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Wind pressure coefficients on low-rise structures and codification

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Abstract. This paper describes the work of the Working Group on wind pressure coefficients on low-rise structures, one of the groups set up by the International Association of Wind Engineering in 1999. General aspects of wind loading on low-rise structures are summarized. The definition, derivation and codification of loading coefficients is described. Comparisons of pressure coefficients on low rise structures are made between a selection of wind loading standards. Recommendations for consistency and for the harmonization of these coefficients are given.

Keywords: codes; low-rise buildings; pressure coefficients; walls; roofs.

1. Introduction

Low-rise structures represent the largest class of structures for which wind loads for design are obtained from national or regional standards, or codes of practice. Consequently the accurate and consistent codification of wind pressures on low-rise structures is of considerable importance for reasons of safety and economy, in all parts of the world affected by strong winds.

This paper describes the definition, derivation and codification of wind pressure coefficients applicable to low-rise structures, on behalf of one of the working groups set up by the International Association of Wind Engineering, to review and make recommendations for the harmonization of international codification of wind loads. Initially the group was interested in pursuing all aspects of wind loading of low-rise buildings, but the emphasis shifted to undertaking a comparative study of

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aerodynamic loading coefficients for low-rise structures from major wind-load codes. This was seen as an important first step in the harmonization of individual country wind-load codes. This paper presents a comparison of the format, terminology and loading coefficients for low-rise structures from several major wind-load codes. Some recommendations are made for possible harmonization of information in these codes; these are given in italics in the main text, and as a group at the end of the paper.

2. General aspects of wind loads on low-rise structures

Wind loads on low-rise buildings and other low-rise structures have been studied actively since the nineteen sixties, with several extensive boundary-layer wind-tunnel and full-scale studies. Earlier wind-tunnel work is generally unreliable due to the use of non-boundary layer flows.

Notably amongst the early boundary-layer wind-tunnel studies, Jensen and Franck (1965) carried out the first extensive studies on low-rise structures for the Danish Standard, and Davenport, *et al.* (1977) studied wind loads on steel-framed industrial buildings in detail, eventually resulting in design data used in the trend-setting Canadian Code NRCC (1995) and quickly adopted by the American Standard ASCE7.

General reviews of wind loads on low-rise buildings have been provided by Holmes (1983, 2001) Stathopoulos (1975, 1984), Krishna (1995), and Surry (1999).

Wind pressure coefficients on rectangular planform buildings are found to be sensitive to roof geometry (e.g. roof pitch, gable or hip type), and height to (along-wind) depth ratio. The across-wind breadth to along-wind depth ratio (horizontal aspect ratio) is usually found to be of lesser significance, although this is not the case for buildings of high roof pitch (Ginger and Holmes 2003).

Wind loads on other low-rise structures, including free-standing walls and hoardings (Letchford and Holmes 1994, Robertson, *et al.* 1997, Letchford 2001), and free-standing, or canopy, roofs (Letchford and Ginger 1992, 1994, Robertson, *et al*. 1985), have also been studied fairly extensively in both boundary-layer wind tunnel and full scale flows. Arched and domed roofs have also received some attention (Johnson, *et al.* 1985, Blessmann 1991), although the question of model scale effects (Reynolds Number similarity) arises in wind-tunnel studies of these buildings. Full -scale studies of arched roofs have been undertaken by Hoxey and Richardson (1984).

Low-rise structures are generally immersed within the roughness layer of atmospheric boundary -layer flows and are often subjected to direct shielding and interference effects from upwind structures. Consequently the variability in loading coefficients even for a defined geometric configuration of structure can be considerable. The variability of wind pressure coefficients is discussed in another paper in this group (Kasperski, *et al.* 2005).

Internal pressures within enclosed low-rise buildings can contribute a significant part of the total wind load on a roof or wall, particularly when there are large openings in the building envelope.

For buildings with sharp edge geometry, there has been generally good agreement between pressure coefficients from wind-tunnel model and full-scale studies, with the exception of local peak pressures on the corners of buildings with near-flat roofs (Cochran and Cermak 1992). These differences need to be considered when codifying local external roof pressures.

Generally, codes and standards have adopted a ‘quasi-steady’ model of wind loads for the specification of wind loads on low-rise structures. In this model (Holmes 1983, 2001), mean pressure coefficients are applied with gust wind speeds (or with mean wind speeds and simple gust factors). However, there are many cases in which this model is violated, and advanced codes and standards have allowed for this with coefficients, or factors, for local pressures on small areas, and reduction factors for large areas, or combinations of pressures from different surfaces.

3. Code formats for buildings

There have been several comparisons of wind load provision across major international codes and standards. Holmes (2001) summarized such a comparison of the following standards: International Standard ISO 4354 (1997), Eurocode pre-Standard ENV1991-2.4 (CEN, 1995), U.S. ASCE7-98, Japanese AIJ (1996), Australian AS1170.2-1989, and British BS6399: Part 2 (1997). Since then, however, the Eurocode prEN1991-1-4.6 (2004), ASCE-7 (2002) AS/NZS1170.2 (2002), and the AIJ have all had significant revisions. The latest AIJ Recommendations however are not yet available in an English-language version.

Recently, a new Chinese Code GB50009 (2001) has been approved, and discussed by Zhang (2003). The background to the Eurocode pressure and force coefficients is specifically described by Guerts, *et al.* (2001). In addition, a study by St Pierre (2002, 2005) has used extensive wind-tunnel data on low-pitch, industrial low-rise buildings to make comparisons with different wind loading codes.

Low-rise structures have been specifically defined as having height/breath (h/b) < 1 and h < 20 m in [19] and H < 60 ft in ASCE7 (2002). The AIJ (1996) provides pressure coefficients for buildings < 45 m and a simplified procedure for buildings less than 15 m in height. AS/NZS1170.2 (2002) uses a height of 25 m to delineate windward wall pressures and this may be considered a demarkation for low rise/high rise.

A consistent definition of a low-rise building is desirable. Whereas, a specific height could be agreed, there also needs to be recognition that 'low-rise' has connotations of the upstream roughness being of a similar height.

3.1. Building geometry

As a minimum, any wind-load standard should include aerodynamic loading coefficients for a rectangular 'box' structure with variable pitch roof. Loading coefficients as a function of aspect and height ratio and roof pitch should be provided.

The geometry of a typical low-rise building is shown in Fig. 1. The breadth (width), depth (length) and height (mean roof height) and roof pitch are indicated and the equivalent symbols used

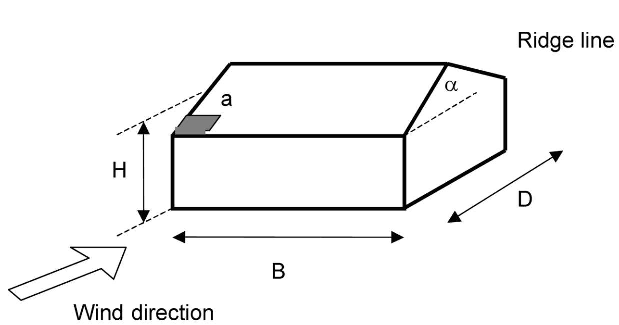

Fig. 1 Geometry of a low-rise, gable-roof building

Table 1 Symbols for building geometry

Code	Country	Width/breadth, perpendicular to wind	Length/depth parallel to wind	Height	Local pressure dimension	Roof slope
ISO 4354	International	b	d	h		α
prEN 1991-1-4.6	European	b	d	h		α
ASCE7-02	USA	B	L	h	a lesser of <0.1B, 0.1L or 0.4h>	θ
AIJ	Japan	B	D	H	l lesser of <B or 2H>	θ
AS/NZS 1170.2:2002	Australia & New Zealand	b	d	h	a lesser of <0.2b, 0.2d or h>	α
BS6399: Part 2	Britain	B	D	H	b, b_1, b_2, b_w lesser of <B or 2H>	α
GB50009-2001	China	B	l	H	(1/6) l	α

for the major wind codes are shown in Table 1. Also shown is a scaling dimension for area loading, a. Typically, aerodynamic loading coefficients are presented for two orthogonal wind directions, usually defined with respect to the roof ridge line, i.e., parallel and perpendicular. The sign convention used is positive towards the surface and negative away from the surface.

3.2. Wind load formulation

Table 2 summarizes the basic wind speeds and presents the wind load formulation for several major wind load codes and standards. Although many formulations start with a mean wind speed, this is soon converted to a gust or peak dynamic pressure to which aerodynamic shape factors are applied to determine appropriate wind loads (see Section 3.4). A further factor accounts for dynamic response. However, the latter is not usually significant for low-rise buildings and has a default value - typically 1 (0.85 in ASCE-7 2002); the codification of dynamic response is discussed in another paper in this group (Tamura, *et al.* 2005). Table 2 also summarizes these formulations. The aerodynamic shape factors C_{fig}, c_{pe}, C_p, C_f, $C_{p,e}$, C_{pe} and μ_s shown in the Table are all quasi- or pseudo-steady mean pressure coefficients.

Table 3 summarizes the two most common terrain/exposure designations corresponding to rural and suburban sites for the seven codes considered. Also shown is the limiting height for application of a wind profile, below this height the wind profile is assumed constant for the purposes of establishing a design wind speed. Terrain categories are also discussed in another paper on codification in this series (Holmes, Baker, *et al.* 2005).

Table 2 Summary of low-rise pressure/force calculation inputs (after Holmes 2001)

Code	Averaging time	Return Period	Velocity	Dynamic Pressure	Building Pressure/Force	Reference height
ISO 4354	10 min	50 years	v	$q_z = (1/2)\ \rho\ v^2$	$w = (q_{ref})(C_{exp})(C_{fig})(C_{dyn})$	Mean roof height, h
prEN 1991-1-4.6	10 min	50 years	$v_b = c_{dir} c_{season} v_{b,o}$	$q_p(z) = c_e(z)\ (1/2\ \rho\ v_b^2)$	$w_e = q_p(z_e)\ c_{pe}$	Maximum roof height, h
ASCE7-02	3 sec	50 years	V	$q_z = (1/2)\ \rho\ K_z K_{zt} K_d V^2 I$	$p = q\ G\ C_p$ or $p = q_h\ (GC_{pf})$	Mean roof height, h
AIJ	10 min	100 years	$U_H = U_o E_r E_g R$	$q_z = (1/2)\ \rho\ U_H^2$	$W_f = q_H\ C_f\ G_f A$	Mean roof height, H
AS/NZS1170.2: 2002	3 sec	500 years	$V_{(des,\Theta)} = \max$ $< V_{sit,\beta} = V_R M_d$ $(M_{z,cat} M_s M_t) >$ over various wind sectors	$(1/2)\ \rho\ {V_{(des,\Theta)}}^2$	$p = (1/2)\ \rho\ {V_{(des,\Theta)}}^2\ C_{fig}\ C_{dyn}$, $C_{fig} = C_{p,e}\ K_a\ K_c\ K_1\ K_p$	Mean roof height, h
BS6399: Part 2	1 hr	50 years	$V_e = V_b S_a S_d S_s S_p S_b$	$q_z = (1/2)\ \rho\ V_e^2$	$p_s = q_s C_{pe} C_a$	Maximum roof height, H, depends on upstream shielding
GB50009-2001	10 min	50 years	Not used	w_o	$w_k = \beta_z\ \mu_s\ \mu_z\ w_o$	Mean roof height, H

Table 3 Summary of rural and urban terrain designations and limiting wind profile heights

Code	Rural terrain	Velocity profile constant below height (m)	Suburban terrain	Velocity profile constant below height (m)
ISO 4354	Informative only	5 - structural design 20 - cladding design		
prEN 1991-1-4.6	II (z_o = 0.05 m)	2	III (z_o = 0.3 m)	5
ASCE7-02	*C*	4.6	*B*	9.1 (Case 1 - low rise methodology)
AIJ	II	5	III	5
AS/NZS1170.2:2002	2 (z_o = 0.02 m)	5	3 (z_o = 0.2 m)	10
BS6399: Part 2	Country & distance from sea	2	Town & distance from sea	2
GB50009-2001	*B*	10	*C*	15

Table 4 Summary of wind directionality factors

Code	Country	Directionality factor	Range
ISO 4354	International	none	
prEN 1991-1-4.6	European	c_{dir} (on velocity)	Refers to National Annexes for actual values
ASCE7-02	USA	K_d (on pressure)	0.85 for all directions for overall and cladding loads
AIJ	Japan	n/a	
AS/NZS 1170.2:2002	Australia New Zealand	M_d (on velocity)	0.95 for all direction overall loads 1.0 for all direction cladding loads or < 0.8 to 1.0 > in 45° sectors
BS6399: Part 2	Britain	S_d (on velocity)	1.0 for all direction or < 0.73 to 1.0 > in 30° sectors
GB50009-2001	China	none	

3.3. Wind directionality

Several codes (BS6399 1997, CEN Eurocode 1 2002, ASCE7 2002 and AS/NZS1170.2 2002) include a factor to account for the lack of alignment of the worst building orientation with the worst wind direction. The British and Australian and New Zealand standards even present directional wind speed information based on analysis of extreme wind speed data for different compass sectors. Table 4 summaries this information.

Directionality is also discussed in a companion paper on codification Holmes, *et al.* (2005).

3.4. Loading coefficients

Research on the wind loading coefficients on a basic low-rise gable-roof building, such as that shown in Fig. 1, has shown their dependency on a number of parameters. These are listed in increasing order of importance as follows (referring to the notation in Fig. 1):

- Roof pitch, α
- Wind direction
- Size of loading area, a
- Vertical aspect ratio, (H/D)
- Boundary layer characteristics (e.g. Jensen Number, H/z_0)
- Horizontal aspect ratio (B/D)

Almost all advanced codes and standards consider the effects of the first three parameters; many also include the vertical aspect ratio. The last two factors are usually not included in the codification process. The horizontal aspect ratio has usually been found not to be a dominant factor for the usual range of values covering most buildings; however there are exceptions as discussed in Section 3.6.

The effect of varying boundary layer, especially turbulence, is quite significant, but can be minimized by basing the loading coefficients on gust wind speeds rather than mean wind speeds,

Table 5 Summary of external aerodynamic shape factors for main structural systems of low-rise buildings

Code	Shape factor	Windward wall	Leeward wall	Side wall	Roof
ISO 4354	$C_{fig}C_{dyn}$	Informative only Function of roof slope and wind direction $0.75 < C_{fig}C_{dyn} < 1.5$	Informative only Function of roof slope and wind direction $-0.55 < C_{fig}C_{dyn} < -1.2$	Informative only Function of roof slope and wind direction $0 < C_{fig}C_{dyn} < -0.9$	Informative only Function of roof slope and wind direction $-2.0 < C_{fig}C_{dyn} < 1.3$
prEN 1991-1-4.6	c_{pe}				
ASCE7-02	C_p Figure 6-6 with $G = 0.85$	0.8 with q_z $GC_p = 0.68$ with q_z	Function of L/B with q_h $-0.5 < C_p < -0.2$ $-0.425 < GC_p < -0.17$	-0.7 with q_h $GC_p = -0.60$	Function of wind direction (parallel or perpendicular to ridge), roof pitch (θ), height (h/L), plan aspect ratio (b/d) and distance from windward edge (x/h) $-1.3 < C_p < +0.4$ with q_h $-1.11 < GC_p < +0.34$
	(GC_{pf}) Figure 6-10	Function of roof angle (θ) with q_h $0.40 < GC_{pf} < 0.80$	Function of roof pitch (θ) with q_h $-0.64 < GC_{pf} < -0.29$	-0.45 with q_h	Function of roof pitch (θ) with q_h $-1.07 < GC_{pf} < +0.69$
AIJ	C_f, C_{pe} with G_{pe}	Table 6.8 0.8 with q_z 0.6 with q_H, for $B/H > 3$	Table 6.8 Function of roof pitch (θ), H/D, B/H with q_H $-1.0 < C_{pe} < -0.4$	Table 6.8 Function of distance from windward edge (x/h) with q_H $-0.7 < C_{pe} < -0.2$	Table 6.8 Function of roof pitch (θ), H/D, B/H with q_H $-1.4 < C_{pe} < +0.42$
AS/ NZS1170.2 :2002	$C_{p,e}$	Table 5.2(A) 0.8 with V_z 0.7 with V_h	Table 5.2(B) Function of roof pitch (α) and plan aspect ratio (d/b) with V_h $-0.75 < C_{p,e} < -0.2$	Table 5.2(C) Function of distance from windward edge (x/h) with V_h $-0.65 < C_{p,e} < -0.2$	Table 5.3(A, B, C) Function of roof type (hip/gable), roof pitch (α), height (h/d), plan aspect ratio (b/d) and distance from windward edge (x/h) $-1.3 < C_{p,e} < +0.5$
BS6399 : Part2	C_{pe}	Table 5 0.8, $D/H < 1$ 0.6, $D/H > 4$	Table 5 -0.3, $D/H < 1$ -0.1, $D/H > 4$	Table 5 Function of distance from windward edge and funnelling $-1.3 < C_{pe} < -0.4$ isolated $-1.6 < C_{pe} < -0.9$ funnelling	Tables 8 - 14 Function of roof type (hip/gable /mono/inverted), eave type, roof pitch (α), height (h/b), plan aspect ratio (b/d) and area size and distance from windward edge $-2.6 < C_{p,e} < +0.8$
GB50009 -2001	μ_s	0.8	-0.7	-0.5	Function of roof pitch : $\alpha \leq 15^{o}$ -0.6; $\alpha = 30^{o}$ 0; $\alpha \geq 60^{o}$ +0.8

and making use of the quasi-steady assumption (see Section 2). If codes or standards are based on mean wind speeds, they can be converted to a gust pressure before being applied to calculate building pressures (e.g. BS6399 1997, CEN Eurocode 1 2004).

The Working Group recommends that, if mean wind speeds are used as a basis for a code or standard, then they be converted to a gust pressure. This enables the quasi-steady assumption to be used, and minimizes the effects of terrain and turbulence.

The external aerodynamic shape factors and their magnitude ranges for main structural systems of low-rise buildings are summarized in Table 5.

Comparisons of external pressure coefficients for a flat roof building of a square planform were made by Holmes (2001). Considerable differences were found between six major codes, especially for local cladding loads, although some codes were similar, indicating a common origin for the data, or code committees copying one another. Such differences also occur for other roof shapes.

Continued effort should be made to harmonize the loading coefficients on simple building shapes in the various national standards.

Internal pressure coefficients for buildings without dominant openings, i.e., all surfaces equally permeable are shown in Table 6. Several codes consider the possibility of dominant openings, for example, windows broken by flying debris, or failed roller doors in an industrial building. These have often been observed in damage inspections following severe windstorms and will produce much higher internal pressure coefficients. Specification of such values should be considered for all codes and standards applicable to high wind regions.

A rational method for the determination of internal pressure should be provided in future wind load codes based on known openings and building surface permeability.

Loading coefficients may be referenced to a wind speed (or a dynamic pressure) at the top of the roof, eaves height, or at average roof height. The latter seems to be the most logical as a single reference height to cover a range of wind directions, and all roof shapes.

Table 6 Summary of internal pressure coefficients for low-rise buildings without dominant openings

Code	Country	Shape factor	Ranges	Reference dynamic pressure
ISO 4354	International	$C_{fig,int}$ with $C_{dyn,int}$ = 1	0 or -0.3 without large openings	
prEN 1991-1-4.6	European	c_{pi}	+0.35 to -0.3 (h/D<0.25) (uniformly distributed openings)	$q_p(z_i)$
ASCE7-02	USA	GC_{pi}	+0.18 or -0.18	q_h
AIJ	Japan	C_{pi} with G_{pi} = 1.3	0 or -0.4 0 or -0.52	q_H
AS/NZS 1170.2:2002	Australia New Zealand	$C_{p,i}$ with K_c of 0.8, 0.95 or 1	0 or -0.3	q_h
BS6399: Part 2	Britain	$C_{pi}C_a$ with C_a < 1.0 and a function of diagonal dimension	-0.3 (and +0.2 for buildings with impermeable internal partitions)	q_H
GB50009-2001	China	Not given	*n/a*	*n/a*

The Working Group recommends that the average roof height be used as a reference height and wind-tunnel data should be collected based on this reference height in the future.

3.5. Wind load combinations

It is recognized in most wind-load codes that the fluctuating and partially-correlated (spatially and temporally) wind loads, will lead to different wind-load distributions for different load effects. It is impossible for a single, unique load distribution to adequately describe all possible load effects. Several codes (BS6399 1997, ASCE-7 2002, AS/NZS1170.2 2002) provide an approach to modify basic load distributions for higher-order load effects. Indeed the NBCC, ISO and American Standards (NRCC 1995, ISO4354 1997, ASCE-7 2002), have a whole separate set of loading coefficients (low-rise methodology) that were optimized for the response of a portal-frame building based on the pioneering work of Davenport, *et al.* (1977). Other codes, (BS6399 1997, AS/NZS1170.2 2002) offer reduction factors for load combinations formed from more than one surface, e.g., overall drag = windward − leeward load coefficients. Holmes (2001) describes various techniques to obtain effective static load distributions from extensive wind-tunnel tests; however these would be difficult to codify, as they require knowledge of a supporting structural system through influence coefficients.

St Pierre, *et al.* (2005), using results from extensive wind-tunnel tests on portal-frame buildings, compared seven different structural responses (load effects) derived from four different wind-load codes and standards, ASCE-7 (2002), AS/NZS1170.2 (2002), ENV (CEN 1995) and NRCC (1995). Significantly, this study found that all these documents underestimated frame bending moments for the end bays of low-pitched, low-rise buildings of various height-to-span ratios. The Eurocode (CEN 1995, 2004) was generally found to perform better than the North American codes. However, since these various codes and standards use different reference wind speeds, the conclusions reached may have been influenced somewhat by the assumptions used to convert the load effects to load coefficients for comparison purposes.

The Working Group recommends that future wind-load codes should recognize that the fluctuating nature of wind loading will lead to different load patterns for different load effects and that effort be made to harmonize the approach to offering load combinations in the various standards. Comparisons of code values with measurements should be made with load effects such as frame bending moments, as well as local pressures and overall wind forces.

3.6. Long, high-pitch buildings

Recent studies of long, low-rise buildings with high-pitch gable roofs have shown that current codes and standards significantly underestimate the wind loads and effects on the gable ends of such buildings (Ginger and Holmes 2003). These shapes are characteristic of storage sheds for products such as sugar cane, or minerals, but such shapes may also occur in terraced town houses, for example. The higher wind loading is produced by wind blowing in directions oblique to the major axes of the building and is consistent with wind loadings measured on free-standing walls (Robertson, *et al.* 1997). Generally, these directions are not explicitly considered by wind codes and standards. The effect is exacerbated for high values of horizontal aspect ratio (B/D ratio in Fig. 1); as discussed in Section 3.4, this parameter is generally not used as a parameter in most documents, when specifying coefficients.

The Working Group recommends that the high loading on long low-rise buildings with high-pitch gable roofs, be actively considered when specifying load coefficients in future codes and standards.

Table 7 Load coefficients contained in various codes and standards (excluding rectangular enclosed buildings)

TYPE	ISO 4354	prEN 1991	ASCE 7-02	AIJ	AS/NZS 1170.2	BS6399	GB50009-2001
Stepped roofs	no	no	yes	no	no	yes	yes
Free-standing walls, hoardings	yes	yes	yes	no	yes	yes	yes
Parapets	no	yes⁺	yes	no	no	yes⁺	yes
Free-standing roofs (canopys)	no	yes	no	no	yes	yes	yes
Attached canopies	no	no	no	no	yes	yes	no
Multispan roofs (enclosed)	no	yes	yes	yes*	yes	yes	yes
Multispan canopies	no	yes	no	no	no	no	no
Arched roofs	yes	yes	yes	yes*	yes	no	yes
Domes	no	yes	yes	yes*	no	no	yes
Bins, silos, tanks	yes	yes	yes	no	yes	no	yes

*Given in commentary section of Japanese language version
⁺Treated as free-standing walls

4. Other low-rise structures

Load coefficients, or shape factors, for other low-rise structures, such as free-standing walls, hoardings and roofs, silos and tanks are found in some wind codes and standards, but not all the major ones. Table 7 summarizes the situation with respect to six of the major documents. The Eurocode 1, CEN (2004), is the most comprehensive document with data given for nearly all types of low-rise structure.

However, loading coefficients for some shapes in some documents in Table 7 date back to earlier wind-tunnel studies in smooth (non boundary-layer) flow, and these are in need of checking with possible revisions required. Also, other structures have not had the same amount of attention given to them, as low-rise buildings of rectangular planform, with regard to fluctuating load effects such as area averaging, corner effects, influence line effects and combinations of loads on various surfaces. This should be a subject of future wind-tunnel research.

The Working Group recommends that further research be undertaken on fluctuating load effects on low-rise structures apart from rectangular gable-roof buildings, as these other structures have generally been neglected in this regard.

5. Conclusions

This paper has summarized the wind loading of low-rise structures from seven major wind load codes. Specific recommendations of the I.A.W.E. Working Group are:

(1) A consistent definition of a low-rise building is desirable. Whereas a specific height could be agreed, there also needs to be recognition that ‘low-rise’ has connotations of the upstream roughness being of a similar height.

(2) As a minimum, any wind-load standard should include aerodynamic loading coefficients for a rectangular ‘box’ structure with variable pitch roof. Loading coefficients as a function of

aspect and height ratio and roof pitch should be provided.

(3) If mean wind speeds are used as a basis for a code or standard, then they should be converted to a gust pressure. This enables the quasi-steady assumption to be used, and minimizes the effects of terrain and turbulence.

(4) Continued effort should be made to harmonize the loading coefficients on simple building shapes in the various standards.

(5) A rational method for the determination of internal pressure should be provided in future wind-load codes based on known openings and building surface permeability.

(6) The average roof height should be used as a reference height and wind-tunnel data should be collected, based on this reference height in the future.

(7) Any future wind-load code should recognize that the fluctuating nature of wind loading will lead to different load patterns for different load effects and that effort be made to harmonize the approach to offering load combinations in the various national standards. Comparison of code values with measurements should be done with load effects such as bending moments as well as local pressures and overall wind forces, as current codes and standards have all recently been found to be inadequate in this regard (St. Pierre, *et al.* 2005).

(8) The high loading on long, low-rise buildings with high-pitch gable roofs, should be actively considered when specifying load coefficients in future codes and standards.

(9) It is recommended that further research be undertaken on fluctuating load effects on low-rise structures apart from rectangular gable-roof buildings, as these other structures have generally been neglected in this regard.

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