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Comparative Analysis of the Effects of Wind Load on Tall Reinforced Concrete Buildings for Ordinary Use in Luanda According to ABNT and Eurocode

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Abstract:
Over time, there has been an increase in technologies and research, as well as the development of human experience in science. In this context, the aspect focused on population growth, particularly in the city of Luanda (capital of Angola) has provided an intense exploration of urban spaces, in order to dispose and/or accommodate populations and, consequently, buildings, which tend to become increasingly taller slender and/or flexible. Wind standards are part of the foundation of this process, and must be constantly checked and compared, in order to design, monitor and build safer buildings, resistant to different static and dynamic loads. Thus, with the aim of evaluating the dynamic effects of wind load under tall reinforced concrete buildings, this research work also aims to analyse the static and dynamic behaviour of a tall reinforced concrete building with a typical structural system, in view of the guarantees structural stability and comfort to users given the slenderness that is one of the main characteristics. The analyses in question were carried out based on the Brazilian standards and the Eurocode, comparing the results in order to know which one best adapts to the local characteristics of the Luanda region. With the aid of these norms, it was possible to quantify the dynamic action of the wind, taking into account mainly the (wind) information provided by the National Institute of Meteorology and Geophysics (INAMET). The building has a typical structural system with a trapezoidal configuration, having 27 floors, 18 m long, 23 m wide and a height of 95.2 m, located in Luanda. The numerical model of the building was developed and analysed in the Robot Structural program, where the responses were evaluated. It is noteworthy that the quantification of the dynamic action of the wind by the Eurocode standard presents greater wind pressure compared to the Brazilian standard, making the structure more effortful. Finally, for a better understanding, the comparison between results obtained based on the norms are presented and discussed, and from these, important conclusions are drawn and then recommendations for future research are presented.
Key Word*: Tall buildings; Reinforced concrete; Wind load; Structural analysis; Dynamic effect.*

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I. Introduction

It is known that natural phenomena affect countless buildings every year. In the particular case of the wind phenomenon, researchers and/or structural engineers must design structural systems capable of withstanding dynamic wind loads without causing substantial damage to buildings. In this context, it can be said that when a structural system does not meet safety requirements in terms of stability and comfort for users, it means that it is not suitable for occupation. A residential building must be able to provide security to its users during its useful life.

Winds are a horizontal dynamic load that generally affects perpendicularly to the contact surfaces of the works[1,2,3,4]. When speeds are too high, they can cause serious structural damage to the elements, due to the thrust and suction they generate. Depending on the characteristics of its climate, each country must have a standard for designing buildings that are safe and resistant to the dynamic action of wind[5,6,7]. The Brazilian and European wind standards define how to calculate the static and dynamic components of the wind load, depending on the region and type of structure. And in the particular case of Angola, however, there is no standard for calculating wind loads on buildings. For this reason, until now, these standards have been used to design and build buildings in the country. However, the standards adopted in the referred standards NBR6123[8] and EC 1-1-4[9] are being compared in order to adopt only one of them in the country, subsequently developing a specific wind calculation standard of Angola, this after several investigations advance and experience in this sector.

With the technological development, it becomes possible to simplify super complex problems, this with the help of computer programs that in turn facilitate the structural engineering sector, in the process of obtaining results of the structural behaviour caused by the wind action, and also facilitates in achieving the most economical structural alternatives.

The internationally known high-rise building arises from the need to make the most of space, so that in little space it is possible to build a building that can accommodate several users. In this regard, the city of Luanda is no different, as for some time now it has begun to notice the construction of many tall buildings, which are also considered slender buildings, where height is more relevant than their horizontal dimensions. And according to Medeiros, Júnior & Brito[10] "in very tall buildings, the force of the wind becomes an agent that causes instability in structures. With this, it is necessary to know how reinforced concrete structures behave as the height of buildings increases and their slender index and what measures must be taken to combat the acting forces". Because they can cause significant horizontal displacements and, consequently, excessive bending moments, which are called dynamic effects, which can lead to ruins in buildings[11,12].

In order to determine the wind speed, it is necessary to analyse the values obtained from meteorological observations, usually made at airports, with a representative height of ten meters, with the tests being carried out over a long period".

The forces caused by the wind on a building generate stresses on its structure, which can be compromised if it has not been designed to absorb the efforts. It then becomes necessary to consider the efforts caused by the action of the wind during the structural design of buildings so that safer buildings are built. In order to consider the action of the wind during the design of a building, it is necessary to have more specific knowledge about the wind-structure interaction[13,14,15]. The loads caused by the action of the wind depend on four parameters, as shown in Fig.s 1 and 2, which are: I) Architectural form of the building, II) Structural asymmetry, III) Wind incidence angle and IV) Interference effects caused by the neighbourhood.

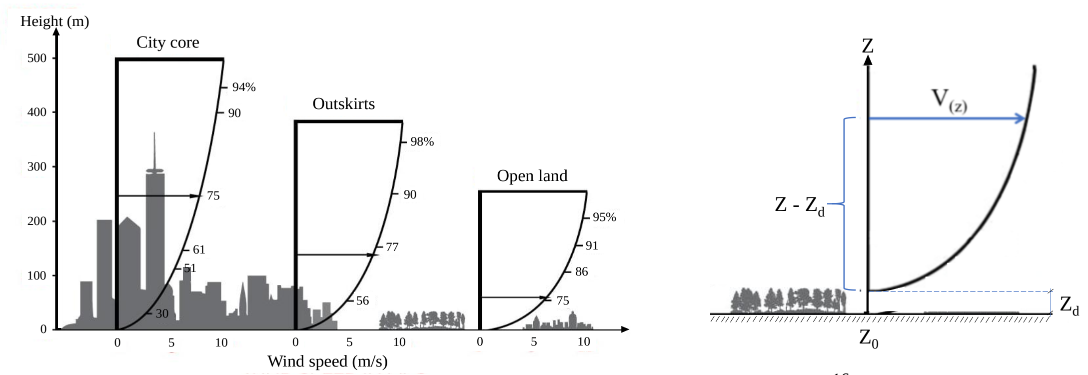


Figure 1. Wind variation as a function of height (Adapted[16]).

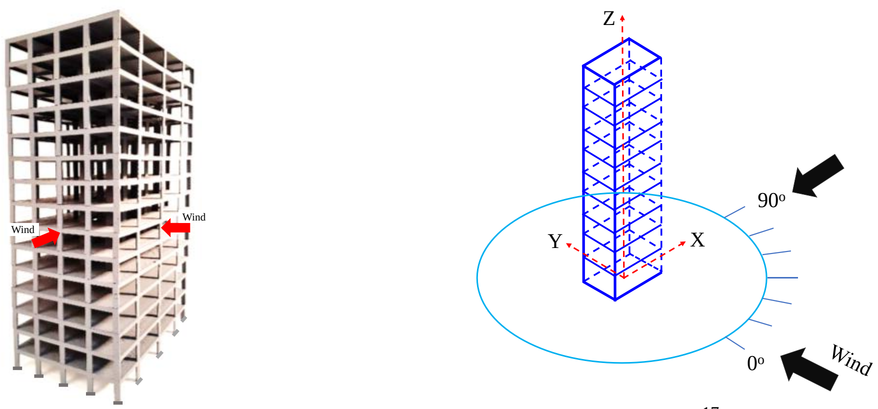


Figure 2. Angle of incidence of the wind load under the building (Adapted[17]).

However, the objective of the present work is to carry out the wind load analysis according to the NBR6123[8] and EN 1-1-4[18] standards applied to a twenty-story reinforced concrete office building structure. seven floors, located in the city of Luanda, specifically in the municipality of Luanda on Avenida de Portugal next to Banco BAI. The building in question consists of a structural system composed of beams, columns, slabs and eardrums, whose structural analysis was developed with the help of finite element software called "Robot Structural". Thus, the loads of the static and dynamic component of the wind in the building were calculated through the two standards, and then the results obtained based on the two standards were compared.

II. Methodology

Evaluation method for evaluating wind loads on tall buildings

The present research work was carried out with the objective of evaluating the wind loads in a tall and slender reinforced concrete building located in the center of the city in the capital of Angola. In order to fulfill the objectives, a descriptive type of research was carried out and as a research technique, the comparison of two standards from different regions/contexts was adopted as a case study, the NBR6123[8] and EN 1-1-4[18] that support studies focused on wind load in structural systems using local data from the city of Luanda. The intended comparison consists of the need to find and/or reveal which of the standards is more viable when applied in the context of Angola, particularly in the province of Luanda (capital).

The characteristic parameters of the wind were obtained according to the prescriptions of the NBR6123[8] and EN 1-1-4[18] standards and the values of the local data of the city in question. With the intention and the need to guard against possible future catastrophes, taking into account the possible negligence and poor quantification of the incident wind loads in our country, it is necessary to collect data on speeds occurring in the city of Luanda, arranged by the National Institute of Meteorology and Geophysics (INAMET), which is the body responsible for controlling incident speed at the level of all provinces in Angola, using a sophisticated radar.

As already mentioned, in this research work, the Robot Structural finite element software was used to evaluate the dynamic wind load, which in many cases are also evaluated based on the use of a wind tunnel, instrument this one that is found and used in the laboratory of the institution of affiliation of the authors in question (ISPTEC). Finally, based on the software in question, a comparison of the results obtained according to the norms is carried out.

Wind load consideration

For the modelling of the wind that affects the structure, the force of the pressure gradient was considered, which is known as the horizontal component of the pressure force. As for the centripetal acceleration, it was possible to observe that the bodies that move in the analysis process follow the curved path according to the acceleration, which is directed towards its center rotation that is mathematically expressed according to Eq. 1, where m is the air mass in motion, V the wind speed and r the radius of curvature.

$$c = -m \times \frac{V^2}{r} \tag{1}$$

Wind direction

In addition to considering the studies on the physical characteristics of the wind, in the process of designing the reinforced concrete structure for safety against the influence of the wind, different wind speeds and directions were also considered. In this context, wind directions are considered to be horizontal. To carry out the structural calculation, initially the wind was considered at 0^o and then at 90^o of the structure (Fig. 2).

Modelling the dynamic force of the wind load

Modelling according to ABNT 6123standard

Knowing that the turbulence generated by buildings causes changes in the average wind speed (V_m), it is possible to conclude that these necessarily cause the phenomena known as dynamic effects that are superimposed on the static effects caused by the average speed. In the case of static forces, these were determined taking into account the location where the building is located, and the basic wind speed (V_0) which is exceeded on average once every 50 years, above 10 m from the ground in the direction horizontal NBR6123[8]. Where, in turn, the characteristic wind speed (V_k) was calculated by multiplying the basic speed with the factors of: topography (s_1), terrain roughness (s_2) and degree of safety (s_3), as expressed in Eq.s 2 and 3. Where the b and p factors are the meteorological parameters listed in section 6 of the standard NBR6123[8], and the gust factor (F_r) which always corresponds to category II. However, V_k allows to determine the dynamic pressure (q) expressed mathematically by Eq. 4

$$V_k = V_0 \times S_1 \times S_2 \times S_3 \qquad S_2(Z) = b \times F_r \times (Z/10)^P \qquad (2)$$

$$q = 0{,}613 \times (V_k)^2 \qquad (3)$$

The drag force $F_a$is obtained based on Eq. 4 where Ca is the drag coefficient, and A_e corresponds to the effective area of the building, which translates as the plane perpendicular to the wind direction. Highlighting that Ca is given by R_e = 70000 V_K L_1, where V_k is given in m/s and L_1 in m[8].

It should be noted that the level of probability and the useful life adopted were considered adequate for normal buildings intended for housing, offices, etc. however, given that there is no specific standard on building safety or corresponding indications in the structural standard, the minimum values of s3 are shown in Tab. 1 of the building safety category.

Table no 1: Building safety categories (Adapted [8]).

Group	Description	S_3
1	Buildings whose total collapse could affect the safety or possibility of rescuing people after a destructive storm 9hospitals, fire stations and security forces, communication centers, etc.)	1,1
2	Buildings for hotels and residences. Buildings for commerce and industry with a high occupancy factor	1,0
3	Buildings for hotels and residences. Buildings for commerce and industry with a high occupancy factor	0,95
4	Fences (tiles, glass, fence panels, etc.)	0,88
5	Temporary buildings. Structures of groups 1 to 3 during construction	0,83

Regarding the dynamic responses, the simplified calculation method was applied considering the structure with a height below 150 m. However, by the simplified method, only the fundamental mode of vibration was retained, leading to errors of 10%, which are acceptable according to NBR6123[8]. Thus, the continuous function that is related to the terrain also called pressure q(z) is calculated based on Eq.s4 and 5. Where, ξ is the dynamic amplification coefficient, Z_r is the reference height and q_0 is the pressure in the reference height.

Therefore, the determination of the s3 factor to be used in the wind speed equation acting on the structural system, the value will be indicated in group 2 (see Tab. 2), which corresponds to a factor equal to 1.

$$\bar{V}_p = 0{,}69 \times V_0 \times S_1 \times S_3 \qquad \bar{q}_0 = 0{,}613 \times \tilde{v}_p \qquad (4)$$

$$q_{(z)} = \bar{q}_0 b^2 [\left(\frac{Z^{2P}}{Zr^{2P}}\right) + \left(\frac{h^p}{Zr^p}\right)\left(\frac{Z^\gamma}{h^\gamma}\right)\frac{1+2\gamma}{1+\gamma+p}\xi] \qquad (5)$$

Regarding the pressure coefficients (Δ_p), the wind force essentially depends on the pressure difference on opposite sides of the parts of the building to be analysed. And these coefficients, however, are given for external and internal surfaces of the structural system and expressed by Eq.6.

$$\Delta_p = \Delta_{pe} - \Delta_{pi} \qquad \Delta_p = (c_{pe} - c_{pi}) \times q \qquad (6)$$

Where, the positive values of the external or internal pressure coefficients correspond to overpressures and negative values correspond to suctions. In this context, when the pressure variation is positive, the effective pressure is indicated in the direction of an external overpressure, and when it is negative, it indicates an effective pressure in the direction of an external suction. Then, in Eq.7, the force of the wind that falls on the flat element of the building in the perpendicular direction is presented mathematically.

$$F = F_e - F_i \qquad F = (c_e - c_i) \times q \times A \qquad (7)$$

As already mentioned, the dynamic analyzes in the investigated structural model were developed with the aid of the finite element program, where the wind was simulated considering loads that do not act in the negative direction of the global X axis, based on the synthetic wind method. Ten loading series were generated with the appropriate probabilistic treatment and applied to the numerical model.

Modeling according to EN 1-1-4

The dynamic actions of the wind on buildings must be determined taking into account both the external pressures and the internal pressures due to the wind. This subitem presents the process for determining the basic wind pressure on the structural system. As in the previous sub-item, to determine the wind speed, wind direction and seasonality coefficients were necessary, according to Eq.s8 and 9.

$$V_b = C_{dir} \times C_{season} \times V_{b,0} \qquad q_p(z) = [1 + 7 \times I_v(z)] - p \times V_{2m}(m) = c_e(Z) \times q_b \tag{8}$$

$$c_e(z) = \frac{q_p(z)}{q_b} \qquad q_b = \frac{1}{2} \times p \times (V_b)^2 \tag{9}$$

The pressure exerted by the wind on the exterior surfaces of buildings which is expressed by Eq. 10 (on the left). And the pressure exerted on the interior surfaces are obtained through Eq. 10 (on the right).

$$W_e = q_p(Z_e) \times C_{pe} \qquad W_i = q_p(Z_i) \times C_{pi} \tag{10}$$

The forces exerted by the wind on the construction as a whole or on one of its components are determined from the force coefficients and pressures on the surfaces. And yet, the force exerted by the wind is expressed by Eq. 12, where the forces $F_{w,e}$, $F_{w,i}$ and F_{fr} are added vectorially. Where F_w, e represents the external forces, $F_{w,i}$and Ffr frictional forces (see Eq. 11 and 12).

$$F_w = C_s \times C_d \times \sum C_f \times p_p(Z_e) \times A_{ref} \qquad F_{w,e} = C_s \times C_d \times \sum w_e \times A_{ref} \tag{11}$$

$$F_{w,i} = \sum w_i \times A_{ref} \qquad F_{fr} = C_{fr} \times q_p(Z_e) \times A_{fr} \tag{12}$$

In the case of wind friction effects on the surface, these are ignored when the total area of all surfaces parallel to the wind is equal to or less than 4 times the total area of all outer surfaces perpendicular to the wind. The $c_s\, c_d$ coefficient can be determined based on the height of the building and the natural frequency.

III. Investigated Structural Model

The building adopted as a case study in this research corresponds to an office building, whose structure consists of pillars, beams and reinforced concrete slabs (Fig. 3). The structural concrete used in the model has compressive strength (f_{ck}) equal to 35 MPa, specific weight (γ_c) of 25 kN/m³, modulus of elasticity (E_{cs}) equal to 25 GPa and Poisson coefficient (v) of 0, two. Permanent loads of 1.0 kN/m^2 and usual accidental design loads corresponding to 1.5 kN/m^2 were added to the slabs of all floors. Furthermore, a total weight of masonry was evenly distributed over the slabs of 2.8 kN/m^2.

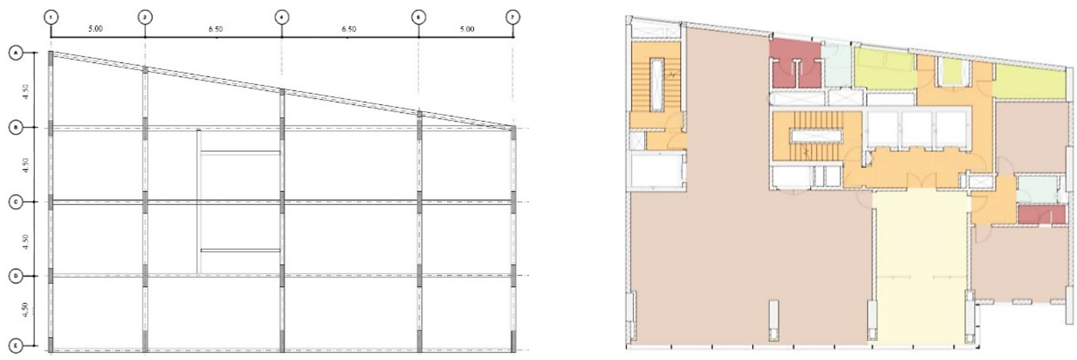


Figure3. Reference floor plan of the structural model of the building - Units in meters.

The model has dimensions in plan of 23.0 m long and 18.0 m wide, as shown in Fig. 4. It has 27 floors, ceiling height of 3.5 m, total height of 95.2 m. The structural system features massive slabs with a thickness equal to 25 cm, beams with sections of 30x60 cm and pillars with sections of mostly 50x80 cm. It is important to point out that for the study of the action of the wind in tall buildings, the height of the building is the biggest constraint when the pressure is exerted on the building under study.

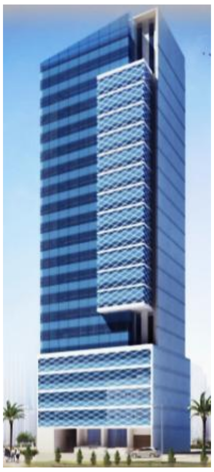


Figure 4. Isometric front view of the building under study.

It is worth noting that the standards used to quantify wind actions recommend a 50-year study to define the basic speed of a region. In the present case, data were obtained from INAMET only for a period of 7 years, which are from 2011 to 2017, respectively. However, for better data filtering, without having to assume a standard value, the highest values were identified, starting from values equal to and greater than 30 km/h, this time the average was calculated to obtain the value of the speed used, for the quantification of wind action in the standards.

IV. Finite Element Modelling

In the numerical modelling of the model, beams and columns are represented by three-dimensional finite elements, where bending and torsion effects are considered. For this, the beam-type finite element is used, a uniaxial element composed of two nodes and each node with six degrees of freedom (translation in X, Y and Z and rotations in X, Y and Z). In this case, the advantage of the beam element consists in the possibility of allowing its nodes to be distanced from the centroid axis of the beams, since the slab and the beam are not positioned on the same axis. And the eccentricity is considered in the modelling process, as it directly affects the values of the natural frequencies of the structural system.

In the case of slabs, these are simulated using finite elements of the shell type, which is defined by four nodes with six degrees of freedom at each node (three translational and three rotational nodes in the X, Y and Z directions). And the complete interaction between the slab and the beams were considered in the analysis, that is, the nodes were coupled to prevent the occurrence of a possible landslide. And as for the concrete material, it is considered that it has an elastic behaviour. As can be seen in Fig. 5, the investigated model has 105,252 nodes, 145,880 elements and 99,5246 degrees of freedom.

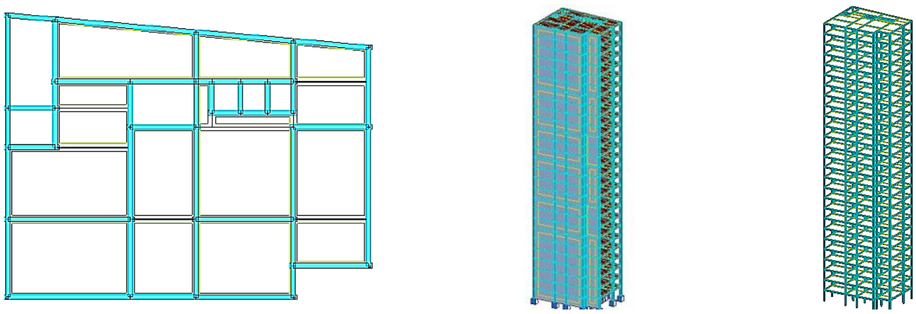


Figure 5. Finite element models of the building developed in Robot Structural.

V. Dynamic Analysis in the Structural Model

From the Robot Structural finite element program, a dynamic analysis was carried out on the model investigated in which the wind was simulated considering the loads that act in the negative direction of the global X axis. floor, located at elevation 95.2 m, as shown in Fig. 6. Thus, the results obtained were compared with the limit values proposed by design standards and recommendations.

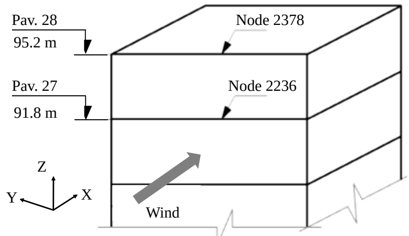


Figure 6. Position of building dynamic response evaluation nodes.

Quantification of wind actions according to NBR6123

Next, the necessary calculations are presented in summary form, for the determination of the pressures acting on the surface of the structural system of the building, according to the Brazilian norm NBR6123[8].

General data for the calculation process:

h (m)	Category V	a (m)	b (m)
95,2	Classe B	23,00	18,00

Group 2- coefficient referring to the useful life time

S_1	Vo (m/s)	$S_2(z) = b\ Fr\ (z/10)^p$ b	p	Fr	z (m)	$S_2(z)$
1	9,68	0,58	0,26	0,77	95,2	0,80

|Characteristic wind speed	Pressure resulting from the static method	Drag force global component of downwind force
$V_k = V0\ S1\ S2\ S3$	$q = 0.613\ (Vk)^2$	$F_a = Ca\ q\ Ae$
V_k (m/s)	q (kN/m^2)	F_a (kN)
7.74	0.037	62.77

Calculation of dynamic response simplified method

$V_p = 0.69\ V_0\ S1\ S3$	$q_0 = 0.613\ (Vp)^2$						
V_p (m/s)	q_0 (kPa)	Zr (m)	h (m)	γ	ξ	P	b
6.68	0.0274	10	95.2	1.2	1.3	0.31	0.5

***Quantifications of wind actions according to* EN 1-1-4**

Next, the necessary data are presented in summary form, for the determination of the pressures acting on the surface of the structural system of the building, according to EN 1-1-4[18].

Definition of dynamic reference pressure

Plan dimension	Total height	Ground	Wind speed (INAMET, 2020).	Local speed	Building with a height of less than 100 m	
A (m^2)	h (m)	Category	V_0 (km/h)	$V_{b,0}$ (m/s)	C_{dir}	C_{season}
18.00×23.00	95.2	IV	34.73	9.68	1.00	1.00

$$V_b = C_{dir} \times C_{season} \times V_{b,0} \qquad V_b = 1 \times 1 \times 9.68 = 9.68\ m/s$$

$$q_b = \frac{1}{2} \times \rho \times V_b^2 \qquad q_b = \frac{1}{2} \times 1.25 \times 9.68^2 \times 10^{-3}\ kN/m^2$$

$$q_b = 5.9 \times 10^{-2}\ kN/m^2$$

In the case of data for determining the average wind taking into account the height of the building, the respective mathematical equations, as such, as well as the steps for obtaining the corresponding values, are immediately followed.

$$C_r(z) = K_r \times ln\left(\frac{Z}{Z_0}\right) \qquad C_0(z) = 1.00 \qquad K_r = 0.234$$

$$V_m(z) = C_r(Z) \times C_0(Z) \times V_b$$

$$I_v(z) = \frac{\sigma_v}{V_m(z)} \qquad \sigma_v = K_r \times V_b \times K_1 \qquad \sigma_v = 2.265\ kN/m^2$$

Dynamic response due to wind loads

In this sub-item, the results are presented in the form of tables based on the NBR6123[8] and EN 1-1-4[18] standards. In Tab.2 and 3 to 6, the values of the peak dynamic pressure results are shown as a function of the height of the building in the direction corresponding to 0 and 90 degrees.

Table no 2: Result of peak dynamic pressure as a function of height according to NBR6123[8], em 0^0 and 90^0.

Reference height	Peak dynamic pressure to 0 degree[$q_{p(}Z)$ (kPa)]	Peak dynamic pressure to 90 degree[$q_{p(}Z)$ (kPa)]
18	0.012	0.013
32.8	0.018	0.018
47.6	0.023	0.022
62.4	0.029	0.026
77.2	0.034	0.030
95.2	0.040	0.040

In the following tables (Tab.3 and 6), the results are represented in terms of quantification of the dynamic actions of the wind based on the standard EN 1-1-4[18], at 0 and 90 degrees. Knowing that the face of the building facing the wind has a length of 18 m (direction corresponding to 0^0), the respective values are presented.

Table no 3: Result of peak dynamic pressure as a function of height according to EN 1 1-1-4[18], in 0^0.

Height (m)	$C_r(z)$	V_m(m/s)	I_v	$q_{p(z)}$ KPa
18	0.676	6.54	0.346	0.092
32.8	0.817	7.91	0.286	0.117
47.6	0.904	8.75	0.259	0.135
62.4	0.967	9.36	0.242	0.148
77.2	1.02	9.87	0.229	0.159
95.2	1.07	10.36	0.219	0.170

Table no 4: Peak dynamic pressure results as a function of height according to EN 1-1-4[18], in 0^0.

Height (m)	A_{ref} (m^2)	$q_{p(z)}$KPa	Fw(kN)	We(kpa)
18	324	0.092	53.65	-0.111
32.8	590.4	0.117	124.34	-0.141
47.6	856.8	0.135	208.20	-0.162
62.4	1123.2	0.148	299.22	-0.178
77.2	1389.6	0.159	397.71	-0.191
95.2	1713.6	0.170	524.36	-0.204

Table no 5: Peak dynamic pressure results as a function of height according toEN 1-1-4[18], in 90^0.

Height (m)	$C_r(z)$	v_m(m/s)	I_v	$q_{p(z)}$ (kPa)
23	0.734	7.12	0.318	0.102
35.3	0.834	8.073	0.281	0.121
47.6	0.904	8.751	0.259	0.135
59.9	0.958	9.273	0.244	0.146
72.2	1.001	9.690	0.234	0.155
95.2	1.07	10.36	0.219	0.170

Table no 6: Peak dynamic pressure results as a function of height according toEN 1-1-4[18], in 90^0.

Height (m)	A_{ref} (m^2)	$q_{p(z)}$KPa	Fw(kN)	We(kpa)
23	529	0.102	97.124	-0.122
35.3	811.9	0.121	176.832	-0.145
47.6	1094.8	0.135	266.036	-0.162
59.9	1377.7	0.146	362.10	-0.175
72.2	1660.6	0.155	463.307	-0.186
95.2	2189.6	0.170	670.017	-0.204

Comparison of results obtained from quantification based on NBR6123 and EC1-1-4

Dynamic responses in terms of maximum horizontal pressure values on the surface perpendicular to the investigated wind load incidence.

After obtaining the quantifications of the dynamic actions based on the two standards, it is noted that the action of the wind in the building of the case study using the EN1-1-4[18], is greater in relation to the quantification made from NBR6123[8], as can be seen from the results described in Tab.7.

It should be noted that in the case of using NBR6123[8], the lowest speed presented by the isopleths was used, which corresponds to 30 m/s. Whereas in the following case, ie using EN 1-1-4[18]the basic speed of 27 m/s was used. And in the case of the data provided by INAMED (National Institute of Meteorology and Geophysics), an average of the speeds was performed as such, resulting, therefore, in 9.68 m/s. Next, in Fig.7, the pressure results are shown in graph form, taking into account the different basic velocities in the direction corresponding to 0 degrees.

Table no 7: Results obtained based on the different basic wind speeds in 0^0.

Height (m)	Dynamic peak wind pressure (9.68m/s)		Dynamic peak wind pressure(30 m/s)	Dynamic wind pressure (27 m/s)
	NBR6123[8]	EC1-1-4	NBR6123[8]	EC1-1-4
18.0	0.092	0.012	0.712	0.111
32.8	0.117	0.018	0.913	0.170
47.6	0.135	0.023	1.048	0.224
62.4	0.148	0.029	1.148	0.275
77.2	0.159	0.034	1.234	0.325
95.2	0.170	0.040	1.321	0.383

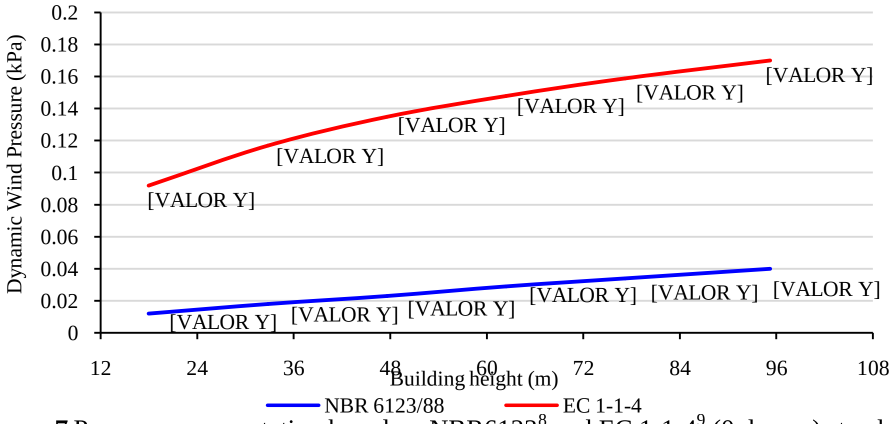


Figure 7. Pressure representation based on NBR6123[8] and EC 1-1-4[9] (0 degree) standards.

Table no 8: Results obtained based on the different basic wind speeds in 90^0.

Height (m)	Dynamic peak wind pressure (9.68m/s)		Dynamic peak wind pressure (30 m/s)	Dynamic wind pressure(27 m/s)
	NBR6123[8]	EC1-1-4[18]	NBR6123[8]	EC1-1-4[18]
23	0.102	0.013	0.794	0.132
35.3	0.121	0.018	0.940	0.180
47.6	0.135	0.022	1.047	0.224
59.9	0.146	0.026	1.132	0.267
72.2	0.155	0.030	1.205	0.308
95.2	0.170	0.040	1.321	0.383

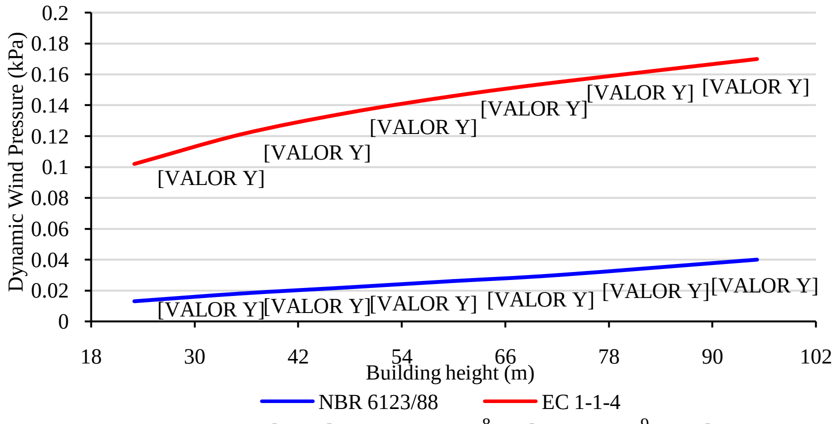
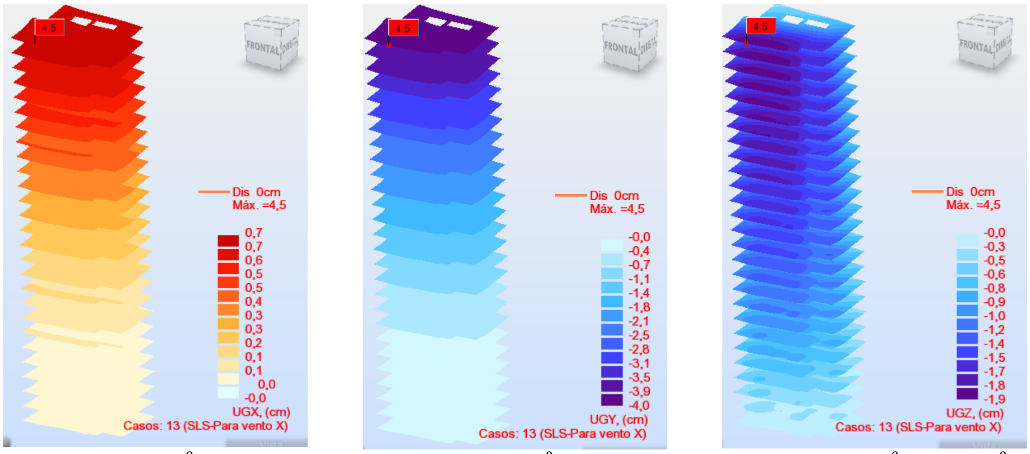


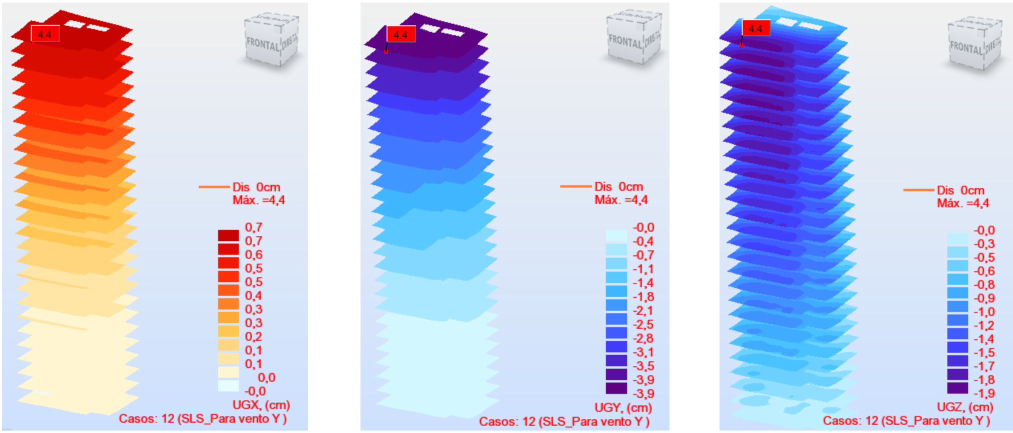
Figure 8. Pressure representation based on NBR6123[8] and EC 1-1-4[9] (90 degrees) standards.

The results of the dynamic behaviour in terms of displacements and buckling of the structural system based on the aid of the finite element software taking into account the application of the two standards and the incidence of wind loads in the 0 degree and 90 degrees, are shown in Fig.s 9 to 12.



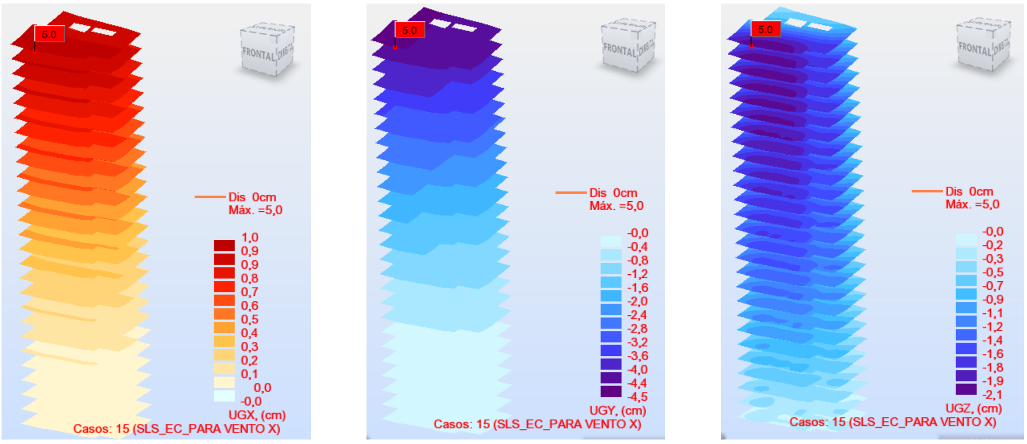
Shift in X in the 0^0 direction　Shift in Y in the 0^0 direction　Shift in X in the 0^0 direction 0^0

Figure 9. Displacement in X, Y and Z considering the standard NBR6123[8].



Shift in X in the 90^0direction　Shift in Y in the 90^0direction　Shift in Z in the 90^0direction

Figure 10. Displacement in X, Y and Z considering the norm NBR6123[8].



Shift in X in the 0^0directio　Shift in Y in the 0^0directio　Shift in Z in the 0^0directio

Figure 11. Displacement in X, Y and Z considering the norm EN 1-1-4[18].

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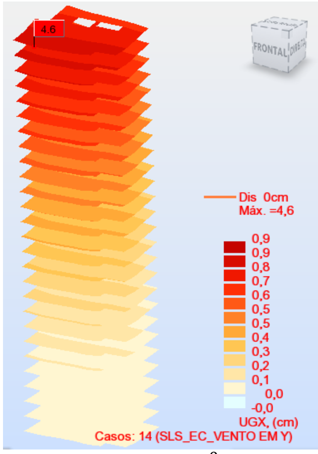
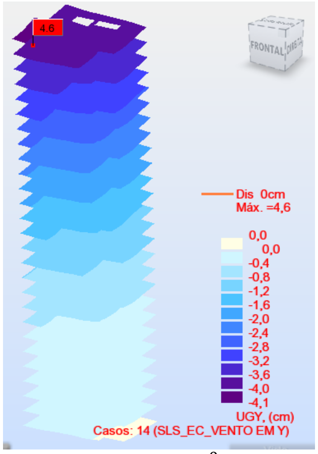
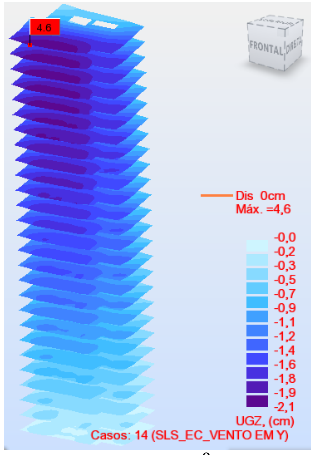


Shift in X in the 90^0direction



Shift in Y in the 90^0direction



Shift in Zin the 90^0direction

Figure 12. Displacement in X, Y and Z considering the norm EN 1-1-4[18].

The Tab.9 presents the maximum displacement and buckling values obtained in the X, Y and Z directions respectively, observed in the investigated building. Tab.s 10 and 11 show the bending moments caused by the beam members and the shear caused by the columns, depending on the combination made for the Ultimate Limit State (ELU) based on the wind.

Table no 9: Displacement results based on maximum ELS and buckling combination.

Direction (angle)	Direction	Displacement (cm)		Maximum buckling (cm)	
		NBR6123[8]	EC1-1-4	NBR6123[8]	EC1-1-4
X (0^0)	X	0.70	1.00	4.50	5.00
	Y	-4.00	-4.50		
	Z	1.90	-2.10		
Y (90^0)	X	0.70	0.90	4.40	4.60
	Y	-3.90	-4.10		
	Z	-1.90	-2.10		

Table no 10: Results of maximum internal forces: bending moment and shear force.

Direction (angle)	Orientation of efforts	Bending moments My (kN.m)	Transverse efforts Vx (kN)	Bending moments My (kN.m)	Transverse efforts Vx (kN)
		NBR6123[8]		EC 1-1-4[9]	
X (0^0)	X	0.00	8646.97	0.00	9202.26
	Y	235.00	0.00	248.77	0.00
	Z	0.00	0.00	0.00	0.00
Y (90^0)	X	0.00	8638.57	0.00	9156.81
	Y	235.76	0.00	252.60	0.00
	Z	0.00	0.00	0.00	0.00

The maximum moments are given as a function of the most unfavourable sign, considering the maximum values of the moment: those with a negative sign given by the analysis made using the software.

Table no 11: Results of minimum internal efforts: bending moment and transverse effort.

Direction (angle)	Orientation of efforts	Bending moments My (kN.m)	Transverse efforts Vx (kN)	Bending moments My (kN.m)	Transverse efforts Vx (kN)
		NBR6123[8]		EC 1-1-4[9]	
X (0^0)	X	0.00	-98.30	0.00	-105.29
	Y	-325.59	0.00	-344.24	0.00
	Z	0.00	0.00	0.00	0.00
Y (90^0)	X	0.00	-98.16	0.00	-105.06
	Y	-326.80	0.00	-350.29	0.00

	Z	0.00	0.00	0.00	0.00

As shown in the tables above, one can clearly observe the differences in wind pressure as a function of height and the standards used, both in one and the other direction respectively X and Y. In this context, the smallest displacements are observed in the X axis, this, even being the smallest side of the areas due to the fact that in this axis the greater rigidity of the structure reduces the efforts of the wind load (in this direction).

The efforts originated by the wind load were obtained from the combination of the actions of the ELU (Ultimate Limit State), these efforts, for a better illustration, the maximum and minimum values of the efforts (transverse and bending moments), the highest values presented in the tables, are from the combination made by the wind load according to EN 1-1-4[18], due to the higher wind pressures presented in Tab. 10. The maximum shear forces are observed in the pillars of the ground floor having considering that all loads in the building are transmitted and thus efforts can be distributed in the foundations.

The highest bending moment is found in the beams on the 21st floor, given the incidence of the wind load acting perpendicularly to the beam element on the upper floors. This is because the wind pressure is greater on the floors above, as wind pressure increases with height.

VI. Conclusions and recommendations

The present research work investigated the behaviour of a structural model, of a tall reinforced concrete building, under the dynamic action not of the wind, aiming to verify which standard is the best for its application in Luanda. The numerical modelling of the building under study was carried out using the Robot Structural program, based on the use of basic discretization techniques, via the finite element method.

Regarding the results obtained in the dynamic analyses, it was verified that the investigated structural model subjected to the action of the wind load presented maximum horizontal displacements of the order of 4.50 cm, maximum buckling of 5.00 cm, maximum bending moment of 252,60 kN.m and shear force of 9202.26 kN.

The smallest displacements are given on the X and Y axis for the Brazilian standard, even though it is the side with the smallest area, this was due to the fact that in this axis there is a structural wall, which reduced the effects of the wind load in this direction.

As previously mentioned, the efforts caused by the wind load on the structure are obtained from the combination of ELU (Ultimate Limit State) actions. These efforts are shown as results in the tables for better illustration. These tables show the maximum and minimum values of efforts (bending moments and shear forces), the highest values presented in the tables are from the combination made by the wind load based on EN 1-1-4[18], due to at higher wind pressures as shown in Tab. 10.

However, the highest bending moment is found in the beams of the twenty-first floor, because of the wind pressure, since in these cases the beams also support horizontal loads, thus causing second order moments, causing greater bending moments in the floor's superiors.

Finally, attention should be drawn to the use of the standard EN 1-1-4[18], due to the parameters it considers and the precision it takes into account. Therefore, structural designers must be warned (for the use of the standard in question), as this fact may substantially alter the stability of the structural system.

Regarding the continuity of the research, the authors intend in the next works, in the numerical models, to consider the effects of the masonry and also the effect of the soil-structure interaction, studying what influence these aspects have on the dynamic response of the buildings.

<u>As recommendations, the authors suggest that:</u>

i) INAMET must carry out a more precise survey of the action of the wind so that in a period of 50 years, studies are obtained focused on the basic wind speed, as recommended in the norms.

ii) Use of bracing in or in both directions, in order to reduce the dynamic action of the wind on the structural system.

iii) Do not use the American standard for the analysis of a tall reinforced concrete building to avoid oversizing the building. That is, to avoid making projects more expensive, since for the region in question, the incidence of wind is very low, with a base wind speed, which in the American standard is defined as equal to 180km/h, which for the reality of Luanda is an excessively high value.

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