Wind Loads and the Wind Environment in the Philippines: Recent Developments in 2006

Benito M. Pacheco[a,b], Ronwaldo E. R. Aquino[a], William T. Tanzo[b], and Nicetos E. Rosaria[c]

[a] *PICE Committee on DMAPS and DQRP, Philippines*
[b] *Vibrametrics, Inc., Philippines*
[c] *SKM Consulting Philippines*

ABSTRACT: Earlier papers, presentations, research works, and reports related to wind loading and/or wind environmental issues in the Philippines are first summarized. Recent developments in 2006 related, first, to dynamic wind loading of lattice towers, and second, to damages due to the passage of Typhoon Milenyo (International Name: Xangsane) are next presented. Lastly, some wind environment issues in the Philippines are briefly discussed.

KEYWORDS: Philippines, APEC-WW, wind loading, wind environment, Typhoon Milenyo, typhoon wind damage

1 INTRODUCTION: PREVIOUS REPORTS

Delegates from the Philippines have attended the first two, previous APEC-WW meetings (Workshop on Regional Harmonization of Wind Loading and Wind Environmental Specifications in Asia-Pacific Economies) held in Japan in November 2004, and in Hong Kong in December 2005. In the country's report presented in 2004, the 2001 National Structural Code of the Philippines (NSCP-2001), including the new wind zone map which featured 3-second gust basic wind speeds, was introduced, and its history was briefly discussed.

The country report presented in 2005 summarized a paper presented at an earlier National Convention of the Philippine Institute of Civil Engineers (PICE), which in turn was based on an earlier comprehensive report submitted to the Center of Excellence (COE) Program for Wind Effects on Buildings and Urban Environment, at the Tokyo Polytechnic University in Atsugi, Kanagawa, Japan. The 2005 country report discussed the need for "typhoon engineering" in the Philippines, related efforts by engineers, available data, various related research work in the Philippines, and areas for improvement in typhoon disaster mitigation efforts in general and in the NSCP-2001 wind loading provisions in particular. A highlight of the 2005 country report was the presentation of damages due to Typhoon Unding (International Name: Muifa) which made landfall in the Philippines in November 2004.

A paper aiming for cooperative work with researchers from other related fields, similar to the country's 2005 report, was presented at the 1st National Meteorological-Hydrological Convention, organized by the Philippine Meteorological Society also in December 2005.

In the 2005 country report presentation, a note was also made on wind environmental issues in the Philippines. Particularly, it was mentioned that, (a) certainly, outdoor air pollution is a growing problem in the rapidly urbanizing greater metropolitan Manila area and that in line with this, the government has enacted the Clean Air Act which regulates pollutant emissions in to the atmosphere; (b) there are no reported cases of indoor air pollution, and as such no research work related to this field, including natural/cross ventilation studies, is known to have been conducted; and (c) there are no reported cases of injuries or damage due to strong pedestrian-level winds in highly urbanized business districts, and likewise, no research related to this field is known to have been conducted.

The next two chapters of the present country report are recent developments related to wind loading issues in the Philippines. Chapter 2 discusses a procedure for accounting for dynamic wind effects in the structural design of lattice towers in the Philippines that is proposed for use with the NSCP-2001. Chapter 3 presents selected photographs of damages due to the passage of Typhoon Milenyo (International Name: Xangsane), and discusses relevant issues in current structural design practices for extreme winds that are re-raised in the aftermath of the typhoon.

The last chapter of the present country report briefly "updates" some of the issues noted in the earlier country report presentation related to the wind environment mentioned above.

2 DYNAMIC WIND LOADING OF LATTICE TOWERS: PROPOSED SUPPLEMENTARY MATERIAL TO THE NSCP-2001

In the previous country report, a new, modified gust effect factor[1] (GEF) formulation, to be used for the dynamic wind loading of various structure types, including buildings and lattice towers, was one identified improvement to the NSCP-2001 wind loading code provisions. This identified improvement should consider recent developments in GEF formulations, including mode shape corrections, and applicability to certain structure types. One provision lacking in the NSCP-2001 is a GEF formulation specifically for lattice towers. The current version of the code only presents a rigid-structure GEF value for structures with natural frequencies greater than or equal to 1 Hz, and that a flexible-structure GEF should be "obtained by a rational analysis that incorporates the dynamic properties of the main wind-force resisting system" for structures with natural frequencies less than 1 Hz, or aspect ratios (ratio of height to least horizontal dimension) greater than 4.

Meanwhile, lattice towers in the Philippines have aspect ratios of around 7 on average. A literature search has thus been conducted for a GEF formulation that is applicable to lattice towers, and compatible with the NSCP-2001. It has also been identified that estimates of dynamic properties of lattice towers are necessary parameters to GEF formulations, and as such, suggestions are also given. The discussion presented in this chapter is largely based on part of the recent study by Aquino [2006]. A paper (by Aquino et al, [2006]) proposing new supplementary material to the NSCP-2001 based on the same study is scheduled for presentation at the upcoming 2006 PICE National Convention.

2.1 An NSCP-2001-compatible GEF formulation applicable to lattice towers

First and foremost, it was identified that the NSCP-2001 rigid-structure GEF may not be applicable to lattice towers, as it was based on the ASCE7-95 rigid-structure GEF which was developed primarily for buildings. The ANSI/TIA/EIA-222-G-2005 (or 222-G) GEF which is specifically for lattice towers although based on the ASCE7-98 GEF for buildings is also identified to be insufficient as it is neither a function of the wind field characteristics nor the dynamic properties of the structure. Furthermore, size reduction effects which may be

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[1] The term "gust effect factor" is equivalent to the term "dynamic response factor."

appropriate for buildings, but not for lattice towers are incorporated in to the ASCE7 GEF, NSCP-2001 rigid-structure GEF, and 222-G GEF. Lastly, the study by Aquino refers to a study by Loredo-Souza & Davenport [2003] which has recommended that resonant response should also be considered even for "rigid" trussed towers with natural frequency greater than 1 Hz.

The selection process in the study narrowed down the selection to the use of Davenport's [1979] formulation which was developed specifically for lattice towers and which has appeared in the 1991 ASCE Manual entitled "Guidelines for Electrical Transmission Line Structural Loading." Davenport's original GRF formulation was converted in to a GEF formulation for compatibility with the NSCP-2001 following the same procedure used in the development of the ASCE7 GEF formulation, together with some other modifications.

The proposed modified Davenport GRF for use with the NSCP-2001 in the design or evaluation of lattice towers is as follows. Note that the equation numbering used herein is that proposed for compatibility with the NSCP-2001. Also, it should be noted that the following may not be suitable for guyed lattice towers.

$$G_t = \frac{1 + 0.85ger\sqrt{Q^2 + R^2}}{1 + 0.85gr} \tag{207-3}$$

where

$$r = 4.9\sqrt{D_0}\,(10/\bar{z})^{1/\alpha} \tag{207-4}$$

$$Q = \sqrt{\frac{1}{1 + 0.27h/l}} \tag{207-5}$$

$$R = \sqrt{\frac{0.017}{\beta}\left(\frac{n_1 \bar{z}}{\overline{V}_{\bar{z}}}\right)^{-5/3}} \tag{207-6}$$

and

$$\overline{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{10}\right)^{\bar{\alpha}} V\left(\frac{1000}{3600}\right)\sqrt{K_{\bar{z}t}K_d}\text{ , in m/s} \tag{207-7}$$

The value of the peak factor g is recommended be taken as 4.0. The value of e, an uncoupling factor, is recommended to be 0.75 for transmission towers with cables, or 1.0 for all other lattice towers (except guyed lattice towers). r is the roughness factor, which is equivalent to twice the turbulence intensity in other codes. Q and R are the non-dimensional background and resonant response factors, respectively, and are modified versions of that in Davenport's original GRF formulation. $\overline{V}_{\bar{z}}$ is the hourly mean wind speed at the effective height $\bar{z}$ of the tower. h is the height of the tower structure in meters, n_1 is the 1st-mode natural frequency of the tower, and β is the total damping ratio of the tower and is taken as the sum of the corresponding structural and aerodynamic damping ratios. V is the 3-second gust basic wind speed in kph, from Figure 207-1 of the NSCP-2001.

The parameters that define the wind field characteristics, specifically D_0, α, l, $\bar{\varepsilon}$, $\bar{b}$, and $\bar{\alpha}$, is given in a proposed Table 207-11 for four different terrain exposure categories. The effective height $\bar{z}$ is taken as two-thirds the height of the tower ($^2/_3h$), but not less than a certain value z_{min} as listed also in the same proposed table. The topographic factor at the effective height $K_{\bar{z}t}$

is as defined in Section 207.5.5 of the NSCP-2001, and evaluated at the effective height or at $z = \bar{z}$. For towers at locations isolated from special topographic features, $K_{\bar{z}t}$ = 1.0. The directionality factor is set as K_d = 0.85 for lattice towers.

(Proposed) Table 207-11. Parameters defining the wind field characteristics in the calculation of the GEF according to Eq. 207-3

Exposure	α	z_g (m)	$\hat{a}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	l (m)	$\bar{\varepsilon}$	z_{min} (m)	D_0
A	5.0	457	1/5	0.64	1/3.0	0.30	0.45	55	1/2.0	18.3	0.025
B	7.0	366	1/7	0.84	1/4.0	0.45	0.30	98	1/3.0	9.1	0.010
C	9.5	274	1/9.5	1.00	1/6.5	0.65	0.20	152	1/5.0	4.6	0.005
D	11.5	213	1/11.5	1.07	1/9.0	0.80	0.15	198	1/8.0	2.1	0.003

A sensitivity analysis of GEF formulations shows that the GEF value is highly sensitive to the dynamic properties assumed. It is therefore important to have good estimates of these dynamic properties such as natural frequency, structural and aerodynamic damping, and even perhaps the mode shape exponent although it is not yet currently considered in the proposed formulation. The GEF formulation presented above still have many limitations and correspondingly many possible future improvements, including mode shape corrections, formulation based on bending moment as opposed to being displacement-based, and so on.

2.2 *Estimates of the dynamic properties of lattice towers*

The suggested estimates of the dynamic properties of lattice towers presented in this section are generally on the conservative side and thus leading to higher wind loads, owing mostly to the insufficient amount of available data, and the general unreliability of full-scale measurements particularly of the structural damping ratio. For example, analysis of data from only thirty-four (34) lattice towers available from literature is conducted. The towers include nine (9) square radio towers on building roofs in Japan, thirteen (13) square transmission towers without cables in Japan, and nine (9) other lattice towers in countries other than in Japan. No measurements on towers in the Philippines is known to have been conducted.

From the analysis, the following general format of the estimate for the natural frequency of lattice towers is thus suggested. Again for guyed lattice towers, other estimation methods need to be used.

$$n_1 = {}^{107}\!\big/_{h} M_a R_{a0} P_a A_a \tag{207-8}$$

where

$$R_{a0} = 1.25(h/B_0)^{-0.2} \tag{207-9}$$

$$M_a = \sqrt{\frac{1}{1+k_m m_r}} \tag{207-10}$$

$$k_m = \frac{3}{\left({}^{B_{0h}}\!\big/_{B_0}\right)^2 + 0.15} \tag{207-11}$$

R_{a0} is an aspect ratio factor for aspect ratios evaluated at the base, M_a is a mass factor, m_r is the mass ratio or ratio of attachments at the top 5% of the tower to the total mass of the whole tower alone, and k_m is a mass ratio factor and is based on the AS3995 or 222-G. The plan-shape factor P_a is taken as 1.0 for square towers, and 0.9 for triangular towers. The amplitude factor is suggested to be A_a = 1.0 for service-level condition (corresponding to approx. 5-year return period basic wind speeds), and 0.83 for strength-level condition (corresponding to 50-year return period basic wind speeds). B_{0h} is the average tower width, or average of the base and top widths, B_0 and B_h, of the tower.

Alternatively, for antenna towers in the Philippines with up to 3 attached antennas and base aspect ratios of up to 7±1, m_r may be taken as 0.05, M_a as 0.9, and R_{a0} = 0.85, or:

Plan-shape	Service-level natural frequency	Strength-level natural frequency
Square	81/h	68/h
Triangular	73/h	61/h

For towers without attachments, m_r = 0, or M_a = 1.0. For such towers in the Philippines with base aspect ratios of up to 7±1:

Plan-shape	Service-level natural frequency	Strength-level natural frequency
Square	91/h	75/h
Triangular	81/h	68/h

It is also mentioned in the study that the natural frequency may be obtained by a modal calculation on an analytical model of the tower, with attachments appropriately modeled as nodal masses. However, it is recommended that this calculated natural frequency is assumed to be a service-level value, and it shall be multiplied by A_a to obtain the appropriate value for the strength-level condition.

For evaluation studies, the natural frequency is recommended to be obtained from full-scale measurements, but it is also recommended that the amplitude of wind and other loads during the time of measurements should be properly documented, together will all pertinent information on the structure being tested. Any computer model of the structure shall then be benchmarked from this full-scale measurement.

It is noted that the natural frequency tends to be dependent upon the design. For example, one case study showed that the natural frequency of a lattice tower is around 10% higher when using a flexible-structure design assumption (resonant effects considered) with around 40% higher wind loads than when using a rigid design (resonant effects neglected). It is thus recommended that the design assumptions in full-scale structures being tested are also documented.

The structural damping ratio β_s at service-level condition is suggested to be taken as

$$\beta_s = 0.0019 n_1 \geq 0.0030 \tag{207-12}$$

where n_1 is the service-level natural frequency. The value 0.0030 is the lowest value of the measured structural damping ratios from the available data.

The structural damping ratio β_s at strength-level condition is suggested to be taken as

$$\beta_s = 0.0027 n_1 \geq 0.0036 \tag{207-13}$$

where n_1 is the strength-level natural frequency. The above equation essentially suggests a 20% larger structural damping ratio at the strength-level condition than at the service-level condition. These suggested estimates so far result in steel lattice towers having higher natural frequencies and lower structural damping ratios than steel buildings of the same height.

The aerodynamic damping ratio β_a at service-level condition is suggested to be taken as

$$\beta_a = \frac{0.0070}{n_1} \geq 0.0070 \tag{207-14}$$

where n_1 is the service-level natural frequency.

The aerodynamic damping ratio β_a at strength-level condition is suggested to be taken as

$$\beta_a = \frac{0.0106}{n_1} \geq 0.0070 \text{ for NSCP Zone I or II, or } V > 162 \text{ kph} \tag{207-15}$$

$$\beta_a = \frac{0.0090}{n_1} \geq 0.0070 \text{ for NSCP Zone III, or } V \leq 162 \text{ kph} \tag{207-16}$$

where n_1 is the service-level natural frequency, and V is the basic wind speed defined as a 3-second gust speed with a 50-year return period at 10-meter height in flat, open country terrain. It is also recommended to obtain the aerodynamic damping ratio from a more detailed analysis (e.g. refer to [Holmes, 1996]) with the appropriate basic wind speed V as parameter, the hourly mean wind speed from Eq. 207-7, a mode shape exponent of 3.0, unit mass at the base, and solidity ratio ε and drag force coefficient C_f evaluated at the effective height, $\bar{z}$ (taken as $^2/_3h$).

The total damping ratio β is then taken as

$$\beta = \beta_s + \beta_a \leq 0.06 \tag{207-17}$$

Alternatively, the total damping ratio β may be taken as 0.01.

2.3 Implications on existing lattice towers

The GEF value calculated using the procedure for typical lattice towers in the Philippines and presented here is approximately 30% to 50% higher than the rigid-structure value being currently used in the design of these towers, or that the gust factor ratio (GFR or ratio of flexible- to rigid-structure GEF) is between 1.3 and 1.5. It is anticipated that many lattice towers designed using a rigid-structure assumption (resonant effects neglected) may have insufficient capacities to resist wind loads at the NSCP-2001-prescribed extreme wind speeds and design factors of safety.

The effective design wind speeds for these towers are lower by 15% to 20% from that prescribed by the NSCP-2001, or that the design return periods are effectively between 15 and 20 years, as opposed to the 50-year return period required in the NSCP-2001. However, it is possible that the wind speeds at specific locations of certain towers may be even lower than that prescribed by the NSCP-2001, and such over-estimates of the design wind speed may actually compensate for the non-consideration of dynamic wind effects, particularly for these certain towers. This again emphasizes the need for a more accurate study on design wind speeds in the Philippines, considering also that the design wind speed is a parameter in the GEF.

The design factors of safety are estimated to be reduced to below code requirements for the same towers, but still not to the point of failure in terms of yielding of steel members. For now, any failure or otherwise of actual lattice towers could be attributed to this non-consideration of dynamic wind effects (rigid-structure design assumption) in addition to other factors related to wind loading (such as under-estimates of the design wind speed, non-consideration of topographic effects, non-consideration of shielding and/or interference effects, inappropriate estimates of dynamic properties, and insufficient estimates of cable loads in the case of transmission towers), or to the design and construction procedures (e.g. inadequate connection detailing, steel material used for construction is different from design specifications, etc.).

In the previous country report (in 2005), photographs of damages due to a typhoon that hit the country in 2004 were presented. One of these photos is that of damaged lattice transmission towers in Naga City, and is shown again in Figure 1 below. It should be noted that the basic wind speed for this location at the time of construction of these towers is approx. 65 m/s as opposed to the current required basic wind speed of 75 m/s, and that at the time, resonant effects have been neglected in the design. However, the typhoon that hit this place only registered maximum 3-second gust winds of about 55 m/s. The ratio of the squares of the design wind speed of the structure to the actual wind speed is approximately 1.4. This is within the range of GFRs calculated using the procedure presented in this chapter. Again there are other factors that may have contributed to the collapse of these towers. But if dynamic wind effects were considered in the design of this tower in the first place, the non-consideration of dynamic wind effects could thus be ruled out as one of the causes of the collapse. Again, a more accurate study on design wind speeds in the Philippines is necessary, as well as all other improvements to the wind loading code in particular and in the design and construction practice for these structures in general.

Figure 1. Damaged lattice transmission towers in Naga City due to a typhoon in 2004
(Photo courtesy of Michael Padua, Typhoon2000.com website)

3 TYPHOON MILENYO: WIND LOADING ISSUES RE-RAISED

3.1 Available Information

From November 27 to 28, 2006, Typhoon Milenyo made landfall in the Philippines. Metro Manila, the seat of government and commerce in the Philippines, was directly hit at around

2:00pm of November 28. Some sources (e.g. the Typhoon2000.com website) have cited that when Milenyo made landfall, the recorded maximum sustained wind speeds of Typhoon Milenyo reached around 63 m/s with recorded gust speeds reaching 78 m/s. In Metro Manila, it is said that the recorded maximum sustained wind speeds reached 35 m/s and that the gust speeds reached 45 m/s. Based on these numbers, Typhoon Milenyo may have exceeded the NSCP-2001-prescribed design wind speeds for some locations, although not necessarily for Metro Manila (with a design gust speed of 55 m/s).

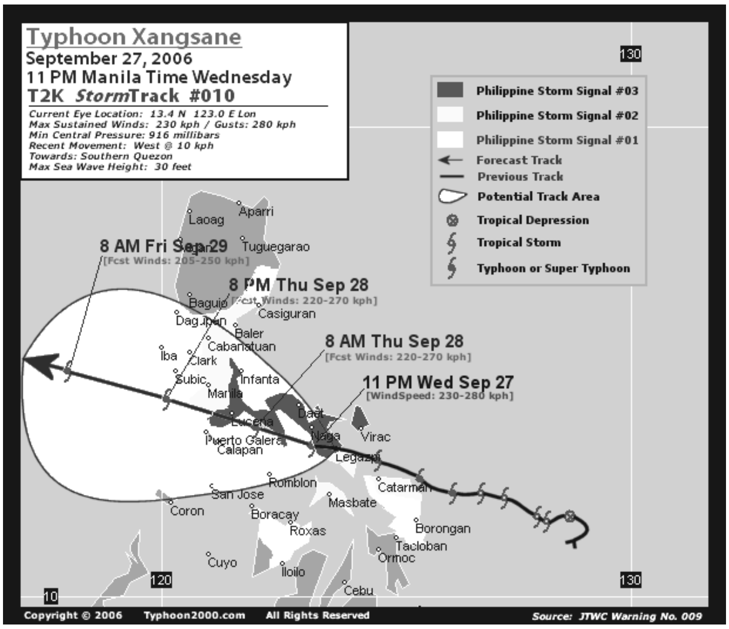

Figure 2. Track of Typhoon Milenyo (International Name: Xangsane) based on Joint Typhoon Warning Center (JTWC) Warning No. 009. Courtesy of Michael Padua, Typhoon2000.com website.

3.2 Damages

The amount of damages, as well as death and injury, due to the winds of Typhoon Milenyo was one of the worst in 11 years particularly for Metro Manila, with approximately US$ 24 million in damages and around 200 deaths. Galvanized iron (GI) roof sheets were blown away, sometimes damaging other structures and in one case killing one person. Many trees were fallen or uprooted, cutting electrical transmission lines, damaging roofs, collapsing walls, and blocking roads and other transport routes. Some cut transmission lines posed as electrical shock hazards, and in fact killed at least two persons. Poles and trussed towers supporting transmission lines, as well as some sign structures and antenna-supporting structures, were also reported to have collapsed, leading to days of power outages and communications breakdown for most of the affected areas. Some of the fallen transmission line poles usually of reinforced concrete construction also damaged adjacent structures, and at least in one case fell on one vehicle. A vehicle in one of the building-lined streets of the Makati City business district was overturned. At least 40 billboards were reported to have collapsed, with at least two reported to have fallen on vehicles leading to the death of its passengers. A collage of selected photographs of damages is presented in Figure 3.

3.3 Wind Loading Issues Re-Raised

Perhaps the most controversial of the damages brought about by Typhoon Milenyo were collapsed billboards (advertisement boards supported usually by truss/lattice structures). A representative of the billboard owners claimed that the design wind speeds for billboard structures were exceeded. There may be some truth to this claim, but again, the importance of a more accurate estimate of extreme wind speeds in the Philippines need to be re-emphasized, starting from better wind speed measurements to better analyses of wind data. The limitations of the NSCP-2001-prescribed wind speeds identified in earlier papers by the authors need to be first addressed.

Figure 3. Collage of selected photos of damages due to Typhoon Milenyo. Photo credits are given in parenthesis. Most of the photos were taken from the Internet websites.

Assuming the design wind speeds are sufficient, there are other issues that may have caused the collapse of these billboard structures. For example, there are some provisions lacking in the NSCP-2001 such as flexible-structure GEF formulations for different types of structures. The tendency of structural designers is to use the rigid-structure GEF, or consult wind loading codes from other countries. In the case of structures such as trussed towers or billboards, the natural frequency may be greater than 1 Hz even though the aspect ratio is much greater than 4. Thus structural designers could technically freely choose between a rigid-structure and a flexible-structure design assumption. For a 'more economical' design, structural designers then tend to use the rigid-structure assumption, although it could be shown (e.g. by Loredo-Souza & Davenport [2003], Aquino [2006], and Aquino et al [2006]) that the use of the flexible-structure design assumption may be more appropriate for such types of structures.

Other issues in the NSCP-2001 wind loading provisions were identified in the 2005 country report, and some were briefly mentioned earlier in Chapter 2, Section 2.3 in the current report.

In summary, the issues (re-)raised in the aftermath of Typhoon Milenyo are as follows:

1. Need for better estimates of extreme wind speeds, and other wind field characterization parameters including wind speed profiles.
2. Improvement in the wind loading code provisions in particular and in the wind design of structures in general, assuming estimates of extreme wind speeds are already sufficient.

4 WIND ENVIRONMENT ISSUES IN THE PHILIPPINES: A BRIEF UPDATE

With respect to wind environmental issues, it was earlier mentioned that there are no known studies on indoor air pollution control or natural/cross ventilation, and pedestrian level wind environments in the Philippines, particularly because there are no known or documented damages, injuries, or the like due to these issues.

However, based on the response of some locals in the Philippines to informal interviews conducted by one of the authors of this report, pedestrian level winds are beginning to pose a problem, particularly in rapidly urbanizing Manila. For example, a respondent in the business district in Makati City has mentioned that wind speeds tend to be amplified at certain intersections in between high-rise buildings. While this is desired particularly for the temporary alleviation of the daily warm, tropical temperatures in the country, the same issue could become a problem during extreme wind events such as the passage of typhoons, or when the number of high-rise building construction in the city has grown to cause such a problem. Typhoon Milenyo for example overturned some vehicles in between high-rise buildings in Makati City.

A respondent residing in a high-rise condominium building has noticed wind naturally flowing through his condominium unit's doors and windows. The respondent mentioned that while for ventilation and "cooling" purposes this "cross-ventilation" is desirable, the respondent noted that during a typhoon, non-structural elements inside his unit such as picture frames tend to be blown away from their original positions, or interior doors tend to vibrate annoyingly.

These wind environment issues are certainly present, and continuing to escalate in the Philippines, particularly in highly urbanized Manila. Aside from the Clean Air Act which aims to control pollutant emmissions in the atmosphere, no further research studies or enactments of other laws or specifications to address these issues are being conducted, for various reasons.

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