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Experimental study on the interference intensity produced by the presence of neighboring buildings in the wind action in a tall building

Estudo experimental sobre a intensidade da interferência produzida, pela presença de edifícios vizinhos, na ação do vento em um edifício alto



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Abstract

The average strain on a building due to the action of the wind, can be significantly altered when considering the presence of one or more neighboring buildings. Such changes can be considered through the use of coefficients that take into account the distance that the neighboring building is from the building being studied. The present work was developed in order to verify the values currently adopted by the Brazilian standard that regulates the wind action in buildings. With the use of a wind tunnel, several tests were carried out in a standardized building considering the presence of other buildings with similar dimensions close to it. The distances between the buildings, the quantity and the layout of the neighboring buildings were taken into consideration. It was possible to conclude that, in general, the presence of the neighboring buildings produced an increase on the strain. Interference, in many situations, increased strain above the rates suggested by the current Brazilian wind action standard.

Keywords: wind action, neighborhood effects, aerodynamics of buildings.

Resumo

Os esforços médios atuantes em uma edificação devidos à ação do vento, podem ser significativamente alterados quando se considera a presença de um ou mais edifícios vizinhos. Tais alterações podem ser consideradas através da utilização de coeficientes que levem em conta a distância que o edifício vizinho está da edificação em estudo. O presente trabalho foi desenvolvido no intuito de verificar os valores atualmente adotados pela norma brasileira que regula a ação do vento em edificações. Com a utilização de um túnel de vento, foram feitos vários ensaios em um edifício padronizado considerando a presença de outros edifícios com dimensões idênticas próximos a ele. Considerou-se o afastamento entre os edifícios, além da quantidade e da disposição das edificações vizinhas. Pôde-se concluir que, de maneira geral, a presença das edificações vizinhas produziu a majoração dos esforços. As interferências, em muitas situações, elevaram os esforços acima dos índices sugeridos pela atual norma brasileira de ação do vento.

Palavras-chave: ação do vento, efeitos de vizinhança, aerodinâmica de construções.

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1. Introduction

The need to better exploit land in urban centers has called for higher and slenderer constructions. The desire of people to live closer to downtown makes these areas become highly valuable and densely constructed. As investors seek to fine cheaper land that may provide a bigger return on investment, more buildings are built on suburban regions. Many of these buildings are unique in the region considering the time they were built. However, with local development other buildings of similar size begin to be constructed in the region. Depending on the distance, these new buildings alter the air flow over the first buildings that makes an isolated situation become one that makes the consideration of the building presence in the neighborhood necessary.
Many researchers have developed studies related to the wind action behavior interference on buildings. Many experimental studies were developed during the years. In the numeric simulation fields, [1] and [2] comment that the presence of local or global interferences, make it extremely difficult to evaluate the interference produced due to the great number of variables involved.
In Brazil, studies related to these interferences have been studied since the end of the 1970s. The works of [3] and [4] considering the uniform and turbulent stream, respectively, in squared section buildings, already pointed to a rise in the strain intensity. Recently, [5] also verified that the rise in strain due to the presence of neighboring buildings in the wind action direction are different of those foreseen in Brazilian standards. Proceeding in this line of study, [6] also observed the elevation of strain through a statistics evaluation considering the presence of a single neighboring building.
The results of these studies performed over ten years caused some standards to establish forms of considering the effects caused by neighboring buildings. Amongst them are New Zealander [7], European [8], Indian [9], and Brazilian [10] that served as orientation for this study.
Considering that the Brazilian standard is currently undergoing a revision process, the objective is to amplify the information gamma in relation to the intensity of the neighboring building's interference in the wind action over another building. The quantity, arrangement and distance that the neighboring building had in relation to the building studied where established as parameters. The wind shear average strain on the base, torsion to the building axis and flexion around the transversal axes on the base of the building studied were evaluated. We expect that the collected data will aid in probable decision making as to how, when and what values should be used to consider the presence of neighboring building in the elaboration of a construction project.

2. Experimental program

2.1 Equipment

The experiments were held using a wind tunnel of limited atmospheric layer of the Construction Aerodynamics Laboratory of the Rio Grande do Sul Federal University (LAC-UFRGS) Professor Joaquim Blessmann in Porto Alegre, Brasil. The test table used was positioned in the tunnel region with a transversal section of 1.30m x .90m with an extension of 9.32m. According to [11], these dimensions, presenting a length/height ratio of 10.4, are appropriate for simulating the characteristics of wind acting on a construction. The models were built in a scale of 1:406. The generated turbulence simulated an exponent of .23 to the power law. Such turbulence is equivalent to categories III and IV classified in [10], that represent plain terrains with numerous and spread out obstacles similar to small cities or area distant to great urban centers. The average wind simulated profile, V(z)/Vref, the turbulence intensity distribution, I1, and the longitudinal scale of turbulence, L1, for the roughness assumed, are shown in Fig. 1, where Vz is the average wind velocity at the height of the gradient wind.
The Commonwealth Advisory Aeronautical Research Council (CAARC) was studied as the standard building. The reduced study

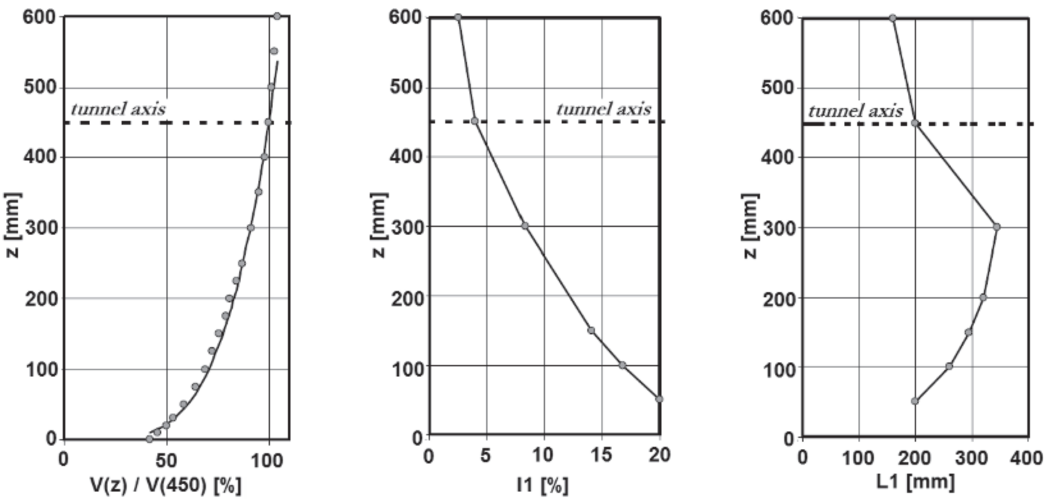
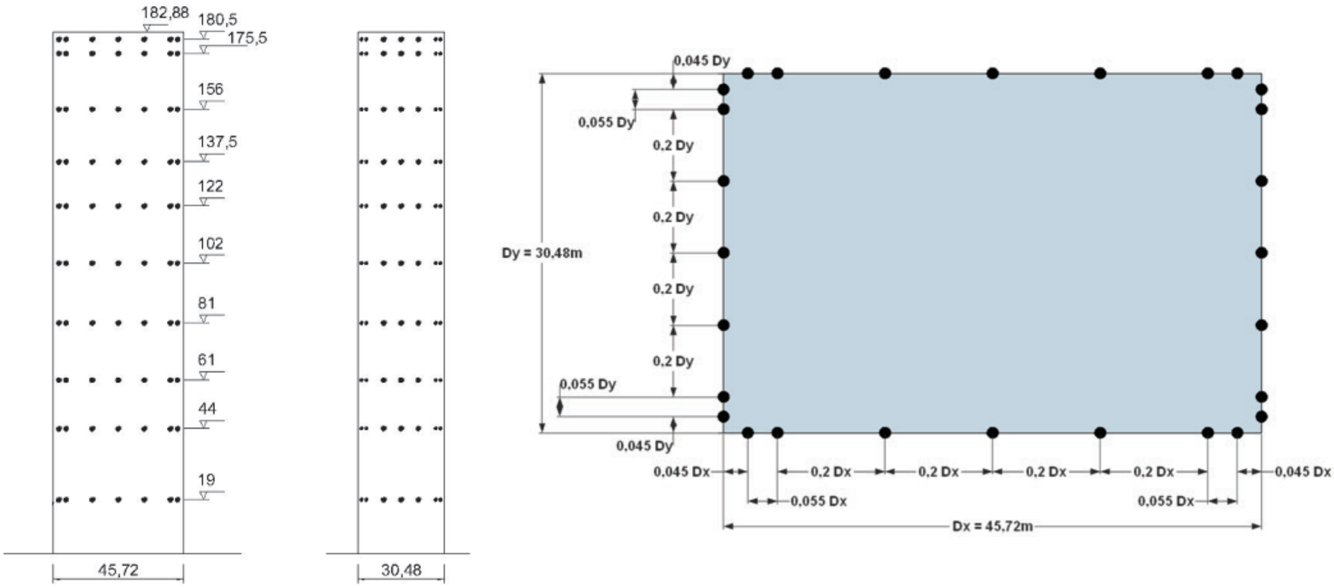


Figure 1
Characteristics of the simulated Wind: (a) Wind profile; (b) turbulence intensity distribution; (c) longitudinal turbulence scale for an exponent p = 0.23

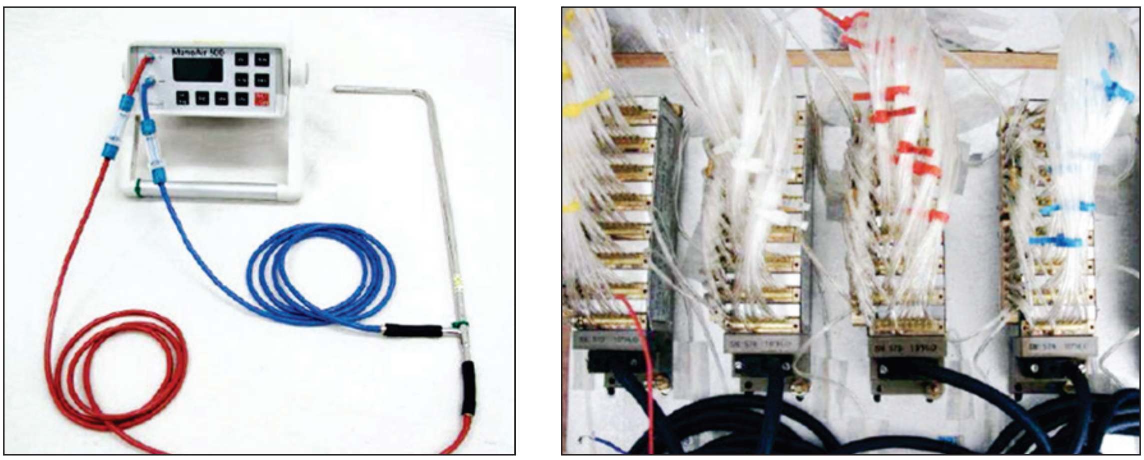
Figure 2
Instrumented model and CAARC standard building muted model

model and the models used as neighboring buildings, presented in Figure 2, measures 75mm x 112mm x 450mm. The study model was built in acrylic, equipped with 280 pressure plugs distributed on the four facades and divided in ten height levels, as shown on Figure 3. The plugs contain the standard location as established by [12], and on regions next to the edges where there are high pressure gradients, as adopted by [13].
The pressure data of each plug where obtained through a micro electric pressure gauge Schiltknecht MANOAIR 500, that also pro-



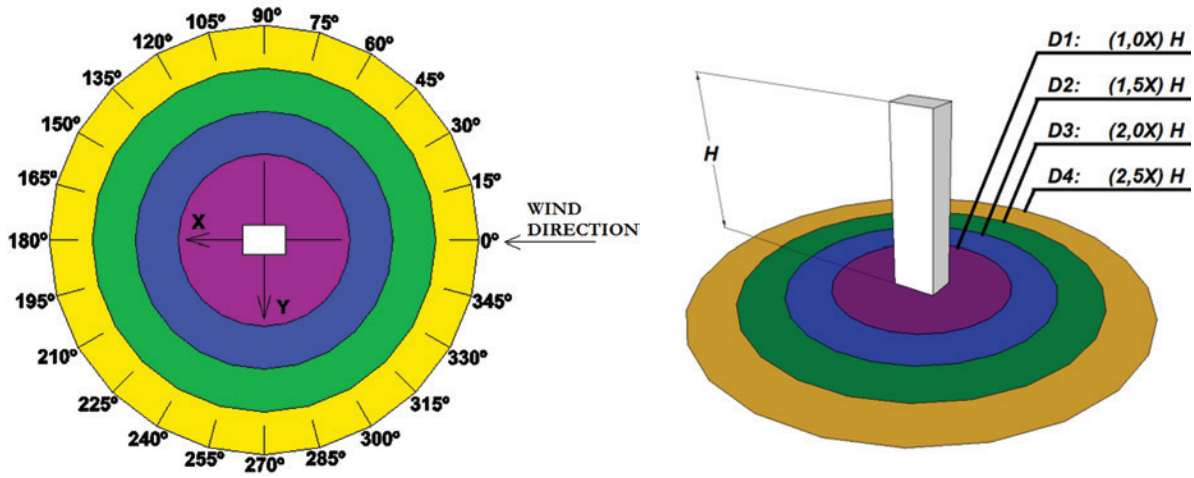
(a) (b)

Figure 3
Pressure plug indicators on the CAARC standard building: (a) pressure plug level quotas (unit: m); (b) transversal section with the placement of the plugs



(a) (b)

Figure 4
Data reading equipment: MANOAIR and connection tubes to the piezometric rings of the wind tunnel; (b) Scanivalve with the 64 pressure measuring channels by module



(a) (b)

Figure 5
(a) Studied wind incidence direction; (b) Distances for the neighboring buildings' positioning

vided the temperature and pressure information on the test chamber at the moment of the experiment. The fluctuating pressures were registered by the Scanivalve ZOC33-Dantec device, at an acquisition rate of 20 kHz and imprecision of .12%. Both devices are shown on Figure 4.

2.2 Study parameters

The incident direction of the wind was taken under consideration from the x axis with a variation of 15º summing twenty-four directions, shown on Figure 5 (a). 8192 pressure readings in mmH_2O in each plug were taken, in an interval of 16 seconds, for each wind direction. As to the distance of the neighboring buildings, inspired in the torsion calculation idea for construction, presented by [10], the building height was used as a parameter. Four distances were studied and respectively named D1 = H, D2 = 1,5H, D3 = 2,0H e D4 = 2,5H, where H is the height of building, as shown on Figure 5(b). Eight types of vicinities were established, named from V1 to V8, where all of them were placed externally to each one of the distances along the alignments presented in Figure 6 totalizing thirty-two tests.

2.3 Strains and interference factors

The dynamic pressure utilized on the pressure calculation is given by expression 1:

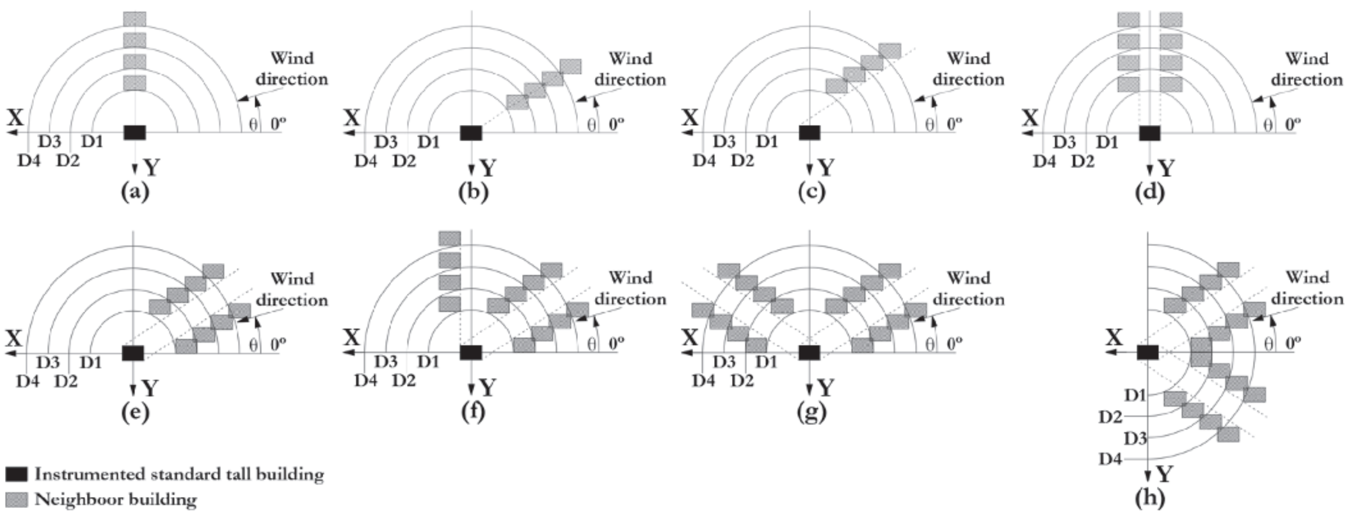


Figure 6
(a) Vicinity V1; (b) Vicinity V2; (c) Vicinity V3; (d) Vicinity V4; (e) Vicinity V5; (f) Vicinity V6; (g) Vicinity V7; (h) Vicinity V8

$$q = k_0 \Delta pa \quad (1)$$

Where:
q: dynamic pressure at a distance
k_0: wind tunnel calibration factor, previously determined, in relation to the atmospheric pressure values to the drainage pressure dynamics; value of 1.185 for the test held with the CAARC Standard Tall Building in the test tunnel.
Δpa: reference pressure
The resulting strength coefficient in the direction of the base axes are the result of the reason between the vectorial sum of the acting forces in the area of influence of each pressure plug, and the product of the dynamic pressure by the total area of the wind incidence face, according to the expression 2 and 3:

$$C_{F_x} = \frac{F_x}{qB_yH} \quad (2)$$

$$C_{F_y} = \frac{F_y}{qB_xH} \quad (3)$$

Where:
Fx, Fy: the global force in direction of axes X and Y respectively;
CFx, CFy: strength coefficient direction of axes X and Y respectively;
q: dynamic wind pressure;
Bx, By: nominal dimensions of the transversal section of the building in direction of axes X and Y respectively.
H: height of the building.
The coefficient of bending moments around the base axes were determined by the reason between the sum of the bending around each main axis and the product of dynamic pressure by the volume of the main building, as presented by expressions 4 and 5:

$$C_{M_x} = \frac{M_x}{qB_xB_yH} \quad (4)$$

$$C_{M_y} = \frac{M_y}{qB_xB_yH} \quad (5)$$

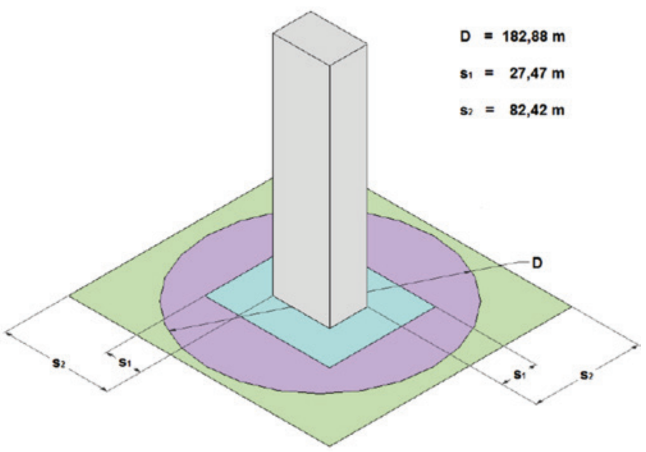


Figure 7
Union of the distance proposals of the strain standards on the CAARC standard building, according to the Brazilian standard

Where:
Mx, My: bending moments around axes X e Y respectively;
C_{Mx}, C_{My}: bending coefficient around axes X e Y respectively;
For determining the torsion moment coefficient around the main building axis, a similar criterion was adopted of the bending moment as presented in expression 6:

$$C_T = \frac{M_T}{qB_xB_yH} \quad (6)$$

Where:
M_T: torsion moment around the torsion axis;
C_T: torsion coefficient;
We adopted the limits established by [10] for result comparison purposes. The Brazilian standard considers the presence of neighboring buildings in two ways depending on the strain studied. Torsion is considered by applying an eccentricity on the resultant wind force acting on the facade. If the effects of the neighborhood are taken in to consideration, the eccentricity between the building axis is 15% of the dimension of the facade in account. Only the buildings that are inside a circle of radius equal to 0.5H or three times the smallest side of the building, "b", from the center of the building being studied, where H is the height of the building, are considered neighboring.
As to base shear 7 and the bending around the base axes, the neighborhood is taken in to account through the strain of the product by the neighborhood factor (FV). The neighborhood factor is defined as being the reason between the aerodynamic coefficient considering the building as neighborhood, by the aerodynamic coefficient considering the isolated building as shown in expression 7.

$$\mathrm{FV} = \frac{C\ building\ with\ vicinity}{C\ isolated\ building} \quad (7)$$

The value of the neighborhood factor varies linearly by 1.3 to 1.0 depending on the reason between dislocation "s" between the buildings and dimensions "d*". The d* value is given by the smallest of the following dimensions:
The smallest side of the building being studied, "b"
the semi-diagonal of the transversal section of the building studied given by: $\frac{1}{2}\sqrt{a^2+b^2}$, where "a" is the biggest side of the building being studied
Once the values are obtained, the neighboring factor is determined as shown below:
s/d* ≤ 1,0 → FV = 1,3
s/d* ≥ 3,0 → FV = 1,0
For the intermediate s/d* values, interpolate linearly.
Figure 7 presents the union of both proposition of distance of the Brazilian standard considering the standard CAARC building.
In the present study the neighborhood factor, expression used by [10], was denominated interference factor (FI). The calculation of the interference factor is done according to that presented in expression 7, and was used for the study of all strains, including torsion.

3. Presentation and results

The figures from 8 to 15 present the values of strain coefficients for the eight neighborhood arrangements proposed. In each figure

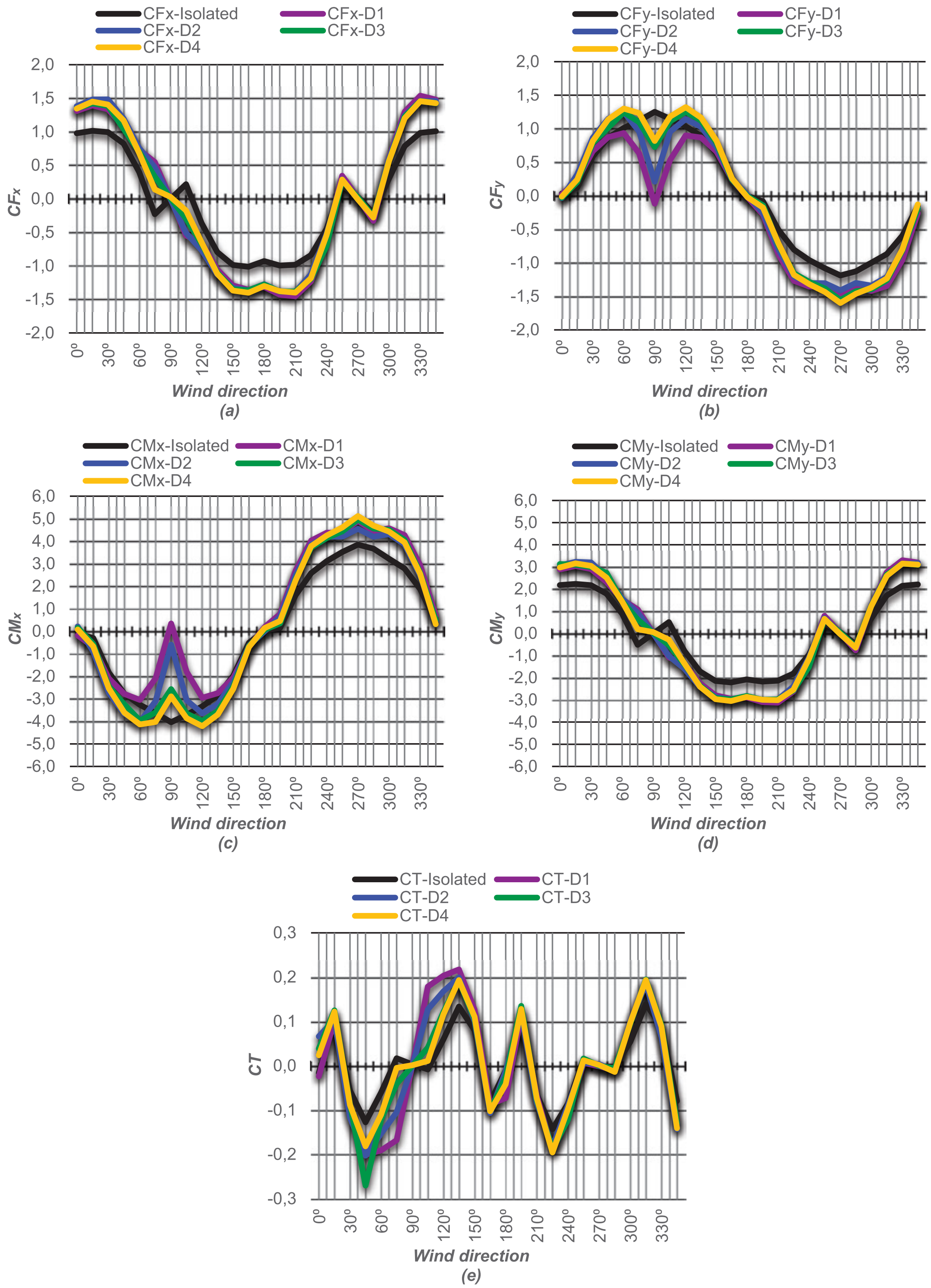


Figure 8
Load coefficients for the vicinity V1: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

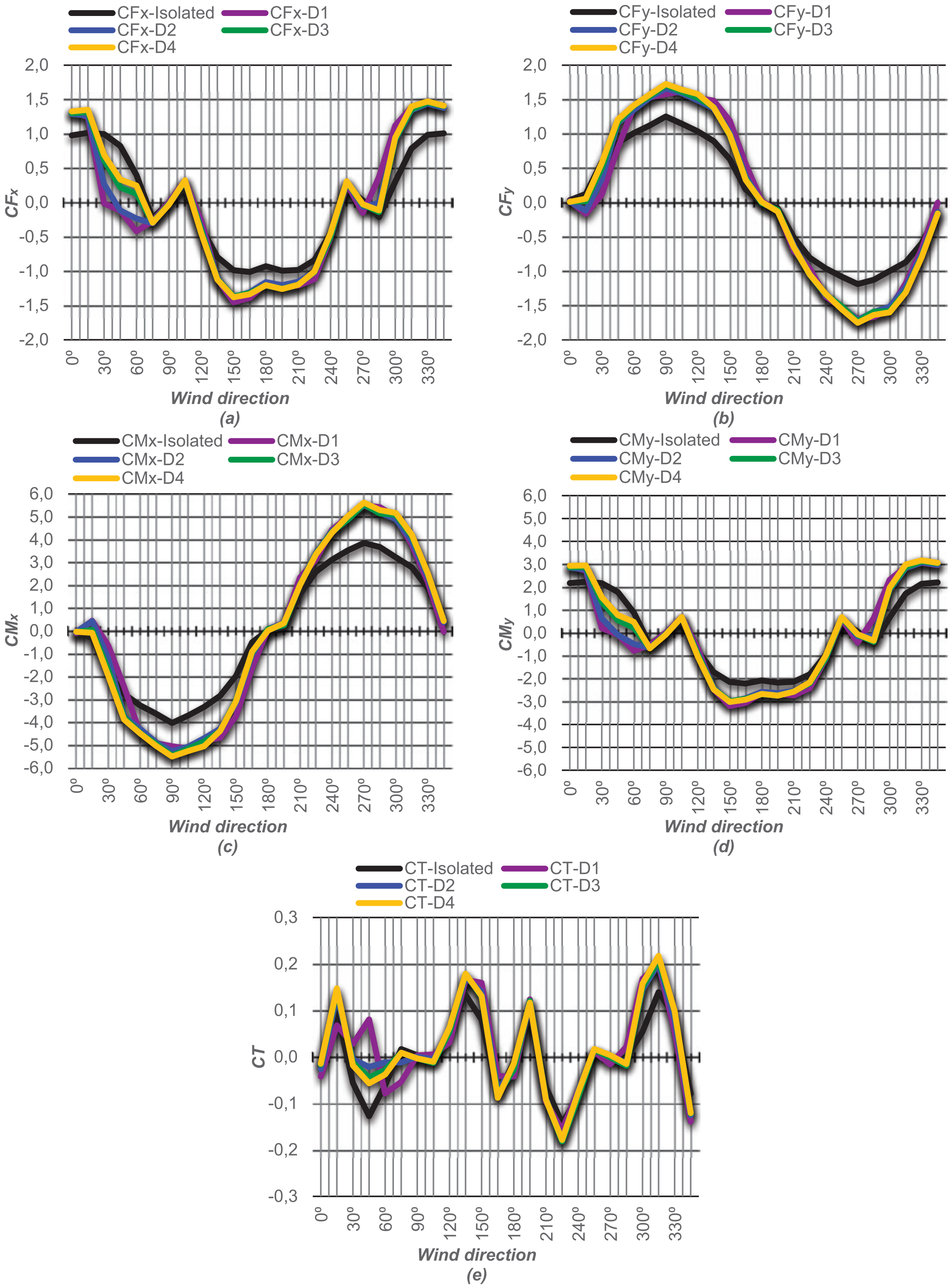


Figure 9
Load coefficients for the vicinity V2: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

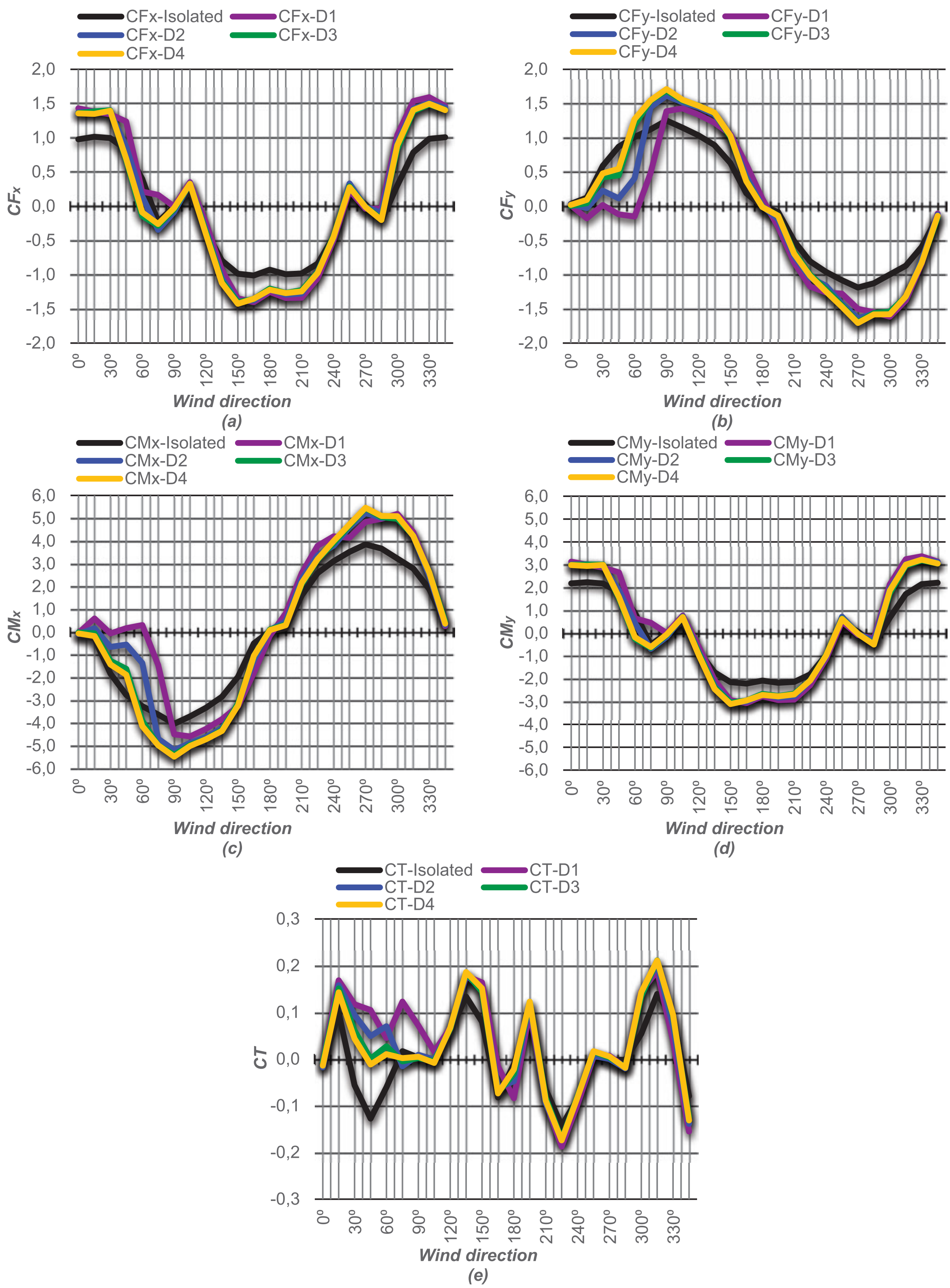


Figure 10
Load coefficients for the vicinity V3: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

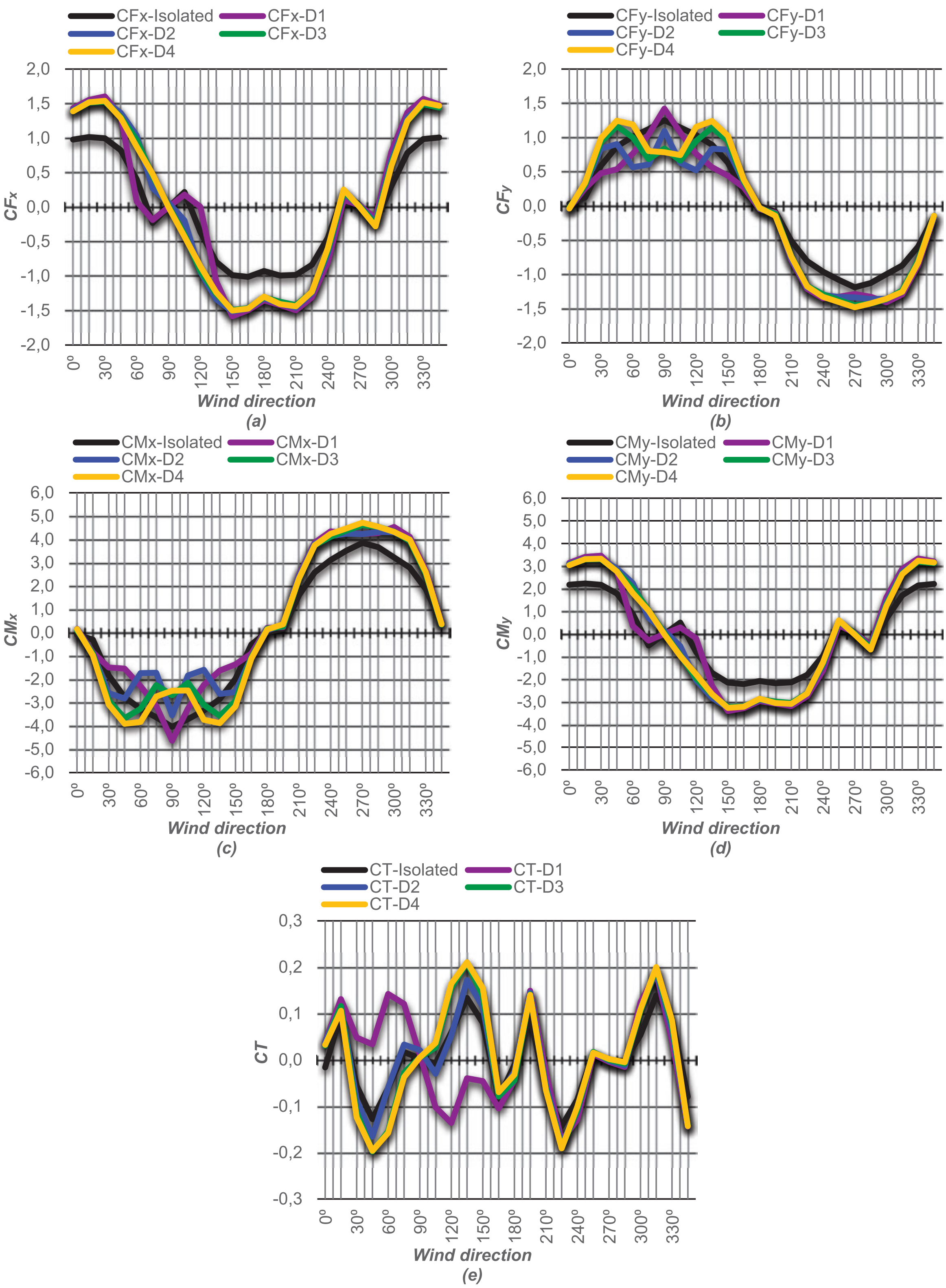


Figure 11

Load coefficients for the vicinity V4: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

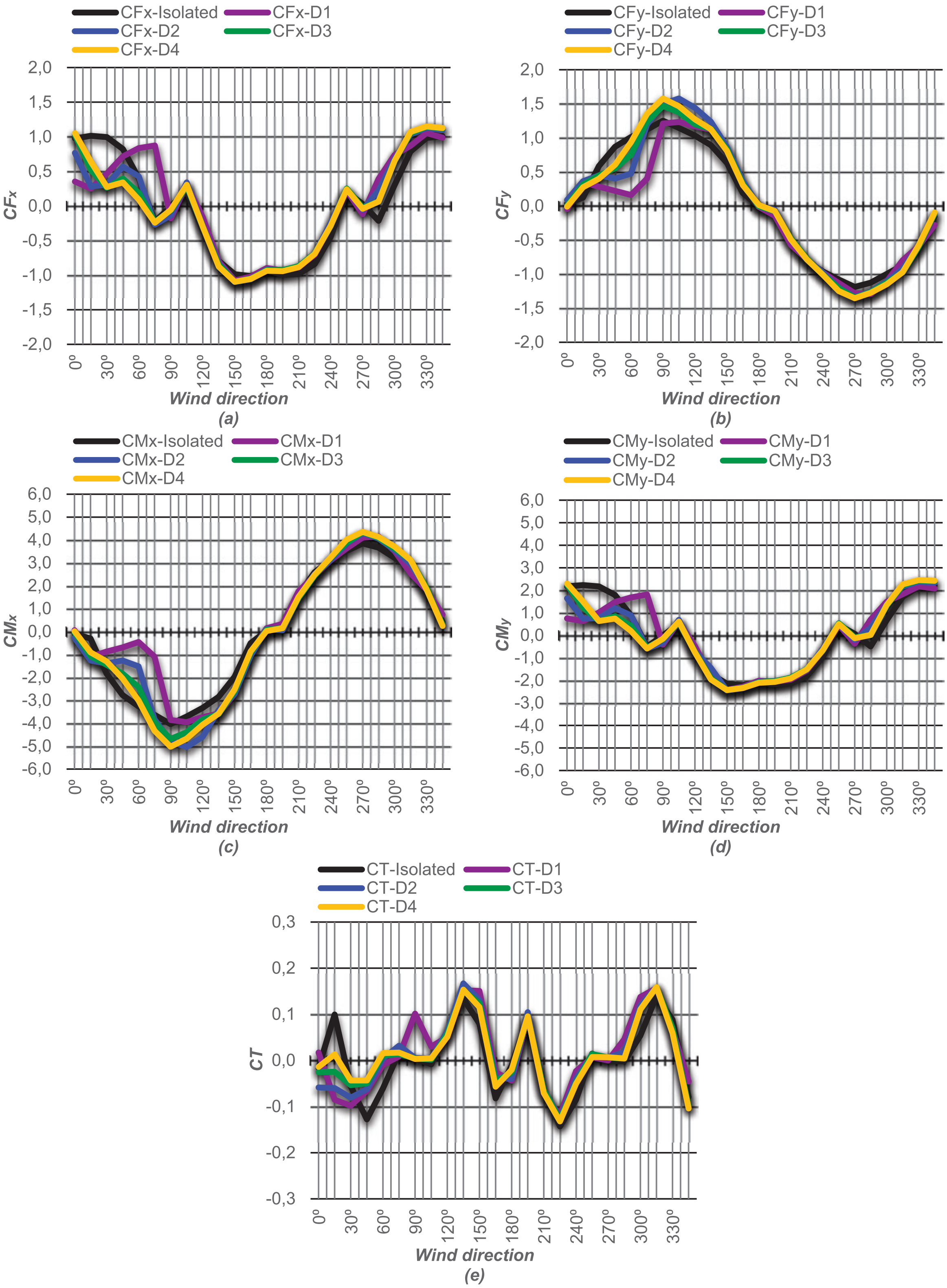


Figure 12
Load coefficients for the vicinity V5: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

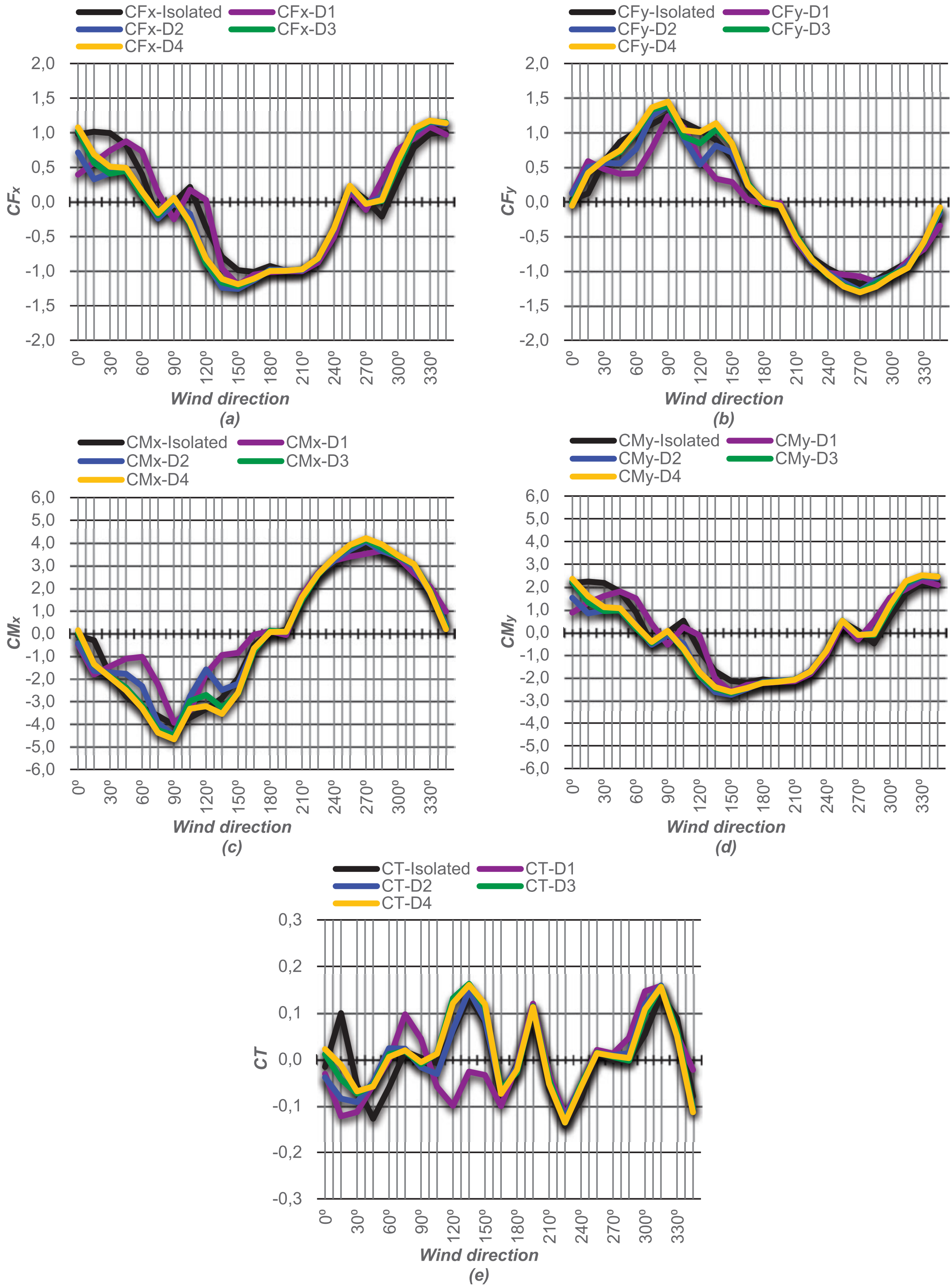


Figure 13
Load coefficients for the vicinity V6: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

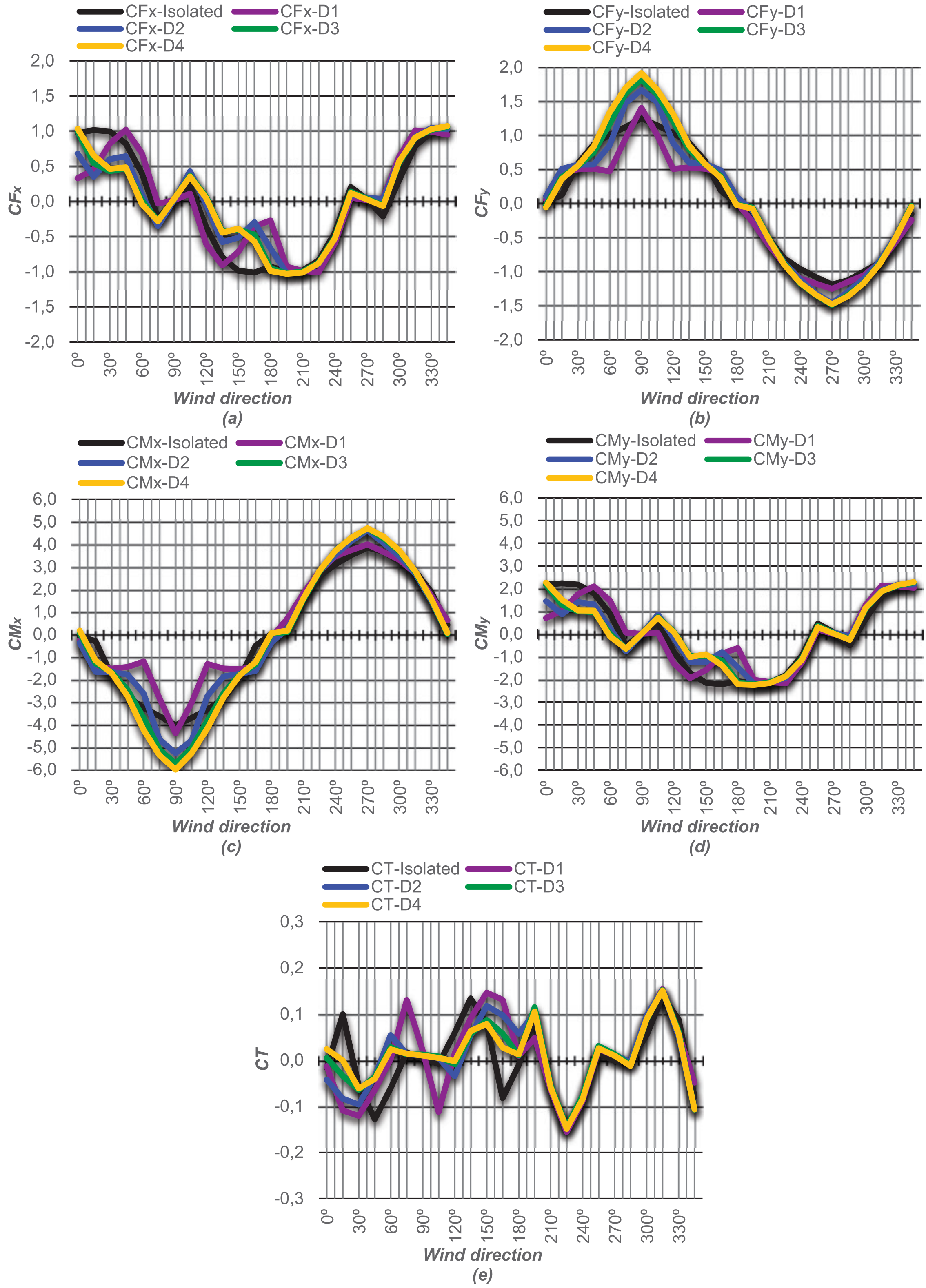


Figure 14
Load coefficients for the vicinity V7: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

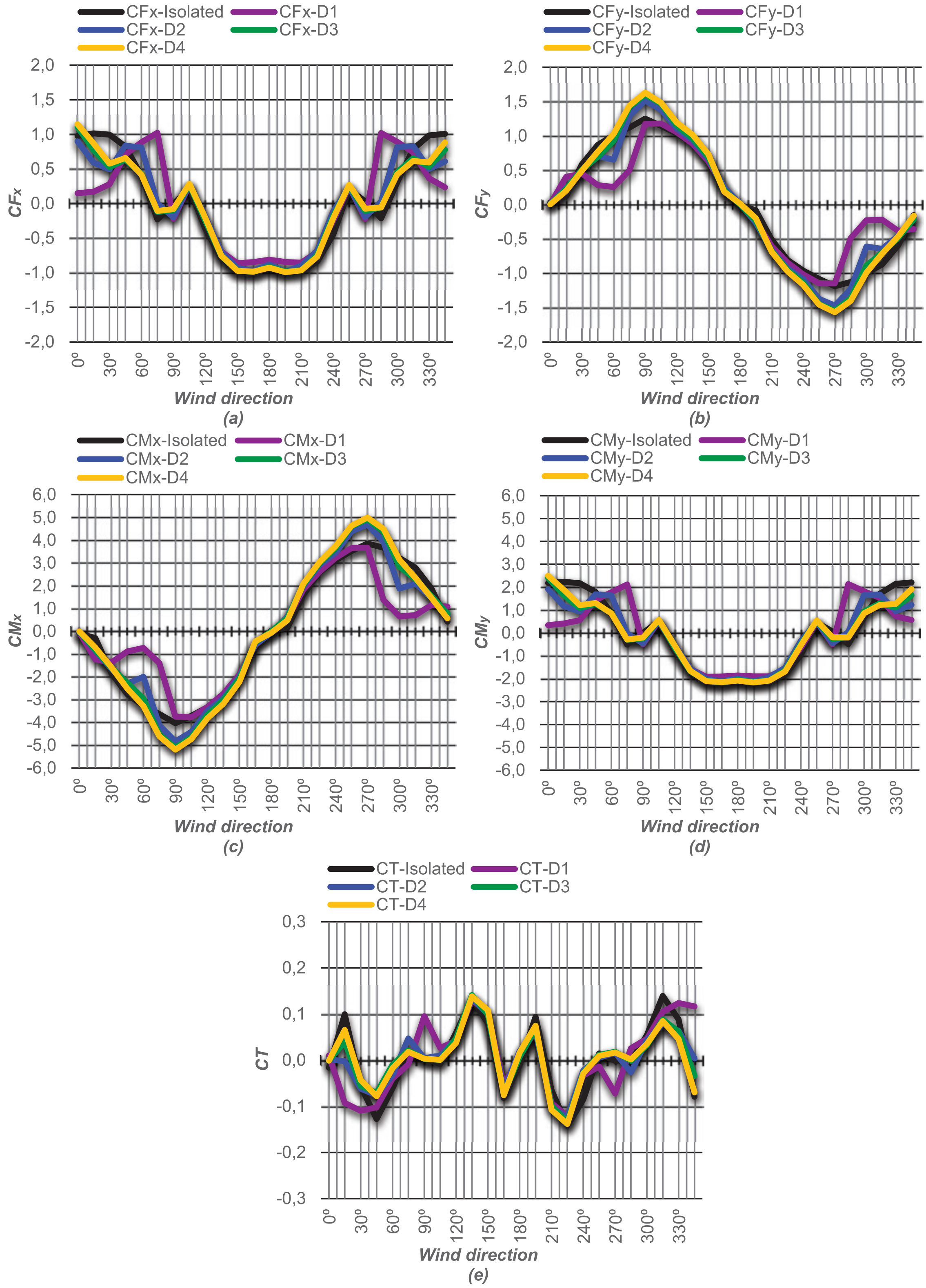


Figure 15
Load coefficients for the vicinity V8: (a) Resultant force in the direction of the X axis; (b) Resultant force in the direction of the Y axis; (c) Base momenta round axis X; (d) Base moment around axis Y; (e) Torsion around building axis

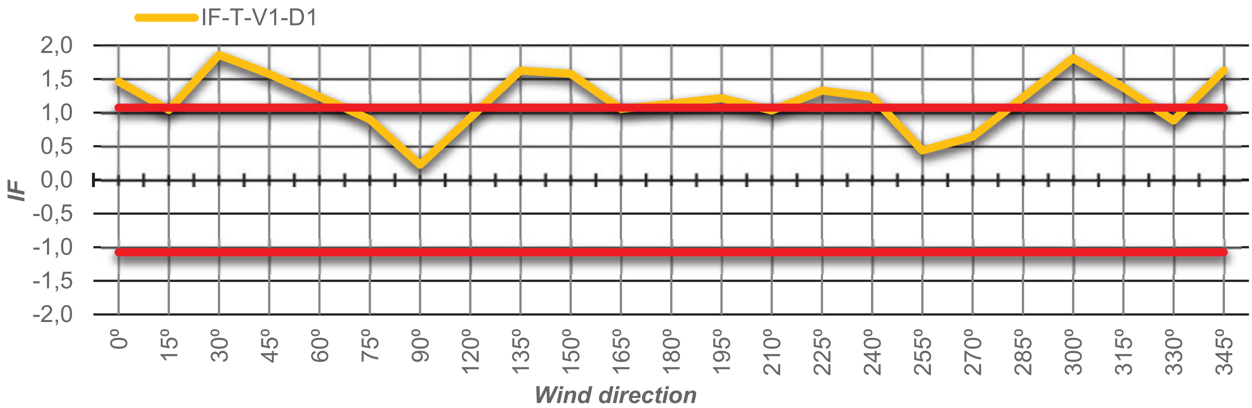


Figure 16
Interference Factor (IF) Analyses of torsion of vicinity V1 positioned at distance D1

it is possible to observe five graphics. The curve that represents the wind action effect on the building when it is considered in isolation was taken as reference. The others, consider the same effect with the presence of neighboring buildings in each of the distance proposed.
Observing the shear on the base in direction of the X axis, an elevation is noted, produced by the presence of neighbors, in every arrangement proposed. In the case of one or two neighbors, this elevation is more generalized, occurring in both the direction of the neighbors more windward as in the direction of those that were leeward. The presence of three and four neighbors provided situations of more evident protection, especially when the group of buildings were windward from the building being studied.
Observing the shear on the base in direction of the Y axis, the protection effect is verified in most of the neighborhood arrangement proposed, especially in distances D1 and D2, when the buildings are positioned windward. The elevations occurred, more sharply, when the buildings were dislocated laterally as to the wind incidence.
As to the bending around the X axis, the protection was more evident when the neighbors were windward and positioned in distances D1 and D2. The presence of more buildings with distance D3 and D4 in a windward position, on the contrary, sharply elevated the bending. In the other cases subtle bending elevations were observed.
For the bending around the Y axis, strain elevation occurred in a generalized manner. It is also possible to observe discrete protection situations with the neighbors at windward, especially when there were three or more buildings.
Finally, analyzing the torsion strain it is observed that the main alterations will occur with the neighbor positioned more windward to the building studied. The sharper elevations will occur with the presence of up to two neighboring buildings. It was also possible to observe that for situations with more than one neighboring building, they alter the wind flow provoking situations of inverted torsion, when compared to the building isolated, especially when the neighbors were positioned in closer distances. The presence of the three or more neighbors lead to protection situations in a bigger number of wind incidence directions.
From the strain coefficient data collection, the interference factor evaluation was done according to expression 7. The result of the calculation of the interference factor was analyzed through graphs as presented in figure 16. The range between the red lines indicate the limits that are contemplated by [10]. The points where the graph is above or below these limits, indicate situations of strain elevation, and represent an interference rate above the unit.
As to the CAARC standard building, following the recommendations of the Brazilian standards, the limit of distance to the torsion

Table 1
Results for distance D1

Loads	Results	Discarded results	IF within the limits of the code	IF above the code limits		Intensity of IF out of code										
						IF ≤ 1.2			1.2 < IF ≤ 1.4			1.4 < IF ≤ 1.6			IF > 1.6	
				Results	(%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)
FX-D1		13	85	94	52.5	17	18.1	57.0	34	36.2	76.0	24	25.5	89.4	19	20.2
FY-D1		17	89	86	49.1	26	30.2	65.7	25	29.1	80.0	23	26.7	93.1	12	14.0
T-D1	192	50	93	49	34.5	14	28.6	75.4	21	42.9	90.1	7	14.3	95.1	7	14.3
MX-D1		20	92	80	46.5	19	23.8	64.5	23	28.8	77.9	21	26.3	90.1	17	21.3
MY-D1		11	86	95	52.5	11	11.6	53.6	34	35.8	72.4	27	28.4	87.3	23	24.2

Table 2
Results for distance D2

Loads	Results	Discarded results	IF within the limits of the code	IF above the code limits		Intensity of IF out of code										
						IF ≤ 1.2			1.2 < IF ≤ 1.4			1.4 < IF ≤ 1.6			IF > 1.6	
				Results	(%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)
FX-D2	192	20	65	107	62.2	34	31.8	57.6	26	24.3	72.7	33	30.8	91.9	14	13.1
FY-D2		16	52	124	70.5	43	34.7	54.0	53	42.7	84.1	22	17.7	96.6	6	4.8
T-D2		59	70	63	47.4	27	42.9	72.9	25	39.7	91.7	6	9.5	96.2	5	7.9
MX-D2		25	55	112	67.1	43	38.4	58.7	41	36.6	83.2	20	17.9	95.2	8	7.1
MY-D2		14	64	114	64.0	33	28.9	54.5	31	27.2	71.9	31	27.2	89.3	19	16.7

strain is the height of the building “1.00H”. As to the other strains, the distance limits vary from 0.15H to 1.00H. Many researchers have studied the dynamic effects produced by the presence of a neighboring building inside this range of distance. In many of these studies such as [14], [15] and even [16] that even worked with a distance of up to 6.7H, verified the elevation of the dynamic responses studied in each of these studies.

In his studies, [5] evaluated the interference of buildings of different heights, with distances of around .25H to .36H, in other words, all were in the limits advised by the Brazilian standard. As advised by the standard, [5] made a strictly statistical analysis of the strains produced by the action of the wind considering the presence of neighboring buildings. For the directions that were not advised by the Brazilian standards, [5] found elevation rates of up to 2.2 as to torsion, and 2.0 for further strains.

The tables from 1 to 4 present the results of this study, discriminated by the distances D1 and D4 respectively. In the data analyses, we strived for a rate that covered a minimum of 95% of the data collected, in accordance with the trusted interval usually used in engineering. The total quantity of the collected results and the quantity of results that had to be rejected of this universe are shown. The rejected values presented a very high interference factor, therefore, while analyzing the strains it is verified that such results did not reflect with reality. This occurred in the cases where the calculations of the interference factor had values that were to small for the numerator and the denominator, and, moreover, the denominator was much smaller than the numerator, leading to incoherent results. The further results were divided between those that were in accordance with the interference factor limits established by the Brazilian standard, and those that exceed those values. Such limits were considered for all strains, including the torsion strain.

As to the D1 distance, only the torsion strain had more than 95% of valid data bellow the interference factor of 1.6. Further strains, although they didn’t reach this percentage were very close to it where the bending around the Y axis was the most distant one including only 87.3% of its value bellow this factor.

On distance D2, only the shear directed to the X axis and again, the bending around the Y axis, did not reach the trust interval for an interference factor of 1.6. Still, these strains had 91.9% and 89.3% of its results bellow this factor. Analyzing the D3 distance, we observed that the torsion and bending around the Y axis had 94.8% and 92.7% respectively, of its results bellow and interference factor of 1.6. With the buildings positioned on distance D4, only the bending around X and Y presented results bellow the trust interval with 93.8% and 92.9% respectively. The data shows that, as the neighboring buildings were positioned at a longer distance,

Table 3
Results for distance D2

Loads	Results	Discarded results	IF within the limits of the code	IF above the code limits		Intensity of IF out of code										
						IF ≤ 1.2			1.2 < IF ≤ 1.4			1.4 < IF ≤ 1.6			IF > 1.6	
				Results	(%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)
FX-D3	192	15	63	114	64.4	32	28.1	53.7	39	34.2	75.7	35	30.7	95.5	8	7.0
FY-D3		13	53	126	70.4	39	31.0	51.4	54	42.9	81.6	24	19.0	95.0	9	7.1
T-D3		37	76	79	51.0	31	39.2	69.0	24	30.4	84.5	16	20.3	94.8	8	10.1
MX-D3		18	49	125	71.8	45	36.0	54.0	49	39.2	82.2	25	20.0	96.6	6	4.8
MY-D3		14	65	113	63.5	30	26.5	53.4	45	39.8	78.7	25	22.1	92.7	13	11.5

Table 4
Results for distance D4

Loads	Results	Discarded results	IF within the limits of the code	IF above the code limits		Intensity of IF out of code										
						IF ≤ 1.2			1.2 < IF ≤ 1.4			1.4 < IF ≤ 1.6			IF > 1.6	
				Results	(%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)	Accumulated results (%)	Results	(%)
FX-D4	192	15	64	113	63.8	33	29.2	54.8	38	33.6	76.3	35	31.0	96.0	7	6.2
FY-D4		18	44	130	74.7	34	26.2	44.8	62	47.7	80.5	26	20.0	95.4	8	6.2
T-D4		29	76	87	53.4	37	42.5	69.3	26	29.9	85.3	20	23.0	97.5	4	4.6
MX-D4		15	46	131	74.0	36	27.5	46.3	59	45.0	79.7	25	19.1	93.8	11	8.4
MY-D4		12	62	118	65.6	36	30.5	54.4	38	32.2	75.6	30	25.4	92.2	14	11.9

the intensity of the neighbor interference reduced. For distances D3 and D4, if we consider an interference factor of 1.6, it is possible to be in accordance with the trust interval for practically all of the strains studied. This rate is already adopted in some situation proposed by [9]. Although, such rates are 23.1% above the biggest foreseen rate by [10] that is of 1.3. For the distances analyzed in this study, the understanding of [10] is that the interferences produced are already contemplated in the considered roughness of the grounds. Therefore, the draftsman doesn't use any factor for measuring strains, in the absence of a more accurate study in a wind tunnel.

4. Conclusions

The presence of neighboring buildings and other constructions significantly interfere on wind flow and, consequently, on the strains produced by their action, independent from the positioning and the quantity of the neighbors. This presence elevated the acting efforts for the situations that were windward as well as of those that were leeward from the building studied. The strain elevation was observed in all distances proposed in this study. It is worth highlight that the distances studied were higher than the distances suggested by the Brazilian norm for the torsion consideration as well as the shear and bending strains. In an effort to determine parameters for the normalization of the neighboring interference factor, it was not possible to reach the 95% criteria of the contemplated results, nominated trust interval, for many of the proposed placements. The necessity of further studies on this interference factor is evident to improve the recommendations that are operative in the Brazilian standard. Such improvement will positively aid draftsmen in their projects, considering that many have the standard parameters as their only source of information to beacon their decisions during a project elaboration.

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