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Designing Buildings Suitable for Life

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DESCRIPTION: This report examines a method of creating an algorithm for automated construction of mathematical models of branched networks of air ducts of systems of ventilation of air.

KEY WORDS: design of building

ABSTRACT: This report examines a method of creating an algorithm for automated construction of mathematical models of branched networks of air ducts of systems of ventilation of air.

I. INTRODUCTION

According to information received by the Committee for the protection of the United States environmental protection Agency (EPA), the levels of major pollutants in air in residential, administrative and commercial buildings is usually 2 - 5 times higher than in outdoor air. In some cases, this excess can be up to 70 times [1]. Since a person spends 70 to 98% of their lives indoors, we can say that the risk to human health from exposure to chemicals inside the building is many times increased.

Portable air flow substances that adversely affect the quality of indoor air can be divided into two main categories: gases and mist. The main problems for human health associated with such gases as radon, CO, NO2 and hydrocarbons. Suspended solids enter the room with tobacco smoke, spores of moulds, dander, spores of plants.

The building is considered "sick" if about 20 % of the population suffer permanent symptoms that disappear when people are out on the street. New buildings are generally more "sick" than old ones because of reduced air exchange, is created to retain heat and also by releasing various chemicals furniture and carpets. Modern economical construction, for example in Russia, in accordance with national building standards leads to the fact that most of newly constructed buildings can be considered "sick".

The most common method of reducing the contamination of indoor air is the use of ventilation and air-conditioning. However, the design of these systems faces a number of complex scientific and engineering problems.

One of the major problems encountered in the design of ventilation systems and air conditioning systems is the problem of delivery of necessary quantity of air in the desired area. It is especially complicated if we are talking about the use of centralized systems with highly branched network of air ducts.

The unsatisfactory results of the calculation of such networks arising from the use of traditional methods of calculation, due to a number of assumptions, which we discuss here will not. Their essence is clearly visible in the pre-commissioning activities related to adjustment of a network for output at design airflows. And, alas, how often this goal is not achievable. For example, by using additional resistances finally made the necessary ratios of air flow in branches of a network of ducts, but suddenly noticed that due to their setup and hence additional load on the fan, reducing the total amount of air in the network. What to do next ? Order, buy and install a new more powerful fan and then repeat all from the beginning ?

In our opinion, the solution to this situation lies in the field of preliminary mathematical modelling of a complex network of ducts, closed at the specific aerodynamic characteristics of fans.

2. Formalized topological methods creating mathematical models of systems of air ventilation

The development of formalized methods of generating the equations of mathematical models of branched networks of ducts allows not only to significantly simplify their conclusion, but also to fully automate this process, which is a necessary condition for creation of modern systems of the automated designing of systems of air ventilation. The solution to this issue is equally important in creating complexes professional programs has its own built-in image editor and take advantage of the additional capabilities of the external image editors, such as AutoCAD, which can be used to solve applied problems have a computational nature. The question of which of these ways is better, not

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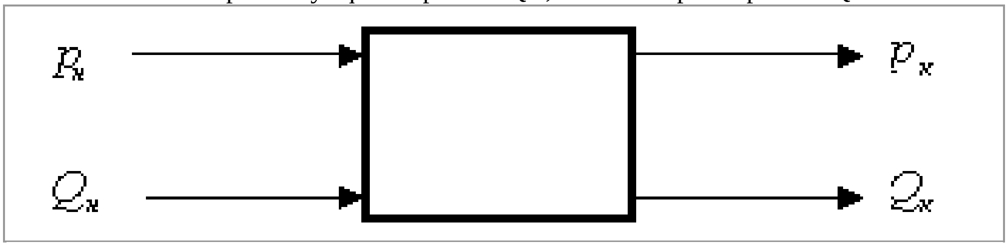
considered here, since all depends on the ratio between the graphical and computational difficulties encountered when solving a specific problem.

This report describes a topological method of formation of mathematical models of branched networks of air ducts of ventilation systems with tree structure.

Ductwork can be represented as a set of interconnected, individual elements, e.g. straight sections of ducts, fans, filters, etc. This abstract basic element of the network would be wise to provide in the form of a quadripole on which input pressure and air flow are respectively equal to pH and QH, and the output of pK and QK.



Picture 1.
Abstract element of the pneumatic line as a four-terminal

The characteristics (transfer functions) of elementary network elements can be set in various ways. So, for example, to describe the flow of air along straight sections of ducts, various types of equations are usually used that describe this flow under certain conditions with varying degrees of accuracy. The characteristics of elements such as fans, filters, air heaters are usually set using the so-called aerodynamic characteristics, which are a set of raw experimental data that reflect the dependence of pressure loss on air flow during its passage through the element. In some cases, the characteristic of the element can be set in a semi-empirical way, that is, when using the values of the local resistance coefficients in combination with the equation of air movement.

In this work, when describing the steady flow of incompressible air in absolutely rigid ducts, a model with lumped parameters is adopted. In this case, the equations of motion and air continuity for the j-th network element (duct section) will have the form

$$p_{jн} = p_{jк} + \left(\lambda_j \frac{l_j}{d_{экв_j}} + \zeta_j\right) \cdot \frac{\rho|Q_j|}{2F_j^2} \cdot Q_j \qquad (1)$$

$$Q_{jн} = Q_{jк} = Q_j = F_j \upsilon_j \qquad (2)$$

where P_JH and P_JK are the air pressure in the initial and final section of the jth section of the duct, Pa;
p_{iH} and p_{iK} are the air flow rate at the inlet and outlet of the j-th duct section, m3 / s, respectively;
υ_j is the air velocity in the jth section of the duct;
F_j - flow area of the j-th duct section, m2;
l_j - is the length of the j-th section of the duct, m;
$d_{эквj}$ - equivalent diameter of the j-th section of the duct, m;
ζ_j - is the coefficient of local resistance of the jth section of the duct;
p - air density, kg / m3;
$\lambda_j$is the drag coefficient along the length of the jth section of the duct.
The aerodynamic characteristic of a network element can be determined as follows

$$p_{jн} = p_{jк} + f(Q_j) \qquad (3)$$

$$Q_{jн} = Q_{jк} = Q_j \qquad (4)$$

Before proceeding to the description of the algorithm of forming mathematical models of ventilation will make the following definitions.

As part of the network of ducts shall mean the section of the network with the same air flow. In the General case, the network might consist of sections. In that case, if such land is, in turn, consists of several sections with different speed of air movement, it can be easily reduced to a single equivalent.

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The term air line we mean a chain of such sites is directed from the air inlet or air distribution units to the fan, which is the root of the whole scheme. The number of such overhead lines on the discharge side of the fan is denoted as kH, and on the suction side of kV. Then the total number of overhead lines in the diagram will be

$$k=kH+kV \quad (5)$$

External schema node will be called node located at its peripheral part. In our case it implies a different air intake and air distribution devices. The number of external nodes in a circuit is equal to the number of overhead lines.

Internal schematic node will be called node, which connects with the one preceding part of the circuit (the parent phase) and, at least, at least the two following sites (child sites). Thus as the direction of movement from one schema element to another, taken direction from the root schema element, which is the fan as the pressure side and suction side. The total number of internal nodes in a circuit having a tree structure, is determined by the ratio

$$m=n-k \quad (6)$$

Consider the algorithm of the mathematical model of the ventilation system on the example of the design scheme shown in Fig. 2.

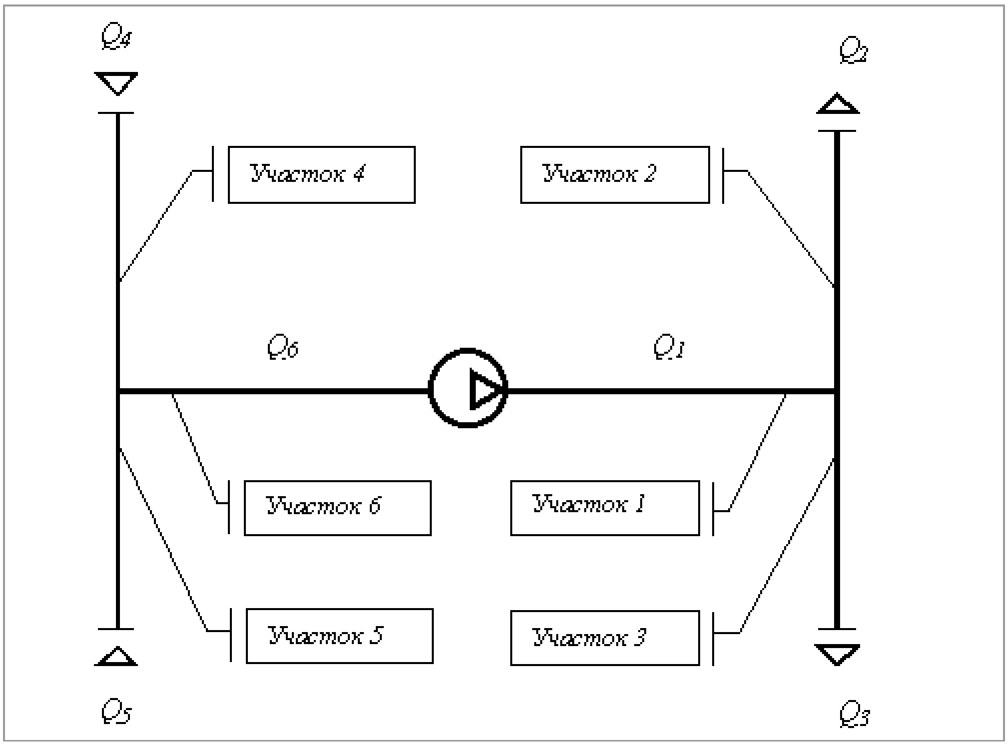

Figure 2

An example of the design scheme of an air ventilation system.

This scheme consists of six sections, that is, n = 6. And it has two overhead lines on the discharge and suction side, that is, kH = 2 and kB = 2. In this case, the total number of overhead lines k = kH + kB = 2 + 2 = 4.

On the discharge side there are lines 1 and 2. Line 1 consists of sections 2 and 1, and line 2 consists of sections 3 and 1. On the suction side there are lines 3 and 4. Line 3 consists of sections 4 and 6, and line 4 - from sections 5 and 6. The number of external nodes of the circuit is 4, and the number of internal nodes is 2.

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The system of equations describing the movement of air on the suction side consists of two equations of motion and one equation of air flow and can be written as follows:

$$\left.\begin{aligned} p_{4н} &= p_{6н} + \left(\lambda_4 \frac{l_4}{d_4} + \zeta_4\right)\frac{\rho|Q_4|\cdot Q_4}{2F_4^2} + \left(\lambda_6 \frac{l_6}{d_6} + \zeta_6\right)\frac{\rho|Q_6|\cdot Q_6}{2F_6^2}, \\ p_{5н} &= p_{6н} + \left(\lambda_5 \frac{l_5}{d_5} + \zeta_5\right)\frac{\rho|Q_5|\cdot Q_5}{2F_5^2} + \left(\lambda_6 \frac{l_6}{d_6} + \zeta_6\right)\frac{\rho|Q_6|\cdot Q_6}{2F_6^2}, \\ Q_4 + Q_5 &= Q_6. \end{aligned}\right\} \quad (7)$$

The equations of system (7) can be interconnected through another element of the circuit - a fan, the aerodynamic characteristic of which can be represented as follows:

$$\left.\begin{aligned} p_н &= p_в + f(Q_1), \\ Q_н &= Q_в = Q_1 = Q_6, \end{aligned}\right\} \quad (8)$$

where *ph* and *pB* are the air pressure on the discharge and suction side of the fan, Pa, respectively; *qh* and *qk* - respectively, the air flow on the discharge and suction side of the fan, m3 / s.Обозначимвеличиныдавленийвоздухавконцезамыкающихэлементовсетикак

$$p_{2к} = p_2, p_{3к} = p_3, p_{4к} = p_4, p_{5к} = p_5, \quad (9)$$

and note that, if air is taken from the volumes and enters the volumes with atmospheric pressure, then the quantities

p2 = p3 = p4 = p5 = pa = 0.

Thus, the mathematical model describing the movement of air in the studied system can be written in the form of the following system of nonlinear algebraic equations

$$\left.\begin{aligned} &\left(\lambda_1 \frac{l_1}{d_1} + \zeta_1\right)\frac{\rho|Q_1|\cdot Q_1}{2F_1^2} + \left(\lambda_2 \frac{l_2}{d_2} + \zeta_2\right)\frac{\rho|Q_2|\cdot Q_2}{2F_2^2} - p_н + p_2 = 0, \\ &\left(\lambda_1 \frac{l_1}{d_1} + \zeta_1\right)\frac{\rho|Q_1|\cdot Q_1}{2F_1^2} + \left(\lambda_3 \frac{l_3}{d_3} + \zeta_3\right)\frac{\rho|Q_3|\cdot Q_3}{2F_3^2} - p_н + p_3 = 0, \\ &\left(\lambda_4 \frac{l_4}{d_4} + \zeta_4\right)\frac{\rho|Q_4|\cdot Q_4}{2F_4^2} + \left(\lambda_6 \frac{l_6}{d_6} + \zeta_6\right)\frac{\rho|Q_6|\cdot Q_6}{2F_6^2} + p_в - p_4 = 0, \\ &\left(\lambda_5 \frac{l_5}{d_5} + \zeta_5\right)\frac{\rho|Q_5|\cdot Q_5}{2F_5^2} + \left(\lambda_6 \frac{l_6}{d_6} + \zeta_6\right)\frac{\rho|Q_6|\cdot Q_6}{2F_6^2} + p_в - p_5 = 0, \\ &p_н - p_в - f(Q_1) = 0, \\ &Q_1 - Q_2 - Q_3 = 0, \quad Q_6 - Q_4 - Q_5 = 0, \quad Q_1 - Q_6 = 0. \end{aligned}\right\} \quad (10)$$

This system consists of eight equations and contains eight unknowns Q1, Q2, Q3, Q4, Q5, Q6, pH, pB and, therefore, can be solved with respect to these unknowns.

$$\left(\lambda_j \frac{l_j}{d_j} + \zeta_j\right)\frac{\rho}{2F_j^2} = \alpha_j \quad (11)$$

Now let's try to write the system of nonlinear equations (10) in matrix form. The number of rows of this matrix will be equal to the number of equations of system (10) and determined from the side of the fan discharge. The next kB lines are from the suction side. Then the line, with the number kH + kB + 1, which contains the aerodynamic characteristic of the fan. On this, that part of the system of equations that contains the equations of motion of air ends.

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And the next m + 1 lines reflect the equations of air flow. As the columns of this matrix, we mean the numbers of sections of the circuit, with 1 «i« n + 2. The last two columns are used to connect the discharge and suction parts of the circuit.

$$\left[\begin{array}{cccccc|cc} \alpha_1|Q_1| & \alpha_2|Q_2| & 0 & 0 & 0 & 0 & -1 & 0 \\ \alpha_1|Q_1| & 0 & \alpha_3|Q_3| & 0 & 0 & 0 & -1 & 0 \\ \hline 0 & 0 & 0 & \alpha_4|Q_4| & 0 & \alpha_6|Q_6| & 0 & 1 \\ 0 & 0 & 0 & 0 & \alpha_5|Q_5| & \alpha_6|Q_6| & 0 & 1 \\ \hline -\frac{f(Q_1)}{Q_1} & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ \hline 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & -1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{array}\right] * \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \\ Q_5 \\ Q_6 \\ p_н \\ p_в \end{bmatrix} = \begin{bmatrix} -p_2 \\ -p_3 \\ p_4 \\ p_5 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (12)$$

We denote the vectors of the unknown and right-hand sides of the dimension in expression (12)

$$\boldsymbol{x} = [x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8]^T = [Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, p_н, p_в]^T,$$

as

$$\boldsymbol{B} = [-p_2, -p_3, p_4, p_5, 0, 0, 0, 0]^T. \quad (13)$$

Then the matrix of compounds A

$$\boldsymbol{A}(\boldsymbol{x}) = \left[\begin{array}{cccccc|cc} \alpha_1|x_1| & \alpha_2|x_2| & 0 & 0 & 0 & 0 & -1 & 0 \\ \alpha_1|x_1| & 0 & \alpha_3|x_3| & 0 & 0 & 0 & -1 & 0 \\ \hline 0 & 0 & 0 & \alpha_4|x_4| & 0 & \alpha_6|x_6| & 0 & 1 \\ 0 & 0 & 0 & 0 & \alpha_5|x_5| & \alpha_6|x_6| & 0 & 1 \\ \hline \frac{f(x_1)}{x_1} & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ \hline 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & -1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & -1 & 0 & 0 \end{array}\right] \quad (14)$$

(x)

Given the notation (13) and (14), the system of equations (12) can be written in a more compact vector form:

$$\boldsymbol{A}(\boldsymbol{x}) \cdot \boldsymbol{x} = \boldsymbol{B} \quad (15)$$

It should be borne in mind that, despite the matrix form of writing, the system of equations (15) is essentially nonlinear. This is due at least to the fact that the loss of air pressure along the length and in the local resistances of the ducts can have a quadratic character. Moreover, the aerodynamic characteristics of many elements, such as fans, filters, etc., are not set by the analytical method at all. Therefore, in fact, one has to solve a system of nonlinear equations. For this, the system of equations (15) is transformed to the form:

$$\boldsymbol{F}(\boldsymbol{x}) = \boldsymbol{A}(\boldsymbol{x}) \cdot \boldsymbol{x} - \boldsymbol{B} = 0 \quad (16)$$

The algorithm considered above can be fully automated if, when forming the circuit, the structure of the data representation in the form of a tree is used as its elements. Figure 3 shows a part of the tree diagram, which shows the $_i$-th plot in combination with other neighboring plots. Each $_i$-th duct section has a pointer to the parent (previous) section P_j and may have pointers to the next section N_j and two daughter sections $C_j^{(1),}$ $C_j^{(2).}$

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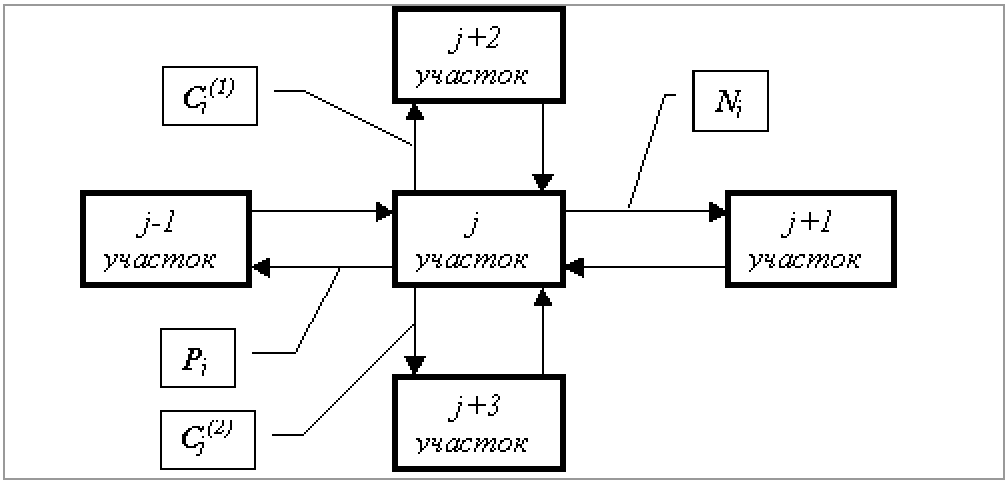

Figure 3
Structural representation of data in the form of a tree.

For automated processing of data contained in such structures, it is most convenient to use recursive procedures and functions, since there are no uniquely defined simple methods that allow you to bypass the elements of this tree in the shortest and most rational way.

FINDINGS

This algorithm for the formation of a mathematical model of an extensive network of ducts was used to create software that allows aerodynamic calculations of ventilation and air conditioning systems. A comparison of the performed calculations with the experimental data obtained during the commissioning of specific objects showed that this algorithm qualitatively correctly describes all the possible processes that may occur during the transportation of air to the consumer. And in quantitative measurement, its use leads to a slight excess of air pressure losses in the range of (10-15)% in relation to experimental data. It should be especially noted that when using this algorithm, it is possible to take into account such phenomena as excess or decrease in air pressure (relative to atmospheric) in air-conditioned rooms, the ability to control air distribution elements.

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