FACULTY OF MECHANICAL ENGINEERING CTU IN PRAGUE

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

Ventilation

4. Natural ventilation

Bachelor / Master degree course

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Principle of ventilation

Natural ventilation

- is driven by pressure differences across the building envelope, caused by wind and air density differences because of temperature differences between indoor and outdoor air
- the flow of air through open windows, doors, grilles and other planned building envelope penetrations

Mechanical (forced) ventilation

- intentional movement of air into and out of building using mechanical force
- is driven by fans

Hybrid ventilation

Natural ventilation

The air flow is driven by pressure differences across the building envelope.

Pressure difference is caused by:

- air density differences (temperature differences between indoor and outdoor air)
- wind pressure

Natural ventilation

- **natural ventilation by large openings** (permanent)
- **shaft ventilation** (permanent)

heat source

- **interupted natural ventilation** (time limited)
- **infiltration** (time limited)

depends on
outdoor climatic
conditions

Natural ventilation

Balanced natural ventilation

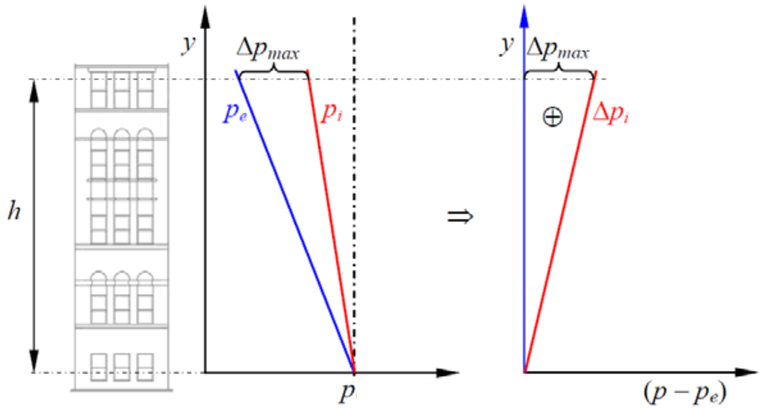
- for ventilation in industry with permanent heat gain – natural ventilation by large openings
- infiltration and interrupted ventilation – residential application etc.

Natural local exhaust

- shaft ventilation – industry

Natural ventilation

Stack pressure - hydrostatic pressure caused by the mass of a column air located inside or outside a building



Natural ventilation

Stack pressure difference

$$p_o = p - \rho_o g y$$
$$p_i = p - \rho_i g y$$

$$\Delta p = p_i - p_o = p - \rho_i g y - (p - \rho_o g y) = g y (\rho_o - \rho_i)$$

$$\Delta p_{max} = g \int_0^h (\rho_o - \rho_i)\, dy$$

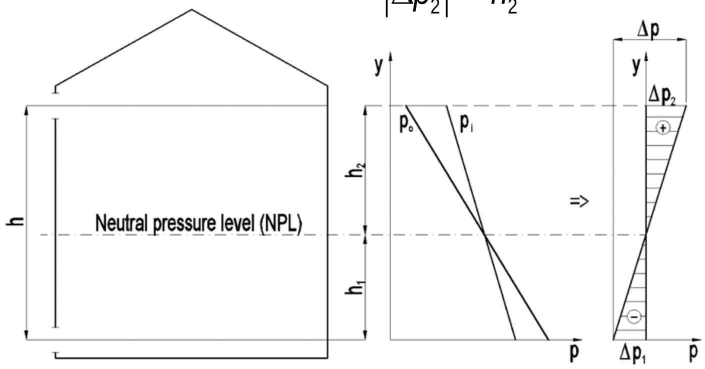
$$\Delta p_{max} = g h (\rho_o - \rho_i)$$

Natural ventilation

Neutral pressure level

$$\Delta p_{max} = |\Delta p_1| + |\Delta p_2|$$

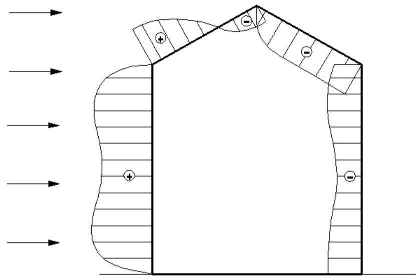
$$\frac{|\Delta p_1|}{|\Delta p_2|} = \frac{h_1}{h_2}$$



Natural ventilation

Wind pressure

$$p_w = C_p \frac{w^2}{2} \rho$$



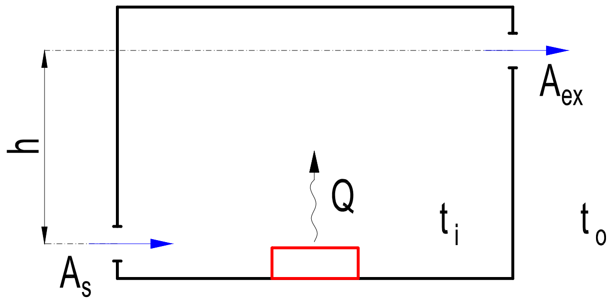
where C_p is wind surface pressure coefficient (empirical); it depends on wind direction, orientation of the building surface, …

C_p = -1.4 to 1.4

Natural ventilation by large openings

Technical rooms

(boiler room, current transformer room, junction exchange station, …)



→ **Goal** = design of openings area A_{ex}, A_s

Natural ventilation by large openings

Mass air flow

$$\dot{M} = \frac{\dot{Q}}{c\left(t_{ex} - t_s\right)}$$

$$t_s = t_o$$

$$t_{ex} = t_i$$

Openings area

$$M_{ex} = M_s = M$$

$$\mu_{ex} A_{ex} \rho_{ex} w_{ex} = \mu_s A_s \rho_s w_s \leftarrow \quad w_s = \sqrt{\frac{2\Delta p_s}{\rho_s}}$$

$$\frac{\Delta p_s}{\Delta p_{ex}} = \frac{\mu_{ex}^2}{\mu_s^2} \frac{\rho_{ex}}{\rho_s} \frac{A_{ex}^2}{A_s^2}$$

Natural ventilation by large openings

Discharge coefficient for opening μ

$$\mu = \alpha\varphi$$

where φ ...velocity coefficient [-]

α …coefficient of contraction [-]

$$\varphi = \frac{w}{w_t}$$ real and theoretical velocity ratio

$$\alpha = \frac{A'}{A}$$ real and theoretical area ratio

$$\mu = \frac{wA'}{w_t A} = \frac{V}{V_t}$$ real and theoretical volume flow ratio

Natural ventilation by large openings

Discharge coefficient for opening μ

Opening	H/B	Shutter angle α				
		15°	30°	45°	60°	90°
Supply air with louver	1	0,15	0,3	0,44	0,56	0,64
	0,5	0,13	0,27	0,39	0,56	0,61
Single baffle center-hinged	1	0,15	0,3	0,44	0,56	0,64
	0,1	0,13	0,27	0,39	0,56	0,61

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Natural ventilation by large openings

Pressure difference (stack effect)

$$\Delta p = hg\left(\rho_o - \rho_i\right) \qquad \rho = 1{,}293\frac{p}{101325}\frac{273}{273+t}$$

for pressure differences Δp_s, Δp_{ex} can be written

$$\Delta p = \Delta p_s + \Delta p_{ex}$$

Openings area [m^2]

$$A_s = \frac{M_s}{\mu_s\sqrt{2\Delta p_s \rho_s}} \qquad A_{ex} = \frac{M_{ex}}{\mu_{ex}\sqrt{2\Delta p_{ex}\rho_{ex}}}$$

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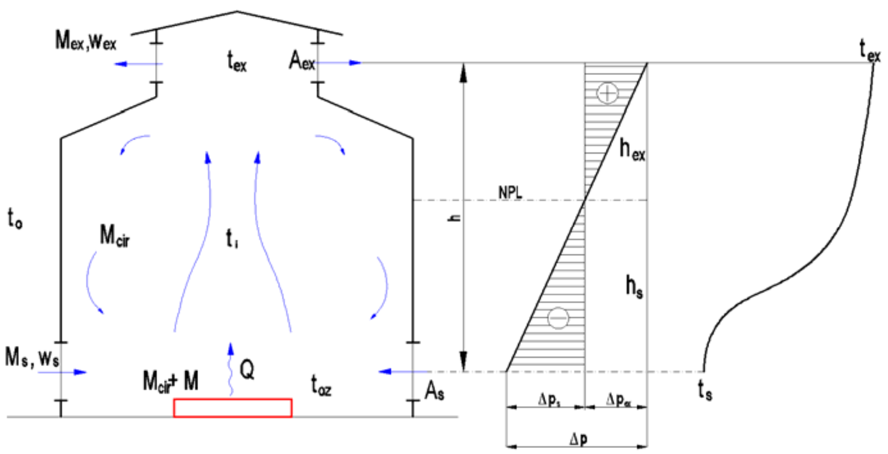
Natural ventilation by louvers

Industrial halls



Natural ventilation by louvers

Pressure difference (stack effect)

$$\Delta p = hg\left(\rho_o - \rho_i\right) \qquad t_i = \frac{t_{oz} + t_{ex}}{2}$$

Vertical air temperature changes $\rightarrow$ coefficient of heat removal efficiency B [-]

$$B = \frac{M_{rec}}{M + M_{rec}}$$

Natural ventilation by louvers

Heat balance

$$M_{rec}ct_{ex} + Mct_o = (M + M_{rec})ct_{oz}$$

$$B = \frac{t_{oz} - t_o}{t_{ex} - t_o} < 1$$

B = 0,25 to 0,4

- Summer: $t_{oz} - t_o \leq 5$ K; t_o = 25 °C
- Winter: $t_{oz,min}$ = 10 °C; t_o = 0 °C

} in Czech Rep.

Natural ventilation by louvers

Heat coefficient *B*

Industry application		*B*
Steel mill	basic furnace	0,30 - 0,35
	electric furnace	0,35 - 0,40
	cast hall	0,25 - 0,30
Rolling mill	furnace	0,25 - 0,30
	rolling section	0,25 - 0,45
Foundry	melting-house, cupola	0,40 - 0,45
	cast into ingots	0,37 - 0,40
	cooling section	0,65 - 0,70
Glass factory	tank furnace	0,26 - 0,30
	pot furnace	0,26 - 0,28

Natural ventilation by louvers

Louvers area calculation

- see page 11 to 14

Location of the openings in summer (by the floor) and winter (smaller openings and higher location - up to 4 m).

Shaft ventilation

- pressure difference due to stack effect

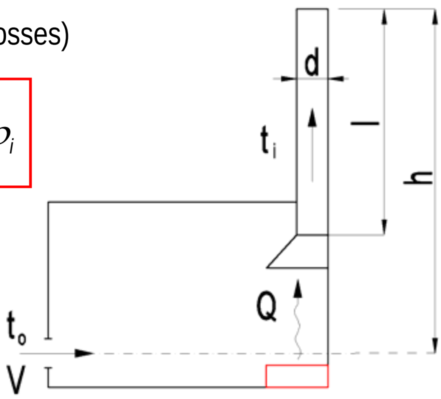
$$\Delta p = hg\left(\rho_o - \rho_i\right)$$

- pressure loss (friction and local losses)

$$\Delta p_{loss} = \left(\lambda \frac{l}{d} + \sum \zeta + 1\right)\frac{w^2}{2}\rho_i$$

$$\Delta p \geq \Delta p_{loss}$$

$$\dot{V} = \frac{\dot{Q}}{\rho c\left(t_i - t_o\right)}$$



Shaft ventilation

- **assumption:** the pressure in the shaft is approximately equal to atmospheric pressure

$$p_i = p_o$$

- effect of the area of the supply opening

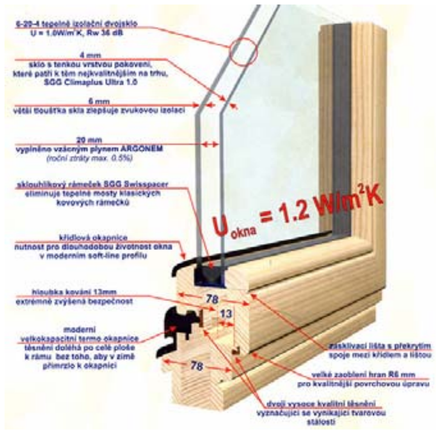
Infiltration

- uncontrolled natural ventilation through the cracks, gaps around closed windows and doors, mortar joints
- air leakage through the building envelope

- possitive effect of infiltration $\rightarrow$ ventilation
- negative effect of infiltration $\rightarrow$ heat losses in winter

- present $\rightarrow$ tight windows

Infiltration



Infiltration

Airflow through the gaps

$$V_o = \sum (i \cdot l) \Delta p^n$$

where Δp ...pressure difference across the leakage path [Pa]

i ... flow coefficient [m³/(s.m.Pa^{0,67})]

l ... lenght of the gaps [m]

n ... flow exponent n = 0,67

Ventilation heat loss

$$Q_{vent} = V_o \rho c \left(t_i - t_o\right)$$

Infiltration

Example:

Room 10 m², height 2,6 m, window 1,2 x 1,5 m, t_o = -12 °C, t_i = 20 °C

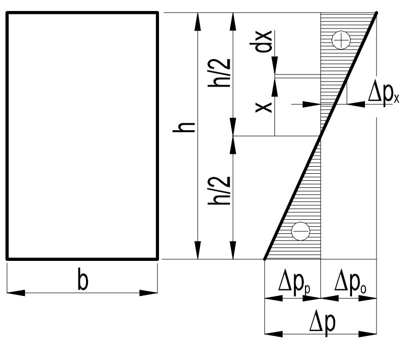
	i [m³/(m.s.Pa^0,67)]	*I* [h⁻¹]	Q_{vent} [W]
Old windows	0,00019	0,80	240
Requirements	0,00001 to 0,000087	0,02 to 0,36	6 to 109
Common windows	0,000025	0,10	31
Top windows	0,000004	0,02	5

Interupted natural ventilation

- casual opening of the window
- lower and higher parts of the window
- mass balance

$$\dot{M}_o = \dot{M}_{ex} = \dot{M}$$

$$\dot{M}_o = \mu \rho_e w_o S_o$$



$$d\dot{M} = \mu \rho_o \sqrt{\frac{2\Delta p_x}{\rho_o}} b dx = \mu \sqrt{2gx(\rho_o - \rho_i)\rho_e} b dx$$

Interupted natural ventilation

$$M = \mu b\sqrt{2g(\rho_o-\rho_i)\rho_o}\int_0^{h/2} x^{1/2}dx = \mu b\sqrt{2g(\rho_o-\rho_i)\rho_o}\,\frac{2}{3}\left(\frac{h}{2}\right)^{3/2}$$

$$= \mu\frac{2}{3}b\sqrt{2g(\rho_o-\rho_i)\rho_o\left(\frac{h^3}{8}\right)}\ldots$$

$$M = \mu\frac{1}{3}b\sqrt{g(\rho_o-\rho_i)\rho_o h^3}$$

Natural ventilation of technical room

Example 1: Junction exchange station
Calculate A_s = ? and A_{ex} = ?

Internal heat gains	Q = 5 kW	
Outdoor air temperature	t_o = 30 °C	(in summer)
Max. indoor air temperature	t_i = 35 °C	(in summer)
Atmospheric pressure	p = 100 kPa	

h = 3 m
$\mu_s = \mu_{ex}$ = 0.65
$A_{ex} = A_s$

$$\rho = 1.293\frac{p}{101325}\frac{273}{273+t}$$

Natural ventilation by louvers

Example 2: Calculate A_s = ? and A_{ex} = ?

Internal heat gains	Q = 150 kW	
Outdoor air temperature	t_o = 25 °C	(summer)
Temp. in occupied zone	... see lecture	
Atmospheric pressure	p = 100 kPa	

h = 12 m

B = 0.35

μ_s = 0.75; μ_{ex} = 0.65

A_{ex} / A_s = 1 / 2

$$\rho = 1.293 \frac{p}{101325} \frac{273}{273 + t}$$

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Thank you for your attention

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