XLIII CILAMCE
21-25, November, 2022
FOZ DO IGUAÇU - PR - BRAZIL

Neighborhood and wind direction effects on wind pressure distribution on the low-rise building roof

Vitor Gabriel de Oliveira Camilo[1], Marco D. de Campos[1]

[1]*Institute of Exact and Earth Sciences, Federal University of Mato Grosso, Av. Valdon Varjão, 6390, Barra do Garças, 78605-091, Mato Grosso, Brazil*
vitor.camilo@sou.ufmt.br, marco.campos@ufmt.br

Abstract. Low-rise buildings are the majority of the houses that are constructed all over the world. Experiments of the wind loads acting on these buildings provide vital information to design secure structures and adverse weather conditions resistants, considering the basic parameters in the analysis of gable buildings as roof slopes and the wind direction. This study estimated the distribution of wind pressures around the contour of buildings with gable roofs, considering diverse neighborhood conditions such as the number and geometric configuration of buildings on the ground, in conjunction with the different angles of wind incidence. The simulations took place with *Ansys Workbench* software, and the *RNG K-Epsilon* turbulence model and tetrahedral mesh were employed. The application validation of the CFD technique occurred in the double sloped pitched roof structure. The results showed good concordance with the literature. The pressure coefficients were analyzed, and in the flow visualization, highlighted the attachment points and the recirculation zones.

Keywords: wind action, pressure coefficients, *Ansys*, low-rise buildings.

1 Introduction

The most common building type used in the residential, commercial, and industrial sectors is, arguably, low-rise buildings [1]. Nonetheless, this construction typically receives low priority and limited field observation/inspection of wind loading. Consequently, they suffer the heaviest damage from high winds, entailing massive economic losses for countries [2]. The critical areas of good design and construction for wind resistance are the walls, roofs, and our connections. In particular, the roof structure provides crucial lateral support to load-bearing and non-load-bearing walls. Once the roof structure is partially or fully lost and the roof diaphragm committed, then with the stand wind pressure, there is a considerable reduction in the ability of the walls [2]. Large fluctuating wind loads originating from turbulent background winds pronounced flow separation at sharp edges of buildings (e.g., eaves and building corners), and intermittent flow separation and reattachment on building surfaces are the principal causes of wind damage to low-rise buildings [3]. Low-rise buildings are seldom tested for wind actions, while tall buildings are often so [1]. In this work, the pressure coefficients were determined for the methodology validation, considering a single structure with double slopes, according to Fouad *et al.* [4]. On remaining applications also calculated the pressure coefficients for two and three buildings with gabled roofs. The basic parameters considered in the analysis include neighborhood conditions and wind direction.

2 Methodology

For the geometry modeling, was used the *Autodesk AutoCAD* software. For the CFD technique validation, according to Fouad *et al.* [4], the models were placed inside the domain of 9 H width, 9H height, and 21H length (Fig. 1d). Here, H = 6 m is the maximum height of the building. In agreement with Fouad *et al.* [4], For the other applications, considering diverse neighborhood conditions such as the number and geometric configuration of buildings on the ground, in conjunction with the different angles of wind incidence, was adopted the control volume, according to Franke *et al.* [5] (Fig. 1b-c). The boundaries are 5H from the inlet and both sidewalls, 6H from the model base, and 15H behind the building to allow flow development (Fig. 1e). Here, H=3.72 m is the maximum height of the building and boundary conditions. Table 1 shows the non-dimensional parameters.

The *Ansys Fluid Flow* software, and the *RNG K-Epsilon* turbulence model, was adopted for simulations.

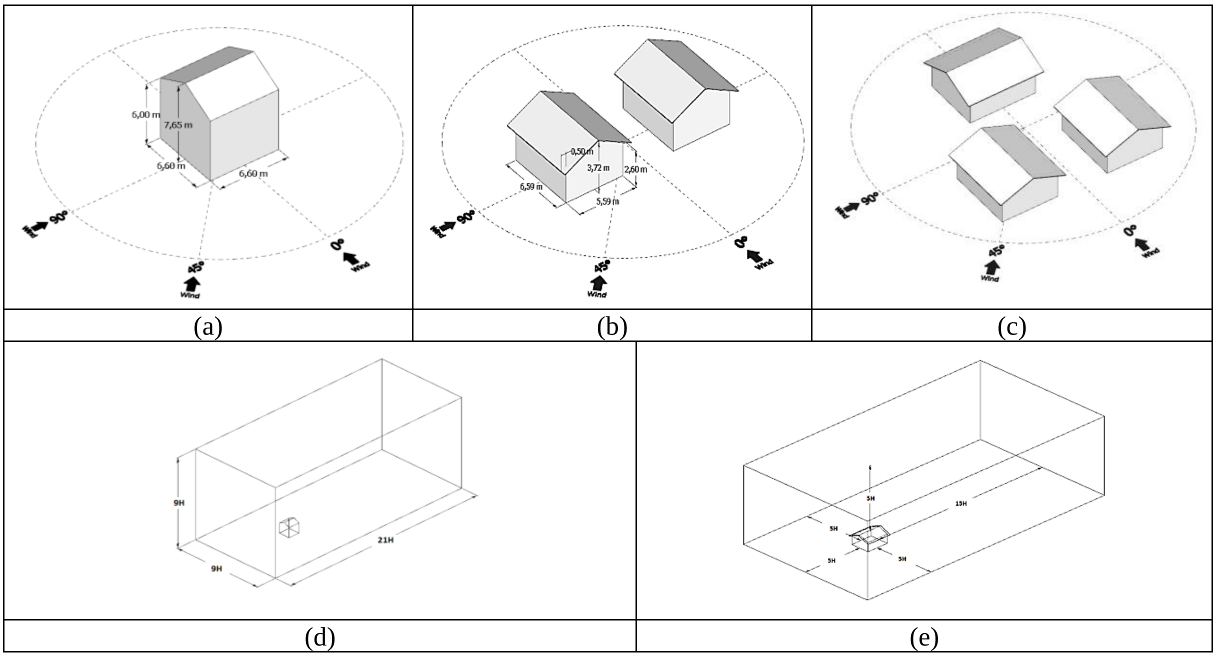


Figure 1. (a), (b), (c) Geometry and different angles of incidence of the wind, and (d), (e) the control volume.

Table 1. Boundary conditions and non-dimensional parameters.

Condition	*Parameters*
Method of mesh	Tetrahedron
Reference pressure	101325 [Pa]
Air temperature	25 [°C]
Specific mass	1.185 kg/m³
Inlet	35 [m/s]
Relative pressure of outlet	0 [Pa]
Roughness	0.01 [m]

3 Numerical applications

Application 1 (*single structure with double slopes*): This is the usual sloping roof that slopes in two directions and the two inclinations meet at the ridge. The gable roof is permissible on any structure. The short gable roof building has a length 6.6 m, a width of 6.6 m, a gable height of 6 m, and a roof slope equal to 26.6° [4]. The mesh formed by tetrahedrons resulted in 2331763 elements and 489871 nodes. Here, 1.225 kg/m^3 for air density and a wind speed of 44.76 m/s incidents at 0° were adopted orthogonally to the side face of the building.

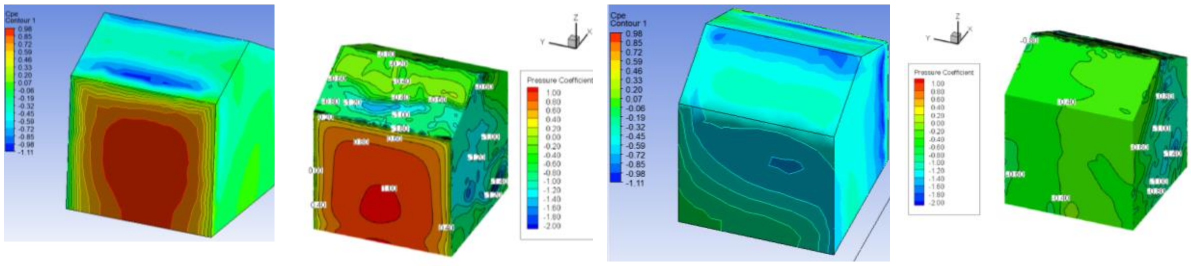
In all applications, the local pressure coefficients, defined by $Cpe=\Delta p/q$, where *Cpe* is the external pressure coefficient, Δp is the difference in the external pressure coefficient, and q is the dynamic pressure, were calculated.

Figure 2 shows an agreement between the isobaric lines [4] and those generated by *Ansys* in this work. The pressure distribution values on the facades and roof are the same, with a slight change in distribution. The windward face of the building presented external pressure coefficients ranging from 0.20 to 0.98 (Fig. 1a), in line with Fouad *et al.* [4], whose values ranged from 0.00 to 1.00 (Fig. 2b). The values ranging between -0.85 and 0.07 (Fig. 2c) diverge from Fouad *et al.* [4] on the leeward side. The coverage showed the highest negative values in the windward region, with a minimum pressure coefficient of -1.11, agreeing with -1.20 in Fouad *et al.* [4]. The downstream section showed values similar to those in the literature of -0.19 (Figs. 2c and 2d).

The following applications simulated the flow with different wind incidence angles. It was considered a wind speed of 35 m/s acting on two and three buildings opening with double slopes. Next, considering different wind incidence angles (0°, 45° and 90°), two configurations will be investigated (Fig. 1b-c).

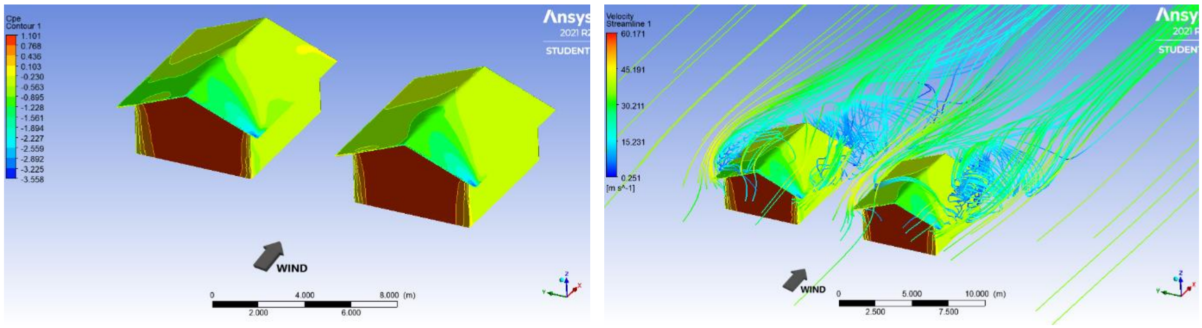
Application 2 (***two buildings side-by-side with double slopes***)

Case 1 (*incident wind at 0°*): The color hue represents the pressures on the building surface, corresponding to the external pressure coefficients. Cool colors represent suction regions, while warm colors represent overpressure regions (Fig. 3a). Figure 3 shows the streamlines. With the incidence of wind at 0°, vortex shedding in the structure was evident (Fig. 3b). This phenomenon consists, basically, of the retardation of air particles due to friction with the surface, where small masses of dammed air detach and flow away from the course and, as the air moves, there is a change in pressure at the surface, according to Leet *et al.* [6].



(a) Present work (b) Fouad *et al.* [4] (c) Present work (d) Fouad *et al.* [4]

Figure 2. Flow pressure distribution of the (a), (b) windward, and (c), (d) leeward facades.



(a) (b)

Figure 3. (a) *Cpe* and (b) streamlines for the wind incident at 0°, perpendicular to the front facade of the buildings.

Case 2 (*incident wind at 45°*): When the wind blows obliquely onto the corner of a roof, a flow pattern appears with the formation of conical vortices similar to those found at the ends of airplane wings, according to Holmes [7]. They constitute a discharge of the existing vorticity in the aerodynamic field around the construction. They are responsible for any accidents, with partial or total removal of the roof of buildings due to the intense suction caused, according to Blessmann [8]. The conical-shaped vortex extends along both roof edges. This area will be vulnerable to highly fluctuating and extreme forces. In this case, the pressures are among the highest that occur in low-slope roofs, with square or rectangular plants, although, generally, the affected areas are small. According to Fig. 4a, there was a reduction in Cpe_{max}, which is more intense in the corners of buildings where the wind hits.

At the corners of the eaves of the buildings occur the largest suction zones. Originated by the top vortices conical-helical shape, they appear in pairs, from the corner of the building to the windward side (Fig. 4b). The suction values in this region reached, in the module, values between 2.0 and 3.0, in agreement with Blessmann [8].

Case 3 (*incident wind at 90°*): The largest overpressure zones are formed on the windward face of the building when the wind is perpendicular to one of the facades. Between them, the external pressure coefficients are negative (Fig. 4c). The base vortices between buildings were the cause of these suctions (Fig. 4d). These vortices, in turn, originate near the ground with an approximately horizontal axis. Then, they develop helically from the facade center until the two ends, escaping through the sides with increased speed [8].

Small changes in overpressures on the windward façade are due to base vortices. Close to the side facades, they caused increased local velocities (Fig. 4c) and, as a result, high suctions with pressure coefficients reached, in a module, between 1.5 and 2.0 (Fig. 4d), in agreement with the literature [8].

Application 3 (***three buildings with double slopes***): In the same conditions as the previous application, on three buildings abreast with double slopes, was considered wind incidence angles 0°, 45°, and 95°.

Case 1 (*incident wind at 0°*): With the wind at 0°, the building added to the windward side presented high overpressure on the wind's face, represented by warm colors (Fig 4e). The increase in wind speed passing through the building originated from a suction at the corners of the roof, represented by cold colors in Fig. 4(e-f).

For the buildings arranged side by side, there was a decrease in the maximum values of the contours of the maximum pressure coefficients. This fact resulted in smaller overpressure zones. In these buildings, the largest suction zones were also detected, provoked by the leeward base vortices of the first building in addition to the wake interference flow regime. There, an attempt to reconstitute the atmospheric boundary layer occurs, which did not happen due to the proximity of the constructions, making the flow turbulent enough for an unbalanced formulation of vortices incident on the leeward structure (Fig 4f).

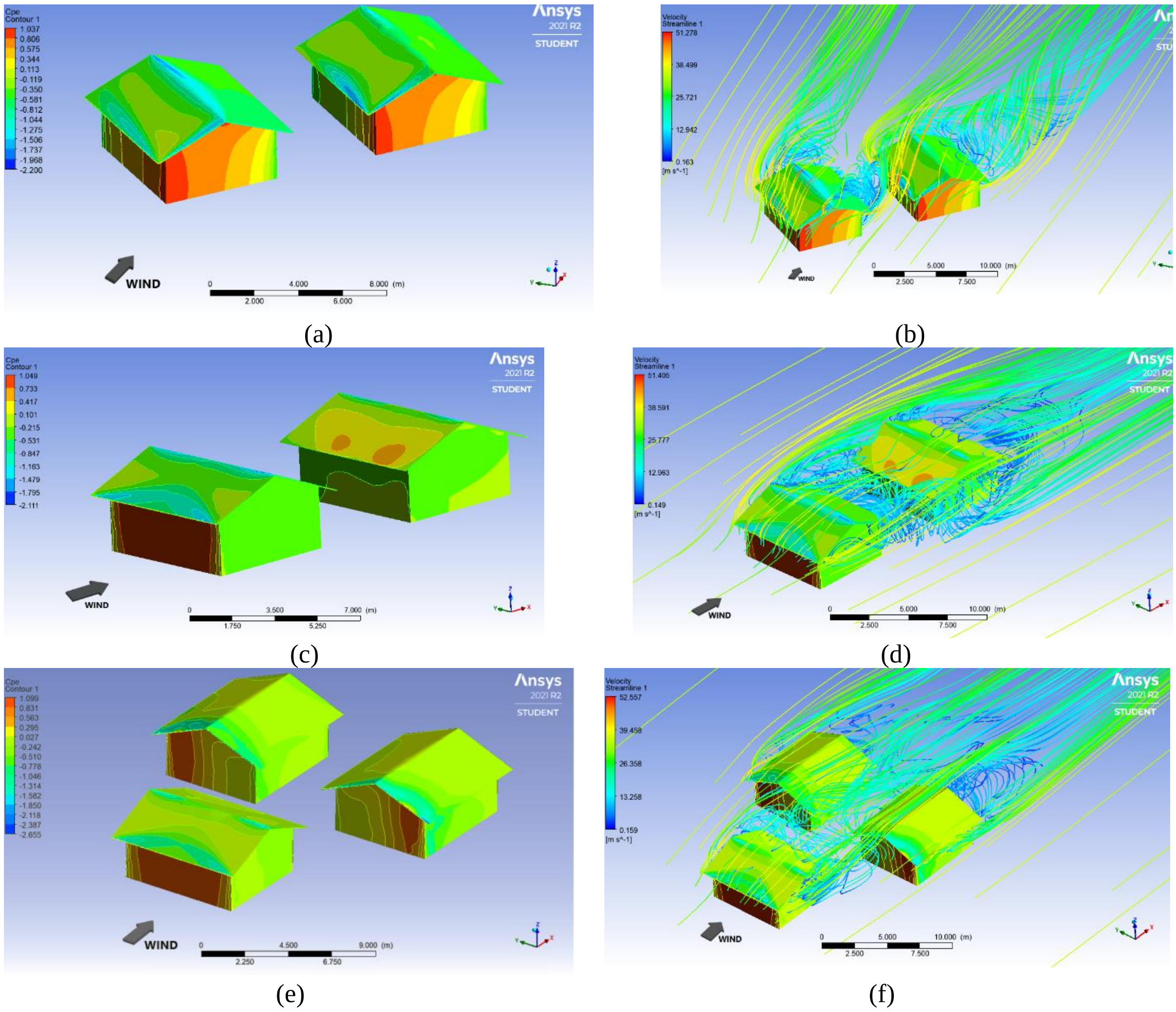


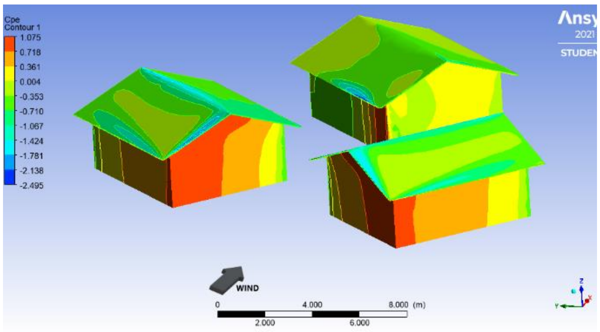
Figure 4. *Cpe* and streamlines for the wind incident at (a), (b) 45°; (c), (d) 90°in the buildings, and (e), (f) for the wind incident at 0°, perpendicular to the front facade of the buildings.

Case 2 (*incident wind at 45°*): Here, an abundance of vortices was formed and, consequently, areas with higher pressure coefficients (Fig 5a-b) due to the incidence of wind in the corners of the buildings. These corners of the buildings on the windward side presented the highest zones of overpressure (Cpe_{max} =1.075). The top vortices caused intense suction in the corners of the eaves of the buildings. The suction values in this region reached, in the module, Cpe_{min} = 2.495, in agreement with [8]. The incidence of these vortices can be harmful to the structural response of the buildings, both for the generating structure and the receiving building [9].

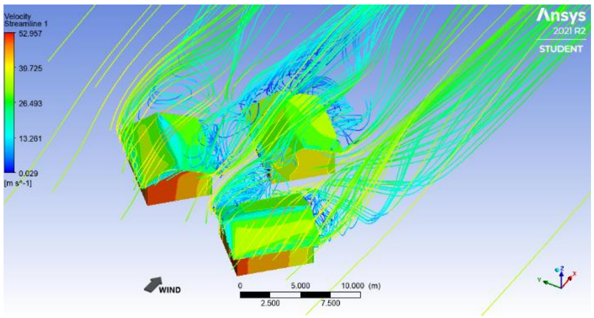
Case 3 (*incident wind at 90°*): The windward faces had the highest overpressure zones with the wind perpendicular to the buildings. The external pressure coefficients are negative on the faces between the buildings (Fig. 5c). As a result of wind funneling between very close edifications and accelerating the airflow, the Venturi effect generated these suctions. It was possible to identify an intense suction on the inside of the ridge of the leeward construction due to the increase in wind speed when passing through the windward building (Fig 5d).

4. Conclusions

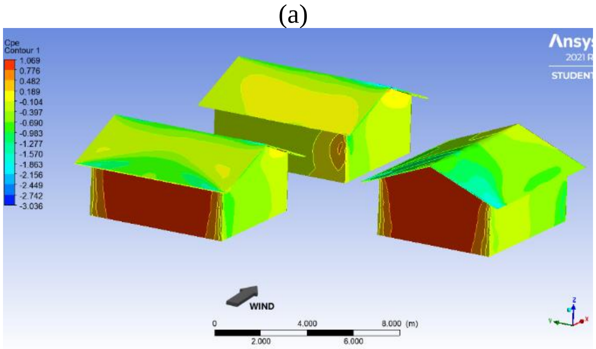
This paper presents pressure coefficients of low-rise building roofs as obtained from *Ansys Workbench* software. For validation methodology, a single structure with double slopes, according to [F], was considered. The comparison of the distribution of isobaric lines showed a difference in the leeward face. The values coincided with the windward facade and the roof. For three wind orthogonal incidences to the low-rise building design purposes have presented the results for external pressure coefficients.



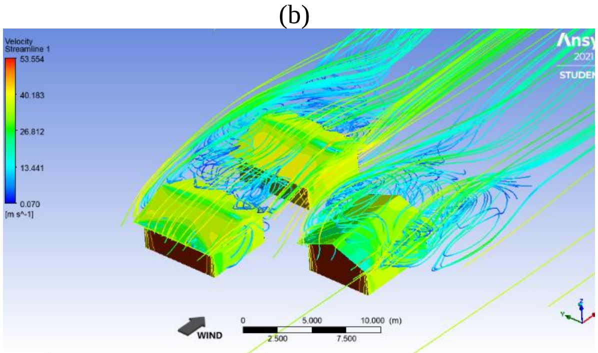
(a)



(b)



(c)



(d)

Figure 5. *Cpe* and streamlines for the wind incident at (a), (b) 45°, and (c), (d) 90°in the buildings.

With the wind at 0° and the addition of the third building, there was a decrease in the contours of the maximum coefficients in the leeward structure, indicating smaller overpressure zones when compared to the two-building model. However, there were the larger suction zones noticed in these conditions. This effect is to the leeward vortices in the first building and the flow interference in the wake.

Now, when the wind is at 45° and the third building, there was an increase in areas with higher pressure coefficients when compared with the two-building model. In this case, the most intense suction zones occurred in the corners of the eaves of the buildings. Finally, with the wind at 90° in two buildings, the largest overpressure zones were formed on the windward face of the building when the wind was perpendicular to one of the facades. High suction also occurred, caused by increased local velocities. With the presence of the third building, the suction on the faces between the buildings intensified. Due to the increase in wind speed at the leeward ridge of the building, there was intense suction.

Finally, these results can motivate the elaboration of a roadmap to reduce the accidents in buildings due to wind. Furthermore, this material would fill a gap for scholars in the area and could decrease low-rise roof accidents.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors or has the permission of the owners to be included here.

References

[1] D.P.P. Meddage, C.S. Lewangamage and A.U. Weerasuriya, "On the deviation of mean pressure coefficients in wind loading standards for a low-rise, gable-roofed building with boundary walls", *Structures*, vol. 36, p. 50-64, 2022.

[2] M. J. Crosbie, "Buildings at risk: wind design basics for practicing architects". Washington: American Institute of Architects, 1998.

[3] T. Stathopoulos, "Wind loads on low-rise buildings: a review of the state of the art". *Engineering Structures*, vol. 6, n. 2, p. 119–135, 1984.

[4] N. S. Fouad, G. H. Mahmoud and N. E. Nasr, "Comparative study of international codes wind loads and CFD results for low rise buildings". *Alexandria Engineering Journal*, vol. 57, p. 3623–3639, 2018.

[5] J. Franke, A. Hellsten, H. Schlünzen and B. Carissimo, "Best practice guide for the CFD simulation of flows in the urban environment, COST Action 732: Quality assurance and improvement of microscale meteorological models". Hamburg: COST Office, 2007.

[6] K. M. Leet, C. M. Uang, J. T. Lanning and A. M. Gilbert, "Fundamentals of Structural Analysis". New York: McGraw-Hill, 2018.

[7].J. D. Holmes, "Wind Loading of Structures". London: Spon Press, 2001.

[8] J. Blessmann, "Aerodinâmica das construções". Porto Alegre: Ed. da UFRGS, 2011 (*in Portuguese*).

[9] J. Blessmann, "Introdução ao estudo das ações dinâmicas do vento". Porto Alegre: Ed. da UFRGS, 2005 (*in Portuguese*).