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METHOD OF CALCULATING THE SEASON HEAT REQUIREMENTS FOR VENTILATION PURPOSES IN RESIDENTIAL BUILDINGS

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ABSTRACT

Heat requirements of ventilation systems are becoming a dominant factor to be considered in energy balances prepared for residential buildings. This results from a consistent improvement of thermal insulating power and better tightness of partitions, as well as from the standards that ventilation systems have to meet in relation to the quality of the indoor air. This factor, despite variable volumes of the air exchanged with the external environment, is not always considered in most estimates of thermal power quantities. The assessment of seasonal heat demands which provides grounds for the selection of the components and quantities of heat sources, often does not account for the thermal power requirements needed for ventilation, which may lead to considerable discrepancies in relation to actual heat quantities. The discussed method of estimating mean multi-annual thermal energy consumption by ventilation systems, is based on relating the changed air multiple to the outdoor temperature.

1. INTRODUCTION

Heat supplies needed for the ventilation of buildings, in view of a consistent improvement of thermal insulating power and better tightness of partitions, are becoming a dominant factor in energy balances. The estimation of the exact quantity of heat needed for ventilation is strictly connected with the accurate calculation of the volume of the air infiltrated to a building or to its particular rooms, and pertains to these buildings where the essential outdoor air stream is provided by natural air change methods (buildings with natural ventilation ducts).

Despite the changes in the volume of the air exchanged with the external environment in consequence of the changes in the external parameters, this factor is not considered in most estimates of nominal and seasonal heat demands (see the methods laid down in national and international standards and guidelines [3, 4]), as the methods of calculating the thermal requirements of buildings assume a constant number of ventilating air changes (in most cases 1 air change rate/hour) in the course of a whole heating season.

2. REVIEW OF THE METHODS CALCULATING SEASONAL HEAT REQUIREMENTS FOR THE VENTILATION OF BUILDINGS

From the point of view on the external climactic parameters, the methods determining mean multi-annual consumption of thermal energy in the course of a given heating season comprise:

- degree-day basis method;
- method based on determining thermal power consumption for some particular months of a heating season, following an hourly day course typical for this particular month;
- method based on determining thermal power consumption in some particular hours of a heating season. A comparable course of climactic parameters for these particular hours is compiled in the form of mean multi-annual values, or by random choice of multi-annual mean months, with the corresponding 'levelling' of the boundary values.
- referential synthetic year method. A synthetic year is a set of hourly courses of some particular climactic elements; at the same time, the length of the courses does not exceed 8760. Special selection of this length leads to fairly accurate annual (seasonal) forecast of thermal energy consumption, after the particular thermal power consumption values calculated for the courses are converted to annual (seasonal) values.

3. METHOD IMPROVING THE ACCURACY OF ESTIMATING THE QUANTITY OF HEAT REQUIRED FOR VENTILATION

Better accuracy of estimating the quantity of heat energy required for the ventilation needs of a building in a heating season, involves better assessment of the volume of the air flowing through this building, which is regarded as a homogeneous spatial area. Assuming that such approach is consistent with the degree-day based method used to determine the consumption of thermal power by central heating and ventilation systems:

$$Q_w \quad \sum_{t_e\ t_{en}}^{t_e\ t_k} \dot{V}(t_e)*z(t_e)*c_{pp}*\rho_p*(t_{iw}-t_e)+V_£*n_£(t_e)*[t_£-t_i] \tag{1}$$

generally $V(t_e)$ may be represented as:

$$\dot{V}(t_e) \quad V_B*\frac{V(t_e)}{V_B} \quad V_B*n(t_e) \tag{2}$$

The number of air changes for a given flat may be expressed as:

$$n(t_e) \quad \frac{\sum_i n_M(t_e)*V_M(t_e)}{\sum V_M} \tag{3}$$

whereas:

$$n_M(t_e) \quad \frac{V_M(t_e)}{V_M} \quad \frac{1}{V_M}\left[\sum_{t\ t_e-8}^{t\ t_e+8}\sum_{w\ 0}^{w\ 7} V_M(t'_e, w)\right] \tag{4}$$

Likewise, it is possible to express the number of air changes for a bathroom.

Generally $V(t_e)$ may be represented as:

$$\dot{V}(t_e) \quad \sum_i a_i * l_i * \left(|p_{ei} - p_{iM}|\right)^{\frac{2}{3}} * \mathrm{sgn}(\Delta p) \tag{6}$$

The pressure difference in the above expression depends on the shape of a building, distribution of leaks, number and dimensions of vents, speed and direction of winds, location of this building.

$$p_{ei} \quad p_w + p_t \tag{7}$$

The impact of the wind on the building evokes changes in the static pressure at the partitions in relation to the pressure of free outdoor air flow conditions. An increase in the pressure occurs at the in- blowing partitions, resulting in the flow of the air form the outside to the inside of the building (infiltration). As far as the other partitions are concerned, the pressures may be negative, which can lead to exfiltration.

The pressure related to the impact of the wind is expressed as:

$$p_w \quad \frac{c_k * \rho_e * w^2}{2} \tag{8}$$

The pressure related to the difference in temperature as:

$$p_t \quad H * g * (\rho_e - \rho_i) \tag{9}$$

p_{iM} [6] pressure is determined on the basis of the law of conservation of mass in a flat:

$$\sum a_i * l_i * |p_{ei} - p_{iM}|^{2/3} * \mathrm{sgn}(\Delta p) \quad \sum a_k * |p_{iM} - p_{eD}|^{1/2} * \mathrm{sgn}(\Delta p) \tag{10}$$

Coefficient a_k is derived from the following dependence:

$$V = a_k * \Delta p^{1/2} \tag{11}$$

$$\Delta p \quad \frac{\lambda * l_k}{d_e} * \frac{w_k^2 * \rho_{pk}}{2} + \sum \xi * \frac{w_k^2 * \rho_{pk}}{2} \tag{12}$$

$$w_k \quad \frac{V}{F_k} \tag{13}$$

$$a_k \quad \frac{V}{\Delta p^{1/2}} \tag{14}$$

Pursuant to the discussed method providing better accuracy for the calculation of the quantity of heat needed for ventilation, a computer program called VETNAT was created to determine the volume of the air infiltrated to a given type of building through leaks in window openings, assuming the principles presented below

4. ASSUMPTIONS FOR VENTNAT COMPUTER PROGRAM

To calculate the volume of the air infiltrated through leaks in widow openings by computer-aided methods, the following assumptions have been made:

- the building in horizontal and vertical projection has a rectangular solid shape,
- the partitions and external doors are tight, each kitchen and each bathroom are equipped with a separate vent,
- on the particular floors of the building the pressure is constant along the same height,
- coefficient c_k, which is a conversion coefficient of the pressure evoked by the wind acting on the wall surface, has a constant (mean) value,
- all the interior doors are open, except for the bathroom and the WC,
- the bathroom and the WC doors have ventilating holes,
- the gravity pressure between the bathroom and other rooms is used to overcome the flow resistance through the vents in the bathroom doors,
- all doors connecting the flat with the staircase are sealed by completely air-tight doors,
- the value of heat permeability coefficient is assumed as 1,0 and 0,33 $m^3/h\ m\ (Pa)^{2/3}$,
- the height of the building floors is equal to 2.8 m.

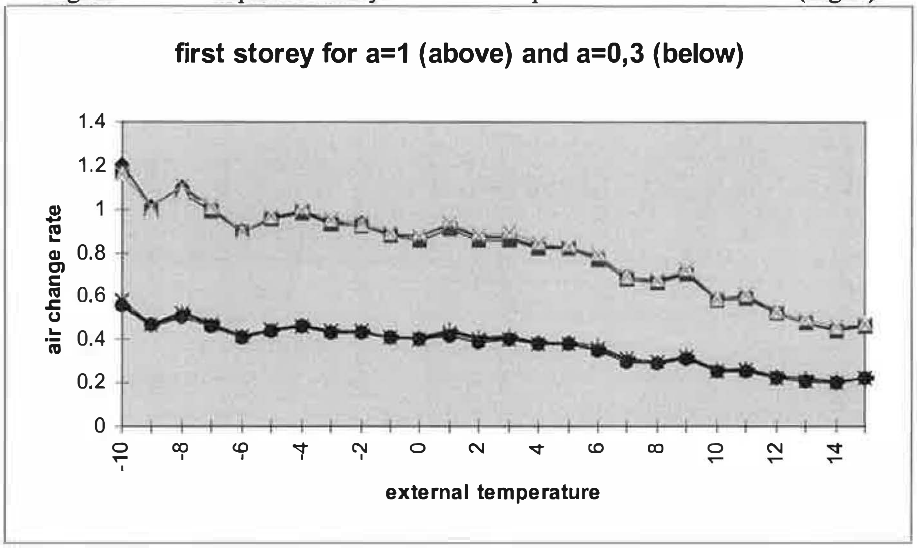
5. OUTDOOR CLIMACTIC CONDITIONS ASSUMED FOR THE ANALYSES

The outdoor climate assumed for the analyses were monthly courses chosen as the means of a 30-annual period. The basic criteria for the choice were mean monthly values of outdoor air temperature, amplitude of temperature variations in 24 hours, wind speed and intensity of sun rays in relation to the multi-annual mean monthly values. The mean courses were selected for several towns representative to the whole Polish territory.

6. RESULTS AND ANALYSIS OF CALCULATING THE VOLUME OF INFILTRATED AIR BY MEANS OF VETNAT COMPUTER PROGRAM

The calculations provided the data on the volume of the ventilating air flowing through the vents, as well as the information on the leaks performance in the partitions of the analysed buildings. On the grounds of the calculation results, it was possible to derive the curves of mean volumes of the air infiltrated through the leaks in the window woodwork, depending on the outdoor temperature (wind speed and wind direction, together with the frequency of wind blows were related to the daily mean temperature of the outdoor air) and tightness (Fig.1).

The observations of the changes in the amount of the air flowing through the flats situated on particular floors reveal that the function of the air change multiple, which depends on the building height, shows a decreasing tendency (Fig.2, after conclusions), irrespective of the tightness (in the discussed range). In the case of the flats situated on lower floors, the air change multiple is a function of the outdoor air temperature, but in the case of higher floors it depends mainly on the wind speed and wind direction (Fig.1.).



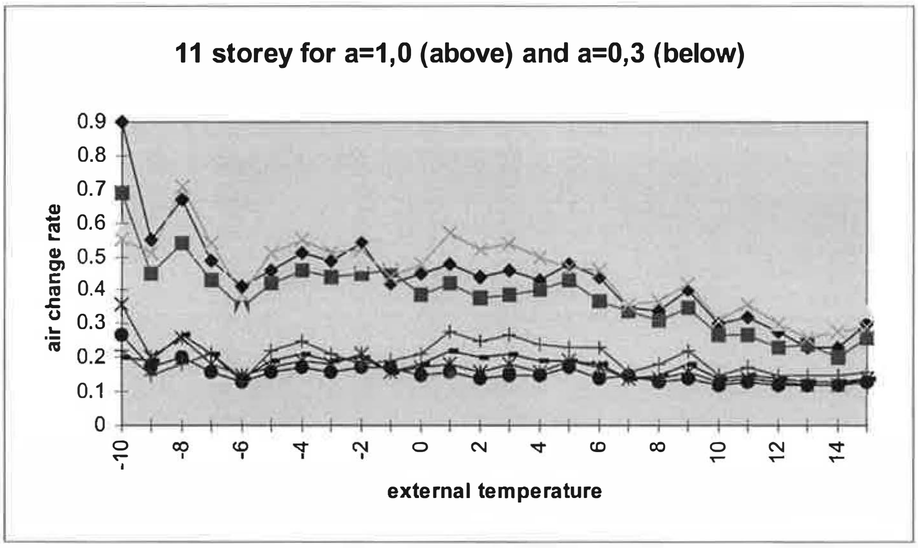


Fig. 1. Exemplary courses of the variability of the air changes multiple through leaks in window openings, expressed as the wind pressure function and outdoor air temperature function for different tightness and floors of an 11-floor building.

7. CONCLUSIONS AND RECAPITULATION OF THE RESULTS

The results obtained in the course of the calculations refer to a natural ventilation system with separate vents and the tightness in accordance with PN-91/B-02020 standard. The following conclusions may be drawn:

- The discussed way of improving the accuracy of estimating seasonal thermal power requirements needed to heat up the air infiltrated through the leaks in window woodwork, in the case of natural air flow through the building, has been devised for occurrence frequency t_e, but it seems to be applicable for other methods as well.
- The constant number of ventilating air changes has been assumed as 1 h^{-1} in one whole heating season, such volume is difficult to achieve with good tightness of windows and air flow through the leaks.
- The air change multiple values obtained in the calculations are variable in relation to the degree of tightness, building height, outdoor air temperature. For the flats situated on lower floors the mean value of the air change multiple is about 0.75 h^{-1} (for a=1.0) and 0.35 h^{-1} (a=0.33), whereas for the highest floor flats it is 0.5 and 0.2 h^{-1} respectively.
- The windows which are characterised by good tightness should be equipped with in-blowing air gaps with adjustable degree of openness. In such case, the estimates of seasonal thermal heat power quantity needed to heat up ventilating air should assume the air change multiple in the range from 0.3 to 0.5 h^{-1}.
- The discussed method should contribute to better selection of energy-efficient ventilation systems for residential buildings. Initial calculations have indicated the possibility of applying the method to determine thermal power quantities required by central heating and ventilation systems of buildings to select the most suitable heat sources.

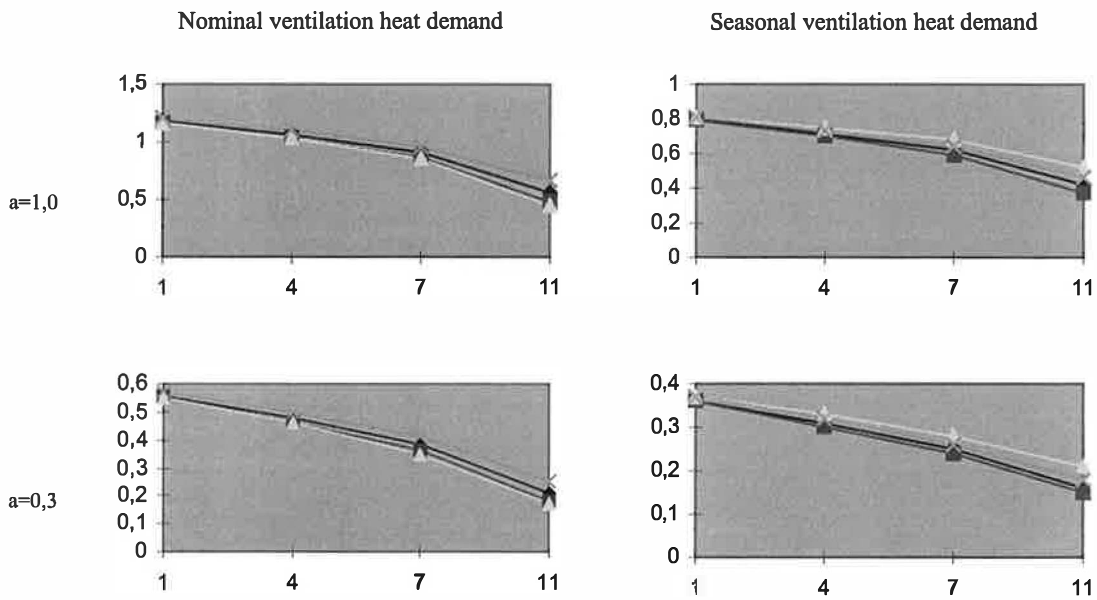


Fig.2. Dependence between the infiltrated air change multiple and the number of floors.

NOTATIONS:

ρ-	air density
λ-	linear losses coefficient in the flow through the vent
$\sum\varsigma$	sum of the in-situ resistance in the flow through the vent
a_i, l_i	air permeability and leak length coefficient
a_k	air flow coefficient in the vent
c_k	dynamic pressure conversion coefficient
c_{pp}, p_p	specific heat and air density
d_e	vent equivalent diameter [m]
F_k	vent cross-section [m^2]
g	acceleration of gravity
H	distance between the centre of the window (door) and the reference line assumed at the height of the chimney exhaust
i	number of flats in the building
l_k	vent length [m.]
$n(t_e)$	number of infiltrated air changes in the building at given outdoor temperature
$n_L(t_e)$	air change multiple for the bathroom (in consideration of the air let out of the bathroom through the vent), [1/h]
$n_M(t_e)$	air change multiple in the flat at given outdoor air temperature
n_{miesz}	number of flats in the building
p_i	indoor air density

$(p_{ei} - pi)$	pressure difference evoking the air flow through the leak at given te
$p_{iM}-p_{eD})$	pressure difference evoking the air flow through the vent
p_{pk}	density of the air flowing through the vent [kg/m3]
Q_w	thermal power consumption for the ventilation of the building in a heating period
t_e	mean daily outdoor temperature
t_{en}	multi-annual mean daily outdoor minimal temperature
t_{iw}	mean temperature of the air let out of the building
t_k	temperature at the end of the heating period or temperature of the equilibrium between the internal gains and heat losses
t_L	air temperature in the bathroom
V	volume of the air flowing through the vent
$V(t_e)$	mean volume of the outdoor air flowing into the building at outdoor temperature t_e
V_B	cubic capacity of the building
V_L	cubic capacity of the bathroom
V_M	cubic capacity of the flat
$V_M(t_e)$	volume of the air infiltrated to the flat at given outdoor temperature
w	wind speed
w_k	velocity of the air flow through the vent, [m/s]
$z(t_e)$	number of the days in the heating season

7. REFERENCES

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