Development of a Program for Calculating the Air Regime of a Building

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Abstract. The article describes the main differences between a specialized program for calculating the air regime of a building and universal software systems. Algorithms for creating a mathematical model, calculation algorithms and applications are given. A brief description of the principles of the program, the requirements for computer technology and software are given.

1. Introduction

Specialists in the field of construction and ventilation of buildings have been interested in the distribution of air flows inside the building for a long time. Many scientists in the world have dealt with these issues. In Russia, the works of V. P. Titov, V. E. Konstantinova, E. H. Kitaytseva, E. G. Malyavina are known [3, 4, 5, 6], etc. Currently, it is increasingly necessary to perform calculations of the air regime not of an "empty" building, but of a building equipped with various ventilation systems that significantly affect the picture of the distribution of air flows. When studying the air regime of a building, the question of the most accurate calculation of expenses through ventilation grilles, supply valves in high-rise buildings with dense windows and doors, taking into account the action of smoke removal systems before and during a fire, is acute. It is almost impossible to perform such calculations manually with a large number of influencing factors. For such calculations, a specialized program is needed that will allow you to calculate the air regime in any building and under different meteorological conditions. A specialized calculation program should have the ability to conveniently enter initial information, quickly calculate with various variants of boundary conditions. Then a specialized program will have an advantage over a universal program.

The program should allow you to calculate the air mode of a building with natural and mechanical ventilation. The calculation method should take into account the influence of wind and gravitational pressures, the resistance to air permeability of the external elements of the building (windows, entrance doors, supply valves), internal connections between rooms, the operation of mechanical and natural ventilation systems. To calculate the air flow in a building during a fire, it is necessary to take into account the air temperature in different parts of the building.

2. Calculation module

The calculation module of the program should contain algorithms for calculating the air regime, taking into account the internal air temperatures of each room. There are many tasks when you need to perform calculations for specified temperatures. For example, the calculation of the air mode in case of a fire in a building or the calculation with an open window. Such calculations are currently very...
relevant, especially in high-rise construction. The ability to perform such calculations is achieved by setting the user temperature in each specific module (room) or automatically for the whole building. To perform the calculations, it is necessary to make changes to the formula for determining the external and internal pressures. The external pressure on the windward, windward and side facades is determined for each element bordering the external air by the expression:

\[ P_{\text{ext}} = (H - h_i) p_{\text{ext}} g + p_{\text{ext}} v^2 \cdot (C_w, C_{nw}, C_l - C_{nw}) \cdot k_{\text{din}} / 2 \]  

where \( H \) is the height of the building, m, from the level of the average planning mark of the ground to the top of the ventilation shaft;
\( h_i \) - the estimated height, m, from ground level to the center of the window in question, the balcony door, the entrance door to the building, etc.;
\( p_{\text{ext}} \) - density, kg/m\(^3\) of outdoor air;
\( g \) - acceleration of gravity, 9.8 m/s\(^2\);
\( C_w, C_{nw}, C_l - C_{nw} \) - aerodynamic coefficients depending on the configuration of the building and the position of the enclosing structure, -0.6...0.8 according to regulatory documents or tests. \( w \) - windy side, \( nw \) - no windy side, \( l \) - lateral side;
\( K_{\text{din}} \) - is the coefficient of accounting for changes in wind velocity pressure depending on the height of the building, adopted according to regulatory documents or tests, 0.5...1.

The gravitational pressure at an arbitrary height in a building is defined as the sum of the gravitational pressure in the center of the air-permeable element of the room at this level and the sum of the gravitational pressures in the higher rooms (if there is a direct vertical connection):

\[ P_g^i = \sum_{i=1}^{n} P_g^i + \rho_{\text{int}} \cdot g \cdot h_i \]  

where \( \Sigma P_g \) is the sum of the pressures of the higher gravitational rooms calculated at the previous step, Pa;
\( \rho_{\text{int}} \) - density, kg/m\(^3\), of internal air;
\( h_i \) - is the position of the center of the breathable element relative to the floor of the higher floor, m.

When calculating the internal pressure, some difficulties may arise, since the vertical connections between the floors are limited in the building. If we consider a residential building, the connection between the floors is provided through a stairwell (if it is inside the building), an elevator shaft, natural ventilation systems, a plumbing cabinet and leaks in the ceilings. Accordingly, if vertical connections are excluded, the influence of the internal air temperature on the flow distribution pattern in the building will be excluded. In residential buildings, to speed up the calculation, you can take an apartment for a single volume. The apartments will be connected vertically through ventilation systems and a hall that opens into a staircase and elevator node. In the common hall, in a high-rise building, a smoke extraction valve is usually installed. Most valves do not have a high tightness, which also needs to be taken into account in the calculation.

For the correct calculation of air distribution in the ventilation system, it is necessary to take into account the change in air temperature when mixing flows. This is especially important if the temperatures differ by an order of magnitude, as in a fire. It is required to make an automatic adjustment of the temperature of the transported air in the natural ventilation system. The adjustment of the mixture temperature should be performed at each calculation cycle, based on the heat balance equation:

\[ C_1 \cdot G_1 \cdot t_1 + C_2 \cdot G_2 \cdot t_2 - C_3 \cdot (G_1 + G_2) \cdot t_x = 0 \]  

where \( C_1, C_2, C_3 \) are the specific heat capacities of the air before (1, 2) and after the mixture (3), kJ/(kg · K);
\( G_1 \) and \( G_2 \) – flow rates of the mixed air, kg/s;
\( t_1 \) and \( t_2 \) are the temperatures of the mixed air, K;
\( t_x \) - the temperature of the mixture, K.
A distinctive feature of the ventilation system path is the variability of the resistance characteristics of the shaped parts, depending on the desired air flow rates for individual parts of the system. The difficulty lies in the fact that the known formulas for determining the coefficients of local resistances of tees (crosses) give too large a spread of values with a slight change in the determining factors. This was described in detail in [2].

To enter the initial information on the calculation of natural ventilation systems, a special graphical interface is additionally required.

Immediately before the calculation, the initial approximations of the internal pressures of the premises are set, the air flow rates in the sections of the ventilation network are taken. A mathematical model of the air regime of a building is formed, in which each room, floor, tee or crosspiece in the ventilation system is a calculated node of the model.

Next, the preliminary characteristics of the resistances of the ventilation network sections are determined. After setting the preliminary data in the main calculation block, the system of equations is calculated sequentially from floor to floor and from room to room, during which the condition is checked for the accuracy of linking the model nodes. At the same time, the air temperatures in the network sections are adjusted. When the specified accuracy is reached, the calculation stops. If there is an exhaust grate of the ventilation system in the room, during the calculation, there is an appeal to the program block responsible for the calculation of ventilation systems. It recalculates the characteristics of the network sections taking into account the changed indoor pressures and local resistance coefficients. The corrected values of the resistance characteristics of the corresponding network sections are substituted into the main system of equations of the mathematical model.

The calculation cycle in the program consists of:
- according to pre-set and calculated parameters, almost complete linking of costs for the building as a whole is made;
- correction of indoor air temperatures is performed, if necessary;
- continuation of the calculation with the changed parameters;
- saving intermediate results to control changes in the state and the possibility of continuing the calculation.

3. Input of the initial data and the type of presentation of the calculation results

For most users, when calculating typical multi-storey buildings, a program is needed that will work in the environment of popular Windows operating systems. That does not require the purchase or lease of a special supercomputer. This can be achieved through the use of flexible logic, efficient calculation algorithms, a modular structure for setting source data and an improved graphical interface. The performance of a modern desktop computer is sufficient to calculate a typical model of a 20-storey building in a short period of time.

Flexible logic implies the ability of the program to adjust the calculation process without the user's participation, depending on the situation, the user sets only the required accuracy. This is solved by using a dynamically changing relaxation coefficient depending on the number of iteration cycles and changes in the accuracy of linking systems of equations.

With the help of a modular structure, you can specify rooms that have a complex configuration. Any complex room can be represented as a series of interconnected rectangular modules, in which there must be at least one breathable element or passage. All modules are the same, they differ only in the presence or absence of certain breathable elements (windows, doors). Almost every room can be represented from several modules to get a more accurate geometric view of the room. Then, before starting the calculation, the modules are combined into rooms to reduce the number of calculation equations and speed up the calculation.

The program should allow you to work with databases to use the coefficient of accounting for changes in wind velocity pressure depending on the height of the building and elevation marks, air permeability resistances of windows, doors and supply valves of various designs, which facilitates the input and allows you to speed up the processing of initial data. The resulting result should be clear and
understandable. The presentation in the form of graphs and tables is recommended. It is necessary to display air flows, heat loads for the premises of the building both in the plans for each, and in the context of the entire building as a whole, in the form of diagrams of the distribution of costs (pressures, pressure differences) for natural ventilation systems by the height of buildings

4. References

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