NATURAL SHAFT VENTILATION - MEASUREMENT, SIMULATION, CONTRIBUTION TO BASIC VENTILATION

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Abstract

Extremely low air flow values have been found in newly constructed buildings with very tight envelopes. Very low rates of air flow through ventilation shafts are often caused by extreme high resistances of tight windows and doors. The exact determination of the chain of flow resistance factors, beginning with those of the building envelopes (of the building elements forming the envelope) through inner space up to the shaft heads, permits us to carry out realistic calculations of the efficiency of air infiltration and of shaft ventilation; this efficiency depends on the kind of window and door construction and on their position respectively. An enhanced algorithm is mentioned.

The concept of "natural ventilation" has been subdivided by the planners under

- infiltration and exfiltration through cracks and slots
- window airing (requiring activities by the inhabitants)
- shaft ventilation, consisting predominantly of exfiltration systems for interior rooms, rarely complete "natural ventilation" systems (consisting of infiltration and exfiltration shafts)

Experience gained about air exchange rates in Austrian dwellings (4) directed attention to natural shaft ventilation. Figure 1 illustrates the situation in well maintained "massive buildings" with wooden frame windows without special sealing and air shafts for rooms in the interior with existing air change rates of $n_i = 0.61 \pm 0.11\ h^{-1}$. Most of the buildings constructed since 1970 possess a very tight building envelope and infiltration rates of $n_i = 0.15 \pm 0.07\ h^{-1}$. In these buildings no significantly higher infiltration rates due to the existing shaft construction could be found. Two reasons for an envolvement in this matter can be cited:

- Shaft ventilation could contribute importantly to the hygienic improvement of indoor air.
- The first series of field measurements permit us to expect a great divergence between the air volume stream expected by the planners and that actually measured.

Field measurement results agree largely with the results obtained with an enhanced algorithm. This showed that the important influence of shaft ventilation efficiency is due to the entrance stream resistance of the building envelope and interior barriers (doors) obstructing the flow.

Figure 2 demonstrates empirical data from shaft air flow in a dwelling with

wooden frame windows without special sealing with different positions of the window and the interior door. When using corresponding pressure loss factors caused by barriers there is good agreement with calculation results. To be able to calculate infiltration we would have to know whole buildings leakage, which is the summation of all the microleaks. Our model is restricted to the dominant part:

window- and door slots.

Developing Esdorn's examination (2) of slot-air flows we found an estimate of the total pressure loss factor with different slot-width and length values in the flow directions (Figure 3)

To demonstrate the importance of the pressure loss factor the volume air stream has been computed by means of fixed parameters:

- shaft cross section
- average roughness of shaft interior surface
- temperature difference
- wind velocity
- different values of effective shaft height (Figure 4)

CALCULATION MODEL:

The calculation based on a one-cell model takes account of the chain of flow resistance factors, beginning with those of the building envelope through the inner space up to the head of the shaft, including also the wind effect on the shaft head and the internal pressure.

1. Transport promoting pressures

1.1. Buoyancy pressure (stack effect)

$$\Delta p_s = (\rho_a - \rho_i) g \cdot h_e \qquad (1)$$

or by using the ideal gas law:

$$\Delta p_s = \rho_a \cdot g \cdot h_e \frac{\Delta T}{T_i} \qquad (2)$$

Δp_s	Differential pressure (outside - inside) due to stack effect	[Pa]
ρ_a	Density of outside air	$[kg \cdot m^{-3}]$
ρ_i	Density of inside air	$[kg \cdot m^{-3}]$
g	Acceleration of gravity	$[m \cdot s^{-2}]$
h_e	Effective height of shaft	[m]
ΔT	inside-outside temperature difference	[K]
T_i	Absolute interior temperature	[K]

1.2. Wind induced pressure

$$\Delta p_w = (c_{pi} - c_{pa}) \frac{\rho_a \cdot v_s^2}{2} \qquad (3)$$

Δp_w	Differential pressure due to wind effect	[Pa]
c_{pi}	Pressure factor for interior room	[-]
c_{pa}	Pressure factor on the head of shaft	[-]

v_s Wind velocity at the level of the shaft end [ms^{-1}]

2. Restricting pressures

2.1. Pressure loss by friction

$$\Delta p_f = \lambda \cdot \frac{l}{d_H} \cdot \frac{\rho_i \cdot v_i}{2} \tag{4}$$

Δp_f	Differential pressure due to friction	[Pa]
λ	Friction factor	[-]
l	Flow distance in shaft	[m]
d_H	Hydraulic diameter	[m]
v_i	Average air velocity in shaft	[ms^{-1}]

2.2. Pressure loss due to single resistances in shaft

$$\Delta p_r = \Sigma\zeta \cdot \frac{\rho_i v_i^2}{2} \tag{5}$$

Δp_r	Difference pressure due to single resistances	[Pa]
ζ	Pressure loss factor	[-]

2.3. Pressure loss due to infiltration through slots (windows, doors)

$$\Delta p_i = z \cdot \frac{\rho_a v_f}{2} \tag{6}$$

z	Total pressure loss factor due to slot infiltration	[Pa]

$$z = \Sigma\zeta_s + \frac{\lambda_s l_s}{d_{Hs}} \tag{7}$$

v_f	Average air velocity in the slot	[ms^{-1}]

The volume air stream results from the balance equation:

$$\Delta p_s + \Delta p_w = \Delta p_f + \Delta p_r + \Delta p_i \tag{8}$$

An iterative loop in the computer programme is a likelihood. In case of very tight envelopes one may assume that infiltration obtains only through window- and door slots. In order to estimate the amount of infiltration we have developed the model described in greater detail in (1).

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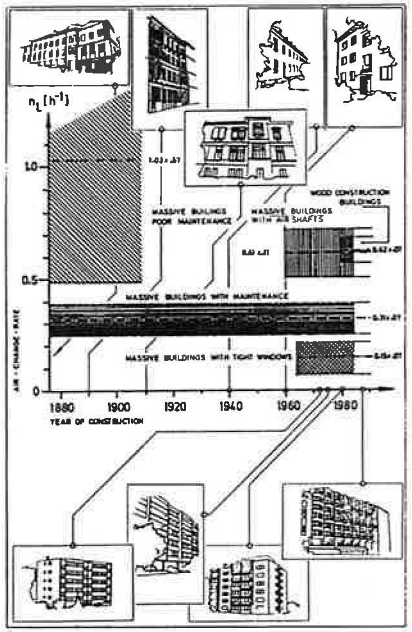

Figure 1:

Air infiltration rates in Austrian residences under winter conditions

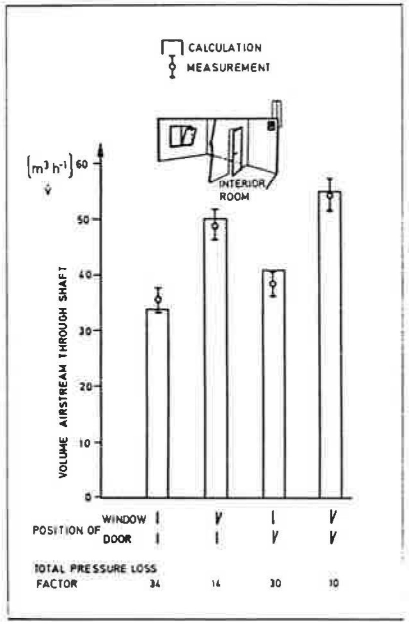

Figure 2:

Volume air stream through shaft vs. open/closed positions of the window and the interior door

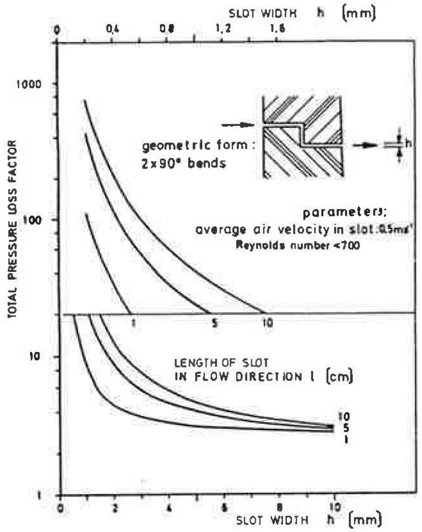

Figure 3:

Total pressure loss factor vs. slot width with different values of the length of slot in flow direction

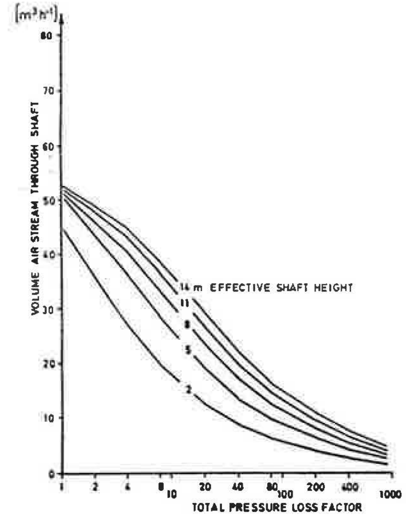

Figure 4:

Volume air stream through shaft vs. total pressure loss factor with different values of effective shaft height, examples calculated on the basis of the indicated model.

parameters:

shaft cross section	10/10 cm
temperature diff.	20 K
wind velocity	3 ms^{-1}
terrain class	III
wind pressure factor	-0.5
average roughness of shaft intern.surface	0.003 m

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AIR OUTLETS FOR DISPLACEMENT FLOW AND THEIR INFLUENCE ON FLOW PATTERN WITH VARIOUS KINDS OF HEAT SOURCES

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Abstract

Displacement flow is enabled by air outlets which inject the air with a very low and unidirectional velocity. The flow pattern in the room is mainly influenced by the kind and distribution of heat sources in the room. In recent years displacement flow has become and more popular, as a type of flow in air conditioned spaces. Three main tasks, namely

- to save energy,
- to improve comfort, and
- ventilation efficiency

were the main reasons to think about the advantages of this flow.

Equally distributed outlet and heat sources

The main difference between displacement and dilution or mixing flow is that the distribution of heat sources and the location of air outlets have an important influence on the flow, because buoyancy has an important local impact.

Two general types of displacement flow can be differentiated:

1. Flow from the ceiling to the floor,
2. Flow from the floor or the lower parts of the side walls to the ceiling.

The original understanding of displacement flow is a piston flow. This type is stable in a limited region of Ar-Numbers (see Annex).

In case of equal distribution of heat sources and air outlets this limitation was found by (1)

with Ar < 40 for downward and
Ar < 400 for upward flow.

Downward flow

Downward flow of this type is found in clean rooms with so called unidirectional flow. The total ceiling is covered by fabric which produces unidirectional flow. Downward flow with local outlets is given in the case of operation room air outlets.