















The described results are all associated to a wind velocity of 27 km/h and correspond to values of pressures expected at the real structure.

#### **4. CFD ANALYSIS**

This part of the paper is dedicated to the evaluation of pedestrian comfort to windy conditions that may develop in and around the building of the air terminal, considering aerodynamic and architectural issues, and magnitude and direction of the wind at the construction site. The objectives of this part of the study are: determine the pedestrian-level wind distribution, detect critical comfort areas (Stathopoulos y Baskaran, 1996) and identify the source of any undesirable wind conditions. The analysis and distribution of velocities and pressures is performed using Computational Fluid Dynamics.

##### *4.1 Human comfort*

Human comfort outdoors can be affected by a wide range of parameters including the speed of the wind, temperature of the air, relative humidity, solar radiation, the quality of the air, human activity, type of clothing, age of persons, etc.; so, the acceptability of wind conditions in any atmosphere will always be, to some extent, subjective.

From research studies (Lawson, 1990; Mohamed, 2013) some parameters have been derived to evaluate the comfort of pedestrians walking in areas of strong winds. However, wind tunnel studies have shown that these levels of comfort must be modified to include the effects of wind gusts or peaks of high velocities of short duration, that is, 3 seconds (3s).

##### *4.2 Mathematical model*

A 3D finite volume numerical model was developed to perform various simulations. A general view of the mesh used for the study of the air terminal building is shown in Fig. 9.

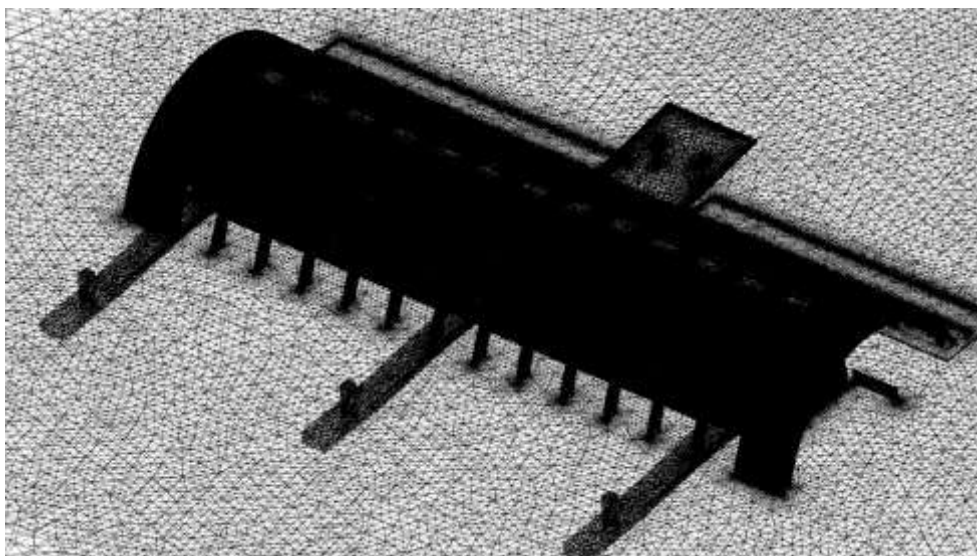




Fig. 9 Discretization of the numerical domain for the air terminal building.

#### 4.3 Numerical results

For each direction of analysis three plots were prepared. The first shows the wind speeds that could be reached at 1.5 m above the floor level; the second shows wind speed contours or streamlines, also at 1.5 m above the floor level; and the last plot presents a perspective of the 3D model in order to illustrate how the wind "bathe" the structure. Also, for the description of the effects of wind on pedestrians, the areas or zones shown in Fig. 10 were used; these are areas within the terminal building between the two domes, both the land side and air side; in the inner part of the internal or glass dome (last waiting area) identification zones were not defined because the wind does not penetrate into this area.

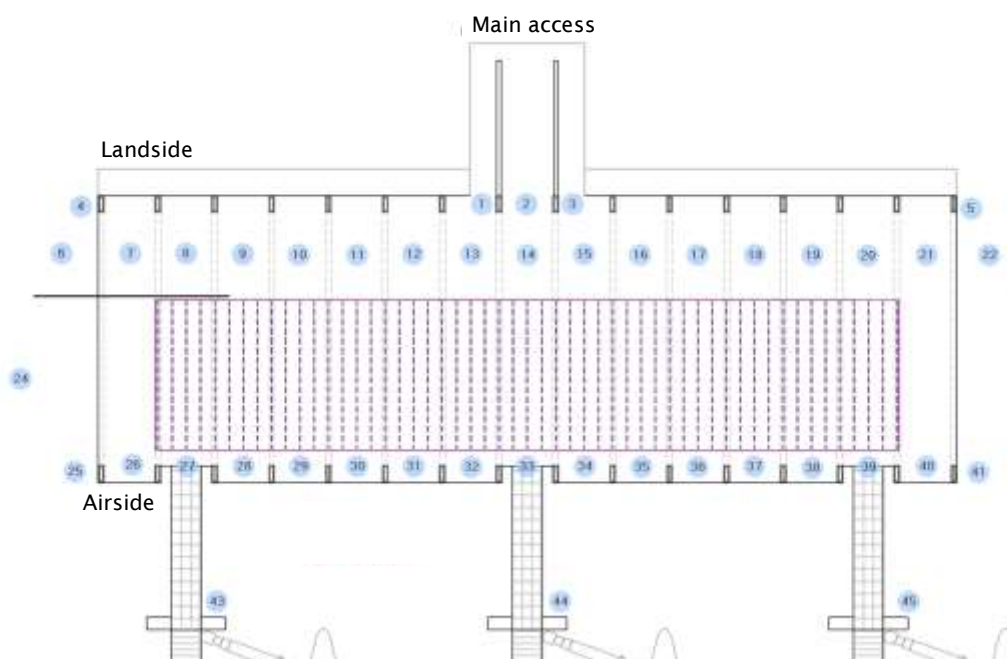


Fig. 10 Zones for description of comfort analysis

An example of the aforementioned plots is presented in Figs. 11 to 13. These correspond to an incident wind flow at  $90^\circ$  with respect to the longitudinal axis of the terminal building.

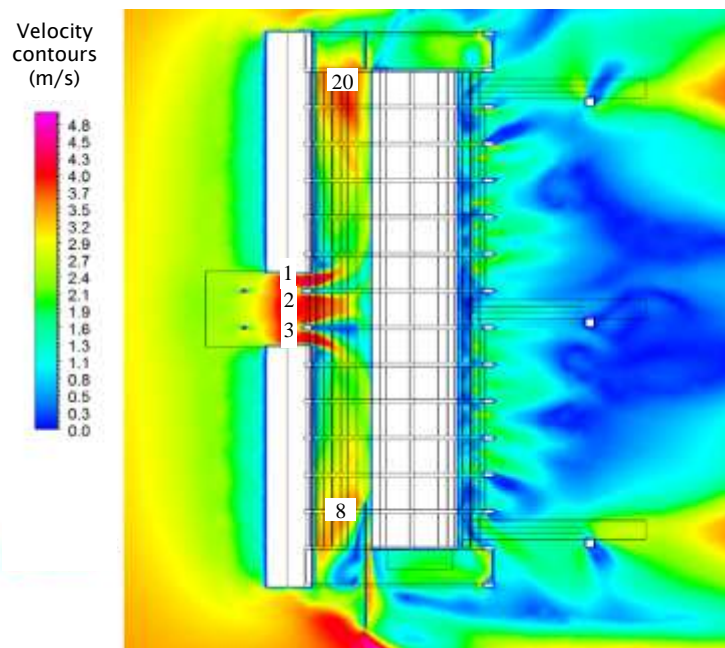


Fig. 11 Plan view of velocity contours, incident wind at 90°

Figs. 11 shows that for zones 1, 2, 3, 8, and 20 within the terminal building, wind speeds around 4.5 m/s are developed. However, this value meets the criteria of comfort for people who remain standing and walking. This value is on the edge of the criterion comfort for people seated or having a sedentary activity. It should be remembered that the model does not consider any kind of door at zones 1, 2 and 3.

Figs. 12 and 13 show the effect at the corners: increased pressures and dispersion of the streamlines, as reported in the literature (Dyrbye, 1997; Simiu, 1978).

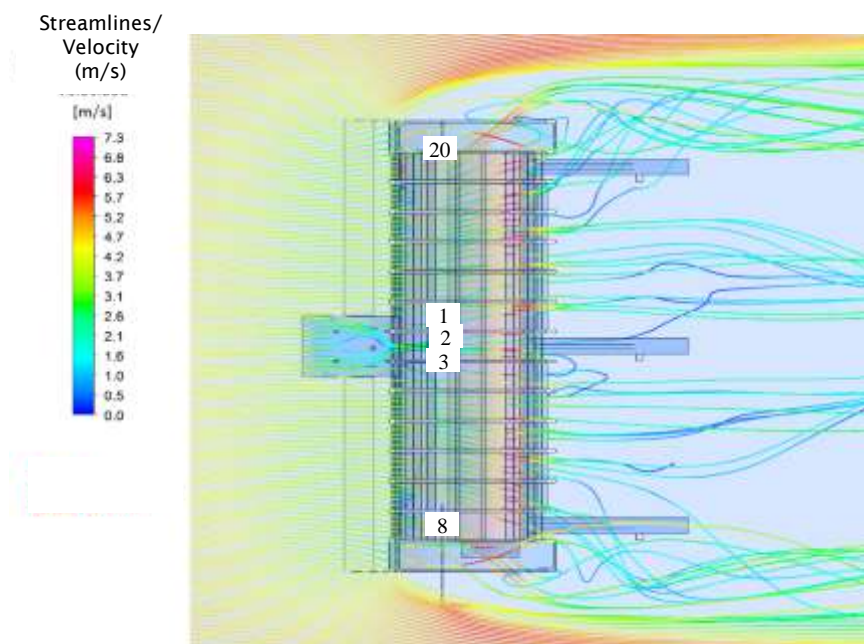


Fig. 12 Plan view of streamlines, incident wind at 90°

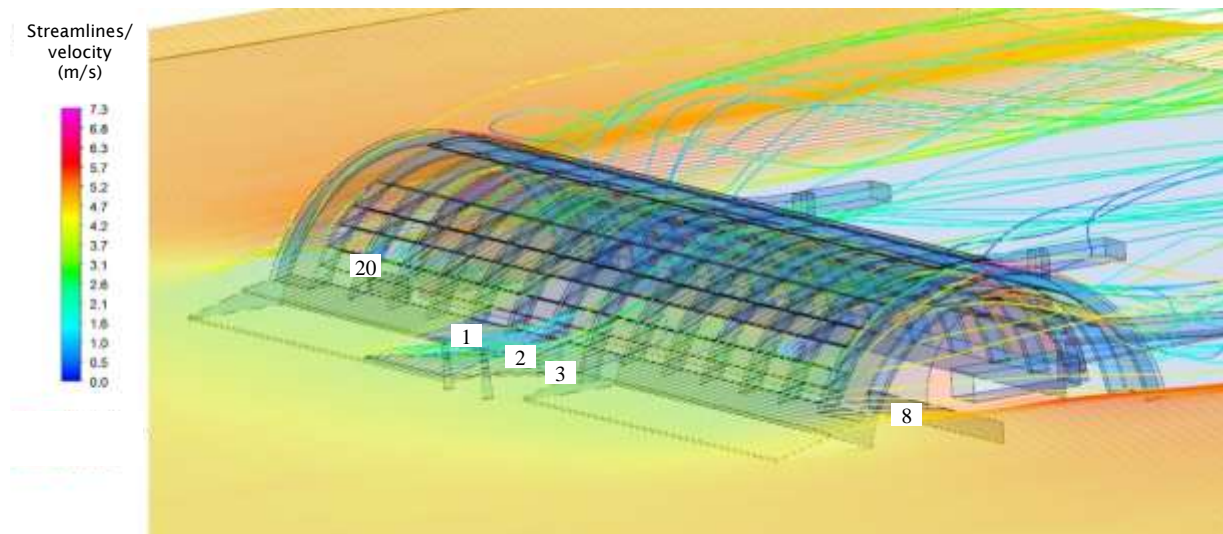


Fig. 13 Isometric view of streamlines, incident wind at 90°

## 5. CONCLUSIONS

For different return periods, mean speeds of wind were determined at the construction site of a new air terminal. The hourly average regional speed for the site under study, in accordance with the Manual of Civil Works (MOC, 2008), is 127.8 km/h for a return period of 200 years; in this study the estimated value based on the provided data and statistical analysis, was 130.8 km/h.

The predominant wind direction in the area of the airport, was identified in the sector 240° to 270°.

Using a 3D printer, a rigid 1:100 scale model was built. This model was used in the wind tunnel to determine magnitudes of pressures in the concrete and glass arches of the terminal building. The wind speed on the scale model was simulated with a magnitude of 7.5 m/s (27 km/h) (according to the speeds of the generated boundary layer profile) and for different directions of incidence in intervals of 10°, including the dominant direction.

The maximum values of pressures recorded at the 1024 instrumented points of the model during the testing in the wind tunnel were:

- 2.7 kPa, maximum pressure, concrete arch
- -3.35 kPa , maximum suction, concrete arch
- 3.69 kPa (net pressure: external pressure minus internal pressure, concrete arch)
- -2.48 kPa (net suction: external pressure minus internal pressure, concrete arch)
- -3.03 kPa maximum pressure, internal glass structure
- -2.92 kPa, mean pressure media, internal glass structure

- -1.57 kPa maximum pressure , cantilever slab, entrance
- -1.15 kPa maximum mean pressure, cantilever slab, entrance
- -2.52 kPa, maximum pressure, jet bridge
- -2.0 kPa maximum mean pressure, jet bridge

In accordance with the Manual of Civil Works (MOC, 2008), the value of pressure for structural design would be 224.61 kg/m<sup>2</sup> (2. 20kPa). Based on this value and the analysis of the results of the tests in the wind tunnel, possible design problems are not identified, however, this statement must be verified by the designer, particularly with regard to the effects of suctions. Additionally, the designer should check the possible impact of "projectiles" (debris) towards the inside of the air terminal.

Regarding the CFD analysis, the "venturi effect" occurring between the two structures (concrete and glass) of the terminal building was clearly visualized. In the numerical simulations, a wind speed of 5 m/s was used, which is equivalent to a wind that can be categorized as "gentle breeze" on the Beaufort scale. Nonetheless, areas completely opposite to the areas of incidence of the wind, showed, in some analyses, magnitudes of velocities that exceeded comfort levels according to international standards.

However, the results of the analyses reveal situations that for higher speeds (highly likely in the area of the new air terminal), comfort issues may be generated, so it is recommended to provide mitigation measures for the effects of the wind circulating inside the terminal.

## **ACKNOWLEDGEMENTS**

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## **REFERENCES**

- Dyrbye, C. Hansen, S.O. (1997). "Wind Loads on Structures". Ed. Wiley & Sons, Ltd.
- Lawson, T. V. (1990). "The determination of the wind environment of a building complex before construction". Report Number TVL 9025, Department of Aerospace Engineering, University of Bristol, Bristol, United Kingdom.
- MOC, (2008), "Manual de Diseño de Obras Civiles", Diseño por viento. Recomendaciones y Comentarios, Instituto de Investigaciones Eléctricas, Comisión Federal de Electricidad.
- Mohamed, F. and Karadelis, J. (2013). "CFD simulation for wind comfort and safety in urban area: A case study of coventry University Central Campus". International Journal of Architecture, Engineering and Construction. Vol 2, No 2, June 2013
- Ruiz-Huerta, L., Ortega-Rodriguez, A. and Caballero-Ruiz, A, "Relation between tip size, deposition speed and roughness in FDM technology", 2014, ASPE 2014 Spring Topical Meeting: Dimensional Accuracy and Surface Finish in Additive Manufacturing; Berkeley, CA; United States; 13 April 2014 through 16 April 2014; Code 107516, Pages 214-218
- Ruiz-Huerta, L., Caballero-Ruiz, A., Vega-Alvarado, L., Yañez - San Vicente, R. and Castro-Espinosa, H., "Model – Support material interaction inspection by X-ray

Computed Tomography in FDM Additive Manufacturing Process”, ASPE 2015 Spring Topical Meeting: Achieving Precision Tolerances in Additive Manufacturing; North Carolina State University, Raleigh, North Carolina, USA; April 26-29; pages 160-163.

Sakr, M., y Karadelis J., (2013), “CFD Simulation for Wind Comfort and Safety in Urban Area: A Case Study of Coventry University Central Campus”, International Journal of Architecture, Engineering and Construction, Vol. 2, No. 2, June.

Simiu, E. y Scanlan, R.H., (1978), “Wind Effects on Structures - An Introduction to Wind Engineering”, John Wiley & Sons, New York.

Stathopoulos, T. and Baskaran, B. A. (1996). “Computer simulation of wind environmental conditions around buildings.” Engineering Structures, 18(11), 876–885.