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A NUMERICAL METHOD FOR AIR-CHANGE RATE OF BUILDINGS CALCULATED

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This paper describes a short analysis of some results of calculations air flows and the ventilative heat losses in buildings.

1. INTRODUCTION

The research work has been made in residential blocks with the natural /gravitational/ ventilation, prove that there are accidental conditions /Nantka M. 1978/. It refers both to values characteristic for ventilation's action and parameters of the indoor climate. The analysis of large number of measurements allows to name the most important factors distrib ventilation processes, namely:

- External conditions as temperature, wind and layout
- Internal conditions that vary according to the conditions of utilization
- Structural properties of blocks and types of ventilation system applied.

The full investigations could not have been made in residential blocks. Therefore, for further tests one of the methods of computation has been chosen. This method based on the air flow and pressure drop balance in all flats and the stairwell of the building.

2. THE METHOD OF THE ANALYSIS

Each building has a large number of rooms. These rooms are connected through permability for air elements /windows, doors and ventilation ducts/.

All flats contact with the stairwell and external surroundings due to those elements. Taking into account that the air flow from the outside of the block and from the stairwell is correct /look Fig.1/, air flows and pressure drop balance can be expressed as follows:

- For all flats:

$$(1)\quad \sum_{ij=1}^{k,m} [Z_{12ij}(p_{z ij}-X_{ij})^{1/c}+Z_{3ij}(Y-X_{ij})^{1/c}-Z_{4ij}(X_{ij}+p_w+\Delta p-\Delta p_s)^{1/c}]=0$$

- For the stairwell

$$(2)\quad Z_D(p_{z1}-Y)^{1/c}+\sum_{ij=1}^{k,m}[Z_{okij}(p_{zij}-Y)^{1/c}-Z_{3ij}(Y-X_{ij})^{1/c}]=0$$

The dependeces /1/, /2/ are the equation system composed for /km + 1/ nonlinear equations and /km + 1/ of unknown quality /x - pressures in the flat, Y - pressure at the top of stairwell/. In this study a digital computer technique has been used /Nantka M. 1979/. To use the programme the air flows in the building under consideration were defined by a series of interconected nodes. The balance's solution /Newton - Raphson's method/ demands defining of accurate data of external, internal and constructional factors.

3. SHORT ANALYSIS OF SOME RESULTS

Change of air flows in buildings with natural ventilation are schematically shown in Fig.2. Ventilation ducts in the flats located in the upper part of blocke generates larger vacuum than in the flats located at the bottom of blocks. Those factors cause air flowing through the stairwell from the bottom to the top of it /look Fig.2 A/.

If the air temperature increases in ventilation ducts to +40^{o}C, the paths of air flowing in the stairwell change /Fig.2 B/. Simultanecusly, in ventilation ducts for the flats on the top of block, the direction of air flowing changes.

This reverse air flowing zone depends upon the directions and wind velocities. This zone may include five to six upper most floor levels of the eleven - storeys blocks.

In buildings located in towns the greatest changes take place in blocks shielded with the other /Fig.2c/. In flats located on top of the building in question exterior air does not flow in. For example in the eleven-storeys blocks air infiltration through windows contains from two to three top floor levels /t_z=-20^{o}C, w=5 m/s/ and from six to seven top floor levels /t_z=+20^{o}C, w=10m/s/.

The results of calculations provide a material for estimation of the period of correct work of natural ventilation. Figure 2 D presentes it for eleven - storeys blocks. A common frequency /tz,w/ for grounds situated betwen 50^o-52^o latitude /Esdorn H. 1975/ and calculated data /lines/ of air exhaust that equal to normative qualities /$\dot{V}_n$/ are shown. In the eleven - storeys residential blocks the quality of exhausted air is less than required values in 90 percent resisive changes of external conditions.

The changes of air flowing in blocks for the mechanical ventilation are in accordance with required ones /Kantka M. 1981/.

The influence of ventilation on energy losses in blocks is presented in Fig. 3. Total heat losses may be expressed by amount of the conductive /Q_p/ and the air infiltration heat flow /Q_v/. On the top right side of Fig. 3 the range of air-change rate for the first and eleventh floor level of blocks have been compared. On the left side of the graph demanded energy heats are compared for the mentioned levels. This calculation includes 95 percent of the recisive changes of external conditions. The infiltrational heat demanded is expressed as percentage to the total heat losses

$$\frac{\dot{Q}_V}{\dot{Q}_P+\dot{Q}_V}=\frac{n}{n+\bar{k}(\varrho c)A_z/K} \qquad (3)$$

The external walls in examined blocks /look Fig.1/ may be described by the average thermal transmittances /$\bar{k}$/ of gross enclosure area, which is equal 1,25 W/m^2K. The air-change rate in flats /results of calculations/ equals from 0,1 to about 4 per hour. The ventilative heat losses in buildings with the natural ventilation equal about 45-55 percent of total heat losses. If one applies the mechanical centilation /MWWM/ and assumes a minimum of air-change rate /0,5 per hour/, these heat losses may be lowered to 20-25 percent.
The greater saving of total energy consumption /about 40 percent/ can be obtained, if heat resistance for external walls is increased and the systems that supply necessary amount of fresh air by ventilation ducts are applicated.

4. SUMMARY AND CONCLUSION

The best method of analysis of the air-change rate in residential buildings is to apply a digital computer programme, based on the air flow and pressure drop balance /look Fig.4/. The estimation of processes is quick and comparatively easy to achieve data for practical application.

The natural ventilation depends on such meteorological factors like the velocity and direction of wind and outer temperature. Those are the forces acting and simultaneously the factors that deforme air-change rate. The air flows in blocks with the mechanical system is slightly influenced by the weather. Interior climate and possibilities of regulation of the air flows approximate. Therefore, the mechanical ventilation is necessary in big blocks of flats.

There is also possibility to reduce ventilation heat losses for these systems and, in further, saving the consumption energy.

NOMENCLATURE

A_Z - the total area of building's m^2
c - exponent of pressure term in air infiltration equation,
$\bar{k}$ - the average thermal transmittance of gross enclosure area, W/m^2K
K - the air volume of the building, m^3
n - the air-change rate, h^{-1}
p_w - pressure on the roof of buildings, Pa
Δp - fan pressure /in the mechanical system/, Pa
p_s - resistance of air flow in ventilation ducts, Pa
Z - leakage coefficient, m^3/h /Pa/ $^{1/c}$
ϱc - the specific heat capacity of air, J/m^3K
$\dot{Q}_p$ - the conductive heat flow, W
$\dot{Q}_v$ - the ventilative heat flow, W
m,k- quantity the exterior walls /for windows/ and quantity the floor levels of buildings

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Esdorn H. /1975/. Lüftungswärmebedorf von Gebäden unter Wind - und Auftriebseinflüssen. Forschungs bericht F 1357

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Table.1 The comparison of average measured values and standard deviations in one examined building

Season	Floor levels	Exhaust air (kitchens) Arithmetic mean [m³/h]	Exhaust air (kitchens) Standard deviation [m³/h]	Exhaust air (bathrooms) Arithmetic mean [m³/h]	Exhaust air (bathrooms) Standard deviation [m³/h]	Pressure differences between outdoor and indoor environment Arithmetic mean [Pa]	Pressure differences between outdoor and indoor environment Standard deviation [Pa]	Pressure differences between stairwell and flats Arithmetic mean [Pa]	Pressure differences between stairwell and flats Standard deviation [Pa]	Indoor temperature (living rooms) Arithmetic mean [°C]	Indoor temperature (living rooms) Standard deviation [°C]
Winter $t_z = -4°C$ $w = 1.5$ m/s	1	74.0	10.5	55.2	9.8	+9.92	3.17	-5.64	2.21	18.1	1.4
	7	42.3	7.1	30.6	6.0	+1.85	0.92	+0.93	0.61	20.8	0.6
	11	67.1	8.8	50.8	10.2	-3.90	1.77	+4.22	1.34	24.6	1.3
Spring $t_z = +4°C$ $w = 4-6$ m/s	1	31.0	11.2	31.1	13.4	+0.33	0.20	+2.21	0.99	17.8	1.2
	7	22.2	9.3	15.0	8.5	+0.88	0.62	+0.35	0.21	19.1	1.0
	11	35.0	13.8	31.0	19.8	+2.54	1.98	+3.28	1.22	19.0	2.8

Season	Floor levels	Air humidity Arithmetic mean [%]	Air humidity Standard deviation [%]	Air velocity in the vicinity of windows Arithmetic mean [m/s]	Air velocity in the vicinity of windows Standard deviation [m/s]	Air velocity (in centre of rooms) Arithmetic mean [m/s]	Air velocity (in centre of rooms) Standard deviation [m/s]	The carbon oxide concentration [mg/dm³]	Characteristic data of equation infiltration $V = Z_{12}(\Delta p)^{1/c}$ Coefficient of proportion $m^3/mh(Pa)^{1/c}$	Characteristic data of equation infiltration Exponent
Winter	1	55	5.0	0.38	0.15	0.15	0.10	0.036	22.8	1.5[illegible]
	7	35	5.2	0.15	0.05	0.05	0.05	0.092	4.3	1.26
	11	30	4.8	0.15	0.10	0.10	0.10	0.040	12.4	1.18
Spring	1	40	6.0	0.35	0.15	0.05	0.05	0.042	19.8	1.53
	7	45	6.4	0.25	0.10	0.05	0.05	0.048	5.1	1.14
	11	50	7.2	0.54	0.25	0.15	0.15	0.029	28.5	1.13

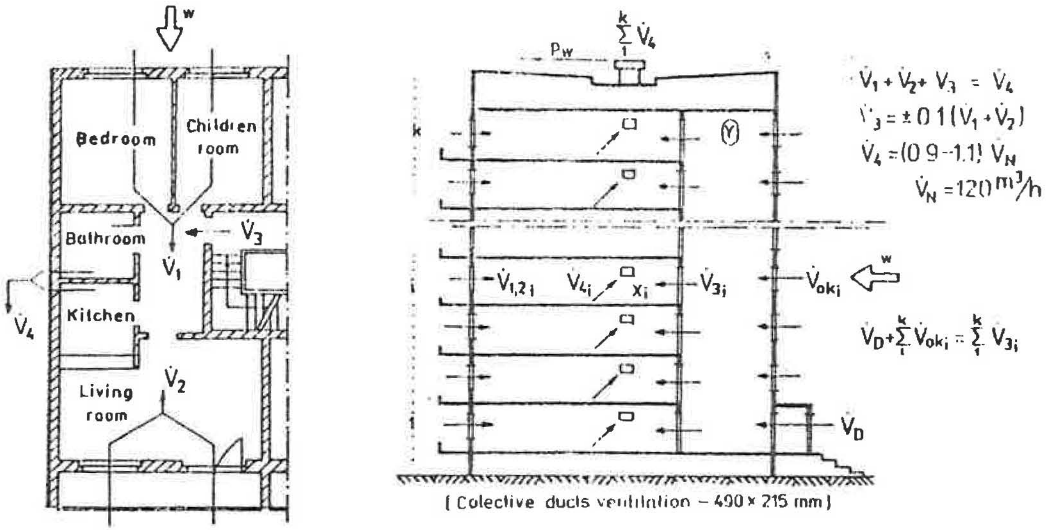

Fig.1. Internal layout of building and the correct of air flow (the nonlinear equations 1).

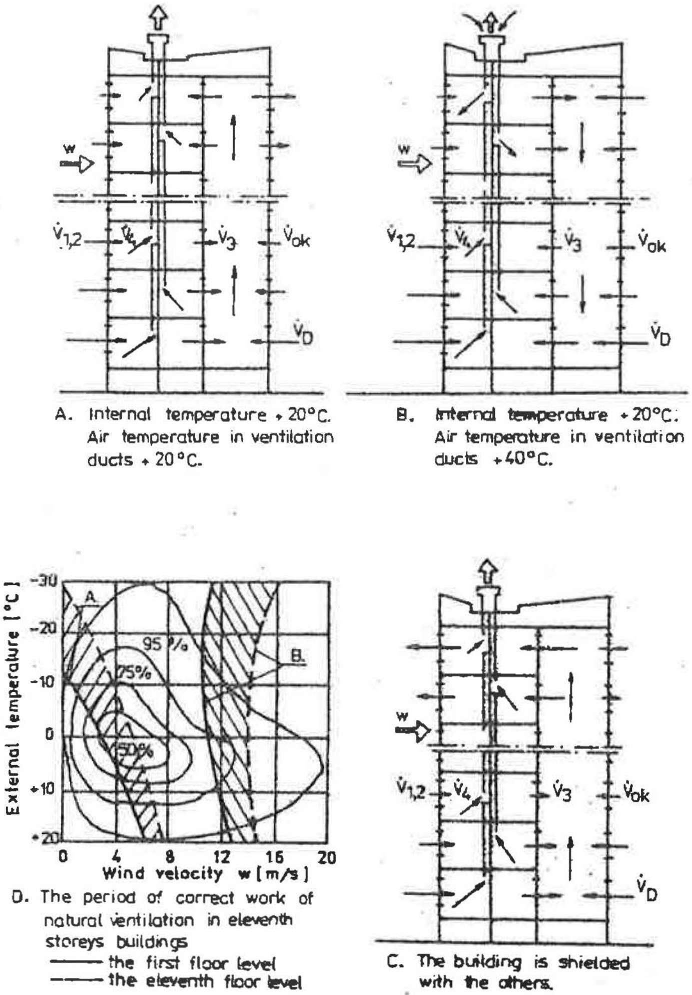

Fig.2. Air flows in buildings with the natural ventilation (schematically A, B, C) and ventilation efficiency (D-calculated lines of air exhaust are equal to normative qualities $\dot{V}_N$)

Table 2 The characteristic data for examined buildings.

Number of floor levels	Number of flats in one segment of buildings	Total area of flats [m^2]	Height of flats [m]	Total area of enclosure [m^2]	The ratio of gross area enclosure to the building volume [m^{-1}]	Percentage of window area [%]	Average heat thermal transmittance [W/m^2K]
11	44	7712	2.6	3072	0.40	20.2	1.25

Table 3. Recomendated dimensions of ventilation ducts and motive parameters

Number of floor levels		<5	5-7	8-10	11-13	14-15	>16
Dimensions of ventilation ducts [mm]	branch off collective	—	100	100	100	100	100
	collective	100	150	200	250	315	350
Vacuum of exhausted fan [Pa]		66	137	147	167	178	186
Air resistances in exhausting register [Pa]		50	118	137	137	147	157

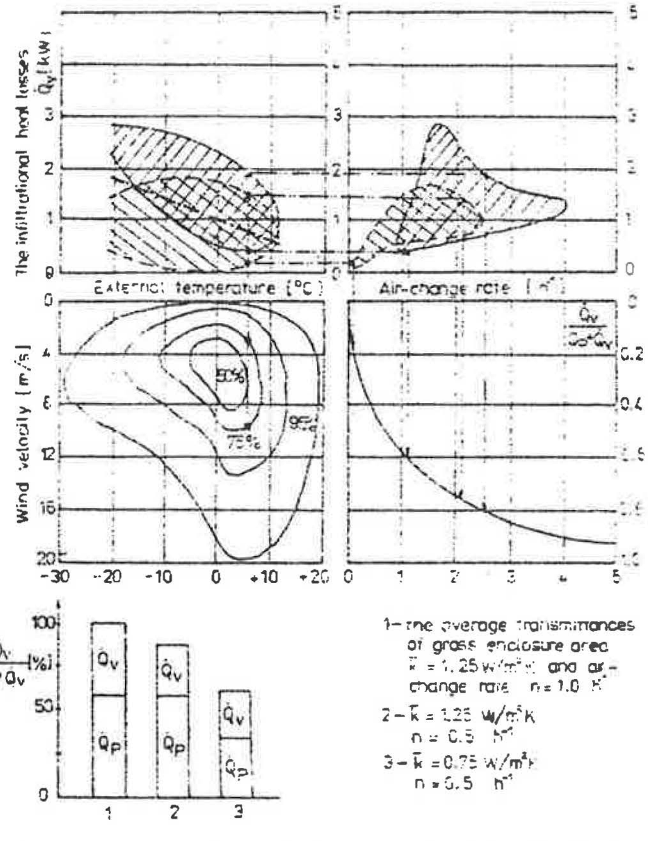

Fig.3. Comparision of demanded energy heat for the first (——) and the eleventh floor level (– – –) of examined buildings.

— · — · — the normative qualities (MWWM)

The total heat losses

$$Q = \bar{k}A\Delta t + nqck\Delta t = Q_p + Q_v$$

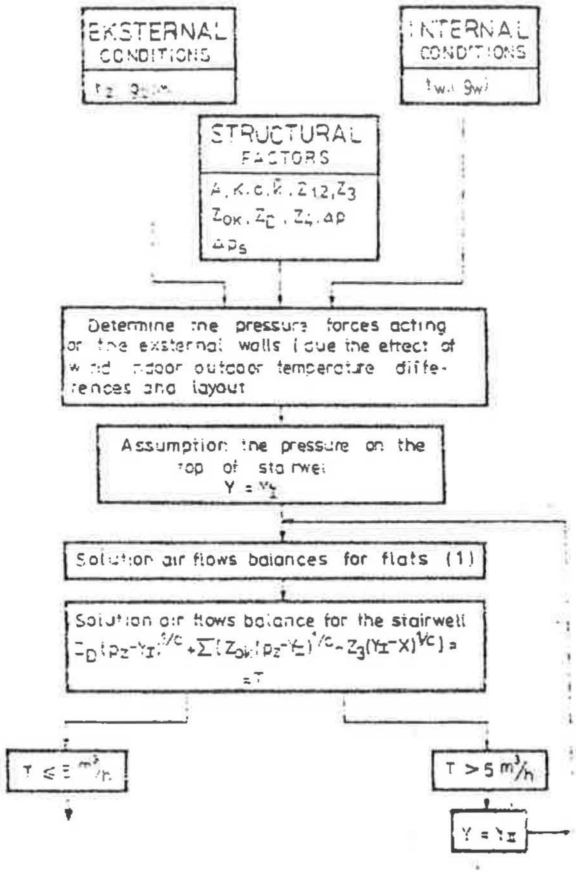

Fig.4. Concept of determining the air change rates in buildings