Numerical investigation of wind loads on an industrial shed with rounded eaves with different height-width relationships

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Abstract. Pressure distributions due to wind in low structures are commonly estimated using computational analysis tools as an alternative to wind tunnel studies. Studies have shown that the rounded eaves attenuate the suctions present in the upper region of this device. Therefore, this work analyzes the behavior of the external pressure coefficients in an industrial shed with rounded eaves, considering the following height-to-width ratios (H/B): H/B=0.5, H/B=0.75, H/B=1.00 and H/B= 1.25. The pressure distributions for wind at 45° and 90° were determined using Ansys Workbench software. In the analysis of the height-width ratio, the results indicated that the external pressure coefficients were more intense in the 90° configuration and, in the 45° wind, there was a change in the position affected by the high suctions from the H/B=1.00.

Keywords: wind action, industrial shed, eaves, *Ansys*, pressure coefficient.

1 Introduction

There are few recent studies in the literature on structures with rounded eaves. Extreme winds are one of the central causes of roof collapse in low-rise buildings, making it necessary to investigate devices capable of mitigating the high suctions that arise.

Some studies have addressed the roofs of low-rise buildings due to their recurring use and sensitivity to high wind loads. For example, Tariq *et al.* [1] analyzed numerically the external pressure generated by the wind on the gable roof of a low-rise building. In this case, they investigated three roof inclinations for the same wind direction and thus concluded that the maximum pressure coefficients shifted from negative to positive values as the roof inclination increased. Kwan and Kopp [2] conducted tests on wind tunnel models to determine the effects of curvature on the aerodynamics of the models and the pressure fields of low-rise buildings. These results indicated that the pressure coefficients varied continuously as a function of the radius of curvature of the edge, and the models showed uncertain measurements in the pressure fields from a given radius-height ratio. Therefore, in this work, we numerically analyzed the behavior of the external pressure coefficients with the variation of the height-width ratio and wind direction in a building with rounded eaves.

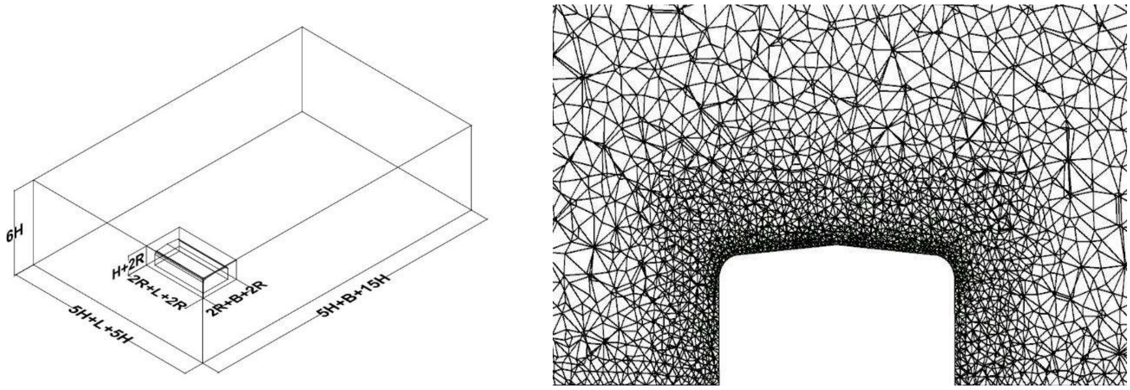
2 Methodology

The geometries were modeled using *Autodesk AutoCad 3D Basics* software, varying the height (H) as a function of the width B=15.00 m (Table 1). The control volume was composed of a subdomain whose distance from all sides of the geometry is equal to twice the eaves rounding radius (R). The geometry was arranged in a domain (Fig. 1) according to Franke *et al.* [3]. The results were obtained through numerical simulation with *Ansys*

Workbench R2023 software, using the *Fluid Flow* (CFX) analysis system and the *RNG k-Epsilon turbulence model*. The boundary conditions applied are indicated in Table 2.

Table 1. Dimensions of the models used in the study for radius (R), length (L), width (B) and height (H).

	R	***L***	***B***	***H***	***H/B***
Model 1	1.35	30.00	15.00	7.50	0.50
Model 2	1.35	30.00	15.00	11.25	0.75
Model 3	1.35	30.00	15.00	15.00	1.00
Model 4	1.35	30.00	15.00	18.75	1.25



(a) (b)

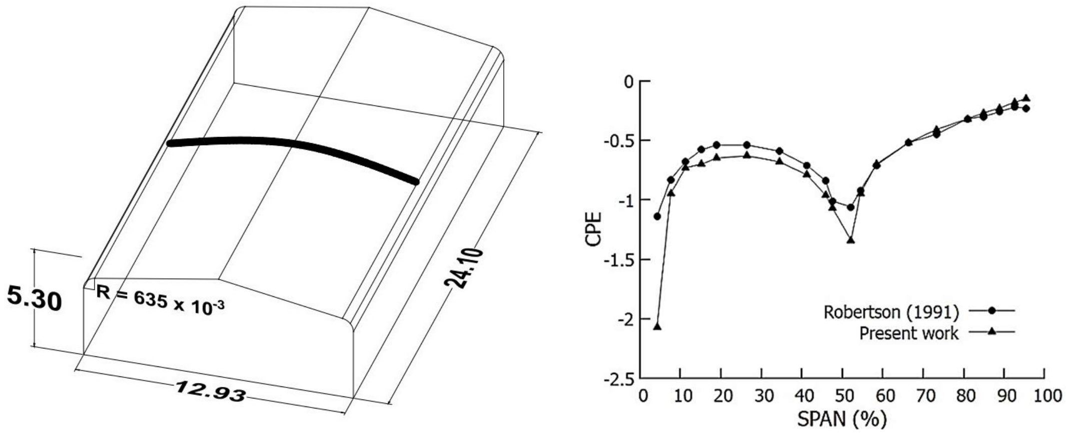
Figure 1. (a) Geometry and control volume and (b) geometry, mesh and control volume used.

Table 2. Boundary conditions and non-dimensional parameters.

Condition	*Parameters*
Method of mesh	Tetrahedron
Reference pressure	101325 [Pa]
Air temperature	25 [°C]
Turbulence intensity	Medium (5%)
Flow regime	Subsonic
Inlet	$U/U_{\mathrm{ref}}=(z/z_{ref})^{\alpha}$
U_{ref}	10 [m/s]
z_{ref}	5.3 [m]
α	0.16
Relative pressure of outlet	0 [Pa]
Wall - Ground	Rough wall
Model wall roughness	Smooth wall
Roughness	0.01 [m]

3 Numerical applications

Application 1 (*Validation*): Quantitatively, the *T-test* was used to evaluate a statistically significant difference between the means of two *Cpe* samples. Thus, were extracted from 20 points in the mid-section of the roof (Fig 2a) according to the geometrical settings of [4]. Furthermore, an *F-test* was applied to define whether the data variances were supposedly equivalent or different. Considering the *null hypothesis* (H_0) that the means are not statistically significant, assuming two samples with equal variances, two-tailed distribution, and significance $\alpha' = 0.05$, and using *Microsoft Excel* software obtained a *p-value* = 0.45. As *p-value* > α', we do not reject the *null hypothesis* (H_0) and consider the difference between the means in the *Cpe* values insignificant. Thus, the numerical simulation overestimated the pressures in the region at ~0.00% of the span and the ridge, while it presented good agreement in the leeward region (Fig. 2b).



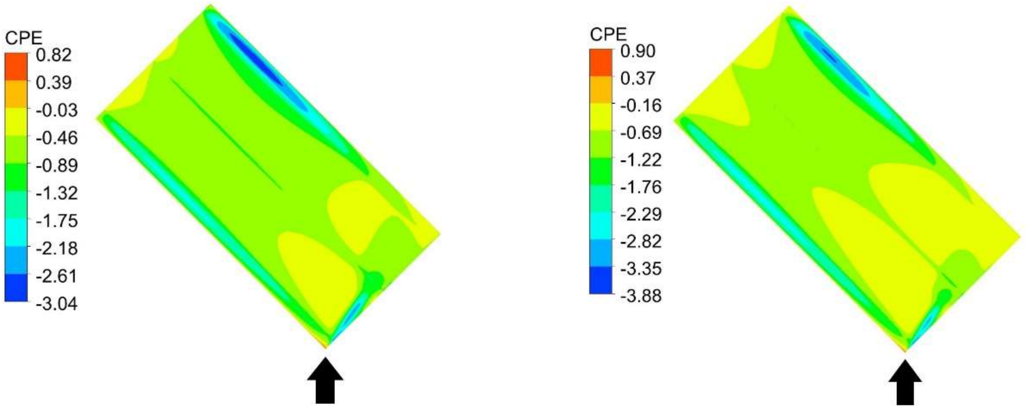
(a) (b)

Figure 2. (a) Dimensions, in meters, of the geometry with emphasis on the mid-section of the roof, and (b) pressure distributions

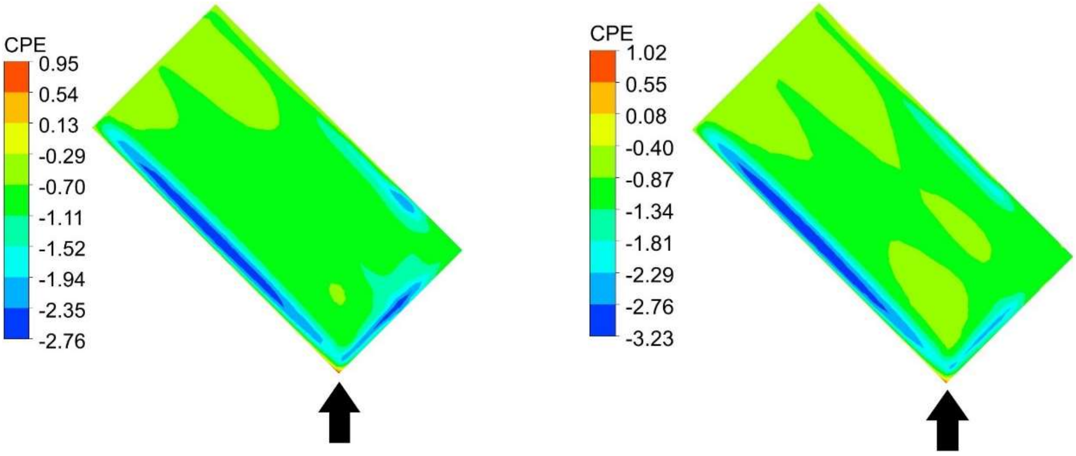
Application 2 (*variation in height-width relationships with wind at 45º*): The pressure distribution was similar in *Models 1* and *2*, in which the highest suctions on the leeward side occurred due to the separation of the flow at the rounded eave (Fig. 3a-b) and the development of conical vortices on the windward side, which promoted the reallocation of the flow downstream. Consequently, this caused more intense negative pressures on the leeward side.

Now, the *Models 3* and *4* also presented similar pressure contours (Fig. 3c-d). Here, compared to *Models 1* and *2*, the suction peaks occurred in a region with a larger area of windward coverage. In Model 3, a low-pressure zone occurred in the opposite region to that observed in *Models 1* and *2*. In *Model 4*, this region occurred in the center of the leeward eave.

Due to this configuration, all the models formed upstream conical vortices and, as indicated in the literature, caused the appearance of negative pressures at the edges of the windward region [5].



(a) (b)



(c) (d)

Figure 3. *Cpe* contour map on the roofs of (a) *Model 1*, (b) *Model 2*, (c) *Model 3*, and (d) *Model 4* considering variation in height-width relationships and wind at 45º.

Application 3 (*variation in height-width relationships with wind at 90º*): The variation in height-width relationships increased the suction values at the windward eave. Thus, *Models 3* and *4* presented high suctions in a larger region of the eave. On the other hand, a lower magnitude of *Cpe* at the ridge. Thus, the suctions of *Models 2, 3,* and *4* were relatively similar (Fig. 4). In addition, *Models 2* and *3* presented the most intense *Cpe* along the ridge. On the leeward side, the suctions were concentrated in certain regions of the eave (Fig. 5). These areas close to the corners of the geometry resulted in lower suction magnitudes in *Model 3* at approximately ~100.00% of the span (Fig. 4).

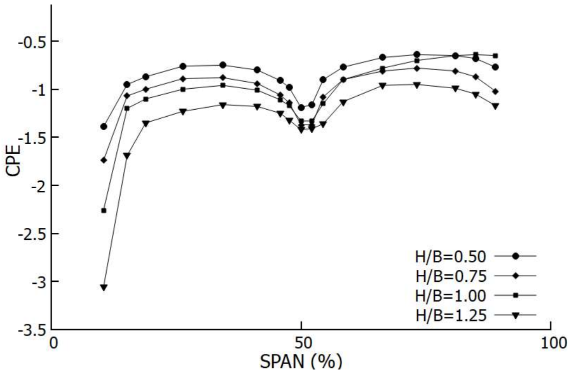
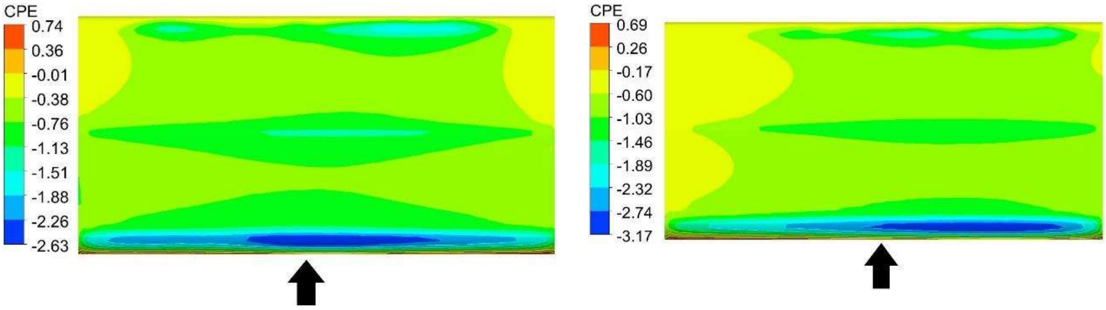


Figure 4. *Cpe* for 17 points in the middle section of the roof as a function of width.



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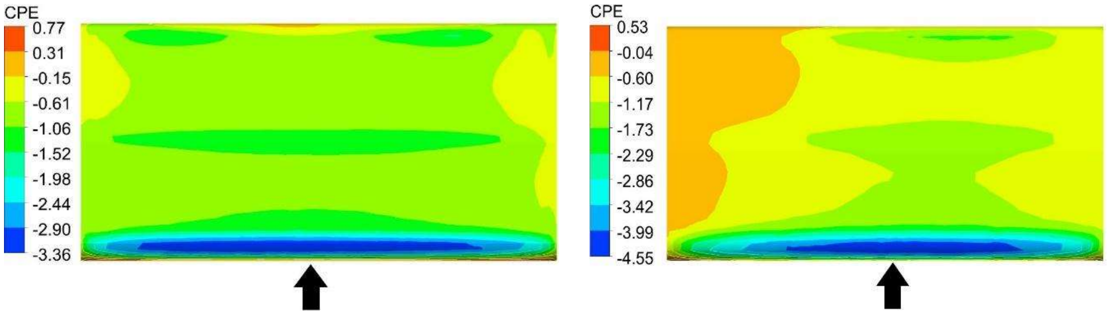

(c) (d)

Figure 5. *Cpe* contour map on the roofs of (a) *Model 1*, (b) *Model 2*, (c) *Model 3*, and (d) *Model 4* considering variation in height-width relationships and wind at 90º.

4 Conclusions

In this study, the influence of the variation in the height-to-width ratio was analyzed in an industrial warehouse with rounded eaves using the numerical simulation software Ansys Workbench.

Considering a full-scale experiment, the pressure coefficients were determined to validate the methodology, obtaining good agreement. In a second application, the external pressure coefficients for different *H/B* ratios with the wind at 45°. The highest magnitude of suction occurred at *H/B*=0.75, which was the model most damaging to the leeward eaves. The *H/B*=1.00 ratio generated the lowest suction and, on the other hand, affected an extensive region of the eaves and edge on the windward side. Finally, a third application investigated the external pressure on the roof with the *H/B* variation and with the wind at 90°. The relation *H/B*=1.25 ratio was the most damaging to the windward eaves and presented the most intense suction among the models. The *H/B*=1.00 ratio generated the highest forces along the ridge.

Therefore, these results expand the studies on usual engineering structures that use rounded eaves. Future works could investigate new height-width relationships in addition to other wind directions, roof slopes, or building length and width.

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