Calculating Wind Loads on Buildings Using the Envelope Procedure of ASCE 7-22 Code

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Credit: 2 PDH

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COURSE CONTENT

Introduction

Structures must be built to withstand wind loads prescribed by the code, as must their constituent parts. To ensure the safety and stability of structures against wind forces, the fundamental component of structural engineering known as wind load cannot be ignored, which is the force that the wind exerts on a structure (Fig. 1).

ASCE 7 offers techniques for determining the design wind pressure depending on two types of applications: components and claddings (C&C) or the main wind force-resisting system (MWFRS). Given that the most recent version of ASCE7-22 is consistent with the International Building Code (IBC), which considers the most recent developments and structural engineering research , wind load analysis will be utilized to ensure the safety and longevity of buildings even in the face of severe wind conditions.

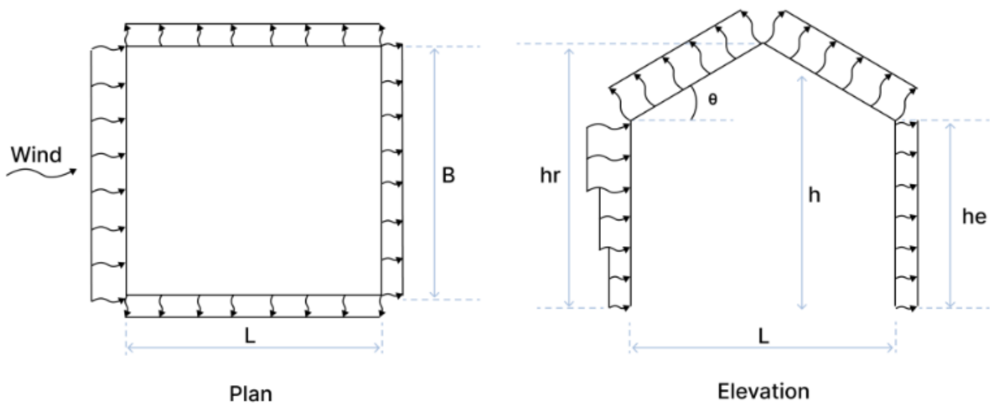


Figure 1 : Wind loads exerted on a structure by the wind

Importance of wind load checks

Light weight structures like steel and timber structures are more likely to fail under wind impacts due to their small weights compared to concrete ones; hence, it is more important to calculate wind load combinations and check their efficiency and stability to resist.

This course gives enough information about how wind loads are calculated using the envelope procedure of ASCE 7-22 Code to enable the professional engineer to correctly understand the standard wind load requirements. The examples extensively reference sections of the standard as well as its figures and tables. A copy of ASCE 7-22 Code is required in order to work with these courses and follow the examples.

Highlights of the Major Modifications to ASCE 7-22's Wind Load Provisions

ASCE/SEI 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (commonly referred to as ASCE 7-22), developed and published by the American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI), will be the primary reference standard for structural loads in the 2024 *International Building Code, 2024 International Residential Code, and the 8th Edition (2023) Florida Building Code*. The standard specifies minimum structural design loads and other criteria for the design of buildings and other structures for dead, live, soil, flood, tsunami, snow, rain, atmospheric ice, earthquake, wind, and tornado loads. It also provides criteria on how to assess load combinations.

This overview highlights a few of the key significant changes to the wind loading design provisions contained in ASCE 7-22, as compared to the previous version (ASCE 7-16), that will affect building design. The topics in this overview include:

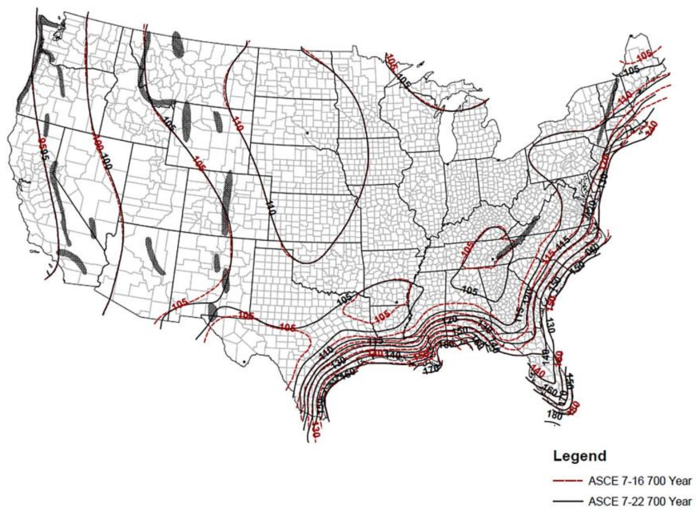
♣ Changes to the basic wind speed maps
♣ Change to the Wind-borne Debris Region (WBDR)
♣ Changes to the component and cladding external pressure coefficients (GCp) for roofs of buildings with roof slopes greater than 7°

Changes to the Basic Wind Speed Maps

The basic wind speed maps in ASCE 7-22 have been revised primarily in hurricane-prone regions. These changes are the result of ongoing improvements to the hurricane simulation model that is used to develop the wind speeds in hurricane-prone regions. The changes also include better wind speed estimates in the areas where hurricane wind speeds transition to non-hurricane wind speeds adjacent to the hurricane-prone coast.

Summary of changes to basic wind speeds in hurricane-prone regions:
♣ Decreases along the North-Atlantic coast
♣ Minor adjustments in the Carolinas and Virginia
♣ Increases along the Florida panhandle and big bend areas
♣ Slight decreases along the coastal areas of Alabama, Mississippi, and Louisiana
♣ Increases along the coastal areas of Texas

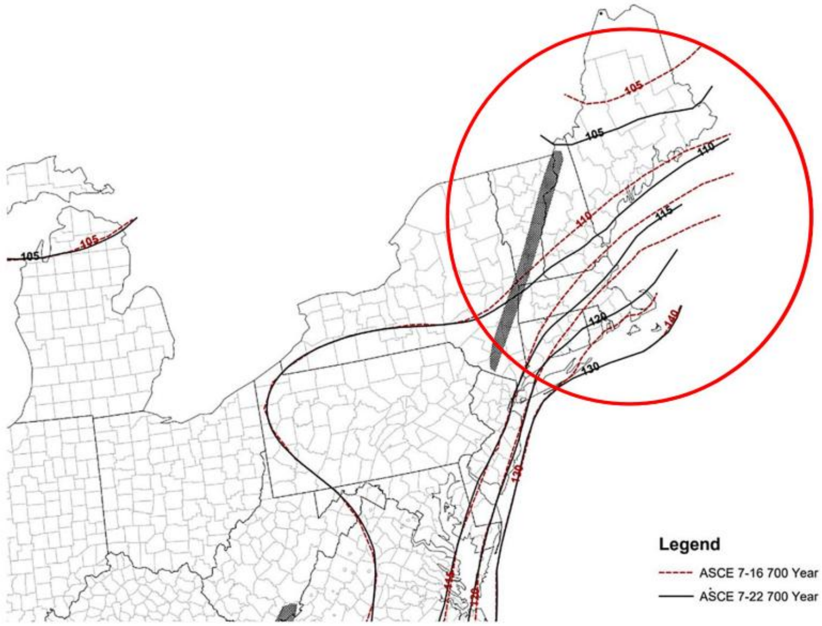
Figure 2 illustrates the changes to the basic wind speeds for Risk Category II buildings and structures in ASCE 7-22. The red dashed contours are the ASCE 7-16 Risk Category II wind speeds. The black contours are the ASCE 7-22 Risk Category II wind speeds. Similar adjustments occur for the Risk Category I, III, and IV maps.



(Source: Adapted from Figure 26.5-1B of ASCE 7-16 and Figure 26.5-1B of ASCE 7-22 with permission)

Figure 2: Comparison of basic wind speeds for Risk Category II buildings and structures in ASCE 7-16 and ASCE 7-22

Figure 3 provides a more detailed view of the changes along the North-Atlantic coast. Basic wind speeds for the North-Atlantic region have been decreasing from previous versions for the last three editions of ASCE 7. While wind speed contours have generally moved closer to the coast, reflecting slightly lower wind speeds, the shift of the 130- miles-per-hour (mph) contour completely off the coast is notable. (The 130 mph Risk Category II wind speed is the trigger in the *International Residential Code* for the *Wind Design Required Region* and one of the triggers for the *Wind-borne Debris Region*. The North-Atlantic is now completely out of both regions and conventional construction as permitted in the *International Residential Code* will be permitted throughout the area.)



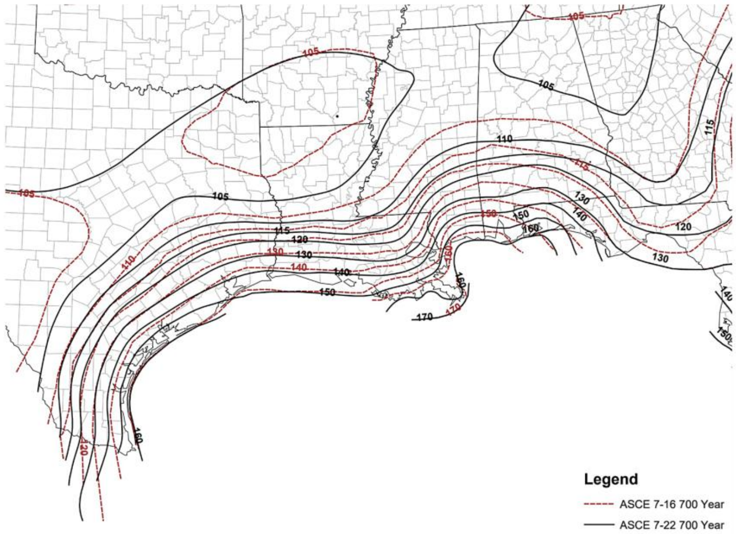
(Source: Adapted from Figure 26.5-1B of ASCE 7-16 and Figure 26.5-1B of ASCE 7-22 with permission)

Figure 3: Basic wind speed changes along the North-Atlantic coast for Risk Category II buildings and structures

Figure 4 provides a more detailed view of the changes along the Gulf coast. Along the south Texas coast, basic wind speeds have increased by approximately 10 mph. Further inland (130 mph and less) wind speeds are slightly lower.

Along the coastal areas of Louisiana, Mississippi, and Alabama wind speeds have generally decreased for most areas. The decrease is more significant in some areas than others. For example, the ASCE 7-16 Risk Category II wind speed for Mobile, Alabama, is 154 mph. In ASCE 7-22, the Risk Category II wind speed is 146 mph (approximately a 5% decrease). For Gulf Shores, Alabama, the wind speed is essentially the same in ASCE 7-22 as it is in ASCE 7-16.

In the Florida panhandle area, wind speeds have increased in some areas of the western part of the panhandle. For example, the ASCE 7-16 Risk Category II wind speed for Destin, Florida, is 142 mph. In ASCE 7-22, the Risk Category II wind speed is 152 mph (approximately a 7% increase). In the big bend area of Florida (informal region of Florida generally stretching from the Apalachicola River to the St. Johns River), the wind speeds have increased from ASCE 7-16 but are essentially the same as they were in ASCE 7-10. (While the 7th Edition (2020) *Florida Building Code* did adopt ASCE 7-16, it did not adopt the ASCE 7-16 Risk Category II basic wind speed map and maintained the ASCE 7-10 Risk Category II basic wind speed map.)



(Source: Adapted from Figure 26.5-1B of ASCE 7-16 and Figure 26.5-1B of ASCE 7-22 with permission)

Figure 4: Basic wind speed changes along the Gulf coast for Risk Category II buildings and structures

Changes to the Wind-borne Debris Region

As with ASCE 7-16, areas within hurricane-prone regions where the basic wind speed is 140 mph or greater are included in the WBDR unconditionally. However, the location of the WBDR has undergone a small but significant change in hurricane-prone regions where the basic wind speed is less than 140 mph but greater than or equal to 130 mph. The locations where the WBDR applies have been revised as follows:

ASCE 7-22

26.12.3.1 Wind-Borne Debris Regions. Glazed openings shall be protected in accordance with Section 26.12.3.2 in the following locations:

- Within 1 mi (1.6 km) of the ~~coastal~~ mean high water line where an Exposure D condition exists upwind of the water line and the basic wind speed is equal to or greater than 130 mi/hr (58 m/s), or
- In areas where the basic wind speed is equal to or greater than 140 mi/h (63 m/s).

The term "coastal mean high-water line" is not a defined term, and its interpretation has varied across jurisdictions in the hurricane-prone region due to confusion about the intent. The new criteria in ASCE 7-22 deletes the word "coastal" and adds language to require that an Exposure D condition exist upwind of the water line. This trigger now applies to locations that are within a mile of any body of water (located in hurricane-prone regions where the basic wind speed is equal to or greater than 130 mph and less than 140 mph) and an Exposure D condition exists upwind of the water line. In hurricane-prone regions, Exposure D applies where a water exposure prevails in the upwind direction for 5000 feet or 20 times the height of the building. The impact of this change is illustrated in Figure 5 for the Panama City area of Florida where the basic wind speed ranges from 130 mph to 140 mph.

For area A, buildings within 1 mile of the mean high-water line of the Gulf of Mexico where the basic wind speed is equal to or greater than 130 mph are clearly within the WBDR. However, for area B, the initial point to measure "1 mile from the coastal mean high-water line" was not clear in ASCE 7-16 and earlier editions. In ASCE 7-22, this ambiguity has been removed. In the bay area (area B), any building located within 1 mile of the mean high-water line of the bay that has exposure to a water surface that prevails for at least 5000 feet from the shoreline will be in the WBDR.

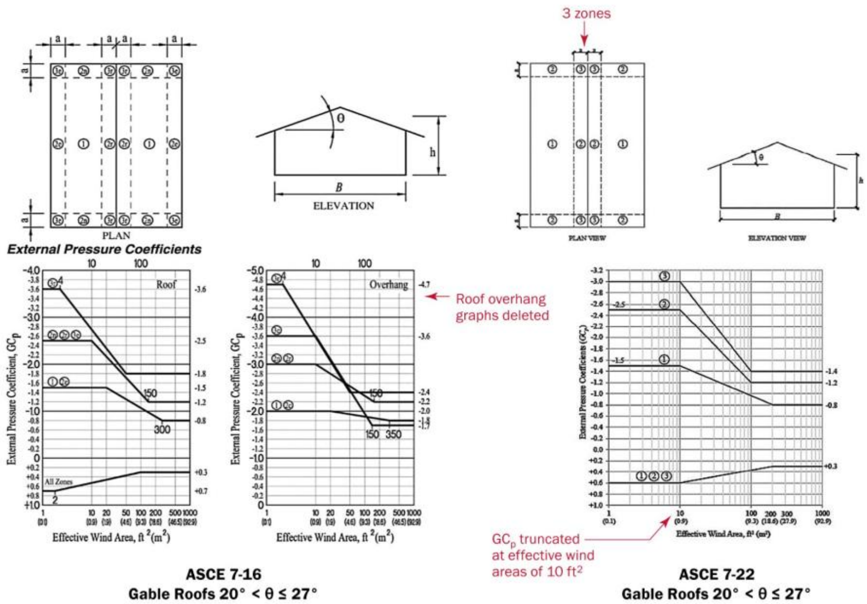
Figure 5: Changes to the location of the WBDR in ASCE 7-22

Changes to External Pressure Coefficients for Roofs of Buildings with Gable and Hip Roofs Having Slopes Greater than 7 Degrees

Component and cladding external pressure coefficients, GCp, have been revised again in ASCE 7-22 for buildings with gabled and hipped roofs and roof slopes greater than 7°. The changes represent simplifications to the zones on the roofs and lower pressure coefficients for some zones. The external pressure coefficients for flat roofs ($\theta \leq 7°$) are unchanged from ASCE 7-16. For buildings with gable and hip roofs and slopes of $7° < \theta \leq 45°$, the changes include:

♣ Simplified log graphs with three zones
♣ All zones truncated at effective wind areas of 10 square feet (ft^2)
♣ Roof overhang loads determined by summing the roof surface GCp with the adjacent wall surface GCp

The changes mostly result in no change or reductions in roof pressure coefficients and corresponding design loads on buildings with roof slopes greater than 7° as compared to ASCE 7-16. However, the change back to three zones greatly simplifies the figures. Figure 6 is an excerpt of Figure 30.3-2C in ASCE 7-16 and ASCE 7-22 and is annotated to provide specific pointers to the changes to the figure. Table 1 highlights the effect of these changes in ASCE 7-22 by providing examples of how the design wind pressure changes for a few select zones.



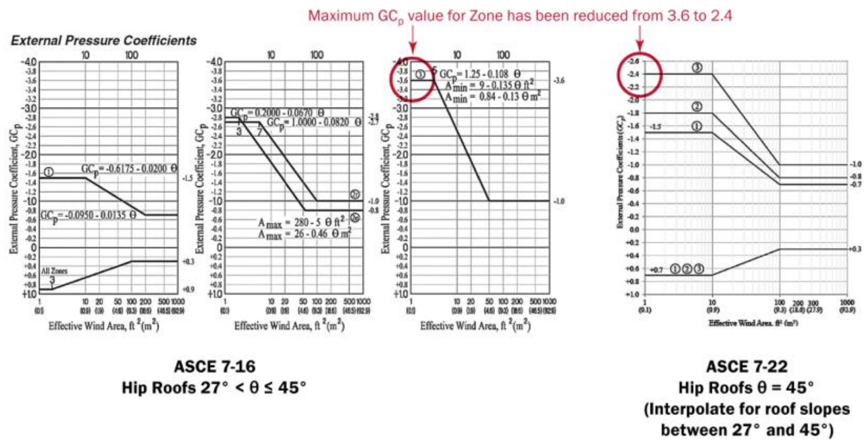
(Sources: ASCE 7-16 and ASCE 7-22)

Figure 6: Annotated excerpt of Figure 30.3-2C in ASCE 7-22 (Gable roofs, 20°< θ ≤ 27°) as compared to ASCE 7-16

Table 1. Example Changes to Roof Component and Cladding Design Pressures for Enclosed Buildings

Zone	ASCE 7-16 GC_p	ASCE 7-22 GC_p	Design Pressure Change for Minimum Effective Wind Area
Gable roofs, 20° < θ ≤ 27°			
3r (ASCE 7-16) 3 (ASCE 7-22)	-3.6	-3.0	-16%
Gable roofs, 27° < θ ≤ 45°			
3e (ASCE 7-16) 3 (ASCE 7-22)	-3.2	-2.5	-21%

External pressure coefficients for hip roofs have been particularly simplified. The delineation of GC_p graphs based on h/B ratios for certain roof slopes has been deleted. Figure 7 provides a representative example of how the determination of external pressure coefficients for hip roofs has been simplified.



(Sources: ASCE 7-16 and ASCE 7-22)

Figure 7: Comparison of External Pressure Coefficients, GCp, for Hip Roofs with θ > 27° from Figure 30.3-2H in ASCE 7-16 and Figure 30.3-2G in ASCE 7-22

Separate graphs for roof overhang external pressure coefficients for gable and hip roofs with slopes 7° < θ ≤ 45°have been deleted. Roof overhang external pressure coefficients for these shapes are now addressed in Section 30.7 and are determined by the sum of the GC_p of the overhang's top and bottom surfaces determined by the applicable roof and wall external pressure coefficients. Figure 8 illustrates the determination of roof overhang external pressure coefficients, GC_p.

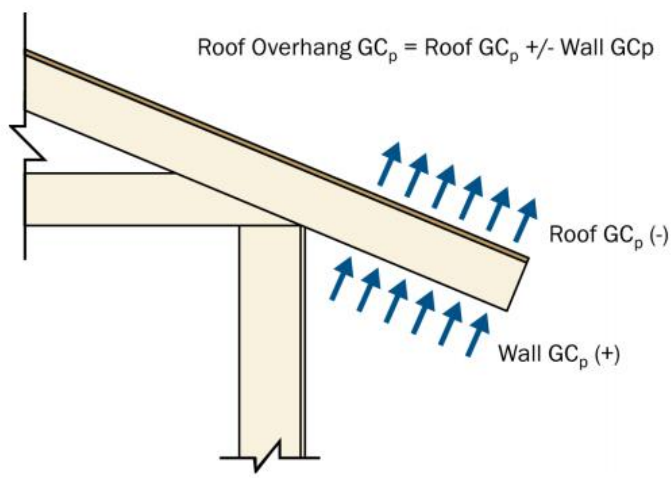


Figure 8: Determination of Roof Overhang GCp

Other Changes to ASCE 7-22

See the References section for more information on the changes described in this fact sheet and for information on the summary of additional wind loading changes listed below:

♣ Deletion of the simplified methods (Chapters 27, 28, and 30)
♣ Revisions to the velocity pressure exposure coefficient, Kz (Section 26.10)
♣ New Chapter addressing tornado design (Chapter 32, See FEMA's ASCE 7-22 Tornado Loads Fact Sheet: TBD)
♣ New criteria for roof pavers (Section 30.12)
♣ New provisions for ground-mounted solar panels (Section 29.4.5)
♣ Adjustments to the topographic multiplier, Kzt (Section 26.8)
♣ New provisions for Main Wind Force Resisting System and Component and Cladding loads on elevated buildings (Sections 27.3.1.1 and 30.3.2.1)
♣ Revised wall external pressure coefficients, GCp, for h > 60 feet (Section 30.4)
♣ New provisions for attached canopies on buildings with h > 60 feet (Section 30.9)
♣ Roof pressure zones for buildings with stepped flat roofs and heights ≤ 60 feet have been updated to reflect the appropriate flat roof pressure zones (Figure 30.3-3)
♣ (ASCE7HazardTool.online).

Engineers can reduce the chance of failure during extreme weather events by making sure that structures are built to securely withstand wind loads by adhering to ASCE 7-22 rules. Always consult the most recent edition of ASCE 7-22 for the most precise and current specifications.

<u>Advantages of Envelope Procedure of ASCE 7-22</u>

According to ASCE 7-22, there are two ways to calculate wind loads: the Directional Procedure (Chapter 27) and the Envelope Procedure (Chapter 28) on the MWFRS of buildings. However, they differ significantly in their approach and applicability. Here's a comparison of their advantages:

Envelope Procedure (Chapter 28, ASCE 7-22):

- **Advantages:**
  - **Simplified Application for Low-Rise Buildings:** The Envelope Procedure is specifically tailored and simplified for low-rise buildings (mean roof height $h \leq$ 60 ft) meeting certain other geometric limitations. This simplification can lead to quicker calculations and a more straightforward application for these common building types.
  - **Considers Maximum Effects Regardless of Wind Direction:** The procedure uses combined gust effect factors and external pressure coefficients (GCp) that are developed to *envelope* the maximum structural actions (like uplift, shear, and moments) that would occur under various wind directions. This means you don't need to analyze multiple specific wind directions to find the critical loading.
  - **Basis for Prescriptive Methods:** The Envelope Procedure forms the basis for many simplified and prescriptive wind load methods found in building codes,

making it inherently linked to common construction practices for simpler structures.

Directional Procedure (Chapter 27, ASCE 7-22):

- **Advantages:**
    - **Applicable to All Building Types and Heights:** The Directional Procedure is a more fundamental and generally applicable method that can be used for buildings of any height and complexity, including those outside the limitations of the Envelope Procedure.
    - **Provides More Detailed and Potentially More Economical Design:** By analyzing wind loads from specific critical wind directions, the Directional Procedure can sometimes result in more refined and potentially less conservative design forces compared to the enveloped maximums of the Envelope Procedure. This can lead to more efficient material usage and cost savings for complex or tall structures.
    - **Better Understanding of Actual Load Distribution:** The Directional Procedure provides a clearer understanding of how wind loads are distributed on the building for specific wind directions, which can be crucial for the detailed design of individual structural members and connections.
    - **Required for Complex Geometries:** For buildings with unusual shapes or significant irregularities, the assumptions inherent in the Envelope Procedure might not be valid, making the Directional Procedure the more appropriate choice.

In summary:

- **Use the Envelope Procedure when:** You have a low-rise building meeting the specified limitations and desire a simpler, quicker method that inherently considers the maximum wind effects without analyzing multiple directions.
- **Use the Directional Procedure when:** You have a building outside the low-rise limitations, a complex geometry, or you need a more detailed understanding of wind load distribution for specific wind directions, potentially leading to a more economical design.

It's important to note that both procedures are valid under ASCE 7-22 for low-rise buildings meeting the criteria, and professional engineers must choose the method they are most comfortable with and that best suits the specific project requirements. For buildings outside the scope of the Envelope Procedure, the Directional Procedure is mandatory.

Applicability and Key Steps of Envelope Procedure for Wind Loads on Low-Rise Buildings according to ASCE 7-22

1. Applicability:

- **Low-Rise Building Definition (ASCE 7-22 Section 26.2):** To qualify for the Envelope Procedure, a building must meet **all** of the following criteria:

  - It must be an **enclosed, partially enclosed, or partially open building**. These enclosure classifications are defined in ASCE 7-22 Section 26.2 and Table 26.13-1 (used for internal pressure coefficients).
  - The **mean roof height (h)** must be ≤ **60 feet (18.3 meters)**. The mean roof height is the average height of the roof surface, except that eave height shall be used for roof angles ≤ 10 degrees.
  - The **mean roof height (h)** must not exceed the **least horizontal dimension** of the building. This means if your building is 50 feet wide and 100 feet long, the mean roof height cannot be greater than 50 feet.
  - The building must have a **simple diaphragm building** as defined in Chapter 26. This generally implies a relatively rigid horizontal structure that distributes lateral loads.
  - The building **cannot** have an **arched, barrel, or unusually shaped roof**. These roof types require the Directional Procedure or wind tunnel testing.
- **Why These Limitations?** The Envelope Procedure uses simplified pressure coefficients that are based on typical wind flow patterns around relatively simple, low-rise building shapes. These assumptions may not be valid for taller or more complex structures where wind flow becomes more intricate.

Key Steps in Detail:

Step 1: Determine the Risk Category (ASCE 7-22 Table 1.5-1):

  - The Risk Category classifies buildings and other structures based on the potential consequences to human life, health, and welfare in the event of failure. This category influences the importance factor (I) used in other load calculations (like seismic), but it's a fundamental characteristic of the building that needs to be established early.

Step 2: Determine the Basic Wind Speed (V) (ASCE 7-22 Figure 26.5-1A to 1D):

- The basic wind speed is the 3-second gust speed at 33 feet (10 meters) above ground in Exposure C (open terrain) with an annual probability of exceedance of 0.01 (approximately a 50-year mean recurrence interval).
- You must use the appropriate wind speed map for the determined Risk Category. ASCE 7-22 provides separate maps for Risk Categories I, II, III, and IV.
- For special wind regions (near mountainous terrain and gorges), local jurisdiction requirements govern.

Step 3: Determine Site Factors (K_{zt} and K_e) (ASCE 7-22 Table 26.10-1 and Section 26.10):

- **Topographic Factor (K_{zt}) (ASCE 7-22 Section 26.8):** This factor accounts for the speed-up effect of wind over hills, ridges, and escarpments. If the building is located in such a topographic feature, K_{zt} will be greater than 1.0. If the site is relatively flat, K_{zt} can be taken as 1.0. Determining K_{zt} involves considering the shape and dimensions of the topographic feature and the building's location relative to its crest.
- **Ground Elevation Factor (K_e) (ASCE 7-22 Section 26.9 and Table 26.9-1):** This factor accounts for the change in air density with elevation. It's a new factor in ASCE 7-22. While ASCE 7-22 permits K_e = 1.0 for all elevations, considering it can lead to more accurate wind load calculations, especially at higher elevations where air density is lower.

Step 4: Calculate the Velocity Pressure (qz) (ASCE 7-22 Equation 26.10-1):

- The velocity pressure is the dynamic pressure of the wind at a specific height (z) above the ground. For the Envelope Procedure applied to the MWFRS of low-rise buildings, the velocity pressure is evaluated at the mean roof height (h), so it becomes q_h.

The equation is:

$$q_z = 0.00256 * K_z * K_{zt} * K_e * V^2 \quad \text{(in lb/ft}^2\text{) (for V in mph)}$$
$$q_z = 0.613 * K_z * K_{zt} * K_e * V^2 \quad \text{(in N/m}^2\text{) (for V in m/s)}$$

Where:

At height z, the velocity pressure exposure coefficient (K_z) is calculated. For the Envelope Procedure, use K_h (evaluated at mean roof height h) from ASCE 7-22 Table 26.10-1 based on the exposure category.

K_{zt} is the topographic factor.

K_e is the ground elevation factor.

V is the basic wind speed.

Step 5: Determine the Internal Pressure Coefficient (GC_{pi}) (ASCE 7-22 Table 26.13-1):

- The internal pressure acting inside a building depends on its enclosure classification:
  - **Enclosed Buildings:** Have openings that comply with specific leakage requirements. GC_{pi} values are ±0.18.
  - **Partially Enclosed Buildings:** Have a larger percentage of openings in one or more surfaces. GC_{pi} values are ±0.55.
  - **Open Buildings:** Have no enclosure. GC_{pi} = 0.0.
  - **Partially Open Buildings:** Have permanent openings. GC_{pi} values are determined based on the percentage of openings.
- The positive and negative GC_{pi} values must be considered to determine the most critical loading conditions (outward and inward pressures).

Step 6: Determine the External Pressure Coefficients (GC_{pf}) (ASCE 7-22 Figure 28.3-1):

- This is a crucial step specifically to the Envelope Procedure for low-rise buildings. Figure 28.3-1 provides a set of external pressure coefficients (GC_{pf}) that are constant for specific roof and wall zones.
- The zones are defined based on the building geometry (dimensions L and B, where L is the longer horizontal dimension and B is the shorter horizontal dimension) and the mean roof height (h).
- You will need to determine the appropriate L/B and h/L ratios to select the correct GC_{pf} values for windward wall, leeward wall, sidewall, and various roof zones.
- Note that these GC_{pf} values already incorporate the gust effect factor (G).

Step 7: Calculate the Design Wind Pressures (p) (ASCE 7-22 Equation 28.3-1):

- The design wind pressure on each surface is calculated using the following equation:

  $$p = q_h * [(GC_{pf}) - (GC_{pi})]$$

  Where:

  - p is the design wind pressure in lb/ft² (or N/m²).
  - q_h is the velocity pressure evaluated at the mean roof height h.
  - GC_{pf} is the external pressure coefficient for the specific surface or zone from ASCE 7-22 Figure 28.3-1.
  - GC_{pi} is the internal pressure coefficient (positive and negative values must be considered).

Applying the Pressures:

- The resulting pressures are applied perpendicular to the surfaces of the building.

- For the MWFRS, these pressures are used to determine the overall forces and moments acting on the structural frame.

In summary, the Envelope Procedure simplifies wind load determination for specific low-rise buildings by providing enveloped external pressure coefficients that account for various wind directions. It involves a step-by-step process of determining site-specific wind parameters and applying these coefficients to calculate design pressures on different building surfaces.

EXAMPLE 1

The following example describes how wind loads on structures are calculated using the Envelope Procedure from Chapter 28 of ASCE 7-22 are given in this course. There are a number of restrictions on using this process. The building must be low-rise, as specified in ASCE 7-22, Chapter 26, Section 26.2. This is the main restriction. To be regarded as a low-rise structure, a structure needs to fulfill the following requirements:

1) Building that is entirely enclosed, partially enclosed, or partially open (these definitions are found in ASCE 7-22, Chapter 26, Section 26.2).
2) Mean roof height ≤ 60 ft.
3) Mean roof height < the least horizontal direction.
4) There are no arches, barrels, or oddly curved roofs on the building.

The pressures calculated by this method (**Envelope Procedure)** are limit state design pressures for strength design. The load factor for the wind load to be 1.0 for loads determined as indicated in ASCE 7-22 Chapter 2, Section 2.3. If allowable stress design is to be used, the load factor for the wind load is 0.6, as shown in Chapter 2, Section 2.4.

This example shows How to determine a large, one-story commercial / warehouse structure's design wind pressures using the envelope procedure. The building's dimensions and framing are seen in Figure 9. In Table 2, specific building data are displayed.

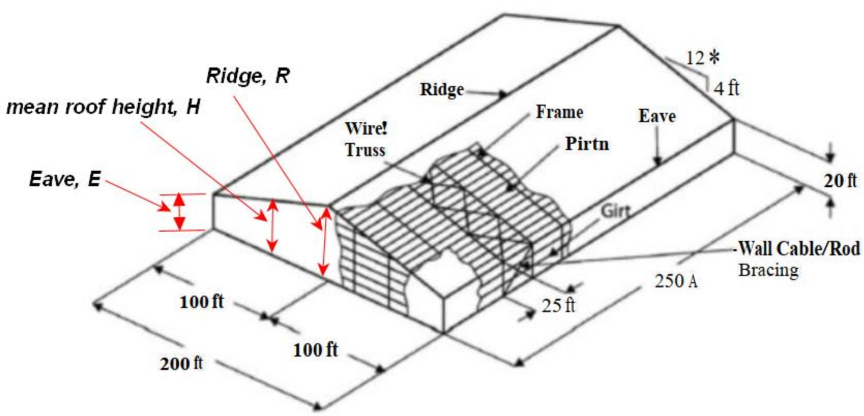


Figure 9: Building characteristics of commercial / warehouse metal building

Table 2. Data for Commercial/Warehouse Metal Building

Location	Lat: 31.81772, Long: –85.833578 (near Banks, Alabama)
Terrain	Flat farmland
Dimensions	200 ft x 250 It in plan
	Eave height of 20 ft
	Roof slope 4:12 (18.4 degrees)
Framing	Rigid frames span die 200 ft direction
	Rigid frame bay spacing is 25 ft
	Lateral bracing in the 250 ft direction is provided by a wind truss spanning the 200 ft to side walls and cable/rod bracing in the planes of the walls
	Girts and purlins span between rigid frames (25 ft span)
	Girt spacing is 6 ft 8 in.
	Purlin spacing is 5 ft
Cladding	Roof panel dimensions are 2 ft wide
	Roof fastener spacing on purlins is 1 ft on center
	Wall panel dimensions are 2 ft x 20 ft
	Wall fastener spacing on girts is 1 ft on center
	Openings are uniformly distributed

The building in this example has a mean roof height h = 36.7 ft and a least horizontal dimension of 200 ft. Therefore, it qualifies as a low-rise building, and the Envelope Procedure is permitted to be used. The procedure provided in ASCE 7-22, Chapter 28, Section 28.3 is used for this example.

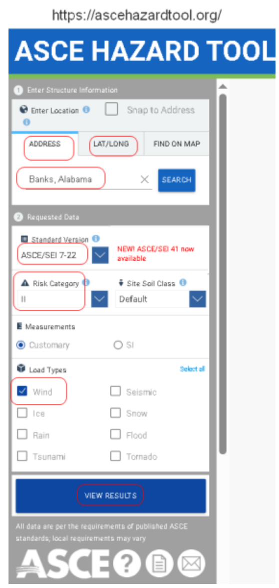
1. **Step 1. Determine the Risk Category (or Building Classification): "I", "II", "III" or "IV"**

According to ASCE 7-22 Table 1.5-1, structures are assigned a "Risk Category" in order to apply safeguards for flood, wind, tornado, snow, earthquake, and ice. The risk to human life, health, and welfare posed by their failure or damage as a result of their occupancy or usage is the basis for this classification.

The building function is commercial-industrial. It is not considered an essential facility and structural failure would not pose a substantial risk to human life. Therefore, in accordance with Table 1.6-1 of ASCE 7-22, ***Risk Category II*** is the appropriate classification.

2. **Step 2. Determine the Basic Wind Speed**

The selection of basic wind speed is addressed in ASCE 7-22, Chapter 26, Section 26.5.1. Using the geographic coordinates provided, the basic wind speed is ***V=116 mph*** (ASCE 7 Hazard Tool(see image below), https://ascehazardtool.org/).



The ASCE 7 Hazard Tool is a totally free of charge website that gives structural design parameters for earthquake, ice, tsunami, tornado, wind, flood, rain, snow, and other loads for various ASCE 7 editions. Addresses or latitude/longitude coordinates can be entered to obtain the pertinent site-specific structural design characteristics.

3. Step 3. DETERMINE WIND LOAD PARAMETERS

1) ***Wind Directionality Factor***: ***K_d = 0.85*** for buildings (Table 26.6-1 of ASCE 7-22).
The wind directionality factor, K_d, was transferred from the velocity pressure equation, q, to the design wind pressure equation, p, in ASCE 7-22. This calculator does not reflect the update, however the results are thought to differ only little.
The Wind Directionality Factor, K_d, is a load reduction factor to take into account it is very improbable that the maximum wind speed and the weakest direction of the building will coincide. Values for K_d provided in ASCE 7-22 is as per below.

2) ***Exposure Category***:
According to ASCE 7-22 Section 26.7.3, structures are categorized using a "Exposure Category" in order to assign velocity pressure exposure coefficients, Kh and Kz. They are described in ASCE 7-22, section 26.7.3.

The upwind exposure for each wind direction is based on the roughness of the ground surface, which is established by vegetation, natural topography, and built infrastructure. ASCE 7-22's section 26.7.2 defines the surface roughness classifications.

The building is located on flat and open farmland and does not qualify for Exposure B or D. Therefore, ***Exposure C*** applies (Chapter 26, Sections 26.7.2 and 26.7.3). Values of K_z are obtained from Table 26.10-1 of ASCE 7-22.

3) ***Topographic Factor:*** K_{zt} ***= 1.0*** for flat terrain (Chapter 26, Section 26.8).

According to ASCE 7-22 Section 26.8, the wind speed-up impact across isolated hills and escarpments is taken into consideration by the Topographic Factor, Kzt. Consult ASCE 7-22's Figure 26.8-1 to find the values of topographic multipliers K1, K2, and K3.

4) ***Ground Elevation Factor***: The ground elevation factor, K_e is a new factor in ASCE 7-22. K_e ***= 1.0*** for locations less than 1,000 ft in elevation above sea level (Chapter 26, Section 26.9).

5) ***Enclosure Classification***: **"Enclosed", "Open", "Partially Enclosed" or "Partially Open"**

According to ASCE 7-22 Section 26.2, rigid constructions are assigned a "Enclosure Classification" in order to define the internal pressure coefficient, or GCpi. Section 26.2 of ASCE 7-22 defines the classes.

Openings are assumed to be designed for the applicable component and cladding loads. Therefore, the enclosure classification is an ***enclosed building***.

6) ***Internal Pressure Coefficient***: $(GC_{pi,}) = \pm 0.18$ for enclosed buildings (Table 26.13-1 of ASCE 7-22).

4. Step 4. Determine the Velocity Pressure Exposure Coefficient

Note that the Envelope Procedure (Chapter 28 of ASCE 7-22) uses the mean roof height as the basis for all the wind pressure calculations [Equation (28.3-1)]. The velocity pressure exposure coefficient, K_h, is determined from Table 26.10-1 of ASCE 7-22 based on the mean roof height of the building.

The mean roof height for this building is at an elevation halfway between the eave height and the ridge height. The eave height is 20 ft, the roof slope is 4:12, and the building width is 200 ft. Therefore, the mean roof height is calculated as follows:

$h = 20\ ft + (½)\ (4/12)\ (100) = 36.7\ ft$

$K_h = 1.02$ from Table 26.10-1

5. Step 5. Determine Velocity Pressures

The velocity pressures are computed using the equation no. 26.10-1of ASCE 7-22 :

$$q_h = 0.00256\ K_h K_{zt} K_e V^2 \text{ psf} \qquad (26.10\text{-}1)$$

Where

V = 115 mph

K_{zt} = 1.0

K_e = 1.0

K_h = 1.02 (K_z at a height of 36.7 ft for Exposure C- Table 26.10-1)

The resulting ***velocity pressure*** calculated at mean roof height is

q_h = 0.00256 (1.02) (1.0) (1.0) $(115)^2$ = 34.6 psf

6. Step 6. Determine the External Pressure Coefficients, GC_{pf}, for Each Load Case

The roof and wall external pressure coefficients are provided in Figure 28.3-1 of ASCE 7-22 and vary depending on the roof slope, θ.

The external pressure coefficients for this building are shown in Tables 3 and 4.

Table 3. Load Case 1 (θ = 18.4 degrees) by Building Surface

	Building Surface							
	1	2	3	4	1E	2E	3E	4E
GC_{pf}	0.52	−0.69	−0.47	−0.42	0.78	−1.07	−0.67	−0.62

Note: Pressure coefficient is calculated by linear interpolation.

Table 4. Load Case 2 (θ = 0-90 degrees) by Building Surface

	Building Surface											
	1	2	3	4	5	6	1E	2E	3E	4E	5E	6E
GC_{pf}	−0.45	−0.69	−0.37	−0.45	0.40	−0.29	−0.48	−1.07	−0.53	−0.48	0.61	−0.43

7. Step 7. Calculate Wind Pressure, *p*

The equation for determining design wind pressures for MWFRS using the Envelope Procedure for low-rise buildings is given by Equation (28.3-1) in Chapter 28, Section 28.3.1 of ASCE 7-22:

$$p = q_h K_d[(GC_{pf}) - (GC_{pi})](\text{lb/ft}^2) \qquad (28.3\text{-}1)$$

Where
q_h = q_z = 34.6 psf
K_d = 0.85
(GC_{pf}) = see Tables 3 and 4
(GC_{pi}) = ± 0.18

Using the basic load cases, The structure needs to be designed for every wind direction depicted in Figure 28.3-1 of ASCE 7-22 and, if applicable, the torsional load cases shown in Figure 28.3-2 of ASCE 7-22.

To design for every direction of the wind , the load patterns shown in Figure 28.3-1are applied to each building comer in turn as the reference comer. This results in eight load patterns (specific drawings for each of the 8 load patterns are shown in Commentary Figure C28.3-1 of ASCE 7-22).
Since both positive and negative internal pressures need to be taken into account, there are sixteen separate load cases. The number of separate loading patterns required for design can be

lowered to eight if the structure is symmetrical. (Load Cases 1 through 4 with two internal pressures).

Calculate the width of Zone a:
The width of Zone a is the smaller of a =(0.1)(200) = 20 ft;

or (0.4)(36.7)=14.7 ft (controls);

but not less than (0.04)(200)=8 ft or 3 ft.

Note that most edge zones are 2a (29.4 ft) wide, whereas the edge zones on the end wall (5E and 6E) perpendicular to the ridge are a (14.7 ft) wide.

Calculate Design Wind Pressures:
Design wind pressures for Load Cases1and 2 are shown in Tables 5 and 6.

Table 5. Design Wind Pressures, Load Case 1 (θ = 18.4 degrees)

		Design Pressure (psf)	
Building Surface	(GC_{pf})	$(+GC_{pi})$	$(-GC_{pi})$
1	0.52	10.0	20.6
2	−0.69	−25.6	−15.0
3	−0.47	−19.1	−8.5
4	−0.42	−17.6	−7.0
1E	0.78	17.6	28.2
2E	−1.07	−36.8	−26.2
3E	−0.67	−25.0	−14.4
4E	−0.62	−23.5	−12.9

Table 6. Design Wind Pressures, Load Case 2

		Design Pressure (psf)	
Building Surface	(GC_{pf})	$(+GC_{pi})$	$(-GC_{pi})$
1	−0.45	−18.5	−7.9
2	−0.69	−25.6	−15.0
3	−0.37	−16.2	−5.6
4	−0.45	−18.5	−7.9
5	0.40	6.5	17.1
6	−0.29	−13.8	−3.2
1E	−0.48	−19.4	−8.8
2E	−1.07	−36.8	−26.2
3E	−0.53	−20.9	−10.3
4E	−0.48	−19.4	−8.8
5E	0.61	12.6	23.2
6E	−0.43	−17.9	−7.4

Example Calculation for Surface 1:

p = (34.6)(0.85)[0.52- (±0.18)] = +10.0 or +20.6

Application of Pressures on Building Surfaces 2 and 3

According to Note 8 of Figure 28.3-1 of ASCE 7-22, if the roof pressure coefficient, GCPf, is negative in Zone 2, it must be applied as far away from the roof's edge as 0.5 times the building's horizontal dimension measured parallel to the direction of the tire MWFRS being designed or 2.5 hours, whichever is less. For the remaining portion of Zone 2 that reaches the ridge line, the pressure coefficient GCpf for Zone 3 will be applied. This means that the distance from the roof's edge is the smaller of:

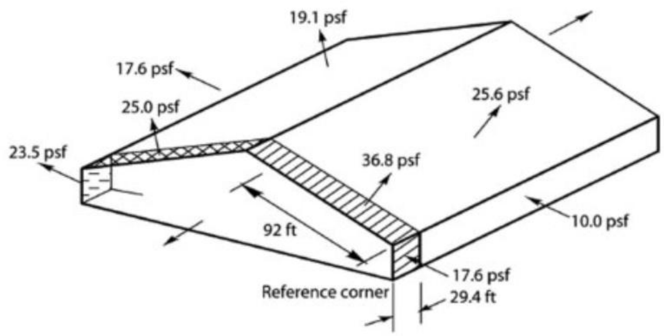
(0.5)(200)= 100 ft for transverse direction,
(0.5)(250)= 125 ft for longitudinal direction, or
(2.5)(36.7)= 92 ft for both directions (controls).

Therefore, Zone 3 applies over a distance of 105 ft -92 ft = 13 ft in what is normally considered to be Zone 2 (adjacent to ridge line).

Basic Loading Cases

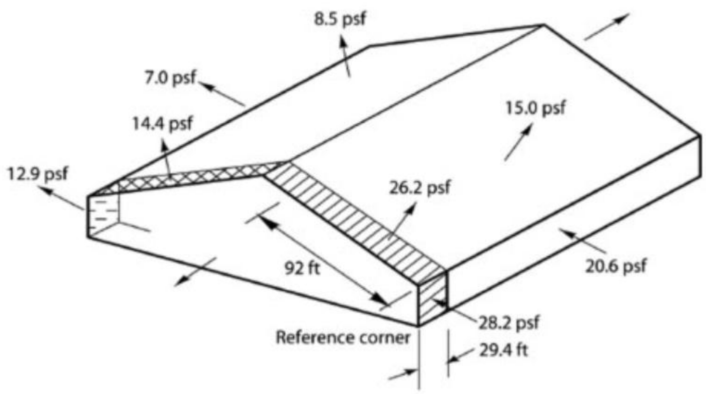
As long as the design is carried out by applying loads for each of the four comers, the two loading scenarios specify all the necessary combinations because the structure is symmetrical. The rigid frames, the wind truss that spans the building in a 200-foot direction, and the rod/cable bracing in the wall planes (see Figure 9) are to be designed using the combinations shown in Figures 10 through 13.

Figures 10 through 13 show design pressure cases for one reference corner. These cases are to be considered for each comer.



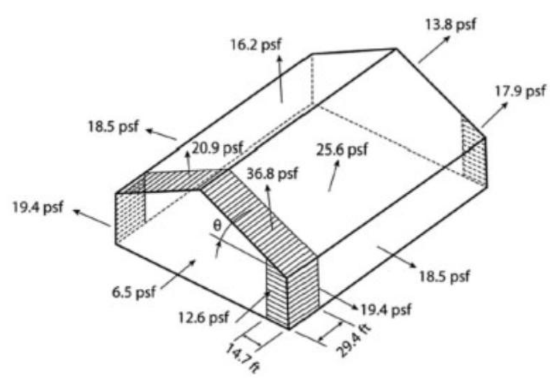
Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 10. Design pressures for Load Case 1 with positive internal pressure



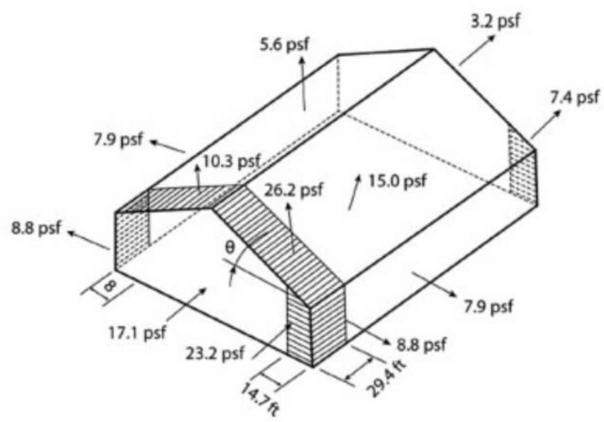
Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 11. Design pressures for Load Case 1 with negative internal pressure



Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 12. Design pressures for Load Case 2 with positive internal pressure



Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 13. Design pressures for Load Case 2 with negative internal pressure

Torsional Load Cases

Because the mean roof height, h = 36.7 ft, is greater than 30 ft, and if the roof diaphragm is assumed to be rigid, torsional load cases need to be considered (see ASCE 7-22, Chapter 28, Section 28.3.2 if the building is designed with a flexible diaphragm). The external pressure coefficients in T zones are provided in Figure 28.3-2 of ASCE 7-22 and are 25% of the full design pressures.

The full design forces will be applied to other surfaces. Tables 7 and 8 display the T-zone pressures with positive and negative internal pressures for the longitudinal and transverse axes, respectively.

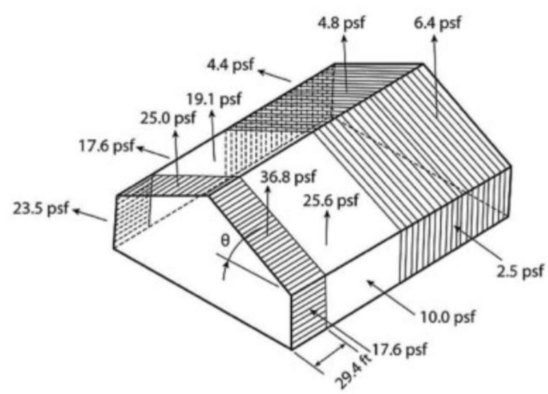
Table 7. Design Wind Pressure for Zone T, Load Case 3

	Design Pressures (psf)	
Building Surface	$(+GC_{pi})$	$(-GC_{pi})$
1T	2.5	5.2
2T	−6.4	−3.8
3T	−4.8	−2.1
4T	−4.4	−1.8

Table 8. Design Wind Pressure for Zone T, Load Case 4

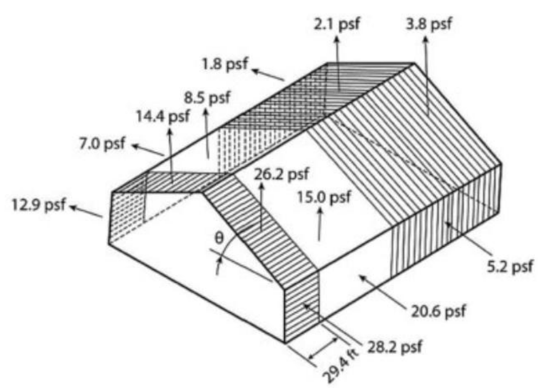
Building Surface	Design Pressures (psf) ($+GC_{pi}$)	Design Pressures (psf) ($-GC_{pi}$)
1T	−4.6	−2.0
2T	−6.4	−3.8
3T	−4.0	−1.4
4T	−4.6	−2.0
5T	1.6	4.3
6T	−3.4	−0.8

Figures 14 through 17 show design pressure cases for one reference comer. These cases are to be considered for each comer.



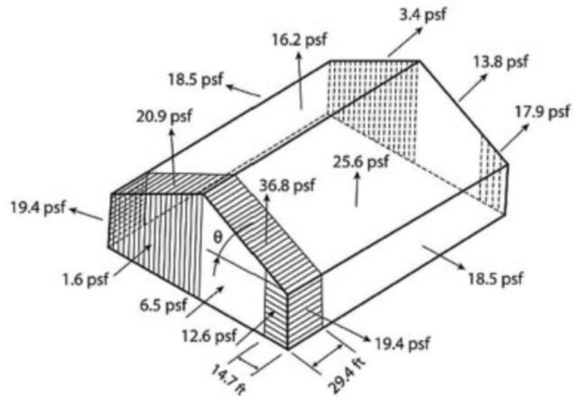
Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 14. Torsional Load Case 3 with positive internal pressure



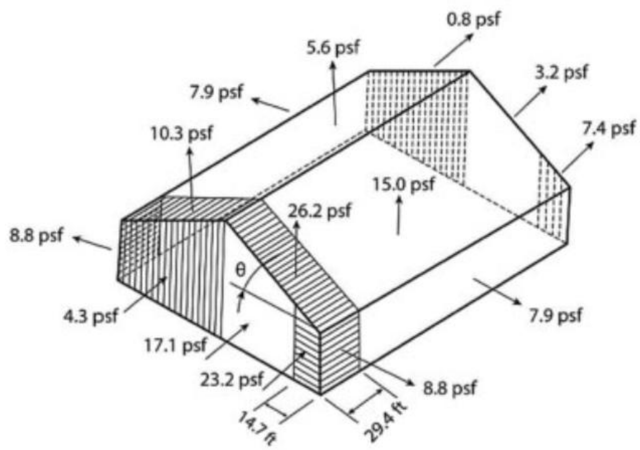
Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 15. Torsional Load Case 3 with negative internal pressure



Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

Figure 16. Torsional Load Case 4 with positive internal pressure

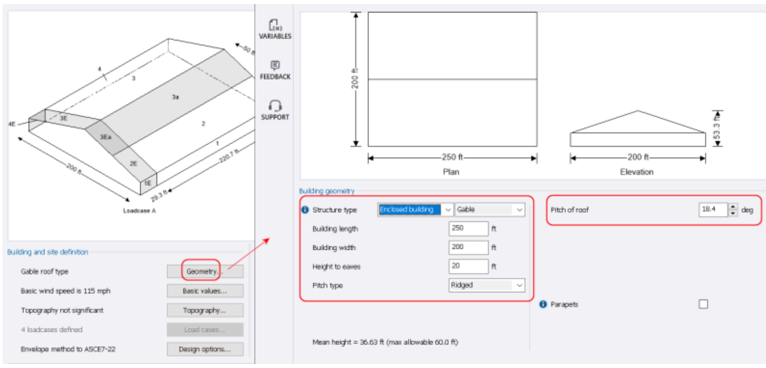


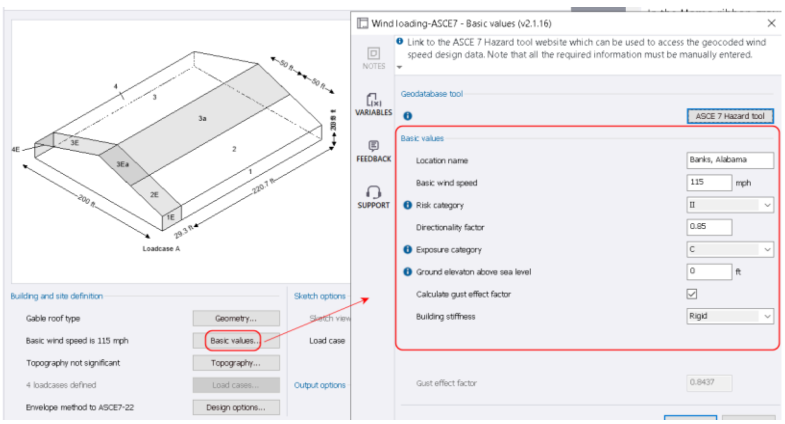
Note: The pressures are assumed to be uniformly distributed over each of the surfaces shown.

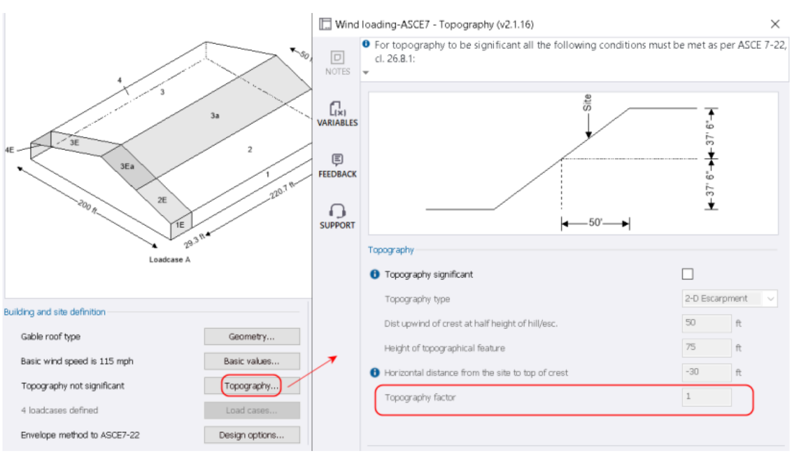
Figure 17. Torsional Load Case 4 with negative internal pressure

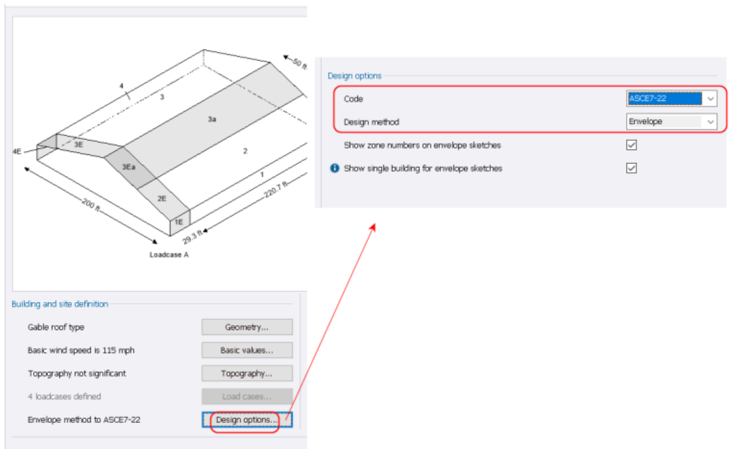
EXAMPLE 2

The previous example was solved by Tekla Tedds software (***free trial version***). The steps are as follows:







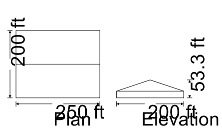


<u>**The Calculation Note is**</u>

<u>**WIND LOADING**</u>

In accordance with ASCE7-22

Using the envelope design method



Building data

Type of roof;	Gable
Length of building;	b = **250.00** ft
Width of building;	d = **200.00** ft
Height to eaves;	H = **20.00** ft
Pitch of roof;	α_0 = **18.4** deg
Mean height;	h = **36.63** ft
End zone width;	a = max (min(0.1′min(b, d), 0.4′h), 0.04′min(b, d), 3ft) = **14.65** ft

Plan length of Zone 2/2E when GC_{pf} negative; L_{Z2} = min(0.5 ′ d, 2.5 ′ H) = **50.00** ft

Plan length of Zone 3/3E encroachment on zone 2; L_{Z3} = max(0 ft,0.5 ′ d - L_{Z2}) = **50.00** ft

General wind load requirements

Basic wind speed; V = **115.0** mph

Risk category; II

Velocity pressure exponent coef (Table 26.6-1); K_d = **0.85**

Ground elevation above sea level; z_{gl} = **0** ft

Ground elevation factor; K_e = exp(-0.0000362 ´ z_{gl}/1ft) = **1.00**

Exposure category (cl 26.7.3); C

Enclosure classification (cl.26.12); Enclosed buildings

Internal pressure coef +ve (Table 26.13-1); GC_{pi_p} = **0.18**

Internal pressure coef –ve (Table 26.13-1); GC_{pi_n} = **-0.18**

Topography

Topography factor not significant; K_{zt} = 1.0

Velocity pressure

Velocity pressure coefficient (Table 26.10-1); K_z = **1.02**

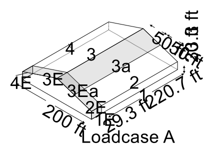
Velocity pressure; q_h = 0.00256 ´ K_z ´ K_{zt} ´ K_e ´ V^2 ´ 1psf/mph^2 = **34.5** psf

Design wind pressures

Design wind pressure equation; $p = K_d * q_h * ((GC_{pf}) - (GC_{pi}))$

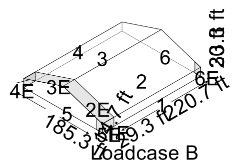
Design wind pressures – Loadcase A

Zone	**GC_{pf}**	**$p_{(+GCpi)}$ (psf)**	**$p_{(-GCpi)}$ (psf)**	**Area (ft^2)**	**$+F_{wi}$ (kips)**	**$-F_{wi}$ (kips)**
1	0.52	9.9	20.4	4414	43.5	90.2
2	-0.69	-25.5	-15.0	11629	-296.9	-174.1
3a	-0.47	-19.0	-8.5	11629	-221.2	-98.4
3	-0.47	-19.0	-8.5	23258	-442.5	-196.8
4	-0.42	-17.5	-6.9	4414	-77.1	-30.4
1E	0.78	17.6	28.2	586	10.3	16.5
2E	-1.07	-36.7	-26.1	1544	-56.6	-40.3
3Ea	-0.67	-25.0	-14.5	1544	-38.7	-22.3
3E	-0.67	-25.0	-14.5	3089	-77.3	-44.7
4E	-0.62	-23.4	-12.8	586	-13.7	-7.5



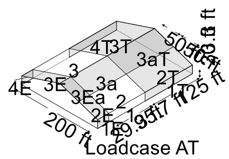
Design wind pressures – Loadcase B

Zone	GC_{pf}	$p_{(+GCpi)}$ (psf)	$p_{(-GCpi)}$ (psf)	Area (ft^2)	$+F_{wi}$ (kips)	$-F_{wi}$ (kips)
1	-0.45	-18.5	-7.9	4414	-81.6	-35.0
2	-0.69	-25.5	-15.0	23258	-593.8	-348.1
3	-0.37	-16.1	-5.6	23258	-375.4	-129.7
4	-0.45	-18.5	-7.9	4414	-81.6	-35.0
5	0.40	6.5	17.0	6998	45.2	119.1
6	-0.29	-13.8	-3.2	6998	-96.5	-22.6
1E	-0.48	-19.4	-8.8	586	-11.4	-5.2
2E	-1.07	-36.7	-26.1	3089	-113.3	-80.7
3E	-0.53	-20.8	-10.3	3089	-64.4	-31.7
4E	-0.48	-19.4	-8.8	586	-11.4	-5.2
5E	0.61	12.6	23.2	329	4.1	7.6
6E	-0.43	-17.9	-7.3	329	-5.9	-2.4



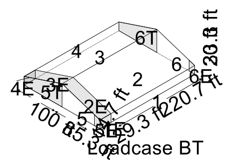
Design wind pressures – Loadcase AT

Zone	GC_{pf}	$p_{(+GCpi)}$ (psf)	$p_{(-GCpi)}$ (psf)	Area (ft^2)	$+F_{wi}$ (kips)	$-F_{wi}$ (kips)
1	0.52	9.9	20.4	1914	18.9	39.1
2	-0.69	-25.5	-15.0	5042	-128.7	-75.5
3a	-0.47	-19.0	-8.5	5042	-95.9	-42.7
3	-0.47	-19.0	-8.5	10085	-191.9	-85.3
4	-0.42	-17.5	-6.9	1914	-33.4	-13.2
1E	0.78	17.6	28.2	586	10.3	16.5
2E	-1.07	-36.7	-26.1	1544	-56.6	-40.3
3Ea	-0.67	-25.0	-14.5	1544	-38.7	-22.3
3E	-0.67	-25.0	-14.5	3089	-77.3	-44.7
4E	-0.62	-23.4	-12.8	586	-13.7	-7.5
1T	0.13	-1.5	9.1	2500	-3.7	22.7
2T	-0.17	-10.3	0.2	6587	-68.1	1.4
3Ta	-0.12	-8.7	1.8	6587	-57.4	12.2
3T	-0.12	-8.7	1.8	13173	-114.8	24.3
4T	-0.10	-8.3	2.2	2500	-20.8	5.6



Design wind pressures – Loadcase BT

Zone	GC_{pf}	$p_{(+GCpi)}$ (psf)	$p_{(-GCpi)}$ (psf)	Area (ft^2)	$+F_{wi}$ (kips)	$-F_{wi}$ (kips)
1	-0.45	-18.5	-7.9	4414	-81.6	-35.0
2	-0.69	-25.5	-15.0	23258	-593.8	-348.1
3	-0.37	-16.1	-5.6	23258	-375.4	-129.7
4	-0.45	-18.5	-7.9	4414	-81.6	-35.0
5	0.40	6.5	17.0	3481	22.5	59.3
6	-0.29	-13.8	-3.2	3481	-48.0	-11.2
1E	-0.48	-19.4	-8.8	586	-11.4	-5.2
2E	-1.07	-36.7	-26.1	3089	-113.3	-80.7
3E	-0.53	-20.8	-10.3	3089	-64.4	-31.7
4E	-0.48	-19.4	-8.8	586	-11.4	-5.2
5E	0.61	12.6	23.2	182	2.3	4.2
6E	-0.43	-17.9	-7.3	329	-5.9	-2.4
5T	0.10	-2.3	8.2	3663	-8.6	30.1
6T	-0.07	-7.4	3.2	3663	-27.1	11.6



Summary:

The calculation of wind pressures obtained using the Tekla Tedds program are identical to those obtained from the step-by-step manual process.

References

1) ASCE. 2017. ASCE 7-16. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. American Society of Civil Engineers.
2) ASCE. 2021. ASCE 7-22. *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. American Society of Civil Engineers.
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4) Timothy A. Reinhold, and T Eric Stafford, " Wind Loads: Guide to the Wind Load Provisions of ASCE 7-22", Reston, VA: ASCE, ASCE Press.
5) Tekla Tedds Software, free trial version 2024 , Trimble, Inc