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Calculation Of Infiltration And Transmission Heat Loss In Residential Buildings By Digital Computer

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Introduction

When entering upon the design of the heating system of a building the first thing required is to estimate the heat loss, i.e. the maximum heating demand. This must necessarily be done both for each room separately and for the entire building. The value of the heat demand chosen should of course be of sufficient magnitude, but on the other hand over-estimation should be avoided, if aspiring to an optimum economic result, as over-estimation would lead to unnecessary investments and reduced efficiency.

The heat demand is made up of the transmission heat loss, due to heat escaping through the walls, etc., and the infiltration heat loss, corresponding to the heat required for warming the air leaking in through cracks around windows and doors, etc., and supplied through the ventilation equipment. The infiltration heat loss may amount to no less than 50% of the total heat demand in the case of residential buildings, equipped with a mechanical exhaust system.

A sufficiently exact estimate of the infiltration heat loss constitutes the main difficulty when calculating the total heat demand. It presupposes a knowledge of the leakage characteristics of the cracks and the pressure differences in them, arising from the effect of the wind, the temperature difference of outdoor and indoor air (stack effect) and the pressure difference caused by the ventilation equipment, i.e. of the pressure conditions of the building. The leakage characteristics of the cracks may be estimated with sufficient accuracy on the basis of measuring results. An analysis of the pressure conditions, on the other hand, requires complicated and time-consuming calculations.

Such calculations are not generally possible in connection with practical designing work. It is necessary to resort to simplified calculating methods involving large safety margins, which usually result in over-estimating the heating plant capacity. In Finland for instance this over-estimation amounts to about 20% according to an investigation carried out.[1]

In order to improve the accuracy of the heat demand calculations without prolonging the calculation time a digital computer programme has been developed which is described below in detail. This programme has been written in Fortran for the I.B.M.-1620 digital computer.[2] As the computing times are rather long using this type of computer, the programme will be amended in the near future to suit digital equipment of greater speed.

The programme differs from ordinary calculating methods in that it makes possible, in addition to accurate calculation of the infiltration heat loss, a calculation utilizing the heat capacity of the building structures. This reduces the heat demand and improves the economy of the heating plant if, during periods of severe cold likely to be encountered very seldom, a small reduction of the indoor temperature is accepted. In order to increase the comfort of indoor spaces, compensation for radiation to cold surfaces has been added to the programme.

The programme has proved an effective aid in ventilation calculations and investigation work also. By means of it the effect of the air-tightness of windows, wind force, outdoor temperature, building height, etc., on pressure conditions, air leakage, action of the ventilating equipment and heat demand may be studied. It is possible, for example, by means of meteorological data to settle at what combination of outdoor temperature and wind velocity the maximum heat demand would be obtained, or to what extent the heat demand may be reduced by increasing the heat capacity of the structures.

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Calculation of the heat demand

The heat demand is divided into transmission heat loss $\dot{Q}_t$ and infiltration heat loss $\dot{Q}_i$, which may be calculated using the conventional formulae for stationary heat transmission, viz.:

$$\dot{Q}_t = \sum_v k_v A_v (\theta_{id} - \theta_{od}) \qquad \ldots (1)$$

$$\dot{Q}_i = \sum_v c_p \dot{m}_v (\theta_{id} - \theta_v) \qquad \ldots (2)$$

where k is the coefficient of heat transmission of the partition, A the corresponding area, θ_{id} indoor design temperature, θ_{od} outdoor design temperature, c_p specific heat of the air at constant pressure, $\dot{m}$ the mass flow of the air penetrating through cracks or ventilation apertures and θ the corresponding temperature. The summary includes all the partition walls, etc., and air flow into the space in question. The heat capacity of the structures and the radiation to cold walls, etc., are observed by means of corrections applied to the outdoor and indoor temperatures. Any percentage additions, as generally employed in ordinary by manual calculation methods, are not made.

The heat demand is calculated for each room and the entire building at different wind directions. With regard to the output for the rooms the programme chooses the maximum value for each room. Attention should be paid to the fact that the heat demand of the building by no means corresponds to the sum of the maximum demands of the rooms, as is often assumed in ordinary by manual calculations, being generally much smaller.

The mass flow of the air entering through cracks around windows and doors and through ventilation apertures has been calculated by means of the formula:

$$\dot{m} = \pm C|p - p_x|^n \qquad \ldots (3)$$

where C is a constant dependent on the size of the crack (or aperture), p the pressure outside the crack and p_x the inside pressure behind the crack, n being an exponent dependent on the type of crack, the numerical value of which is 2/3 as used in the programme. The $\pm$ sign will be selected according to the sign of $p - p_x$. The greatest difficulty encountered in calculating the heat demand is caused by the estimation of the pressures required for the use of formula (3), i.e. the pressure conditions of the building.

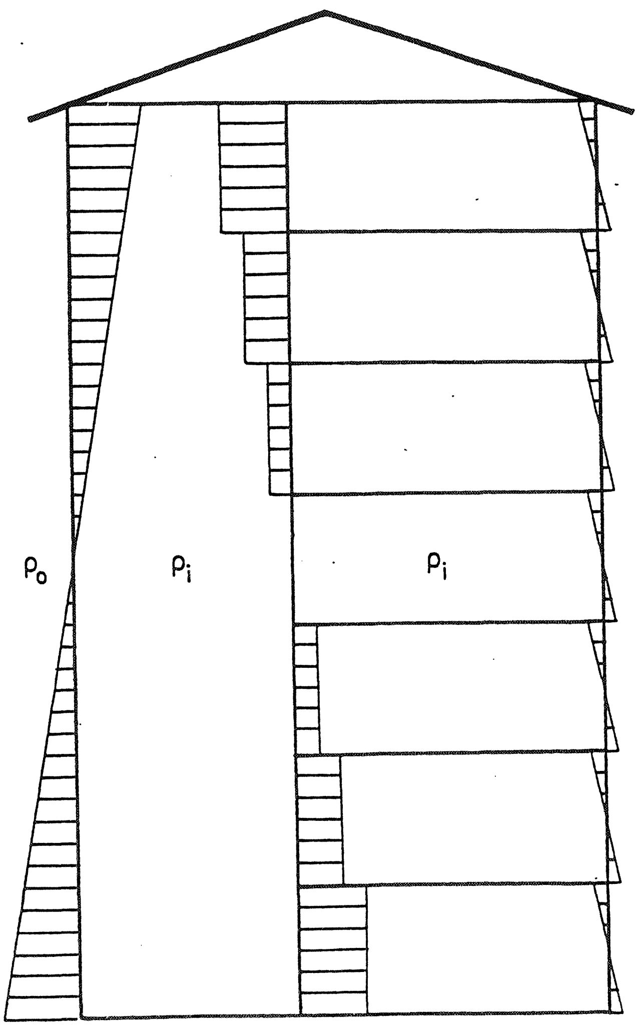

Fig. 1—Schematic presentation of pressure differences caused by stack effect.

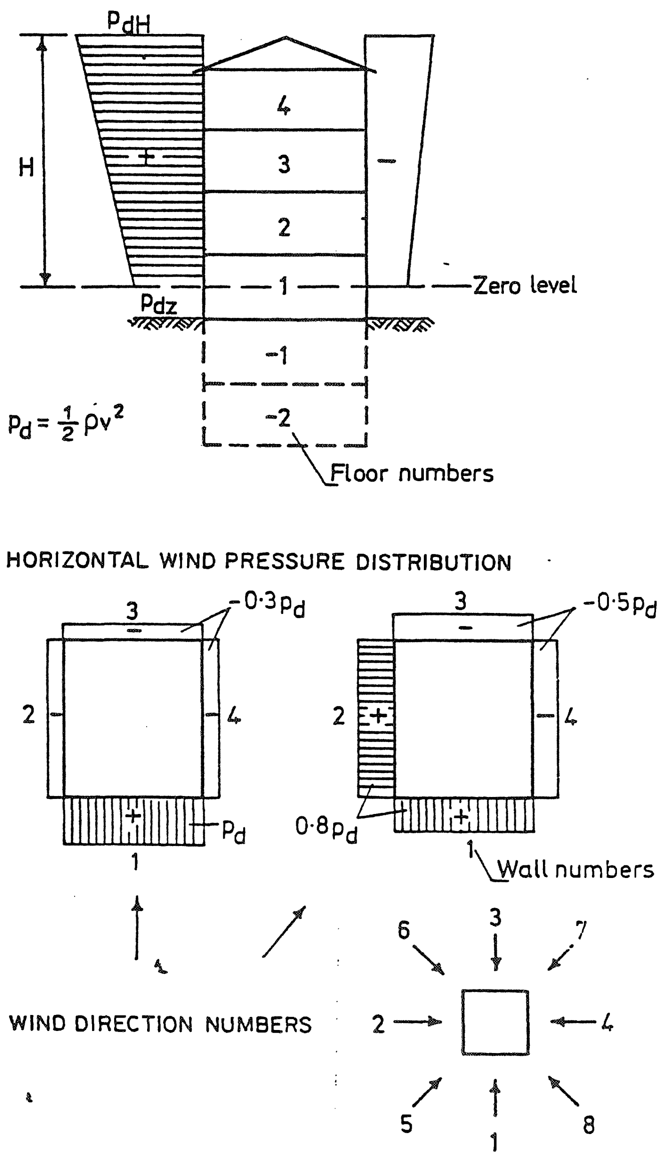

Fig. 2—Wind pressure distribution and numbering of walls, floors and winds.

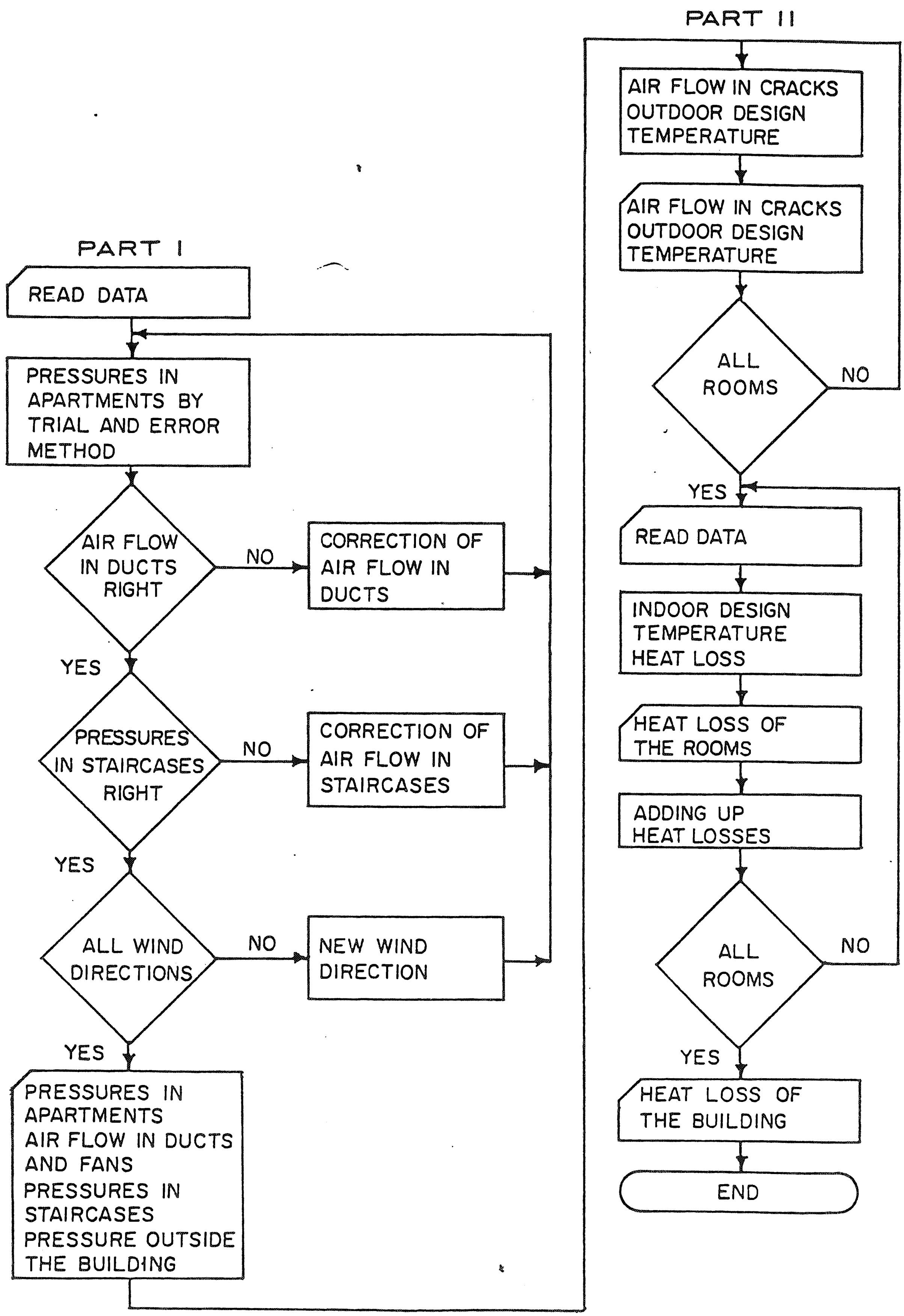

Fig. 5—Flow chart of the programme.

Calculation of pressure conditions

The calculation of pressure conditions is based on the fact that the quantity of air entering each apartment, staircase and other limited space of a building through window and door cracks and ventilation apertures is equal to the quantity of air escaping in the same way. As the air flow conforms to formula (3), the following equation of balance may be written for each space:

$$\sum_{v} \pm C_v |p_v - p_z|^{n_v} = 0 \quad \ldots (4)$$

The summary should of course include all the cracks and apertures.

The air balance equations, the number of which is the same as the number of spaces, form a set of equations, permitting the estimation in principle of the pressures of the different spaces, if the pressures outside the building and in the air ducts behind the ventilation apertures are known. The form of the equations is such that a solution is nearly impossible in practice without the aid of a computer. Using the digital computer programme, the solution is effected by trial and error method, viz. correction of assumed pressures until a satisfactory balance is arrived at. When using the comparatively slow I.B.M.-1620 computer the accuracy prescribed has been a deviation between the entering and escaping air flow of maximum $\pm 10\%$ for apartments and maximum $\pm 20\%$ for staircases.

When estimating the pressure conditions, the starting point used in the programme is the static pressure p_z prevailing out of doors at zero level, generally at mean height of the first storey above ground level. The static pressure p_{st} at level h above zero level would then be:

$$p_{st} = p_z - h\rho g \quad \ldots (5)$$

where ρ is the average density of the air along the distance h, and g the acceleration due to gravity. The density has been assumed to be a function of the temperature only, calculated by means of the equation of state of gases using the normal atmospheric pressure of 101325 N/m^2.

According to the aforesaid the pressure of an apartment if considered constant may be written:

$$p_a = p_z - h\rho_o g + \Delta p_a \quad \ldots (6)$$

where h is the height of the apartment above zero level, Δp_a the pressure either over or below the static outdoor pressure (at the same level) of the apartment and ρ_o the outdoor air density. The value of the height h used in this and the following equations corresponds to the distance between the mean height of the apartment and zero level. The output gives the value of Δp_a for each apartment.

The pressure of a high, tower-shaped space, as for example a staircase, decreases when moving upwards in accordance with formula (5). If the indoor temperature is higher than outdoors, as is generally always the case in winter time, the air density in the staircase is lower than out of doors. The ensuing pressure difference (stack effect) affects the pressure conditions of the building as shown schematically in Fig. 1.

The staircase pressure p_s has been calculated in the programme by means of the following formula:

$$p_s = p_z - h\rho_i g + \Delta p_s \quad \ldots (7)$$

where h is the height above zero level of the point in question, ρ_i the air density of the staircase and Δp_s the pressure difference at zero level between the staircase pressure and the static atmospheric pressure. The output gives the value of Δp_s for each staircase.

The pressure at the outside surface of the building is made up of the static atmospheric pressure and the wind pressure. An accurate estimate of the wind pressure presupposes model tests, which as a rule are not feasible in practical design work.

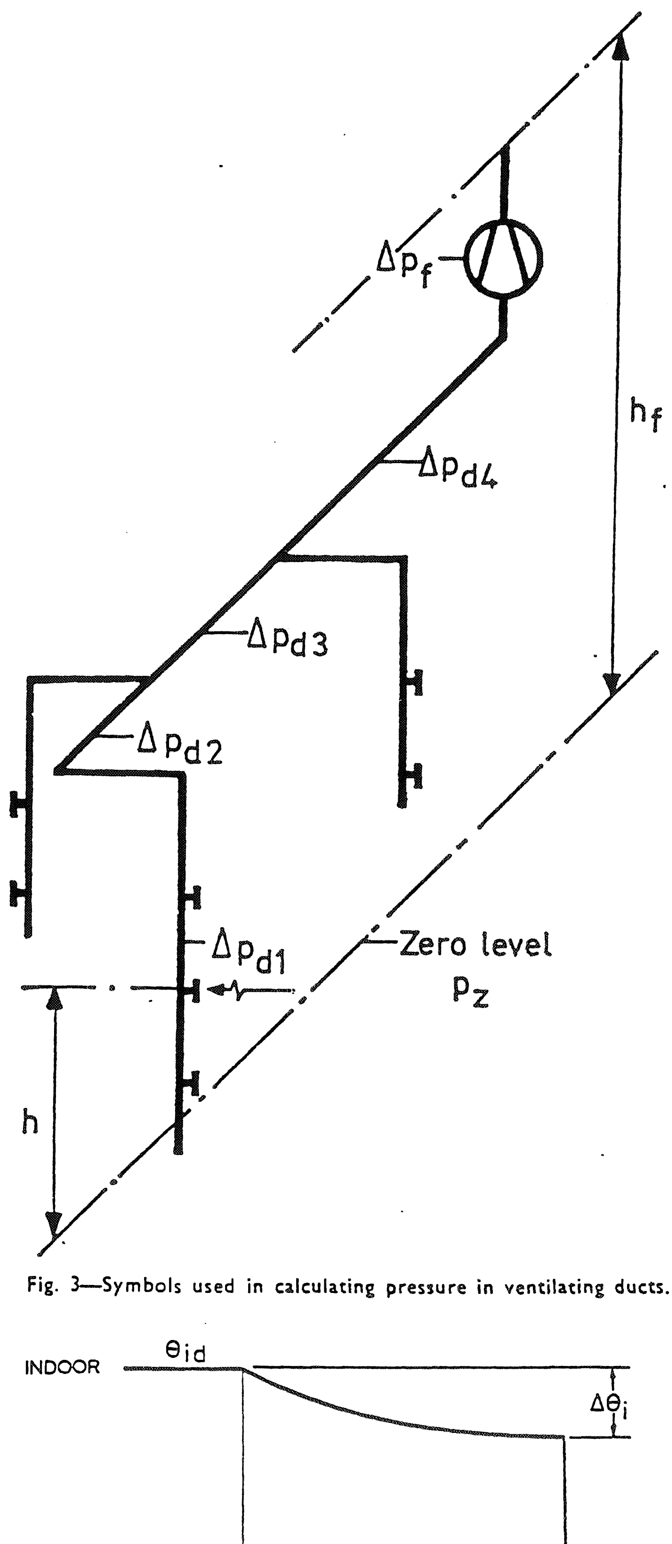

Fig. 3—Symbols used in calculating pressure in ventilating ducts.

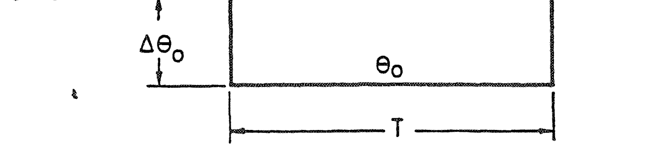

Fig. 4—Simplified cold period and its effect on indoor temperature.

E	X	A	M	P	L	E		H	O	U	S	E							

Number of fans		Number of ducts		Number of wall types		Building height [m]			Floor height [m]			Outdoor temperature 2-day mean [°C]			Outdoor temperature 5-day mean [°C]				Wind directions							
																			1	2	3	4	5	6	7	8
	2	1	5	1	5	2	4			2	8	—	2	7	—	2	4	1	1	1	1	1				

Dynamic pressures of wind

Wall 1						Wall 2						Wall 4						Wall 4						*a* DTI [°C]	
Down			Up			Down			Up			Down			Up			Down			Up				
	2	0		4	0		1	0		2	0		1	0		2	0		2	0		4	0	3	

Wall types

	No.		*K* [W/m^2 deg C] *b*						*C* [kJ/m^2 deg C] *c*						*RI* [m^2 deg C/W] *d*				*DT* [°C] *e*			*T* [°C] *f*			
Col.	1	2	3					8	9					14	15			18	19		21	22			25
	0	1		0	7	4	5			2	0	1			0	1	2	9							
	0	2		0	4	9	2				8	5			0	1	2	9							
	0	3								2	0	3			0	1	2	9							
	0	4								1	8	2			0	1	2	9							
	0	5		1	2	3	5								0	1	2	9					—	5	
	0	6		0	3	8	3			1	8	1			0	1	2	9	1	0					
	0	7		0	7	6	8			3	9	7			0	1	2	9							
	0	8																	8	0					
	0	9		2	3	3	0					3	8		0	1	1	2							
	1	0		2	0	9	0					9	7		0	1	1	2							
	1	1		3	4	9	0				1	1	5		0	1	1	2							
	1	2		2	5	3	1								0	1	1	2							
	1	3		0	8	1	5			2	5	1			0	1	2	9							
	1	4								1	0	5			0	1	2	9							
	1	5		0	5	1	7								0	1	2	9					—	5	
	1	6																							

(*a*) Accepted indoor temperature drop.
(*b*) Coefficient of heat transmission.
(*c*) Efficient heat capacity.
(*d*) Inside film resistance.
(*e*) Correction for outdoor temperature or for radiators surface temperature.
(*f*) Temperature of adjacent space.

Fig. 6—Data Sheet A: Initial information and wall types with specifications.

Vertical ducts

	Nr		Fan Nr	$Ki\ \left[\frac{N\,s^2}{m^3\,g^2}\right]$							e
Col.	1	2	3	4							11
	0	1	1			5	9	3	—	0	6
	0	2	1			3	7	5	—	0	6
	0	3	1			4	6	5	—	0	6
	0	4	1			7	2	4	—	0	6
	0	5	1			3	2	5	—	0	6
	0	6	1			7	3	0	—	0	6
	0	7	1			6	1	1	—	0	6
	0	8	1			7	2	1	—	0	6
	0	9	1			2	3	1	—	0	6
	1	0	1			1	2	1	—	0	6
	1	1	1			2	3	4	—	0	6
	1	2	1			1	1	5	—	0	6
	1	3	1			3	7	8	—	0	6
	1	4	2				6	6	—	0	6
	1	5	2				8	4	—	0	6
	1	6									
	1	7									

(*a*) Coefficients determining fan performance curve.
(*b*) Pressure loss coefficient for horizontal duct.
(*c*) Air temperature in fan.
(*d*) Height of fan from zero level.
(*e*) Pressure loss coefficient for vertical duct.

Therefore an approximate pressure distribution in accordance with Fig. 2 has been used in the programme. The figure shows also the numbering of walls and wind directions used in the programme.

The pressure p_o against the outside walls has been calculated by means of the formula:

$$p_o = p_z - h\rho_o g + C\left(p_{dz} + \frac{h}{H}(p_{dH} - p_{dz})\right) \qquad \ldots (8)$$

where C is a coefficient dependent on wind direction and the wall in question in accordance with Fig. 2, p_{dz} the dynamic wind pressure at zero level and p_{dH} the dynamic wind pressure at level H above zero level.

The effect of the ventilation equipment on the pressure conditions is taken into account by treating ventilation apertures in the same way as cracks. For this purpose it is necessary to know the pressure in the air duct behind the ventilation aperture. Using the symbols of Fig. 3 the corresponding formula may be written:

$$p_d = p_z + \Delta p_f + \sum_v \Delta p_{dv} + (h_f - h)\rho_i g - h_f \rho_o g \qquad \ldots (9)$$

where Δp_f is the pressure produced by the fan (exhaust $-$, supply $+$), $\sum_v \Delta p_{dv}$ the pressure loss in the duct and equipment attached to the fan (exhaust $+$, supply $-$), h_f the height of the warm part of the duct (the fan) above zero level, h the height above zero level of a point corresponding to pressure p_d, ρ_i the density of the air in the duct and ρ_o the density of the air outside the building. In case of a duct with natural draught $\Delta p_f = 0$.

The fan pressure and the pressure loss in the duct are dependent on the airflow, the former in accordance with the fan performance curve and the latter in such a way that the pressure losses between branch-off points vary approximately in direct proportion to the square of the corresponding airflow, viz. $\Delta p_{d1} \sim \dot{m}_{d1}^2$, $\Delta p_{d2} \sim \dot{m}_{d2}^2$ and so on, Fig. 3. This dependence has been taken into account in the programme approximately, by using the tangent through the working point on the performance curve instead of the curve itself and by dividing the duct into two parts only for the calculation of the variation in pressure loss, the loss of the horizontal part varying as the square of the fan airflow and the loss of the vertical one as the square of the airflow in the vertical duct.

Utilization of the heat capacity of the structure

By permitting a slight reduction of the indoor temperature (2-3 deg C) during periods of severe cold, which, according to statistics, only rarely occur, the heat stored in the structure may be usefully employed, thus reducing the heat demand to

Fans

	Nr	$C_1\ \left[\frac{N}{m^2}\right]$ a	$C_2\ \left[\frac{N\,s}{m^2\,g}\right]$ a	$Kv\ \left[\frac{N\,s^2}{m^2\,g^2}\right]$ b	t [°C] c	H [m] d
Col.	1	2 … 7	8 … 14	15 … 22	23 … 25	26 … 29
	1	— 3 8 6 . 5	1 . 5 2	3 7 6 — 0 6	2 0	2 4
	2	0	0	0	1 0	2 4
	3					
	4					
	5					

Fig. 7—Data Sheet B: Fan performance and duct pressure loss.

	Floor		Apart-ment		Room		Indoor temp. [°C]		Crack type		Crack length [m]				Crack coeff.			Const. supply or exhaust [q/s]					Wall		Length [m]				Width [m]				Wall type				
Col.	1	2	3	4	5	6	7	8	9	10	11			14	15		17	18				22	23	24	25			28	29			32	33	34			
		1		1		1	1	8	0	2		8	3	4	1								0	1		3	8			2	8		0	1			
																						Col. 35	0	1		2	4	2		1	7	5	0	9	46		
																						Col. 47	0	1		0	8			2	2		1	0	58		
																						Col. 59	0	1		2	0			0	3		0	8	0	7	72
		1		1		1	1	8	0	2		6	0	0	1								0	2		3	4			2	8		0	1			
																							0	3		3	0			2	8		0	4			
																							0	4		3	6			3	8		0	3			
																							0	5		3	6			3	8		0	3	0	7	
		1		1		2	1	8	0	3		7	6	5	1								0	1		3	0			2	8		0	1			
																							0	1		1	5	0		1	5	5	0	9			
																							0	1		1	3	0		0	5		0	8			
																							0	2		1	4			2	8		0	4	0	7	
		1		1		2	1	8															0	3		3	8			2	4		0	3			
																							0	4		3	8			2	4		0	3			
																							0	5		3	8			2	8		1	4			
																																			0	7	
		1		1		3	1	8	0	2	1	0	1	7	1								0	1		4	2			2	8		0	2			
																							0	1		2	7	6		1	5	5	0	9			
																							0	1		2	0	0		0	5		0	8			
																							0	2	1	0	2			2	8		0	4	0	7	

Fig. 8—Data Sheet C: Wall and crack dimensions.

some extent. In the programme this is achieved by correcting the outdoor temperature according to the method introduced by G. Brown.[3]

As a starting point a simplified situation as shown in Fig. 4 is used. The outdoor temperature has remained equal to the design value θ_{od} during a period of time of considerable length. The heat demand has been estimated on the basis of this value, and as long as it prevails, the indoor temperature may be kept equal to the design value θ_{id}. At the beginning of the cold period the outdoor temperature is assumed to drop suddenly by an amount $\Delta\theta_o$, remaining constant during the whole period T of severe cold and rising again to its original value. The indoor temperature has decreased by $\Delta\theta_i$ during the cold period. Supposing the temperature change in the walls, etc., to be so slow that the temperatures correspond to the stationary condition all the time, an equation between $\Delta\theta_o$ and $\Delta\theta_i$ may be derived in the following way:

When the indoor temperature decreases by $d(\Delta\theta_i)$, the quantity of heat

$$dQ = Cd(\Delta\theta_i) \qquad \ldots (10)$$

will be released from the structure; C is the effective heat capacity of the room. This corresponds to the quantity of heat, which during the time dt required for the temperature drop would be needed for covering the transmission and infiltration heat losses due to the temperature difference $\Delta\theta_o - \Delta\theta_i$, reduced by that amount of heat, which in consequence of temperature difference $\Delta\theta_i$ enters the room with the air to be supplied at constant temperature and through the basement floor and the adjacent inside spaces remaining at constant temperature.

$$dQ = (G_o + \dot{C}_o)(\Delta\theta_o - \Delta\theta_i)dt - (G_g + G_i + \dot{C}_s)\Delta\theta_i dt \qquad \ldots (11)$$

In this equation G_o is the heat conductance of the walls, etc., in contact with the outside air (= the transmission heat loss at unit temperature difference), $\dot{C}_o(=\dot{m}_o c_p)$ the capacity flow of the air leaking into the room from the outside through the cracks = the infiltration heat loss at unit temperature difference, G_g the heat conductance from the basement floor, assumed to stay at constant temperature, G_i the heat conductance of walls against adjacent inside spaces (at constant temperature) and $\dot{C}_s(=\dot{m}_s c_p)$ the capacity flow of air supplied into the room (at constant temperature).

From equations (10) and (11) and solving the equation for the initial values $t=0$, $\Delta\theta_i=0$ and $t=T$, $\Delta\theta_i=\Delta\theta_i$ we have:

$$\Delta\theta_o = \Delta\theta_i \frac{1 + \dfrac{G_g + G_i + \dot{C}_s}{G_o + \dot{C}_o}}{1 - e^{-\dfrac{G_o + G_g + G_i + \dot{C}_o + \dot{C}_p}{C}T}} \qquad \ldots (12)$$

The design outdoor temperature may then be calculated from the equation:

$$\theta_{od} = \theta_o + \Delta\theta_o \qquad \ldots (13)$$

The construction data required when using equations (12) and (13) and the permissible temperature drop are given in connection with the input data. The airflows (capacity flows) are calculated by the programme of the basis of pressure conditions. The duration of the cold period T should be chosen so as to get the most unfavourable (i.e. the lowest) value of the design outdoor temperature with regard to the heat demand. This is taken care of by the programme by calculating θ_{od} for outdoor temperatures representing the same probability of occurrence (for instance once every 30 years) and corresponding to the mean values of cold periods of both two and five days' duration respectively, separately for each room. The lowest value thus obtained is used for calculating the final heat demand.

Compensation for radiation to cold surfaces

Cold window and wall surfaces, as is generally known, increase the heat emission by radiation of the persons in a room. A compensation for this heat loss should be made by installing radiators along cold walls and, if required, by increasing the indoor temperature.

The programme calculates the average radiation temperature θ_{sm} (°K) of the surfaces in contact with the outside air (viz. walls, roof and floor) using the formula:

$$\theta^4_{sm} = \frac{\Sigma A_v \theta_{sv}^4}{\Sigma_v A_v} \qquad \ldots (14)$$

where A signifies the area of the different parts of the surfaces

Design Outdoor Temperature: 22·15. Apartment 2. Room 1. Floor 8. Wind 4

Heat loss of rooms

Apartment	Room	Floor	Heat loss	Infiltration	Indoor temperature	Wind	Pressure
1	1	1	1918·78	·468	20·16	1	−38·409
1	1	2	1838·71	·445	20·16	1	−34·876
1	1	3	1749·91	·417	20·16	1	−31·120
1	1	4	1640·48	·378	20·16	1	−26·692
1	1	5	1528·22	·332	20·16	1	−22·583
1	1	6	1423·42	·283	20·16	1	−19·249
1	1	7	1318·53	·226	20·16	1	−16·407

Heat loss of building

Wind	Heat loss	Infiltration
1	163988·00	·405
4	168640·00	·422

Fig. 9—Output examples of heat loss calculation. Temperatures in °C, heat loss in W, pressures in N/m². Infiltration heat loss may be obtained multiplying heat loss by coefficient under heading 'Infiltration'.

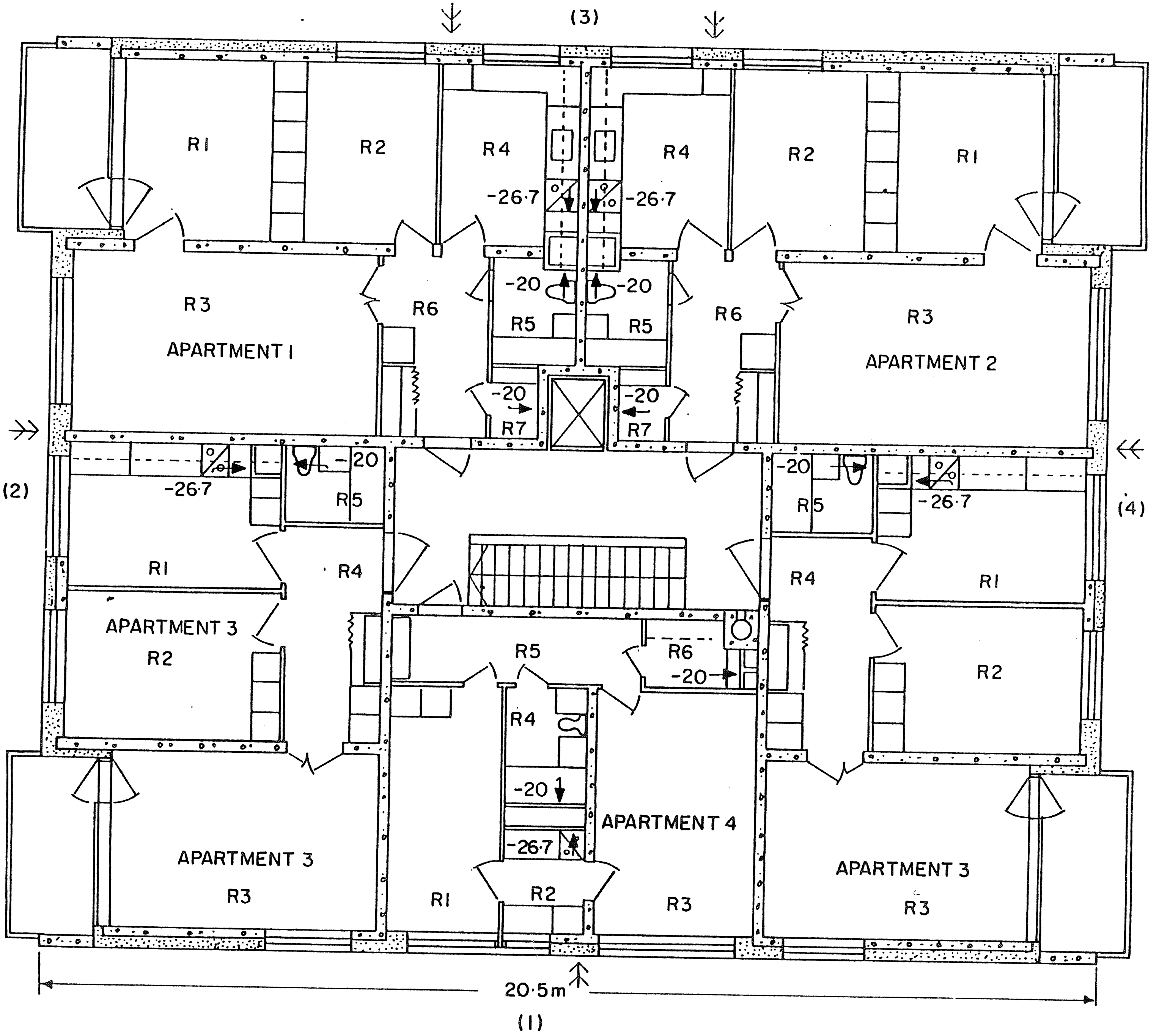

Fig. 10—Floor plan of the example house with apartment, room and wall numbers and design exhaust air flows in 10^{-3} kg/s.

(window, radiator, etc.) and θ_s the corresponding surface temperatures (°K).

On the basis of these radiation temperatures the programme chooses the coldest surface and calculates the indoor design temperature by formula:

$$\theta_{id} = \theta_i + C(\theta_i - \theta_{sm}) \quad \ldots (15)$$

where θ_i is the minimum indoor temperature to be stated among the input data and θ_{sm} the average radiation temperature (°C) calculated according to formula (14). The value of the coefficient C has so far been 0·5. From a physiological point of view it might be reasonable to base the correction of the indoor temperature on the average of radiation temperatures of all the surfaces of the room in question. The necessary change of the programme is easily feasible. It should be considered however, that unsymmetrical radiation cannot be completely compensated in any other way than using properly designed counter radiators.

Flow-diagram of programme, input, output and limitations

The programme, the flow-diagram of which is shown in Fig. 5, is divided into two parts. The first part calculates by trial and error method the pressures of apartments and staircases and the airflow in the ducts and fans at all wind directions. The second part calculates the air flows through cracks and ventilation apertures and the design outdoor temperature, which due to the limitations of the memory capacity of the computer require intermediate output. After the results have been re-read, there follows the calculation of indoor design temperatures and subsequently the calculation of heat demands. The last phase comprises the adding up of the heat demands of the rooms to obtain the heat demand of the building.

Input data are given on sheets, of which the A sheets, Fig. 6, contain initial information such as the heading, the number of fans, air ducts and walls of different types, floor levels and building heights, weather data and the thermal properties of the wall types in question. B sheets, Fig. 7, give the flow characteristics of fans and air ducts and C sheets, Fig. 8, the dimensions and other characteristics of partition surfaces, ventilation apertures and cracks for each room. In this connection details of filling out of sheets are not described here, but it may be mentioned that all data are given in accordance with the SI-system.

An example of an output is shown in Fig. 9. First the design outdoor temperature and the designating numbers of the room and the wind which determine the estimation of this temperature are indicated. Then the results for each separate room are shown, arranged horizontally and finally the results for the building are given. If required, the output of the pressure of the apartments and staircases and the airflow in ducts and cracks may also be obtained.

The programme is intended mainly for residential buildings. For this reason each apartment has been treated as a limited space, where the pressure at a definite wind direction and velocity is the same for all the rooms. Further it has been assumed that the apartments are in contact with the staircases without corridors. These constitute the most important limitations of the programme. When using the programme for other buildings than residential ones, the conditions should be changed accordingly in conformity with the above mentioned. As regards other limitations, caused mainly by the memory of the I.B.M.-1620 computer, the following maximum numbers which must not be exceeded, may be mentioned, viz. air ducts not more than 25, different apartments not more than 100 (apartments of the same type on different floors are considered as a single one), staircases not more than four and fans not more than five. The product of the number of apartments times the number of wind directions must not exceed 1000.

Effect of wind on heat loss and infiltration of a multi-storey building

Finally, as an example of the use of the programme, the results of calculations whose purpose was to investigate the effect of the wind on heat loss and infiltration of an eight-storey residential building are put forward.

The floor plan of the building is shown in Fig. 10. The numbering of the rooms and the nominal air flow of the mechanical exhaust used in the calculation are indicated in the figure. The make-up air enters through the cracks. The leakage characteristics of the cracks assumed in accordance with DIN Standard 4701, are shown in Fig. 11. The pressure drop of the exhaust air apertures at nominal airflow amounts to approximately 100 N/m², that of the vertical duct to 20 N/m² and that of the horizontal duct on the attic floor to 35 N/m². The outdoor and indoor temperatures were −27°C and +18°C respectively. The calculations were carried out assuming the fan running at half speed, in which case the air flow amounted to approximately 60% of the nominal value.

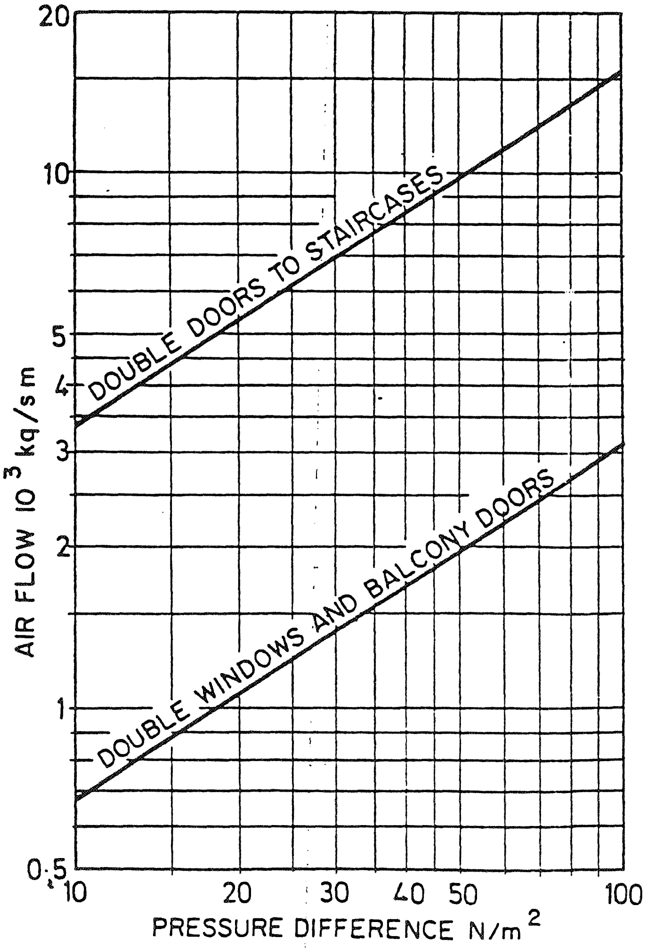

Fig. 11—Crack flow rates used in the example.

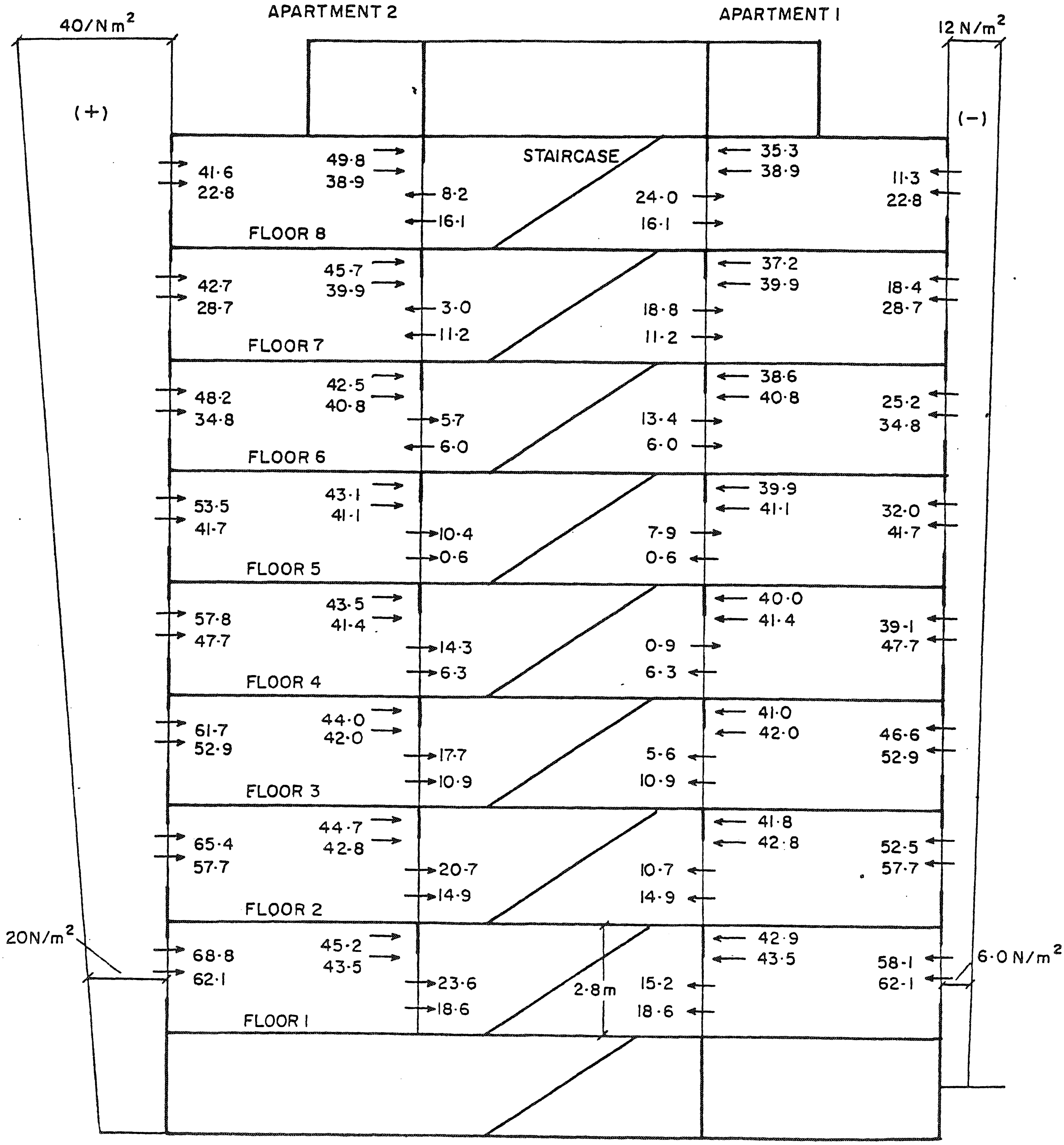

Fig. 12—Effect of wind on the airflow in cracks and exhaust inlets in apartments 2 and 1 of the example house. Wind blowing perpendicular to the wall 4 of apartment 2. Upper numbers indicate the flow in 10^{-3} kg/s with wind pressures given and lower numbers with no wind. Outdoor temperature −27°C, indoor +18°C.

Table 1.—Effect of wind on the heat loss of apartments 1 and 2 of the example house[a, b]

Apartment	Floor	No wind		Wind[c]			
		Infiltration heat loss W	Total heat loss W	Infiltration heat loss W	Change %	Total heat loss W	Change %
1	1	2588	5076	2424	−6·3	4912	−3·2
1	2	2404	4892	2189	−9·0	4675	−4·4
1	3	2205	4693	1942	−12·0	4428	−5·7
1	4	1989	4477	1630	−18·1	4116	−8·1
1	5	1790	4224	1334	−25·5	3820	−9·6
1	6	1449	3936	1050	−27·5	3536	−10·2
1	7	1197	3684	766	−36·0	3252	−11·7
1	8	966	4488	489	−49·4	3959	−11·8
2	1	2588	5076	2885	+11·5	5373	+5·9
2	2	2404	4892	2744	+14·1	5230	+6·9
2	3	2205	4693	2594	+17·6	5080	+8·2
2	4	1989	4477	2433	+22·3	4919	+9·8
2	5	1790	4224	2255	+16·0	4741	+12·2
2	6	1449	3936	2040	+40·8	4526	+15·0
2	7	1197	3684	1822	+52·2	4308	+16·9
2	8	966	4030	1768	+83·0	4843	+20·2

Notes
(*a*) Floor plan of the example house shown in Fig. 10 and elevation drawing in Fig. 12.
(*b*) Outdoor temperature −27°C, indoor temperature +18°C.
(*c*) Wind blowing perpendicular to the wall 4 of the apartment 2. Dynamic pressure of the wind on the roof level 40 N/m corresponding to approximately 8 m/s and on the first floor level 20 N/m² corresponding to approximately 5·5 m/s.

From the results obtained the infiltration heat losses and total losses of the symmetrical apartments 1 and 2 at no wind and in case of wind blowing at right angles to wall 4 of apartment 2 have been indicated in Table 1. The table includes further the percentage value of the change in heat loss in comparison with the values at no wind. Fig. 12 shows the airflow (totals) through cracks in outside walls and staircases and through ventilation apertures indicated in the elevation drawing of the building.

On closer examination of the results, attention is drawn to the very considerable variations of the infiltration heat loss. Due to the effect of the wind it increases on the top floor by up to 83% increasing the total heat loss by 20%, diminishing at the side sheltered from the wind by 50% reducing the total heat loss by 12%. The differences in the vertical direction also are considerable, especially on the lee-side.

The airflow between apartments and staircase is interesting. On the lower floors its direction is toward the staircase, being the contrary on the upper floors resulting in the odour of cooking extending upwards to the upper storeys. Attention is further drawn to the magnitude of the airflow from the staircase into the apartments, which on the lee-side of the top-storey amounts to 68% of the airflow through the ventilation apertures.

Notwithstanding the effect of the wind on the heat loss of the individual apartment being considerable, the wind does not in this case affect the heat loss of the entire building to any great extent, as shown in Table 2. This is mainly due to the fact that the apartments of the example building do not extend right through the building from one side to the other.

Table 2.—Effect of wind on the heat loss of the exampl house[a, b]

Wind	Infiltration heat loss W	Change %	Total heat loss W	Change %
1[c]	67793		165348	
4[d]	71166	+5·0	168640	+2·0

Notes
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References

1. Leiponen, P.: Overestimation of Heating Load with Resulti Drawbacks (in Finnish), Thesis for the Degree of Diplo Engineer, Finland Institute of Technology, 1965.
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3. Brown, G.: New Methods in Estimating the Heating a Cooling Loads of Buildings (in Swedish), VVS 33 (196 Nr. 1, pp. 5-16.

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