Special aspects of calculation of infiltration in residential and public buildings

Kirill Zubarev\textsuperscript{1,2,3*} and Marina Timofeeva\textsuperscript{1}

\textsuperscript{1}National research Moscow State University of Civil Engineering, 26, Yaroslavskoye Shosse, Moscow, 129337, Russia
\textsuperscript{2}Research Institute of Building Physics of Russian Academy of Architecture and Construction Science, 21, Lokomotivny proezd, Moscow, 127238, Russia
\textsuperscript{3}Peoples' Friendship University of Russia (RUDN University), 6, Miklukho-Maklaya Street, Moscow, 117198, Russia

Abstract. In the current paper, the methods of calculating infiltration for different ways of the ventilation system operation have been reviewed. The calculation of infiltration losses of buildings in cases of organizing natural and mechanical supply and exhaust ventilation, as well as recent scientific research in this area, has been considered. The calculation of natural ventilation with the values of air exchange given in Set of Rules 54.13330.2016 "Residential multi-apartment buildings" has been compared with the calculation of mechanical ventilation taking into account different glazing of the building facade. The influence of gravitational and wind components of pressure on various facades of the building has been analyzed. The gravitational and wind effects on the building are illustrated as a pressure diagram. The calculation of the specific heat flux for heating the infiltrated outdoor air on each floor is presented. The scientific studies of infiltration losses with a mechanical balanced supply and exhaust ventilation system proposed by A.S. Kubenin in his scientific work have been considered. The method of calculating the amount of infiltrated air for residential and public buildings has been thoroughly researched. Studies of heat consumption for one or more windward facades are presented. Criteria conditions of different schemes of filtration air exchange at different wind directions are formulated. Keywords: building heat losses, infiltration heat losses, infiltration, ventilation, natural ventilation, mechanical supply and exhaust ventilation system.

1 Introduction

1.1 Human comfort in the room

Nowadays, comfort plays an important role in human life. But what does «comfort» mean? The state of environment in which a person feels comfortable and where he can have easy and rational access to its resources to meet their needs for normal functioning of the human body as well as satisfaction of aesthetic pleasure can be called comfort. Comfortable
conditions for human life can be created by maintaining the constancy of air parameters inside the room where the person stays [1–3].

In the premises of residential and public buildings, optimal or permissible microclimate parameters in the service area should be provided. Optimal parameters are a combination of values of microclimate indicators which together with long and consistent impact on a person provide normal thermal state of the body with minimal stress of thermoregulation mechanisms and a feeling of comfort for at least 80% of people in the room. In turn, the permissible microclimate parameters have a wider range of minimum and maximum boundary values. A wide range of values is determined by the fact that it combines the values of microclimate indicators which together with long and consistent impact on a person can cause an overall and local feeling of discomfort as well as well-being impairment and work decrement with growing tension of thermoregulation mechanisms, although they do not cause health damage or deterioration [4–12].

The main features of indoor air characterizing the microclimate in residential and public buildings are [13–17]:
- air temperature;
- speed of air movement;
- relative humidity;
- resulting room temperature;
- local asymmetry of the resulting temperature.

For a comfortable stay of a person in a room, the main features listed above must be maintained at certain values. To maintain comfortable air exchange, heating and ventilation systems are used [1–12]. Infiltration studies are closely related to the geometric shape of the building and other building sciences [18–26].

2 Materials and Methods

2.1 Calculation of infiltration with a natural ventilation system in the building

In the premises of residential buildings, optimal features are mainly maintained due to the natural ventilation system. Natural ventilation is a ventilation system that does not contain electrical equipment (fans, motors, drives, etc.). The air movement in it occurs due to the difference in temperature, the pressure of the outside and inside air and wind pressure. Supply air enters the building through windows [13].

The amount of supply air corresponds to the value of the air exchange of the premises and is determined by paragraph 9 of Set of Rules 54.13330.2016 "Residential multi-apartment buildings". The values of air exchange in the premises of residential buildings are presented in accordance with Set of Rules 54.13330.2016 "Residential multi-apartment buildings" [13] (table 1).

With natural ventilation, the heating of the outside air falls on the devices of the heating system. The amount of heat required to heat the infiltration air for residential buildings can be calculated using the following formula [13]:

\[ Q(t_{\text{ext}} - t_{\text{int}})_{\text{inf}} \]

where \( Q_{\text{inf}} \) – infiltration heat losses, W; \( L \) – the amount of exhaust air, \( m^3/h \); \( t_{\text{ext}} \) – outdoor temperature, \( ^\circ C \); \( t_{\text{int}} \) – indoor temperature, \( ^\circ C \).
Table 1. The values of air exchange in the premises of residential buildings according to Set of Rules 54.13330.2016 "Residential multi-apartment buildings".

<table>
<thead>
<tr>
<th>Room</th>
<th>The value of air exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedroom, common room (or living room) and children room with a total area of the apartment less than 20 m² per person</td>
<td>3 m³/h per 1 m² of living area</td>
</tr>
<tr>
<td>The same conditions as the above mentioned, but the total area of the apartment is more than 20 m² per person</td>
<td>30 m³/h per person, but not less than 0.35 h⁻¹</td>
</tr>
<tr>
<td>Pantry, linen storage, check-room</td>
<td>0.2 h⁻¹</td>
</tr>
<tr>
<td>Kitchen with electric stove</td>
<td>60 m³/h</td>
</tr>
<tr>
<td>Room with gas-using equipment</td>
<td>100 m³/h</td>
</tr>
<tr>
<td>Room with heat generators heating capacity up to 50 kW with height less than 6 m:</td>
<td></td>
</tr>
<tr>
<td>- with open combustion chamber &lt;..&gt;</td>
<td>1.0 &lt;..&gt;</td>
</tr>
<tr>
<td>- with closed combustion chamber &lt;..&gt;</td>
<td>1.0 &lt;..&gt;</td>
</tr>
<tr>
<td>Bathroom, shower room, toilet, combined bathroom</td>
<td>25 m³/h</td>
</tr>
<tr>
<td>Elevator engine room</td>
<td>As per calculation</td>
</tr>
<tr>
<td>Garbage chamber</td>
<td>1.0 &lt;..&gt;</td>
</tr>
</tbody>
</table>

<..> Air exchange by multiplicity should be taken equal to the total volume of the room (apartment).

<..> When installing a gas stove, the air exchange must be increased by 100 m³/h.

2.1 Calculation of infiltration in the case of a mechanical supply and exhaust ventilation system in the building

For the premises of public buildings, a mechanical ventilation system is mainly used. Mechanical, or forced, ventilation is a set of equipment that provides the flow of air masses into the premises using ventilation ducts. The movement of air in the ducts is conducted by fans. Supply air penetrates through a network of air ducts and a ventilation chamber [14].

The flow rate of infiltration air depends on the aerodynamics of the building and on the excess pressure affecting the walls of the building [14].

Natural forces impact the building, which causes two pressure components (gravitational and wind components) the diagram of which is shown below (Fig.1) [14].

![Fig. 1. Plot of the air pressure difference in a building with balanced ventilation.](image-url)
The wind component that depends on the chosen windward side as well as on the area of the windows of the building is calculated using the Titov formula [14]:

\[
P_{0V} = P_{VH}A_{0.H} + P_{VB}A_{0.B1} + P_{VB}A_{0.B2}.
\]

where \( P_{0V} \) – wind component of pressure, Pa; \( P_{VH} \) – excessive wind pressure on the windward facade, Pa; \( A_{0.H} \) – glazing area of the windward side of the facade, \( m^2 \); \( P_{VB} \) – excessive wind pressure on the side facade, Pa; \( A_{0.B} \) – glazing area on the side of the facade, \( m^2 \); \( A_{0.3} \) – glazing area of the windward side of the facade.

The flow rate of air passing through 1 \( m^2 \) window on each floor for the windward and lateral sides can be determined by the formula [14]:

\[
g_{INF,iF,B} = \frac{1}{R_{INF.WIN}} \left( \frac{\Delta P_{IFB}}{10} \right)^{2/3}.
\]

where \( R_{INF.WIN} \) – window air resistance, \( m^2 \cdot h/\text{kg} \).

Based on the obtained values, the specific heat flux for infiltrated outdoor air heating on each floor (both on the windward and lateral sides), as well as heat consumption for infiltration in the rooms, is calculated.

If the room faces one facade, therefore [14]:

\[
Q_{inf.i} = \sum A_{win_{inf}}
\]

where \( q_{INF,iF} \) is taken for the corresponding floor from the variant when the facade which the room faces is the windward one; \( \sum A_{win} \) – the total area of the windows in the room, \( m^2 \).

If the room faces two or more facades, we compare the options for total heat consumption for infiltration at different wind directions:

\[
Q_{inf.1} = q_{INF,IF}^1 \cdot A_1 + q_{INF,IB}^1 \cdot A_2,
\]

\[
Q_{inf.2} = q_{INF,IF}^2 \cdot A_2 + q_{INF,IB}^2 \cdot A_1.
\]

where \( q_{INF,IF}^1 \) and \( q_{INF,IB}^2 \) – specific heat flux for heating the infiltrated outside air on the each floor for the lateral sides, \( W/m^2 \); \( q_{INF,IF}^1 \) and \( q_{INF,IB}^2 \) – specific heat flux for heating the infiltrated outside air on the each floor for the windward sides, \( W/m^2 \); \( A_1 \) and \( A_2 \) – the area of windows in the room facing the 1st and 2nd facades, respectively, \( m^2 \) [14];

Herein, \( A_1 \) and \( A_2 \) – the area of windows in the room facing the 1st and 2nd facades, respectively, \( m^2 \); indexes 1 and 2 at the values \( q_{INF} \) mean the numbers of options.

After calculating one side, the same calculations are made taking, sequentially, neighboring sides as windward ones [14].

### 3 Results and Discussion

A.S. Kubenin has analyzed the zones of infiltration and exfiltration and using the level \( \xi \) that is the dimensionless height of the critical section dividing the building into zones of infiltration predominance and the zone of exfiltration predominance formulated a set of dimensionless determining parameters that affect the filtration air exchange in the building [15].
A.S. Kubenin has developed and formulated a methodology of calculating the amount of infiltrated air for residential and public buildings. In the absence of wind, the location of the level line is determined analytically [15]:

\[
\xi_0 = \frac{h_0}{H} = \frac{1}{1 + \delta_3},
\]

\[
p_\circ = \left(\frac{\rho_{\text{ext}} - \rho_{\text{int}}}{\sigma_{\frac{3}{2}}}\right)^{\frac{3}{4}}\frac{3}{1 + \delta_3}.
\]

After finding \(h_0\) the values \(h_{\text{mor}}\) and \(h_{\text{dow}}\) are determined [15].

Further, the criteria conditions for each filtration air exchange scheme with different wind conditions are formulated [15]:

\[
\begin{align}
Eu &< \frac{2}{\sigma \left(1 + \delta_3\right)} \\
Eu &< \frac{1 + \sigma}{1 + \delta_3} \quad (9)
\end{align}
\]

\[
\frac{1 + \sigma}{1 + \delta_3} < Eu < \frac{3}{\sigma \left(1 + \delta_3\right)} \quad (10)
\]

\[
\frac{3}{\sigma \left(1 + \delta_3\right)} < Eu < \frac{1 + \sigma}{1 + \delta_3} \quad (11)
\]

\[
\begin{align}
Eu &> \frac{2}{\sigma \left(1 + \delta_3\right)} \\
Eu &> \frac{1 + \sigma}{1 + \delta_3} \quad (12)
\end{align}
\]

where: \(Eu\) – the Euler number that within the framework of dissertation research characterizes the measure of the predominance of wind pressure over gravitational pressure (hydrostatic); \(\delta\) – a simplex linking the air densities outside and inside the building; \(\sigma\) – a simplex characterizing the ratio of the areas of permeable translucent structures of the leeward and windward parts of the building [15].

4 Conclusion

Calculation of infiltration when organizing a natural system of ventilation in a building and a mechanical supply and exhaust ventilation system is performed according to fundamentally different algorithms. With natural ventilation, infiltration predominates due to the compensation of air exchange. When organizing supply and exhaust ventilation, it is necessary to take into account wind and gravitational loads on the building. Recent scientific studies show the need to clarify the density difference between the air entering the building and leaving it, which determines the line of delimitation of infiltration and exfiltration zones.
References

15. A.S. Kubenin, Development of methods of mathematical modeling of the air regime of residential and public buildings to improve the accuracy of calculating the characteristics of air exchange, Ph.D. theses (Moscow, 2021)
23. I. Vorobyeva, E3S Web of Conferences 203, 01028 (2020) https://doi.org/10.1051/e3sconf/202020301028
24. I.V. Vorobyeva, E3S Web of Conferences 224, 03020 (2020). https://doi.org/10.1051/e3sconf/202022403020
25. I.V. Vorobyeva, E3S Web of Conferences 224, 03021 (2020) https://doi.org/10.1051/e3sconf/202022403021
26. I.V. Vorobyeva, E3S Web of Conferences 224, 03022 (2020) https://doi.org/10.1051/e3sconf/202022403022