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PREDICTION OF HEAT LOSSES INFILTRATION USING THE JOINT CUMULATIVE DISTRIBUTION FUNCTION OF OUTDOOR TEMPERATURE AND WIND SPEED

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1. Introduction

Heat loss from buildings continues to present a substantial proportion of the prime energy consumed in many countries. With improved insulation of the building shell, heat loss due to ventilation-whether controlled or by infiltration-has become a significant fraction of the building´s overall heat loss.

Temperature difference and wind speed are the main climatic parameters, that influence the annual heat loss through infiltration and selection of design heat loss. In the paper, there is presented mathematical model of correlation between external temperature and wind speed, by which is possible :

- to choice of an appropriate level of airtightness, or to determine what part of time the infiltration secure the air change in desired range
- to calculate the design heat loss at chosen probability of heat loss exceedance of heated space.

The last one is presented in the case study where the heat loss was calculated at 1% time exceedance through curtain wall at various combinations of heat transmission coefficients (U - value) and the air-tightness (F - value).

2. Statistical model of climatic data

One of the possibilities of the graphic presenting of the system of two random quantities can be seen on Figure 1, where hourly data are worked up from 10 year´s period, from October 15 to April, 15. On the vertical axis opposite the wind speed scale there is its marginal probability, which fulfils the condition

$$P(v \leq v_i) = \int_0^{v_i} \int_{-\infty}^{\infty} p(v,\ t_o)\ dt_o\ dv \qquad (1)$$

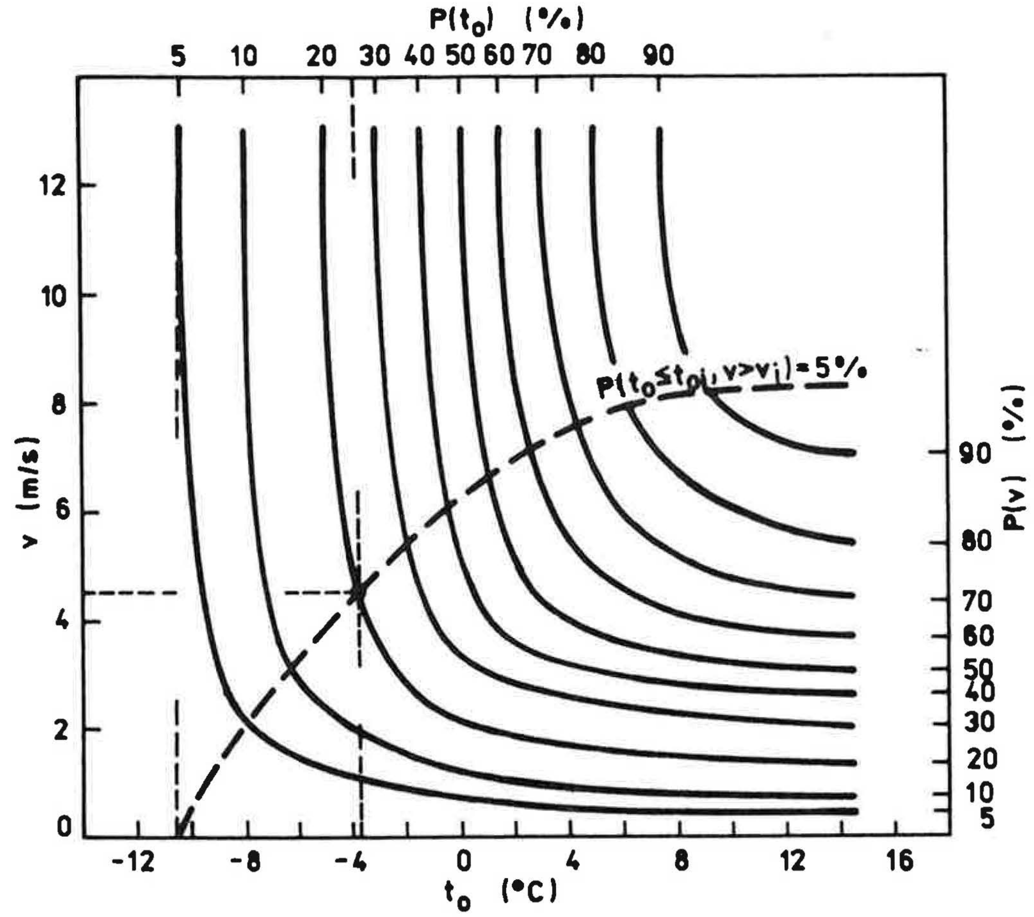

Fig. 1. Joint cumulative distribution function of outdoor temperature and wind speed.

where: $p(v, t_o)$ = joint probability density function of the wind speed and the outdoor temperature

Similarly the opposite lying horizontal coordinates represent the outdoor remperature and its corresponding marginal probability

$$P(t_o \leq t_{o,i}) = \int_{-\infty}^{t_{o,i}} \int_{0}^{\infty} p(t_o, v)\, dv\, dt_o \qquad (2)$$

Each point on the graph, or on the isoline representing the quantil, with the coordinates $t_{o,i}$ and v_i represents their simultaneous cumulative probability

$$P(t_o \leq t_{o,i}, v \leq v_i) = \int_{-\infty}^{t_{o,i}} \left(\int_{0}^{v_i} p(t_o, v)\, dv \right) dt_o \qquad (3)$$

For example on Figure 1 there is shown 20% probability, that the temperature will be lesser or equal t_o = -3.7 °C and at the same time the wind speed lesser or egual $v = 4.5$ (m/s).

For the heat load calculation the appearance of the higher wind speeds at lower temperatures is interesting, i.e. the probability in the form

$$P(t_o \leq t_{o,i}, v > v_i) = \int_{-\infty}^{t_{o,i}} \int_0^{\infty} p(t_o, v)\, dv\, dt_o - \int_{-\infty}^{t_{o,i}} \left(\int_0^{v_i} p(t_o, v)\, dv \right) dt_o \qquad (4)$$

Equation 4 is practically the difference of Equations 2 and 3. That means, that each point with coordinates $t_{o,i}$ and v_i (-3.7, 4.5 - Figure 1) is characterized with two probabilities : 1 - according to Equation 3 (20% - Figure 1), 2 - according to Equation 4 (5% - Figure 1).

At the given percent of probability that temperature will be lesser or equal $t_{o,i}$ and at the same time the wind speed greater then v_i, we can find the point set fulfilling Equation 4. It is possible to lay a curve over these points, which characterizes the functional dependance between the temperature and the wind speed at a given percent of the probability (5% - Figure 1). It is necessary to include in the calculation the temperature (t_o = -10 °C, Figure 1), the marginal probability of which equals the given level of probability. For the heat losses calculation this represents the minimum temperature in calm.

3. Design heat loss calculation

The heating load of the building necessary for designing of the heating system depends on many factors. These are first of all the external climate conditions, thermo-technical properties of the building (insulation and air-leakage of the building envelope, thermal mass of the building etc.), situation of the building, what part of the day it will be used, internal load, and the nature of its occupancy. On the basis of these factors, and of course in accordance with econamical relations, the probability level of the heat loss exceedance is estimated, which is decisive for the selection of the design outdoor weather conditions.

The task of this study is not the analysis of these influences when calculating the heat losses. Instead, the influence of wind and temperature on the total heat losses at 1% probability exceedance of the heat losses is being investigated. The calculation is based on the correlation of the outdoor temperature, the wind speed and its direction, and on the basis of the U - value correlation and F - value of the curtain wall.

The necessity of the design outdoor temperature and the wind speed correlation was proved in reference (1). The author has stated that the independent selection of the design outdoor temperature and the wind speed aims at considerable over-estimate of the heat loss. He also proved that the peak value of the heat losses can be mostly reached at mild temperatures with higher wind speed.

3.1. Data presentation

For the selection of the outdoor design values meteorological data (2) covering a 10-year period from 16th October till 15th April for a single site (Bratislava Airport) were used. The informations were based upon the average hourly measurements during the whole day in an open country at the height of 10 m. On the basis of this data the joint cumulative distribution function of outdoor temperature and the wind speed for eight directions was elaborated. From this function using the least square method the functional dependence between the outdoor temperature and the wind speed which were exceeded for only 1% of the time was found for all eight directions. The best fit was expressed by the exponential function

$$v_{\alpha} = a^{t_o} \cdot b + c \qquad (5)$$

where: a, b, c = eguation coefficients

α = wind direction (α = N, NW, W etc.)

Figure 2 presents the graphic expression of Equation 5 and the temperature t_o = -13.0 °C, for which the probability to be reached or exceeded independent of the speed equals 1%.

3.2. Calculation model

The transmission heat loss was calculated supposing the steady state conditions and for calculation the infiltration heat loss was employed the well-known crack method, while the wind speed was expressed by the Equation 5.

3.3. Example calculation

For the illustration how the weather conditions effect the heat loss value by means of the described procedure, we can calculate the heat loss of the room in the hypothetical residential-building. Supposing that the quality of the building as to suit the most suitable choice of outdoor

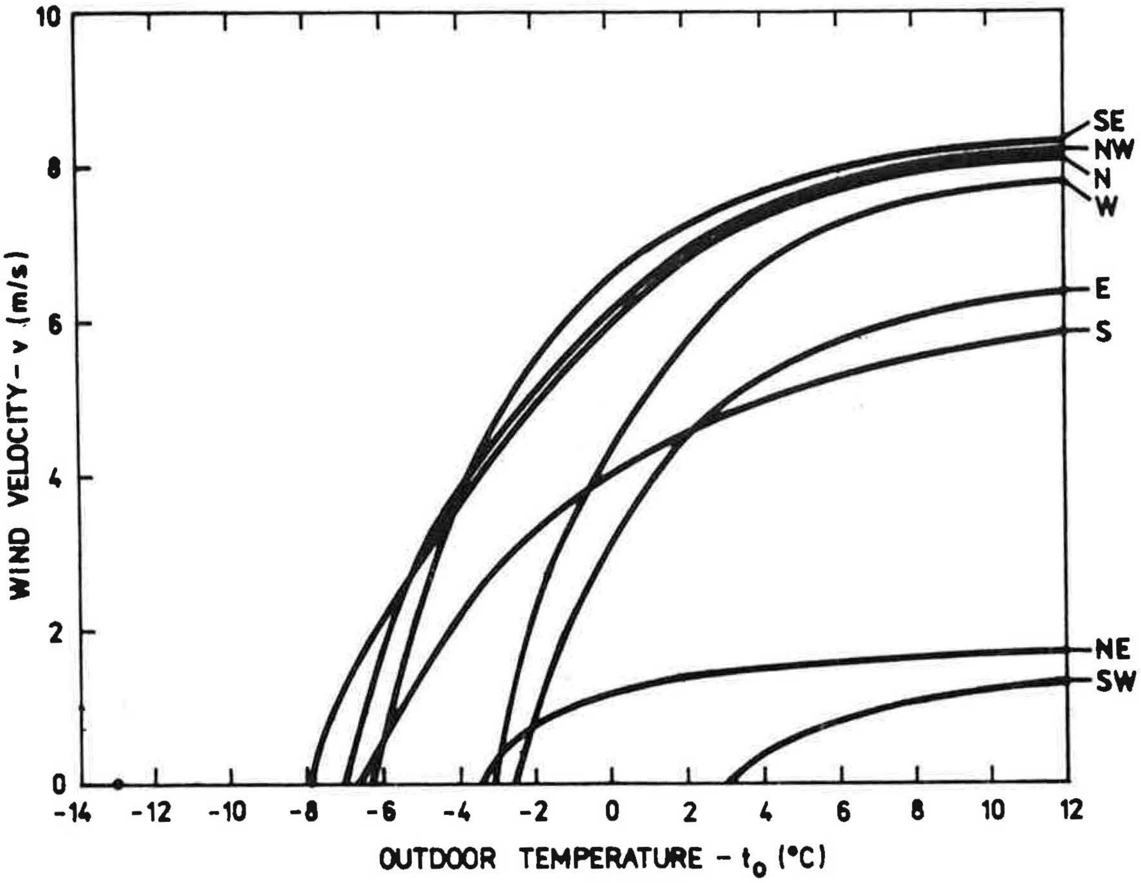

Fig. 2. Wind-temperature dependance at 1% time exceedance for various wind directions.

weather conditions is at 1% probability exceedance of the heat losses. The building is 56 m high and 33 x 21 m in plan situated in the urban area characterized according to Table 1 in reference (3), the terrain class IV. The curtain wall of the building consists of the segments 1.5 m wide and 2.8 m high. We assume in the example the heat loss of the room, vhich is situated in the middle of the greater wall of the building, occurs only through the curtain wall consisting of two segments described above. The heat loss of the room was calculated in three different height levels of the building, for four room orientations: N, NW, W and SW. The values of wind pressure coefficients and height of the neutral pressure level (NPL) were used from reference (4), and the inside temperature t_i = 20 °C was assumed.

The peak value of heat losses for individual cases were calculated on a programmable pocket calculator. The results can be seen of Figures 3, 4. To estimate the proportion of the infiltration and transmission heat losses on the total losses, Table I was worked out.

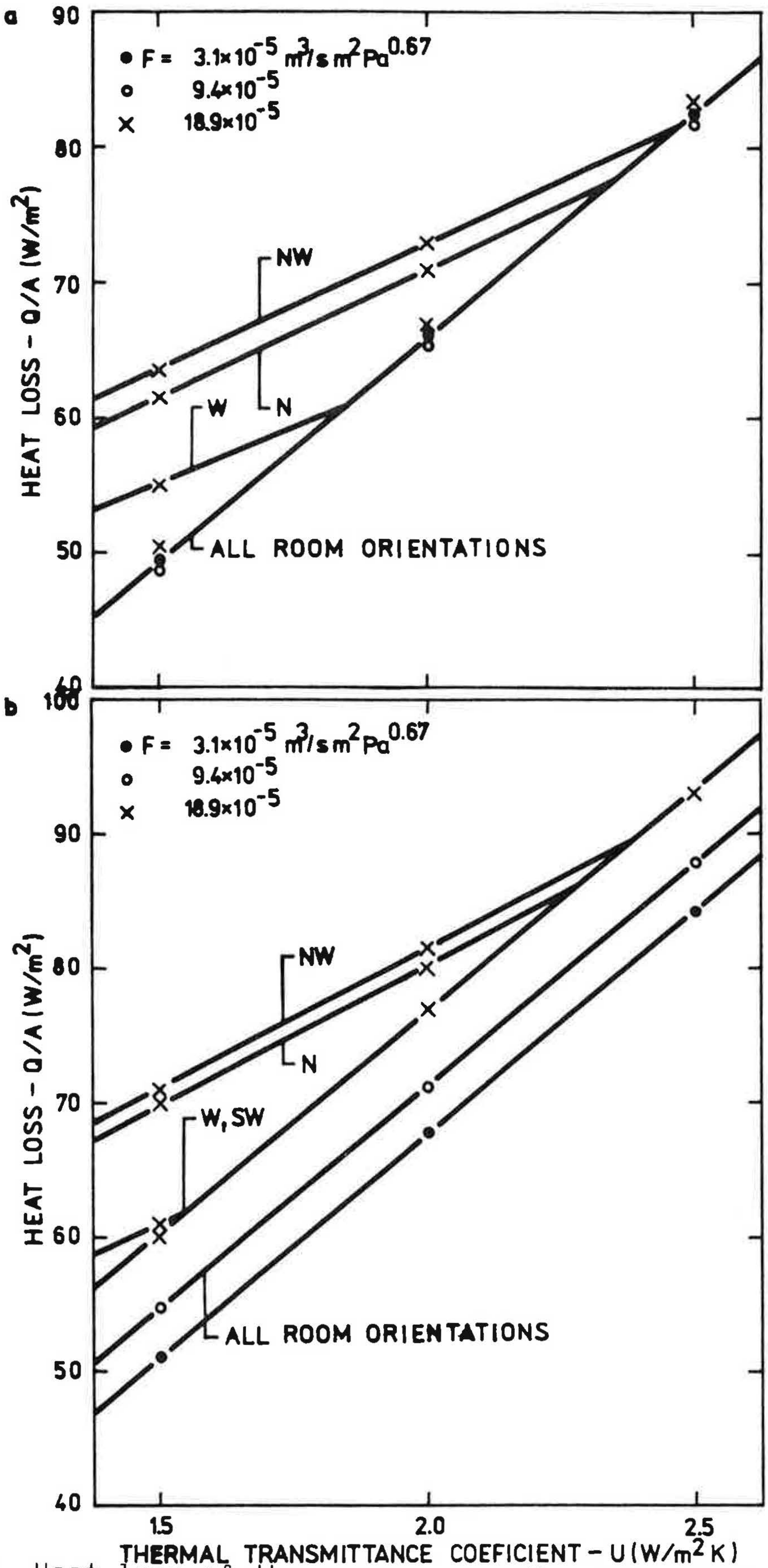

Fig. 3. Heat loss of the room a - on the 18th floor, b - on the 13th floor.

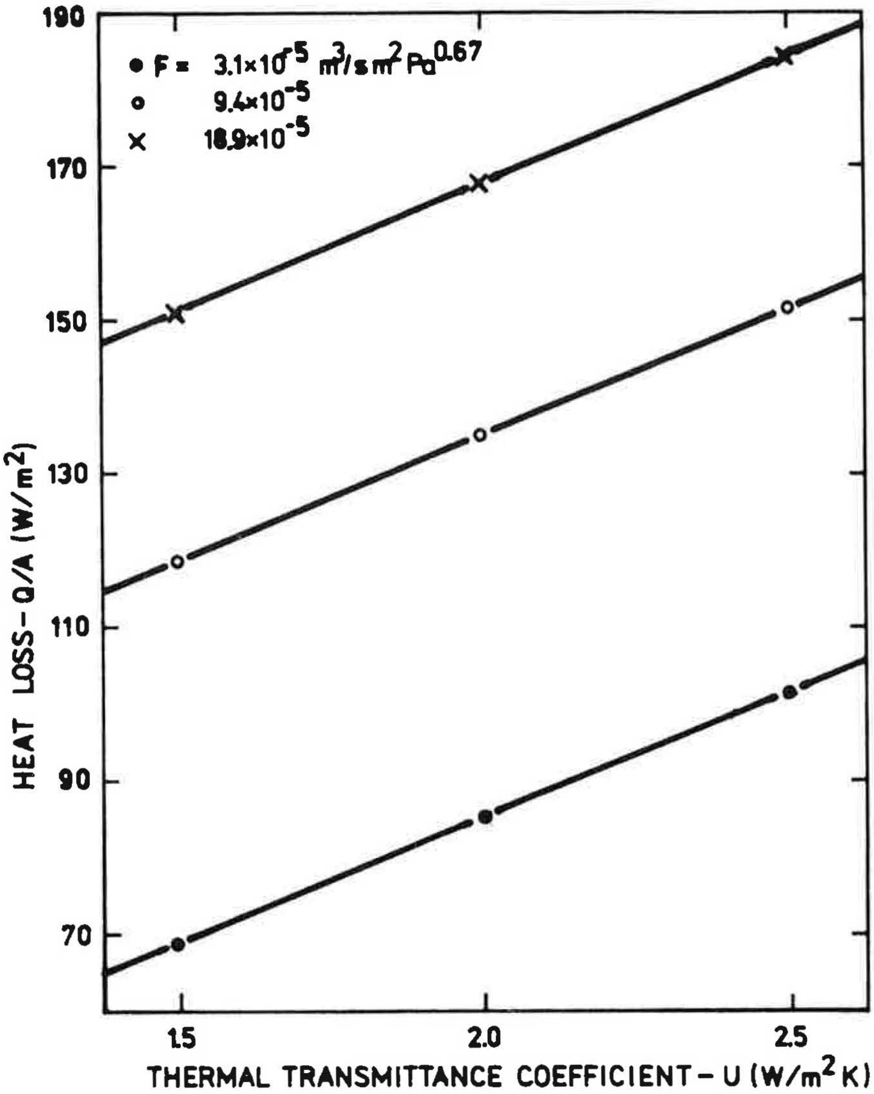

Fig. 4. Heat loss of the room on the 3rd floor.

4. Conclusions

The main findings of the preliminary analysis of data are as follows:

- The heat lossed of the rooms above the NPL (18th floor) show that the heat losses are caused at the tight or average curtain walls only thrugh conductive transmission. The infiltration effect is evident only with the loose curtain wall.

- The heat losses of the rooms under the NPL (13th floor) show similar properties as the previous with the difference that the certain small percent forms also the stack-induced infiltration.

- For rooms situated well below the NPL (3rd floor), the heat losses in the total extent of U-values and F-values are only the function of the outdoor temperature.

Table 1. Proportion of infiltration and transmission heat loss.

Floor	F - value (m^3/m^2 s $Pa^{0.67}$)	U - value (W/m^2 K)	Infiltration/Transmission heat loss % Room orientation N	NW	W	SW
18th	$3.1 \cdot 10^{-5}$	1.5	0	0	0	0
		2.0	0	0	0	0
	$9.4 \cdot 10^{-5}$	2.5	0	0	0	0
	$18.9 \cdot 10^{-5}$	1.5	24*	28*	11*	0
		2.0	7*	10*	0	0
		2.5	0	0	0	0
13th	$3.1 \cdot 10^{-5}$	1.5	4	4	4	4
		2.0	3	3	3	3
		2.5	2	2	2	2
	$9.4 \cdot 10^{-5}$	1.5	11	11	11	11
		2.0	8	8	8	8
		2.5	6	6	6	6
	$18.9 \cdot 10^{-5}$	1.5	41*	44*	23*	22
		2.0	22*	23*	16	16
		2.5	13	13	13	13
3rd	$3.1 \cdot 10^{-5}$	1.5	33	33	33	33
		2.0	25	25	25	25
		2.5	20	20	20	20
	$9.4 \cdot 10^{-5}$	1.5	99	99	99	99
		2.0	74	74	74	74
		2.5	59	59	59	59
	$18.9 \cdot 10^{-5}$	1.5	199	199	199	199
		2.0	149	149	149	149
		2.5	120	120	120	120

* A part of heat loss is also wind-infiltration and in other cases only stack effect.

5. References

(1) Jackman P.J., Heat loss in buildings as a result of infiltration, Bldg.Ser. Eng., April 1974, 6-15.

(2) MO, Private communication. Meteorological Office, Bratislava

(3) Klems J.H., Methods of estimating air infiltration through windows, Energy and Buildings, Sept. 1983, 243-252.

(4) Lee Y. et al., Distribution of wind and temp.-induced.., Journal of Ind. Aerodyn., 1982, 10, 287-301.