STATICA

Mastertent Pavilion esagonale

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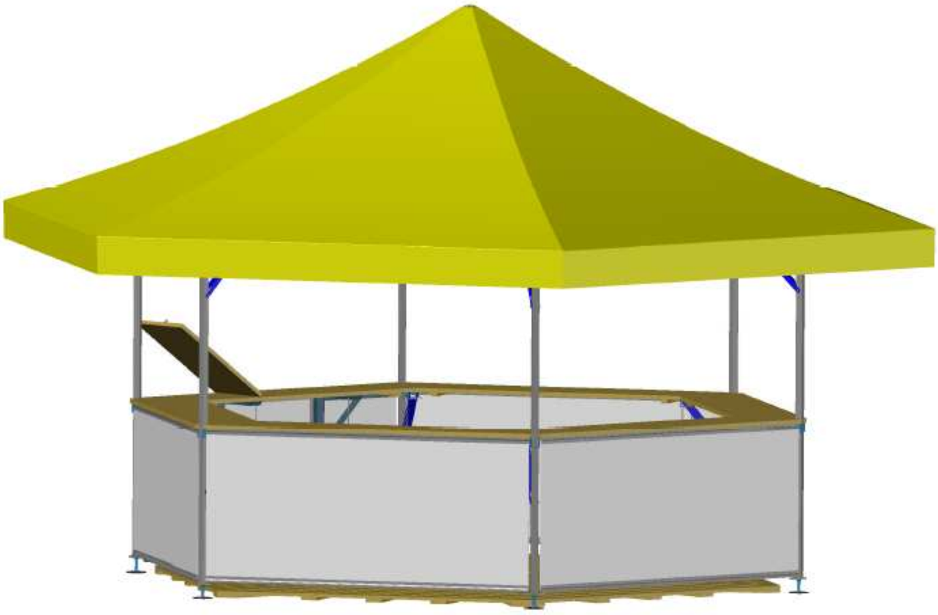
Massimo Maffeis
Engineering and Consulting



Structure: **Hexagonal Kiosk Ø6 m**

Object: **Stability report**

Type: **Temporary structure**

Project and manufacture:

ZINGERLEMETAL

Structural design:

Dr. Ing. Massimo Maffeis Profession legally qualified and register in Engineer Order in Vicenza (ITALY) with position n°1989

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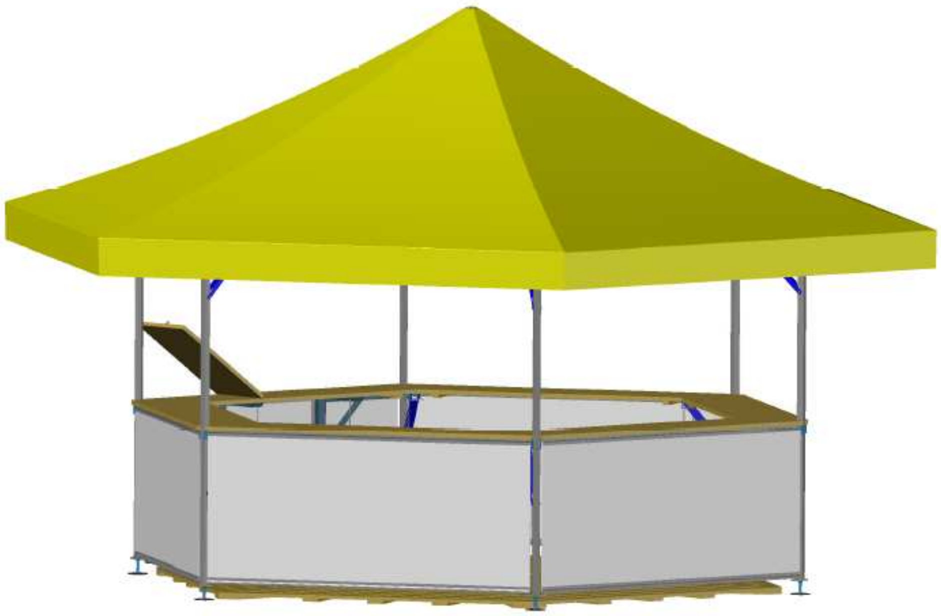
INDICE

1 INTRODUTION

The structure consists on a temporary hexagonal kiosk with an external diameter of 6m, here below it is possible to find an image of structure:



Pic 1 General view of structure

On this report it is possible to find an analysis of the stability of structure; the scope is to find the limit of speed after the uplift of kiosk.

Particularly we want to find two limits:

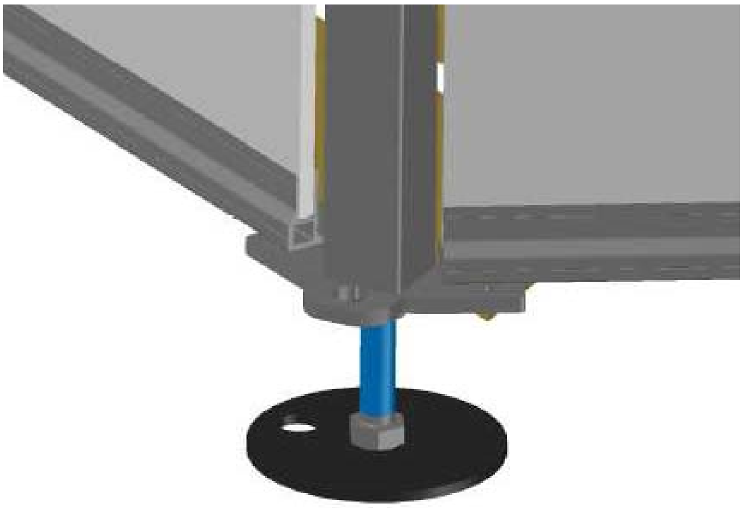
- The uplift of structure when only self weight of structure contrasts the wind load;
- The uplift of structure when the self weight of structure and the pickets at the base of columns contrast the wind load.

The analysis of steel structure and membrane roof is not scope of this report.

1.1 TYPE OF INSTALLATION

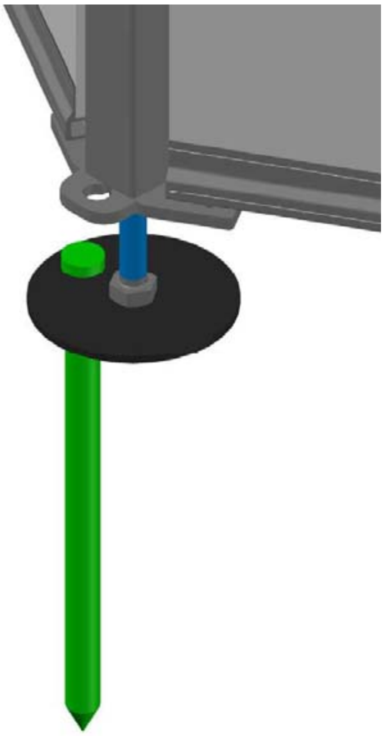
It is possible to find two types of installation of the tent:

- Installation without base pickets (in this case the wind speed supported it will be lower)



Pic 2 Structure without pickets

- Installation with base pickets (in this case the wind speed supported it will be bigger):



Pic 3 Structure with belts

2 STANDARDS AND RULES

UNI EN 13782 “Temporary structures”

UNI EN 1991-1-1 “Loads on structures”.

UNI EN 1991-1-4 “Loads on structures – Wind load”

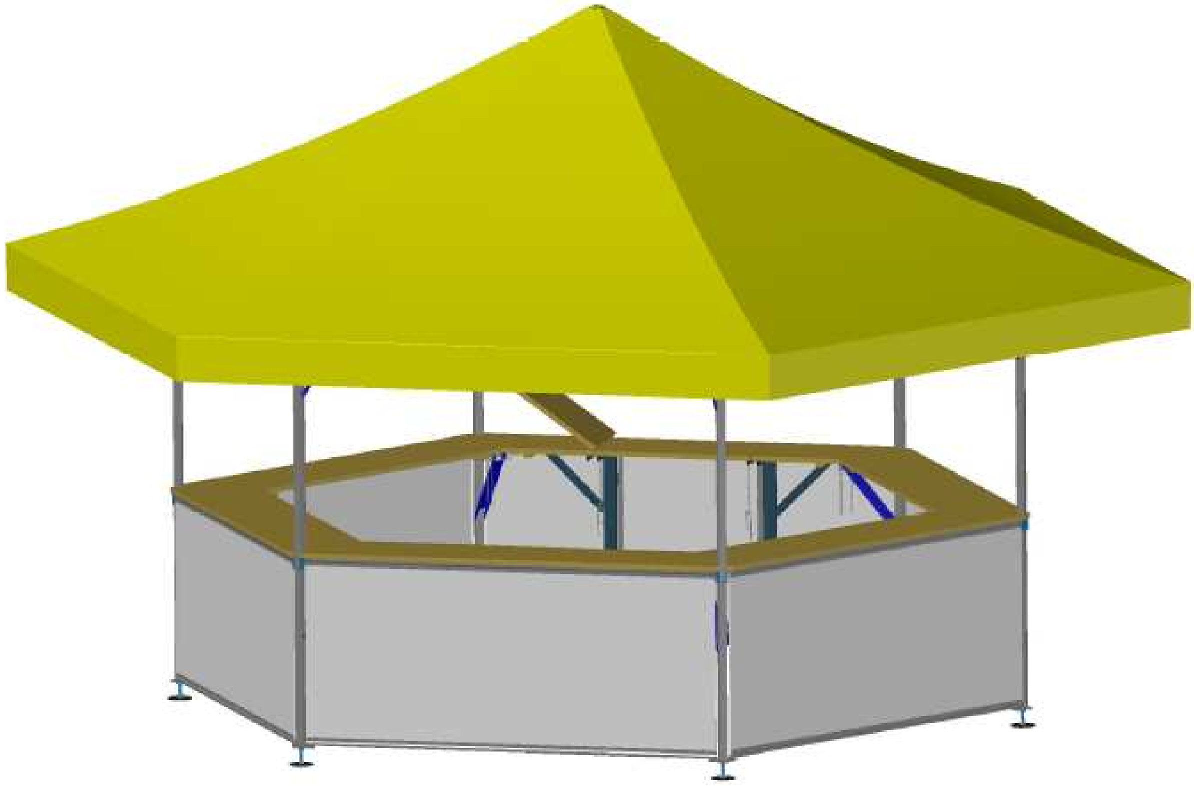
The covering is calculated as a membrane in elastic material field and non linear geometry (big displacements).
The analysis is realised with the finite elements software code STRAUS by G+D Computing.

3 LOADS

The load follow reported will be used for definitions of load combination.

3.1 Weight (Pp)

This case takes into account the self weight of each element. In accord with the indications of manufacture, the total weight of structure, when is installed as shown on the image, is 278kg:



Pic 4 Exercise installation (weight 278 kg)

3.2 Wind (Wind)

The wind load is calculated for temporary structure in according with UNI EN 13782.
We have fixed the maximum wind fundamental velocity ($V_{b,0}$) that the structure can support and than we have calculate the base velocity as:

$$V_b = C_{dir} x C_{season} x C_{prob} x V_{b,0}$$

C_{dir} = 1 (UNI EN 1991-1-4 §4.2)
C_{season} = 0.8 (UNI EN 1991-1-4 § 4.2 and UNI EN 13782 § 6.4.2 where C_{season} = C_{Tem}=0.8)
C_{prob} = $\left(\frac{(1-Kx\ln(-\ln(1-p))}{1-Kx\ln(-\ln(0.98))}\right)^n$ (UNI EN 1991-1-4 §4.2)

The characteristic value of velocity ($V_{b,0}$) is calculated for a mean return period (Tr) of 50 years; the analyzed structure is an itinerant structure that, in according with UNI EN 13782, has a Tr=10, so it is possible to reduce the V_b value as specified:

$$V_b = C_{dir} x C_{season} x C_{prob} x V_{b,0} = 1x0.8x\left(\frac{(1-0.2x\ln(-\ln(1-0.1))}{1-0.2x\ln(-\ln(0.98))}\right)^{0.5} xV_{b,0} \text{ m/s}$$

K = 0.2 (UNI EN 1991-1-4 §4.2)
n = 0.5 (UNI EN 1991-1-4 §4.2)
p = $1/T_r$ = 1/10 = 0.1

The exposure factor (C_e) is calculated in according with UNI EN 1991-1-4 § 4.4 §4.5; the terrain category of the site is II that has a z_0 value of 0.05 m, with this parameter it is possible to calculate the C_e value.

$$l_v(3.5) = \frac{k_i}{C_0(z)x\ln(z/z_0)} = \frac{1}{1x\ln(3.5/0.05)} = 0.24$$

$$C_r(3.5) = k_r x \ln\left(\frac{z}{z_0}\right) = 0.19\left(\frac{z_0}{z_{0,II}}\right)^{0.07} \ln\left(\frac{z}{z_0}\right) = 0.19\left(\frac{0.05}{0.05}\right)^{0.07} \ln\left(\frac{3.5}{0.05}\right) = 0.81$$

$$C_e(3.5) = [1+7xl_v(3.5)]xC_r{}^2(3.5)xC^2{}_0 = [1+7x0.24]x(0.81)^2 x(1)^2 = 1.73$$

The peak velocity pressure is:

$$q_p(z) = C_e(z)\ \frac{1}{2}\delta V_b^2$$

The pressure coefficient (Cpe) is applied in according with our CFD analysis. (Please check the annex at the end of this report).
The pressures applied at the structure on the fem analysis are:

$$W_e = q_p x C_{pe}$$

3.3 Snow

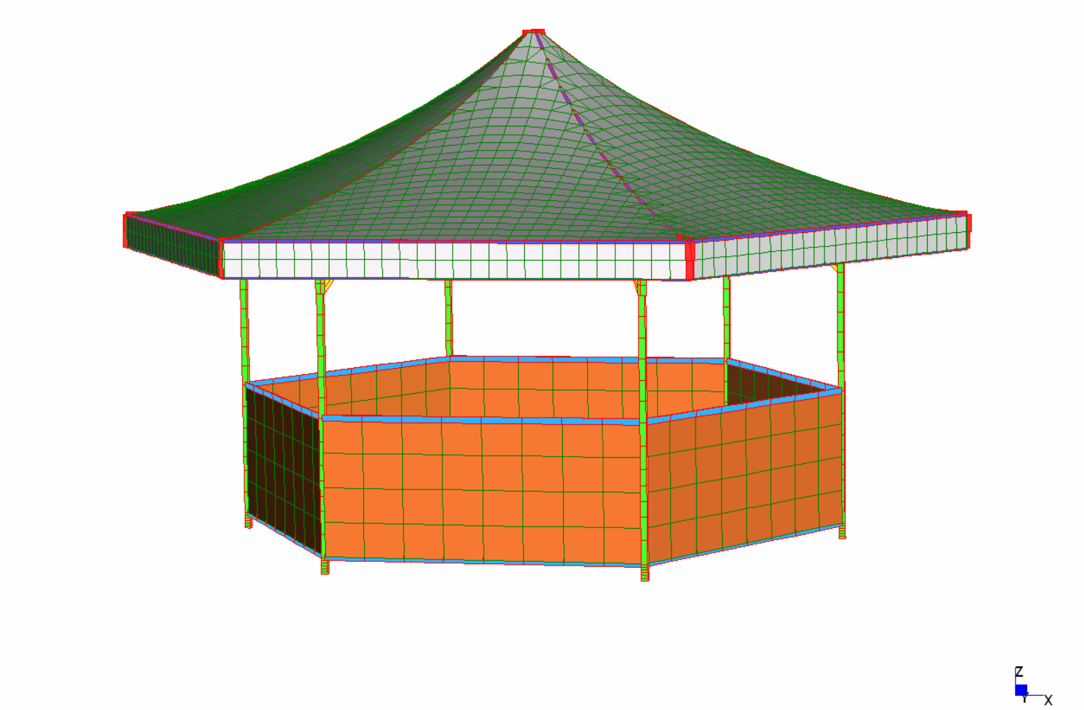
In accord with UNI EN 13782 the snow load is not considered for temporary structure.

3.4 Load combinations

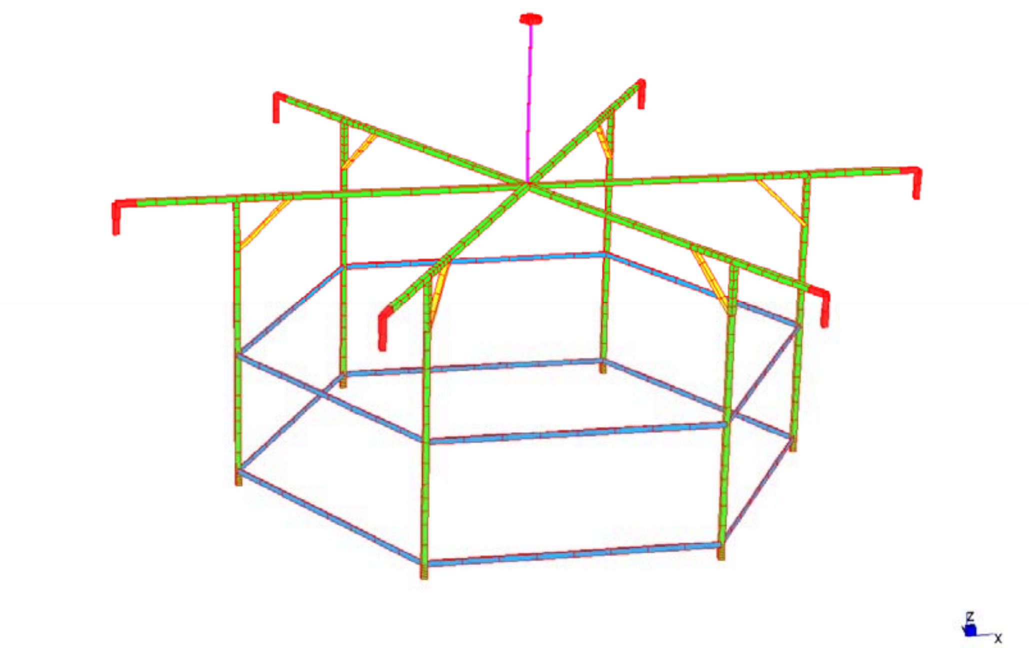
COMB 1: 1,0 X Pp + 1,0 X Wind

4 STABILITY ANALYSIS

The structure has been studied using a FEM analysis to study the real behavior of kiosk. Here below it is possible to find two images, the first image shows the total structure (steel, membrane and wood), the second image shows only the steel structure:



Pic 5 Total structure

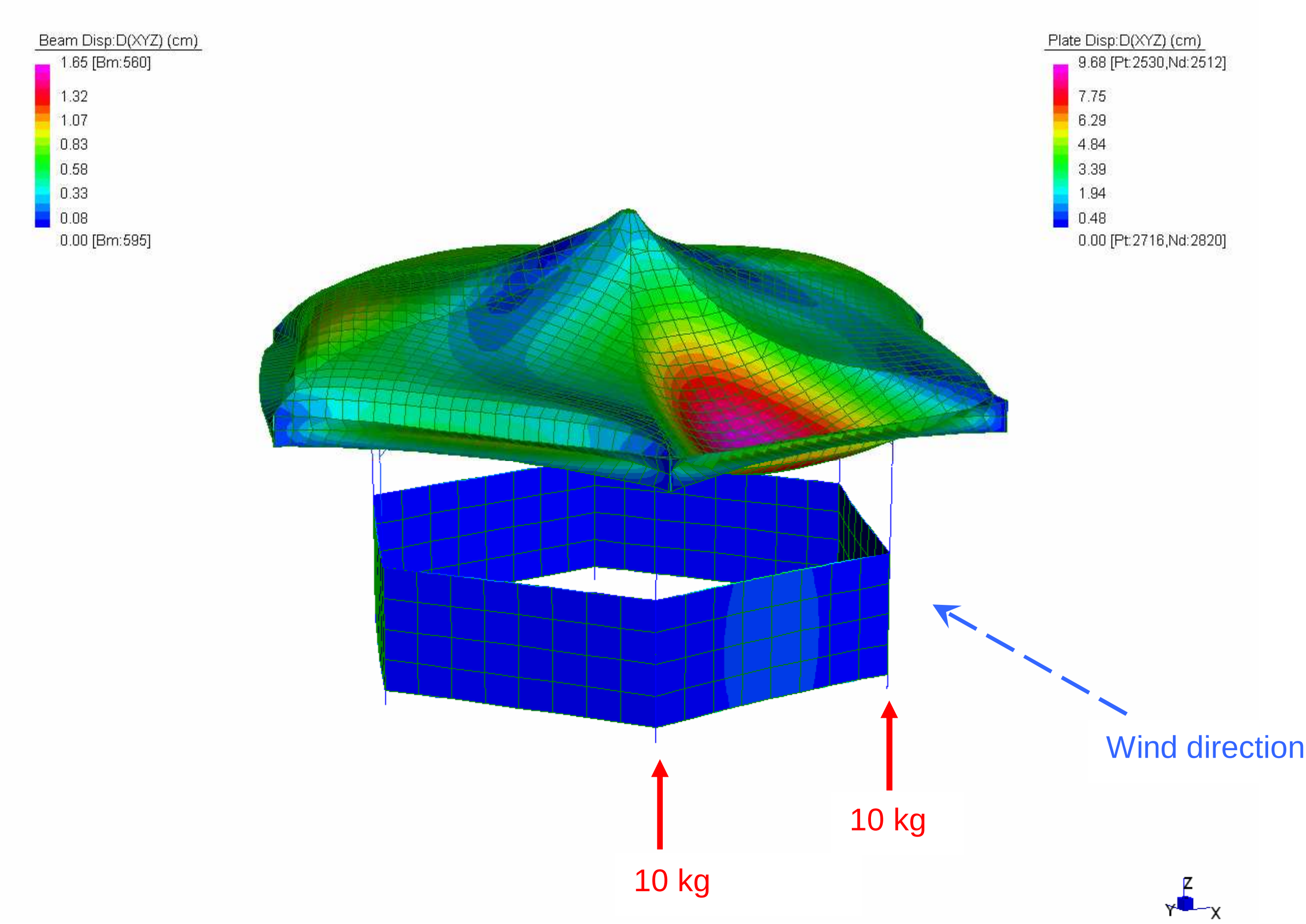


Pic 6 Steel structure

4.1 Installation without pickets

In this case the tent will be installed without pickets at the base of columns; the maximum wind speed supported **(V_{b0}) is 14 m/s** (~50km/h) that creates a peak velocity pressure of 11 kg/m^2

With this speed, when the wind direction is +y, the two bases on the front of structure have a vertical load reaction that is about 10 kg. This means that the structure is close to the limit of uplifting.

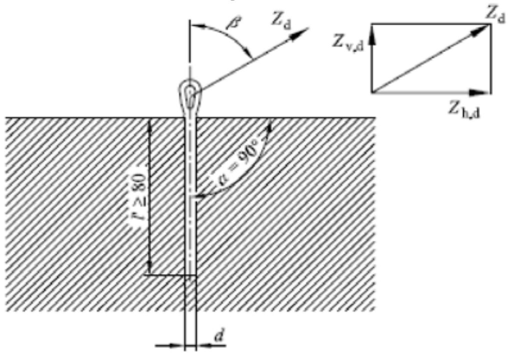


Pic 7 Displacements (V_{b0}= 14m/s)

4.2 Installation with pickets

In this case the tent will be installed with pickets at the base of columns; the maximum wind speed supported **(V_{b0}) is 18 m/s** (~65km/h) that creates a peak velocity pressure of 18 kg/m^2

If we consider having a cohesive soil with a consistency between medium and hard it is possible to find the exercise load in according with UNI EN 13782 as specified:



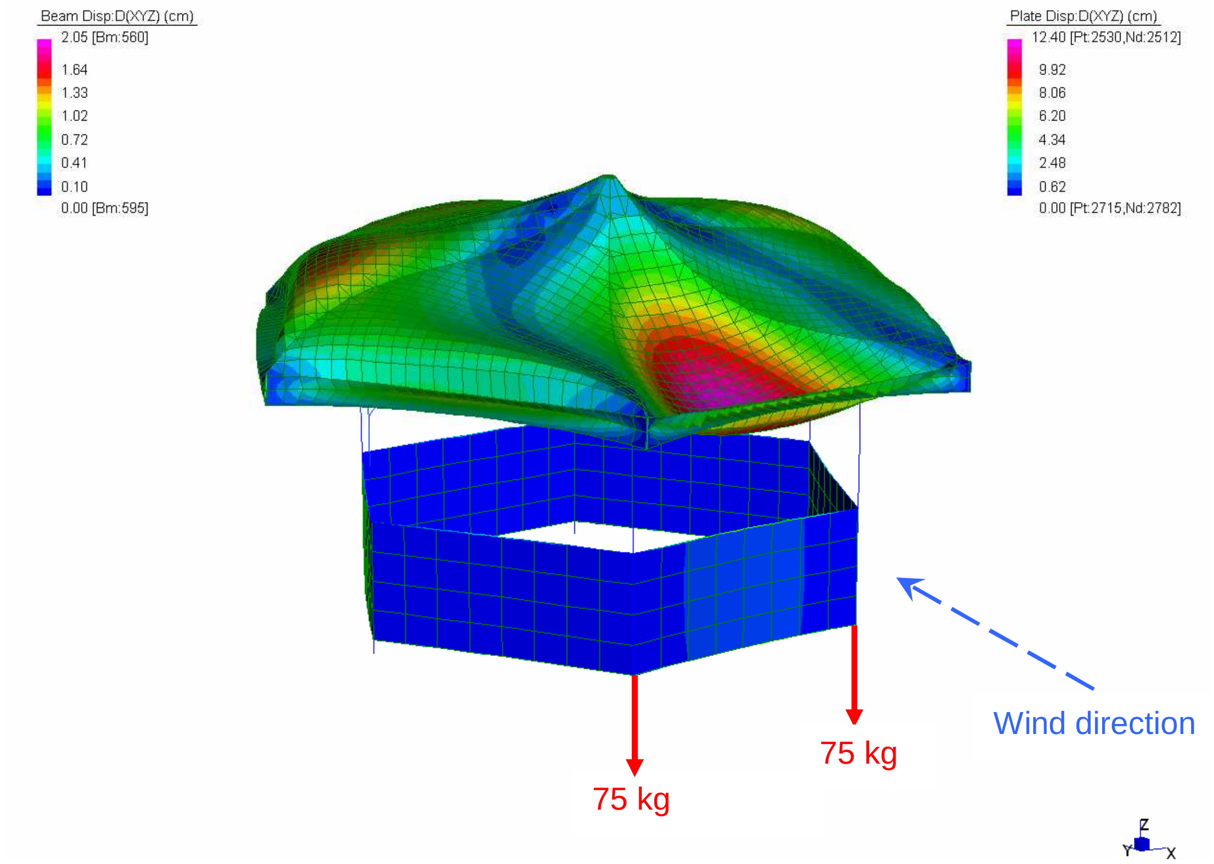
$$Z_d = 10xdxl$$

So the resistance of load for a picket Ø20 x 40cm is:

$$Z_u = 10xdxl = 10x2x40 = 800N = 80kg$$

However it is important to conduct the necessary investigations on site in according with UNI EN 13782 to calculate the real resistance of picket, particularly to helical elements or different type of soil.

When the wind direction is +y, the two pickets on the front of structure have a vertical load reaction that is about -75 kg. This means that the structure is close to the limit of uplifting.



Pic 8 Displacements (V_{b0}= 18m/s)

5 CONCLUSION

Here below it is possible to find some important points that summarize the analysis:

- The structure is a temporary tent, so in according with UNI EN 13782 snow load is not considered and the base velocity can be reduced as specified;

- The structure without pickets at the base of columns can support a wind that has a fundamental speed of 14 m/s (~50km/h)

- The structure with pickets at the base of columns can support a wind that has a fundamental speed of 18 m/s (~65km/h). In this case the pickets have a length of 40cm and a diameter of Ø20 mm

6 CONCLUSION

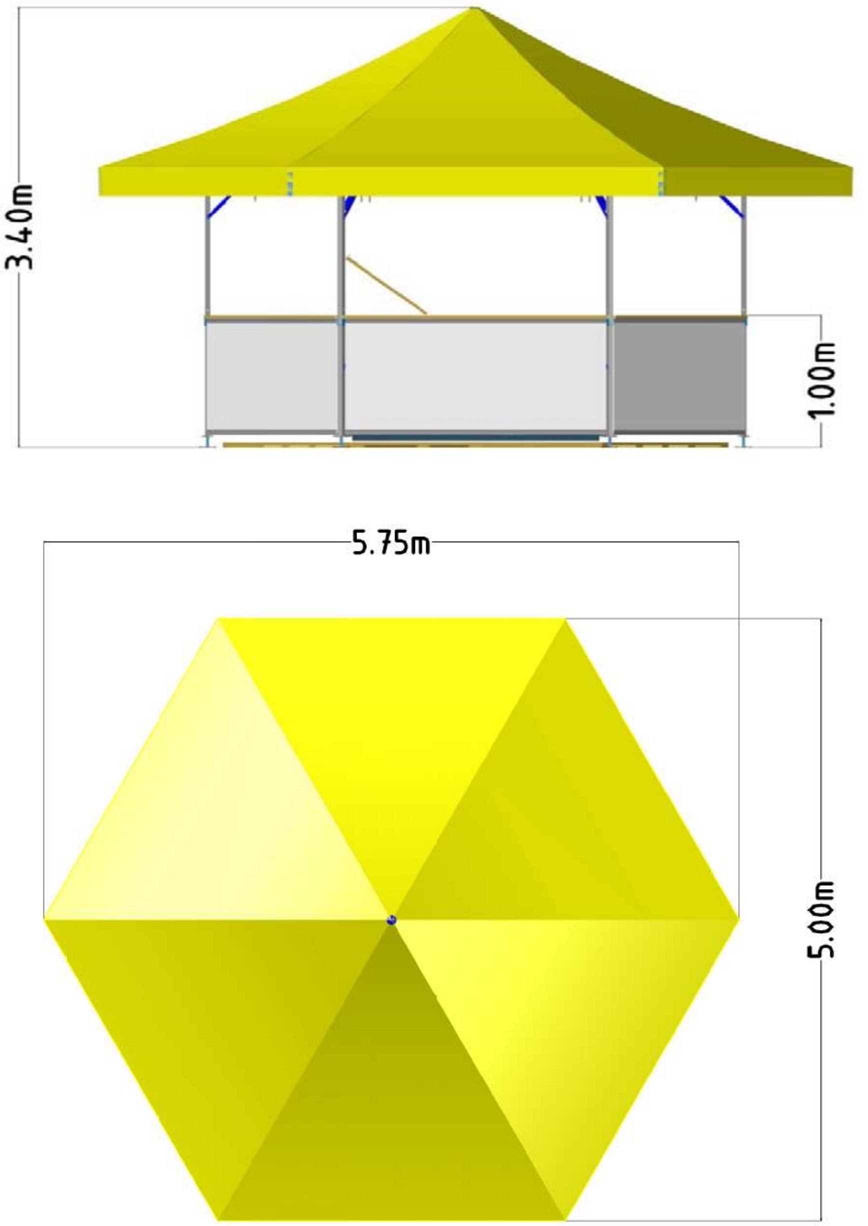
6.1 INTRODUCTION

CFD (Computational Fluid Dynamic) analysis allows the modelling of various natural phenomena regarding heat transfer in both solid and fluids, turbulence, advection of species in both solid and fluids, structural mechanics, and free surface.
The CFD analysis of temporary tent structure concerns turbulence and fluid motion modelling using a stabilised finite element method (FIC) to calculate the effect of wind on surfaces (pressure). The objective of this study is to provide the area-averaged wind loads for the structural design of the tensile covering structure. Thne wind pressure values on the fabric surface are determined as combination of both topside and underside of the membrane because the structure is considered open.
A safe and economic construction and design of the structure against wind require the realistic assessment of the structural (area-averaged) peak wind pressures acting on the fabric. For that purpose suitable CFD modelling is required.
The following paragraphs describe the CFD analysis methodology and results.

6.2 CFD ANALYSIS

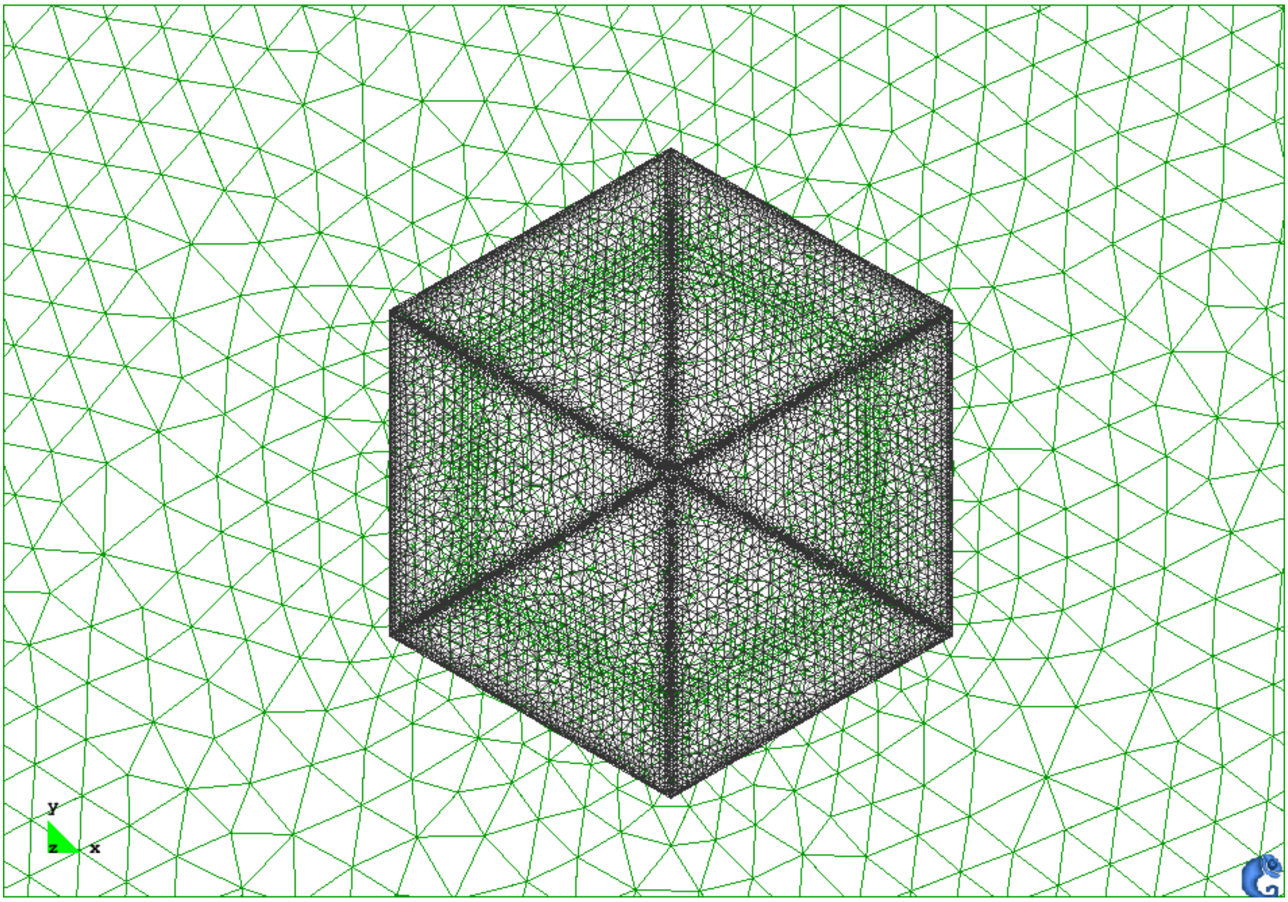
6.2.1 Model and mesh dimensions

CFD analysis model has been created with the original dimensions of the project (see picture below).

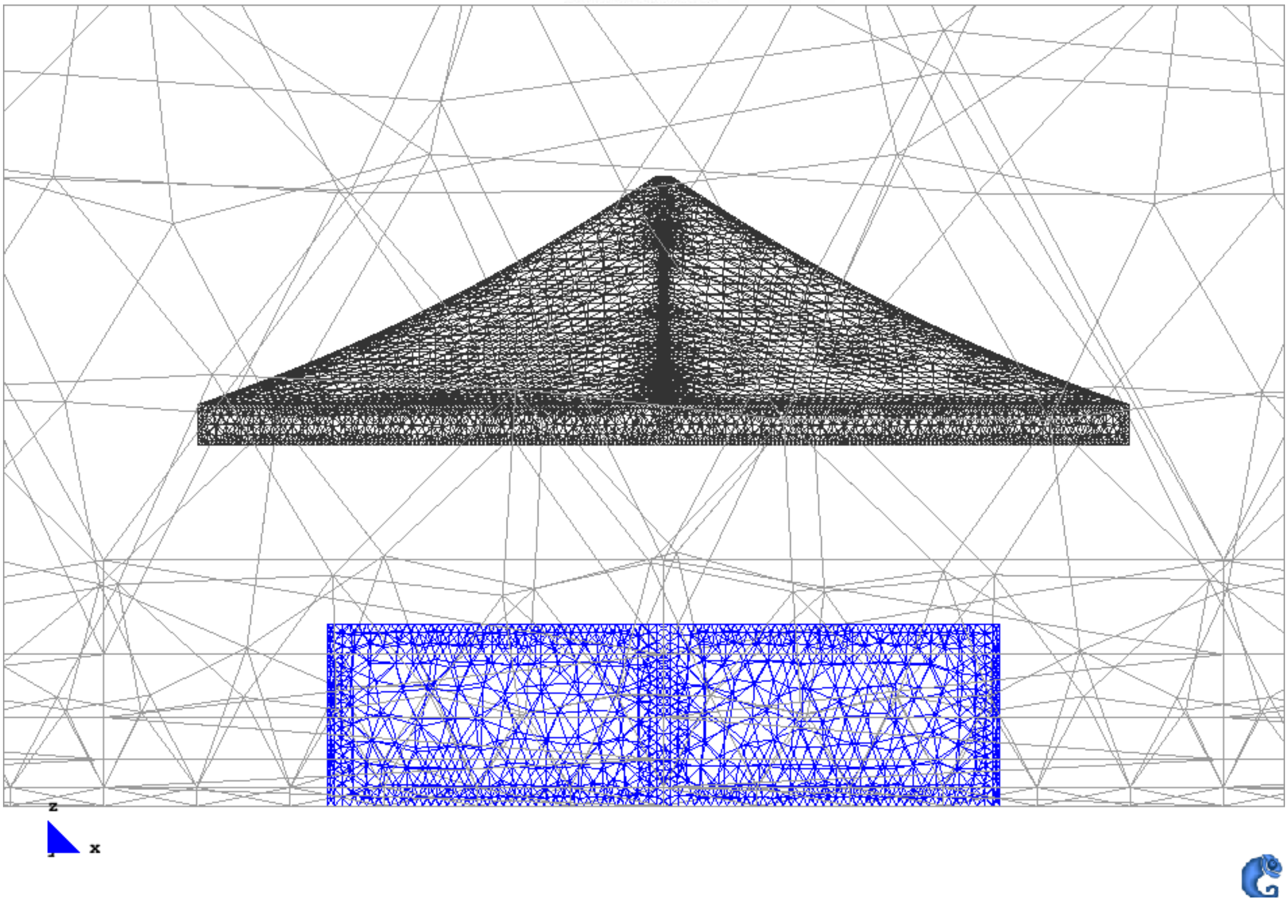


Pic 9 Referring dimensions of the analysed model.

A computational mesh of about 90000 nodes has been created. The following pictures show some views of 3D grid details: the grid is structured in the external part of the control volume with a decreasing cell height near the ground, while the grid is unstructured and finer close to the tensile covering to better fit to the structure shape. The cell dimension range is between 2.5 (fabric surface) to 600 cm (full scope, far from the ground). This means that simulation outputs (pressure and velocity values) are collected every 2.5 cm on the fabric surface.



Pic 10 Top view: computational mesh detail of the fabric covering. Mesh dimension range is between 2.5 to 10 cm.



Pic 11 Lateral view: computational mesh detail of the region between the ground and the tent. The mesh cells became thicker close to the ground to better describe the wind velocity profile.

6.3 DESIGN WIND SPEED

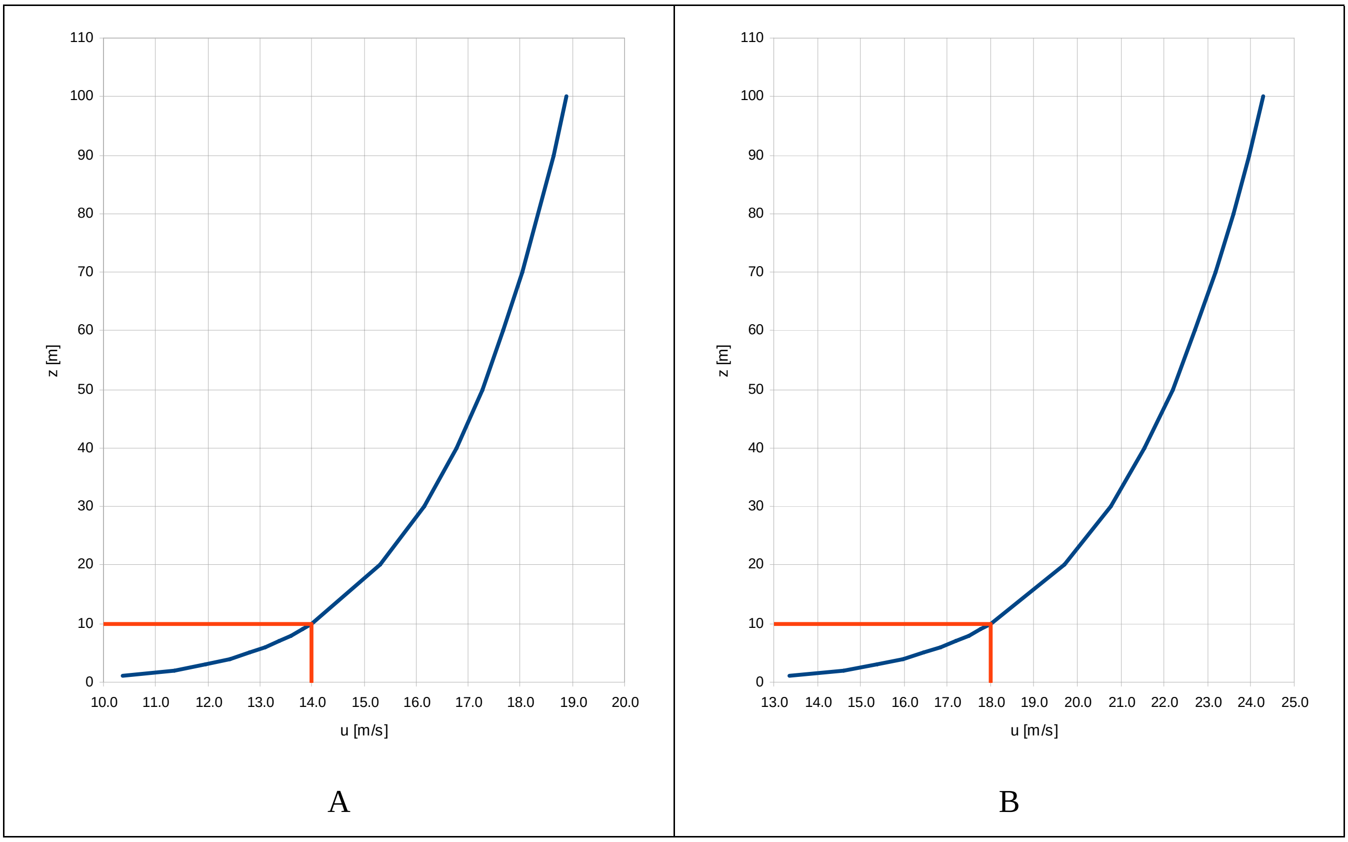
The aim of the CFD analysis is to determine the values of the aerodynamic factor Cp (Coefficient of Pressure) to calculate the wind loads on the different parts of the structure.

The wind base velocity (V_b) considered in the CFD model is increased step by step of 2m/s to gain the maximum wind load value which the tent can stand for the different anchor systems (with or without pickets). The wind base velocity values are shown below:

- without pickets solution: $V_{b,14} = 50.0 km/h \approx 14 m/s$
- with belts solution: $V_{b,18} = 65.0 km/h \approx 18 m/s$

The wind velocity profiles are described in the picture below and it's obtained by the following formula:

$$V_z = V_{10m} \cdot \left(\frac{z}{10}\right)^{0.13}$$

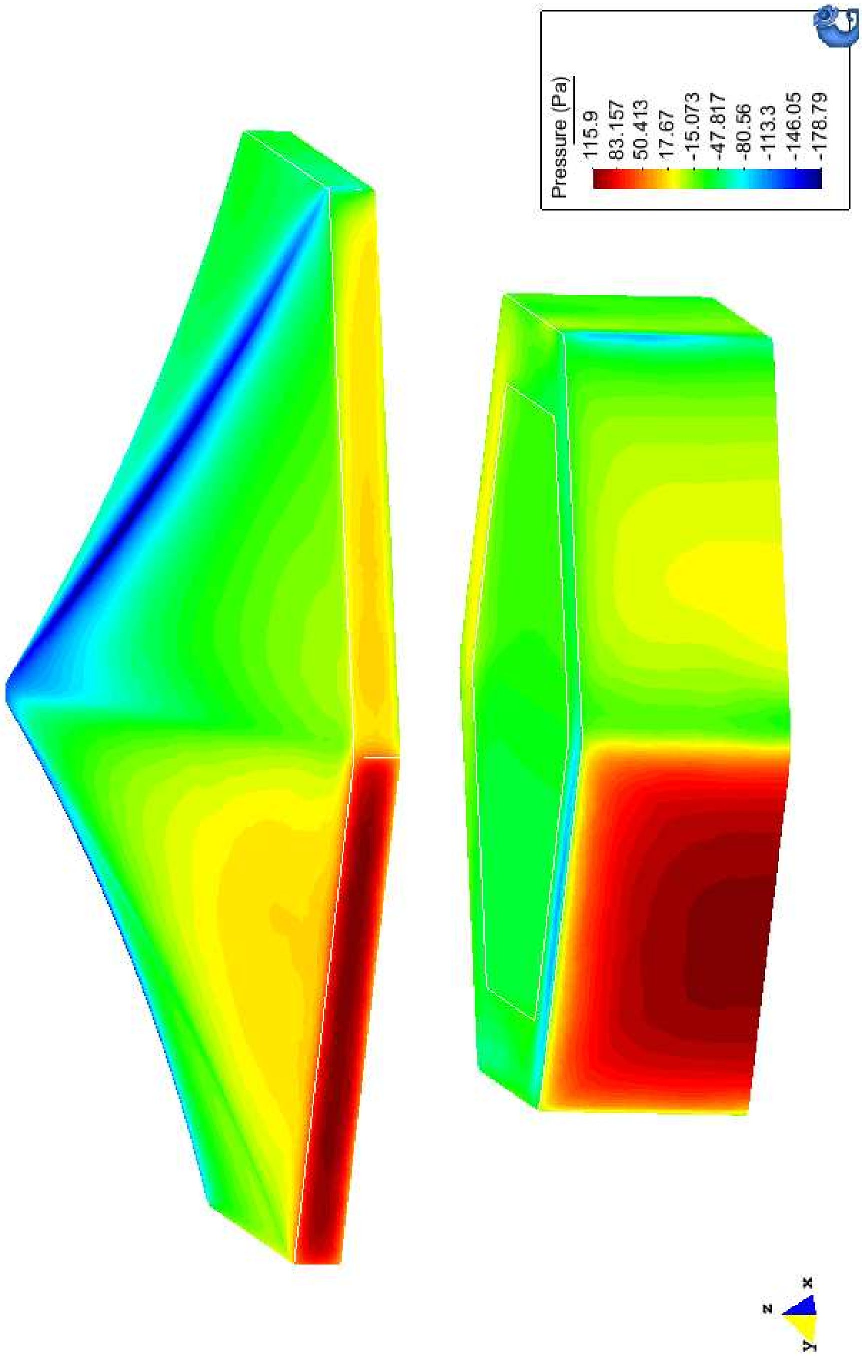


Pic 12 Wind velocity profile over vertical coordinate z. The base wind velocity values A) V(10m)=14m/s and B) V(10m)=18m/s is highlighted in red.

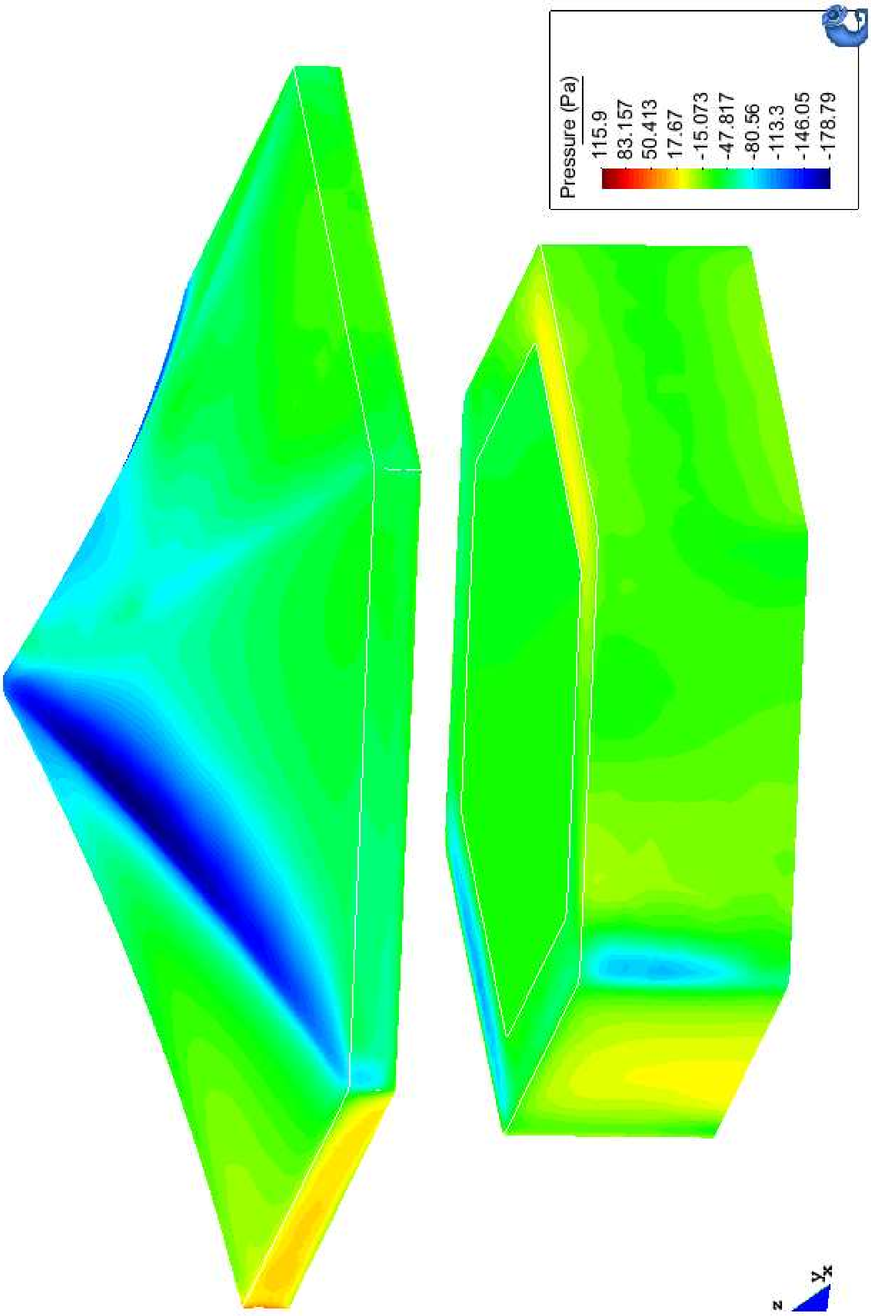
Different pressure values over the time are considered to obtain reasonable pressure distribution values, to take into account the turbulence effects and to gain the load worst case.

6.4 CFD ANALYSIS OUTPUTS

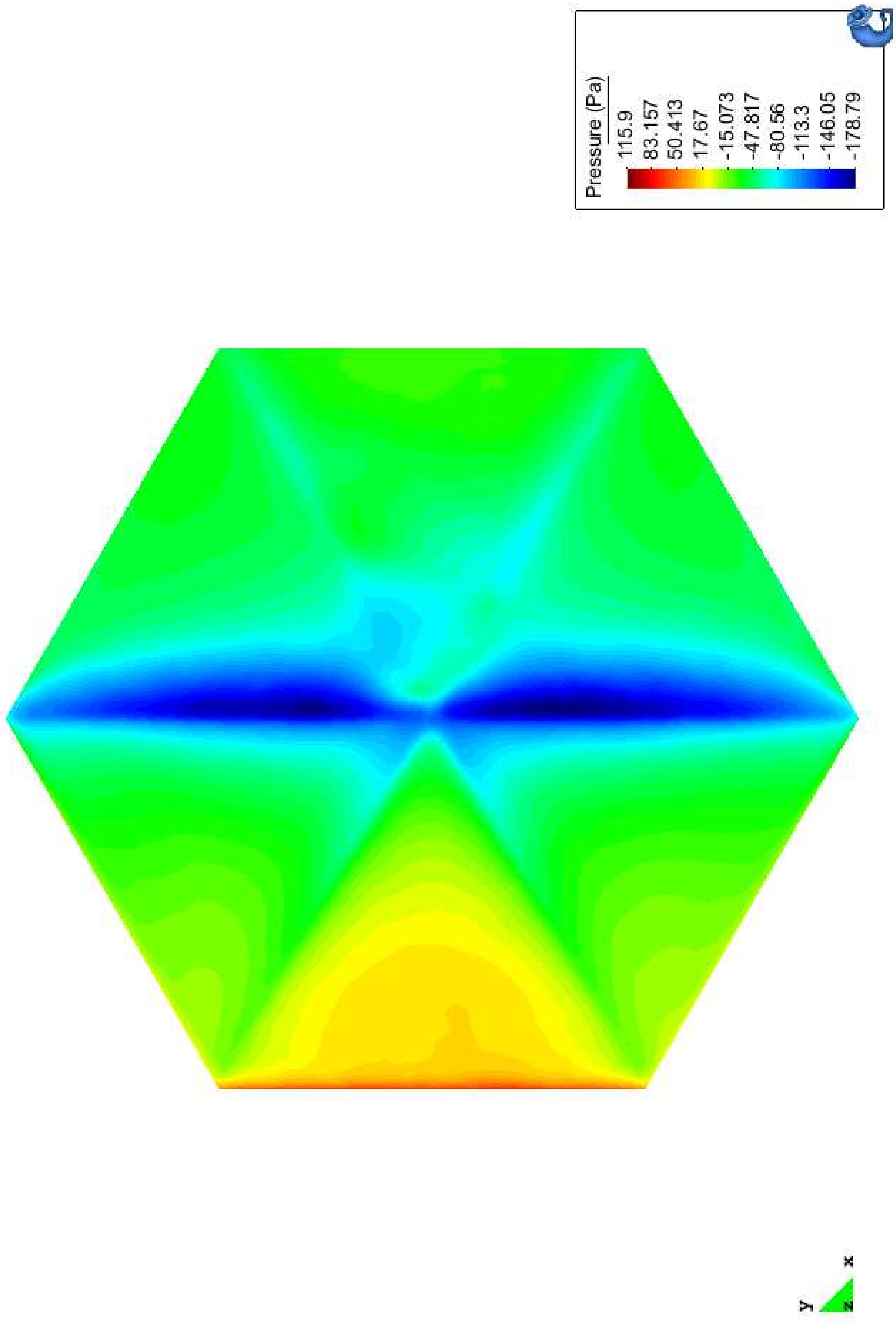
6.4.1 Wind velocity = 14m/s - Wind direction = 90° (positive Y axis)



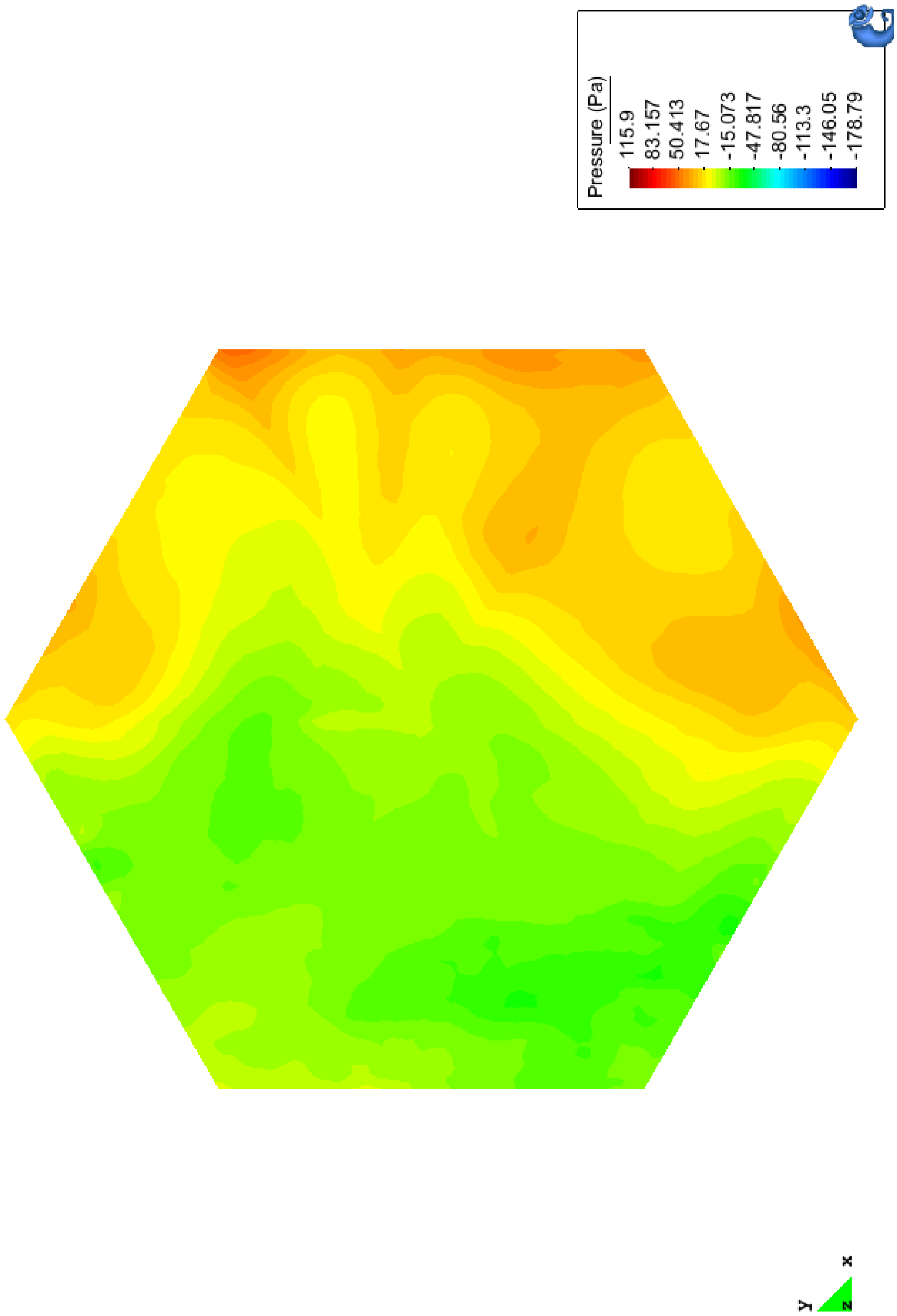
Pic 13 Windward view: outer side pressure distribution.



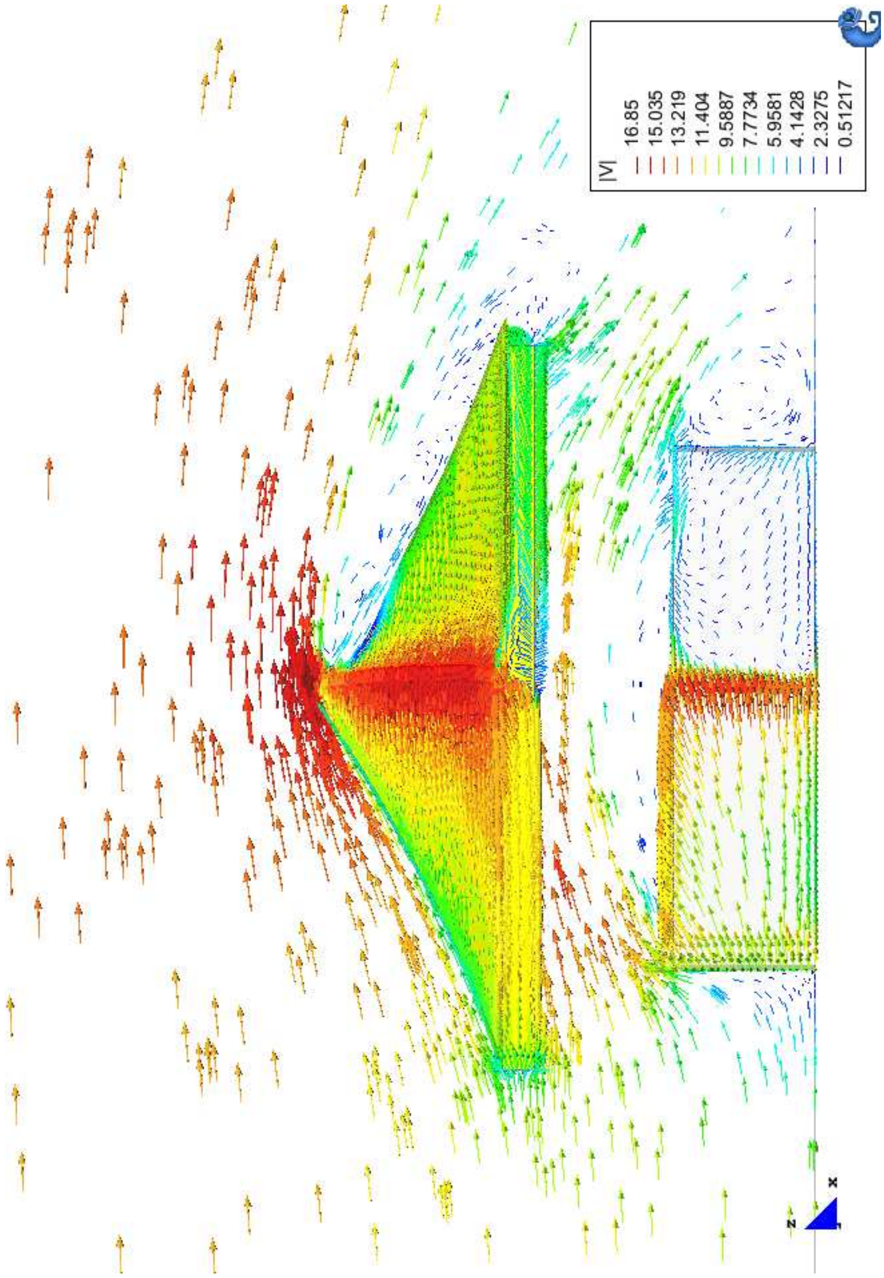
Pic 14 Leeward view: outer side pressure distribution



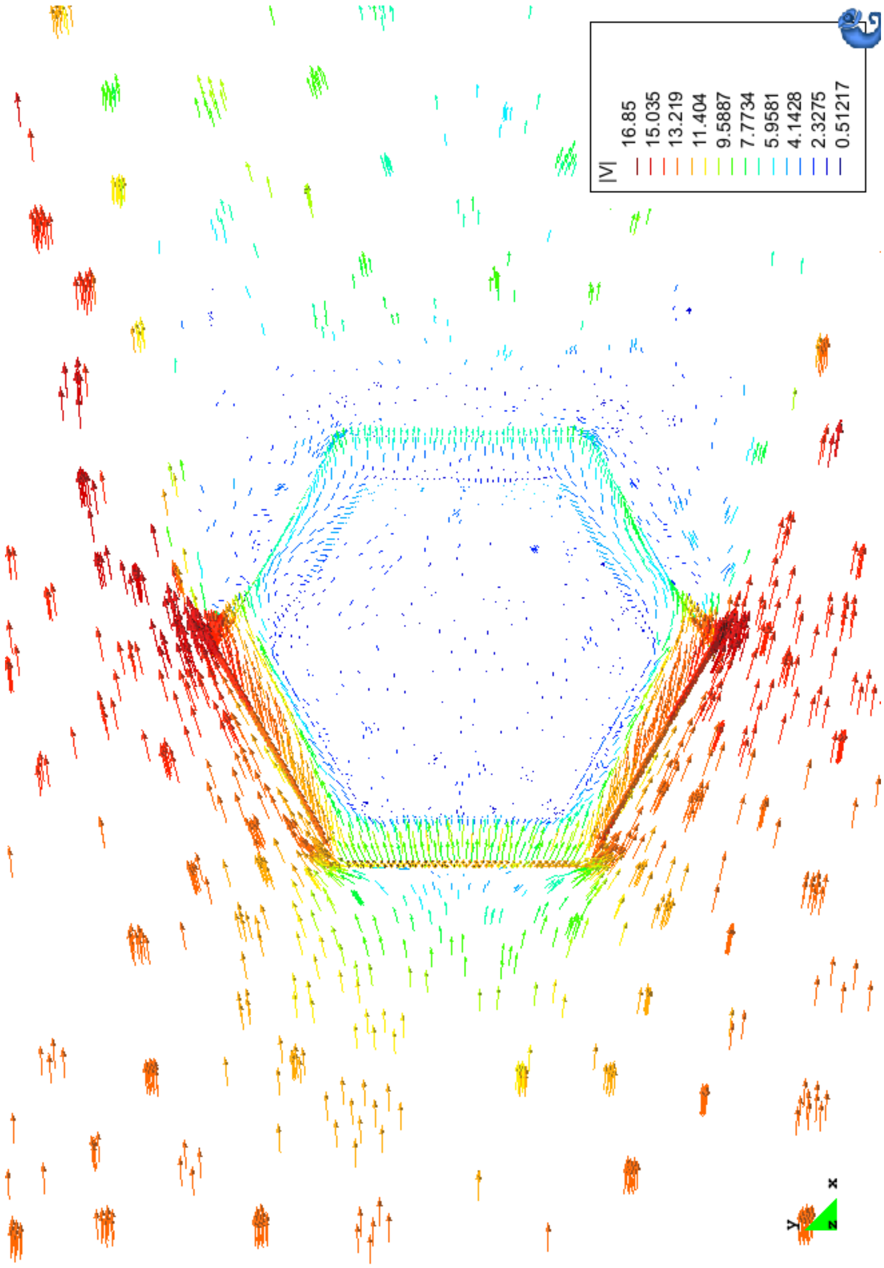
Pic 15 Top view: roof outer side pressure distribution.



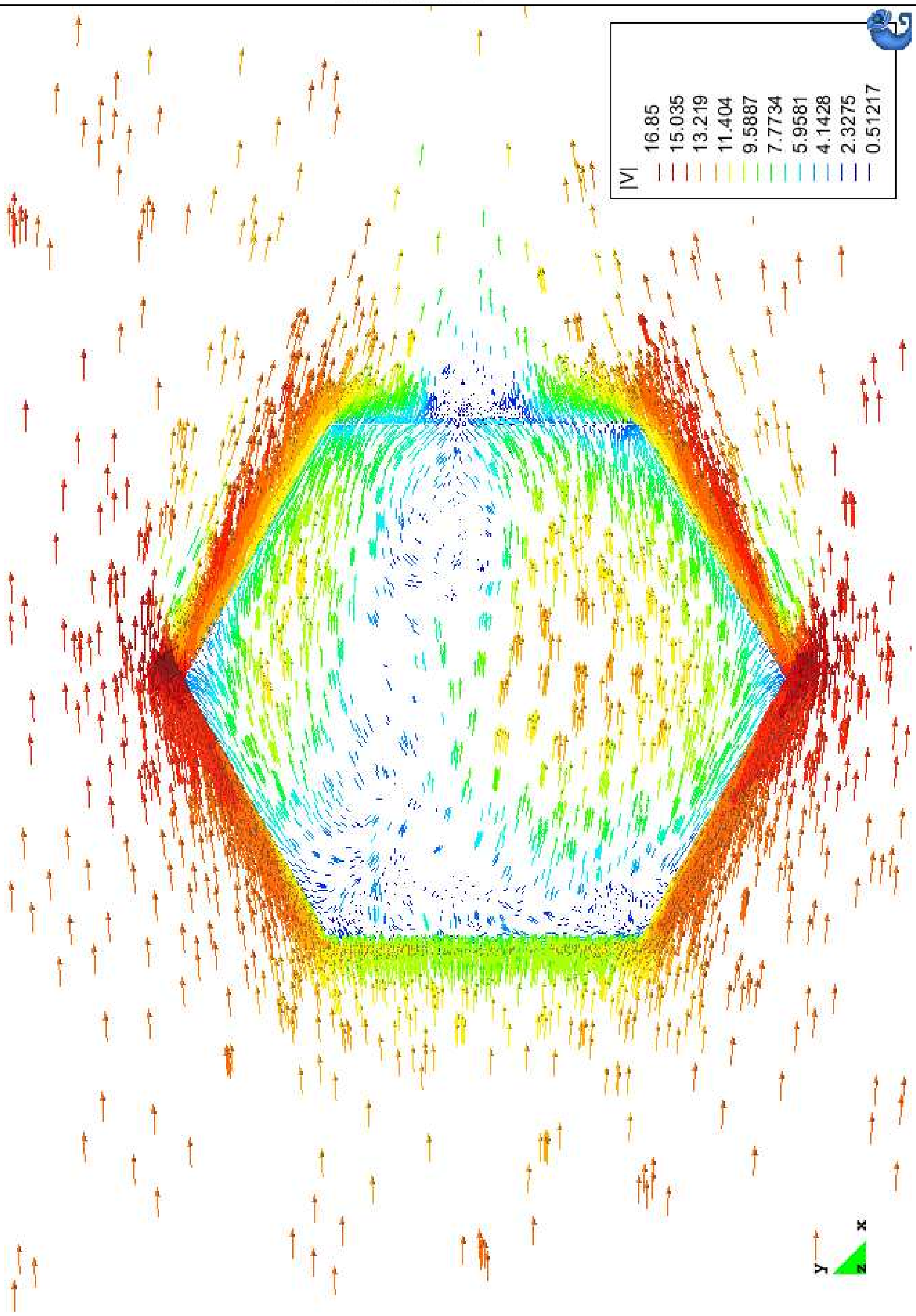
Pic 16 Top view:roof inner side pressure distribution.



Pic 17 Lateral view: turbulence analysis by wind velocity vectors on vertical cutting plane.

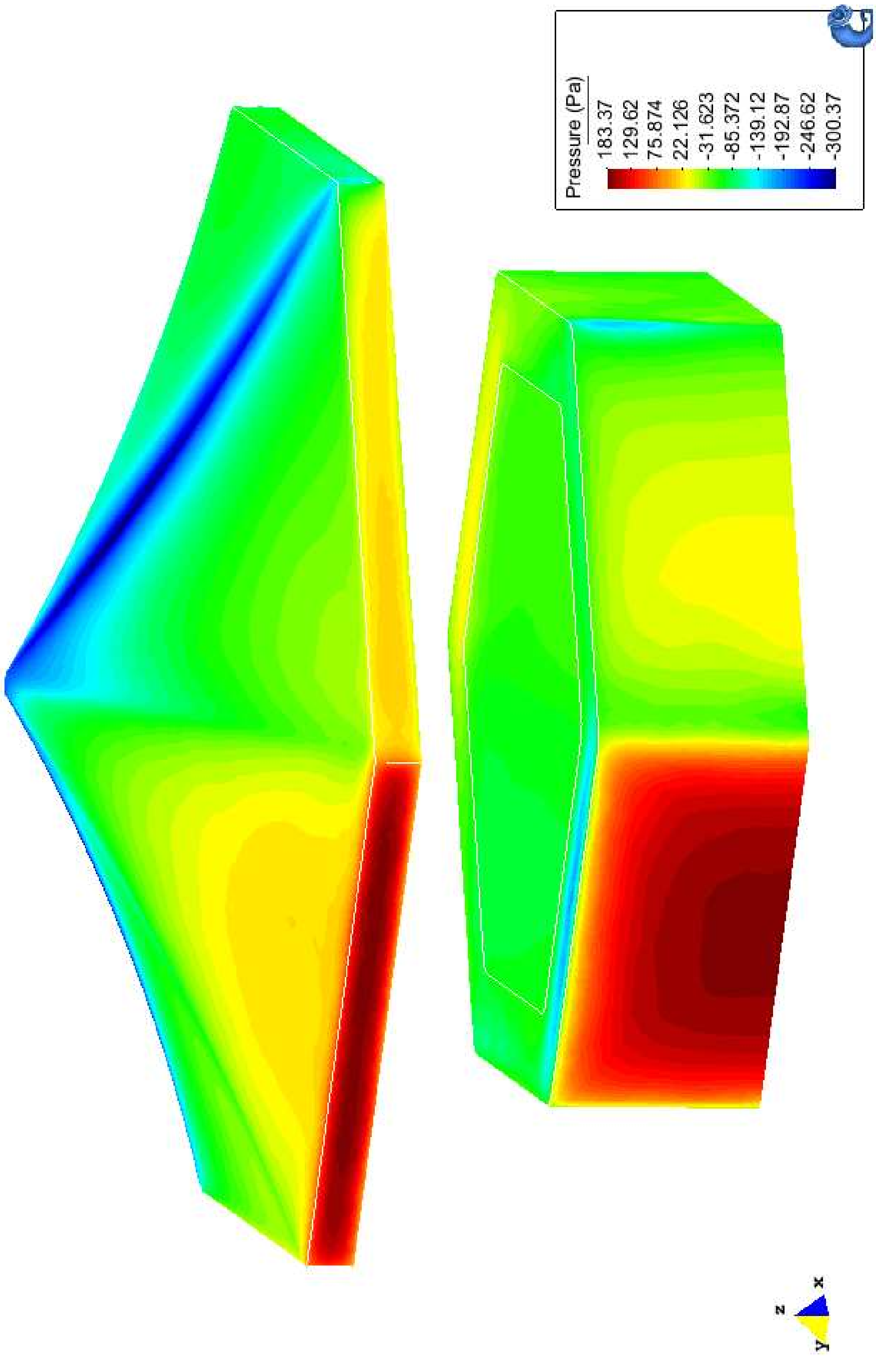


Pic 18 Top view: turbulence analysis by wind velocity vectors on 0.50m height horizontal cutting plane.

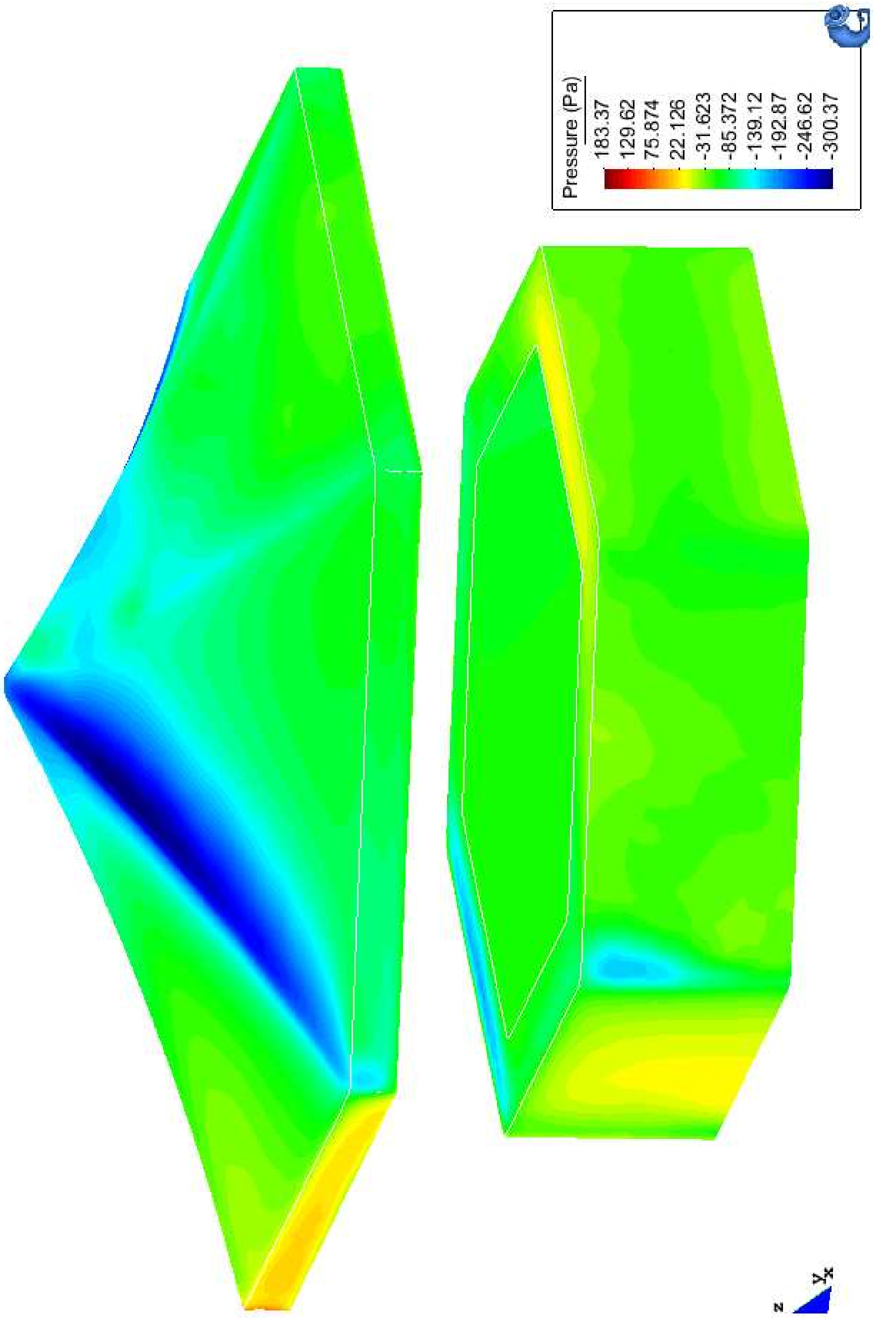


Pic 19 Top view: turbulence analysis by wind velocity vectors on 2.20m height horizontal cutting plane.

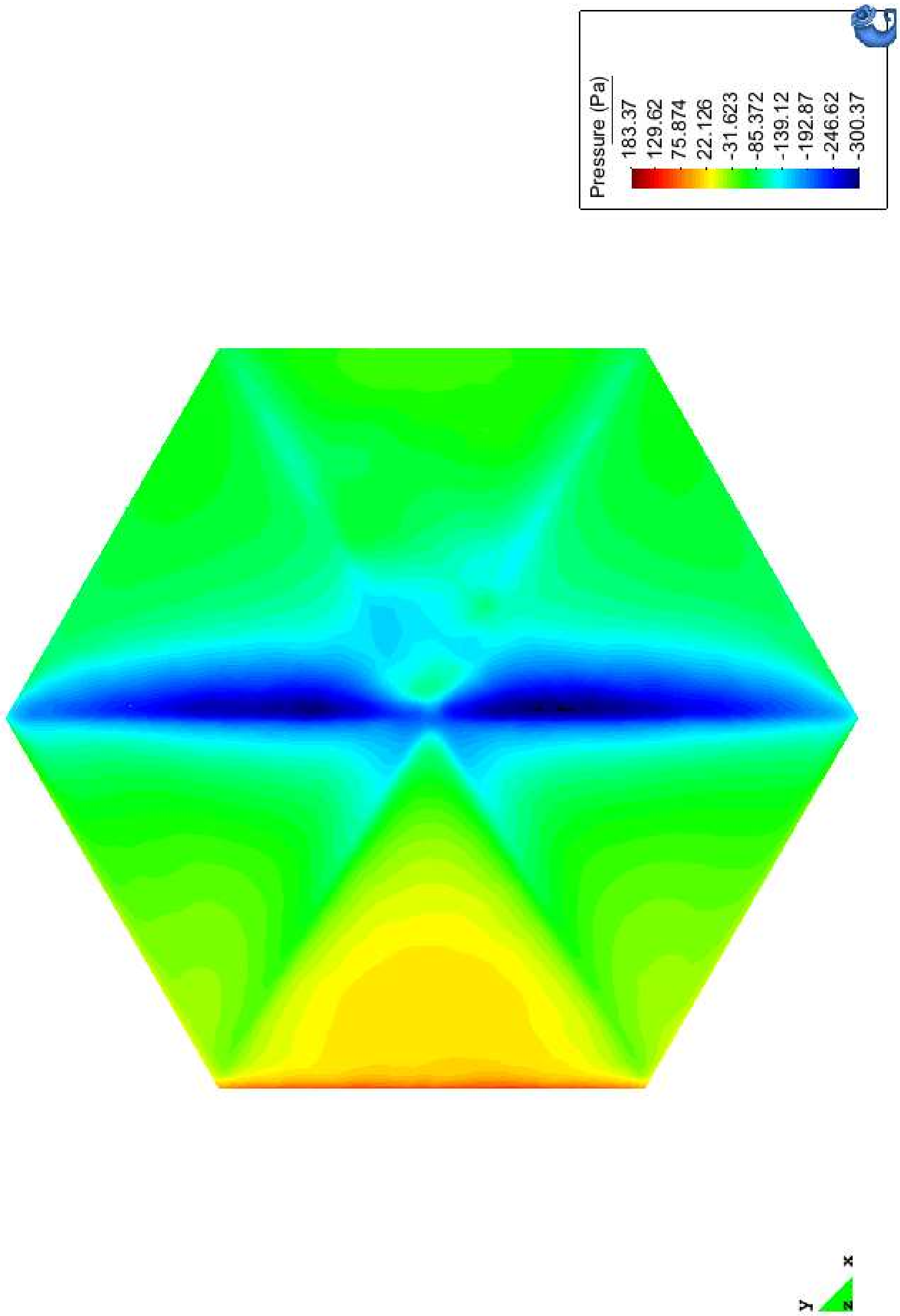
6.4.2 Wind velocity = 18m/s - Wind direction: 90°(positive Y axis)



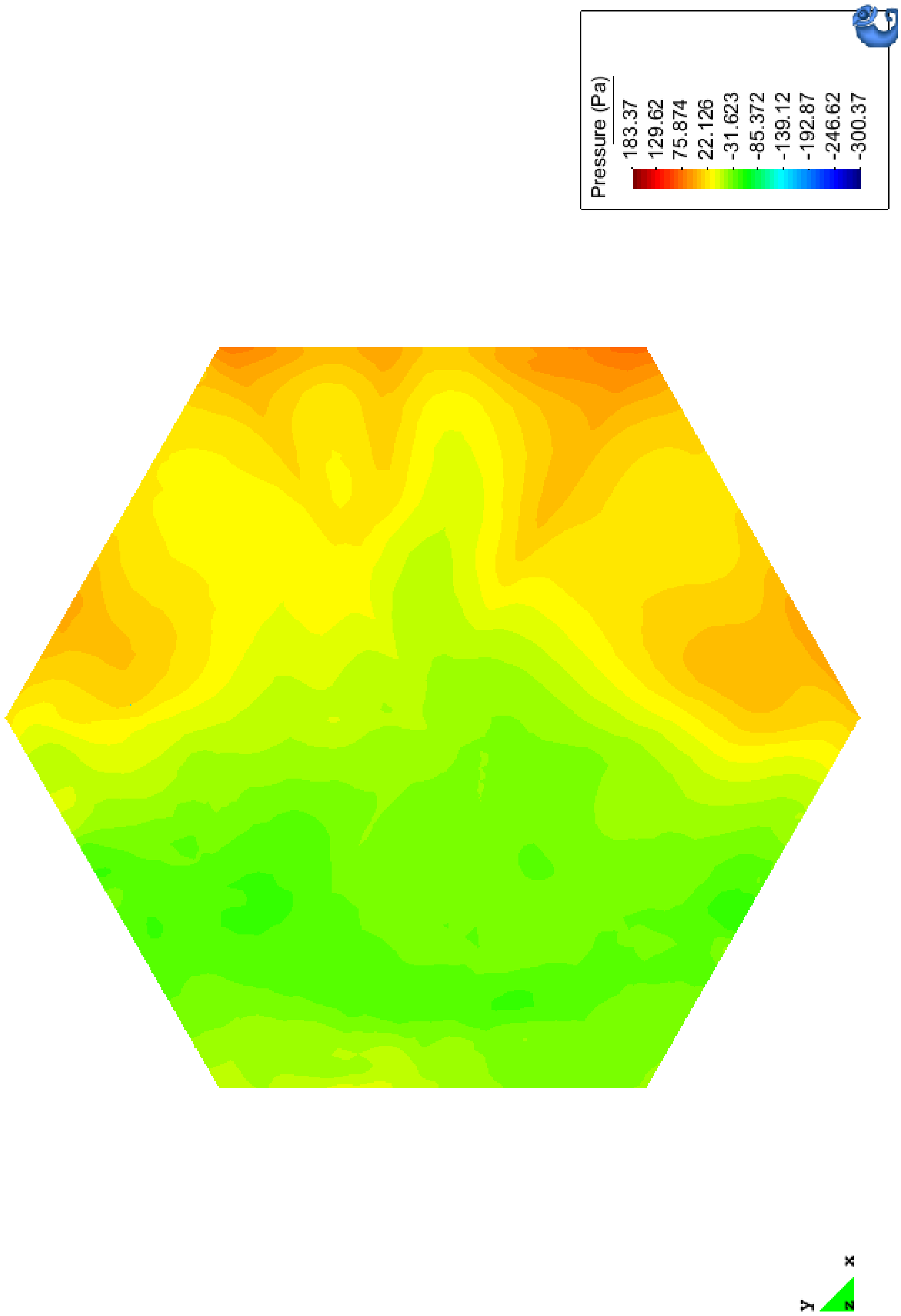
Pic 20 Windward view: outer side pressure distribution.



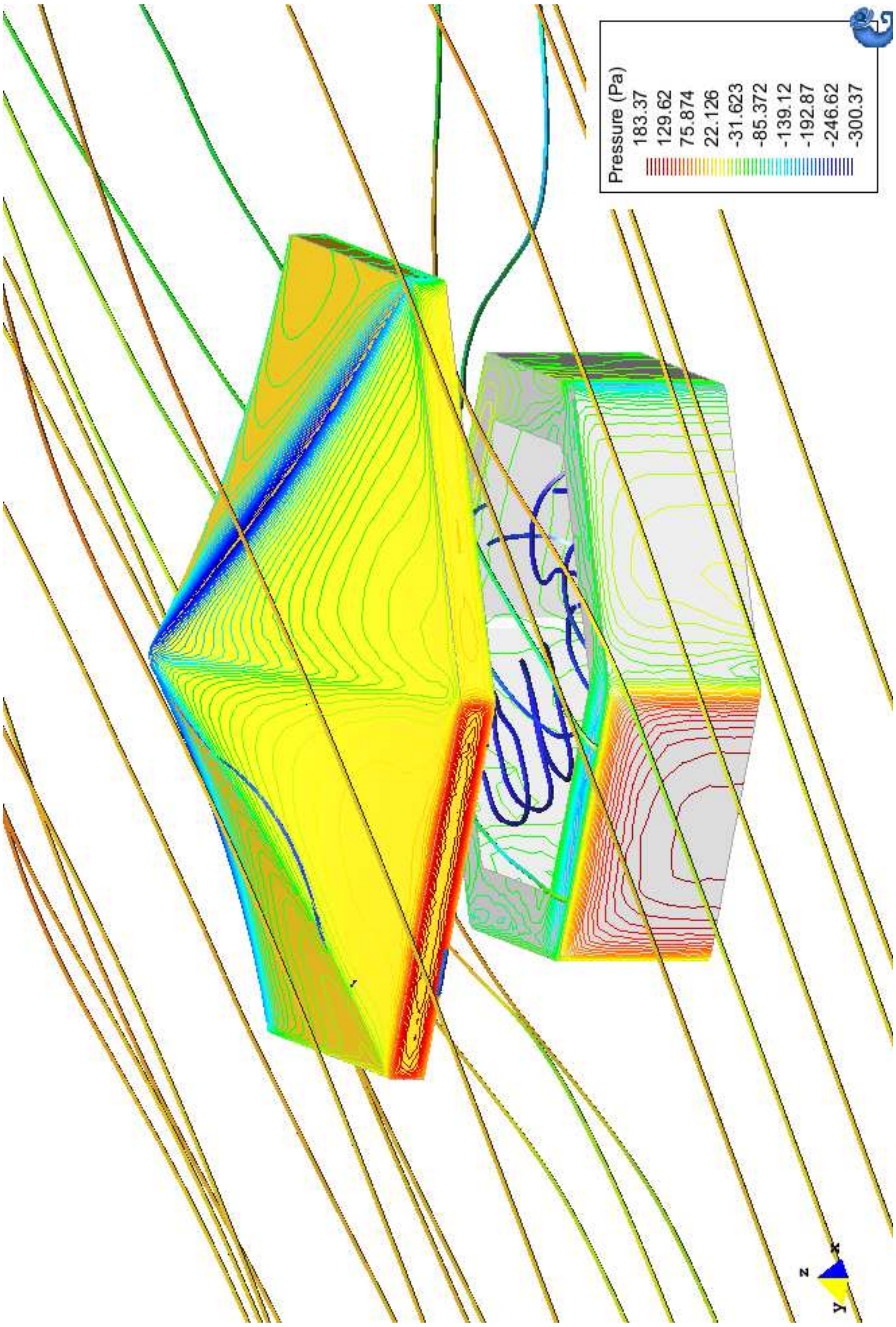
Pic 21 Leeward view: outer side pressure distribution.



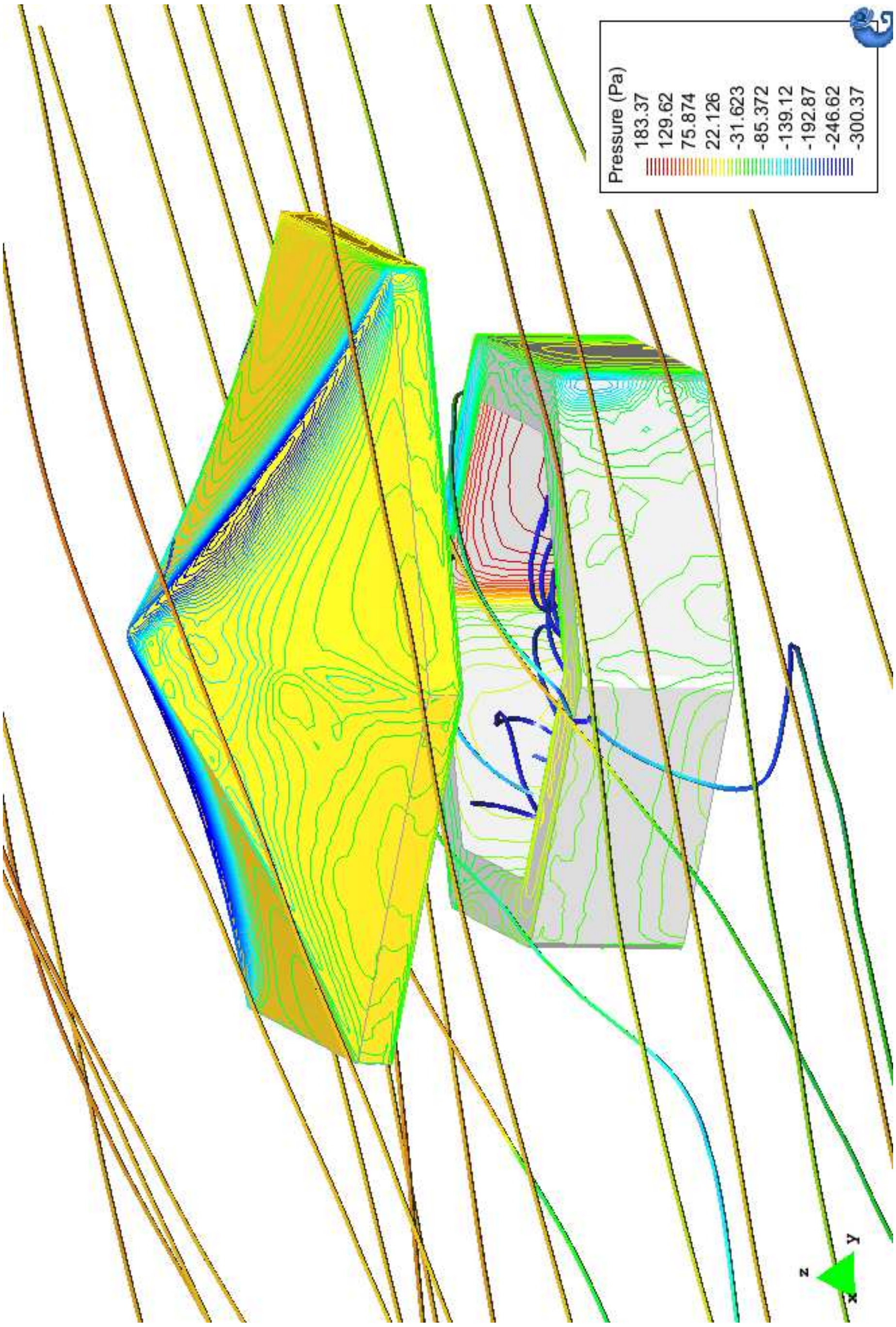
Pic 22 Top view: roof outer side pressure distribution.



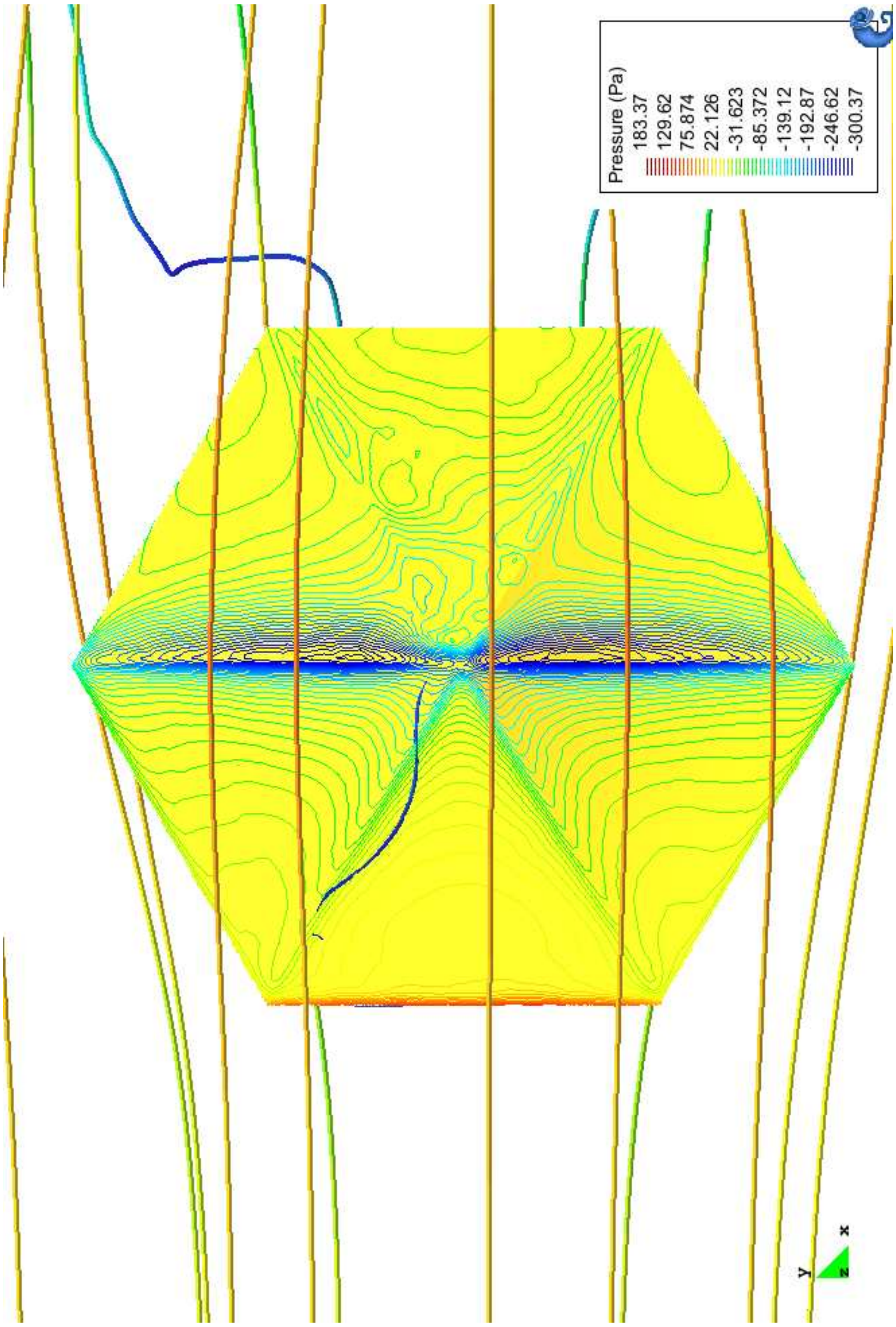
Pic 23 Top view:roof inner side pressure distribution.



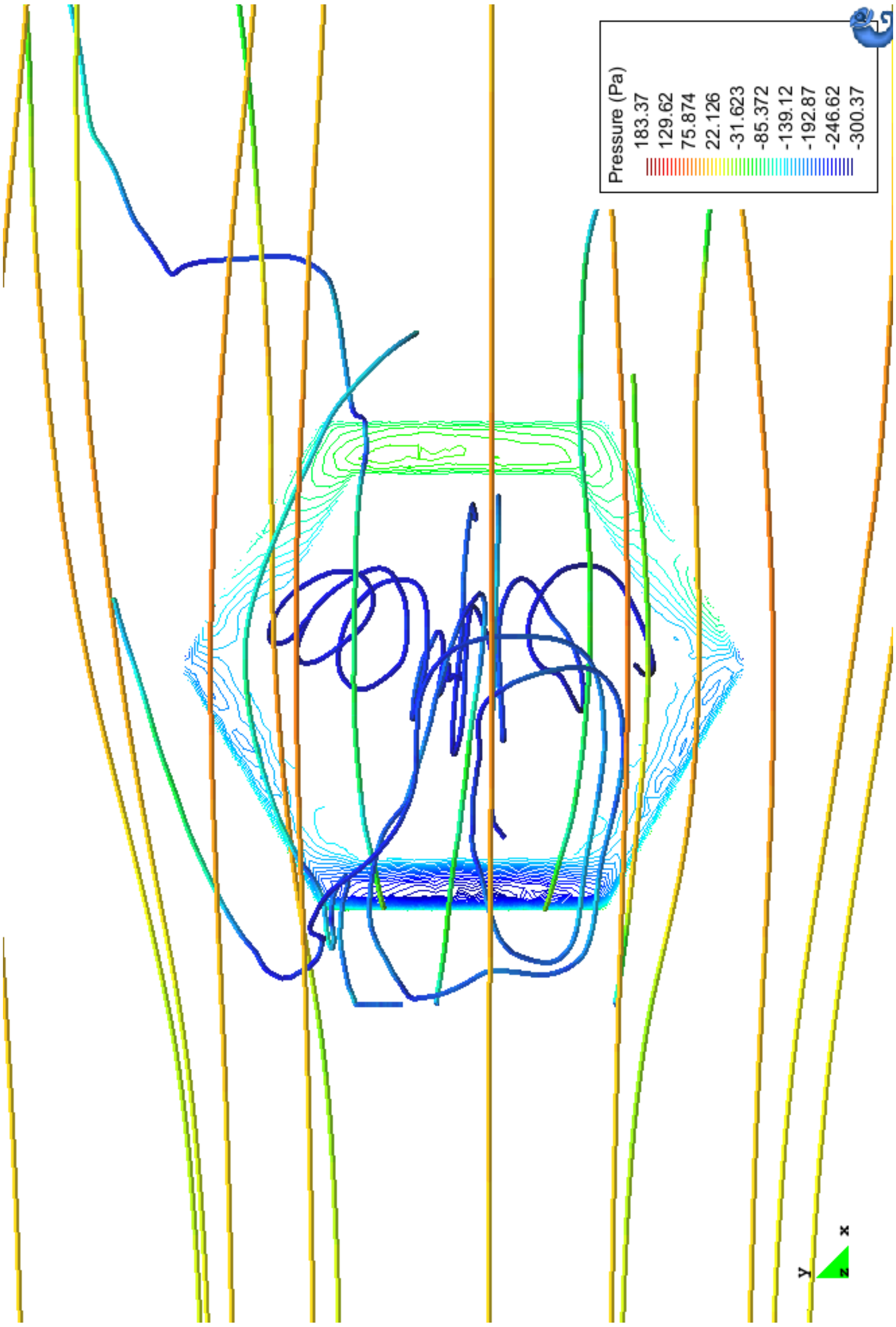
Pic 24 Windward isometric view: turbulence analysis by wind velocity stream lines around the structure and pressure iso-lines on structure surface.



Pic 25 Leeward isometric view: turbulence analysis by wind velocity stream lines around the structure and pressure iso-lines on structure surface.



Pic 26 Top view: turbulence analysis by wind velocity stream lines and pressure iso-lines on roof outer side surface.



Pic 27 Top view: turbulence analysis by wind velocity stream lines under the roof.

6.5 NET PRESSURE COEFFICIENT (Cp)

The pressure coefficient values are calculated as ratio between the sum of outer and inner local pressure value obtained by the CFD analysis of the structure (value ranges are shown in paragraph 6.2 figures) and the reference pressure value q_b:

$$C_{p,n} = \frac{(P_o + P_i)_n}{q_{b,v}}$$

where

$C_{p,n}$ is the pressure coefficient in the node n

$(P_o + P_i)_n$ is the sum of outer and inner pressure value in the node n

$q_{b,v}$ is the reference pressure value for the wind velocity v:

$q_{b,v} = 12.3 kg/m^2$ with $v_b = 14 m/s$

$q_{b,v} = 20.3 kg/m^2$ with $v_b = 18 m/s$

$q_{b,v}$ is calculated as shown in paragraph 3.