Example: Determination of loads on a building envelope

This worked example explains the procedure of determination of loads on a portal frame building. Two types of actions are considered: wind actions and snow actions.

### Basic data

- **Total length**: \( b = 72,00 \text{ m} \)
- **Spacing**: \( s = 7,20 \text{ m} \)
- **Bay width**: \( d = 30,00 \text{ m} \)
- **Height (max)**: \( h = 7,20 \text{ m} \)
- **Roof slope**: \( \alpha = 5,0^\circ \)

Height above ground:

\[
\begin{align*}
  h &= 7,30 \text{ m} \\
  \alpha &= 5^\circ \\
  h' &= 7,30 - 15 \tan 5^\circ = 5,988 \text{ m}
\end{align*}
\]

### 1 Wind loads

#### Basic values

Determination of basic wind velocity:

\[
v_b = c_{dir} \times c_{season} \times v_{b,0}
\]

Where:

- \( v_b \) basic wind velocity
- \( c_{dir} \) directional factor
- \( c_{season} \) seasonal factor
- \( v_{b,0} \) fundamental value of the basic wind velocity

Fundamental value of the basic wind velocity (see European windmap):

\[
v_{b,0} = 26 \text{ m/s (for Aachen - Germany)}
\]

Terrain category II \( \Rightarrow z_0 = 0,05 \text{ m} \)

\[
z > z_{\text{min}}
\]

\[
v_b = c_{dir} \times c_{season} \times v_{b,0} = 26 \text{ m/s}
\]

For simplification the directional factor \( c_{dir} \) and the seasonal factor \( c_{season} \) are in general equal to 1,0.

#### Basic velocity pressure

\[
q_b = \frac{1}{2} \times \rho \times v_b^2
\]

where:

- \( \rho \) air density \( = 1,25 \text{ kg/m}^3 \)

\[
q_b = \frac{1}{2} \times 1,25 \times 26^2 = 422,5 \text{ N/m}^2
\]

#### Peak pressure

\[
q_{p}(z) = \left[1 + 7l(z)\right] \frac{1}{2} \times \rho \times v_{m}(z)^2
\]

Calculation of \( v_{m}(z) \)

\[
v_m(z) = c_{dir}(z) \times c_{0}(z) \times v_b
\]

Calculation of \( v_{ad}(z) \)

\[
v_{ad}(z) = c_1(z) \times c_0(z) \times v_b
\]
Where: $c_o(z)$ is the orography factor
$c_r(z)$ is the roughness factor

$$c_o(z) = k_r \times \ln \left( \frac{z}{z_o} \right) \quad \text{for} \quad z_{\text{min}} \leq z \leq z_{\text{max}}$$

$$c_r(z) = c_r(z_{\text{max}}) \quad \text{for} \quad z \leq z_{\text{min}}$$

Where: $z_o$ is the roughness length
$k_T$ is the terrain factor, depending on the roughness length $z_o$ calculated using

$$k_T = 0.19 \times \frac{z_o}{z_{o,B}}$$

Where: $z_{o,B} = 0.05$ (terrain category II)

$z_{\text{min}}$ is the minimum height
$z_{\text{max}}$ is to be taken as 200 m

Calculation of $l_v(z)$

$turbulence intensity$

$$l_v(z) = \frac{k_r}{c_o(z) \times \ln(z/z_o)} \quad \text{for} \quad z_{\text{max}} \leq z \leq z_{\text{max}}$$

$$l_v(z) = l_v(z_{\text{max}}) \quad \text{for} \quad z < z_{\text{max}}$$

Where: $k_t$ is the turbulence factor recommended value for $k_t$ is 1.0
$z = 7.30 \text{ m}$

so: $z_{\text{min}} < z < z_{\text{max}}$

$$q_p(z) = \left[ 1 + \frac{7}{c_o(z_{\text{max}}) \times \ln(z_{\text{max}}/z_o)} \right] \times \frac{1}{2} \times \frac{\rho \times v_s^2}{\text{wind profile}}$$

$$\times \left( \frac{k_t \times \ln(z/z_o)}{\text{turbulence}} \right)$$

$\left[ \text{wind profile} \right]$

$\left[ \text{turbulence} \right]$
b) duopitch roofs

with $\alpha = 5.0^\circ$, $\theta = 0^\circ$ (wind direction)

e = \min(\beta, \frac{h}{2}) = \min(72.00, 14.60) = 14.60 \text{ m}

$G$: $c_{pe} = -1.2$

$H$: $c_{pe} = -0.6$

$I$: $c_{pe} = -0.6$

$J$: $c_{pe} = 0.2 / -0.6$

$\Rightarrow c_{pe} = -0.6$

(see Table 7.4a, Note 1)

The internal pressure coefficient depends on the size and distribution of the openings in the building envelope.

Within this example it is not possible to estimate the permeability and opening ratio of the building. So $c_{pi}$ should be taken as the more onerous of $+0.2$ and $-0.3$. In this case $c_{pi}$ is unfavorable when $c_{pi}$ is taken to $+0.2$.

Wind loads

The wind loadings per unit length $w$ (in kN/m) for an internal frame are calculated using the influence width (spacing) $s = 7.20 \text{ m}$:

$$w = (c_{pe} + c_{pi}) \times q_p \times s$$

Internal and external pressures are considered to act at the same time. The worst combination of external and internal pressures are to be considered for every combination of possible openings and other leakage paths.

Characteristic values for wind loading in [kN/m] for an internal frame:

- zones D, E, G, H, I and J

- G: $w = 9.18$

- H: $w = 5.25$

- J: $w = 5.25$

- I: $w = 5.25$

- D: $w = 4.59$

- E: $w = 3.28$

The wind pressure acting on the internal surfaces of a structure, $w_i$, should be obtained from the following expression

$$w_i = q_p(z_i) \times c_{pi}$$

where: $z_i$ is the reference height for the internal pressure

$c_{pi}$ is the pressure coefficient for the internal pressure
2 Snow loads

General

Snow loads on the roof should be determined as follows:

\[ s = \mu_i \times c_e \times c_t \times s_k \]

where:
- \( \mu_i \) is the roof shape coefficient
- \( c_e \) is the exposure coefficient, usually taken as 1.0
- \( c_t \) is the thermal coefficient, set to 1.0 for normal situations
- \( s_k \) is the characteristic value of ground snow load for the relevant altitude

Roof shape coefficient

Shape coefficients are needed for an adjustment of the ground snow load to a snow load on the roof taking into account effects caused by non-drifted and drifted snow load arrangements.

The roof shape coefficient depends on the roof angle.

\[ 0^\circ \leq \alpha \leq 30^\circ \Rightarrow \mu_1 = 0.8 \]

Snow load on the ground

The characteristic value depends on the climatic region.

For a site in Aachen (Germany) the following expression is relevant:

\[ s_k = (0.264 \times 2 - 0.002) \times \left[ 1 + \left( \frac{A}{256} \right)^2 \right] \text{kN/m}^2 \]

Where:
- \( z \) is the zone number (depending on the snow load on sea level), here \( z = 2 \)
- \( A \) is the altitude above sea level, here \( A = 175 \text{ m} \)

\[ s_k = (0.264 \times 2 - 0.002) \times \left[ 1 + \left( \frac{175}{256} \right)^2 \right] = 0.772 \text{kN/m}^2 \]

\[ s = 0.8 \times 1.0 \times 1.0 \times 0.772 = 0.618 \text{ kN/m}^2 \]

spacing = 7.20 m

\[ \Rightarrow \text{for an internal frame:} \]

\[ s = 0.618 \times 7.20 = 4.45 \text{ kN/m} \]

\[ s = 4.45 \text{ kN/m} \]