Influence of the Inlet Size on the Natural Ventilation System Operation in a Residential Multi-storey Building

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Abstract. When equipping the buildings with tight windows, the designers are required to take into account the aerodynamic resistance of the supply devices. The apartment plans, which became much more complicated over the past twenty years, resulted in increasing the number of prefabricated ducts of natural exhaust ventilation systems in each apartment of a residential house. Aerodynamic calculations of each exhaust system shall consider the ventilation paths starting from the outside air in the supply unit of a living room and ending above the exhaust shaft of the system. The results were obtained on the basis of the air mode calculations of the building as a whole. In this article, the calculation of the building air mode has been carried out by the iterative method. The object of the study was a section of a residential building with 18 residential floors equipped with natural ventilation systems. The article considers two options of the air inflow: through the swing-out window sash with 0.231 m² open area and through the supply valves in each room of the apartment with 0.0036 m² live section of one valve. It has been shown that in case of insufficient area of supply devices it is impossible to provide the ventilation air design flow rate under design ventilation conditions even with the help of air ducts of unrealistically large sizes.

1. Introduction

Previously, aerodynamic calculations of a natural exhaust ventilation system have been performed assuming that the supply devices do not have aerodynamic resistance, since the area of the cracks in the windows was sufficient to pass large air flows [1]. Nowadays, when the house windows are provided tight, the situation changed. It is necessary to bear in mind both the outdoor air uncontrolled infiltration into the rooms and the aerodynamic resistances of the inflow openings to enable the required outdoor air ventilation rates [2, 3, 4].

It should be taken into account, that the layout of the apartments became much more complicated than twenty years ago. The entrance doors of the apartments, as a rule, go out into common floor halls-corridors, which are separated by the doors from the elevator halls, being united with all the floors of a multi-storey building by the total volume of the elevator shaft. Stairwells are often separated from the elevator halls by passageways across the street.

Ventilation systems in modern multi-storey residential buildings are performed with a vertical prefabricated duct and floor-by-floor branches. Each apartment has several trunks of vertical prefabricated ducts – at least three ones, as the exhaust hoods from the toilets and the bathrooms are made independent. The kitchen has been already separated as an independent system for years. The
common volume of the apartment requires adjustment of all ventilation systems in such a way, that each system removes the design air flow from the apartment at the same indoor air pressure at each exhaust grille.

Unfortunately, there are rather often complaints about an incorrect operation of natural ventilation systems on the upper floors, especially at the beginning and the end of the heating period. Therefore, the task of this article is to check the capabilities of natural ventilation systems to provide fresh air to the living rooms in the design ventilation period.

2. The calculation Method
The temperature of +5 °C and the calm have been considered as ventilation design outdoor conditions. It is believed that at a temperature above +5 °C, the windows may be opened, and the desired air exchange of the apartment will be enabled by increasing the inlet opening area. A designer selects the configuration and the dimensions of the system air ducts for the specified conditions to provide the required exhaust air rate on all floors in each system serving different rooms of the apartment. In this case, the designer has to take into account the inlet opening aerodynamic resistance.

The aerodynamic design of each exhaust system should take into consideration a ventilation path, which starts from the outdoor air in the supply unit of a living room and ending above the exhaust shaft of the system.

The results were obtained on the basis of the air mode calculations of the building as a whole. This approach is used by many authors [5, 6, 7, 8]. In this article, the calculation of the building air mode was carried out by the iterative method. The system of air balances of all premises of the building and units of exhaust ventilation systems was solved by a consistent linkage of balances in separate groups of the rooms, starting with the elevator hall, the riser of the apartments and ending with the corridor.

3. Description of the investigation object

Figure 1. Plan of a typical floor of a section of a 19-storey residential building
A section of a 19-storey residential building has been considered as the object of the research. The city district infrastructure facilities are located on the ground floor of the building. Eighteen floors are residential ones: from the 2nd to the 19th. There is a technical unheated attic above the top residential floor. There are three apartments on each residential floor (figure 1): a two-room apartment with one-way orientation of the windows (apartment 1), a two-room apartment with two-way orientation of the windows (apartment 2) and a three-room apartment with the windows overlooking two opposite facades (apartment 3).

The residential rooms are provided with a natural system of the supply and exhaust ventilation. All exhaust shafts go individually by 1 m above the roof into the atmosphere.

The article considers two options of the air intake: through the swing-out window sash with an open area of 0.231 m$^2$ and through the supply valves in each room of the apartment with 0.0036 m$^2$ live section of one valve. The project design rates of the exhaust air were taken 60 m$^3$/h from the kitchen; 25 m$^3$/h from the lavatories. It has been assumed, that the window sash was open in one room, and the supply valves were open in all rooms.

4. Calculation results

First of all, attention has to be drawn to the required adoption of different sizes of the air duct sections in exhaust ventilation systems of the building with the air inflow both through the swing-out window sashes and the supply valves. The floor branches have been provided 150x150 mm in size for kitchens and 100x150 mm for lavatories in the building with swing-out window sashes on all floors and from the 2nd to the 11th floors in the building with supply valves, 150x150 mm from the 12th to the 19th floors. All grilles on the lower floors are equipped with inserts of different aerodynamic resistances to maintain approximately the same air rate on all floors. The section of prefabricated ducts increases from bottom to top. In the building with the intake through the swing-out window sashes in the kitchen systems the duct sections increase from 200x250 mm to 350x400 mm and for the lavatories from 200x200 mm to 200x350 mm. The building with the apartment supply valves have greater cross sections of the kitchen ducts increasing from 400x500 mm to 800x800 mm and from 200x250 mm to 600x550mm for lavatories. Despite a significant expansion of the precast duct, as the air flow in the system increases, it turned to be impossible to keep the design air exchanges of the apartments within the design ventilation mode on the floors above the 11th floor (figure 2).

![Figure 2. The air rates removed by natural ventilation systems from the apartments 1: 1, 2 – from the lavatories when the window swing-out sash is open, 3 – from the kitchens when the window swing-out](image-url)
sash is open, 4, 5 – from the lavatories when the air supply valves are open, 6 – from the kitchens when the air supply valves are open.

This state of affairs is explained by the fact, that with a big area of the intake opening in the building with the inflow through a swing-out window sash an internal pressure is formed in the apartment rooms, almost equal to the outer one: the aerodynamic resistance of the supply device is small. In the building with the intake through the valves, a part of the available ventilation pressure is lost to overcome the resistance of the valve leading to an increased difference between the outdoor and the indoor air pressure in the rooms (figure 3).

Figure 3. The internal pressure of the apartments: 1, 2, 3 – with an opened window swing-out sash, 4, 5, 6 – with the opened valves

Figure 4. The rates of the air removed by natural ventilation systems in the heating design outdoor conditions: from the apartment 1 with the intake through the valves: 1, 2 – from the lavatories, 3 – from the kitchens; with the intake through a window swing-out sash: 4, 5 – from the lavatories, 6 – from the kitchens
It is interesting to note, that regardless of whether the apartment is one-side or two-side oriented, the air pressure is the same in all apartments under the design ventilation conditions, as the design outdoor conditions assume no wind.

For calculation results of the air mode of a building with open intake valves under the heating design conditions see below (figure 4): at the outdoor air temperature of -25°C and the wind speed of 2 m/s. The air rate exceeds the normative values on the lower floors and is slightly bigger than these ones on the upper floors.

5. Conclusions
1. The aerodynamic calculations of ventilation systems must absolutely consider the aerodynamic resistance of the intake device.
2. The right choice of the natural ventilation system configuration enables the maintenance of the normative air exchange of the apartments according to the design ventilation conditions.

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