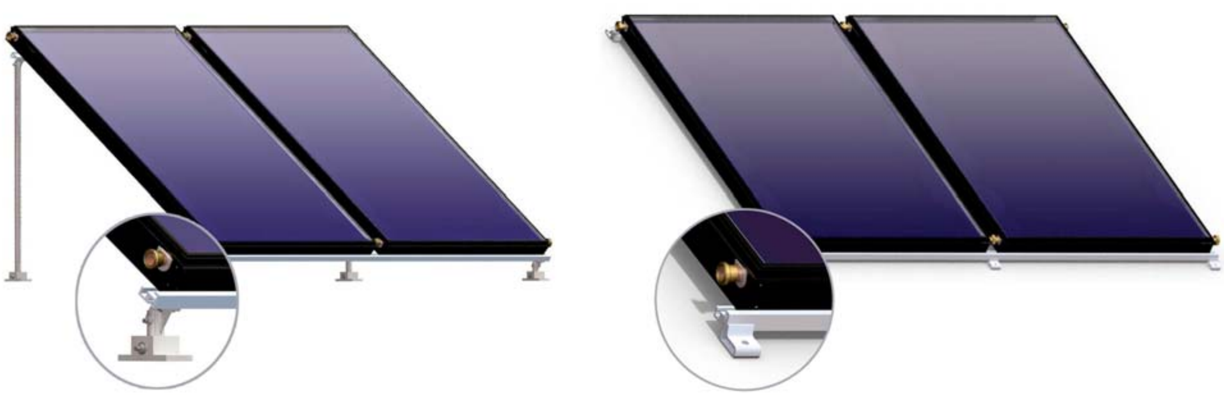
Solar Collector Rack and Flush Mount

Code-Compliant Installation Manual



Loading Analysis for Heliodyne Solar Thermal Collector Installations

EXCELLENCE BY DESIGN

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1.0 Introduction

This manual provides documentation on the process for determining the wind and seismic loading forces that a Heliodyne solar thermal collector installation may be subjected to. This information can be used to supply the local building department or authority having jurisdiction with documentation to assist in the permitting process associated with a Heliodyne solar thermal system. The procedures and methods referenced in this document are based upon the American Society of Civil Engineers (ASCE) Standard 7-05, Minimum Design Loads for Buildings and Other Structures, with reference to specific chapters pertaining to wind loads (Chapter 6) and seismic loads (Chapter 13).

2.0 Scope

To provide documentation on the computational methods and equations used to determine structural wind and seismic loads that a Heliodyne solar thermal system may be subjected to.

3.0 Installer Responsibilities

The installer of a Heliodyne solar thermal system is solely responsible for:

- Complying with all applicable local building code requirements, and/or all national building code requirements. This includes any that may supercede those materials or procedural requirements that may be provided in this manual.
- Determining and assessing the site-specific conditions that may affect the proper installation of a Heliodyne solar thermal system. This shall include building and or structural considerations, environmental considerations, and any client-specific considerations.
- Using only those materials specified in this installation manual. Use of non-specified materials may void the warranty of certain products, but more importantly increases the probability of system performance and safety issues arising due to an improper installation.
- Structural considerations should include roof loading design capabilities, roof rafter locations and sizes. The effect of the various wind, seismic, and snow loading factors must be taken into consideration.
- Roof penetrations require the proper waterproof sealing procedures be carried out. Factors influencing proper sealing methods for the specific roof construction must be taken into consideration.
- Maintaining a safe worksite and conducting the installation procedures described within this manual in a safe manner. This includes the use of suitable personal protective equipment (PPE) such as safety glasses, suitable gloves, and the use of an appropriate safety harness when working at heights.

4.0 Wind and Seismic Force Loading Determinations

4.1 Overview on the various loadings affecting and installation

A Heliodyne solar thermal collector installation can be situated on the roof of an existing building, on the roof of a support structure built specifically to locate the thermal collectors, or at the ground level. Regardless of the location, the thermal collectors and the supporting racking structure are subjected to a variety of additional loading forces. For flush-mounting installations, where the addition of a rack mounting support structure is not required, the collectors are still subject to loading forces. These forces are wind loading forces, seismic forces, snow loading forces, rain loading forces, and ice loading forces. Depending upon the specific location of a given installation one of these forces will be the dominate force, meaning that the force exerted on the collector array from a specific source is greater than the forces exerted on the collector array from the remaining sources. In most instances the greatest force that exerted on a collector array results from wind loading forces. Individual site considerations and the specific installation type will ultimately dictate the importance of each of the three loading forces. The installer of a Heliodyne solar thermal system is recommended to check with the local building department or authority having jurisdiction as to specific force loadings that may apply to a specific installation location.

4.2 Wind Loading Design Calculations and Tables

The requirements relating to design loads are specified from the American Society of Civil Engineers (ASCE) Standard 7-05. The determination of the design wind load, expressed both as the uplift force and the downward force, is carried out in a multi-step process during which frequent reference to ASCE-complied tables or figures is required. Although procedural and computational differences exist between the various methods to be employed for determining the design wind loading characteristics of a specific installation, the basic process for carrying out the design wind loading analysis is the same. Site specific variable values, such as the basis design wind speed, building height, building type, surrounding surface topography, etc must be determined, and used in accordance with, the specified computational methods provided in ASCE 7-05.

There are three methods that can be used to determine the system design wind loading values for a specific installation: Method 1 – The Simplified Procedure, Method 2 – The Analytical Procedure, and Method 3 – The Wind Tunnel Procedure. These procedures are spelled out in the ACSE 7-05, chapter 6 documentation. A limitation which requires wind tunnel analysis applies to flexible buildings or other structures. For installation of Heliodyne solar thermal systems using rack mounting structures, Method 2, The Analytical Procedure, is used. For installation of a Heliodyne solar thermal system using flush mounting methods, Method 1, the Simplified Procedure, may be applied.

CASE I: The Analytical Method for Determining Design Wind Loads

Design Wind Loading Determination: Example Calculation

The analytical method for determining design wind loads should be used when Heliodyne solar thermal collectors are to be installed in a rack-mounted configuration. As stipulated in ASCE 7-05, the design wind loading values for a specific installation must be determined from one of the following methods: 6.5.12, 6.5.13, 6.5.14, or 6.5.15, as applicable.

6.5.12 lays out the procedure for design wind load calculations on enclosed and partially enclosed buildings. 6.5.13 specifies the procedure for design wind loads on open buildings with monoslope, pitched, or troughed roofs. 6.5.14 deals with design wind loads on solid freestanding walls and solid signs, whereas 6.5.15 applies to design wind loads on other structures.

For rack-mounted installations involving Heliodyne solar thermal collectors, section 6.5.13 best describes the installation type. Per 6.5.13.2, the net design pressure is determined from the following equation:

$$p = q_h * G * C_n$$

with p = design wind pressure (lb/ft2)
q_h = velocity pressure evaluated at the mean roof height (lb/ft2)
G= gust effect factor
C_n = net pressure coefficient

The evaluation of this equation can be accomplished, if and only if, the value of various, application-specific information is determined. This information is provided in the ASCE 7-05 Chapter 6 documentation in the form of tables, figures, equations, and other information.

In essence the design analysis procedure involves evaluation of the site and structure-specific installation according to the various building or structure-defining criteria in the ASCE documentation. This evaluation process involves determining the wind speed for the specific location of the installation. Figures of the US, including all basic wind speed areas as well as special wind areas, are provided from ASCE 7-05, Chapter 6, figure 6-1. This information, as well as the structure or building height, classification, including a determination of the surrounding topography classification, serves as input in determining certain ASCE design factor values. Others are calculated. Reference to specific ASCE 7-05 equations and evaluation criteria will be made, but a review of the full documentation text is recommended for a thorough presentation of all information.

From the net design pressure equation, or net wind-loading pressure, we further define the velocity pressure, q_h, as follows from Chapter 6, section 6.5.10:

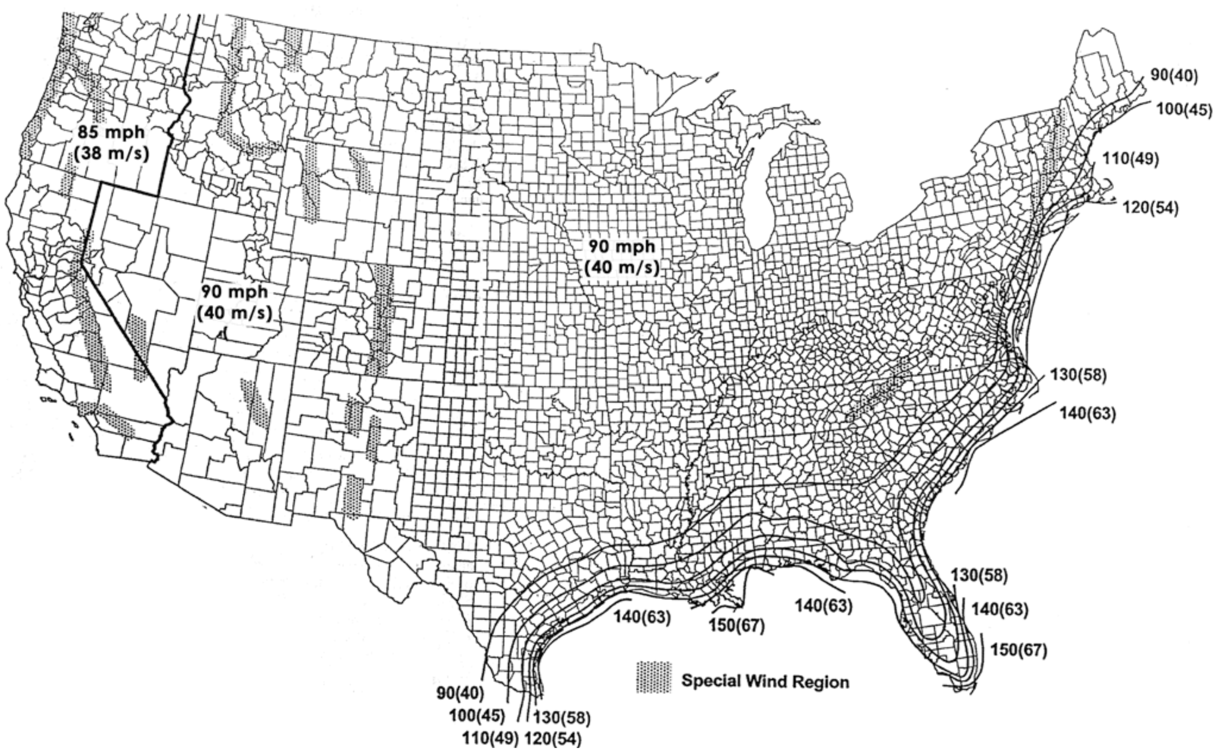
$$q_h = 0.00256 \times K_z \times K_{zt} \times K_d \times V^2 \times I$$

with K_z = velocity pressure exposure coefficient per 6.5.6.6
K_{zt} = topographical factor per 6.5.7.2
K_d = wind directionality factor per 6.5.4.4
V = basic wind speed per 6.5.4
I = importance factor per 6.5.5

Determining V: The basic wind speed

To determine the basis wind speed for a specific location, method 6.5.4 references figure 6-1, providing the specific installation does not fall within a special wind region. In these instances, the basic wind speed shall be determined per section 6.5.4.1 and 6.5.4.2. Figures 6-1A, 6-1B, and 6-1C can then be used to determine the basic wind speed for a given special wind region. Figure 6.1 provides the design 3-second gust wind speeds applicable to most areas of the US where a given installation is likely to occur. The local building department may also have information regarding the area-specific design wind speed information. It is recommended that the installer of a Heliodyne solar thermal system check with the local building department on any special basic design wind speed values that they may require. This is important for all areas, including those covered in special wind regions.

Figure 1: Basic Design Wind Speeds



For the purposes of documenting the calculation procedure in one case, we shall assume **V = 85 mph**. At this time we can also determine a value for K_d, the wind directionality factor. Method 6.5.4.4 refers the user to table 6-4 to determine the appropriate K_d value. In this instance, and in all instances involving the installation of a Heliodyne solar thermal system using a rack-mounting structure, **K_d = 0.85**

In order to determine K_{zt}, the wind topographical factor, we must first look to 6.5.7.2. This defines K_{zt} as follows:

$K_{zt} = (1 + K_1K_2K_3)^2$

with K_1, K_2, and K_3 being given in Figure 6-4.

Considering the topographical factor, the escarpment configuration for wind conditions most closely resembles that of a Heliodyne solar thermal collector installation in the rack-mounted configuration installed on a building roof. Figure 6-4 defines the values for various K_1, K_2, and K_3 factors, providing a factor-specific calculation is first made.

For K_1, we must determine H/L_h, for K_2 we must determine x/L_h, and for K_3 we must determine z/L_h.

L_h = distance upwind of crest to where the difference in ground elevation is half the height hill or escarpment.

H = height of hill or escarpment relative to the upwind terrain

z = height above local ground level

x = distance (upwind or downwind) from crest to the building site

Before we consider how the specifics of a given installation could affect the value of z or x as defined above, let us first make note of an important fact. L_h in most instances tends towards 0 since the building face is likely to be vertical. This fact leads to values for computations involving Lh in the denominator to approach infinity. For such cases K_2, and K_3 equal 0. In reality K_1 also equals zero, but an exception requires that K1 = 0.72.

For $H/L_h > 0.5$, a value of 0.5 shall be used to evaluate the value of K_1.

This gives us $K_{zt} = (1 + K_1K_2K_3)^2 = (1 + 0.72 \times 0 \times 0)^2 =$ **$1 = K_{zt}$**

The importance factor I is determined from table 6-1 based on building and structure categories listed in table 1-1. In this case, a Heliodyne solar thermal collector structure is classified as category I. From table 1-1, an importance factor of 0.87 is determined**. I = 0.87**. Table 1 provide below contains information that has been compiled from both ASCE tables 6-1 and 1-1 relating the building occupancy category and the associated importance factor I.

Table 1: Building Categories and Importance Factor Values

Occupancy Category	Category Description	Example Building Types	Importance Factor[A]	Importance Factor[B]
I	Buildings and other structures that represent a low hazard to human life in the event of a failure, including, but not limited to:	Agricultural facilities Certain temporary facilities Minor Storage Facilities	0.87	0.77

II	All buildings and other structures expect those listed in Occupancy Categories I, III, and IV		1.0	1.0
III	Buildings and other structures that represent a substantial hazard to human life in the event of a failure, including, but not limited to:	Building where more than 300 people gather Schools with a capacity > 250 Day Cares with a capacity > 150 Buildings for colleges with a capacity > 500 Health Care facilities with a capacity > 50 or more resident patients Jails and Detention facilities Power Generation stations Water and Sewage treatment facilities Telecommunications Centers Buildings that manufacture or house hazardous materials	1.15	1.15
IV	Buildings and other structures designated as essential facilities, including, but not limited to:	Hospitals and other health care facilities having surgery or emergency treatment Fire, rescue, ambulance and police stations Designated earthquake, hurricane, or other emergency shelters Designated emergency preparedness communication and operation centers Power generation stations and other public utility facilities required in an emergency Ancillary structures required for operation of Occupancy Category IV structures Aviation control towers, air traffic control centers, and emergency aircraft hangars Water storage facilities and pump structures required to maintain water pressure for fire suppression Buildings and other structures having critical national defense functions	1.15	1.15

[A]non-Hurricane prone regions and hurricane prone regions with basic wind speed, V = 85 to 100 mph, and Alaska
[B]Hurricane prone regions with basic wind speed V > 100 mph

The last unaccounted for variable is K_z, the velocity pressure coefficient. Method 6.5.6.6 refers to table 6-3 for determining the value of K_z. Before doing this, however, we must first consider the exposure category, defined through section 6.5.6.3. This is a function of the specific site installation.

There are three exposure categories, Category B, Category C, and Category D. They are defined in the ASCE documentation as follows:

Exposure category B applies when the ground surface, as characterized by surface roughness category B, prevails in the upwind direction for a distance of at least 2600 ft (792 m) or 20 times the height of the building, whichever is greater. An exception to this rule applies to buildings whose mean roof height is less than or equal to 30 ft, in which the upwind distance may be reduced to 1500 ft (457 m).

Exposure category C applies to all installation location that is not defined by either exposure category B or exposure category D, and is defined by surface roughness category C.

Exposure category D applies where the ground surface roughness , as defined by surface roughness category D, prevails in the upwind direction for a distance greater than 5000 ft (1, 524 m) or 20 times the building height, whichever is greater. Exposure category D shall extend into downwind areas of surface roughness category B or C for a distance of 600 ft (200 m) or 20 time the height of the building, whichever is greater.

Should a given site be located in a transition zone between exposure categories, the category resulting in the largest wind forces shall be used. An exception to this rule is given as follows in the ASCE documentation:

> *An intermediate exposure between the preceding category is permitted in a transition zone provided that it is determined by a rational analysis method defined in the recognized literature.*

As Heliodyne recommends that every installation be conducted in the safest possible manner, we would advise installers to always use conservative estimates when determining the wind loading exposure category for a particular installation.

The surface roughness categories, which ultimately determine the surface exposure categories, are given in 6.5.6.2 as follows:

Surface Roughness B: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

Surface Roughness C: Open terrain with scattered obstructions having heights generally less than 30 ft. This category includes flat open country, grasslands, and all water surfaces in hurricane prone regions.

Surface Roughness D: Flat, unobstructed areas and water surfaces outside hurricane prone regions. This category includes smooth mud flats, salt flats, and unbroken ice.

Since a specific installation will fall into one of the three categories, for the purposes of this example we shall assume that Surface Roughness B, and therefore Exposure Category B. Tabulated data by exposure category is provided in this documentation.

When looking at table 6-3 to determine the value for K_z applying to Exposure Category B, we find that the table is divided by the height above ground level of the building and structure, and categorized according to low-rise buildings designed using figure 6-10 and all components and cladding (Case I), and low-rise buildings designs not utilizing figure 6-10 and all main wind force resisting systems in other structures (Case II). Case II applies in this instance, since figure 6-10 is used for low-rise buildings of the enclosed, or partially enclosed, type. For the purposes of this tabulation the height above ground level, z, shall be assumed to be 20 ft. Later tabulations will be based upon various heights according to exposure category as stated earlier.

These assumed values for this case of z = 20 ft, Exposure Category B, Case II give $\mathbf{K_z = 0.62}$

We can now calculate qh from the formula provided earlier.

$q_h = 0.00256 \times K_z \times K_{zt} \times K_d \times V^2 \times I = 0.00256 \text{ x } 0.62 \text{ x } 1 \text{ x } 0.85 \text{ x } (85)^2 \text{ x } 0.87 =$ **8.51 lb/ft2**

Now recall that $p = q_h * G * C_n$

With G = 0.85, C_n is determined using Figure 6-18A. In this example, we will use a solar collector mounting angle of 35°. For the wind up-load, or lift we have C_n = -1.8, and for the wind down-loading force we have C_n = 2.1. These values were linearly interpolated between figure 6-18a entries for 30° and 37.5°.

Thus for the design wind pressure p, for a rack-mounted installation of Heliodyne solar thermal collectors, at a tilt angle of 35°, at a structure height of20 ft, we have

P uplift force = (8.51 x 0.85 x -1.8) = **-13.02 lb/ft2**

P down-force = (8.51 x 0.85 x 2.1) = **15.19 lb/ft2**

In the installation of a Heliodyne solar thermal system it is possible that the structure height above the ground, as well as the installation location and wind considerations, can vary widely. To aid in the ease of information retrieval, the calculation process outlined above, with references to the relevant ASCE 7-05 Chapter 6 documentation, has been used to tabulate data at recommended installation tilt angles, namely 35° for domestic hot water applications and 45° for combination domestic hot water and space heating applications, by Exposure Category for varying structure heights and basic wind speed values. These tables are based upon calculations with the following assumptions:

- K_d, the wind directionality factor, = 0.85
- K_{zt}, the topographical factor, = 1.0
- G, the gust effect factor, = 0.85
- I, the importance factor, = 0.87

Heliodyne recommends that the installer check with the local building department or authority having jurisdiction to verify that these values are applicable to the specific installation.

Table 2: Design Wind Pressures for Exposure Category B, 35° Mounting Angle

	Basic Wind Speed (mph)							
Height Above Ground (ft)	75	80	85	90	95	100	110	120
0 - 15	(-9.32) 10.87	(-10.60) 12.37	(-11.97) 13.97	(-13.42) 15.66	(-14.95) 17.45	(-16.57) 19.33	(-20.05) 23.39	(-23.86) 27.84
20	(-10.14) 11.83	(-11.53) 13.46	(-13.02) 15.19	(-14.60) 17.03	(-16.27) 18.98	(-18.02) 21.03	(-21.81) 25.44	(-25.95) 30.28
25	(-10.79) 12.59	(-12.28) 14.33	(-13.86) 16.17	(-15.54) 18.13	(-17.32) 20.20	(-19.19) 22.38	(-23.22) 27.08	(-25.95) 32.23
30	(-11.45) 13.35	(-13.02) 15.19	(-14.70) 17.15	(-16.48) 19.23	(-18.37) 21.43	(-20.35) 23.74	(-24.62) 28.73	(-29.30) 34.19
40	(-12.43) 14.50	(-14.14) 16.50	(-15.96) 18.62	(-17.90) 20.88	(-19.94) 23.26	(-22.09) 25.78	(-26.73) 31.19	(-31.81) 37.12
50	(-13.25) 15.45	(-15.07) 17.58	(-17.01) 19.85	(-19.07) 22.25	(-21.25) 24.79	(-23.55) 27.47	(-28.49) 33.24	(-33.90) 39.56
60	(-13.90) 16.22	(-15.81) 18.45	(-17.85) 20.83	(-20.01) 23.35	(-22.30) 26.02	(-24.71) 28.83	(-29.90) 34.88	(-35.58) 41.51
70	(-14.55) 16.98	(-16.56) 19.32	(-18.69) 21.81	(-20.96) 24.45	(-23.35) 27.24	(-25.87) 30.18	(-31.31) 36.52	(-38.93) 43.47
80	(-15.21) 17.74	(-17.30) 20.19	(-19.53) 22.79	(-21.90) 25.55	(-24.40) 28.47	(-27.04) 31.54	(-32.71) 38.16	(-38.93) 45.42
90	(-15.70) 18.31	(-17.86) 20.84	(-20.16) 23.52	(-22.60) 26.37	(-25.19) 29.38	(-27.91) 32.56	(-33.77) 39.40	(-40.19) 46.88

100	(-16.19) 18.89	(-18.42) 21.49	(-20.79) 24.26	(-23.31) 27.20	(-25.97) 30.30	(-28.78) 33.58	(-34.82) 40.63	(-41.44) 48.35

Table 3: Design Wind Pressures for Exposure Category B, 45° Mounting Angle

Basic Wind Speed (mph)

Height Above Ground (ft)	75	80	85	90	95	100	110	120
0 - 15	(-8.80) 12.17	(-10.02) 13.85	(-11.31) 15.63	(-12.68) 17.52	(-14.12) 19.52	(-15.65) 21.63	(-18.94) 26.18	(-22.54) 31.15
20	(-9.57) 13.24	(-10.89) 15.06	(-12.30) 17.00	(-13.79) 19.06	(-15.36) 21.24	(-17.02) 23.53	(-20.60) 28.47	(-24.51) 33.88
25	(-10.19) 14.09	(-11.60) 16.03	(-13.09) 18.10	(-14.68) 20.29	(-16.35) 22.61	(-18.12) 25.05	(-21.93) 30.31	(-26.09) 36.07
30	(-10.81) 14.94	(-12.30) 17.00	(-13.89) 19.19	(-15.57) 21.52	(-17.34) 23.98	(-19.22) 26.57	(-23.25) 32.15	(-27.67) 38.26
40	(-11.74) 16.22	(-13.35) 18.46	(-15.08) 20.84	(-16.90) 23.36	(-18.83) 26.03	(-20.87) 28.84	(-25.25) 34.90	(-30.05) 41.53
50	(-12.51) 17.29	(-14.23) 19.67	(-16.07) 22.21	(-18.01) 24.90	(-20.07) 27.74	(-22.24) 30.74	(-26.91) 37.20	(-32.02) 44.27
60	(-13.13) 18.15	(-14.94) 20.65	(-16.86) 23.31	(-18.90) 26.13	(-20.07) 29.11	(-22.24) 32.26	(-28.24) 39.03	(-33.60) 46.45
70	(-13.74) 19.00	(-15.64) 21.62	(-17.65) 24.40	(-19.79) 27.36	(-22.05) 30.48	(-24.44) 33.77	(-29.57) 40.87	(-35.19) 48.64
80	(-14.36) 19.85	(-16.34) 22.59	(-18.45) 25.50	(-20.68) 28.59	(-23.04) 31.85	(-25.53) 35.30	(-30.90) 42.71	(-36.77) 50.83
90	(-14.83) 20.49	(-16.87) 23.32	(-19.04) 26.32	(-21.35) 29.51	(-23.79) 32.88	(-26.36) 36.43	(-31.89) 44.09	(-37.95) 52.47
100	(-15.29) 21.13	(-17.40) 24.05	(-19.64) 27.15	(-22.02) 30.43	(-24.53) 33.91	(-27.18) 37.57	(-32.89) 45.46	(-39.14) 54.10

Table 4: Design Wind Pressures for Exposure Category C, 35° Mounting Angle

Basic Wind Speed (mph)

Height Above Ground (ft)	75	80	85	90	95	100	110	120
0 - 15	(-13.90) 16.22	(-15.81) 18.45	(-17.85) 20.83	(-20.01) 23.35	(-22.30) 26.02	(-24.71) 28.83	(-29.90) 34.88	(-35.58) 41.51
20	(-14.72) 17.17	(-16.74) 19.54	(-18.90) 22.05	(-21.19) 24.72	(-23.61) 27.55	(-26.16) 30.52	(-31.66) 36.93	(-37.67) 43.95
25	(-15.37) 17.93	(-17.49) 20.40	(-19.74) 23.03	(-22.13) 25.82	(-24.66) 28.77	(-27.33) 31.88	(-33.06) 38.57	(-39.35) 45.91
30	(-16.02) 18.70	(-18.23) 21.27	(-20.58) 24.01	(-23.08) 26.92	(-25.71) 30.00	(-28.49) 33.24	(-34.47) 40.22	(-41.02) 47.86
40	(-17.01) 19.84	(-19.35) 22.57	(-21.84) 25.48	(-24.49) 28.57	(-27.29) 31.83	(-30.23) 35.27	(-36.58) 42.68	(-43.54) 50.79
50	(-17.82) 20.79	(-20.28) 23.66	(-22.89) 26.71	(-25.67) 29.94	(-28.60) 33.36	(-31.69) 36.97	(-38.34) 44.73	(-45.63) 53.23
60	(-18.48) 21.56	(-21.02) 24.53	(-23.73) 27.69	(-26.61) 31.04	(-29.65) 34.59	(-32.85) 38.32	(-39.75) 46.37	(-47.30) 55.19
70	(-19.13) 22.32	(-21.77) 25.40	(-24.57) 28.67	(-27.55) 32.14	(-30.70) 35.81	(-34.01) 39.68	(-41.15) 48.01	(-48.98) 57.14
80	(-19.79) 23.08	(-22.51) 26.26	(-25.41) 29.65	(-28.49) 33.24	(-31.75) 37.04	(-35.17) 41.04	(-42.56) 49.65	(-50.65) 59.09
90	(-20.28) 23.66	(-23.07) 26.91	(-26.04) 30.38	(-29.20) 34.06	(-32.53) 37.95	(-36.05) 42.05	(-43.62) 50.89	(-51.91) 60.56
100	(-20.60) 24.04	(-23.44) 27.35	(-26.46) 30.87	(-29.67) 34.61	(-33.06) 38.57	(-36.63) 42.73	(-44.32) 51.71	(-52.74) 61.54

Table 5: Design Wind Pressures for Exposure Category C, 45° Mounting Angle

Basic Wind Speed (mph)

Height Above Ground (ft)	75	80	85	90	95	100	110	120
0 - 15	(-13.13) 18.15	(-14.94) 20.65	(-16.86) 23.31	(-18.90) 26.13	(-21.06) 29.11	(-23.34) 32.26	(-28.24) 39.03	(-33.60) 46.45
20	(-13.90) 19.21	(-15.81) 21.86	(-17.85) 24.68	(-20.01) 27.67	(-22.30) 30.83	(-24.71) 34.16	(-29.90) 41.33	(-35.58) 49.19
25	(-14.52) 20.07	(-16.52) 22.83	(-18.65) 25.78	(-20.90) 28.90	(-23.29) 32.20	(-25.81) 35.68	(-31.23) 43.17	(-37.16) 51.37
30	(-15.13) 20.92	(-17.22) 23.80	(-19.44) 26.87	(-21.79) 30.13	(-24.28) 33.57	(-26.91) 37.19	(-32.56) 45.00	(-38.74) 53.56
40	(-16.06) 22.20	(-18.27) 25.26	(-20.63) 28.52	(-23.13) 31.97	(-25.77) 35.62	(-28.55) 39.47	(-34.55) 47.76	(-41.12) 56.84
50	(-16.83) 23.27	(-19.15) 26.48	(-21.62) 29.89	(-24.24) 33.51	(-27.01) 37.33	(-29.93) 41.37	(-36.21) 50.06	(-43.09) 59.57
60	(-17.45) 24.12	(-19.86) 27.45	(-22.41) 30.99	(-25.13) 34.74	(-28.00) 38.70	(-31.02) 42.89	(-37.54) 51.89	(-44.67) 61.76
70	(-18.07) 24.98	(-20.56) 28.42	(-23.21) 32.08	(-26.02) 35.97	(-28.99) 40.07	(-32.12) 44.40	(-38.87) 53.73	(-46.26) 63.94
80	(-18.69) 25.83	(-21.26) 29.39	(-24.00) 33.18	(-26.91) 38.12	(-29.98) 41.45	(-33.22) 45.92	(-40.20) 55.57	(-47.84) 66.13
90	(-19.15) 26.47	(-21.79) 30.12	(-24.60) 34.00	(-27.58) 38.12	(-30.72) 42.47	(-34.00) 47.06	(-41.19) 56.94	(-49.02) 67.77
100	(-19.46) 26.90	(-22.14) 30.60	(-24.99) 34.55	(-28.02) 38.74	(-31.22) 43.16	(-34.59) 47.82	(-41.86) 57.86	(-49.81) 68.86

Table 6: Design Wind Pressures for Exposure Category D, 35° Mounting Angle

Basic Wind Speed (mph)

Height Above Ground (ft)	75	80	85	90	95	100	110	120
0 - 15	(-16.84) 19.65	(-19.16) 22.36	(-21.63) 25.24	(-24.25) 28.30	(-27.02) 31.53	(-29.94) 34.93	(-36.23) 42.27	(-43.12) 50.30
20	(-17.66) 20.60	(-20.09) 23.44	(-22.68) 26.46	(-25.43) 29.67	(-28.33) 33.06	(-31.40) 36.63	(-37.99) 44.32	(-45.21) 52.74
25	(-18.31) 21.37	(-20.84) 24.31	(-23.52) 27.44	(-26.37) 30.77	(-29.38) 34.28	(-32.56) 37.98	(-39.40) 45.96	(-46.88) 54.70
30	(-18.97) 22.13	(-21.58) 25.18	(-24.36) 28.42	(-27.31) 31.87	(-30.43) 35.51	(-33.72) 39.34	(-40.80) 47.60	(-48.56) 56.65
40	(-19.95) 23.27	(-22.70) 26.48	(-25.62) 29.89	(-28.73) 33.51	(-32.01) 37.34	(-35.45) 41.38	(-42.91) 50.07	(-51.07) 59.58
50	(-20.77) 24.23	(-23.63) 27.57	(-26.67) 31.12	(-29.90) 34.89	(-33.32) 38.87	(-36.92) 43.07	(-44.67) 52.12	(-53.16) 62.02
60	(-21.42) 24.99	(-24.37) 28.43	(-27.51) 32.10	(-30.85) 35.99	(-34.37) 40.10	(-38.08) 44.43	(-46.08) 53.76	(-54.84) 63.98
70	(-21.91) 25.56	(-24.93) 29.09	(-28.14) 32.83	(-31.55) 36.81	(-35.16) 41.02	(-38.95) 45.45	(-47.13) 54.99	(-56.09) 65.44
80	(-22.57) 26.33	(-25.67) 29.95	(-28.98) 33.81	(-32.49) 37.91	(-36.21) 42.24	(-40.12) 46.80	(-48.54) 56.63	(-57.77) 67.40
90	(-22.89) 26.71	(-26.05) 30.39	(-29.40) 34.31	(-32.97) 38.46	(-36.73) 42.85	(-40.70) 47.48	(-49.24) 57.45	(-58.61) 68.37
100	(-23.38) 27.28	(-26.60) 31.04	(-30.03) 35.04	(-33.67) 39.28	(-37.52) 43.77	(-41.57) 48.50	(-50.30) 58.68	(-59.86) 69.84

Table 7: Design Wind Pressures for Exposure Category D, 45° Mounting Angle

Height Above Ground (ft)	**Basic Wind Speed (mph)** 75	80	85	90	95	100	110	120
0 - 15	(-15.91) 21.99	(-18.10) 25.02	(-20.43) 28.24	(-22.91) 31.66	(-25.52) 35.28	(-28.28) 39.09	(-34.22) 47.30	(-40.72) 56.29
20	(-16.68) 23.06	(-18.98) 26.23	(-21.42) 29.61	(-24.02) 33.20	(-26.76) 36.99	(-29.65) 40.99	(-35.88) 49.60	(-42.70) 59.02
25	(-17.30) 23.91	(-19.68) 27.20	(-22.22) 30.71	(-24.91) 34.43	(-27.75) 38.36	(-30.75) 42.51	(-37.21) 51.43	(-44.28) 61.21
30	(-17.91) 24.76	(-20.38) 28.18	(-23.01) 31.81	(-25.80) 35.66	(-28.74) 39.73	(-31.85) 44.02	(-38.54) 53.27	(-45.86) 63.40
40	(-18.84) 26.04	(-21.44) 29.63	(-24.20) 33.45	(-27.13) 37.50	(-30.23) 41.79	(-33.50) 46.30	(-40.53) 56.03	(-48.23) 66.67
50	(-19.61) 27.11	(-22.32) 30.85	(-25.19) 34.82	(-28.24) 39.04	(-31.47) 43.50	(-34.87) 48.20	(-42.19) 58.32	(-50.21) 69.40
60	(-20.23) 27.97	(-23.02) 31.82	(-25.99) 35.92	(-29.13) 40.27	(-32.46) 44.87	(-35.97) 49.72	(-43.52) 60.16	(-51.79) 71.59
70	(-20.69) 28.61	(-23.55) 32.55	(-26.58) 36.74	(-29.80) 41.19	(-33.20) 45.90	(-36.79) 50.86	(-44.52) 63.37	(-52.98) 73.23
80	(-21.31) 29.46	(-24.25) 33.52	(-27.37) 37.84	(-30.69) 42.42	(-34.19) 47.27	(-37.89) 52.37	(-45.84) 63.37	(-54.56) 75.42
90	(-21.62) 29.89	(-24.60) 34.01	(-27.77) 38.39	(-31.13) 43.04	(-34.69) 47.95	(-38.44) 53.13	(-46.51) 64.29	(-55.35) 76.51
100	(-22.08) 30.53	(-25.13) 34.73	(-28.37) 39.21	(-31.80) 43.96	(-35.43) 48.98	(-39.26) 54.27	(-47.51) 65.67	(-56.54) 78.15

For tables 2 through 7 the values provided within brackets refer to the uplift force, while the other values refer to the down force.

Array Design Dead and Live Loading Values

With the analysis of the design wind loading factors determined, the dead and live loads for a Heliodyne solar thermal system must now be determined.

The dead load, expressed in lb/ft^2, is the combined mass of the collectors, including fluid within the collectors, and the associated mounting equipment divided by the footprint of the collector array. Heliodyne solar thermal collectors are available in three different sizes, and the collectors should be mounted at one of two suggested mounting angles. Collectors intended for domestic hot water heating and pool heating applications should be mounted at a tilt angle equal to 35°, while collectors intended for both domestic hot water and space heating applications should be mounted at a tilt angle of 45°.

The dead load values for the three sizes of Heliodyne solar thermal collectors, mounted at either of the suggested tilt angles have been provided in the following table.

Mounting Angle: 35°

Collector Model	**Area (ft^2)**	**Total Weight (lbs)**	**Rail/Footing Weight (lbs)**	**Total Dead Load (lb/ft^2)**
Gobi 406	21.8	110.3	9.9	5.06
Gobi 408	26.39	134.3	9.9	5.09

Gobi 410	32.89	161.3	9.9	4.90

Mounting Angle: 45°

Collector Model	Area (ft^2)	Wet Weight (lbs)	Rail/Footing Weight (lbs)	Total Dead Load (lb/ft^2)
Gobi 406	19.02	110.3	9.9	5.80
Gobi 408	22.79	134.3	9.9	5.89
Gobi 410	28.38	161.3	9.9	5.68

Using the area of the specific array of collector(s) and the design wind loading (uplift force), the uplift force on the collector array installation can be determined.

Using the area of the specific array of collector(s) and the design wind loading (down force), the total array live load can be determined.

CASE II: The Simplified Method for Determining Design Wind Loads

Wind Loading Determination

In installations involving Heliodyne solar thermal collectors in a flush mount arrangement, the simplified method may be used to determine the design wind loads. Per method 6.4.2.1, the simplified design wind pressure P_{net} is given as

$$P_{net} = \lambda \times K_{zt} \times I \times p_{net30}$$

Where λ = adjustment factor for building height and exposure

K_{zt} = topographical factor evaluated at the mean roof height

I = importance factor

P_{net30} = simplified design wind pressure for Exposure B, at h = 30 ft, and fore I = 1.0

In order to determine K_{zt}, the wind topographical factor, we must first look to 6.5.7.2. This defines K_{zt} as follows:

$$K_{zt} = (1 + K_1K_2K_3)^2$$

with K_1, K_2, and K_3 being given in Figure 6-4.

Considering the topographical factor, a Heliodyne solar thermal collector installation in the flush-mounted configuration installed on a sloped, building roof does not constitute an escarpment, hill, or ridge configuration. These definitions are considerations are provided in section 6.5.7.1. Since these do not apply, from 6.5.7.2 we shall take $\mathbf{K_{zt} = 1.0}$.

In order to determine λ, or the adjustment factor for building height and exposure, we must first determine the specific installation exposure category. The surface roughness categories, which ultimately determine the surface exposure categories, are given in 6.5.6.2 as follows:

Surface Roughness B: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

Surface Roughness C: Open terrain with scattered obstructions having heights generally less than 30 ft. This category includes flat open country, grasslands, and all water surfaces in hurricane prone regions.

Surface Roughness D: Flat, unobstructed areas and water surfaces outside hurricane prone regions. This category includes smooth mud flats, salt flats, and unbroken ice.

Since a specific installation will fall into one of the three categories, for the purposes of this example we shall assume that Surface Roughness B, and therefore Exposure Category B applies.

From figure 6-2, we can see that the value of λ depends upon the building, and ultimately the solar thermal collector installation height. For the purposes of this example we shall take a value of **λ = 1.0**, noting that for Exposure Category B this value applies to structures 30 ft in height and below. Table 7 provides the adjustment factor for building height and exposure and is taken directly from ASCE 7-05, figure 6-2, page 40.

Table 7: Adjustment Factor λ for Building Height and Exposure

Mean Roof Height (ft)	Exposure Category		
	B	C	D
15	1.00	1.21	1.47
20	1.00	1.29	1.55
25	1.00	1.35	1.61
30	1.00	1.40	1.66
35	1.05	1.45	1.70
40	1.09	1.49	1.74
45	1.12	1.53	1.78
50	1.16	1.56	1.81
55	1.19	1.59	1.84
60	1.22	1.62	1.87

The importance factor I is determined from table 6-1 based on building and structure categories listed in table 1-1. In this case, a Heliodyne solar thermal collector structure is classified as category I. From table 1-1, an importance factor of 0.87 is determined. **I = 0.87**

We are now ready to determine p_{S30}, or the net wind pressure for Exposure Category B, 30 ft height, with an importance factor I of 1.0. Before doing this, however, we must consider the location of the solar thermal collectors on the roof, as well as the general location of the installation.

The first step involves determining the location-specific basic wind speed. This is done by referring to figure 6-1 from the ASCE Chapter 6 documentation, or Figure 1 in this document. This figure provides basic design wind speed values, as well as the general location of the special wind regions that are scattered throughout the mountains and in hurricane-prone areas. For the purposes of this example, a basic design wind speed of **85 mph** shall be assumed to apply to the given location. Heliodyne recommends that the installer check with the local building department or authority having jurisdiction to determine if there are any special basic design wind values that they require as the basis for their review and permitting process.

The next step involves determining the proper roof setback length, a, required for the installation of Heliodyne solar thermal collectors in a flush-mount configuration. This is a function of the given building's width and height. In this example a setback length of 3 ft shall be assumed. This applies to roof heights of 10 to 60 ft, with widths from 10 to 30 ft. Table 7 given below provides calculated data for the required roof zone setback length, a, for various building height and width, or least horizontal dimension, combinations.

Table 7: Roof Zone Setback Length (a)

	Least Horizontal Dimenions (ft)													
Roof Height (ft)	10	15	20	25	30	40	50	60	70	80	90	100	125	150
10	3	3	3	3	3	4	4	4	4	4	4	4	5	6
15	3	3	3	3	3	4	5	6	6	6	6	6	6	6
20	3	3	3	3	3	4	5	6	7	8	8	8	8	8
25	3	3	3	3	3	4	5	6	7	8	9	10	10	10
30	3	3	3	3	3	4	5	6	7	8	9	10	12	12
35	3	3	3	3	3	4	5	6	7	8	9	10	12.5	14
40	3	3	3	3	3	4	5	6	7	8	9	10	12.5	15
45	3	3	3	3	3	4	5	6	7	8	9	10	12.5	15
50	3	3	3	3	3	4	5	6	7	8	9	10	12.5	15
55	3	3	3	3	3	4	5	6	7	8	9	10	12.5	15
60	3	3	3	3	3	4	5	6	7	8	9	10	12.5	15

Per the notes provided on figure 6-3, a is determined as follows:

a: 10% of the least horizontal dimension or 0.4h, whichever is smaller, but not less than either 4% of the least horizontal dimension of 3 ft.

Considering the case of with a least horizontal dimension of 70 ft, we arrive at the following results for heights 10, 15, and 20 ft.

Case 1: h = 10 ft. 70 ft x 0.10 = 7 ft, while 0.4h = 0.4 x 10 = 4 ft. Since 4 ft < 7 ft, use 4 ft.

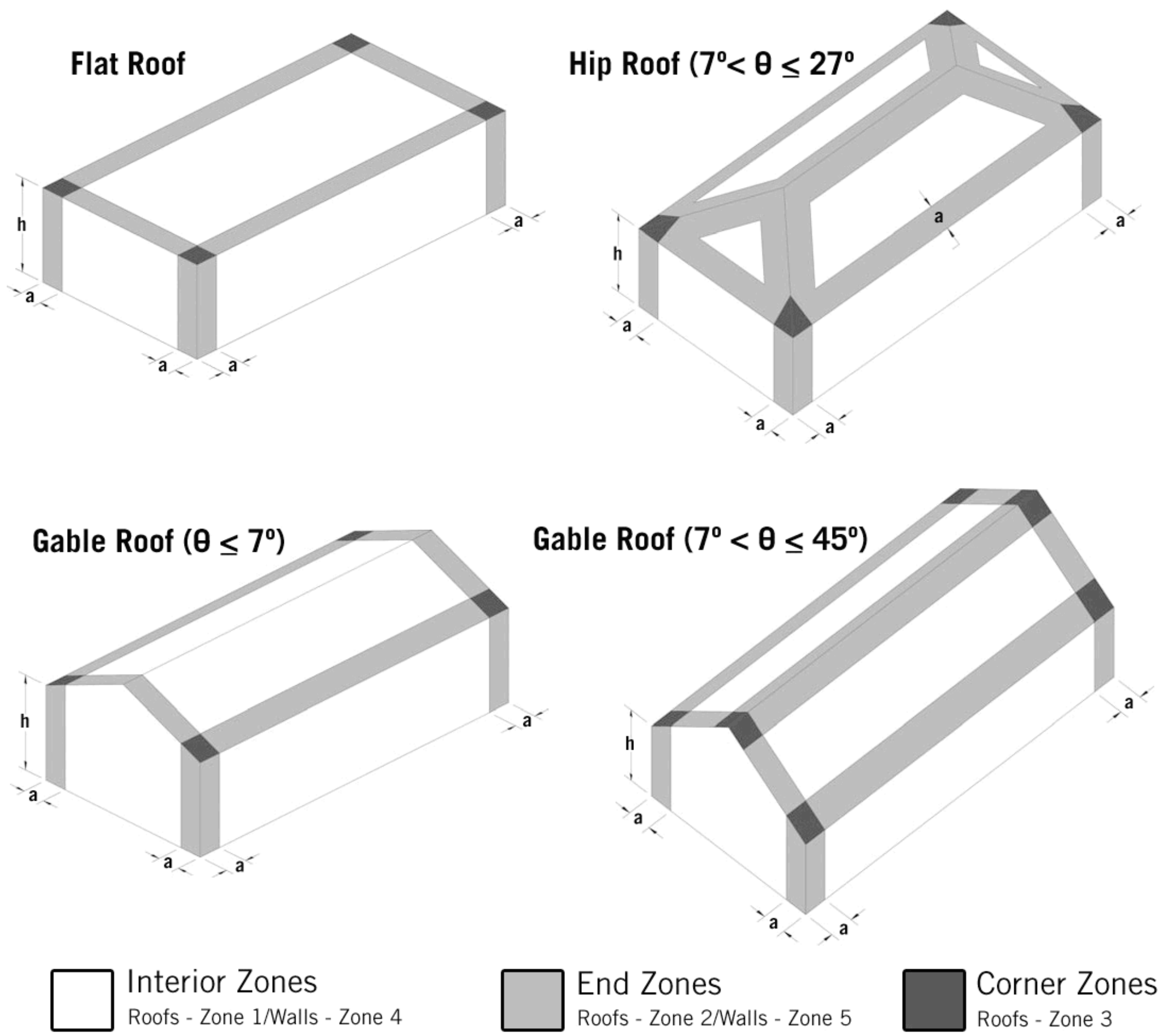
Case 2: h = 15 ft. 70 ft x 0.10 = 7 ft, while 0.4h = 0.4 x 15 = 6 ft. Since 6 ft < 7 ft, use 6 ft.

Case 3: h = 20 ft. 70 ft x 0.10 = 7 ft, while 0.4h = 0.4 x 20 = 8 ft. Since 8 ft > 7 ft, use 7 ft.

In this manner values not directly provided in table 7 can be calculated as needed. Note that in the case of a horizontal dimension of 125 ft, we must rely upon the exception that a minimum of 4% of the least horizontal dimension is required for a proper setback length.

Since 125 ft x 0.10 = 12.5 ft, and 0.4h at h = 10 ft = 4 ft, but 4/125 = 3.2%. Thus 125 ft x 0.04 = 5 ft.

Figure 2 given below provides a visual depiction of the roof zone setback length for various types of roofs on buildings with a height ≤ 60 ft. This information was obtained in ASCE 7-05, figure 6-3, page 41.



Using the roof setback zone length from above, the next step is to determine where the solar thermal collectors will be located on the roof, more specifically in which roof zone the collectors will be located. There are three possible zone classifications: Zone 1: interior zone, Zone 2: end zone, or Zone 3: corner zone. In this instance we shall assume that the collectors will be located in Zone 1. It shall also be assumed for the purposes of this example that the roof slope falls between 7° and 27°. Note that it is possible for an array of collectors to be located in more than one zone.

Considering the case of a zone 1 location, with a roof slope between 7° and 27°, we must now determine one last variable before determining the value of p_{net30}. This is the effective wind area, measured in ft^2, and is defined as the minimum total continuous area of collectors to be installed. In this instance we shall assume that our installation consists of two, Gobi 406 collectors, each with an area of 26.94 ft^2. The total effective area is therefore 53.88 ft^2.

When looking at figure 6-3 we find entries in the effective wind area (ft^2) category for 10, 20, 50, and 100 ft^2. In this case we shall use the values for p_{net30} determined from an effective wind area value of 50 ft^2. From figure 6-3, with a basic design wind speed of 85 mph, we find that we have a net downward pressure of **6.0 lb/ft2,** and a net upward pressure of **-11.1 lb/ft2.**

With all of the variable values accounted for we are now ready to calculate the net design wind loading pressure, P_{net}, in both the downward and upward directions.

P down-force = $P_{net} = \lambda \times K_{zt} \times I \times p_{net30} = 1.0 \times 1.0 \times 0.87 \times 6.0$ **= 5.22 lb/ft2**

P uplift force = $P_{net} = \lambda \times K_{zt} \times I \times p_{net30} = 1.0 \times 1.0 \times 0.87 \times -11.1$ = **-9.66 lb/ft2**

The full figure 6-3 information, taken from ASCE 7-05, Chapter 6, pages 42 through 44, is provided on the following page in table 8.

Table 8: Net Design Wind Pressure, P_{net30} (lb/ft^2)

	Zone	Effective Wind Area (ft^2)	Basic Wind Speed V (mph) 85		90		100		105		110		120	
Roof 0° to 7°	**1**	**10**	5.3	-13.0	5.9	-14.6	7.3	-18.0	8.1	-19.8	8.9	-21.8	10.5	-25.9
	1	**20**	5.0	-12.7	5.6	-14.2	6.9	-17.5	7.6	-19.3	8.3	-21.2	9.8	-25.2
	1	**50**	4.5	-12.2	5.1	-13.7	6.3	-16.9	6.9	-18.7	7.6	-20.5	9.0	-24.4
	1	**100**	4.2	-11.9	4.7	-13.3	5.8	-16.5	6.4	-18.2	7.0	-19.9	8.3	-23.7
	2	**10**	5.3	-21.8	5.9	-24.4	7.3	-30.2	8.1	-33.3	8.9	-36.5	10.5	-43.5
	2	**20**	5.0	-19.5	5.6	-21.8	6.9	-27.0	7.6	-29.7	8.3	-32.6	9.8	-38.8
	2	**50**	4.5	-16.4	5.1	-18.4	6.3	-22.7	6.9	-25.1	7.6	-27.5	9.0	-32.7
	2	**100**	4.2	-14.1	4.7	-15.8	5.8	-19.5	6.4	-21.5	7.0	-23.6	8.3	-28.1
	3	**10**	5.3	-32.8	5.9	-36.8	7.3	-45.4	8.1	-50.1	8.9	-55.0	10.5	-65.4
	3	**20**	5.0	-27.2	5.6	-30.5	6.9	-37.6	7.6	-41.5	8.3	-45.5	9.8	-54.2
	3	**50**	4.5	-19.7	5.1	-22.1	6.3	-27.3	6.9	-30.1	7.6	-33.1	9.0	-39.3
	3	**100**	4.2	-14.1	4.7	-15.8	5.8	-19.5	6.4	-21.5	7.0	-23.6	8.3	-28.1
Roof > 7° to 27°	**1**	**10**	7.5	-11.9	8.4	-13.3	10.4	-16.5	11.4	-18.2	12.5	-19.9	14.9	-23.7
	1	**20**	6.8	-11.6	7.7	-13.0	9.4	-16.0	10.4	-17.6	11.4	-19.4	13.6	-23.0
	1	**50**	6.0	-11.1	6.7	-12.5	8.2	-15.4	9.1	-17.0	10.0	-18.6	11.9	-22.2
	1	**100**	5.3	-10.8	5.9	-12.1	7.3	-14.9	8.1	-16.5	8.9	-18.1	10.5	-21.5
	2	**10**	7.5	-20.7	8.4	-23.2	10.4	-28.7	11.4	-31.6	12.5	-34.7	14.9	-41.3
	2	**20**	6.8	-19.0	7.7	-21.4	9.4	-26.4	10.4	-29.1	11.4	-31.9	13.6	-38.0
	2	**50**	6.0	-16.9	6.7	-18.9	8.2	-23.3	9.1	-25.7	10.0	-28.2	11.9	-33.6
	2	**100**	5.3	-15.2	5.9	-17.0	7.3	-21.0	8.1	-23.2	8.9	-25.5	10.5	-30.3
	3	**10**	7.5	-30.6	8.4	-34.3	10.4	-42.4	11.4	-46.7	12.5	-51.3	14.9	-61.0
	3	**20**	6.8	-28.6	7.7	-32.1	9.4	-39.6	10.4	-43.7	11.4	-47.9	13.6	-57.1
	3	**50**	6.0	-26.0	6.7	-29.1	8.2	-36.0	9.1	-39.7	10.0	-43.5	11.9	-51.8
	3	**100**	5.3	-24.0	5.9	-26.9	7.3	-33.2	8.1	-36.6	8.9	-40.2	10.5	-47.9
Roof > 27° to 45°	**1**	**10**	11.9	-13.0	13.3	-14.6	16.5	-18.0	18.2	-19.8	19.9	-21.8	23.7	-25.9
	1	**20**	11.6	-12.3	13.0	-13.8	16.0	-17.1	17.6	-18.8	19.4	-20.7	23.0	-24.6
	1	**50**	11.1	-11.5	12.5	-12.8	15.4	-15.9	17.0	-17.5	18.6	-19.2	22.2	-22.8
	1	**100**	10.8	-10.8	12.1	-12.1	14.9	-14.9	16.5	-16.5	18.1	-18.1	21.5	-21.5
	2	**10**	11.9	-15.2	13.3	-17.0	16.5	-21.0	18.2	-23.2	19.9	-25.5	23.7	-30.3
	2	**20**	11.6	-14.5	13.0	-16.3	16.0	-20.1	17.6	-22.2	19.4	-24.3	23.0	-29.0
	2	**50**	11.1	-13.7	12.5	-15.3	15.4	-18.9	17.0	-20.8	18.6	-22.9	22.2	-27.2
	2	**100**	10.8	-13.0	12.1	-14.6	14.9	-18.0	16.5	-19.8	18.1	-21.8	21.5	-25.9
	3	**10**	11.9	-15.2	13.3	-17.0	16.5	-21.0	18.2	-23.2	19.9	-25.5	23.7	-30.3
	3	**20**	11.6	-14.5	13.0	-16.3	16.0	-20.1	17.6	-22.2	19.4	-24.3	23.0	-29.0
	3	**50**	11.1	-13.7	12.5	-15.3	15.4	-18.9	17.0	-20.8	18.6	-22.9	22.2	-27.2
	3	**100**	10.8	-13.0	12.1	-14.6	14.9	-18.0	16.5	-19.8	18.1	-21.8	21.5	-25.9
Wall	**4**	**10**	13.0	-14.1	14.6	-15.8	18.0	-19.5	19.8	-21.5	21.8	-23.6	25.9	-28.1
	4	**20**	12.4	-13.5	13.9	-15.1	17.2	-18.7	18.9	-20.6	20.8	-22.6	24.7	-26.9
	4	**50**	11.6	-12.7	13.0	-14.3	16.1	-17.6	17.8	-19.4	19.5	-21.3	23.2	-25.4
	4	**100**	11.1	-12.2	12.4	-13.6	15.3	-16.8	16.9	-18.5	18.5	-20.4	22.0	-24.2
	4	**500**	9.7	-10.8	10.9	-12.1	13.4	-14.9	14.8	-16.5	16.2	-18.1	19.3	-21.5
	5	**10**	13.0	-17.4	14.6	-19.5	18.0	-24.1	19.8	-26.6	21.8	-23.6	25.9	-28.1
	5	**20**	12.4	-16.2	13.9	-18.2	17.2	-22.5	18.9	-24.8	20.8	-22.6	24.7	-26.9
	5	**50**	11.6	-14.7	13.0	-16.5	16.1	-20.3	17.8	-22.4	19.5	-21.3	23.2	-25.4
	5	100	11.1	-13.5	12.4	-15.1	15.3	-18.7	16.9	-20.6	18.5	-20.4	22.0	-24.2
	5	500	9.7	-10.8	10.9	-12.1	13.4	-14.9	14.8	-16.5	16.2	-18.1	19.3	-21.5

Table 8 (cont'd): Net Design Wind Pressure, P_{net30} (lb/ft^2)

	Zone	Effective Wind Area (ft^2)	Basic Wind Speed V (mph)											
			125		130		140		145		150		170	
Roof 0° to 7°	1	10	11.4	-28.1	12.4	-30.4	14.3	-35.3	15.4	-37.8	16.5	-40.5	21.1	-52.0
	1	20	10.7	-27.4	11.6	-29.6	13.4	-34.4	14.4	-36.9	15.4	-39.4	19.8	-50.7
	1	50	9.8	-26.4	10.6	-28.6	12.3	-33.2	13.1	-35.6	14.1	-38.1	18.1	-48.9
	1	100	9.1	-25.7	9.8	-27.8	11.4	-32.2	12.2	-34.6	13.0	-37.0	16.7	-47.6
	2	10	11.4	-47.2	12.4	-51.0	14.3	-59.2	15.4	-63.5	16.5	-67.9	21.1	-87.2
	2	20	10.7	-42.1	11.6	-45.6	13.4	-52.9	14.4	-56.7	15.4	-60.7	19.8	-78.0
	2	50	9.8	-35.5	10.6	-38.4	12.3	-44.5	13.1	-47.8	14.1	-51.1	18.1	-65.7
	2	100	9.1	-30.5	9.8	-33.0	11.4	-38.2	12.2	-41.0	13.0	-43.9	16.7	-65.4
	3	10	11.4	-71.0	12.4	-76.8	14.3	-89.0	15.4	-95.5	16.5	-102.2	21.1	-131.3
	3	20	10.7	-58.5	11.6	-63.6	13.4	-73.8	14.4	-79.1	15.4	-84.7	19.8	-108.7
	3	50	9.8	-42.7	10.6	-46.2	12.3	-53.5	13.1	-57.4	14.1	-61.5	18.1	-78.9
	3	100	9.1	-30.5	9.8	-33.0	11.4	-38.2	12.2	-41.0	13.0	-43.9	16.7	-56.4
Roof > 7° to 27°	1	10	16.2	-25.7	17.5	-27.8	20.3	-32.3	21.8	-34.6	23.3	-37.0	30.0	-47.6
	1	20	14.8	-25.0	16.0	-27.0	18.5	-31.4	19.9	-33.7	21.3	-36.0	27.3	-46.3
	1	50	12.9	-24.1	13.9	-26.0	16.1	-30.2	17.3	-32.4	18.5	-34.6	23.8	-44.5
	1	100	11.4	-23.2	12.4	-25.2	14.3	-29.3	15.4	-31.4	16.5	-33.6	21.1	-43.2
	2	10	16.2	-44.8	17.5	-48.4	20.3	-56.2	21.8	-60.3	23.3	-64.5	30.0	-82.8
	2	20	14.8	-41.2	16.0	-44.6	18.5	-51.7	19.9	-55.4	21.3	-59.3	27.3	-76.2
	2	50	12.9	-36.5	13.9	-39.4	16.1	-45.7	17.3	-49.1	18.5	-52.5	23.8	-67.4
	2	100	11.4	-32.9	12.4	-35.6	14.3	-41.2	15.4	-44.2	16.5	-47.3	21.1	-60.8
	3	10	16.2	-66.2	17.5	-71.6	20.3	-83.1	21.8	-89.1	23.3	-95.4	30.0	-122.5
	3	20	14.8	-61.9	16.0	-67.0	18.5	-77.7	19.9	-83.3	21.3	-89.2	27.3	-114.5
	3	50	12.9	-56.2	13.9	-60.8	16.1	-70.5	17.3	-75.7	18.5	-81.0	23.8	-104.0
	3	100	11.4	-51.9	12.4	-56.2	14.3	-65.1	15.4	-69.9	16.5	-74.8	21.1	-96.0
Roof > 27° to 45°	1	10	25.7	-28.1	27.8	-30.4	32.3	-35.3	34.6	-37.8	37.0	-40.5	47.6	-52.0
	1	20	25.0	-26.7	27.0	-28.9	31.4	-33.5	33.7	-35.9	36.0	-38.4	46.3	-49.3
	1	50	24.1	-24.8	26.0	-26.8	30.2	-31.1	32.4	-33.3	34.6	-35.7	44.5	-45.8
	1	100	23.3	-23.3	25.2	-25.2	29.3	-29.3	31.4	-31.4	33.6	-33.6	43.2	-43.2
	2	10	25.7	-32.9	27.8	-35.6	32.3	-41.2	34.6	-44.2	37.0	-47.3	47.6	-60.8
	2	20	25.0	-31.4	27.0	-34.0	31.4	-39.4	33.7	-42.3	36.0	-45.3	46.3	-58.1
	2	50	24.1	-29.5	26.0	-32.0	30.2	-37.1	32.4	-39.8	34.6	-42.5	44.5	-54.6
	2	100	23.2	-28.1	25.2	-30.4	29.3	-35.3	31.4	-37.8	33.6	-40.5	43.2	-52.0
	3	10	25.7	-32.9	27.8	-35.6	32.3	-41.2	34.6	-44.2	37.0	-47.3	47.6	-60.8
	3	20	25.0	-31.4	27.0	-34.0	31.4	-39.4	33.7	-42.3	36.0	-45.3	46.3	-58.1
	3	50	24.1	-29.5	26.0	-32.0	30.2	-37.1	32.4	-39.8	34.6	-42.5	44.5	-54.6
	3	100	23.3	-28.1	25.2	-30.4	29.3	-35.3	31.4	-37.8	33.6	-40.5	43.2	-52.0
Wall	4	10	28.1	-30.5	30.4	-33.0	35.3	-38.2	37.8	-41.0	40.5	-43.9	52.0	-56.4
	4	20	26.8	-29.2	29.0	-31.6	33.7	-36.7	36.1	-39.3	38.7	-42.1	49.6	-54.1
	4	50	25.2	-27.5	27.2	-29.8	31.6	-34.6	33.9	-37.1	36.2	-39.7	46.6	-51.0
	4	100	23.9	-26.3	25.9	-28.4	30.0	-33.0	32.2	-35.4	34.4	-37.8	44.2	-48.6
	4	500	21.0	-23.3	22.7	-25.2	26.3	-29.3	28.2	-31.4	30.2	-33.6	38.8	-43.2
	5	10	28.1	-37.6	30.4	-40.7	35.3	-47.2	37.8	-50.6	40.5	-54.2	52.0	-69.6
	5	20	26.8	-35.1	29.0	-38.0	33.7	-44.0	36.1	-47.2	38.7	-50.5	49.6	-64.9
	5	50	25.2	-31.8	27.2	-34.3	31.6	-39.8	33.9	-42.7	36.2	-45.7	46.6	-58.7
	5	100	23.9	-29.2	25.9	-31.6	30.0	-36.7	32.2	-39.3	34.4	-42.1	44.2	-54.1
	5	500	21.0	-23.2	22.7	-25.2	26.3	-29.3	28.2	-31.1	30.2	-33.6	38.8	-43.2

Table 8 (cont'd): Roof Overhang Net Design Wind Pressure, Pnet30 (lb/ft2)

	Zone	Effective Wind Area (ft²)	Basic Wind Speed V (mph)							
			90	100	110	120	130	140	150	170
Roof 0° to 7°	2	10	-21.0	-25.9	-31.4	-37.3	-43.8	-50.8	-58.3	-74.9
	2	20	-20.6	-25.5	-30.8	-36.7	-43.0	-49.9	-57.3	-73.6
	2	50	-20.1	-24.9	-30.1	-35.8	-42.0	-48.7	-55.9	-71.8
	2	100	-19.8	-24.4	-29.5	-35.1	-41.2	-47.8	-54.9	-70.5
	3	10	-34.6	-42.7	-51.6	-61.5	-72.1	-83.7	-96.0	-123.4
	3	20	-27.1	-33.5	-40.5	-48.3	-56.6	-65.7	-75.4	-96.8
	3	50	-17.3	-21.4	-25.9	-30.8	-36.1	-41.9	-48.1	-61.8
	3	100	-10.0	-12.2	-14.8	-17.6	-20.6	-23.9	-27.4	-35.2
Roof > 7° to 27°	2	10	-27.2	-33.5	-40.6	-48.3	-56.7	-65.7	-75.5	-96.9
	2	20	-27.2	-33.5	-40.6	-48.3	-56.7	-65.7	-75.5	-96.9
	2	50	-27.2	-33.5	-40.6	-48.3	-56.7	-65.7	-75.5	-96.9
	2	100	-27.2	-33.5	-40.6	-48.3	-56.7	-65.7	-75.5	-96.9
	3	10	-45.7	-56.4	-68.3	-81.2	-95.3	-110.6	-126.9	-163.0
	3	20	-41.2	-50.9	-61.6	-73.3	-86.0	-99.8	-114.5	-147.1
	3	50	-35.3	-43.6	-52.8	-62.8	-73.7	-85.5	-98.1	-126.1
	3	100	-30.9	-38.1	-46.1	-54.9	-64.4	-74.7	-85.8	-110.1
Roof > 27° to 45°	2	10	-24.7	-30.5	-36.9	-43.9	-51.5	-59.8	-68.6	-88.1
	2	20	-24.0	-29.6	-35.8	-42.6	-50.0	-58	-66.5	-85.5
	2	50	-23.0	-28.4	-34.3	-40.8	-47.9	-55.6	-63.8	-82.0
	2	100	-22.2	-27.4	-33.2	-39.5	-46.4	-53.8	-61.7	-79.3
	3	10	-24.7	-30.5	-36.9	-43.9	-51.5	-59.8	-68.6	-88.1
	3	20	-24.0	-29.6	-35.8	-42.6	-50.0	-58.0	-66.5	-85.5
	3	50	-23.0	-28.4	-34.3	-40.8	-47.9	-55.6	-63.8	-82.0
	3	100	-22.2	-27.4	-33.2	-39.5	-46.4	-53.8	-61.7	-79.3

Mounting System Calculations

With the design wind pressures determined from step 1 we are now ready to determine the total design load of the Heliodyne solar thermal system, as well as the required rail and mount spacing values. The total design load for a structure includes both the structure dead load contribution as well as the various force loadings contributions.

Total Design Load Determination:

The total design load, P (lb/ft^2) is given in ASCE 7-05, section 2.4.1. A total of 8 different design loading equations are provided in the ASCE document, though only 4 equations shall be considered in this analysis. They are as follows:

$P = 1.0D + 1.0S$ Equation 1

$P = 1.0D + 1.0P_{net}$ Equation 2

$P = 1.0D + 0.75S^1 + 0.75P_{net}$ Equation 3

$P = 0.6D - 1.0P_{net}$ Equation 4

With P = Total Design Load (lb/ft^2)

D = Maximum Dead Load (lb/ft^2)

S = Snow Load (lb/ft^2)

P_{net} = Net Design Wind Loading

[1]Snow Load Reduction – Per ASCE 7-05, chapter 7, the snow load can be reduced according to the certain site specific considerations such as the roof slope, exposure factor, importance factor, and a thermal factor. For more information on this applicability of this force reduction, please refer to ASCE 7-05 chapter 7 for more information.

The first three equations represent the downward-acting force assessment, while the 4th equation applies to the uplift force assessment. When determining the total design load P value, the maximum computed value of the three different downward loading calculations should be used. The dead load, D, is the weight of the specific thermal collector, with fluid, and associated mounting equipment, divided by the area footprint of the installation. This footprint is based upon the length of the specific Heliodyne solar thermal collector and the distance between attachment points securing either the collector itself, or the rail section to which the solar collector will be secured, to the roof joists.

Using the value of P_{net} as determined previously, along with the snow loading information for the specific installation location (this can be obtained through the application of ASCE 7-05, chapter 7 calculations, or from the local building department or authority having jurisdiction), the total design load P is calculated.

Calculating the distributed load on the mounting rail can now be accomplished. The distributed rail load, w, is expressed in pounds per linear foot (plf), and given by the formula

w (plf) = (P x B)/2

with P = Total Design Load (lb/ft^2)
B = Length of Solar Thermal Collector perpendicular to mounting rails (ft)

In this calculation the total design load P refers to the largest down force determined from equations 1 through 3 from above.

The down force point load, R_{down}, expressed in lbs, at each of the system mounting points must now be determined. R_{down} is given as

R_{down} (lbs) = (P x L x B)/2

with P = Total Design Load (lb/ft^2)
B = Length of Solar Thermal Collector perpendicular to mounting rails (ft)
L = Distance between Collector or Rail Mounting Locations (ft)

In this calculation the total design load P refers to the largest down force determined from equations 1 through 3 above.

It is the installers responsibility to verify that the building structure is sufficiently strong enough to support the point load forces.

The uplift force point load, Rup, expressed in lbs, at each mounting location is now determined from the following formula:

R_{up} (lbs) = (P x L x B)/2

with P = Total Design Load (lb/ft^2)
B = Length of Solar Thermal Collector perpendicular to mounting rails (ft)
L = Distance between Collector or Rail Mounting Locations (ft)

In this calculation the total design load P refers to the uplift force determined from equation 4 above.

Proper sizing of the lag bolts used to secure the collector or rail mounts ensures that they possess adequate strength to resist the uplift forces. Table 9 located on the following page displays the pull-out, or withdrawal, capacities, expressed in lbs, for lag bolts in various types of wood commonly used within the building industry. This table was obtained from the American Wood Council, NDS 2005, tables 11.2A, and 11.3.2A.

Table 9: Lag Screw Pull-Out Capacities (lbs) for Common Lumber Types

Type of Lumber	Specific Gravity	Lag Screw Capacity (lbs/inch of thread

		depth)
Douglas Fir, Larch	0.5	266
Douglas Fir, South	0.46	235
Engelmann Spruce and Lodgepole Pine (MSR 1650 f and higher)	0.46	235
Hem, Fir, Redwood (close grain)	0.43	212
Hem, Fir (North)	0.46	235
Southern Pine	0.55	307
Spruce, Pine, Fir	0.42	205
Spruce, Pine, Fir (E > 2,000,000 psi and higher grades of MSR and MEL	0.5	266

Table Notes:

(1) Thread must be embedded in the side grain of a rafter or other structural member integral with the building structure.

(2) Lag bolts must be located in the middle third of the structural member.

(3) These values are not valid for wet service.

(4) This table does not include shear capacities. If necessary, contact a local engineer to specify lag bolt size with regard to shear forces.

(5) Install lag bolts with head and washer flush to surface (no gap). Do not over-torque.

(6) Withdrawal design values for lag screw connections shall be multiplied by applicable adjustment factors if necessary. See table 10.3.1 in the American Wood Council NDS for Wood Construction.

4.3 Seismic Loading Forces

The seismic design requires for a Heliodyne solar thermal system are provided in ASCE 7-05, Chapter 13: Seismic Design Requirements for Nonstructural Components. From section 13.3.1 the seismic design force, Fp, expressed in lb_f (pounds – force), is applied at the component's center of gravity and distributed relative to the component's mass distribution, according to the following formula:

$$F_p = \frac{(0.4 \times a_p \times S_{DS} \times W_p)}{(R_p/I_p)} \times [1 + 2 \times (z/h)]$$

with
- F_p = Horizontal seismic design force
- a_p = Component application factor per table 13.5-1 or table 13.6-1
- S_{DS} = Design spectral response acceleration parameter in the short period range per ASCE 7-05, section 11.4.4
- W_p = Component operating weight
- R_p = Component response modification factor per table 13.5-1
- I_p = Component importance factor per 13.1.3
- z = Height in structure of point of attachment
- h = average roof height of structure

It should be noted that values for $F_p > 1.6 \times S_{DS} \times I_p \times W_p$ are not required to be taken for the seismic design force basis, while Fp must be $\geq 0.3 \times S_{DS} \times I_p \times W_p$.

In determining the value for a_p, the component application factor, we shall consult table 13.5-1, as the table provides values for both the component application factor, a_p, as well as the component response modification factor, R_p, applicable to architectural components. Using the category of Other Flexible Components, and the sub-category of High Deformability Elements and Attachments, we have

a_p = 2.5 and **R_p = 3.5**

The value for SDS is found by applying the procedure outlined in section 11.4.4. Chapter 11 of ASCE 7-05, Seismic Design Criteria, provides two formulas related the design spectral acceleration parameters.

$S_{DS} = (2/3) \times S_{MS}$
$S_{D1} = (2/3) \times S_{M1}$

S_{DS} refers to the spectral response acceleration parameter at short periods, whereas S_{D1} applies to periods of 1 section. As S_{DS} is the only spectral response acceleration parameter that is used in our equation to determine F_p, we must only determine this value. From 11.4.3, we find that

$S_{MS} = F_a \times S_s$

where short S_s = Mapped Maximum Considered Earthquake (MCE) spectral response acceleration at periods as determined in accordance with section 11.4.1

F_a = Site coefficient as defined in table 11.4-1 and 11.4-2

To determine the MCE we must evaluate the 0.2 second spectral response accelerations as depicted in ASCE figures 22-1 through 22-14.

These figures express the contours of spectral response acceleration values as a percentage of the gravitational force g. When examining these figures, and focusing upon Earthquake prone regions, we find that in most instances, the maximum spectral response acceleration is 200%, or 2.0. As there are some specific areas in which the values of S_s exceed 2.0, the installer of a Heliodyne solar thermal system is recommended to check with the local building department or authority having jurisdiction on site-specific values of Ss, especially in instances where the installation will occur within a region of known earthquake activity.

For our example, which as stated previously will apply in almost all geographic locations, $S_s = 2.0$.

To determine Fa, the site coefficient, we must now refer to ASCE 7-05 table 11.4-1. In order to obtain a value for Fa from this table we must define a site class applicable to the given installation location. Per 11.4.2 the site class is based upon site soil properties. In the absence of sufficient information to determine the site soil class, section 11.4.2 states that a site class D shall apply, unless the authority having jurisdiction on geotechnical data determines that site class E or F soils are present at the site.

For our example a site class D shall be taken to apply. Should the installer of a Heliodyne solar thermal system desire, local engineering personnel should be able to determine the actual site class for a given location.

Using $S_s = 2.0$, with a site class D, table 11.4.1 provides $F_a = 1.0$.

Consequently $S_{MS} = F_a \times S_s = 2.0 \times 1.0 = \mathbf{2.0 = S_{MS}}$

and now $S_{DS} = (2/3) \times S_{MS} = (2/3) \times 2.0 = \mathbf{1.33 = S_{DS}}$

Wp is the weight of the Heliodyne solar thermal system, including the thermal collectors (with fluid), and all associated mounting hardware. As this can vary considerably from one installation to the next, this factor shall remain in the variable form for now.

z, or the height in structure of point attachment, is equal to zero.

h, or the average roof height of structure, can vary considerably from case to case. If the installation is to be carried out in a rack-mounted configuration, h will vary depending upon the installation angle and the specific model of thermal collector. If the installation is to be carried out using a flush-mounting method, then h is independent of the specific collector model. Irrespective of these possible variations, we make use of the fact that the value of h will not affect out evaluation of F_p, since

$(z/h) = 0$ for all values of h as $z = 0$ in all instances.

Lastly we must consider the component importance factor, I_p. Per section 13.1.3, $I_p = 1.0$ unless any of the following three conditions apply:

1. The component is required to function for life-safety purposes after an earthquake, including fire protection sprinkler systems.
2. The component contains hazardous materials.
3. The component is in or attached to an Occupancy Category IV structure and it is needed for continued operation of the facility or its failure could impair the continued operation of the facility.

In this instance we can see that the first two cases do not apply to a Heliodyne solar thermal system. While it is possible that the installation could be conducted on an building or structure belonging to

Occupancy Category IV, for the purposes of this example we shall assume that this is not the case, and therefore $I_p = 1.0$

We are now ready to evaluate Fp.

$$F_p = \frac{(0.4 \times a_p \times S_{DS} \times W_p)}{(R_p/I_p)} \times [1 + \{2 \times (z/h)\}]$$

$$= \frac{(0.4 \times 2.5 \times 1.33 \times Wp)}{(3.5/1.0)} \times [1 + \{2 \times (0/h)\}]$$

$$= 0.38 \times W_p$$

Recall that $Fp \geq 0.3 \times S_{DS} \times I_p \times W_p$

In our case with, $S_{DS} = 1.33$, $I_p = 1.0$, we find that

$$F_p \geq 0.399 \times W_p$$

We must therefore reject our earlier calculation of $F_p = 0.38 \times Wp$ and apply

$$F_p = 0.399 \times W_p$$

as the valid equation for the determination of the horizontal seismic design force.

5.0 Referenced Materials

Throughout this manual reference has been made to the American Society of Civil Engineers (ASCE) standard for determining the minimum design loads for buildings and other structures, referred to as ASCE standard 7-05. Though no specific reference to the International Building Code 2006 was made, the 2006 IBC refers to ASCE standard 7-05 for the determination of design loadings. Lastly reference was made to the pull out capacities of lag bolts as provided in the National Design Specification documentation published by the American Wood Council.