Wind load calculations

Calculations using a real building and special programs. Wind load calculations, its distribution, stiffness and stability of wall panels, their study and practical use.

LAB University of Applied Sciences
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Abstract

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Title of the thesis

Title of the Bachelor’s Thesis Wind load calculations

Calculations using a real building and special programs. Wind load calculations, its distribution, stiffness and stability of wall panels, their study and practical use.

Degree, Field of Study

Engineer (UAS), Civil Engineering

Organisation of the client

Kosplan Oy

Abstract

The thesis was devoted to the study of loads acting on buildings. The parts analyzed and identified in the work included: walls and a roof. More attention was paid to wind loads, as a custom-made calculator was later made on them. The main purpose of the analysis was to define the principle of wind load calculations, as well as to explain the operation of calculation calculators. Previously, calculations were carried out manually, using a large number of materials to find the necessary formulas. However, in the modern world, there are various programs and applications that automate this process. In this thesis, the calculations for loads and stability were studied, and the formulas and the knowledge gained were applied and combined in electronic format, in the form of an Excel file. Of course, there are more complex calculation methods, but this one was the most capacious, demonstrating and explaining all the principles. Then other ready-made calculators were tested and analyzed for subsequent calculations. The main task was to explain and show their features, thereby facilitating their further use by interested parties. The thesis was aimed to show the basic things and give basic information that will allow to start deepening into the topic of loads for future self-studying or using official resources.

Keywords

wind loads, loads, calculations, Excel, civil engineering, house

Contents

1 Introduction

Finland is famous for the quality of its houses. Small low-rise wooden or sometimes concrete houses are very common and popular. Construction standards are treated responsibly, and all necessary measures and rules are invariably observed in the process of construction of new facilities.

Figure 1. An example of a Finnish house (Hillman)

Understanding the effects of loads and their impact on the stability of the entire building is essential to ensure the stability and durability of the building, as well as safety. When a built house “fails” in the form of a sagging roof, thick cracks along the facade and other awkwardness, you need to understand that in most cases the cause of such problems was incorrect design calculations.(Adapted from Simply Architects) Therefore, the profession of a civil engineer is of great importance and carries with its great responsibility, high standards and requirements for understanding your business. In this thesis, some points will be clarified so that the achievement of such a level is faster and easier for everyone.

The purpose of this thesis work is to clarify the principles of calculating wind loads and forces, starting with the most basic facts and definitions. Calculations will be carried out using the house made by the customer (Kospan Oy). At the request of the client, it is also required to develop a simple calculator based on an Excel file, so that you can quickly estimate approximate loads for subsequent calculations and drawings. The main requirement of the client is to quickly obtain information (before that, everything was considered manually or by eye), in order to understand how to proceed further based on it. In addition, the task is to explain the program (to make a guide) for the stiffness of the wall plates for Kosplan Oy. It will make it even easier to carry out calculations and understand which specific plates and fasteners they will need, withstand and fit for a building. However, despite the many points, all explanations and calculations will be performed in the simplest format with idealized conditions. Particular cases are calculated in a similar way but using additional formulas and with less clear and convenient coefficients that can be viewed additionally.

2 Concept of loads

2.1 Types of the loads

To begin with, the very concept of loads should be analysed. In can be anything started with what we count, what we find and why we need it.

Loads in building mechanics – force effects that cause changes in the stress-strain state of structures of buildings and structures. The loads most often considered in the calculation of building structures are the masses of bodies (and not always only the physical mass, and sometimes also the inertial one) and the pressure difference.

In structural mechanics, the following types of loads are distinguished (Adapted from iSo-promat.ru.):

1. Origin:

- No Payloads for the perception of which the structure is being built (equipment, cranes, transport, hydrostatic pressure in dams)
- Self-weight of structures
- Natural loads (wind, snow, earthquakes, etc.)

2. By duration of action:

- The constant is its own weight and some types of payloads
- Temporary, subdivided into:

a) Long

b) Short-term (weight of people, atmospheric load)

c) Special (seismic, temperature, supports settlements).

3. By the nature of the action:

- Static - the magnitude, direction and position of the load are unchanged in time (no inertia)
- Dynamic - loads causing inertial forces.

The structural system of a building must withstand these two types of loads. Their meaning will become clearer if they are disclosed in more detail, as well as by giving examples of these loads. Please note that the example involves loads that have already been mentioned earlier in another principle of separating loads by type.

Static loads:

They act on the structure for a long time and gradually reach their peak without sudden jumps. The building reacts slowly to such loads, and its deformation reaches its maximum at the maximum static force.

This includes:

1. Permanent load - the weight of walls, ceilings, roofs and all permanent elements of the building, including communications.
2. Snow load - the load created by the accumulated snow on the building. It depends on the geometry of the roof, the construction area and the area itself (openness of the territory, wind).
3. Temporary ("live") load - the load that is created by all moving and moving objects, for example, people in the building, temporary equipment / mechanisms, etc. It acts, as a rule, vertically, but can also act horizontally, which reflects its dynamic nature.
4. Impact load - short-term kinetic load from moving vehicles, equipment and mechanisms.

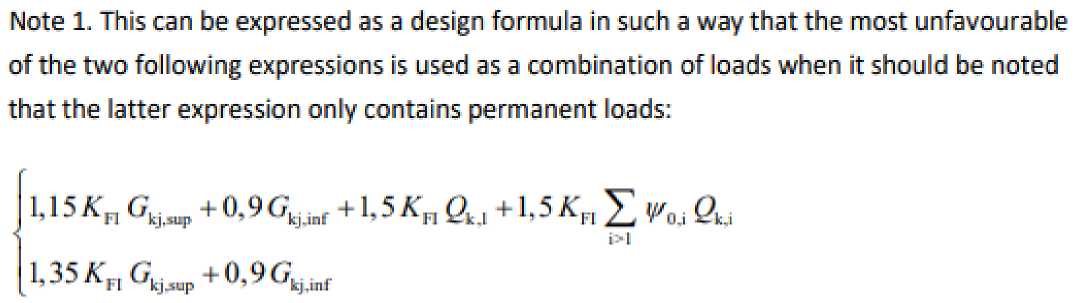
Dynamic loads:

They act on the building for a short time, often with a large and sharp difference in values or in different areas. Under the action of a dynamic load, internal forces are formed in the building, depending on its mass, and the magnitude of the deformation does not always correspond to the magnitude of the applied force.

Two main types of dynamic loads:

- Seismic - characteristic of geographic areas with seismic activity (in such areas, in general, their own specifics of construction and design). However, there is no need for this in Finland.
- Wind load is the force generated due to the kinetic energy of a mass of air moving in a horizontal direction.

When calculating structures, loads and actions should be considered in the most unfavourable combinations. Eurocodes (EN 1990 and EN 1991) mention a large number of load combinations depending on many factors. The values of the coefficients in their calculation are also presented there. Together, these two documents provide a methodology for combination of actions (combinations of loads) for the calculation of limit states. Tables 2, 3 and 4 provide the values to be used in Finland for the symbols of Tables A1.2(A), A1.2(B) and A1.2(C) of SFS-EN 1990.



Note 1. This can be expressed as a design formula in such a way that the most unfavourable of the two following expressions is used as a combination of loads when it should be noted that the latter expression only contains permanent loads:

$$\begin{cases} 1{,}15\,K_{\mathrm{FI}}\,G_{\mathrm{kj,sup}} + 0{,}9\,G_{\mathrm{kj,inf}} + 1{,}5\,K_{\mathrm{FI}}\,Q_{\mathrm{k,1}} + 1{,}5\,K_{\mathrm{FI}} \sum_{i>1} \psi_{0,i}\,Q_{\mathrm{k,i}} \\ 1{,}35\,K_{\mathrm{FI}}\,G_{\mathrm{kj,sup}} + 0{,}9\,G_{\mathrm{kj,inf}} \end{cases}$$

Figure 2. Note 1. (National Building Code of Finland, 2016)

There are basic, additional, and special combinations of loads (Adapted from iSopromat.ru.):

- The main ones are permanent + long-term temporary and one of the most significant short-term temporary loads.
- Additional are permanent + temporary long-term and all short-term temporary loads.
- Special combinations are permanent + temporary long-term + all short-term temporary plus special loads.

When the load exceeds the permissible value, it can lead to sad consequences, such as the destruction of individual parts, as well as the entire structure.

2.2 Wind loads

Why wind load? The fact is that, for example, with a snow load, there are usually no problems because it lends itself to the senses. This load is visible, we can touch it and even weigh it. Unfortunately, the wind load works differently. Wind is the movement of air masses that are not recognized in the surrounding space. We can only feel and see their effect on us or other objects.

2.2.1 The reason of calculating wind loads

Obviously, the wind affects structures, and sometimes even very strongly, dangerously and destructively: it tears off roofs, demolishes and tilts walls and fences, and so on. In connection with this, in the process of studying the wind, there is an opportunity to face many issues related to accounting, calculation and finding the wind force. These points are disclosed in various articles and textbooks. However, non-professionals really do not like to calculate the wind load, and there is an explanation for this - its calculation is much more complicated than the calculation of the snow load.

Figure 3. Consequences of wind loads (KORZHIK.NET 2016)

Figure 4. Consequences of wind loads (KORZHIK.NET 2016)

Mostly it depends on:

- The angle at which the wind hits the structure
- Structure shape (height, width, etc.).
- Terrain type

2.2.2 Wind Damage Prevention Methods

Prevention of wind damage includes strengthening areas where building collapse may happen. All building elements such as walls, foundations and roofs must be strong, and the connections between them must be strong and reliable. For a structure to withstand wind action, it must conduct loads from the roof to the foundation.

The wind acts on the structure by three types of forces:

- Lift load is the pressure of the wind flow, which creates a strong lifting effect, very similar to the effect of the wings of an aircraft. The flow of wind under the roof pushes up; wind flow over the roof pulls up.
- Shear load is the horizontal wind pressure that can cause the walls to sway and tilt the building.
- Lateral load - horizontal pushing and pulling pressure on the walls, which can cause the structure to slide off the foundation or topple over.

Strong wind pressure can shatter doors and windows, rip off roofing and roof decking, and destroy gable end walls. Roof overhangs and other elements that tend to trap air underneath, resulting in high lift forces, are particularly susceptible to damage. Broken windows and doors can seriously damage the contents of a building due to internal wind pressure and water intrusion (Municipality of Anchorage).

The actual impact of wind forces on agricultural buildings depends on their design, structure and environment. Local windbreaks - trees - can help mitigate these impacts.

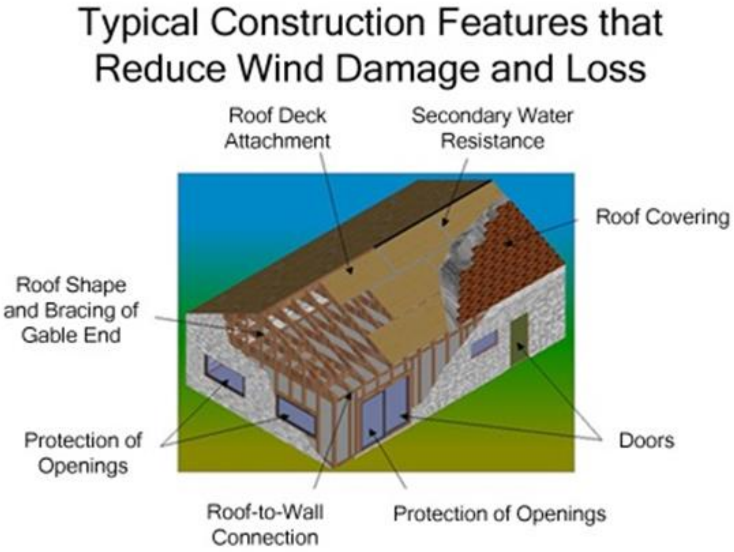


Figure 5. Construction features (Pro-tec 2017)

Fortunately, Finland does not have the highest wind strengths, as well as the low height of buildings, which reduces the chance of the most dangerous cases. However, the influence of wind must be taken into account when calculating the stability and shear of a building.

3 Calculations

3.1 Three stages

In the project, a special Eurocode - EN 1991-1-4 (2005) “Wind actions” was used to study and explain how to calculate wind loads.

Before counting, divide our task into stages. The first is finding the main parameters, indicators, and values such as:

- peak velocity pressure q_p
- basic wind velocity V_b
- reference height Z_e
- turbulence intensity I_v
- mean wind velocity $V_{m.}$

The main task to be reached is to determine the value of peak velocity pressure q_p. In addition to the above, we will have to find other coefficients, that were not mentioned here.

The second one would be finding wind pressures, which is the pressure exerted by moving air (wind) on obstacles.

And the third one is wind forces on structures.

All the parameters are explained in the following text.

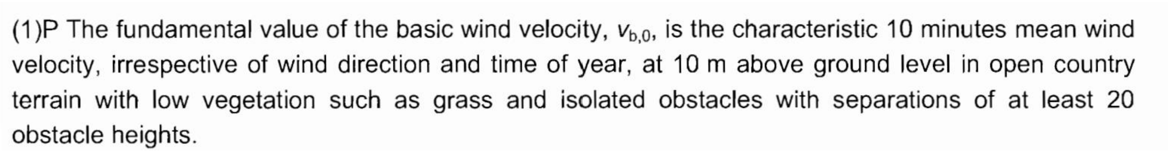
3.1.1 Main parameters

1) Basic wind

The magnitude of wind loads is influenced by various factors. It is important to know where our building is located and to know its dimensions. What is the terrain of the territory we need, what kind of country and region is it, and what is the average wind speed in this place?

a) V_{b0} (fundamental Basic Wind Velocity)

According to RIL 201-1-2011 and the EN 1991-1-4 (2005), we find out that the basic wind speed V_b that we are looking for is called the average value of the wind speed over 10 minutes.



(1)P The fundamental value of the basic wind velocity, $v_{b,0}$, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10 m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

Figure 6. The fundamental basic wind velocity (EN 1991-1-4 2005)

b) V_b is the basic wind velocity

It should be calculated as:

$$V_b = V_{b0} * c_{dir} * c_{season} \tag{1}$$

- V_{b0} is the fundamental value of basic velocity, which was shown before
- $c_{dir} * c_{season}$ are directional and season factors which can be found in National Annex (Often, they are taken as 1)

That is why in most cases the values of “Basic wind velocity” and “Fundamental value of basic velocity” are the same.
Sometimes the coefficient V_{b0} in the formula is replaced by another coefficient c_{prob} in case of annual excess in mean wind velocity.

$$c_{prob} = (\frac{(1 - K * \ln(-\ln(1 - p))}{(1 - K * ln(-ln(0{,}98)))})^n \tag{2}$$

- K is the shape parameter (depending on the coefficient of variation of the extreme-value distribution) (recommended to be taken as 0,2)
- n is the exponent (recommended to be taken as 0,5). (EN 1991-1-4 2005)

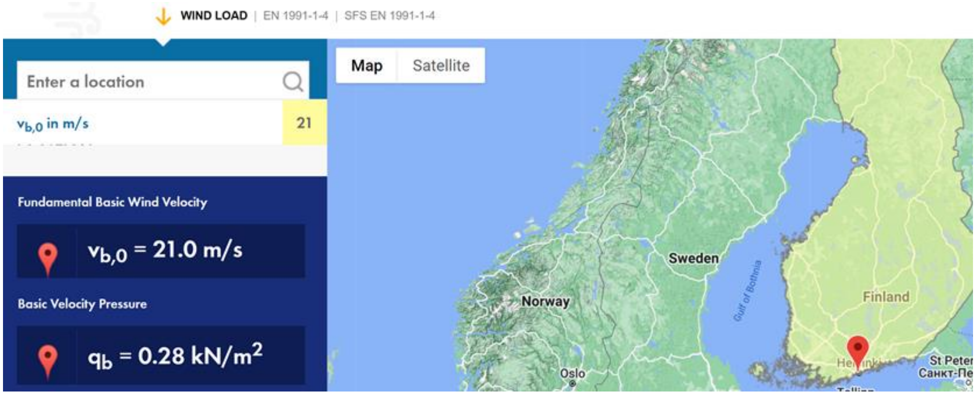
This values may be also given in National Annex.

Basic wind velocity is different:

in continental regions	in sea areas	in zones of the hills/mountains
21 m/s	22 m/s	26 m/s

Table 1. Basic wind velocity (Finnish National Annex 2019)

There is also a website which shows the basic wind velocity. It allows to quickly determine the value just by entering the name of the country or city.



$v_{b,0}$ in m/s: 21

Fundamental Basic Wind Velocity

$v_{b,0} = 21.0$ m/s

Basic Velocity Pressure

$q_b = 0.28$ kN/m^2

Figure 7. Basic wind velocity (Adapted from Dlubal)

2) Mean wind

$$V_{m(z)} = c_{r(z)} * c_{0(z)} * V_b \tag{3}$$

As it shows, it depends on the roughness of the terrain, orography and the main wind speed (basic wind velocity) taken at a certain height Z.

- $c_{r(z)}, c_{0(z)}$ are respectively the factors of these dependents
- $c_{0(z)}$ (the orography factor) is recommended to be taken as 1
- $c_{r(z)}$ (the roughness factor) is calculated separately.

The roughness factor $c_{r(z)}$ takes into account and looks at how the average wind speed changes in the area due to different terrain (height above ground level and the roughness of the terrain on the leeward side of the structure in the considered wind direction).

Let’s start with the small the roughness length explanation.

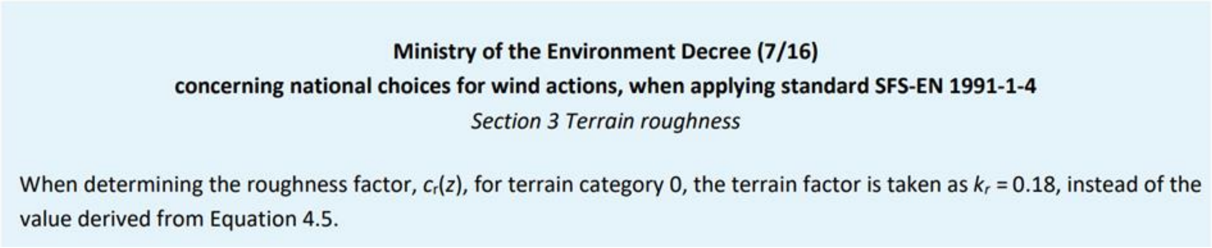
- Z_0 is the roughness length
- k_r - terrain factor
- Zmin is the minimum height
- Zmax is to be taken as 200 m
- $Z_{0,\,II}$ – depends on terrain category.

So, the formulas are:

$$c_{r(z)=K_r * \ln\left(\frac{z}{z_0}\right)}, \text{ for z between } z_{min} \text{ and } z_{max} \tag{4}$$

(5)

$$K_r = 0{,}19 * \left(\frac{z_0}{z_{0,II}}\right)^{0{,}07}$$



Ministry of the Environment Decree (7/16)
concerning national choices for wind actions, when applying standard SFS-EN 1991-1-4
Section 3 Terrain roughness

When determining the roughness factor, $c_r(z)$, for terrain category 0, the terrain factor is taken as $k_r = 0.18$, instead of the value derived from Equation 4.5.

Figure 8. Features of the factor on the territory of Finland (Finnish National Annex 2019)

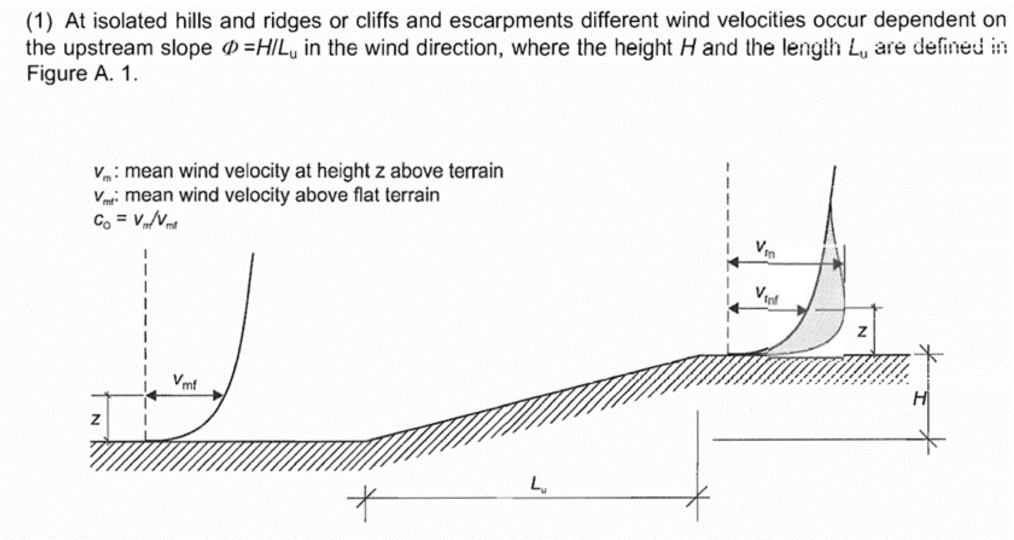
Or:

$$c_{r(z)=c_r(zmin)}, \text{ for } z \le z_{min} \tag{6}$$

The terrain categories and terrain parameters can be found in the special table represented as a Figure 11 and Appendix 1.

When it is a situation when we must choose between two or more categories of terrain in our region, then the area with the smallest roughness length should be used.

Also, if the orography (e.g., hills, rocks, etc.) increases wind speed by more than 5%, it is important to take the effects into account by using the special orography factor c_0. Since the basic principle of the calculation is shown here, we will not go into detail at this point. However, for particular cases, all the necessary information is provided in the EN 1991-1-4 (2005).



(1) At isolated hills and ridges or cliffs and escarpments different wind velocities occur dependent on the upstream slope $\Phi = H/L_u$ in the wind direction, where the height H and the length L_u are defined in Figure A. 1.

v_m: mean wind velocity at height z above terrain
v_{mf}: mean wind velocity above flat terrain
$c_o = v_m/v_{mf}$

Figure 9. Additional materials for calculating the coefficient (EN 1991-1-4 2005)

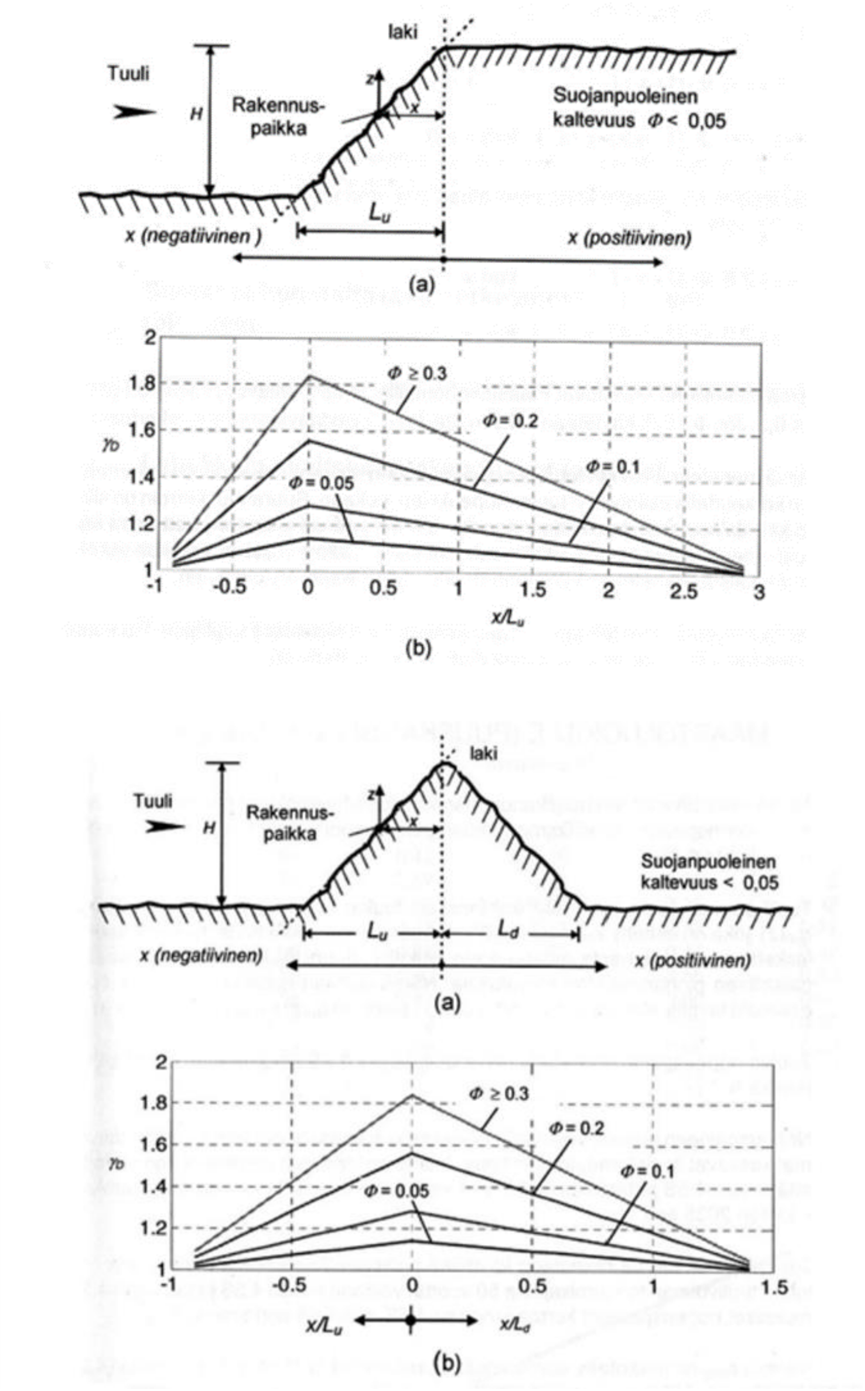


Figure 10. Additional materials for calculating the coefficient 2 (EN 1991-1-4 2005)

It can be seen from the diagrams that the steeper the rise and the closer the building is to its top, the greater the effect of elevation on wind pressure. For gentle irregularities, the effect will be less significant.

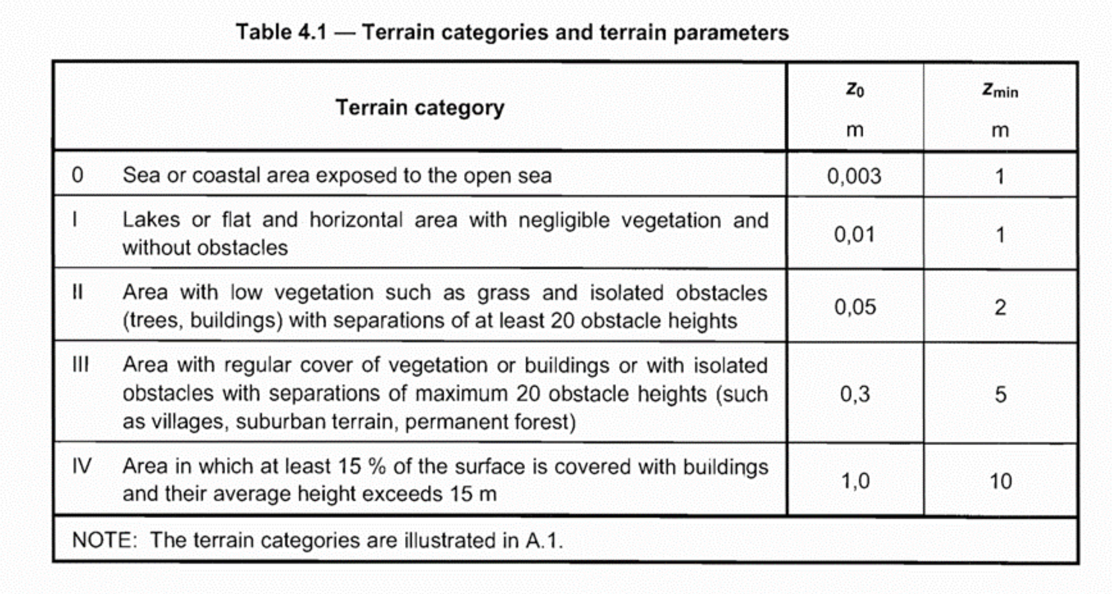


Table 4.1 — Terrain categories and terrain parameters

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A.1.			

Figure 11. Terrain category and parameters (EN 1991-1-4 2005)

The designation of the terrain categories is presented in Appendix 1.

3) Wind turbulence

Turbulence refers to the rapid fluctuations in wind speed. These fluctuations are due to two factors acting separately or simultaneously in combination. The first arises as a result of a friction force that occurs between moving air and the surface of the Earth. In general, this is a change in the speed and direction of the wind as a result of obstacles from natural objects - hills, mountains, forests, as well as human objects - buildings. The second important factor is sudden temperature changes or gradients, due to which the air moves quickly up and down.

The turbulent component of wind velocity has a mean value of 0 and a standard deviation 6_V.

A) Standard deviation 6_V:

$$6_V = K_r * V_b * K_I, \tag{7}$$

where K_I is the turbulence factor, which is supposed to be 1.

B) The turbulence intensity $I_{V(z)}$ at height z:

$$I_{V(z)} = \frac{6_V}{V_{m(z)}} = \frac{K_I}{c_{0(z)} * \ln\left(\frac{z}{z_0}\right)} \text{, for z between } z_{min} \text{ and } z_{max} \tag{8}$$

Or:

$$I_{V(z)} = I_{V(zmin)}, \text{ for } z<z_{min} \qquad (9)$$

4) Peak velocity pressure

The last thing we will look for in this section is the peak velocity pressure.

- ρ- air density, which depends on the height, temperature, and air pressure expected in the area during windstorms

According to the National building code of Finland, the air density is 1,25 kg/m^3.

- $c_{e(z)}$ is the exposure factor calculated as:

$$c_{e(z)} = \frac{q_{p(z)}}{q_b} \qquad (10)$$

- q_b is the basic velocity pressure:

$$q_b = \frac{1}{2} * \rho * V_b^2 \qquad (11)$$

The peak velocity pressure:

$$q_{p(z)} = \left(1 + 7 * I_{V(z)}\right) * \frac{1}{2} * \rho * V_{m(z)}^2 = c_{e(z)} * q_b \qquad (12)$$

If the area is mostly flat and the $c_{0(z)}$ is 1, then we can determine $c_{e(z)}$ by the function in the Figure 11 and make the calculation shorter and easier.

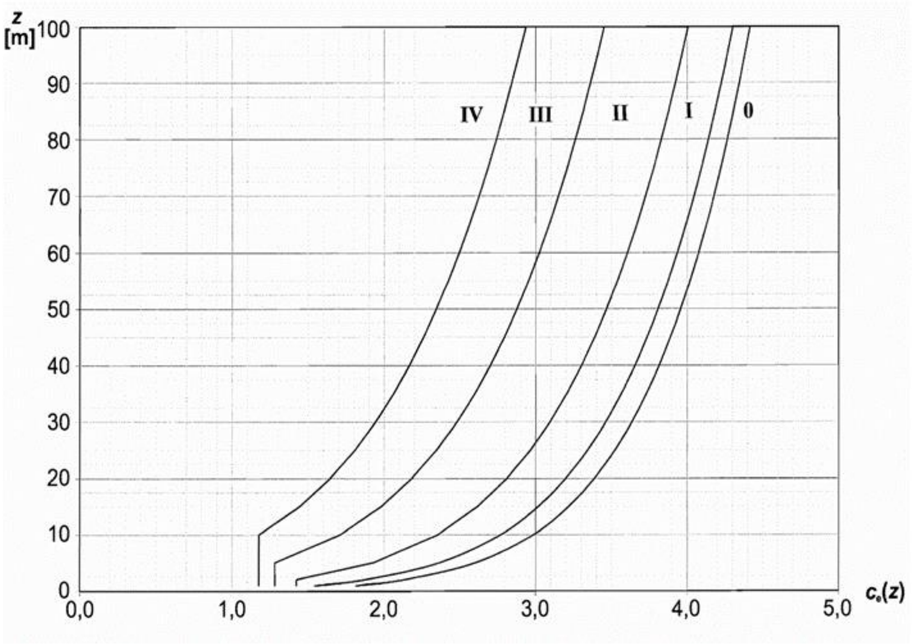


Figure 12. Illustration of the exposure factor (EN 1991-1-4 2005)

If a simplified method is enough for us, then we can also use the tables from RIL 201-1-2011. They are in Finnish, however the meaning is the same and tables are similar, so it is understandable to use. The table shows clearer values than just a graph.

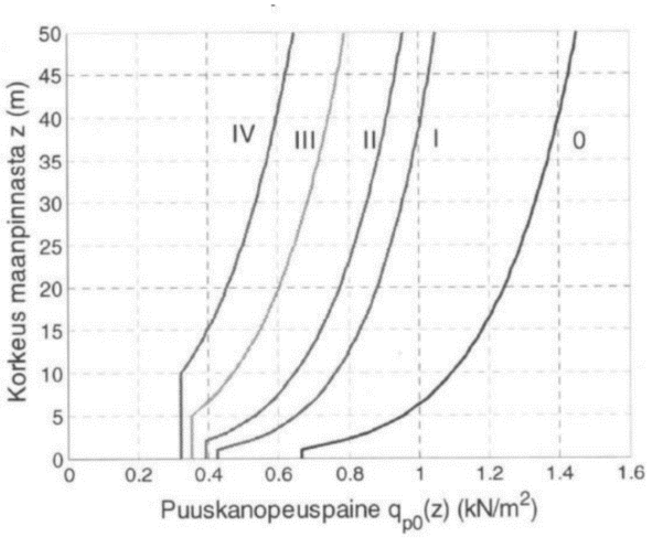
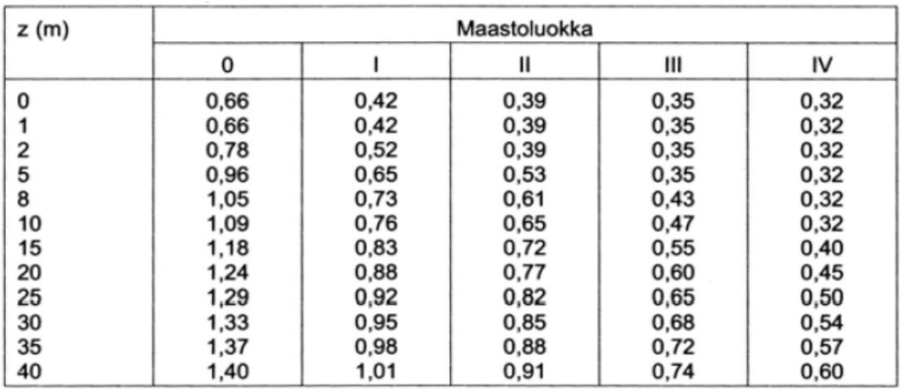


Figure 13. Illustration of the exposure factor (RIL 201-1-2011)



z (m)	Maastoluokka				
	0	I	II	III	IV
0	0,66	0,42	0,39	0,35	0,32
1	0,66	0,42	0,39	0,35	0,32
2	0,78	0,52	0,39	0,35	0,32
5	0,96	0,65	0,53	0,35	0,32
8	1,05	0,73	0,61	0,43	0,32
10	1,09	0,76	0,65	0,47	0,32
15	1,18	0,83	0,72	0,55	0,40
20	1,24	0,88	0,77	0,60	0,45
25	1,29	0,92	0,82	0,65	0,50
30	1,33	0,95	0,85	0,68	0,54
35	1,37	0,98	0,88	0,72	0,57
40	1,40	1,01	0,91	0,74	0,60

Figure 14. Exposure factor table (RIL 201-1-2011)

Once the gust pressure has been determined, the calculation can be continued by two different methods:

- the net wind force method
- the surface pressure method.

3.1.2 Wind pressure

Wind pressure can be divided as external and internal. Here are the formulas:

$$W_e = q_{p(z_e)} * c_{pe} \text{ and } W_i = q_{p(z_i)} * c_{pi}, \text{ where} \quad (13,14)$$

$q_{p(z)}$ is the peak velocity pressure, z is the reference height and c_p is the pressure coefficient.

The "plus" sign of the coefficients determines the direction of the wind pressure on the corresponding surface (active pressure), the "minus" sign - from the surface (suction).

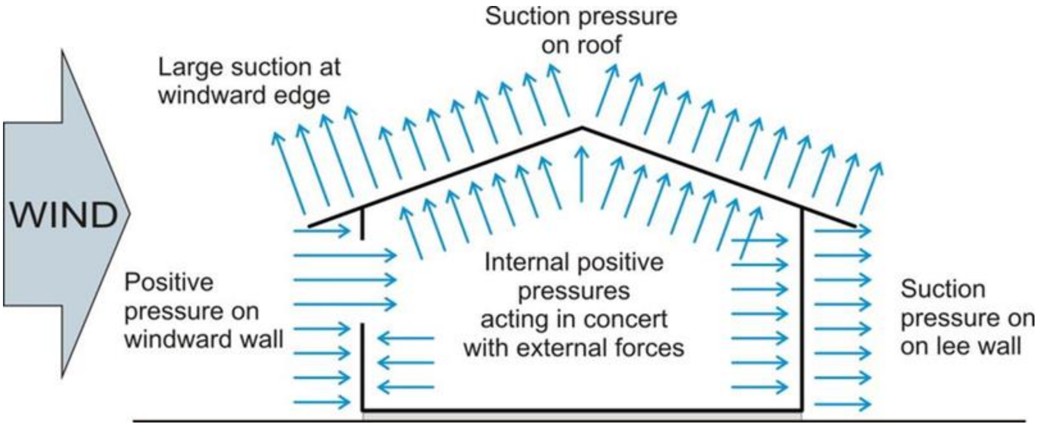
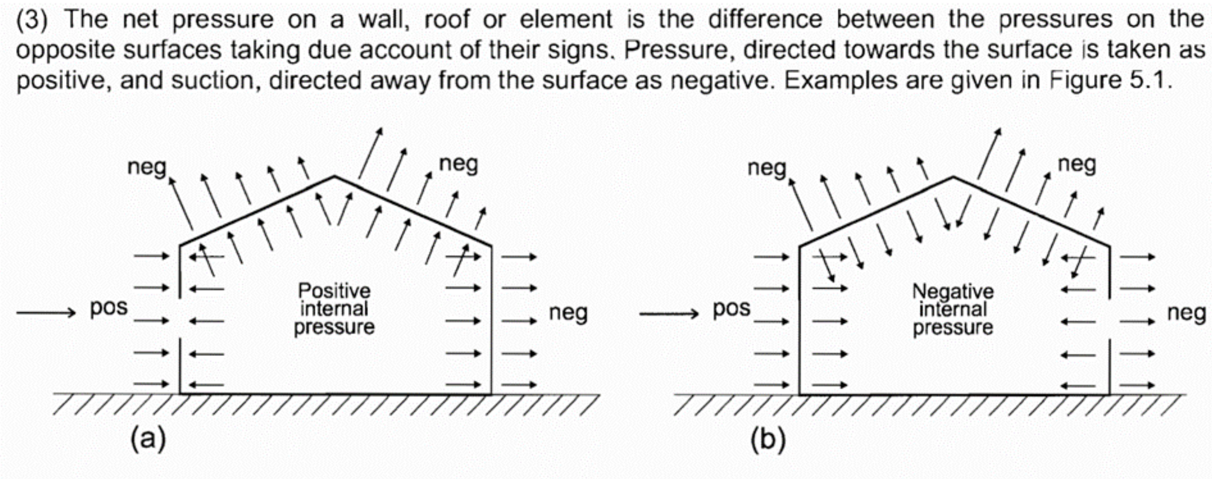


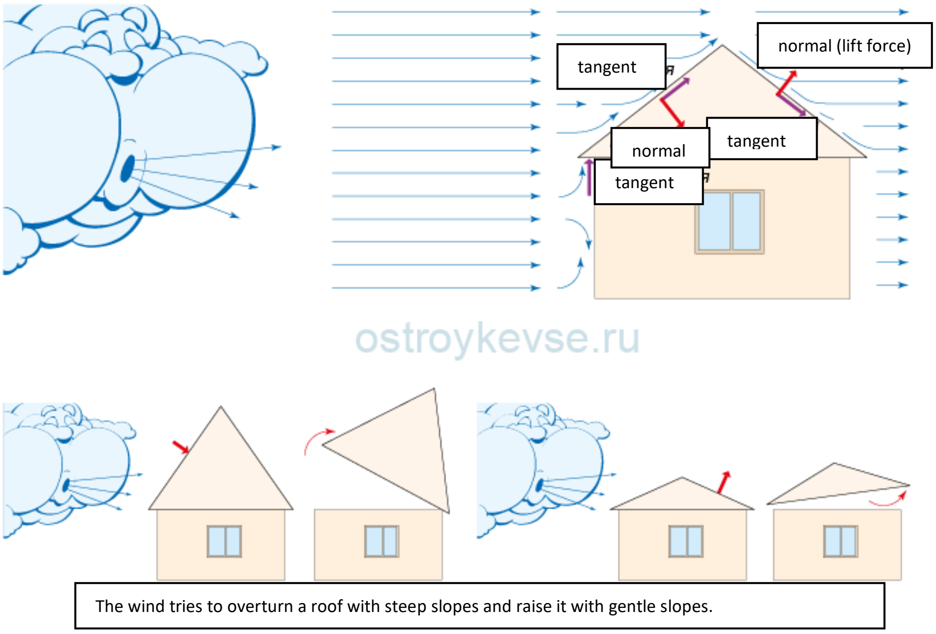
Figure 15. Illustration of wind pressure on a building (Smith and Henderson 2015, 47)



(3) The net pressure on a wall, roof or element is the difference between the pressures on the opposite surfaces taking due account of their signs. Pressure, directed towards the surface is taken as positive, and suction, directed away from the surface as negative. Examples are given in Figure 5.1.

Figure 16. Illustration of wind pressure on a building (EN 1991-1-4 2005)

On a funny and seemingly childish picture below (Figure 17), you can see the principle of how the wind works. With lateral wind pressure, the air flow collides with the wall and roof of the building. At the wall of the house, the flow is swirling, part of it goes down to the foundation, the other, tangentially to the wall, hits the eaves of the roof. The wind flow attacking the roof slope tangentially bends around the roof ridge, captures calm air molecules from the leeward side and rushes away. Thus, three forces arise on the roof at once, capable of tearing it off and overturning it - two tangents on the windward side and a lifting force generated from the difference in air pressure on the leeward side. Another force arising from wind pressure acts perpendicular to the slope (normal) and tries to push the roof slope inward and break it. Depending on the steepness of the slopes, the normal and tangential forces change their value. The greater the angle of inclination of the roof slope, the greater the value of the normal forces and the smaller tangents, and vice versa, on gentle roofs, the tangents take on greater values, increasing the lifting force from the leeward side and decreasing the normal force from the windward side. (Wind load 2015)



The wind tries to overturn a roof with steep slopes and raise it with gentle slopes.

Figure 17. The path of the wind (Wind load 2015)

Pressure coefficients (aerodynamic)

External pressure coefficients can be found from the tables. There are a lot of tables depending on the type of the building and its roof.

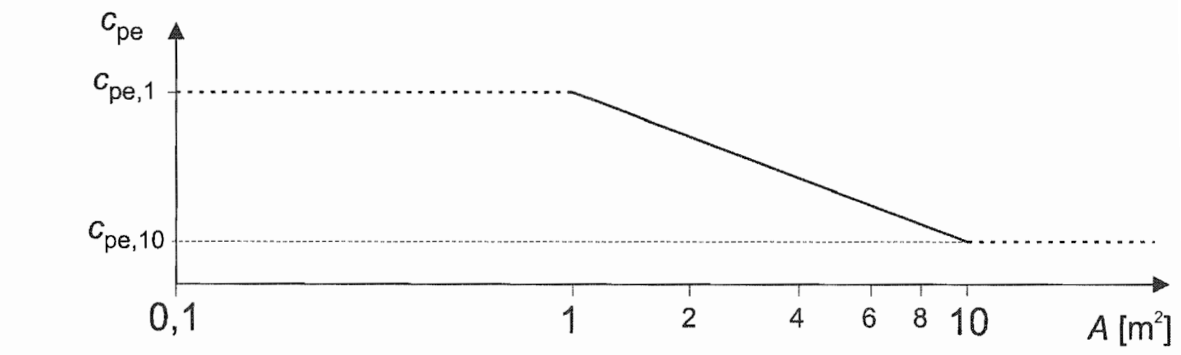
External pressure coefficients

general coefficients

1. when the loaded area is more than 10 m^2 (it can be used for a whole building)

local coefficients

2. when the loaded area is 1 m^2 (it can be used for the small parts, details and fasteners)



The figure is based on the following:
for 1 m^2 < A < 10 m^2 $c_{pe} = c_{pe,1} - (c_{pe,1} - c_{pe,10}) \log_{10} A$

Figure 18. How to determine the c_{pe} (EN 1991-1-4 2005)

Usually, when calculating, it is preferable to count differently. If small data is not important and the calculation is to find values for large elements, then the coefficient is considered as a general one. In more rare and special cases, the local coefficient is used more preferably.

Before finding the coefficients c_{pe}, the building should be divided (namely its walls) into sectors. The separation occurs depending on the ratio of the variables e, d and b. b is the length of the wall of the building which is perpendicular to the action of the wind. e is taken as either b or 2h, whichever is smaller. The figure below shows the division into sections. If e<d then we divide the lateral side parallel to the wind into 3 parts. If e>d, then into 2 parts and if e>5d, then it is one section. The sides perpendicular to the wind remain separated by one section. The dimensions of the sections (their lengths) are determined by the ratio of e and d, as shown in the figure. Depending on the ratio of the side and the height of the wall, other sections may appear on top. More details can be seen in Figure 22, which we use to find the reference height.

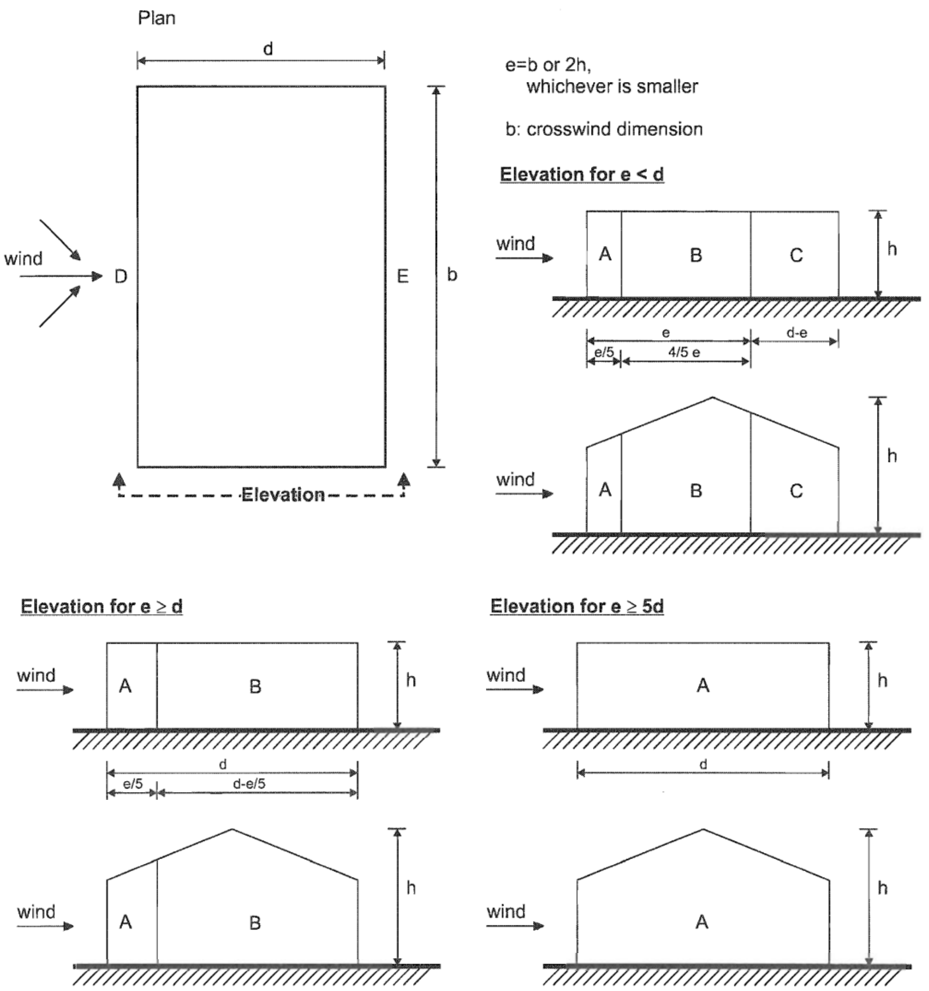


Figure 19. Key for vertical walls (EN 1991-1-4 2005)

Zone	A		B		C		D		E	
h/d	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1
5	-1.2	-1.4	-0.8	-1.1	-0.5		+0.8	+1.0	-0.7	
1	-1.2	-1.4	-0.8	-1.1	-0.5		+0.8	+1.0	-0.5	
<0.25	-1.2	-1.4	-0.8	-1.1	-0.5		+0.7	+1.0	-0.3	

Table 2. Zones and the external coefficients (EN 1991-1-4 2005)

The coefficients for the roof, as well as in general, all calculations and division into sectors are carried out in the same way as for the walls, but they also provide for the angular values of the slope of the roof and the type of roof itself.

Internal pressure coefficients

Internal and external pressure act simultaneously. The worst combination must be considered due to possible openings and other leakage paths.

The coefficient of internal pressure C_{pi} depends on the size and location of the openings in the building envelope (these can be windows, doorways, chimneys, ventilation passages and leaks through these objects and structures). If in at least two sides of a building (facade or roofs) the total area of openings in each side is more than 30% of the area of that side, the structural actions should be considered based on the data in the EN 1991-1-4 (2005). Checks are important for high internal walls (high risk of hazard) when the wall must withstand the full external wind action due to openings in the building envelope.

A building facade is considered dominant if the area of openings on this facade is at least twice the area of openings and leaks in other facades of the building in question. (EN 1991-1-4 2005)

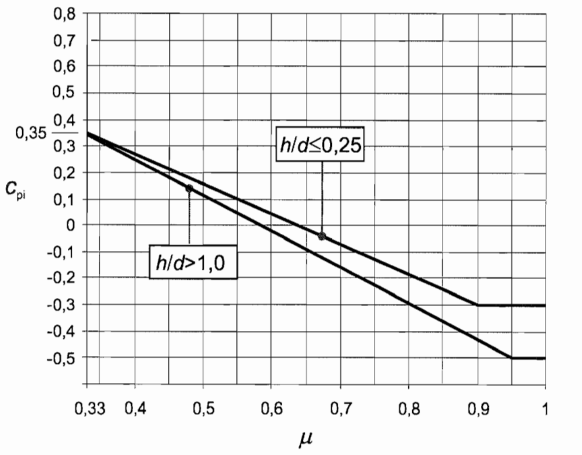
When the area of the openings at the dominant face is twice the area of the openings in the remaining faces:

$$c_{pi} = 0{,}75 * c_{pe} \tag{15}$$

When the area of the openings at the dominant face is at least 3 times the area of the openings in the remaining faces:

$$c_{pi} = 0{,}9 * c_{pe} \tag{16}$$

For buildings without a dominant facade, the internal pressure coefficient C_{pi} should be determined from a Figure 19, which is presented in the bottom.



NOTE For values between *h*/*d* = 0,25 and *h*/*d* = 1,0 linear interpolation may be used.

Figure 20. Key for vertical walls (EN 1991-1-4 2005)

It is the ratio of the height and depth of the building (h/d), and opening μ for each wind direction, which can be found by a special formula:

$$\mu = \frac{\Sigma area\ of\ openings\ where\ c_{pe}\ is\ negative\ or - 0{,}0}{\Sigma area\ of\ all\ openings} \tag{17}$$

3.1.3 Wind forces

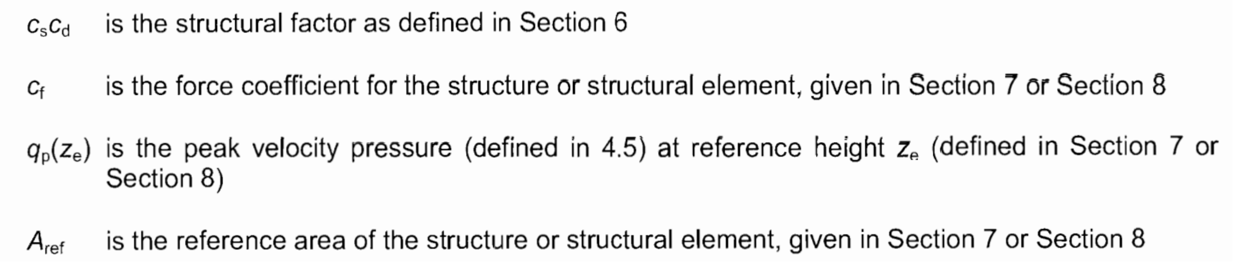
The force is the product of the structural factor, special coefficients, the reference area on which the wind and peak velocity pressure. The wind forces for the whole structure or a structural component should be determined: by calculating forces using force coefficients or by calculating forces from surface pressures.

A) The force for the whole building is:

$$F_w = c_s c_d * c_f * q_{p(z_e)} * A_{ref}\ , \tag{18}$$

otherwise we can summarize different forces on different elements:

$$F_w = c_s c_d * \Sigma c_f * q_{p(z_e)} * A_{ref} \tag{19}$$



c_sc_d is the structural factor as defined in Section 6

c_f is the force coefficient for the structure or structural element, given in Section 7 or Section 8

$q_p(z_e)$ is the peak velocity pressure (defined in 4.5) at reference height z_e (defined in Section 7 or Section 8)

A_{ref} is the reference area of the structure or structural element, given in Section 7 or Section 8

Figure 21. Definition of variables (EN 1991-1-4 2005)

B) The wind force F_w acting on a structure or structural element can be determined by the vector the sum of forces from external and internal pressures.

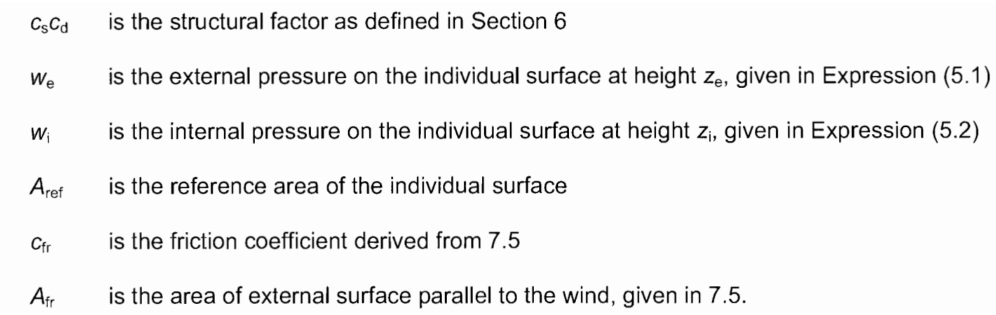
$$F_{w,e} = c_s c_d * \Sigma W_e * A_{ref} \text{ – external forces} \quad (20)$$

$$F_{w,i} = c_s c_d * \Sigma W_i * A_{ref} \text{ – internal forces} \quad (21)$$

$$F_{w,e} = c_{fr} * q_{p(z_e)} * A_{fr} \text{ – friction forces} \quad (22)$$

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other. Frictional forces, such as the traction needed to walk without slipping, can be helpful, but they also greatly hinder movement. Friction forces act in the direction of the wind components parallel to external surfaces. Data for finding the coefficient of friction can be easily taken from the EN 1991-1-4 (2005).

However, it will be problematic to calculate the vector sum from the drawings, so in this case, the first method of the calculation is more preferable.



$c_s c_d$	is the structural factor as defined in Section 6
w_e	is the external pressure on the individual surface at height z_e, given in Expression (5.1)
w_i	is the internal pressure on the individual surface at height z_i, given in Expression (5.2)
A_{ref}	is the reference area of the individual surface
c_{fr}	is the friction coefficient derived from 7.5
A_{fr}	is the area of external surface parallel to the wind, given in 7.5.

Figure 22. Definition of variables 2 (EN 1991-1-4 2005)

The important note is that, while counting walls or other elements, the wind force is calculated as the difference between the external and internal resultant forces.

Finding the required variables

1) Structural factor $c_s c_d$

According to EN 1991-1-4 (2005), the structural factor should take into account how the wind affects the non-simultaneous occurrence of peak wind pressures on the surface (c_s) together with the effect of structural vibrations due to turbulence (c_d).

Structural factor $c_s c_d$	
Size factor c_s	Dynamic factor c_d

Table 3. Structural factor

Usually this factor is taken as 1.

- When the building is less than 15 m

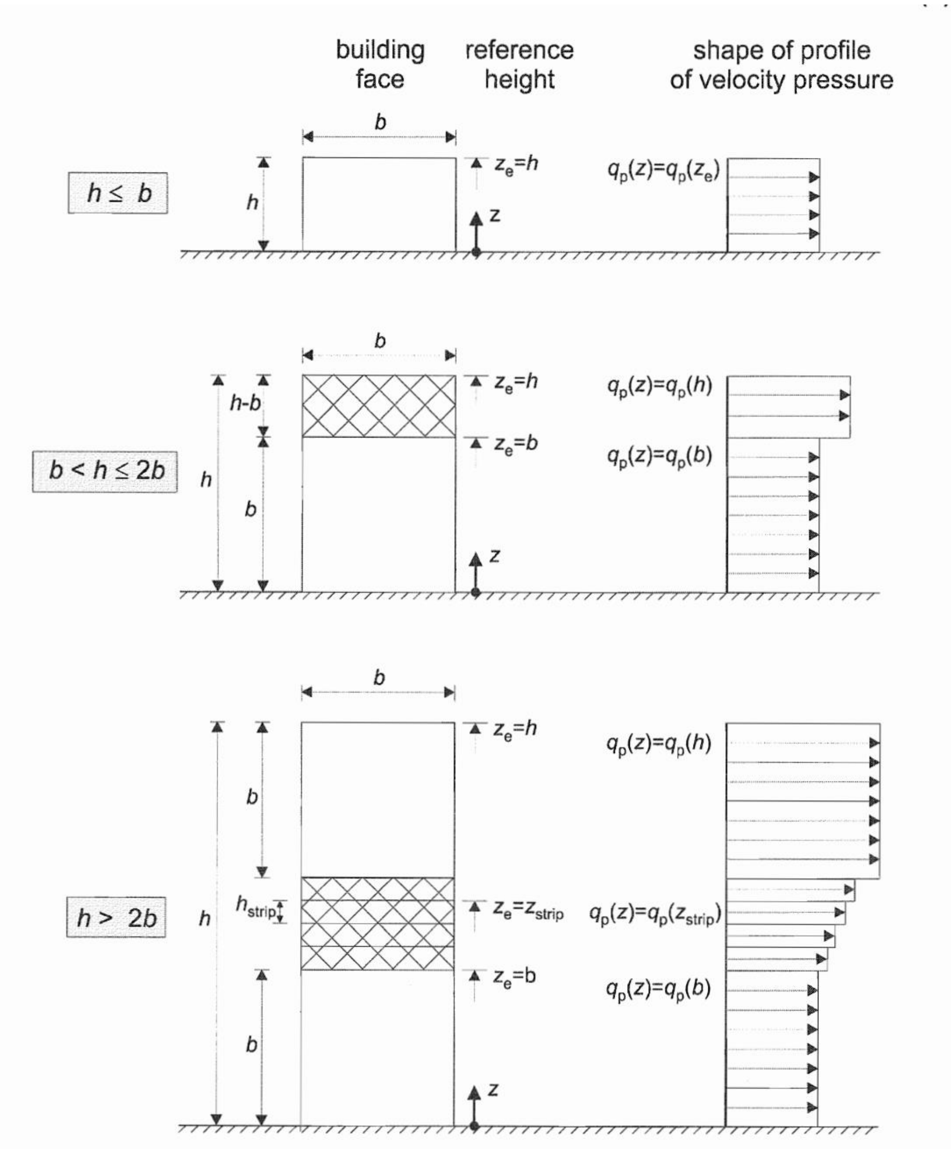
In this case, this option is the most suitable, since the task includes the calculation of low-rise buildings. In addition, as it was mentioned, Finland is dominated by the number of low buildings.

- When a facade and roof elements have a natural frequency of more than 5 Hz
- When frame buildings have load-bearing walls and their high are <100 m and less than 4 times the windward height.

Other cases are written in EN 1991-1-4 (2005) and its Annexes. It presents values not only for buildings, but also for roads, furnaces, etc. In addition, there is a formula for more unique cases and objects.

2) Reference height z_e and area A_{ref}

The structural dimensions and the reference height used are shown in the Figure 23.



NOTE The velocity pressure should be assumed to be uniform over each horizontal strip considered.

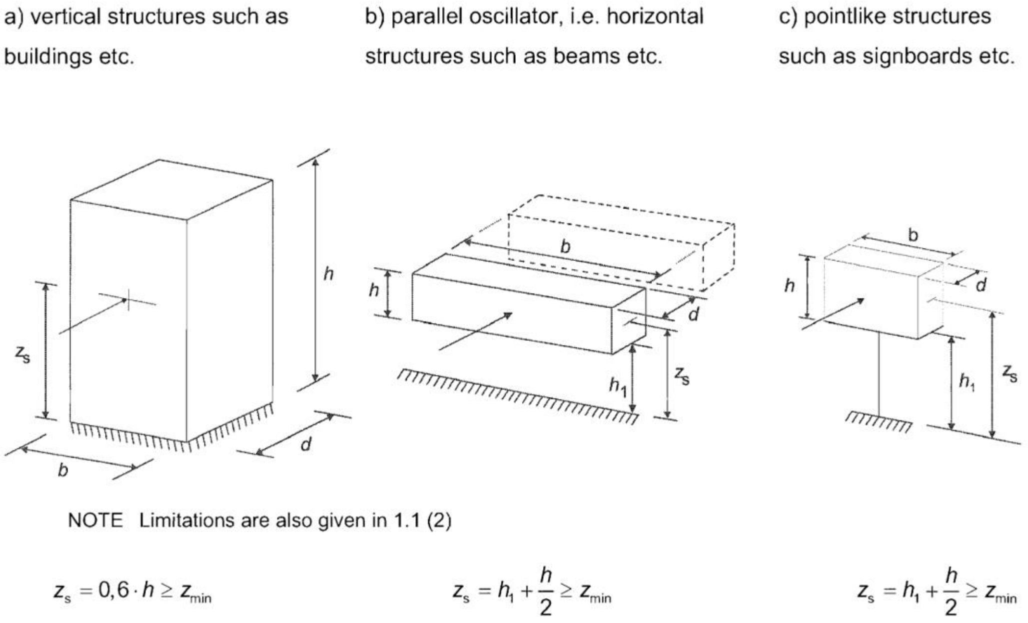
Figure 23. How to find a reference height, depending on a size of the building (EN 1991-1-4 2005)

As it shows, the reference heights Z_e for the windward walls of rectangular buildings depend on the aspect ratio h/b and are always the upper heights of the various parts of the walls. At higher altitudes, the pressure is greater.

There are three cases:

- When h<b, it is counted and taken as 1 object.
- When b<h<2b, it can be regarded as having 2 parts, consisting of: a lower part projecting upwards from the ground to a height equal to b, and an upper part consisting of the remainder.

- h>2b, may be composed of several parts, including: a lower part raised above the ground to a height equal to b; top part extending from top to bottom to a height equal to b, and the middle region, between the top and lower parts, which can be divided into horizontal stripes.



NOTE Limitations are also given in 1.1 (2)

$z_s = 0{,}6 \cdot h \geq z_{min}$

$z_s = h_1 + \frac{h}{2} \geq z_{min}$

$z_s = h_1 + \frac{h}{2} \geq z_{min}$

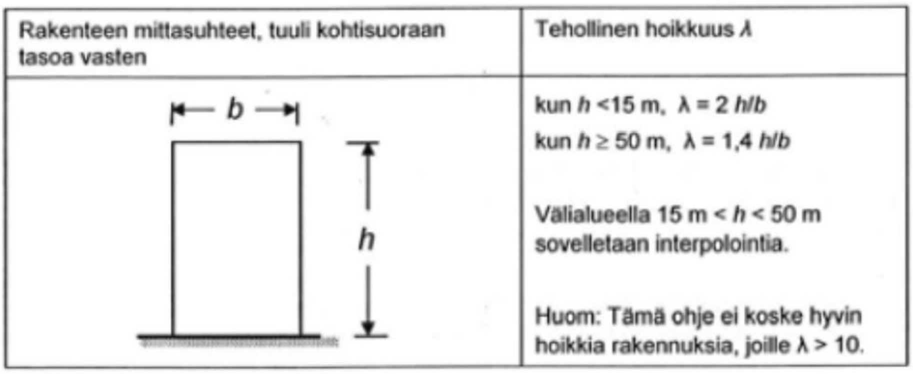
Figure 24. Shapes of structures (EN 1991-1-4 2005)

Reference area is just a height multiplied by width.

$$A_{ref} = h * b \tag{23}$$

3) Force coefficient c_f

To find the force factor, it is necessary to determine the effective slenderness (flexibility) of the building – λ , as well as the power factor – h/b (The b side is the side perpendicular to the wind and the d side is the side facing the wind direction). Everything is found with the help of tables and graphs presented below. Unlike the RIL 201-1-2011, the EN 1991-1-4 (2005) considers this coefficient in great detail and it is highly recommended that the readers familiarize themselves with this. However, the data from the RIL 201-1-2011 for Finnish calculations would be better to use. It's clearer and it is easier to use for quick calculations.



Rakenteen mittasuhteet, tuuli kohtisuoraan tasoa vasten	Tehollinen hoikkuus *λ*
	kun *h* <15 m, λ = 2 *h*/*b* kun *h* ≥ 50 m, λ = 1,4 *h*/*b* Välialueella 15 m < *h* < 50 m sovelletaan interpolointia. Huom: Tämä ohje ei koske hyvin hoikkia rakennuksia, joille λ > 10.

Figure 25. Effective slenderness (RIL 201-1-2011)

There are two ways: through a graph or calculated values in a table. In fact, the table is built on data from the graph. Suitable values must be sought through interpolation.

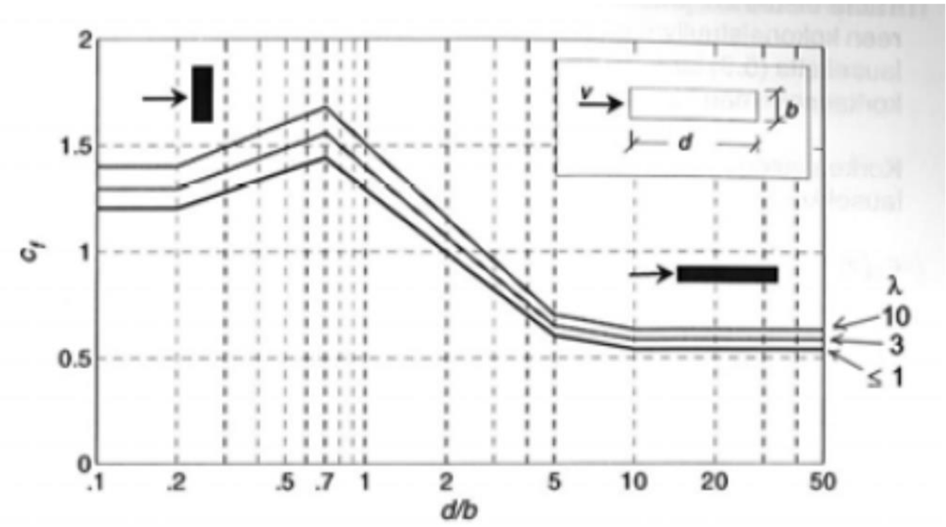
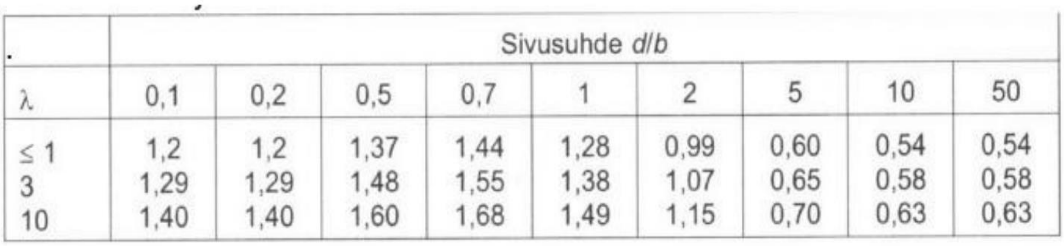


Figure 26. Force coefficient 1 (RIL 201-1-2011)



	Sivusuhde *d*/*b*								
λ	0,1	0,2	0,5	0,7	1	2	5	10	50
≤ 1	1,2	1,2	1,37	1,44	1,28	0,99	0,60	0,54	0,54
3	1,29	1,29	1,48	1,55	1,38	1,07	0,65	0,58	0,58
10	1,40	1,40	1,60	1,68	1,49	1,15	0,70	0,63	0,63

Figure 27. Force coefficient 2 (RIL 201-1-2011)

3.2 Implementation

In this section, an example of calculations is given for wind loads and is shown how the calculator works. The most important thing to do before starting calculations is to define the input data.

The calculation presents a residential two-story wooden building located in the suburbs of Helsinki, Finland. The fundamental value of basic velocity is 21 m/s^2. The roof is shed, the building has many windows and several terraces. The plans of the building and its main section are presented in Figures 29-31.

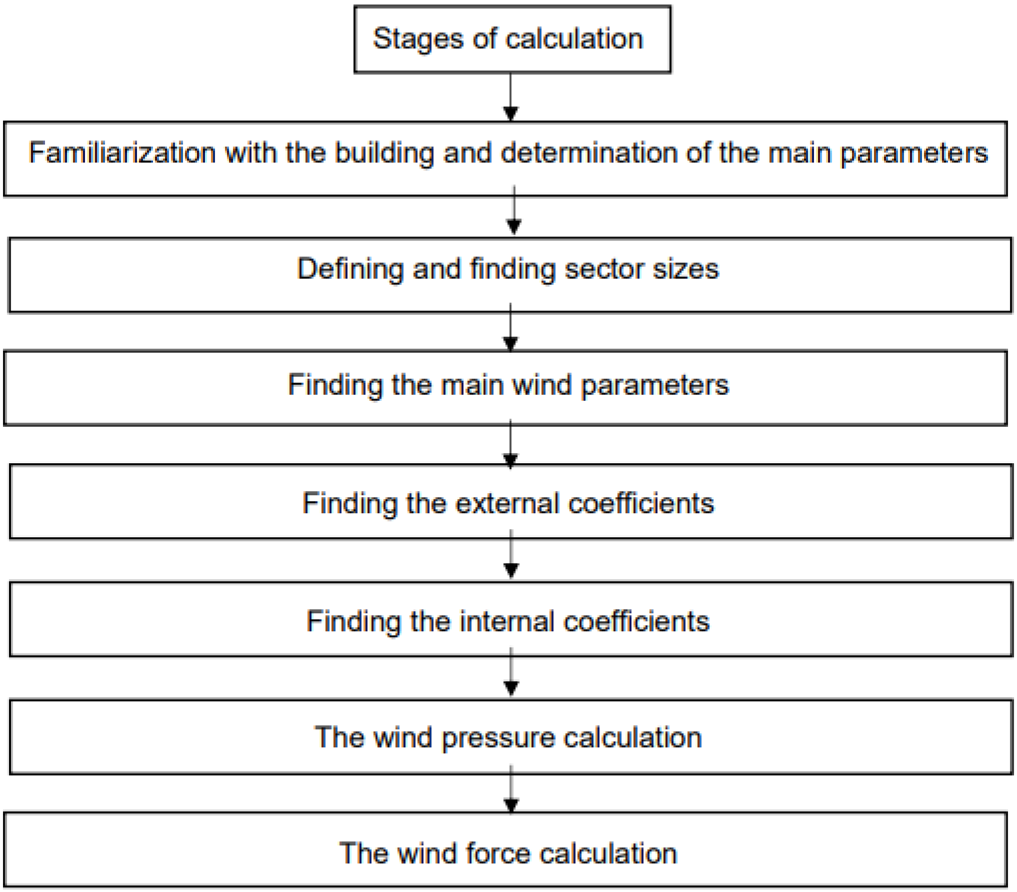


Figure 28. Stages of wind load calculations

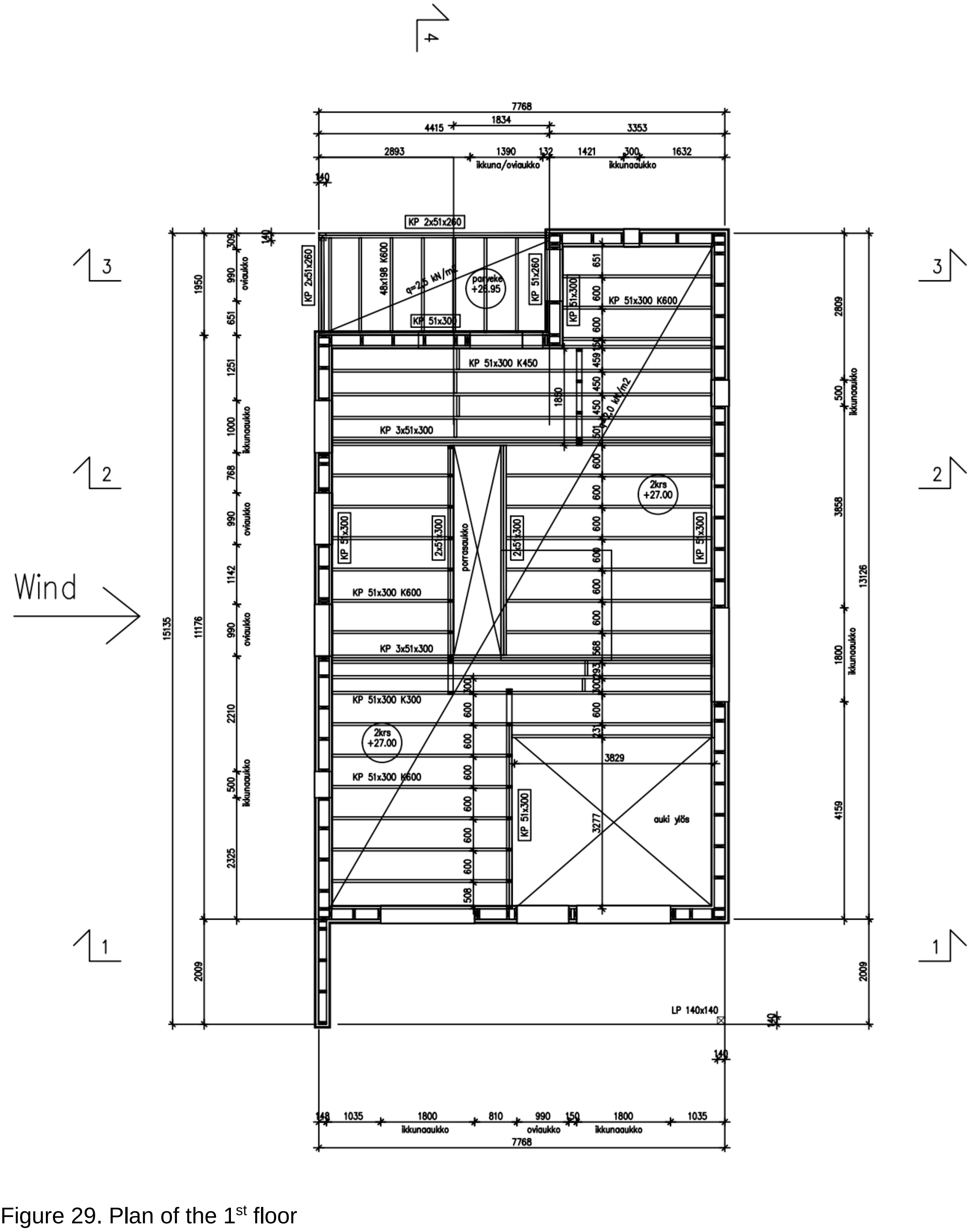


Figure 29. Plan of the 1st floor

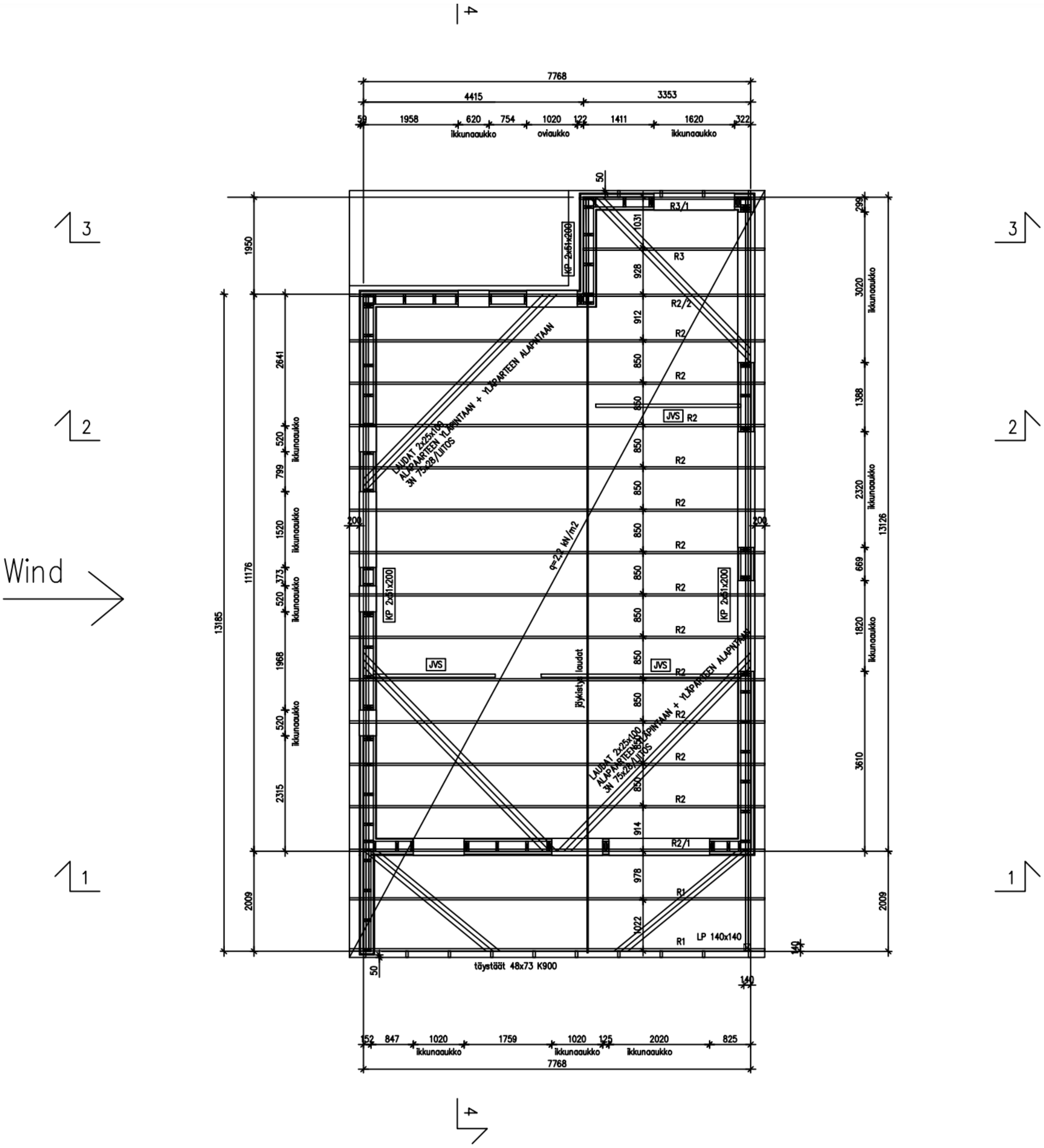


Figure 30. Plan of the 2nd floor

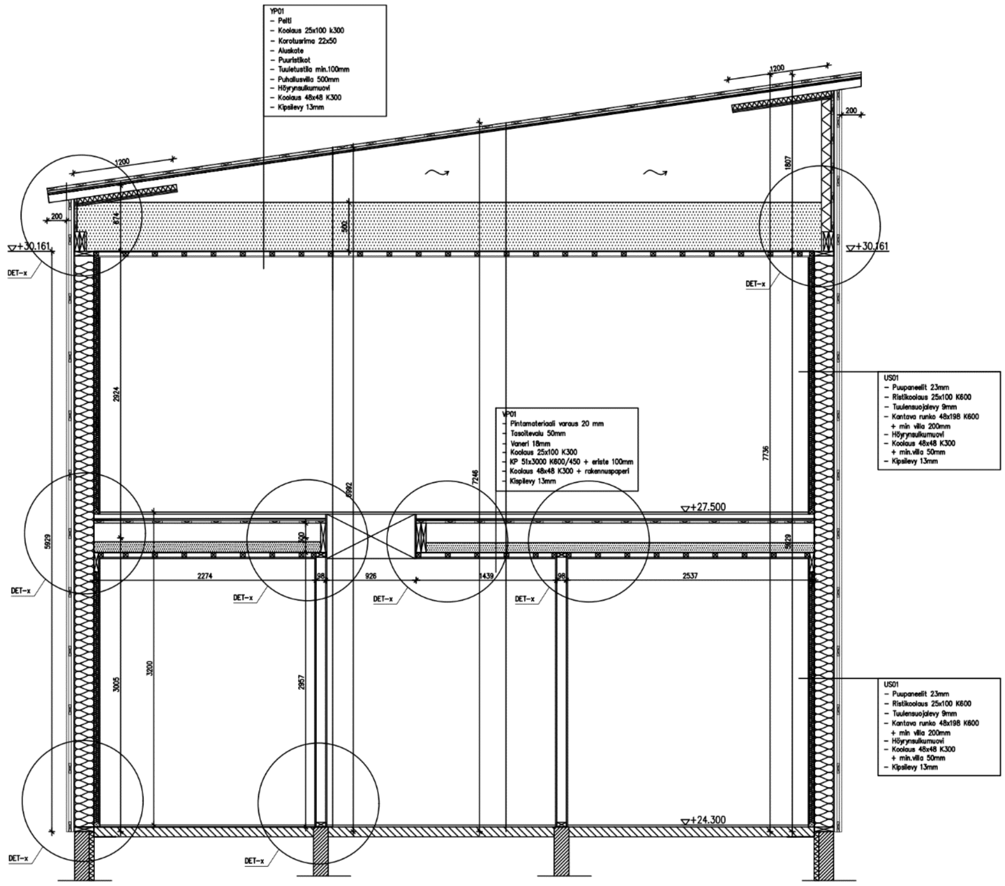


Figure 31. Section 2-2

3.2.1 Familiarization with the building and determination of the main parameters

1) Determine the size of the building.

In our case, an ordinary two-story wooden building is presented, where b=15,135 m, d=7,768 m, h_{left}=6,603 m and h_{right}=7,736 m (h_{1floor}=3,005 m, h_{2froor}=2,924 m and h_{attic}=0,674 m or h_{attic2}=1,807 m – the roof is shed). At the same time, it is important to mention that both floors of the building are identical in size (in further calculations, it will be shown how the calculations take place when the first and 2nd floors are different). However, when constructing the calculator, a simpler type of house was used for easier calculation and clearer control data. The wind, as seen in the picture, is perpendicular to side b.

2) Determine the region and zone.

Given house is located in the suburb of Helsinki, Finland. In this region, the construction of low-rise and mid-rise buildings prevails. The objects themselves do not stand close to each other, but they are not distant from each other at a great distance. According to EN 1991-1-4 (2005), this type of territory is related to the 3rd category (It is an area with regular cover). The territory does not have significant elevation differences and is considered as flat.

3) Determine a reference height.

The calculated height, if considered clearly, will be different for each wall due to a certain slope of the roof. But for simplicity, we accept it along a wall with a lower height.

If h<b, then $z_e=h=6{,}603$ m.

Based on such data, it can be understood that when divided into sectors in the vertical direction, there will be only one zone each.

3.2.2 Defining and finding sector sizes

Next, we are faced with the task of dividing the building into sectors, depending on the configuration of the building. For a better understanding, it is recommended to use Figure 19 and 32.

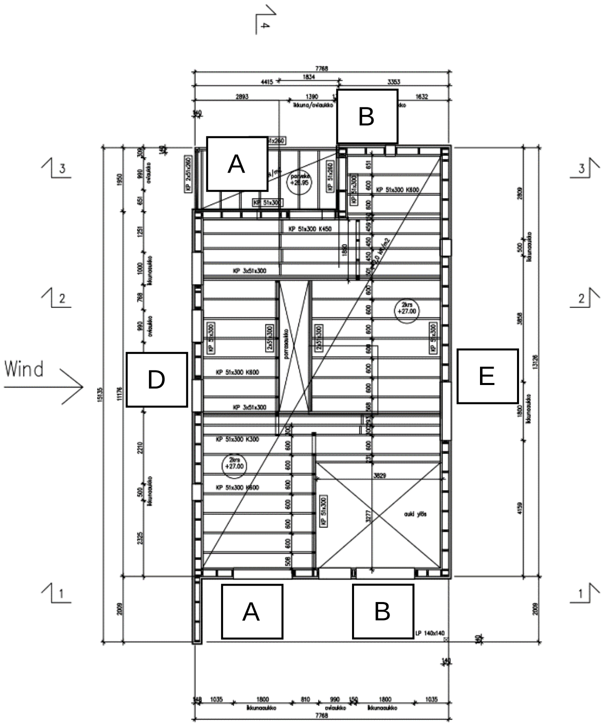


Figure 32. Sector division

In our case:

e=b=15,135 m or e=2h=2*6,603=13,206 m. We take the lower value. e=13,206 m.

Then the length d and e are compared to each other. e>d, but it is less than 5d. Our case is divided as on the picture below.

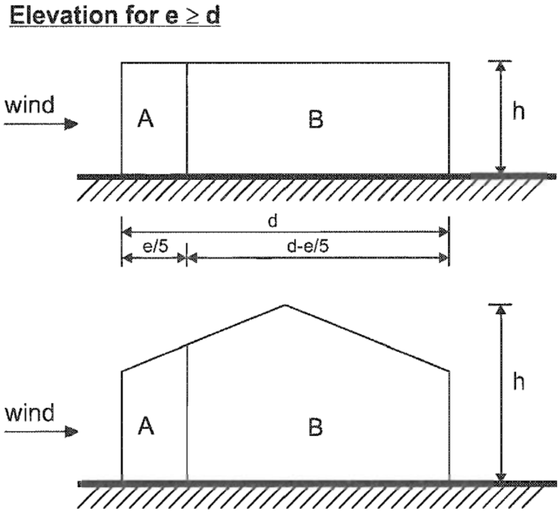


Figure 33. Sections (EN 1991-1-4 2005)

Consequently:

d=7,768 m;

e/5=13,206/5=2,641 m;

d-e/5=7,768-2,581=5,127 m.

Let's find the area of each sector using the standard formulas. The areas of sectors A and B will be found according to the formula for finding the areas of trapezoids.

S_A=1/2*2,641*(6,603+6,992)=17,95 m^2

S_B=1/2*5,127*(6,992+7,736)=37,76 m^2

S_D=6,603*15,135=99,94 m^2

S_E =7,736*13,126=101,54 m^2

(If we assume the second floor of the house is less than the first, then the area of the side will not be one rectangle, but either the sum of two, or the difference between the large area and the area of the missing piece).

3.2.3 Finding the main wind parameters

1) Basic wind velocity and mean wind

$$V_b = V_{b0} * c_{dir} * c_{season} \tag{24}$$

Knowing our region - Helsinki, and the terrain, it is possible to find that the fundamental value of basic velocity is 21 m/s^2 (It is already mentioned in the input data).

- $V_{b0} = 21$ m/s^2.
- $c_{dir} = 1$
- $c_{season} = 1.$

$V_b = 21 * 1 * 1 = 21$ m/s^2.

Then we are going to find the mean wind:

$$V_{m(z)} = c_{r(z)} * c_{0(z)} * V_b \tag{25}$$

- $V_b = 21$ m/s^2
- $c_{0(z)} = 1.$

The roughness factor is calculated as:

$$c_{r(z)=K_r*\ln\left(\frac{z}{z_0}\right)} \text{ , for z between } z_{\min} \text{ and } z_{\max}. \tag{26}$$

From the table in Figure 11, the z_{0III}=0,3 m, z_{minIII}=5 m and z_{0II}=0,05 m are taken. z=h=6,603 m. (It was calculated before)

$$K_r = 0{,}19 * \left(\frac{z_0}{z_{0,II}}\right)^{0{,}07} = 0{,}19 * \left(\frac{0{,}3}{0{,}05}\right)^{0{,}07} = 0{,}2154$$

$$c_{r(z)=K_r*\ln\left(\frac{z}{z_0}\right)=0{,}2154*\ln\left(\frac{6{,}603}{0{,}3}\right)=0{,}666}$$

$V_{m(z)} = c_{r(z)} * c_{0(z)} * V_b = 0{,}666 * 1 * 21 = 13{,}99$ m/s

2) Wind turbulence

While calculating, deviation does not affect too much, because the formula of the turbulence is converted to another by abbreviations and expansion of variables without using it. However, we still calculate it for a more detailed result.

Standard deviation 6_V:

$6_V = K_r * V_b * K_I = 0{,}2154 * 21 * 1 = 4{,}523$ m/s, where K_I =1.

The turbulence intensity:

$I_{V(z)} = \frac{6_V}{V_{m(z)}} = \frac{K_I}{c_{0(z)} * \ln\left(\frac{z}{z_0}\right)} = \frac{4{,}523}{13{,}99} = 0{,}323$

3) Peak velocity pressure

Let's start with the calculation method, since it is more accurate.

ρ=1,25 kg/m^3 - air density

The basic velocity pressure:

$q_b = \frac{1}{2} * \rho * V_b^2 = 0{,}5 * 1{,}25 * 21^2 = 275{,}625 = 0{,}275$ kN/m^2

The peak velocity pressure:

$$q_{p(z)} = \left(1 + 7 * I_{V(z)}\right) * \frac{1}{2} * \rho * V_{m(z)}^2 = c_{e(z)} * q_b \qquad (27)$$

$q_{p(z)} = (1 + 7 * 0{,}323) * 0{,}5 * 1{,}25 * 13{,}99^2 = 398{,}9 = 0{,}399$ kN/m^2

Also, we are going to calculate the exposure factor calculated as:

$c_{e(z)} = \frac{q_{p(z)}}{q_b} = \frac{0{,}399}{0{,}275} = 1{,}45$

Knowing this factor, we can check our calculations by a graphical method.

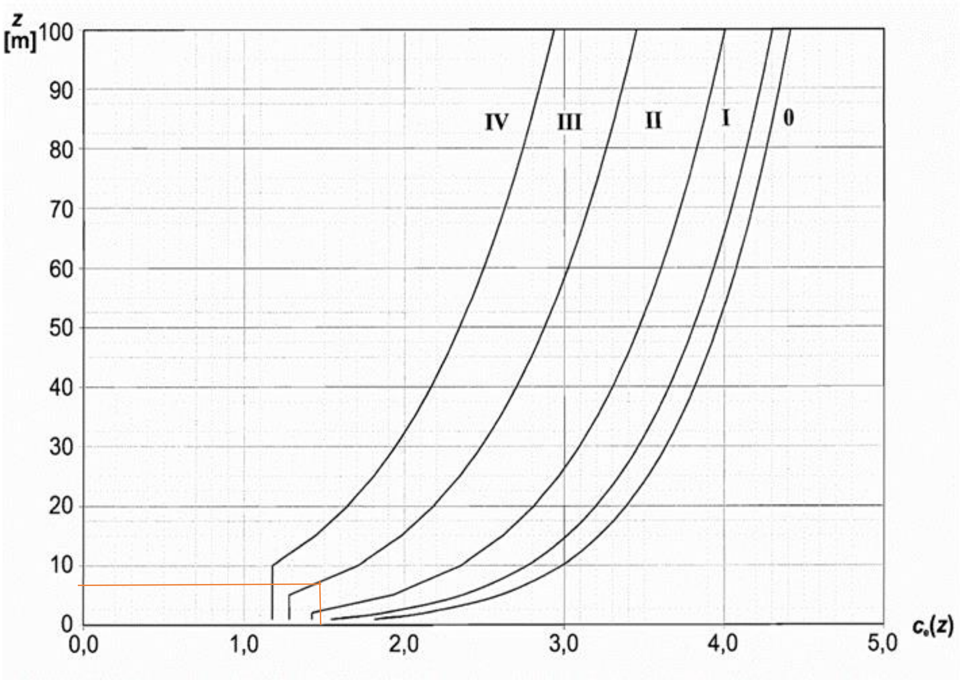


Figure 34. Graphical method (adapted from EN 1991-1-4 2005)

Here, the value of the factor is faster and easier to determine, but the values will be much less accurate. In the case of calculations that do not require perfect accuracy, it can be considered in a similar way.

$c_{e(z)} = 1{,}45$ with a building height of 6,603 m and territory type 3. However, if you do not know the exact value, then it can easily vary from 1,4 to 1,5, which can quite strongly affect further calculations and values.

3.2.4 Finding the external coefficients

h/d=6,603/7,768=0,85

Based on the ratio, we can find the coefficients C_{pe}. Since the building is considered as a large object with large areas and volumes, we take the value of C_{pe} 10.

Zone	A		B		C		D		E	
h/d	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1	Cpe,10	Cpe,1
5	-1.2	-1.4	-0.8	-1.1	-0.5		+0.8	+1.0	-0.7	
1	-1.2	-1.4	-0.8	-1.1	-0.5		+0.8	+1.0	-0.5	
<0.2	-1.2	-1.4	-0.8	-1.1	-0.5		+0.7	+1.0	-0.3	

Table 4. Zones and external coefficients

Linear interpolation is required to find a value between two unknowns. The formula is presented below. Thus, we get the data presented in the Table 5.

$$Y = Y_2 + \frac{Y_1 - Y_2}{X_1 - X_2} \cdot (X - X_2)$$

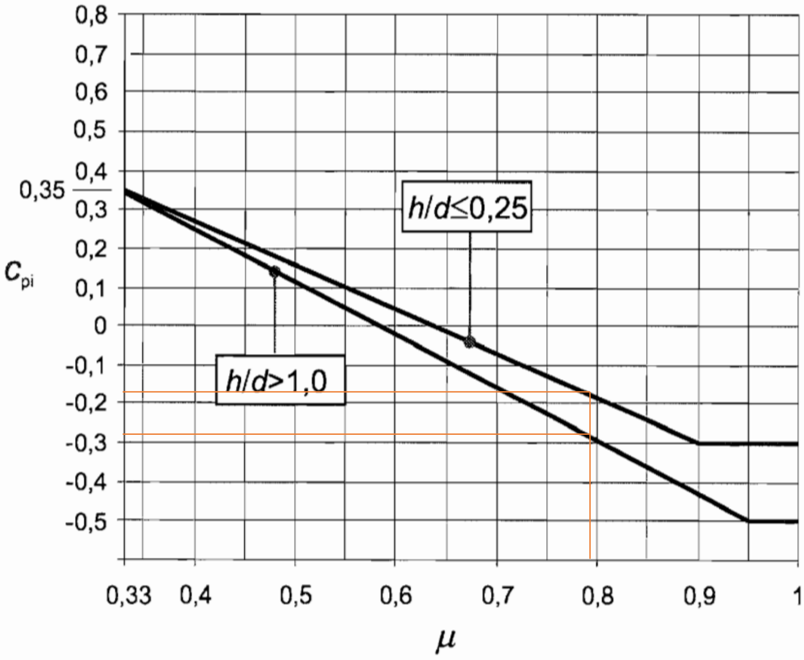
Figure 35. Interpolation (Image: Maria Kupriyanova)

Zone	A	B	D	E
h/d	Cpe,10	Cpe,10	Cpe,10	Cpe,10
0,85	-1.2	-0.8	+0.8	-0.46

Table 5. External coefficients in calculations

3.2.5 Finding the internal coefficients

Now we are faced with the task of dealing with the internal coefficient. In the example there is no dominant facade, so the graphs in the bottom should be used.



NOTE For values between *h*/*d* = 0,25 and *h*/*d* = 1,0 linear interpolation may be used.

Figure 36. Graphs for the internal coefficient (adapted from EN 1991-1-4 2005)

Now the window areas should be counted. We will consider windows of the same height (therefore, we assume in advance that it will be reduced in the formula) and simply add their lengths. An important point is not to forget about the windows of the 2nd floor.

It turns out that:

- Windows of the left wall (the side perpendicular to the wind and being a shadow with a positive coefficient): 1,02*3+0,52*3+1,52=6,14 m

- Top wall windows: 1,42+0,32+0,62+1,02+1,62=5 m
- Windows on the right wall: 0,52+0,72+1,22+3,02+2,32+1,82=9,62 m
- Lower wall windows: 2,02+1,02*2+1,02*2+2,02=8,12 m.

Let's sum up and find the ratio of wall openings with a negative coefficient and all openings.

$$\mu = \frac{\Sigma area\ of\ openings\ where\ c_{pe}\ is\ negative\ or-0{,}0}{\Sigma area\ of\ all\ openings} = \frac{22{,}740}{28{,}880} = 0{,}79 \qquad (28)$$

Now we need to interpolate, since the ratio of height and length that we got lies between the numbers 1 and 0,25. According to the graph, we see that the values of c_{pi} will be between -0,28 and -0,18.

For 0,76 we obtain:

$$c_{pi} = -0{,}25$$

3.2.6 The wind pressure calculation

Next, the useful pressure coefficients for each zone and the wind pressure as a whole are calculated. It is necessary to consider whether it is pressure or suction in order to calculate correctly without confusing the signs.

$$W_{net} = q_{p(z_e)} * c_{p,net} \qquad (29)$$

$$c_{p,net} = c_{pe} - c_{pi} \qquad (30)$$

The calculated data was entered into a Table 6.

	A	B	D	E
c_{pe}	-1,2	-0,8	+0,8	-0,46
c_{pi}	-0,25	-0,25	-0,25	-0,25
$c_{p,net}$	-0,95	-0,55	0,55	-0,21
W_{net}	-0,38	-0,22	0,22	-0,08

Table 6. Wind pressure in our calculation

$q_{p(z_e)} = 0{,}399$ kN/m^2

$W_{netA} = \frac{0{,}399kN}{m^2} * (-0{,}95) = -0{,}38$ kN/m^2

$W_{netB} = \frac{0{,}399kN}{m^2} * (-0{,}55) = -0{,}22$ kN/m^2

$W_{netD} = \frac{0{,}399kN}{m^2} * (0{,}55) = 0{,}22$ kN/m^2

$W_{netE} = \frac{0{,}399kN}{m^2} * (-0{,}21) = -0{,}08$ kN/m^2

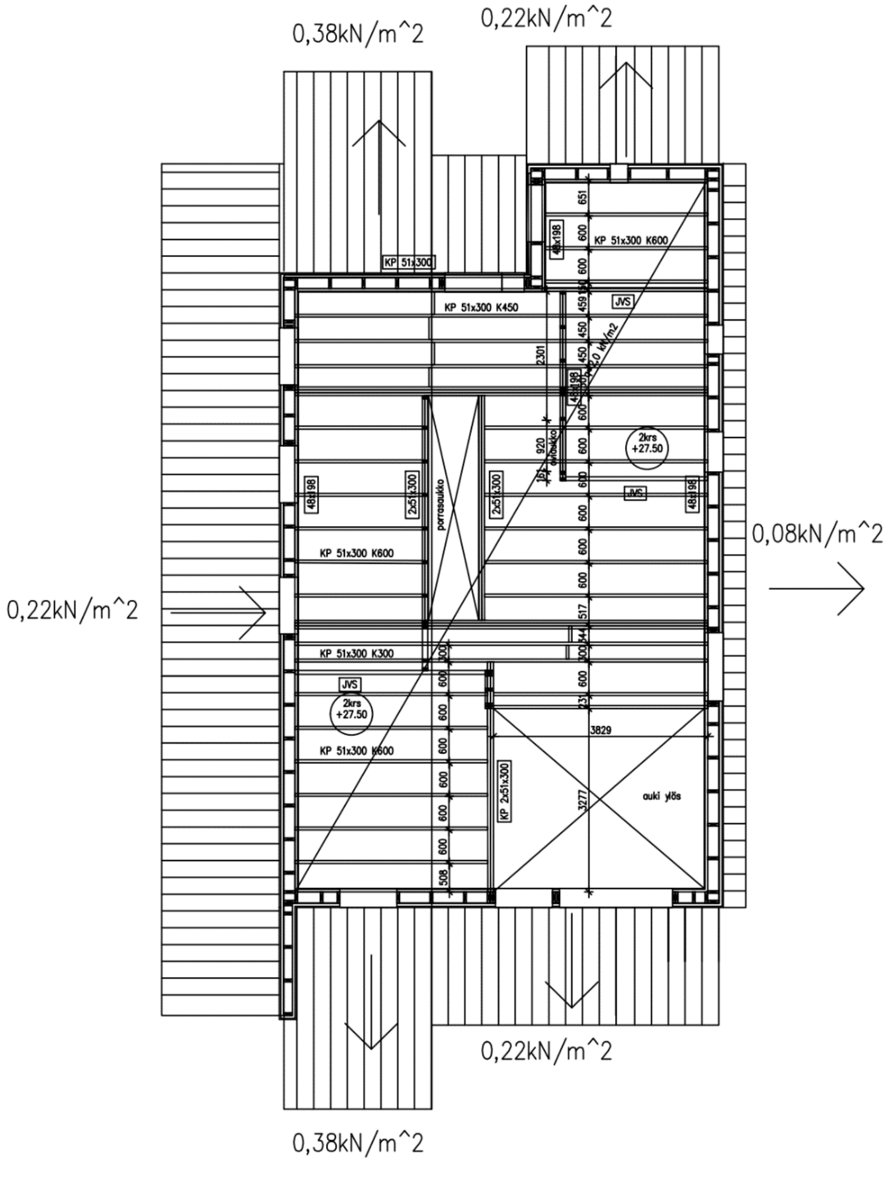


Figure 37. The result of the wind pressure

In this calculation, only one version of the wind direction is considered. As you can see in Figure 37, this is from left to right. Influencing the main wall, the wind also affects the rest. To find the pressure and wind forces under the action of the wind in a different direction, it is required to calculate all the data in the same way as presented above. However, do not forget that the division into sectors in this case will change.

3.2.7 Wind force calculation

Knowing the wind pressure, we can finally calculate the force of the wind. Before that, the formulas for finding the strength of the wind will be shown. This can be done separately from the wind pressure, but the individual coefficients must be found and calculated. This is not laborious, but since we have already found the wind pressure, it will be most beneficial to count through it.

$$F_{w,e} = c_s c_d * \Sigma W_e * A_{ref} \text{ – external forces} \quad (31)$$

$$F_{w,i} = c_s c_d * \Sigma W_i * A_{ref} \text{ – internal forces} \quad (32)$$

There is also a force associated with friction, but in this case, we are not taking it into account to facilitate calculations.

$$F_{net} = F_{w,e} - F_{w,i} \text{ or } F_{net} = c_s c_d * \Sigma W_{net} * A_{ref} \quad (33,34)$$

$c_s c_d = 1$

$F_{netA} = 1 * (-0{,}38) * 17{,}95 = -6{,}82$ kN

$F_{netB} = 1 * (-0{,}22) * 37{,}76 = -8{,}31$ kN

$F_{netD} = 1 * (0{,}22) * 99{,}94 = 21{,}99$ kN

$F_{netE} = 1 * (-0{,}08\ ) * 101{,}54 = -8{,}12$ kN

For structuring and for convenience, we conclude the obtained values in another table (Table 7).

	A	B	D	E
W_{net}	-0,38	-0,22	0,22	-0,08
A_{ref}	17,95	37,76	99,94	101,54
F_{net}	-6,82kN	-8,31 kN	21,99 kN	-8,12 kN

Table 7. Wind force

Let's make one more addition. Although we have found the force acting on each sector, it should be noted that our building is not square. It contains protruding parts, therefore, for a clearer indication of the force values, a certain area should be taken from the sector. In our case, this will affect sectors B and D. The area of the sector should be divided into 2 separate parts. In our case, these will be 2 trapezoids. Then we need to calculate the force on each of these areas.

S_{b1}=1/2*1,774*(6,992+7,246) =12,63 m^2

S_{b2}=1/2*3,353*(7,246+7,736) =25,12 m^2

$F_{netB1} = 1 * (-0{,}22) * 12{,}63 = -2{,}79$ kN

$F_{netB2} = 1 * (-0{,}22) * 25{,}12 = -5{,}53$ kN

Likewise, with the sector D.

S_{d1}=6,603*13,185=87,06 m^2

S_{d2}=6,603*1,95=12,87 m^2

$F_{netD1} = 1 * (0{,}22) * 87{,}06 = 19{,}15$ kN

$F_{netD2} = 1 * (0{,}22) * 12{,}87 = 2{,}83$ kN

The result is presented in Figure 38.

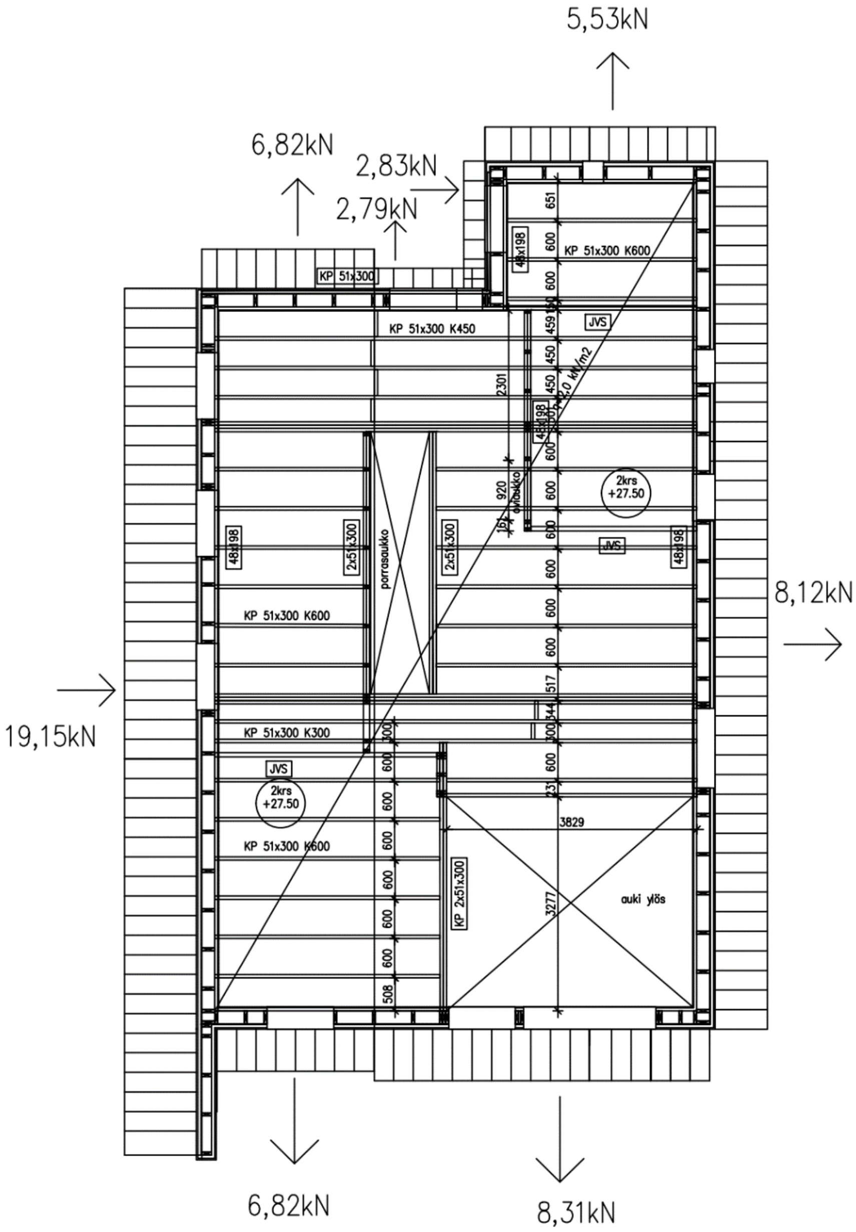
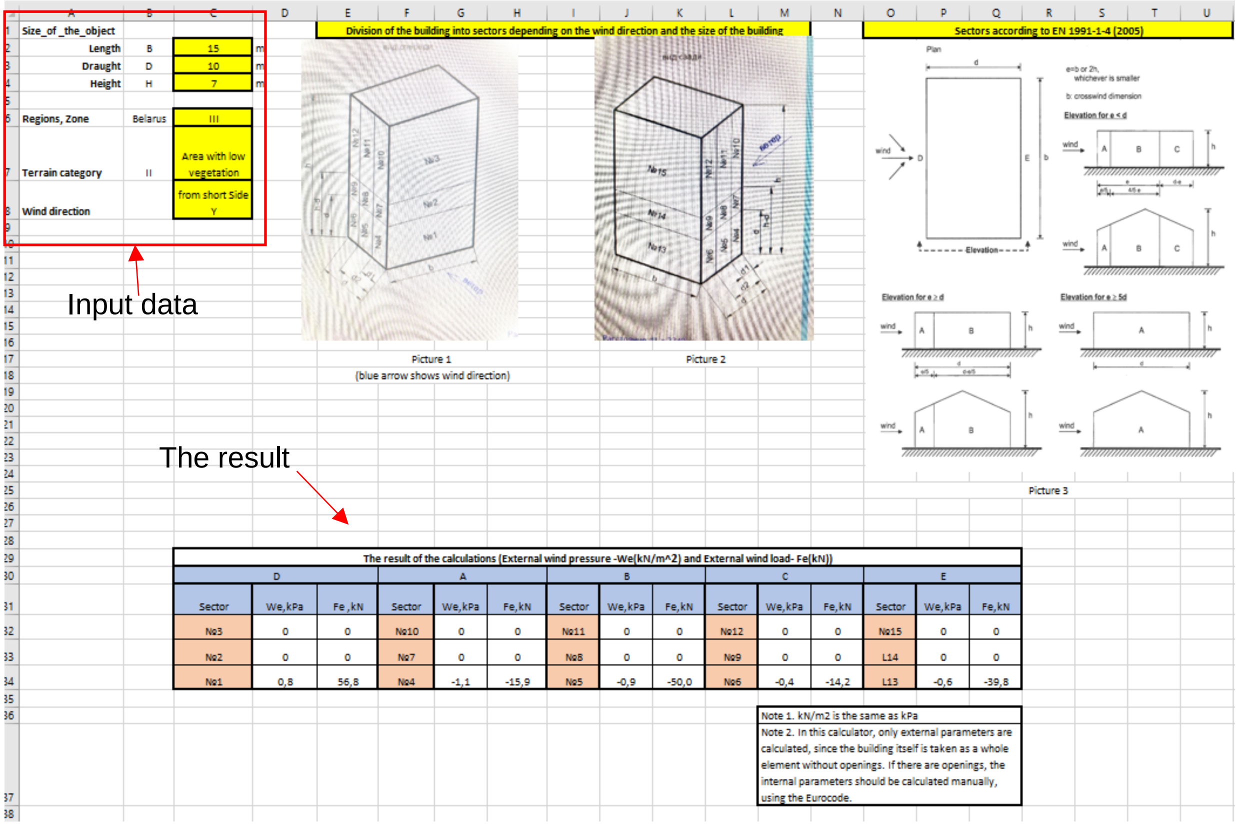


Figure 38. The result of the wind force

Forces are found and now we can move on to a new stage. But up to this point, it would be important to touch on the topic related to the creation of a program for calculating the wind force.

3.2.8 Calculator

Its meaning was that on the main page there is a field for entering basic data on the building, as well as a visual representation of how the building will be divided into sectors. The calculator calculates buildings of different heights, so there are even more of these sectors than in the EN 1991-1-4 (2005) (There is also a division into sectors up). Each sector is marked with a number. All graphs, tables and formulas are located on other tabs of the Excel file and can be viewed if desired. The calculations are made in accordance with the Eurocode (EN 1991-1-4 2005). The result, namely the wind force acting on each sector, is recreated in a table that is both inside the file (in the working tabs) and placed on the main sheet. Thus, through connections and painted formulas, inside it is enough to drive in the basic data regarding the building and the completed table will instantly show the wind values.



Size_of _the_object			
Length	B	15	m
Draught	D	10	m
Height	H	7	m
Regions, Zone	Belarus	III	
Terrain category	II	Area with low vegetation	
Wind direction		from short Side Y	

Division of the building into sectors depending on the wind direction and the size of the building

Picture 1
(blue arrow shows wind direction)

Picture 2

Sectors according to EN 1991-1-4 (2005)

Picture 3

The result of the calculations (External wind pressure -We(kN/m^2) and External wind load- Fe(kN))

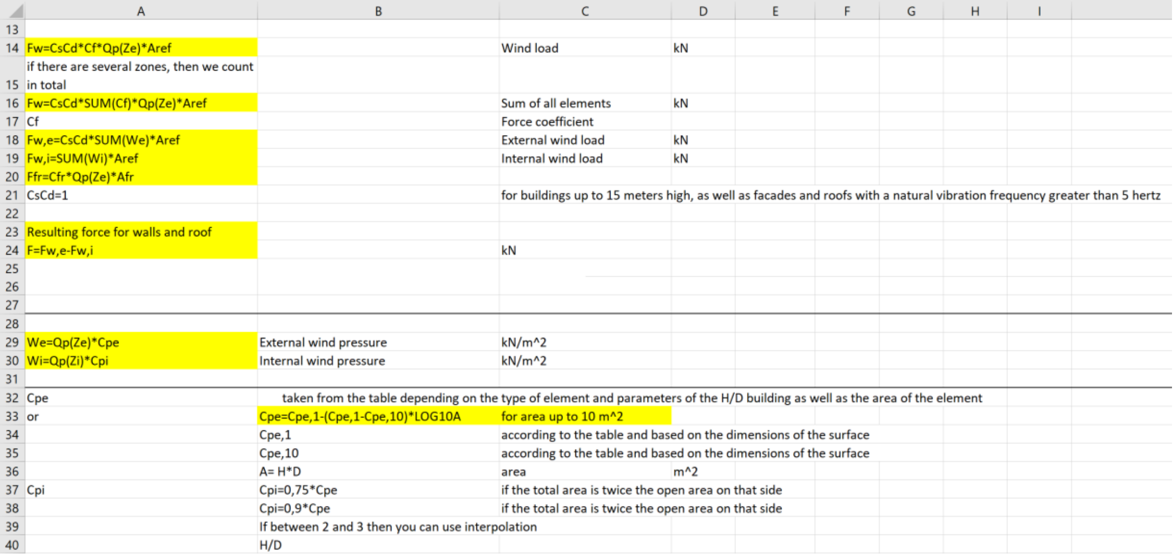
D			A			B			C			E		
Sector	We,kPa	Fe ,kN	Sector	We,kPa	Fe,kN	Sector	We,kPa	Fe,kN	Sector	We,kPa	Fe,kN	Sector	We,kPa	Fe,kN
№3	0	0	№10	0	0	№11	0	0	№12	0	0	№15	0	0
№2	0	0	№7	0	0	№8	0	0	№9	0	0	L14	0	0
№1	0,8	56,8	№4	-1,1	-15,9	№5	-0,9	-50,0	№6	-0,4	-14,2	L13	-0,6	-39,8

Note 1. kN/m2 is the same as kPa

Note 2. In this calculator, only external parameters are calculated, since the building itself is taken as a whole element without openings. If there are openings, the internal parameters should be calculated manually, using the Eurocode.

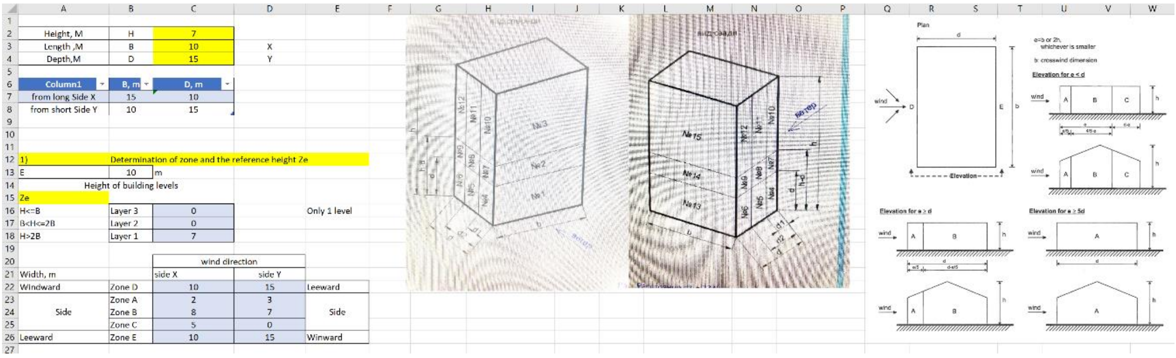
Figure 39. The main page

The second page describes the main formulas used in the calculator, their units of measurement, as well as a short description of the principle for determining the coefficients.

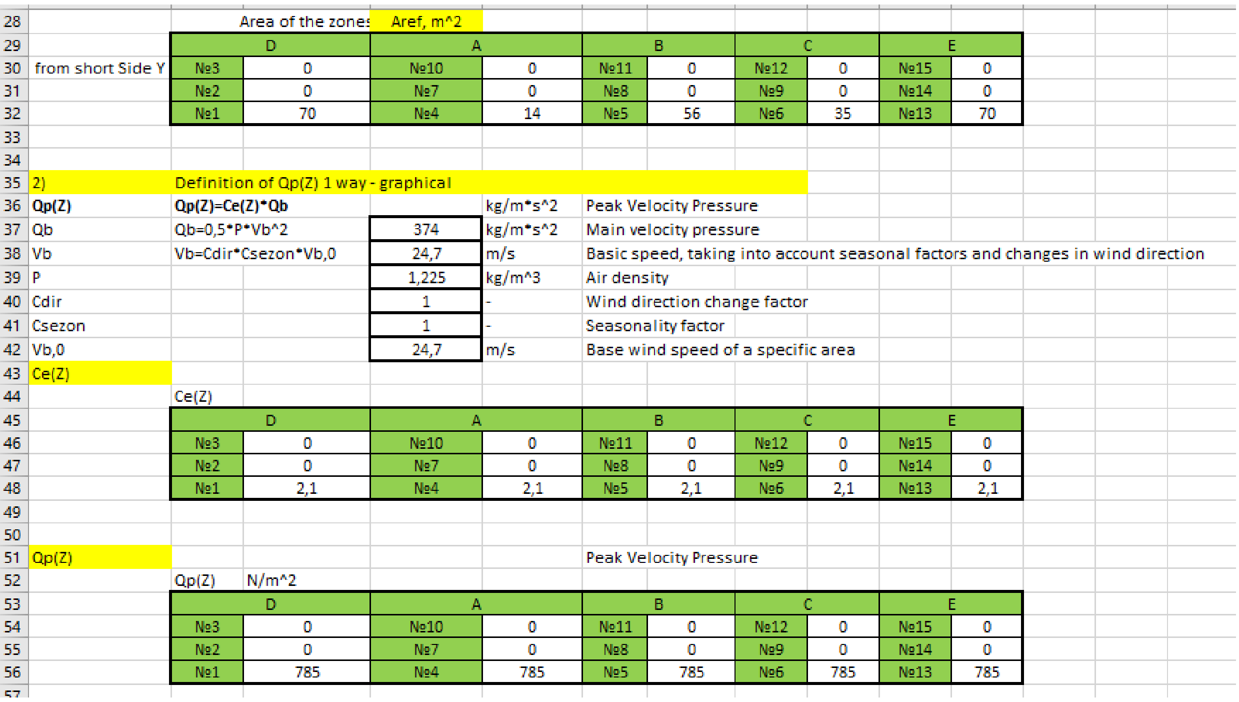


	A	B	C	D
13				
14	Fw=CsCd*Cf*Qp(Ze)*Aref		Wind load	kN
15	if there are several zones, then we count in total			
16	Fw=CsCd*SUM(Cf)*Qp(Ze)*Aref		Sum of all elements	kN
17	Cf		Force coefficient	
18	Fw,e=CsCd*SUM(We)*Aref		External wind load	kN
19	Fw,i=SUM(Wi)*Aref		Internal wind load	kN
20	Ffr=Cfr*Qp(Ze)*Afr			
21	CsCd=1		for buildings up to 15 meters high, as well as facades and roofs with a natural vibration frequency greater than 5 hertz	
22				
23	Resulting force for walls and roof			
24	F=Fw,e-Fw,i		kN	
25				
26				
27				
28				
29	We=Qp(Ze)*Cpe	External wind pressure	kN/m^2	
30	Wi=Qp(Zi)*Cpi	Internal wind pressure	kN/m^2	
31				
32	Cpe	taken from the table depending on the type of element and parameters of the H/D building as well as the area of the element		
33	or	Cpe=Cpe,1-(Cpe,1-Cpe,10)*LOG10A	for area up to 10 m^2	
34		Cpe,1	according to the table and based on the dimensions of the surface	
35		Cpe,10	according to the table and based on the dimensions of the surface	
36		A= H*D	area	m^2
37	Cpi	Cpi=0,75*Cpe	if the total area is twice the open area on that side	
38		Cpi=0,9*Cpe	if the total area is twice the open area on that side	
39		If between 2 and 3 then you can use interpolation		
40		H/D		

Figure 40. Second page



	A	B	C	D	E
1					
2	Height, M	H	7		
3	Length ,M	B	10	X	
4	Depth,M	D	15	Y	
5					
6	Column1	B, m	D, m		
7	from long Side X	15	10		
8	from short Side Y	10	15		
9					
10					
11					
12	1)	Determination of zone and the reference height Ze			
13	E	10	m		
14		Height of building levels			
15	Ze				
16	H<=B	Layer 3	0		Only 1 level
17	B<H<=2B	Layer 2	0		
18	H>2B	Layer 1	7		
19					
20			wind direction		
21	Width, m		side X	side Y	
22	Windward	Zone D	10	15	Leeward
23	Side	Zone A	2	3	Side
24		Zone B	8	7	
25		Zone C	5	0	
26	Leeward	Zone E	10	15	Winward
27					

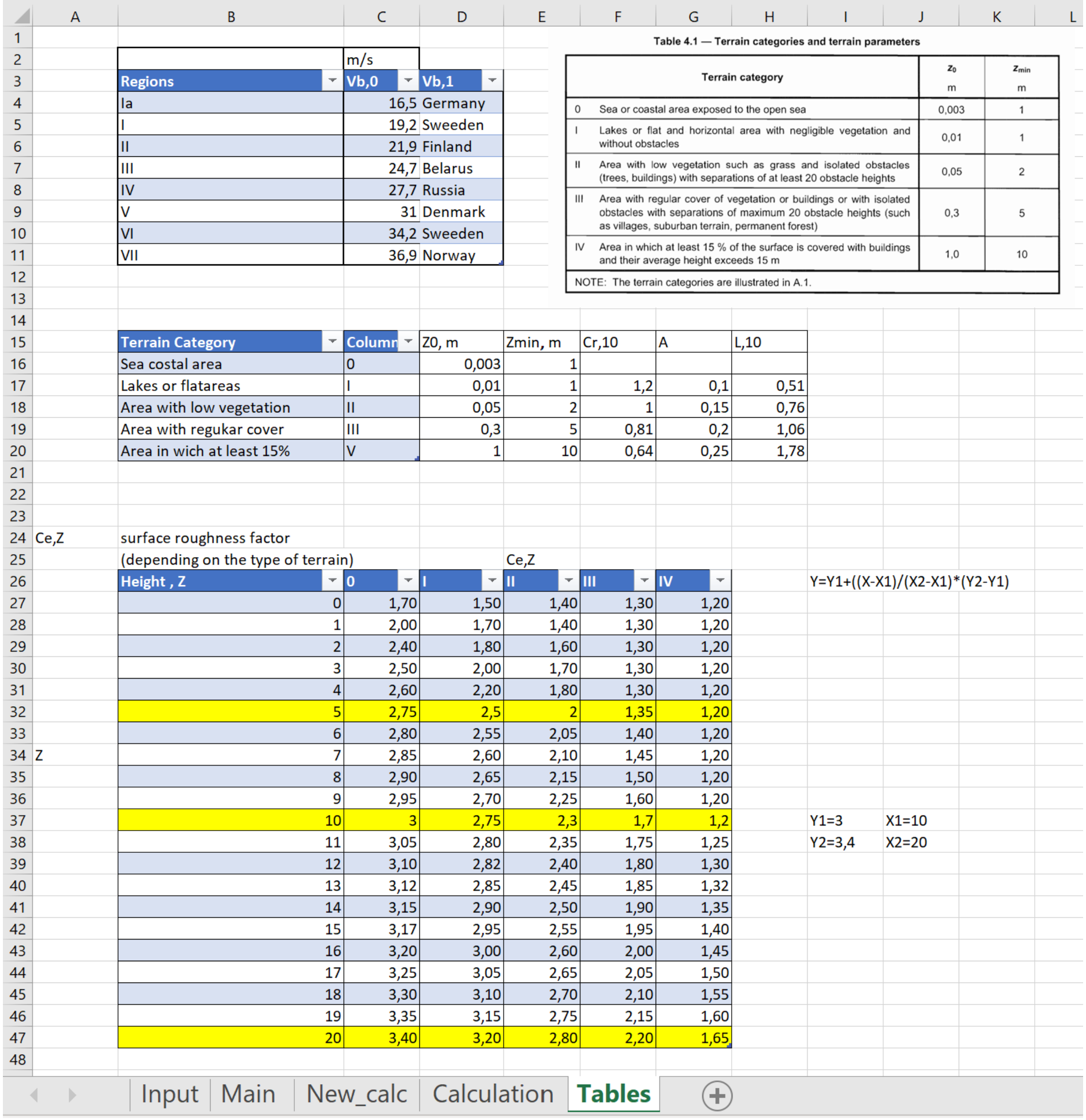


	A	B	C	D	E	F	G	H	I	J	K
28			Area of the zones	Aref, m^2							
29		D		A		B		C		E	
30	from short Side Y	№3	0	№10	0	№11	0	№12	0	№15	0
31		№2	0	№7	0	№8	0	№9	0	№14	0
32		№1	70	№4	14	№5	56	№6	35	№13	70
33											
34											
35	2)	Definition of Qp(Z) 1 way - graphical									
36	**Qp(Z)**	**Qp(Z)=Ce(Z)*Qb**			kg/m*s^2	Peak Velocity Pressure					
37	Qb	Qb=0,5*P*Vb^2		374	kg/m*s^2	Main velocity pressure					
38	Vb	Vb=Cdir*Csezon*Vb,0		24,7	m/s	Basic speed, taking into account seasonal factors and changes in wind direction					
39	P			1,225	kg/m^3	Air density					
40	Cdir			1	-	Wind direction change factor					
41	Csezon			1	-	Seasonality factor					
42	Vb,0			24,7	m/s	Base wind speed of a specific area					
43	Ce(Z)										
44		Ce(Z)									
45		D		A		B		C		E	
46		№3	0	№10	0	№11	0	№12	0	№15	0
47		№2	0	№7	0	№8	0	№9	0	№14	0
48		№1	2,1	№4	2,1	№5	2,1	№6	2,1	№13	2,1
49											
50											
51	Qp(Z)					Peak Velocity Pressure					
52		Qp(Z)	N/m^2								
53		D		A		B		C		E	
54		№3	0	№10	0	№11	0	№12	0	№15	0
55		№2	0	№7	0	№8	0	№9	0	№14	0
56		№1	785	№4	785	№5	785	№6	785	№13	785

Figure 41,42. Calculation page

Figures 41 and 42 show a page with calculations in the calculator. Here all the necessary values for each variable are displayed and solving the problem of finding loads and forces on your own, you can follow the calculations to trace the correctness of your implementation.

The last page includes all the necessary tables translated into excel format, as well as interpolation formulas.



Regions	Vb,0 (m/s)	Vb,1
Ia	16,5	Germany
I	19,2	Sweeden
II	21,9	Finland
III	24,7	Belarus
IV	27,7	Russia
V	31	Denmark
VI	34,2	Sweeden
VII	36,9	Norway

Table 4.1 — Terrain categories and terrain parameters

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10

NOTE: The terrain categories are illustrated in A.1.

Terrain Category	Column	Z0, m	Zmin, m	Cr,10	A	L,10
Sea costal area	0	0,003	1			
Lakes or flatareas	I	0,01	1	1,2	0,1	0,51
Area with low vegetation	II	0,05	2	1	0,15	0,76
Area with regukar cover	III	0,3	5	0,81	0,2	1,06
Area in wich at least 15%	V	1	10	0,64	0,25	1,78

Ce,Z surface roughness factor
(depending on the type of terrain)

Ce,Z

Z

Height , Z	0	I	II	III	IV
0	1,70	1,50	1,40	1,30	1,20
1	2,00	1,70	1,40	1,30	1,20
2	2,40	1,80	1,60	1,30	1,20
3	2,50	2,00	1,70	1,30	1,20
4	2,60	2,20	1,80	1,30	1,20
5	2,75	2,5	2	1,35	1,20
6	2,80	2,55	2,05	1,40	1,20
7	2,85	2,60	2,10	1,45	1,20
8	2,90	2,65	2,15	1,50	1,20
9	2,95	2,70	2,25	1,60	1,20
10	3	2,75	2,3	1,7	1,2
11	3,05	2,80	2,35	1,75	1,25
12	3,10	2,82	2,40	1,80	1,30
13	3,12	2,85	2,45	1,85	1,32
14	3,15	2,90	2,50	1,90	1,35
15	3,17	2,95	2,55	1,95	1,40
16	3,20	3,00	2,60	2,00	1,45
17	3,25	3,05	2,65	2,05	1,50
18	3,30	3,10	2,70	2,10	1,55
19	3,35	3,15	2,75	2,15	1,60
20	3,40	3,20	2,80	2,20	1,65

Y=Y1+((X-X1)/(X2-X1)*(Y2-Y1)

Y1=3 X1=10
Y2=3,4 X2=20

Figure 43. Tables

The work was done with rounding, and it cannot be said that the calculator calculates to the nearest hundredth, but for the customer the goal was quick calculations and further approximate verification. It was necessary to understand whether the layout of the walls is suitable, whether the stiffening ribs work and whether there are critical deviations in the limit values. In this case, the customer assumed in-depth and accurate calculations on their own.

3.2.9 Stiffness and the stiffening walls

Stiffeners are the longitudinal and transverse walls of a building (an apartment building or a non-residential detached building), which give it rigidity and additional resistance to deformation under external loads.

Such ribs enhance the strength of the entire structure of the building and keep it from destruction, so they are always given increased attention. After all, if the building does not provide for stiffening ribs, too large force values will act on the wall, which will lead to deformations, and later to cracks, with subsequent destruction of the wall.

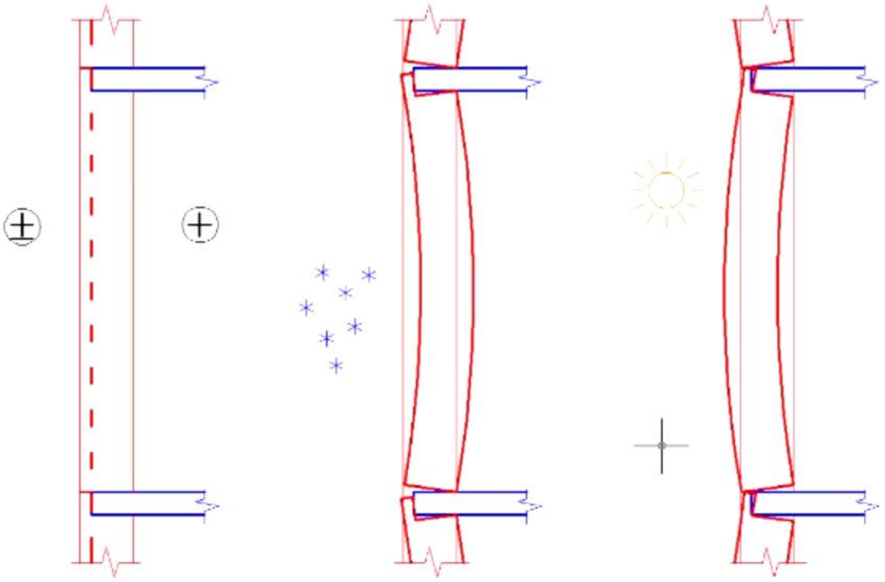


Figure 44. Deformations of the wall (Image: Maria Kupriyanova)

That is why the wind forces acting on the longitudinal walls, which are just like stiffening walls, have to be considered. Moreover, during the text, it will be shown how wind force is distributed. Consider the example of the main wall. We know that a wall perpendicular to the wind is subjected to a wind pressure 0,22 kN/m^2.

In our case, there are 3 walls that take loads. In order to understand what part of the total force goes to a particular wall, it is necessary to calculate what area is perceived by a particular wall. For the first wall, this is half the length between walls 1 and 2 multiplied by the height of the wall. For the 3rd, the situation is quite the same: it is half the length between the 2nd and 3rd sides multiplied by the height of the wall plus the length of the wall on another side. Second wall will then take on half on each side. Having found the areas, we can multiply each by the wind pressure and get the desired force. However, this method is not entirely accurate. After all, we take into account the entire height of the wall without exception.

Therefore, a more universal method is suggested, which is to determine what force acts on each meter along the height of our building (let's call this force unit). Speaking about the height, it is worth adding that the pressure will be distributed similarly. In our calculations, we do not take the load perceived by the foundation. To determine the force acting on each wall, we also determine the lengths, as in the first method. We multiply our unit force by a given distance and get the desired force.

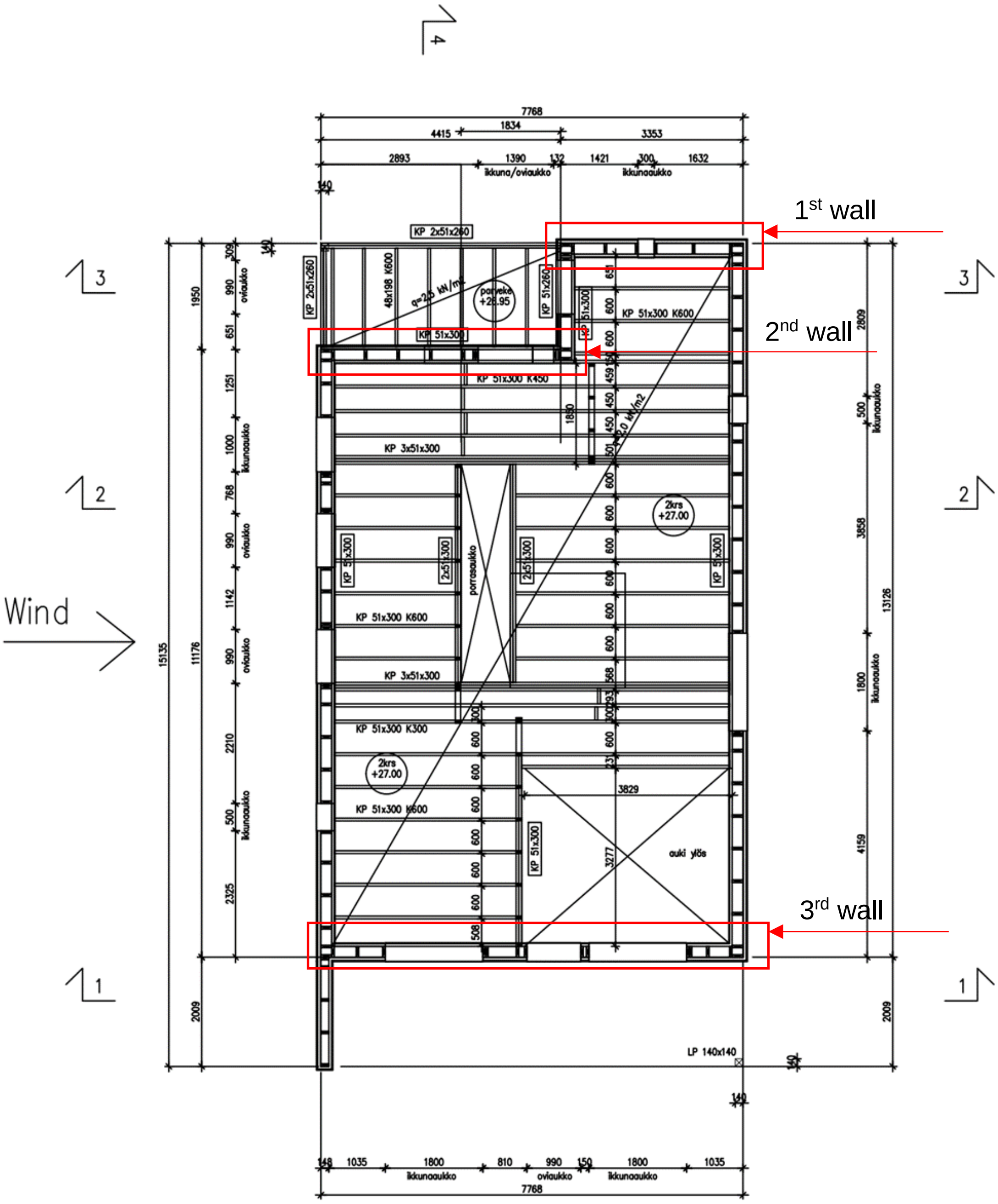


Figure 45. Three walls

Consider the load on our wall perpendicular to the wind as a whole. In the future, the load and forces on it will be distributed to the walls (ribs) perpendicular to this wall. They are to be found. But let's start with the main wall. Let's take a piece of wall meter long and standard height, which we know as the original data. The load will go to the foundation, on the floor of the first floor, the 2nd floor and at the top of the wall (ceiling or the bottom of attic). We will duplicate the heights:

h_{1floor}=3,005 m, h_{2froor}=2,924 m and h_{attic}=0,674 m.

As mentioned earlier, we will not consider the foundation level, due to the fact that we are calculating loads on the walls.

In order to transfer loads, we should know the concept of tributary area (or influence area). This area is the load area that is perceived by the load-bearing structures. For example, for a building with two load-bearing walls located at a distance of 5 meters from each other and on which the ceiling rests, the cargo area for each wall will be 2.5 m* 1 m = 2.5 m^2. Then this figure is multiplied by the load, in order to get a force on each of the elements. The gravitational forces from the slab flows into the wall or column, and the tributary areas helps defining how much of the slab each wall attracts. Then follow the instructions:

- Measure the distance between the selected elements (in our case, these are floors and walls)
- Divide the distance by 2
- Draw a perpendicular line at this point.
- Repeat for all adjacent grid lines and elements until a bounding polygon appears. (Tribby3d)

Influence area, perceiving loads acting on each element will be different. The width of all will be 1 meter and the height will be different. Thus, half of the height of the 1st floor and half of the second floor is used for the first floor. On the foundation half of the 1st floor. And so on.

The force will be:

$$F_{foundation} = 1 * \left(\frac{0{,}22kN}{m^2}\right) * \left(\frac{3{,}005\text{m}}{2}\right) * 1m = 0{,}33\ \text{kN}$$

$$F_{1stfloor} = 1 * \left(\frac{0{,}22kN}{m^2}\right) * \left(\frac{3{,}005\text{m}}{2} + \frac{2{,}924m}{2}\right) * 1m = 0{,}65\ \text{kN}$$

$$F_{2ndfloor} = 1 * \left(\frac{0{,}22kN}{m^2}\right) * \left(\frac{2{,}924\text{m}}{2} + \frac{0{,}674m}{2}\right) * 1m = 0{,}4\ \text{kN}$$

$$F_{ceiling} = 1 * \left(\frac{0{,}22kN}{m^2}\right) * \left(\frac{0{,}674\text{m}}{2}\right) * 1m = 0{,}07\ \text{kN}$$

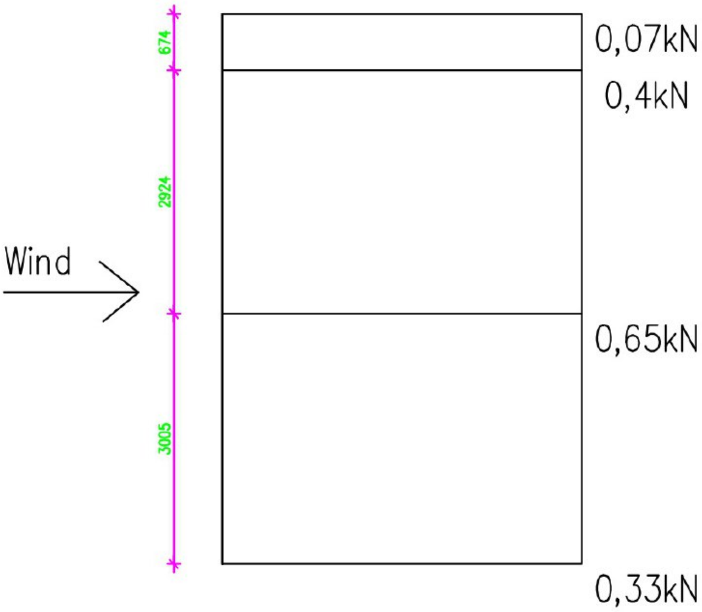


Figure 46. Force distribution

Total force excluding foundation:

F=0,65+0,4+0,07=1,12 kN

In fact, further we also count only by considering the wall horizontally (along its length), and not height. Now, in order to find out what force goes to a particular wall, we find how many reference (or unit) meters can fit in each load area. In other words, we simply expand or narrow our cargo area, 1 meter wide, to the extent we need.

For wall number 1, this is half the distance to the second wall.

F1=F*(1,95/2) =1,12 kN*0,975=1,09 kN

0,975 – how many reference (or unit) meters can fit. Even rather, it means what part of 1m this part of the wall (the load area is) is.

Otherwise it will look like: 1,12 kN/m*1m changes to 1,12 kN/m*0,975 m

For the second wall, this will be half of the distances on each side.

1,12 kN*(11,176/2+1,95/2) =7,35 kN

For the 3rd wall the situation is the same. However, the load area also includes part of the wall from below.

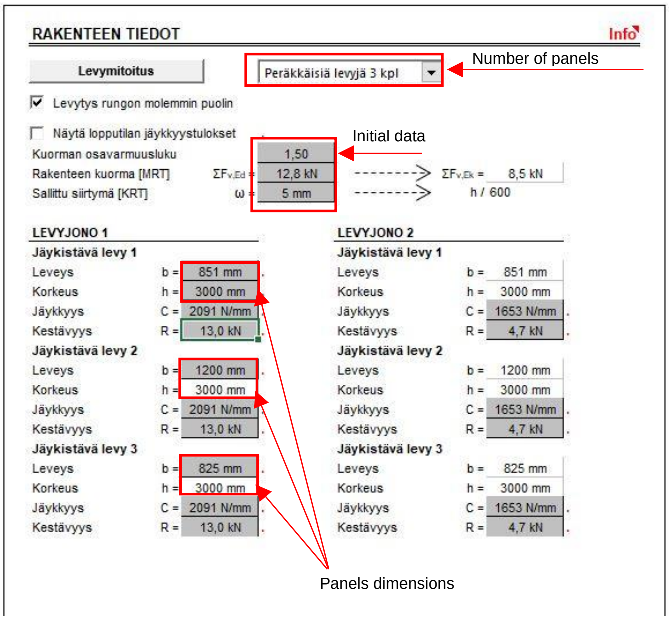
1,12kN*(11,176/2+2,009) =8,5 kN

To determine whether a particular wall can withstand the load and how fasteners (nails, etc.) will work, another calculator should be used from the site PUUINFO (PUUINFO. Sizing program for plate stiffener.). In the next section there will be a little explanation about it.

3.2.10 PuuInfo

Let's take a look at the calculator. The third tab contains a section for entering initial data. In this part, we look at how much the slabs will move and wobble and if this will be within the allowable limits given the given load. From the main one, this is the wind force acting on the wall and wall panels, which we found in the paragraph earlier. The load on the structure is taken taking into account the partial margin of safety equal to the standard 1.5. Therefore, inserting our force into the initial data, we must use not it, but the load, taking into account this additional coefficient. Below is the allowable movement. In the original it is 5 mm.

For a brief explanation, let's use the wall with the highest load. It is logical that in this case we will have 3 calculations, since we do not use slabs at the openings. So, we need one slab of 851 mm length, two slabs of 1200 mm and 1759-1200 =559 mm (the standard size of slabs is 1200 mm so for the most part we try to use them), and one slab on the right, which will also be 825 mm.



RAKENTEEN TIEDOT

Peräkkäisiä levyjä 3 kpl

☑ Levytys rungon molemmin puolin

☐ Näytä lopputilan jäykkyystulokset

Kuorman osavarmuusluku 1,50

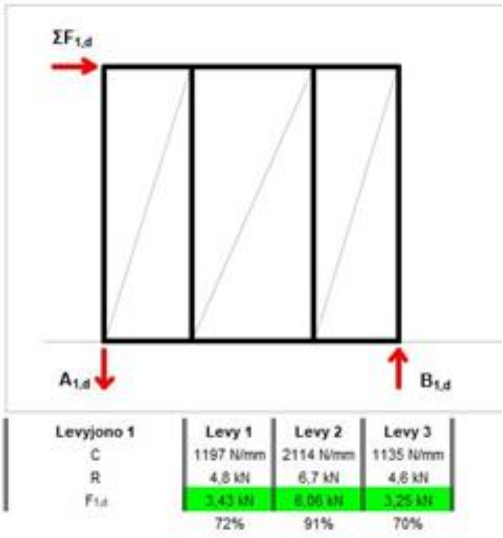
Rakenteen kuorma [MRT] $\Sigma F_{v,Ed}$ = 12,8 kN --------> $\Sigma F_{v,Ek}$ = 8,5 kN

Sallittu siirtymä [KRT] ω = 5 mm --------> h / 600

		LEVYJONO 1	LEVYJONO 2
Jäykistävä levy 1			
Leveys	b =	851 mm	851 mm
Korkeus	h =	3000 mm	3000 mm
Jäykkyys	C =	2091 N/mm	1653 N/mm
Kestävyys	R =	13,0 kN	4,7 kN
Jäykistävä levy 2			
Leveys	b =	1200 mm	1200 mm
Korkeus	h =	3000 mm	3000 mm
Jäykkyys	C =	2091 N/mm	1653 N/mm
Kestävyys	R =	13,0 kN	4,7 kN
Jäykistävä levy 3			
Leveys	b =	825 mm	825 mm
Korkeus	h =	3000 mm	3000 mm
Jäykkyys	C =	2091 N/mm	1653 N/mm
Kestävyys	R =	13,0 kN	4,7 kN

Figure 47. Initial data

Their parameters must be entered below. At the very top, you can initially set the number of panels, and on the right, a drawing will appear in front of us, depending on the parameters of the wall panels that we entered. Also, on the right the results of the calculation can be seen, whether this type and size of the plates suits us, whether they will withstand, what the deviation will be and what force will act on each panel.



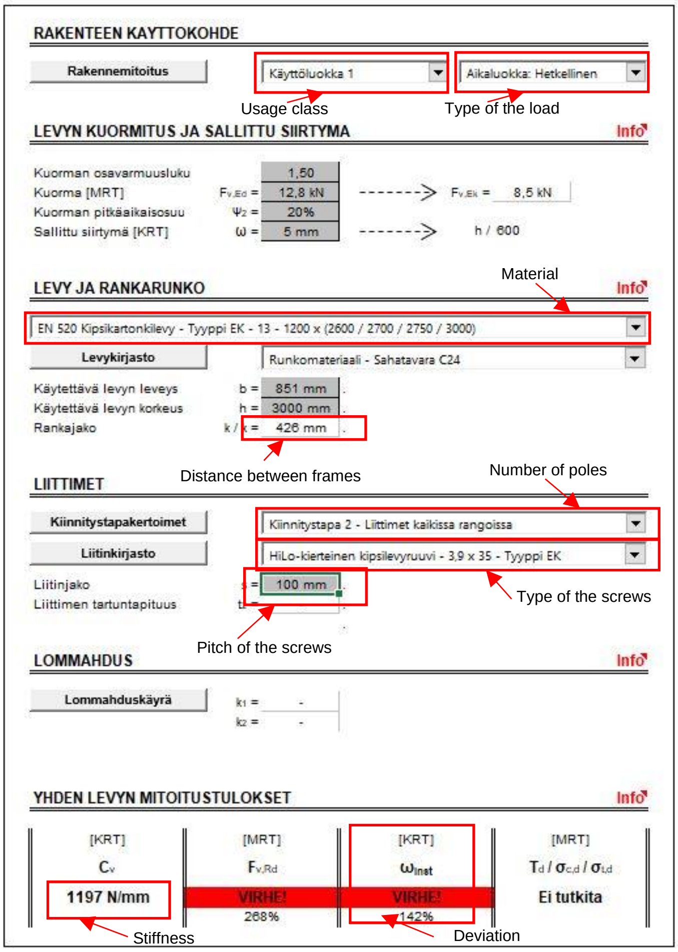
Levyjono 1	Levy 1	Levy 2	Levy 3
C	1197 N/mm	2114 N/mm	1135 N/mm
R	4,8 kN	6,7 kN	4,6 kN
$F_{1,d}$	3,43 kN	6,06 kN	3,25 kN
	72%	91%	70%

Figure 48. Three panels

Next, we need to choose the stiffness(C) and durability(R) of the structure. But we do not know it yet, so we need to go to the next tab and find it for another calculations.

On the second tab, we also enter the initial data. (They are identical). Here the ability of the fasteners to resist pressure, as well as the stability of individual plates, will be calculated. At the top, you can change the usage class and the time that the load will pass (permanent or temporary). In our case, the load is wind load, so we should choose temporary type. Below we can choose the material from which the frame is made of. It can be either plywood or gypsum board. In addition to dimensions, the distance between frames should be specified.

After that, we will choose the type of connection (this is the number of pillars inside the common frame), as well as the type of nails or other connections. The program even can show with what pitch the screws are used. At the very bottom, we see stiffness indicators, deviation, and they are highlighted in red or green. That is how the program let us know whether this or that type of fastening is suitable for us in accordance with the dimensions and materials.



RAKENTEEN KAYTTOKOHDE

Käyttöluokka 1
Aikaluokka: Hetkellinen

LEVYN KUORMITUS JA SALLITTU SIIRTYMA

Kuorman osavarmuusluku 1,50
Kuorma [MRT] $F_{v,Ed}$ = 12,8 kN -------> $F_{v,Ek}$ = 8,5 kN
Kuorman pitkäaikaisosuu Ψ_2 = 20%
Sallittu siirtymä [KRT] ω = 5 mm -------> h / 600

LEVY JA RANKARUNKO

EN 520 Kipsikartonkilevy - Tyyppi EK - 13 - 1200 x (2600 / 2700 / 2750 / 3000)
Runkomateriaali - Sahatavara C24
Käytettävä levyn leveys b = 851 mm
Käytettävä levyn korkeus h = 3000 mm
Rankajako k / k = 426 mm

LIITTIMET

Kiinnitystapa 2 - Liittimet kaikissa rangoissa
HiLo-kierteinen kipsilevyruuvi - 3,9 x 35 - Tyyppi EK
Liitinjako s = 100 mm
Liittimen tartuntapituus t =

LOMMAHDUS

k_1 = -
k_2 = -

YHDEN LEVYN MITOITUSTULOKSET

[KRT]	[MRT]	[KRT]	[MRT]
C_v	$F_{v,Rd}$	ω_{inst}	$T_d / \sigma_{c,d} / \sigma_{t,d}$
1197 N/mm	VIRHE!	VIRHE!	Ei tutkita
	268%	142%	

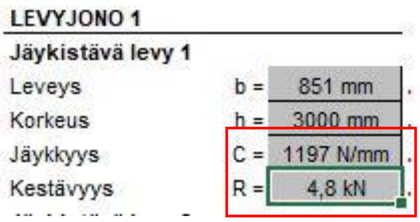
Figure 49. How the second tab looks like

On the right you can find such a part. From here we need the value of durability. This is how much this wall panel can withstand.

LEVYN LEIKKAUSVOIMAKESTÄVYYS LIITTIMIEN PERUSTEELLA
$F_{v,Rd}$ 4,76 kN *Levyn leikkausvoimakestävyys*
EHTO 2,68 < 1

Figure 50. Important box on right

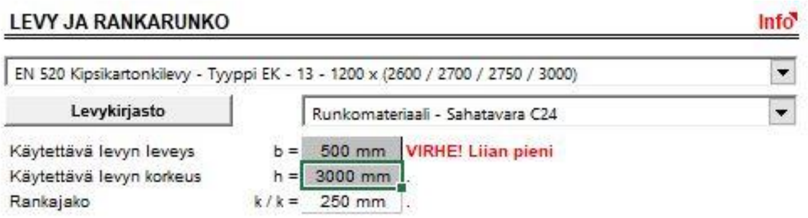
Returning to tab 3, we are faced with the task of changing the values of C and P, which we received in the 2nd tab.



LEVYJONO 1
Jäykistävä levy 1
Leveys b = 851 mm
Korkeus h = 3000 mm
Jäykkyys C = 1197 N/mm
Kestävyys R = 4,8 kN

Figure 51. Further changes

In this order, consider all 4 wall panels. However, if the value of the plate is too small, as, for example, in our case (Figure 48), the calculator will say about it. That means that it should not be taken into the consideration in the calculation.



LEVY JA RANKARUNKO

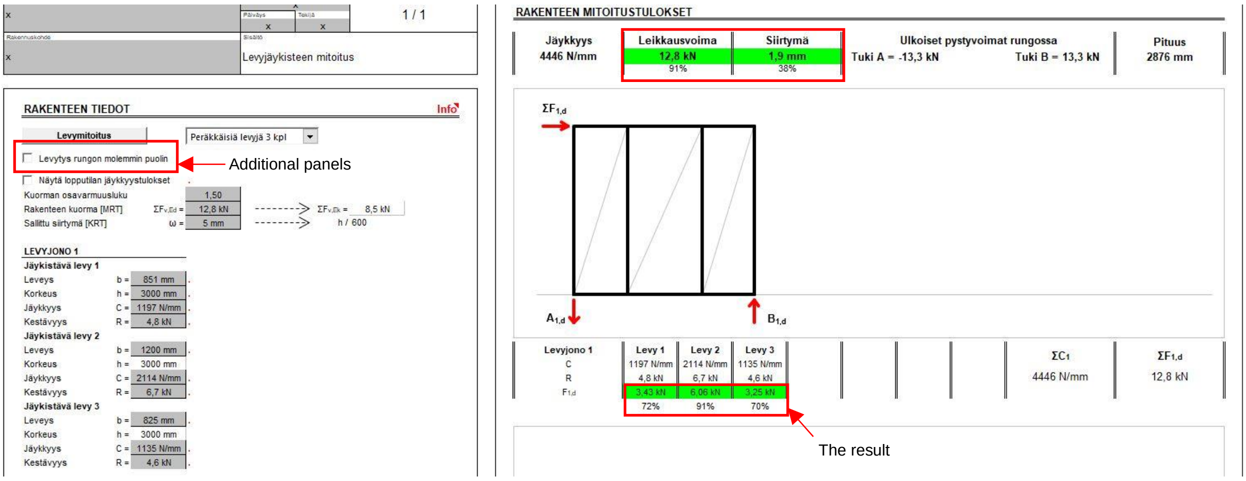
EN 520 Kipsikartonkilevy - Tyyppi EK - 13 - 1200 x (2600 / 2700 / 2750 / 3000)

Runkomateriaali - Sahatavara C24

Käytettävä levyn leveys b = 500 mm VIRHE! Liian pieni
Käytettävä levyn korkeus h = 3000 mm
Rankajako k / k = 250 mm

Figure 52. Too small panel

Knowing the force acting on each of the panels, it is possible to check them on tab number 2 again. The goal is for the values to turn green. When considering three plates at once, we see that everything is fine with the design. It resists pressure and will withstand our load. However, the load on the second plate is greater than on the others. The percentage indicators may be different, but when it is close to 100%, our design should be supplemented with additional panels on the other side. Here a tick in 1 line with the original data will help us.



x
Päiväys x
Tekijä x
1 / 1
Rakennuskohde x
Sisältö Levyjäykisteen mitoitus

RAKENTEEN TIEDOT

Peräkkäisiä levyjä 3 kpl

☐ Levytys rungon molemmin puolin

Additional panels

☐ Näytä lopputilan jäykkyystulokset

Kuorman osavarmuusluku 1,50
Rakenteen kuorma [MRT] $\Sigma F_{v,Ed}$ = 12,8 kN --------> $\Sigma F_{v,Ek}$ = 8,5 kN
Sallittu siirtymä [KRT] ω = 5 mm --------> h / 600

LEVYJONO 1

Jäykistävä levy 1
Leveys b = 851 mm
Korkeus h = 3000 mm
Jäykkyys C = 1197 N/mm
Kestävyys R = 4,8 kN

Jäykistävä levy 2
Leveys b = 1200 mm
Korkeus h = 3000 mm
Jäykkyys C = 2114 N/mm
Kestävyys R = 6,7 kN

Jäykistävä levy 3
Leveys b = 825 mm
Korkeus h = 3000 mm
Jäykkyys C = 1135 N/mm
Kestävyys R = 4,6 kN

RAKENTEEN MITOITUSTULOKSET

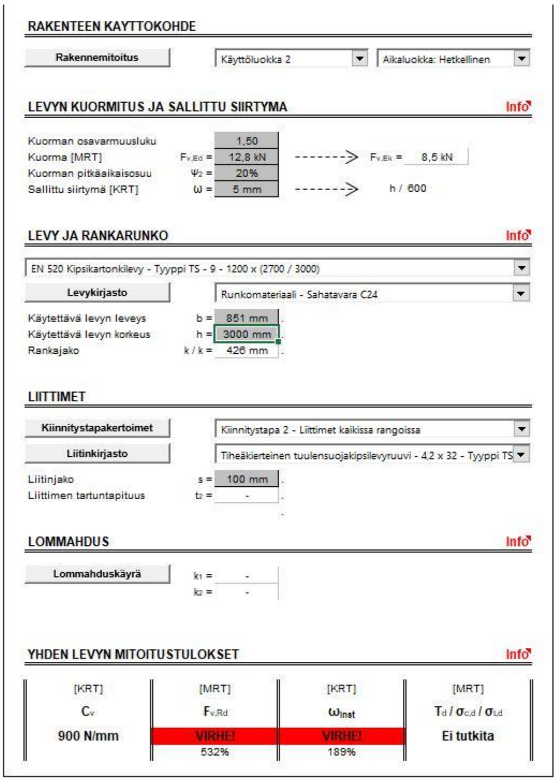
Jäykkyys	Leikkausvoima	Siirtymä	Ulkoiset pystyvoimat rungossa	Pituus
4446 N/mm	12,8 kN 91%	1,9 mm 38%	Tuki A = -13,3 kN Tuki B = 13,3 kN	2876 mm

Levyjono 1	Levy 1	Levy 2	Levy 3	ΣC_1	$\Sigma F_{1,d}$
C	1197 N/mm	2114 N/mm	1135 N/mm	4446 N/mm	12,8 kN
R	4,8 kN	6,7 kN	4,6 kN		
$F_{1,d}$	3,43 kN	6,06 kN	3,25 kN		
	72%	91%	70%		

The result

Figure 53. First result

Subsequently, the actions are repeated, only with additional wind-resistant plates. We find the necessary indicators and try to make sure that the overall design fits in all respects and that the screws in each panel hold tight and do not break out. If this does not work out with ordinary data, it is possible to change the number of ribs (racks) in the frame, change the pitch of the fasteners and change the material (The main thing is that it suits us in meaning and that the dimensions of the plate remain unchanged).



RAKENTEEN KAYTTOKOHDE

Käyttöluokka 2
Aikaluokka: Hetkellinen

LEVYN KUORMITUS JA SALLITTU SIIRTYMA

Kuorman osavarmuusluku 1,50
Kuorma [MRT] $F_{v,Ed}$ = 12,8 kN -------> $F_{v,Ek}$ = 8,5 kN
Kuorman pitkäaikaisosuu ψ_2 = 20%
Sallittu siirtymä [KRT] ω = 5 mm -------> h / 600

LEVY JA RANKARUNKO

EN 520 Kipsikartonkilevy - Tyyppi TS - 9 - 1200 x (2700 / 3000)
Runkomateriaali - Sahatavara C24
Käytettävä levyn leveys b = 851 mm
Käytettävä levyn korkeus h = 3000 mm
Rankajako k / k = 426 mm

LIITTIMET

Kiinnitystapa 2 - Liittimet kaikissa rangoissa
Tiheäkierteinen tuulensuojakipsilevyruuvi - 4,2 x 32 - Tyyppi TS
Liitinjako s = 100 mm
Liittimen tartuntapituus t_2 = -

LOMMAHDUS

k_1 = -
k_2 = -

YHDEN LEVYN MITOITUSTULOKSET

[KRT]	[MRT]	[KRT]	[MRT]
C_v	$F_{v,Rd}$	ω_{inst}	T_d / $\sigma_{c,d}$ / $\sigma_{t,d}$
900 N/mm	VIRHE! 532%	VIRHE! 189%	Ei tutkita

Figure 54. Editing the second panels

The final result should look something like in the Figure 51. Thus, it can be concluded and shown how the load is distributed across the panels, what loads are obtained and whether the structure is stiffed enough.

x

Levyjäykisteen mitoitus

RAKENTEEN TIEDOT

Peräkkäisiä levyjä 3 kpl
☑ Levytys rungon molemmin puolin
☐ Näytä lopputilan jäykkyystulokse
Kuorman osavarmuusluku 1,50
Rakenteen kuorma [MRT $\Sigma F_{v,Ed}$ = 12,8 kN -------> $\Sigma F_{v,Ek}$ = 8,5 kN
Sallittu siirtymä [KRT] ω = 5 mm -------> h / 600

LEVYJONO 1

Jäykistävä levy 1		
Leveys	b =	851 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	1197 N/mm
Kestävyys	R =	4,8 kN
Jäykistävä levy 2		
Leveys	b =	1200 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	2114 N/mm
Kestävyys	R =	6,7 kN
Jäykistävä levy 3		
Leveys	b =	825 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	1135 N/mm
Kestävyys	R =	4,6 kN

LEVYJONO 2

Jäykistävä levy 1		
Leveys	b =	851 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	900 N/mm
Kestävyys	R =	2,4 kN
Jäykistävä levy 2		
Leveys	b =	1200 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	1495 N/mm
Kestävyys	R =	3,4 kN
Jäykistävä levy 3		
Leveys	b =	825 mm
Korkeus	h =	3000 mm
Jäykkyys	C =	858 N/mm
Kestävyys	R =	2,3 kN

Jäykkyys	Leikkausvoima	Siirtymä	Ulkoiset pystyvoimat rungossa	Pituus
7699 N/mm	12,8 kN 74%	1,1 mm 22%	Tuki A = -13,3 kN Tuki B = 13,3 kN	2876 mm

Levyjono 1	Levy 1	Levy 2	Levy 3	ΣC_1	$\Sigma F_{1,d}$
C	1197 N/mm	2114 N/mm	1135 N/mm	4446 N/mm	7,4 kN
R	4,8 kN	6,7 kN	4,6 kN		
$F_{1,d}$	1,98 kN	3,50 kN	1,88 kN		
	42%	52%	41%		

Levyjono 2	Levy 1	Levy 2	Levy 3	ΣC_2	$\Sigma F_{2,d}$
C	900 N/mm	1495 N/mm	858 N/mm	3253 N/mm	5,4 kN
R	2,4 kN	3,4 kN	2,3 kN		
$F_{2,d}$	1,49 kN	2,48 kN	1,42 kN		
	62%	74%	61%		

Figure 55. The final result

4 Summary

When designing a building, it is important to consider all the loads that act on it. The task of engineers is to make the building resistant to all external factors. Incorrect calculations can lead to the fact that the loads exceed the allowable for a certain element of the building and the structure will not withstand and will be destroyed. If during the calculations it becomes obvious that the strength and rigidity of the same wall is not enough, then subsequently it is necessary to strengthen the walls or add stiffening walls. The need to strengthen the walls may arise due to the fact that during the operation the walls are subjected to deformations, defects and damage appear in them. Stiffening of walls increases the strength characteristics and bearing capacity of wall structures.

According to this, the main purpose of this thesis work was the understanding of the process of finding wind loads and wind force on a building. Besides from it, a calculator for calculating them was introduced and a calculator from the Puuinfo.fi site for the stiffness and stability of wall panels was described. By using a ready-made example of a building from the customer, everything was shown in a visual way.

The work on the diploma began with the receipt of the building project by the customer. Initially, it was planned to create a calculation program for a different type of loads, but later the work was changed to finding only wind loads. The reason was that there was less data on them, which could be of the greatest benefit, but at the same time there would not be an overload on the thesis work. At the beginning of the work, it was necessary to understand the principle of calculating loads in order to create a calculation program. The difficulty was the presence of many different coefficients, each of which is considered and accepted depending on the category of factors.

However, after the analysis, everything was extremely simple and understandable. The calculation process has been carried out, all required data, such as loads and forces, have been found. Subsequently, it was determined how the force acting on a certain wall is distributed further and how the wall stiffeners help us. By placing them, we strengthen our structure and make the wall more stable, because these walls become some kind of props and supports, which also take on loads, reducing their impact on the main wall. This is one of the ways to strengthen the structure.

The main questions that arose throughout the work were what kind of loads does the low-rise building experience and can it withstand the forces generated by these loads on the walls, especially the wall panels? Owing to the panel calculation program, it was found that depending on the size of the wall panels, their material, the type of frame and their fastening, it is possible to increase wind resistance to a greater or lesser extent. Based on the calculations for the selected building, everything turned out to be normal and it can be assumed that the calculated and selected walls will withstand the calculated loads.

Thus, it can be said that all the objectives of the thesis work were fulfilled. The work was exciting and gave a lot of new in-depth knowledge. For a long time, the principles of calculating wind loads have been studied and explained, observing all the basic principles and rules specified in the regulatory documents. Thanks to a large number of sources of information, all the data was grouped and described.

The calculator file for the client was created based on the capabilities of the author. However, there were difficulties in creating it, since it was not clear how to sequentially describe the process in a file so that everything looked neat and unloaded. In addition, in any calculations, there are many little things that make them unique. Due to not the most professional knowledge in the field of computer science, many exceptions had to be left as exceptions due to the complexity of programming. But despite this, the main task - to find quickly approximate values, was successfully completed and implemented.

Studying the program for the stiffness of wall panels was very interesting. The program was in Finnish, and it was extremely important to understand its principle most correctly. It turned out to be very useful and multifunctional and was also provided to the customer for subsequent calculations.

While calculating, it is necessary to find loads and check the stiffness not only of the 1st floor level, but also of the roof level and the level of the second floor, since, as mentioned earlier, any element or part of the building that does not pass the stability parameters can lead to bad consequences for the entire building as a whole. In this work, they were excluded, since the main idea of the work was to make a guide for the client, for the correct use of the author's calculator and the Puuinfo calculation in Excel.

After a large amount of studied and updated information, the next step is to give the calculator to the customer and possibly subsequent adjustments. It is useful to have a free program that can be beneficial for work as well as study. Also, there was a desire to delve more into the principle of different building calculation processes. Because using certain formulas wisely, understanding why they are needed and how they work, it is much more pleasant and correct than mindlessly counting numbers.

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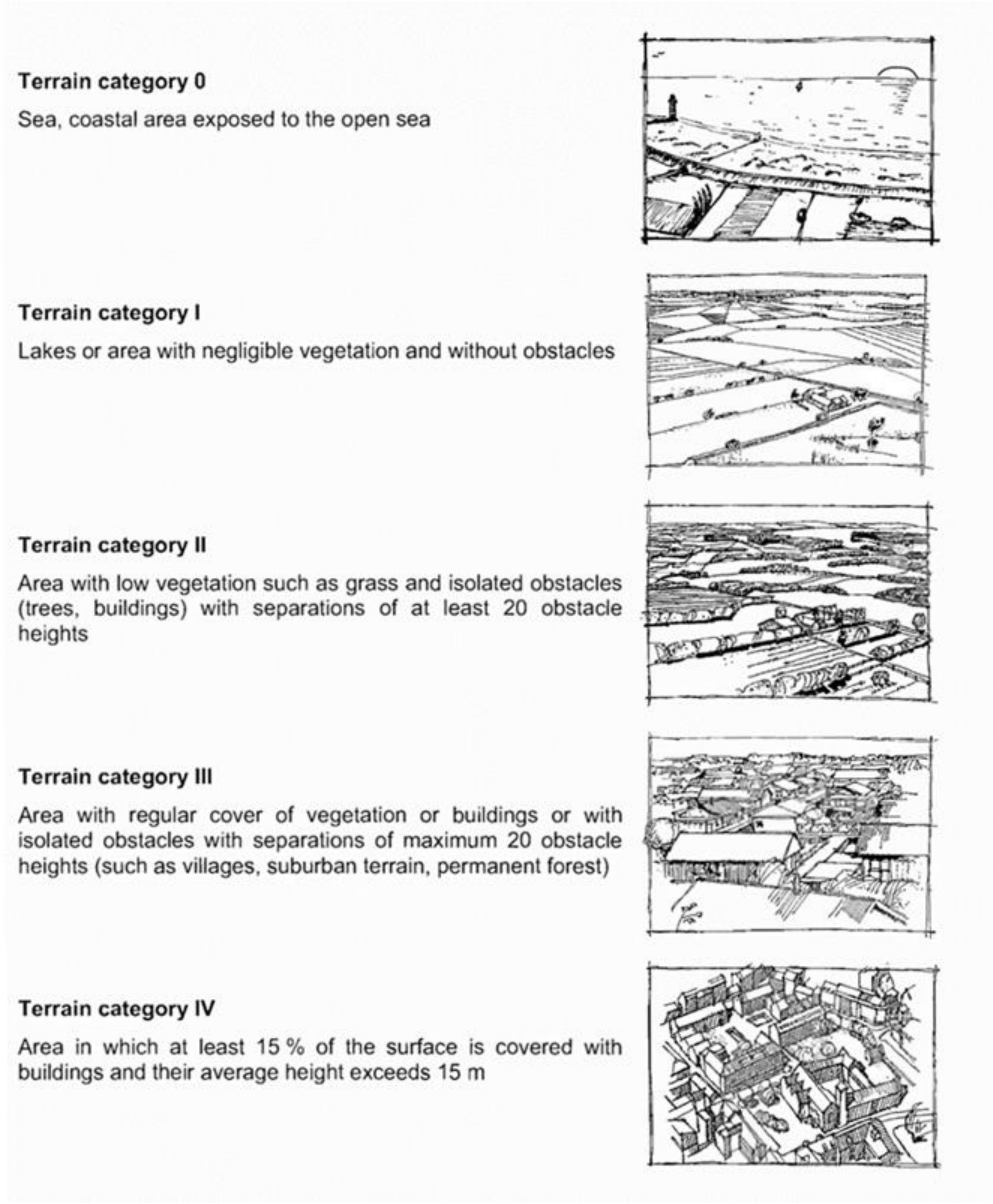
Appendix 1. Terrain category (EN 1991-1-4 2005)



Terrain category 0

Sea, coastal area exposed to the open sea

Terrain category I

Lakes or area with negligible vegetation and without obstacles

Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights

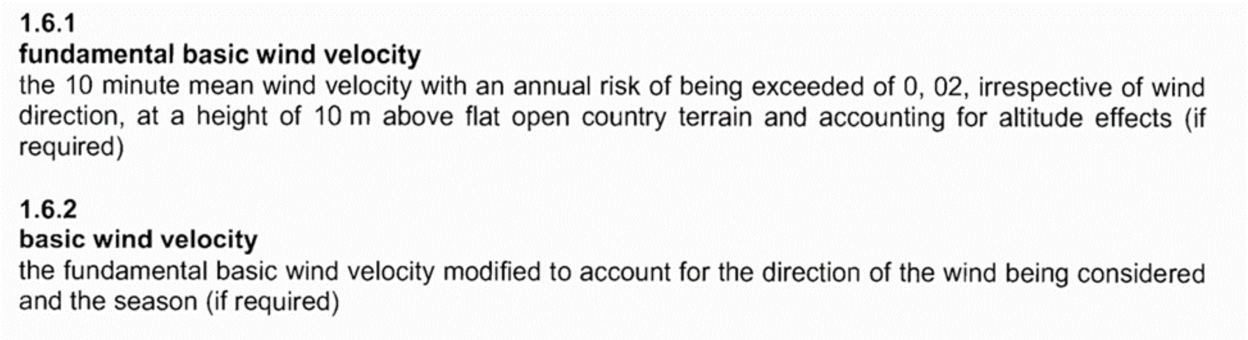
Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)

Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m

Appendix 2. A list of basic definitions (EN 1991-1-4 2005)



1.6.1

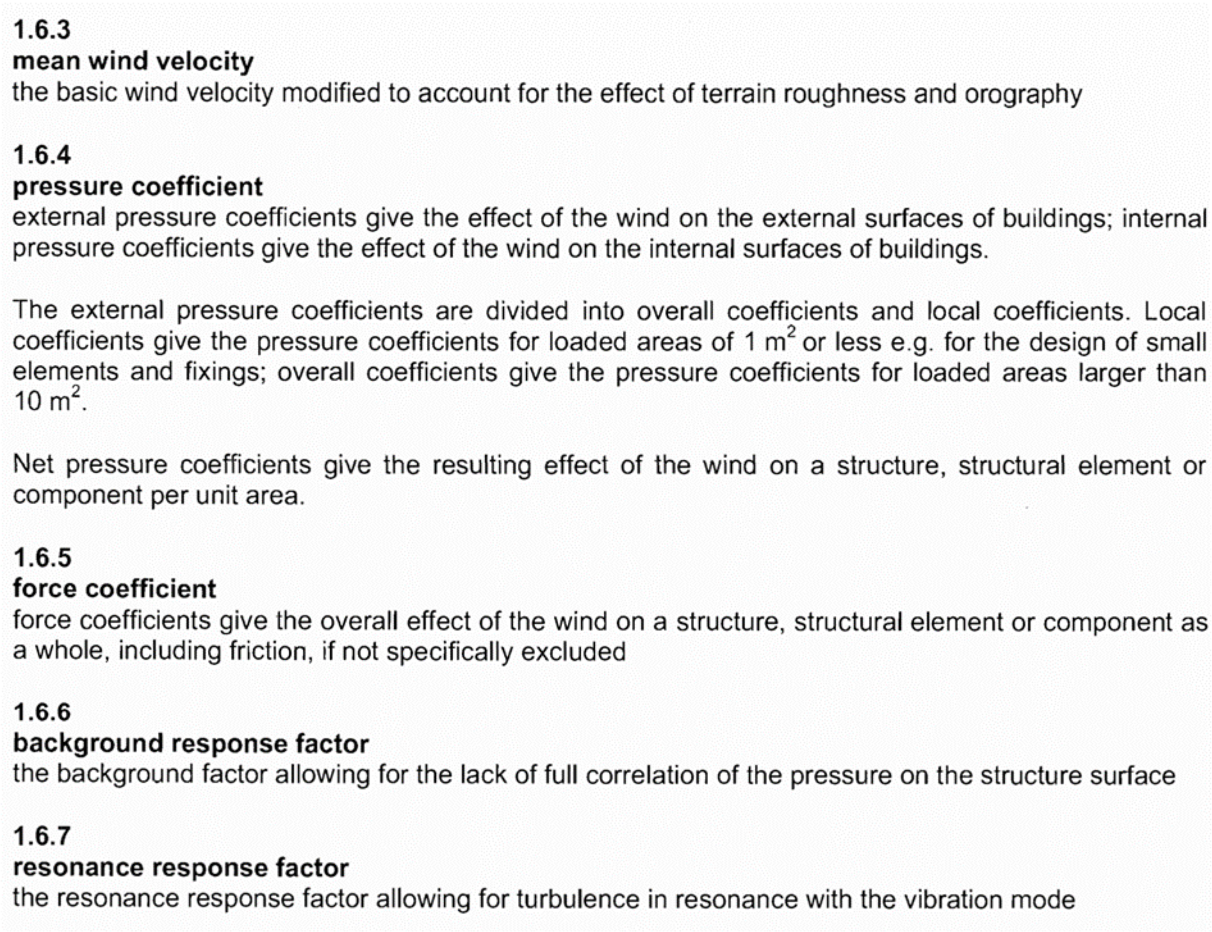
fundamental basic wind velocity

the 10 minute mean wind velocity with an annual risk of being exceeded of 0, 02, irrespective of wind direction, at a height of 10 m above flat open country terrain and accounting for altitude effects (if required)

1.6.2

basic wind velocity

the fundamental basic wind velocity modified to account for the direction of the wind being considered and the season (if required)



1.6.3

mean wind velocity

the basic wind velocity modified to account for the effect of terrain roughness and orography

1.6.4

pressure coefficient

external pressure coefficients give the effect of the wind on the external surfaces of buildings; internal pressure coefficients give the effect of the wind on the internal surfaces of buildings.

The external pressure coefficients are divided into overall coefficients and local coefficients. Local coefficients give the pressure coefficients for loaded areas of 1 m^2 or less e.g. for the design of small elements and fixings; overall coefficients give the pressure coefficients for loaded areas larger than 10 m^2.

Net pressure coefficients give the resulting effect of the wind on a structure, structural element or component per unit area.

1.6.5

force coefficient

force coefficients give the overall effect of the wind on a structure, structural element or component as a whole, including friction, if not specifically excluded

1.6.6

background response factor

the background factor allowing for the lack of full correlation of the pressure on the structure surface

1.6.7

resonance response factor

the resonance response factor allowing for turbulence in resonance with the vibration mode