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VISCMA

CALCULATION OF WIND LOADS ON ROOFTOP EQUIPMENT
PER ASCE7-16

HISTORY

In recent decades, the attention of the industry has primarily been focused on the fears and concerns for proper seismic installations of mechanical equipment. With the concurrence of highly publicized seismic events happening within a few years of each other (late 80’s, early 90’s), many agencies and organizations properly put much more emphasis on the safe design and installation of mechanical systems for these seismic events. Prior to that, seismic design had been mainly focused on structural requirements and many of the codes and standards had been modified to reflect proper building design.

What was being overlooked during this time was the installation of mechanical equipment. Most of the new structures were surviving these events. But the internal systems that make the buildings function, did not. These Mechanical, Electrical and Plumbing (MEP) systems had some well-publicized failures that rendered some hospitals unoccupiable. Since then, the codes and standards have evolved even further to include proper design and installation of mechanical systems. The codes have gone as far as requiring shake table testing of the critical equipment to prove functionality. The equipment’s performance in more recent earthquakes has proven that the updates to the codes have been working.

Through this evolution of the codes, one potentially catastrophic environmental event had been overlooked: wind loading for rooftop mounted equipment. Whereas seismic events are relatively limited in geographic application, wind loads are everywhere. As with seismic, the current structural codes for have been adequately prescribing the design of buildings that can withstand most severe wind events. The structural failure of newly designed buildings due to wind loads is completely unheard of. However, rooftop equipment is still highly vulnerable and has been the subject of publicized failures. This was due to lack of enforcement of code requirements.

This changed after 2004 and 2005 when a series of major hurricanes hitting the Atlantic and Gulf coasts (Charley, Frances and Rita) and then culminating with Hurricane Katrina. These events made it obvious where there had been improper design and installation of rooftop equipment for wind loads. Most of these failures occurred due to improper or non-existing design of the anchorage.

DAMAGE

Most rooftop equipment will be accompanied with some roof penetration. As this equipment is dislodged or displaced, this penetration into the building envelope will be exposed. The accompanying rain will now enter the building and will cause even more damage. Or, the additional wind going through the opening can cause additional damage. Flying debris from the equipment or even the piece of equipment itself can be a major life safety hazard to all people in or around the building. The electrical and gas lines that were attached to this equipment are now uncovered and will subject inhabitants to the risk of fire and/or electrocution.

As the equipment is further displaced from the wind, it will typically take the roof covering with it. This is due to its supports and/or curbs being roofed into the rest of the roof. The roof structure, insulation and other inside ceiling-mounted equipment and utilities will then become subject to rain and wind damage. Due to the ripping of the membrane by the equipment and its supports, the roof is no longer functioning as a source of protection for the inhabitants, and the building must be evacuated. This is one of the events that happened to the Superdome during Katrina. The curbs for the rooftop fans took the roof membrane with them and exposed the interior of the building and people using it as a shelter to the severe elements of the hurricane.

Another concern of dislodged or displaced equipment is the break in the building pressurization. Wind pressures acting on the sides of the building, primarily the glass, are somewhat balanced by the internal pressures pushing out. With a break in the pressurization system, the internal pressures will decrease rapidly. This can easily cause a breakage of the exterior glass on the building. The danger due to broken glass and the additional wind ripping around the inside of the open building has caused many injuries in high wind events.

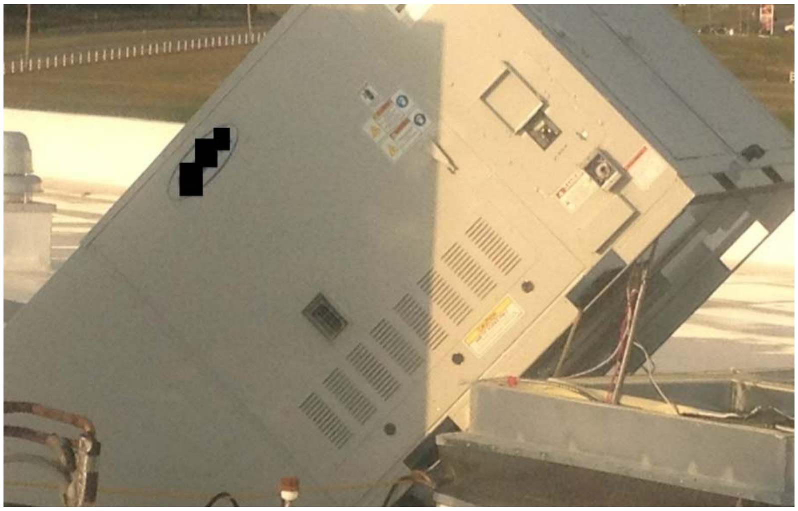
Photos of Typical Failures

Fast food restaurant with the unit barely remaining on the roof.

[redacted]

Overturned unit, exposing the building and its occupants to the wind and rain. Also, the gas lines have been bent and possibly damaged.

Unit knocked off of curb, exposing the building to the elements. Unit not properly attached to curb.



In 2012, Superstorm Sandy was another jarring example the importance of effective wind restraint of mechanical equipment. Due to the storm hitting such a largely populated area, the number of bad installations was significant. Many of these installations showed failure at the attachment to building structure.

CODE EVOLUTION

After the 2004 and 2005 events, the engineers responsible for the wind chapter in ASCE began to improve the standards. IBC 2012 Sec. 1609.1 and ASCE7-10 Sec. 26.1.1 contain clear language stating that wind loads must be considered. With continued lack of enforcement language, the changes were primarily in the calculation of wind forces on equipment. The most dramatic non-technical change emphasizing the increased complexity in performing a proper calculation is the increase from one chapter (Ch 6, ASCE7-05) to five chapters (Ch's 26-30, ASCE7-10). Another change is to the wind load maps. The maps have now changed to reflect the particular building's Risk Category.

The last primary change is to the Load Combinations. Wind is now assumed to be an LRFD calculation and thus will get a factor of 1.0 for LRFD load combinations and a 0.6 for ASD combinations. This is in place of the old factors of 1.6 and 1.0, respectively. This will keep it somewhat consistent with the application of seismic loads even though seismic uses a 0.7 for ASD combinations.

With the higher wind speeds, reflecting an LRFD calculation, engineers must use extreme caution that they are using the current factors for gust, topography, load combination, etc. Otherwise, their calculations will greatly overestimate the applied load. Most of these factors have changed and their values are shown below.

Different versions of ASCE7 have include or excluded vertical uplift during wind calculations in an attempt to balance the cost of additional load combinations and complexity verse the additional accuracy to real high-gust effects.

	ASCE7-05	**ASCE7-10**	**ASCE7-16**
Height from Ground	**IBC2006, IBC2009**	**IBC2012, IBC2015**	**IBC2018**
60+ ft	Horizontal Wind	Horizontal Wind	Horizontal Wind Vertical Wind
0 ft – 60 ft		Horizontal Wind Vertical Wind	

Note that above, we can see that wind calculations done on equipment that were good for IBC2006 and IBC2009 can be extended to above 60 ft. situations in IBC2012 and IBC2015 but not below 60 ft. which can be considered strange. It is good that in IBC2018 (ASCE7-16), they removed that complexity added at the 60 ft. break and require uplift loading no matter the height.

LOAD CALCULATIONS

For Wind Resistant Certification, structural analysis of the MWFRS, internal and external components, and the units mounting configuration will be the primary concern. All applied loads will be determined using ASCE7-16.

Chapter 29 "WIND LOADS ON OTHER STRUCTURES AND BUILDING APPURTENANCES—MWFRS" spells out the requirements for wind resistant design for rooftop equipment. As mentioned above, ASCE 7-10 had a distinct break in method for buildings above 60 feet tall, allowing the vertical force to be removed. This has been eliminated for ASCE 7-16.

Before we start the calculations, we need to make sure we have all of the basic information including:

1. External unit dimensions; Length, width, height and weight
2. Attachment method; directly onto structure, curb or dunnage
3. If curb or dunnage, their heights and attachments to structure
4. Risk Category of building
5. Design wind speed from building location or specification, whichever is greater
6. Height of building at the attachment of the equipment to structure
7. Local terrain features of building (exposure)

There are two basic equations that govern the applied lateral load:

Equation 29.4-2:

$$F_h = q_h(GC_r)\ A_f$$

Where: F_h = lateral wind force
q_h = velocity pressure at mean roof height of the building
(GC_r) = 1.9 for most equipment (depends on the relative size of the building)
A_f = vertical projected area of equipment normal to the wind

Equation 29.4.3

$$F_v = q_h(GC_r)\ A_r$$

Where: F_z = vertical wind force
q_h = velocity pressure at mean roof height of building
(GC_r) = 1.5 for most equipment (depends on the relative size of the building)
A_r = horizontal projected area of equipment

For typical rooftop equipment, different values of GC_r, rarely apply. Rooftop structures that encompass most of the area on the roof would be applicable to the reduced values.

To calculate the velocity pressures, both equations above use the form of the equation below.

$$q_h = 0.00256 * K_h * K_{zt} * K_d * K_e * V^2$$

Where: **0.00256** = air density factor

K_h = velocity pressure exposure coefficient based upon building exposure and height

K_{zt} = topography factor = 1.0 for rooftop equipment

K_d = wind directionality factor (between 0.85 and 1.0, depending on the equipment shape)

K_e = Ground Elevation Factor (from 1.0 at sea-level to ~0.8 in Denver, CO)

V = wind velocity in miles per hour

For ASCE7-16 there is an air density factor based upon the altitude of the site. For certification, all analysis will be performed at sea level (worst case). K_z and K_h are exposure coefficients based upon building exposure and height, per Table 26.10-1 below. Exposure Categories B, C and D, are determined by 'Surface Roughness' in the adjacent area of the building, and is generally:

Exposure B: Urban and suburban areas and others with numerous obstructions.
Exposure C: Open terrain with scattered obstructions, open country and grasslands.
Exposure D: Flat unobstructed areas and water surfaces.

Adjacent areas are defined in section 26.7.3.

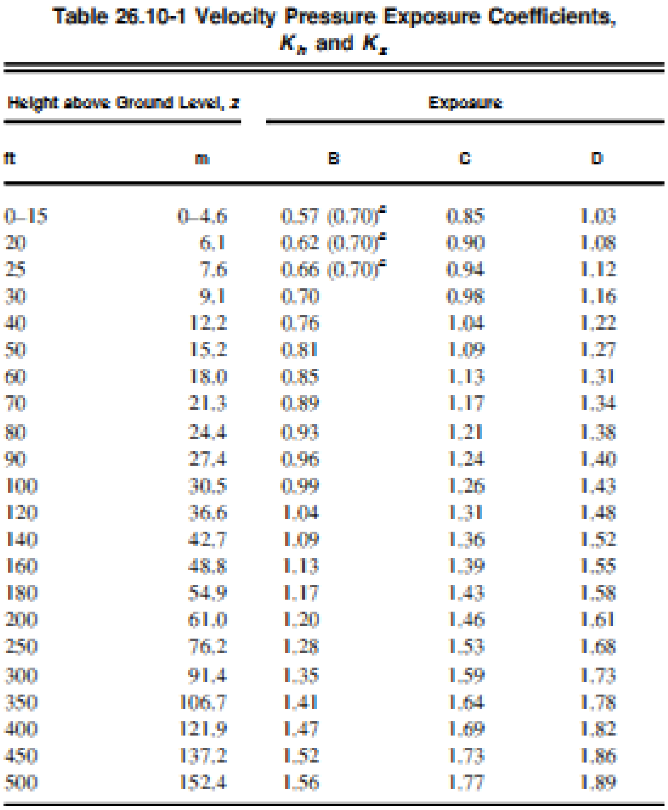


Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70)[c]	0.85	1.03
20	6.1	0.62 (0.70)[c]	0.90	1.08
25	7.6	0.66 (0.70)[c]	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38
90	27.4	0.96	1.24	1.40
100	30.5	0.99	1.26	1.43
120	36.6	1.04	1.31	1.48
140	42.7	1.09	1.36	1.52
160	48.8	1.13	1.39	1.55
180	54.9	1.17	1.43	1.58
200	61.0	1.20	1.46	1.61
250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

To determine the values of the factors of K_{zt}, the following equation is used.

$$K_{zt} = (1 + K_1 {*} K_2 {*} K_3)^2$$

K_1, K_2 and K_3 are factors based upon local topography of the building; ASCE7 Section 26.8.2. These values estimate the increase of wind speed at the tops of hills. This phenomenon is actually an increase in turbulent flow at the boundary layer (ground) due to the movement of the wind up the hill. This turbulent flow drops off rapidly as you get further away from the boundary. At some point, the flow changes back to laminar and the wind speed will match the upstream average speed. Specifically, K_3 is the factor that would change as 'z' changes. Since, by definition, rooftop equipment is at the max value of 'z', it is safe to assume that K_3 is zero, which makes $K_{zt} = 1.0$.

The directionality factor, K_d, is dependent upon the geometry of the equipment in plan view. For square or rectangular sections, $K_d = 0.9$. If the equipment has a rounded or hexagonal shape, $K_d = 0.95$.

Examples:

A. Typical large brand unitary Air Handling Unit: (For the purpose of this example, all horizontal CG's are assumed at to be at the center of the unit)

10 Ton Unit
- Weight = 1200#
- Length = 100"
- Width = 64"
- Height = 51"
- Curb OD = 84"x60"x14" High

Building – Hospital on the South Shore of Long Island
- Risk Category IV
- Height= 45 feet
- Exposure Category 'D'
- Design Wind Speed = 140 mph (From Map 26.5-1B)

Steps:

1. Determine which equation to use
   a. Since the building is less than 60 feet, than we are to use 29.5-2.

2. Calculate q_h
   a. $q_h = 0.00256 * K_z * K_{zt} * K_d * V^2$

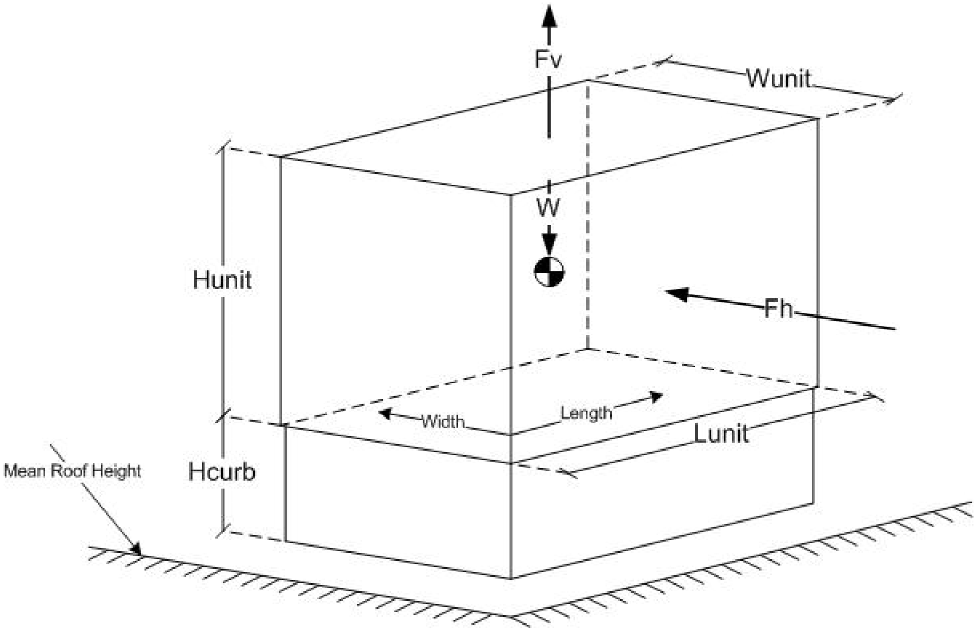
      Kz = 1.245 (Interpolated from 1.22 and 1.27 from table
      Kzt = 1.0
      Kd = 0.9 (Rectangular cross-section)
      $q_h = 0.00256 * 1.245 * 1.0 * 0.9 * 140^2 = 56.2$ psf

3. Calculate Af and Ar
    a. Since the GCr factor is maximized at 1.9, it is acceptable to use the largest single side, instead of the diagonal.

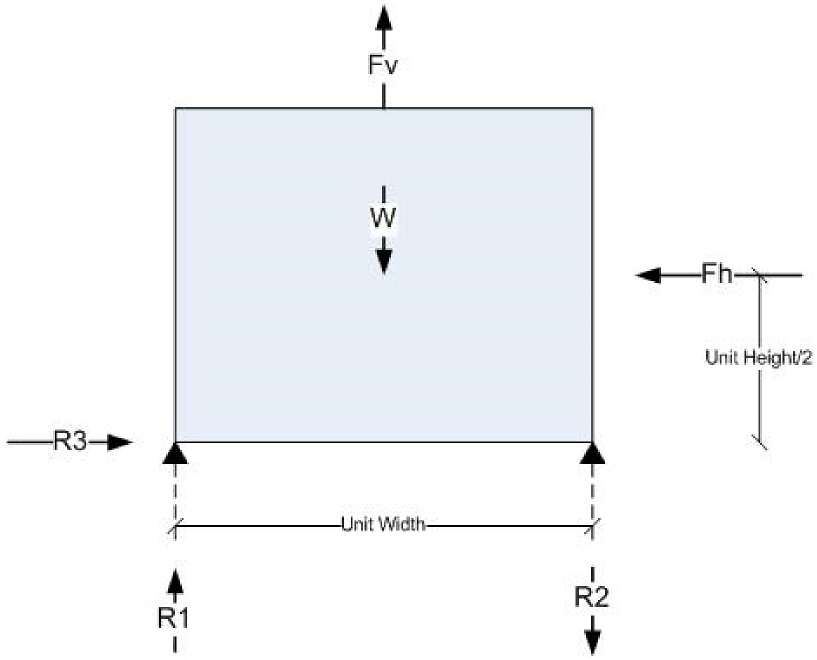
Af = Length*Height/144 = 100”*51”/144 = 35.4 ft^2
Af (with curb) = 100”*65”/144 = 45.1 ft^2
Ar = Length*Width/144 = 100”*64”/144 = 44.4 ft^2

4. Calculate F_h
    a. $F_h = q_h(GC_r)A_f$
    F_h = 56.2*1.9*35.4 = <u>3780#</u>
    Fh (with curb) = <u>4820#</u>

5. Calculate Fv
    a. Fv = qh(GCr)Ar
    Fv = 56.2*1.5*44.4 = <u>3743#</u>



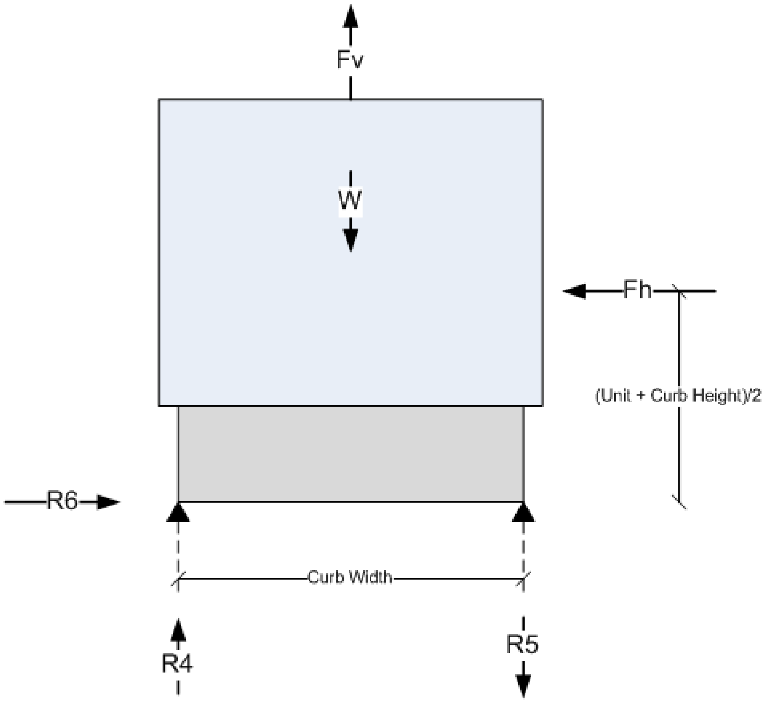
Calculation of Overturning Loads:



R1 = (W-Fv)/2 +Fh*(H/2)/w = 235# (Compression)
R2 = (Fv-W)/2 + Fh*(H/2)/w = 2778# (Tension)
R3 = Fh = 3780# (Shear)

Due to these loads, the windward side of the curb would need to be designed for 2778# of tension pulling up on the curb. Since the direction is unknown, both sides must be designed for this 2778#. Typical units of this size have formed base rails that must be positively attached to. Positive attachment in this case would be bolting, screwing or welding. The capability of the attachment would need to account for the thickness of the base metal of the unit. The curb must also have the capability of carrying the 3780# in shear.

Due to the additional height of the curb, the loads at the base of the curb will be greater.



R4 = (W-Fv)/2 +Fh*(H/2)/w = 1339# (Compression)
R5 = (Fv-W)/2 + Fh*(H/2)/w = 3882# (Tension)
R6 = Fh = 4820# (Shear)

Including the curb increases the tension and shear load dramatically. The base of the curb, at the attachment to building structure, now must be designed for 3882# in tension and 4820# in shear. This also must be a positive attachment to structure.

B. Assume all of the same parameters, except the building height will now be 70 feet.

Steps:

1. Determine which equation to use
    a. Since the building is greater than 60 feet, than we are to use 29.5-1.
2. Calculate q_h
    a. $q_h = 0.00256*K_z*K_{zt}*K_d*V^2$

       Kz = 1.34
       Kzt = 1.0
       Kd = 0.9 (Rectangular cross-section)

$q_h = 0.00256*1.34*1.0*0.9*140^2 = 60.5$ psf

3. Calculate Af and Ar
   a. For this calculation, the diagonal projected area must also be calculated.

      Af = Length*Height/144 = 100"*51"/144 = 35.4 ft^2
      Af (with curb) = 100"*65"/144 = 45.1 ft^2

      Diagonal Af = Diag*Height/144 = 119"*51"/144 = 42.1 ft^2
      Af (with curb) = 119"*65"/144 = 53.7 ft^2

      Ar = Length*Width/144 = 100"*64"/144 = 44.4 ft^2

4. Calculate F
   a. $F = q_z G C_f A_f$

      Per standard, G = 0.85
      Calculate h/d = 51/64 = 0.8
      For Rectangular Cross-sections at h/d < 1, Cf = 1.3 for loads normal to face and 1.0 along diagonal

      Normal to face:
      F = 60.5*0.85*1.3*35.4 = <u>2367#</u>
      F (with curb) = <u>3015#</u>

      Along Diagonal:
      F = 60.5*0.85*1.0*42.1 = <u>2165#</u>
      F (with curb) = <u>2762#</u>

      Use the normal loads for design of curb and attachments.

5. Calculate Fv
   a. Fv = qh(GCr)Ar
      Fv = 60.5*1.5*44.4 = <u>4029#</u>

The horizontal loads at a building height of 70 feet are significantly lower than at 45 feet due to the (GCr) being 1.9 by code. The vertical load, though, is slightly higher. The analysis at this point is similar to Example A.

VISCMA is a non-profit association representing the manufacturers of seismic restraint, vibration isolation and noise control equipment. The primary objectives of the organization are to educate the construction industry on the proper use and application of vibration isolation and seismic restraint and to develop standards to continually improve the industry.

In partnership with FEMA and ASCE, VISCMA also publishes three Seismic Installation and Inspection Manuals designed to assist field personnel.

The association office is located at 994 Old Eagle School Road, Suite 1019, Wayne, PA 19087-1866 and can be reached at 610-971-4850 or info@viscma.com.