations for each apartment, elevator hall and corridor are worked out, which include the consumption of air filtered through the outer fence by the equation (3) and removed by the exhaust ventilation according to the equation (4).

The calculation of iterations is identical to the preliminary calculation. The difference lies in the fact that the balance equations are complemented by air flow through the door leading to the corridor by equation (2) taking into account the pressure in the corridor calculated in the previous stage.

The iterative calculation is ended when the values of the internal pressure in the elevator lobby, apartments and corridors, and thus the air flow through the ventilation system, and penetrating hole on the last two iterations are the same. The residual air flow is 1 kg/h.

Due to the fact that in this example, the scheme of ventilation system with individual exhaust ducts for each grid is accepted, the local resistance coefficients which do not depend on air flow in the elements of systems they do not require recalculation of characteristics of aerodynamic resistance of ventilation ducts.

The comparison of the obtained calculation of the air flow consumption in the apartments according to the requirements of JV 54.13330.2016 [7] $3\text{ m}^3/\text{h}$ per 1 m^2 of a residential area will show if the data are consistent with regulatory requirements or not, taking into account the norm of providing one person with 20 m^2 .

4. Conclusions

The presented in this article calculations can be applied to calculate air renewal of residential buildings with gravity and mechanical ventilation systems. The calculation program of air renewal of the building will let us determine if the volume of supply air and exhaust air values correspond to the standards.

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