# Snow Loads on Solar-Paneled Roofs

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Sponsored by the
Technical Activities Division of the
Structural Engineering Institute of the
American Society of Civil Engineers

**Published by the American Society of Civil Engineers**

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4382
www.asce.org/bookstore | ascelibrary.org



ISBN 978-0-7844-8024-3 (PDF)

Manufactured in the United States of America.

23 22 21 20 19 18 17 16 1 2 3 4 5

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# Acknowledgments

The authors would like to recognize the following organizations for project support in developing this report:

American Iron and Steel Institute

FM Global

Metal Building Manufacturers Association

# INTRODUCTION

The load recommendations contained herein are for snow atop solar paneled roofs. The balanced loads, sliding loads and drift loads are all in terms of uniform or nonuniform downward acting pressures over all or portions of the roof. They are specifically intended for the structural design of roof beams, roof girders, and columns. They are not intended for the structural design of the solar panels themselves nor the above-the-roof-surface solar panel support components. The guide's use of north and south directions assumes a northern hemisphere site location.

Depending on the structural framing of the solar panel support system, the uniform loads recommended herein may resolve into concentrated "point" loads or "line" loads on the roof surface. These resultant, support system dependent, point and line loads should be used for the structural design of the roof deck and roof sheathing panels.

The snow loading recommendations contained herein are based on limited case history information (Corotis et al. 1979; O'Rourke 1979), laboratory studies (Irwin et al. 1984) design criteria (Cattaneo et al. 1981), and engineering judgment. The recommended sliding and drifting load cases in particular are intended to envelop actual distributions of snow loading. As such, refined approaches based on special studies may become available in the future and used to modify the snow load recommendation presented herein. Any such studies should be based on rational methods and an understanding of snow loading processes.

Finally, the recommendations contained herein are intended to cover snow load conditions that result from the presence of solar panels on a roof. The solar panel specific recommendations in this guideline are intended to be used with the snow load procedures in *Minimum Design Loads for Buildings and Other Structures,* Standard ASCE/SEI 7-10, including the load factors and load combinations. (Except for changes to figure and section numbering, this guide is also compatible with ASCE 7-16, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*.) The recommendations are not intended to replace the well-established snow load considerations in the ASCE 7-10 load standard. For example, Fig. 7-9 in ASCE 7-10 is to be used to determine the snow drift load at a roof step, even though the upper or lower level roof happens to have solar panels. In particular, it is recommended that the presence of solar panels on a higher level roof or an upwind roof should be conservatively neglected in the evaluation of sliding loads on a lower level roof, windward roof step drifts, leeward roof step drifts, parapet wall drifts, and gable roof drifts on a downwind roof. These issues are covered in more detail in Sections 3.4 and 4.5 wherein General Recommendations A and B are presented.

# Chapter 1

# SOLAR PANEL TYPES

Four types of solar panels are considered herein.

**Flush Panels:** Flush solar panel modules are installed parallel to but offset from the roof surface. When "direct attached," the airspace is approximately the height of the standing seams (~2 to 4 in.). When "rail mounted," the airspace is about 4 in. above the seams (~6 to 8 in. above flat surface between seams). The photographs in Fig. 1-1 show two examples of flush solar panels.

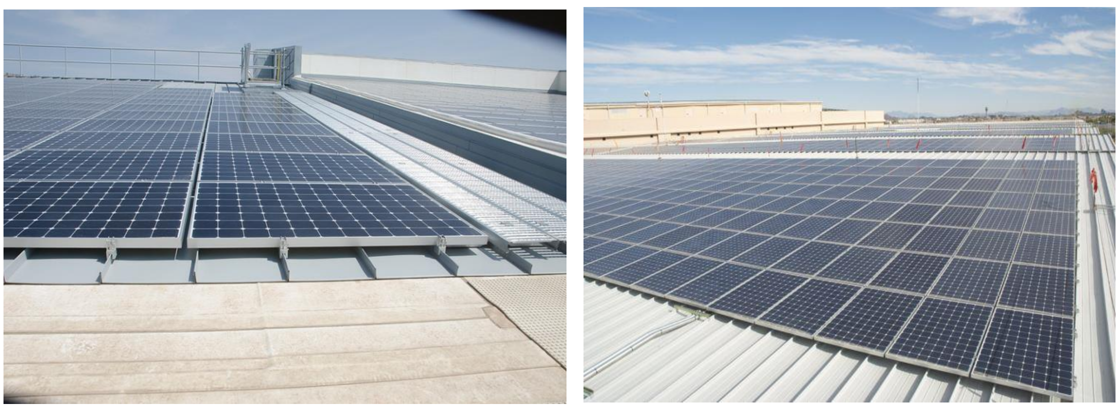


**Fig. 1-1. Typical Flush Solar Panels (Photos courtesy of MBMA)**

**Tilted-Closed Panels:** Tilted–closed solar panels are installed at an angle with respect to the roof surface with the back/north edge closed. The small airspace at the sunward/south and back/north edges is comparable to the standing seam height. The photographs in Fig. 1-2 show two examples of tilted–closed panels.

**Fig. 1-2. Typical Tilted–Closed Solar Panels (Photos courtesy of MBMA)**

**Tilted-Open Panels:** Tilted–open solar panels are installed at an angle with respect to the roof surface, with the back/north edge open. The small airspace at the sunward/south edge is comparable to the standing seam height. The airspace at back/north edge is larger and varies with specific system design. The photographs in Fig. 1-3 show examples of tilted–open solar panels.

**Fig. 1-3. Typical Tilted–Open Solar Panels (Photos courtesy of SLK Solar Corporation)**

**Elevated Panels:** Elevated solar panels are installed at an angle with respect to the roof surface. Large airspaces exist at both the sunward/south and the back/north edges. The photographs in Fig. 1-4 show examples of elevated solar panels.

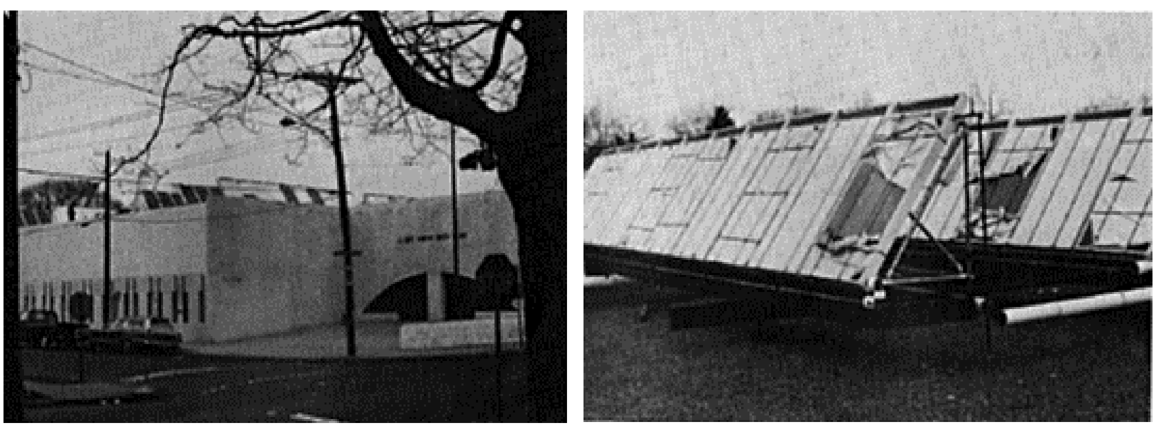


**Fig. 1-4. Typical Elevated Solar Panels**

# Chapter 2
# BALANCED SNOW LOAD CONSIDERATIONS

## 2.1 Thermal Factor, $C_t$

In ASCE 7-10, the thermal factor $C_t$ varies between 0.85 for certain greenhouses to 1.3 for structures intentionally kept below freezing (e.g., freezer buildings). This factor is intended to modify the flat roof snow load based on the expected heat flow up through the roof. One expects large heat flow for greenhouses in winter, which results in melting of roof snow and hence smaller values for the flat roof snow load, $p_f$. Conversely, small heat flow (freezer building in winter) results in little or no melting and hence larger values for the flat roof snow load.

As sketched in Fig. 2-1, a simple thermal model of the roof layer away from solar panel would consist of indoor air temperature $T_i$ (presumably above freezing for most occupancies), a roof insulation layer with thermal resistance, $R_i$, a snow layer with thermal resistance, $R_s$, and outdoor air temperature, $T_o$ (presumably below freezing when snow is present).

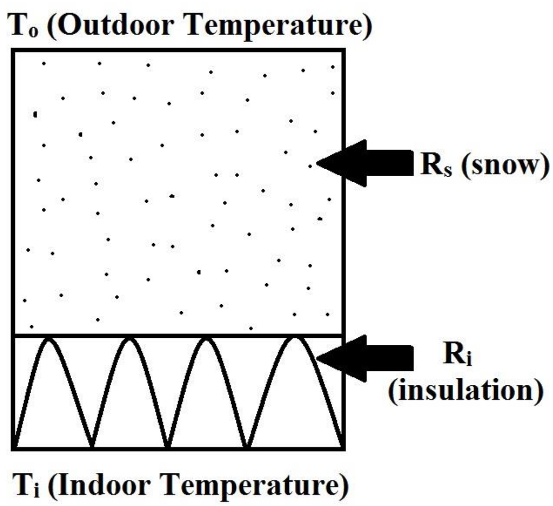



**Fig. 2-1. Simple Thermal Model of Roof and Snow Layer Away from Solar Panels**

Melting occurs at the bottom of the snow layer when the roof/snow interface temperature is nominally 32 °F. For a given combination of $T_i$, $R_i$, and $R_s$, there is an outdoor temperature, $T_o$, which results in an interface temperature of exactly 32 °F. If $T_o$ is lower, the freezing point is within the insulation layer (no melting). If $T_o$ is higher, one gets snow melting at the roof/snow interface and a reduction of roof snow load.

For roofs with solar panels, one expects that the temperature at the surface of the solar panel would, if anything, be somewhat higher than for the same location without solar panels. Hence, one expects that the outdoor close-to-the-roof-surface temperature $T_o$, if anything, would be somewhat higher for a solar-paneled roof. Of course, there would likely be portions of the roof surface shaded by tilted and elevated solar panels. However, the snow atop tilted or elevated panels is not shaded by the solar panels themselves, and the shaded portion of the roof surface may well be free of snow. Hence, considering the roof thermal effects only, one expects somewhat more melting and less roof load for a roof with solar panels compared to the same roof without solar panels. As such, it would be conservative to *neglect* the presence of solar panels where determining the ASCE 7-10 Thermal Factor, $C_t$.. This leads to Recommendation #1.

**Recommendation #1 – $C_t$ Factor:** In the determination of the thermal factor $C_t$ for solar paneled roofs, it is recommended that the presence of solar panels be conservatively neglected.

That is, the $C_t$ factor for a particular roof with solar panels should be the same as that for the roof without solar panels.

## 2.2 Slope Factor, $C_s$

Currently in ASCE 7-10, the $C_s$ factor reduces the balanced roof snow load if conditions are conducive to snow sliding off the roof or for very steep roof slopes snow not initially sticking to the roof surface. The slope factor is a function of roof slope, roof thermal condition, and the presence of obstructions.

In relation to roof snow *away from* solar panels (not sliding snow from the panel, which will be addressed later), the presence of solar panels potentially influences two of these parameters; the thermal condition and the presence of obstructions.

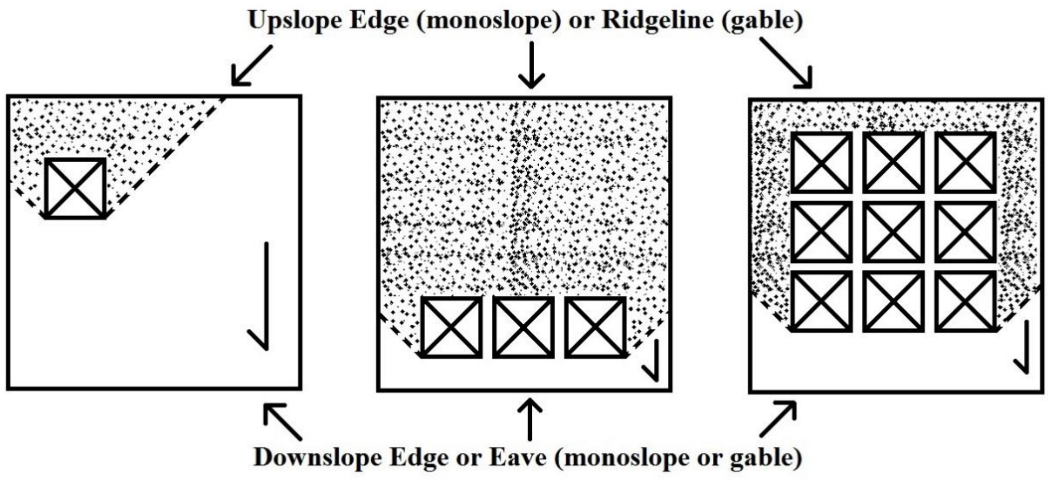
**Thermal Conditions:** The temperature of the solar panel top surface would likely be somewhat higher than the adjacent bare roof. However, one does not expect the *roof surface* temperature to be significantly higher in comparison to roof surface temperature without solar panels. Hence, one expects that the potential for sliding of snow that originally landed on the roof surface (not on the solar panel surface) would not be changed due to solar panel related temperature changes. This leads to Recommendation #2.

**Recommendation #2 – $C_s$ Factor:** It is recommended that the $C_t$ factor used to determine $C_s$ be the same for a roof with or without solar panels.

That is, if a roof without solar panels would be classified as a cold roof with $C_t = 1.1$, the same roof with solar panels would also be classified as a cold roof with $C_t = 1.1$, and ASCE 7-10 Fig. 7.2b should be used to determine the $C_s$ factor.

**Obstruction:** The presence of a flush, tilted-closed, or tilted-open panel atop a sloped roof would likely prevent or impede some of the upslope snow from sliding off a roof. The degree to which elevated panels may impede sliding depends on their support system. Elevated panels with legs or struts supported by bearing beams at the roof surface are expected to obstruct sliding snow to the same degree as other types of panels.

The presence of a single panel located near the ridge (gable roof) or upslope edge (monoslope roof) may only prevent a small portion of the upslope snow from sliding, whereas a long row of panels located close to the roof eave (gable roof) or downslope edge (monoslope roof) would prevent most all of the roof snow from sliding, as sketched in Fig. 2-2.




a) Single panel b) Single row downslope c) Multiple rows

**Fig. 2-2. Sliding Obstructed Roof Portions: Gable or Monoslope Roof (sliding obstructed portions dotted)**

Clearly in the first case, (shown in Fig. 2-2a) the roof is nominally unobstructed for sliding whereas in the second and third cases (shown in Figs. 2-2b and 2-2c), it is nominally obstructed. In all such cases, it seems reasonable to base the sliding obstructed/unobstructed decision on the percentage of the roof surface with obstructed snow, and 25% seems a reasonable value for the percentage. This leads to Recommendation #3.

**Recommendation #3 – $C_s$ Factor:** All snow upslope from the south edge of a flush, tilted-closed, and tilted-open panel (including snow within a 45° plan view line upslope from the corner of such a panel as shown in Fig. 2-3) should be considered sliding obstructed snow. Any roof bay with 25% or more sliding obstructed snow should be considered obstructed for the purposes of determination of the slope factor $C_s$.

Herein, a roof bay means the typically rectangular roof area between adjacent column lines in both the project north-south and the project east-west directions. Note that by the aforementioned proposed language, a large roof with multiple bays (but solar panels on only a portion of the roof surface) could have some sliding obstructed bays and some unobstructed bays. This multibay situation is sketched in Fig. 2-4.

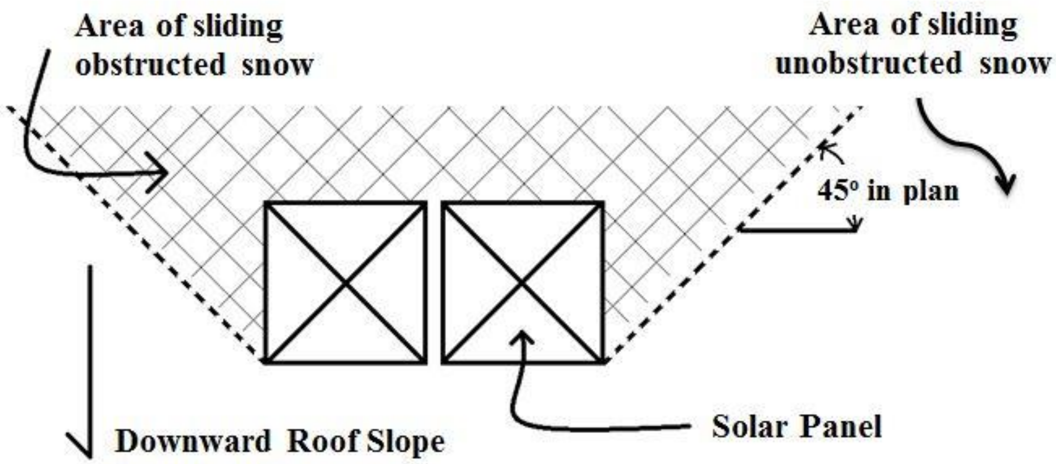



**Fig. 2-3. Sliding Obstructed Snow Upslope of Solar Panel(s): Plan View**

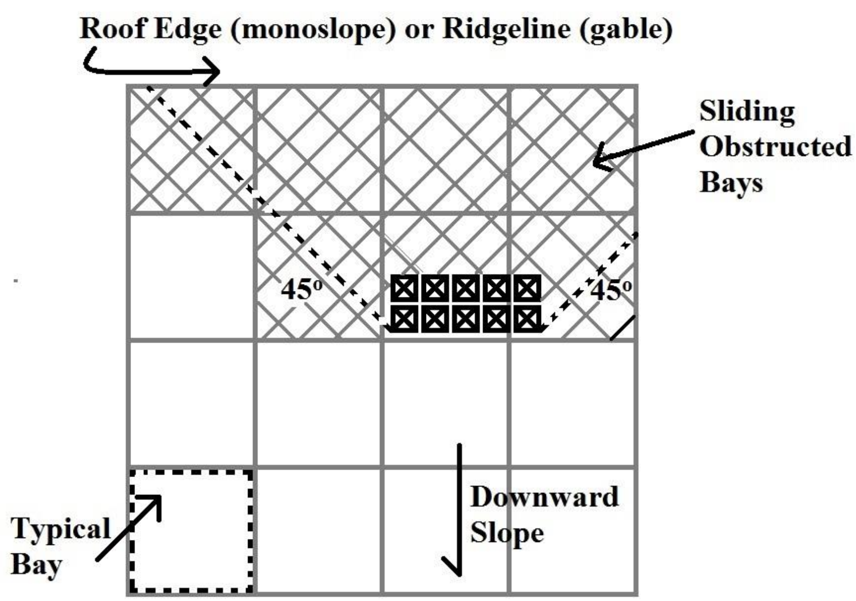



**Fig. 2-4. Plan View: Large Roof with Multiple Bays**

## 2.3 Exposure Factor, $C_e$

In ASCE 7-10, the exposure factor $C_e$ increases or decreases the flat roof snow load depending on the ability of wind to remove snow from the roof. It is a function of the surface roughness category, as well as the local roof exposure. The exposure factor is comparatively large (0.9 to 1.2) for Surface Roughness Category B–Urban/Suburban where near surface wind speeds are comparatively low. The factor is comparatively low (0.8 to 1.0) for Surface Roughness Category D–Mud and Salt Flats where near surface wind speeds are comparatively high.

Within any specific surface roughness category, the exposure factor is a function of the local roof exposure. The factor is lower for a fully exposed roof than for a sheltered roof. “Fully exposed” (no shelter for any side) and “sheltered” (roof tight in among conifers that qualify as obstructions) are fairly well defined. “Partially exposed” is everything else. Note that as per ASCE 7-10, roofs with several large pieces of roof top equipment should not be considered “fully exposed.” In relation to the exposure factor for solar paneled roofs, this document contains a simple conservative approach as the default (Recommendation #4–Exposure Factor $C_e$ Default) and a more complex approach as an alternative (Recommendation #5–Exposure Factor $C_e$ Alternative). In both approaches, all panels are considered to be wind obstructions if the panels extend above the depth of the balanced snow, $h_b$. This is considered reasonable for flush and tilted panels. Because of the possible air gap below elevated panels, the assumption that they act as wind obstructions is open to question. However, the assumption that elevated panels act as wind obstructions is conservative as it results in larger values for $C_e$.

The proposed simple approach is presented as Recommendation #4.

**Recommendation #4–Exposure Factor $C_e$ Default:** For the purpose of determination of the exposure factor $C_e$, roof bays with wind obstructing solar panels shall be classified as either partially exposed or sheltered. If the roof bay without solar panels would be classified as fully exposed, the same roof bay with wind obstructing solar panels should be classified as partially exposed. If the roof bay without solar panels would be classified as partially exposed or sheltered, the same roof bay with wind obstructing solar panels should be classified as sheltered.

Following Recommendation #4, the presence of wind obstructing solar panels converts an otherwise fully exposed roof bay into a partially exposed roof bay, not into a sheltered roof bay. Note in this regard that solar panels typically face south, and as such, they typically do not provide shelter for wind out of the east or west. Hence, a fully exposed roof bay morphs into a partially exposed roof bay (sheltered for north-south wind, not sheltered for east-west wind) as opposed to a sheltered roof bay (sheltered for both north-south and east-west wind).

In the alternative approach, the length of the shelter region downwind from a wind obstructing solar panel is a function of the elevation, $h_c$, of the panel north or back edge above the balanced snow depth. As sketched in Fig. 2-5, the length of the downwind shelter region is taken herein to be 8 $h_c$. Also, for consistency, it is proposed the same 25% trigger value used for obstructed sliding snow be also used for wind sheltered snow. This leads to Recommendation #5.

**Recommendation #5–Exposure Factor $C_e$ Alternate:** The "Exposure of Roof" in ASCE-10 Table 7-2 may be determined as follows. The length of the wind shelter region downwind of a wind obstructing solar panel shall be taken as 8 $h_c$ where $h_c$ is the elevation difference between the north edge of the solar panel and the balanced snow below. If a particular roof absent solar panels would be classified as fully exposed any bay with 25% or more of wind sheltered area should be considered partially exposed, whereas any bay with less than 25% wind sheltered area can be considered fully exposed. If a particular roof absent solar panels would be considered partially exposed due to nonsolar panel obstruction (e.g., parapet walls), then any bay with 25% or more solar panel sheltered area should be considered sheltered. Otherwise, the bay can be considered partially exposed.

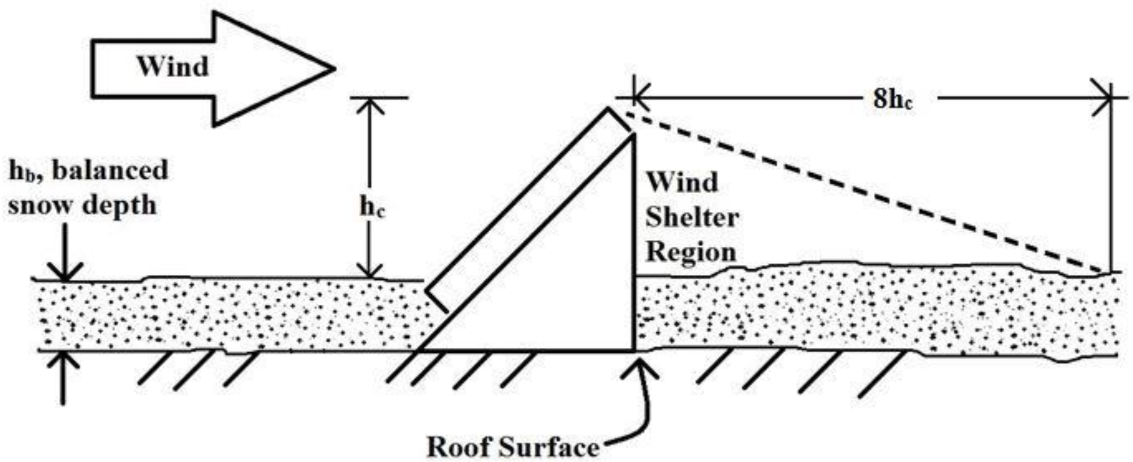



**Fig. 2-5. Wind Shelter Region Downwind of Obstruction**

# Chapter 3
# SLIDING LOADS

In ASCE 7-10, the sliding load provisions envision a sloped upper level roof snow source area, and a lower level roof where the sliding snow surcharge is applied. The lower roof surcharge corresponds to 40% of the upper level flat roof load. The 40% value recognizes that the conditions conducive to snow sliding (e.g., above freezing outdoor temperature, sunshine, etc.) are not always present in winters with heavy snow. Conversely, snow sliding off a roof mounted solar panel is expected to be a somewhat more frequent occurrence due to the expected warmer surface temperatures for the panels themselves. Herein, it is conservatively suggested that the sliding snow surcharge correspond to 100% of the panels "flat roof" snow load.

## 3.1 Sliding Snow Loads for Flush Panels

In ASCE 7-10, sliding snow loading is required for slippery roof surfaces with slopes greater than ¼ on 12. In this regard, the top surface for solar panels would be considered slippery. Hence, for flush panels on nominally flat roofs (roof slope of ¼ on 12 or less) one does not expect sliding snow loading.

Furthermore, in ASCE 7-10, sliding snow loading from an upper to lower roof is reduced if it is blocked by snow already on the lower level roof. Hence, one does not expect sliding snow loading from snow originally atop buried Flush panels. This leads to Recommendation #6.

**Recommendation #6–Sliding Load Flush Panels:** For flush panels, sliding loads need to be considered only for visible panels (top of panel above the balanced snow depth) on roofs with slopes larger than ¼ on 12. The sliding load surcharge corresponds to 1.0 $P_f W_c$ where $W_c$ is the upslope width of the panel or adjacent panels as sketched in Figs. 3-1 and 3-2. It is recommended that the sliding load surcharge should be distributed over a downslope width of $W_c$.

Note that Recommendation #6 applies to sliding loads downslope from solar panels. In these cases, the sliding snow was originally atop the solar panels themselves. Recommendation #6 does not apply to sliding loads already covered in ASCE 7-10. For example, ASCE 7-10 Section 7.9 should still be used to determine sliding loads from an upper level roof onto a lower level roof that happens to have solar panels as will be discussed in more detail in Section 3.4.

For widely spaced panels, the sliding load surcharge is located adjacent to the downslope (typically south) edge of the panel as sketched in Fig. 3-1. For closely spaced panels as sketched in Fig. 3-2, the south edge of the surcharge abuts the north edge of the adjacent downslope panel. That is, in both cases the sliding load surcharge corresponds to an intact slab of snow sliding off the collector panel/panels and ending up immediately downslope of the collector panel/panels. In both cases, the horizontal extent of the surcharge $W_c$ ($W_1$ and $W_2$ in Fig. 3-1, $W_3$ in Fig. 3-2) is the same as the horizontal extent of the panel/panels atop which it was originally located.

To be consistent with ASCE 7-10, the sliding load surcharge would be a separate load case–not to be combined with drifting loads to be discussed later.

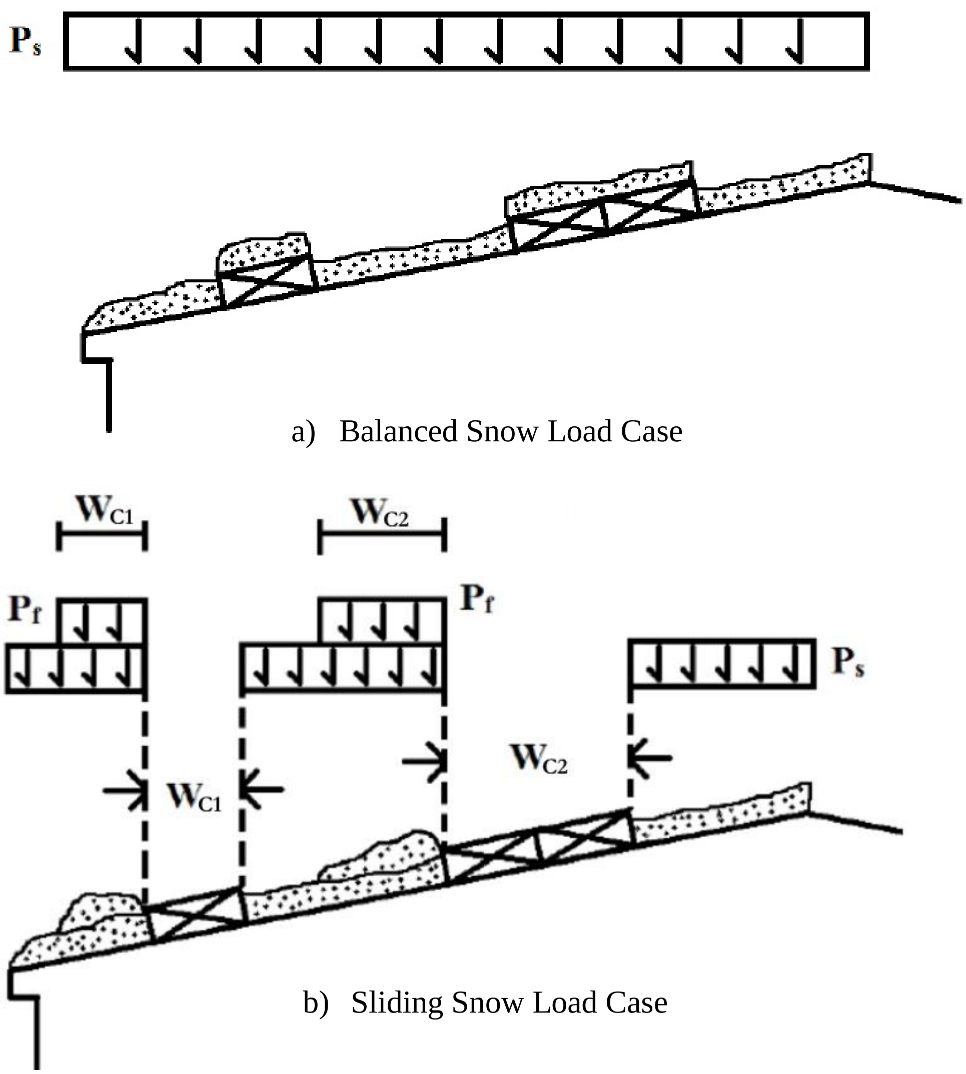



**Fig. 3-1. Balanced and Sliding Load Cases for Widely Spaced Visible Flush Mounted Panels**

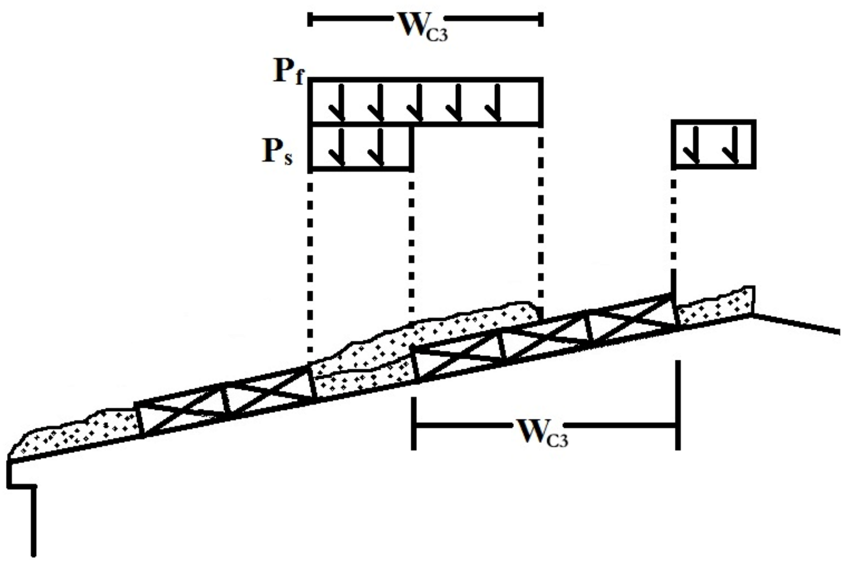



**Fig. 3-2. Sliding Load Case for Closely Spaced Visible Flush Mounted Panels (sliding load at downslope solar panels not shown for clarity)**

## 3.2 Sliding Snow Loads for Tilted Panels

As with flush panels, tilted panels would either be visible or buried. It seems likely that all tilted panels would have an “as-installed” slope of something more than ¼ on 12. Hence, one expects snow sliding loads for all visible (i.e., nonburied) tilted panels.

The same general approach is proposed for tilted-closed panels as for flush panels. The difference is that some tilted-closed panels have a nonvertical back (deflector) closure piece. Because the deflection slopes are commonly in the 20° to 40° range, one expects snow also to slide off the deflector. This leads to Recommendation #7.

**Recommendation #7–Sliding Load Tilted-Closed Panels:** The sliding load for visible tilted-closed panels shall correspond to 1.0 $W_cP_f$ where $W_c$ is the horizontal extent of the portion of the panel above the balanced snow depth $h_b$.

Fig. 3-3 shows a sketch of the resulting sliding load for a tilted–closed panel with a vertical back deflector, which Fig. 3-4 shows the same for a sloped back deflector.

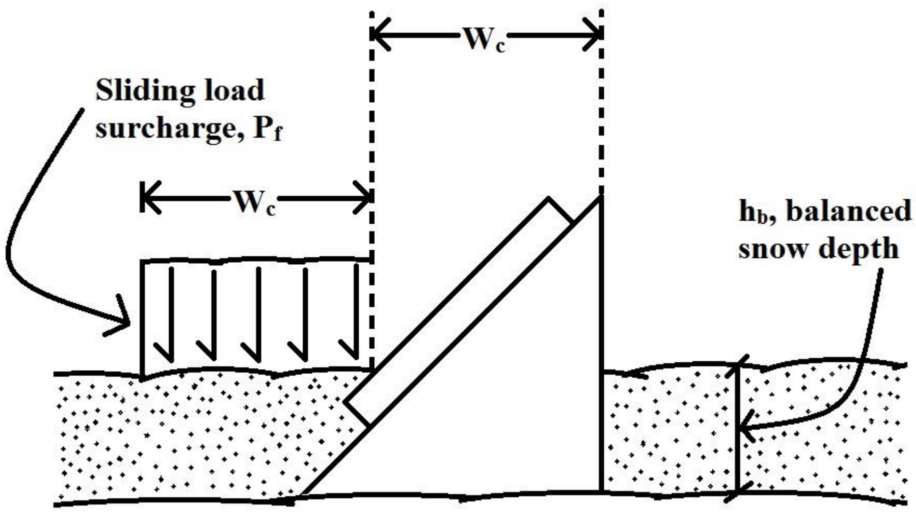



**Fig. 3-3. Distribution of Sliding Snow Surcharge for Tilted-Closed Panels with a Vertical Back Deflector**

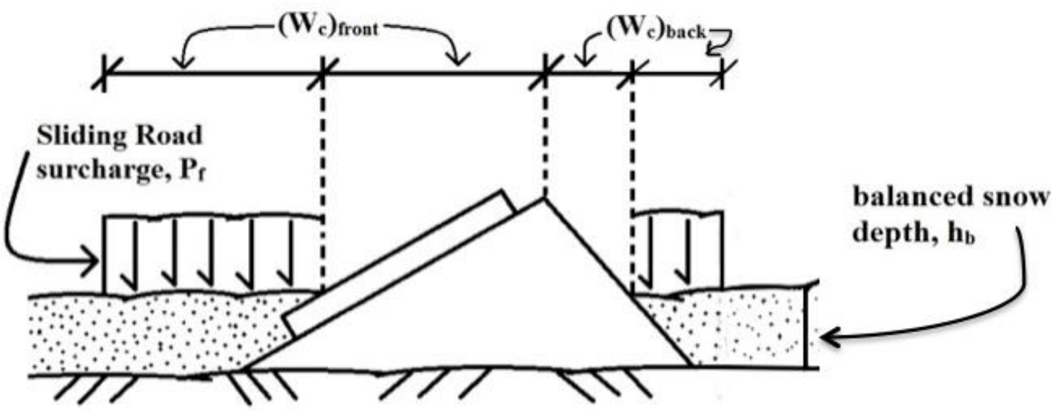
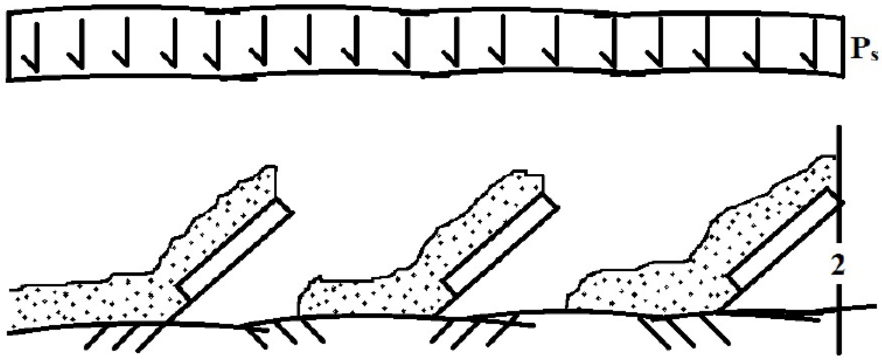


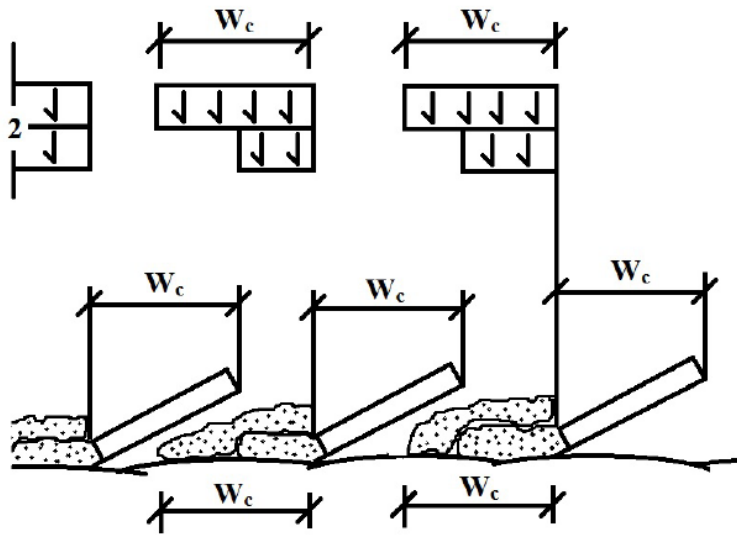

**Fig. 3-4. Distribution of Sliding Snow Surcharge for Tilted-Closed Panels with a Sloped Back Deflector**

The approach for tilted-open panels should follow the same general approach as that for tilted-closed panels as presented. There are two differences because open panels do not have a back deflector: (1) snow potentially sliding off the back is not an issue, and (2) sliding snow from an adjacent row of panels could end up underneath a tilted-open panel to the south.

Fig. 3-5 shows both the balanced load and the proposed sliding load for tilted-open panels with a narrow aisle between rows. For the expected case where the panel protruding width ($W_c$) are the same for adjacent rows, there would be space available beneath a given panel for a portion of the sliding load from a panel to the north.




a) Balanced Load




b) Sliding Load

**Fig. 3-5. Balanced and Sliding Loads for Tilted–Open Panels with Narrow Aisles between Rows**

Load cases (a) and (b), shown in Fig. 3-5 are intended to envelope the effects of solar panels on the primary structural system of the roof. They are thought to be simple and easy to understand, although a bit conservative in relation to the design of the support system of the solar panels themselves and the transfer of load from the panels onto the roof sheathing. Further special studies beyond the scope of this guideline would be needed in order to refine the load cases shown in Fig. 3-5.

## 3.3 Sliding Snow Loads for Elevated Panels

The suggested general approach for elevated panels is the same as that for flush and tilted panels. That is 100% of $P_f$ slides off the panel. Elevated panels would have only south sliding loads, and it is unlikely that they would be buried. Also, because the panels have pole-like supports, sliding loads from an adjacent row to the north could "land" under its neighbor to the south, as with tilted-open panels.

## 3.4 Sliding Loads from/onto Solar Paneled Roofs

The sliding loads discussed thus far correspond to snow which initially fell onto the solar panel surface and subsequently slid onto an adjacent aisle. There are, of course, other possible sliding load situations. The classical sliding load situation addressed by ASCE 7-10 Section 7.9 corresponds to snow sliding off sloped upper level roof onto a lower level roof. It is possible that solar panels could be on either the upper level and/or lower level roof. It seems unlikely that the presence of solar panels on the lower level roof would significantly influence the sliding load from the upper level roof. The presence of solar panels on the upper level roof conceivably could influence the potential for snow sliding. However, the influence is likely a function of the panel type, panel layout (i.e., single panel, single row, multiple rows with aisle parallel to the downslope direction, etc.) and other parameters. Given the lack of available observations, changes to the existing provisions in ASCE 7-10 Section 7.9 seem unwarranted at this time. Also, any solar panel related reduction in the Section 7.9 sliding loads may place the roof at risk should the panels be removed or changed in the future. This leads to General Recommendation A.

**General Recommendation A–Sliding Loads from/onto Solar Paneled Roofs:** It is recommended that the presence of solar panels on either the upper level roof or the lower level roof be neglected when sliding loads are being determined using ASCE 7-10 Section 7.9.

# Chapter 4
# DRIFT LOADS

Solar panels are somewhat similar to small roof top units (RTUs). Current ASCE 7-10 provisions require simultaneous windward drifts on both sides of RTUs. The windward drift is based on the larger of the two fetch distances (distances from RTU to roof edge).

## 4.1 Snow Drift Loads for Flush Panels

One does not expect significant drift loads for roofs with buried flush panels. Similarly, for visible flush panels that do not extend much above the balanced snow ("barely" visible panels), one does not expect significant drifts. Note in this regard that ASCE 7-10 Section 7.7.1 states "If $h_c/h_b$ is less than 0.2, drift loads are not required to be applied." Hence, if the flush panel height $h_p$ as sketched in Fig. 4-1 is greater than 1.2 $h_b$, drift loads are required.

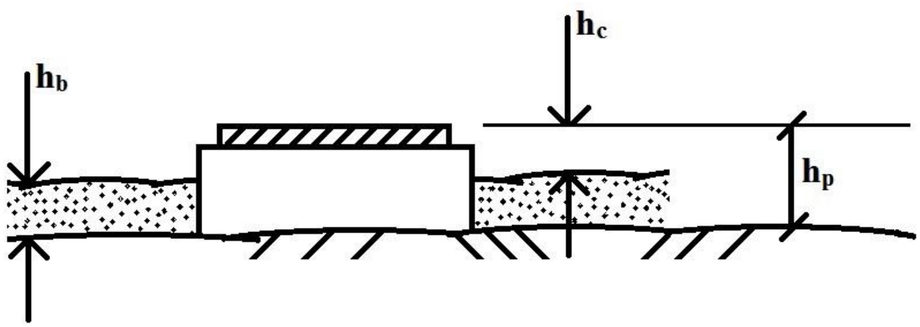



**Fig. 4-1. Geometry for Flush Panels**
**(snow atop panel not shown for clarity)**

As mentioned in Chapter 1, Flush panels are typically 2 to 8 in. above the flat roof surface. Hence, most flush panels are expected to be buried or barely visible. Consider a tall flush panel (rail mounted on tall standing seams) with $h_p$ = 8 in. For such tall panels, one needs to consider drifting only for a balanced snow depth $h_b$ of 6.67 in. or less. For panels with $h_p$ of 2, 4, and 6 in., the corresponding balanced snow depths above which drifting needs to be considered are 1.67, 3.33, and 5 in. respectively.

In ASCE 7-10, the balanced snow depth, $h_b$, is given by the balanced snow load $p_s$ divided by the snow density, $\gamma_s$.

$$h_b = p_s / \gamma_s \qquad (1)$$

where the balanced load is given by

$$p_s = 0.7C_eC_tC_sI_sp_g \qquad (2)$$

and $C_e$, $C_t$, $C_s$, and $I_s$ are the exposure, thermal, slope, and importance factors, respectively. The snow density in lb/ft$^3$ is given by

$$\gamma_s = 0.13p_g + 14 \quad (3)$$

Table 4-1 presents the smallest, typical, and largest snow depth for flat roofs with ground snow loads ranging from 5 to 20 psf. The smallest balanced snow depth corresponds to a heated greenhouse ($C_t$ = 0.85) with low risk to human life ($I_s$ = 0.8), fully exposed and located above the treeline ($C_e$ = 0.7). The typical roof has $C_e = C_t = I_s = 1.0$, while the largest balanced snow depth corresponds to an essential ($I_s$ = 1.2) freezer building ($C_t$ = 1.3) located at a sheltered site in Terrain Category B ($C_e$ = 1.2). Hence for a "typical" flat roof with $h_p$ = 4 in. Flush solar panels, drift loads only need to be considered in location with a design ground snow load of 5 psf (2.86″ < 3.33″). For the same flat roof with $h_p$ = 8 in. panels, drift loads only need to be considered in locations with $p_g$ of 5 or 10 psf (5.49″ < 6.67″).

**Table 4-1. Smallest, Typical, and Largest Flat Roof Snow Depths for Various Ground Snow Loads**

| | *Ground Snow Load, $p_g$* | | | |
|---|---|---|---|---|
| | *5 psf* | *10 psf* | *15 psf* | *20 psf* |
| Smallest:<br>$I_s = 0.8$, $C_t = 0.85$, $C_e = 0.7$; $p_s = 0.33p_g$ | 1.36 in | 2.61 in | 3.76 in | 4.82 in |
| Typical:<br>$I_s = 1.0$, $C_t = 1.0$, $C_e = 1.0$; $p_s = 0.7p_g$ | 2.87 in | 5.49 in | 7.9 in | 10.1 in |
| Largest:<br>$I_s = 1.2$, $C_t = 1.3$, $C_e = 1.2$; $p_s = 1.31p_g$ | 5.37 in | 10.3 in | 14.79 in | 18.9 in |

Drift loads in ASCE 7-10 are a function of the ground snow load and the upwind fetch distance. However, for a roof with flush solar panels, either the panels heights are small enough that drift loads need not be considered in the first place (i.e., $h_p \leq 1.2h_b$) or the space available for drift formation, $h_c$, will be small and control the drift size. Recall that in relation to roof step drifts ASCE 7-10 Section 7.7.1 prescribes a drift height of $h_c$ and a width not to exceed $8h_c$ for cases where the expected drift height based on the ground snow load and fetch distance is larger than the space available for drift formation (i.e., $h_d > h_c$). This leads to Recommendation #8.

**Recommendation #8–Snow Drift for Flush Panels:** Following the ASCE 7-10 provisions, snow drifts at flush solar panels are not required if the panel height $h_p$ is less than $1.2h_b$ or if the row length is less than 15 ft. For low ground snow sites where snow drifts are required, the triangular drift height is $h_c$ (i.e., space available for formation $h_p$–$h_b$), and the width is $8h_c$.

That is, Fig. 4-2 shows the snow drift at a flush solar panel for low ground snow load locations where such drifts are required. Because the north-south width of a single row of solar panels is typically less than 15 ft, a flush panel drift as sketched in Fig. 4-2 is typically only at the north and south edges of the row. For an array of adjacent rows, flush panel drifts are needed on all four edges if both the north-south as well as the east-west array dimensions are 15 ft or larger, as sketched in Fig. 4-3.

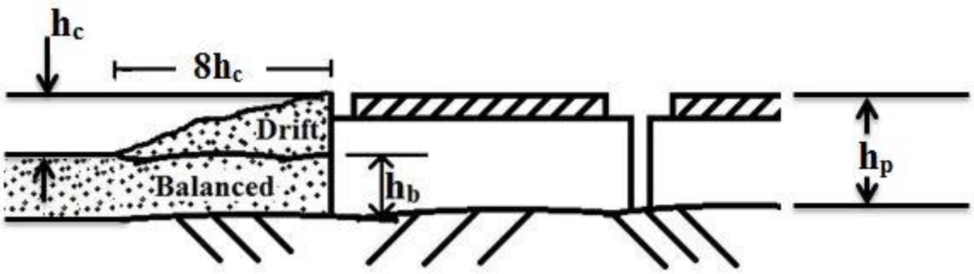



**Fig. 4-2. Flush Solar Panel Snow Drift (drift snow atop panel not shown for clarity)**

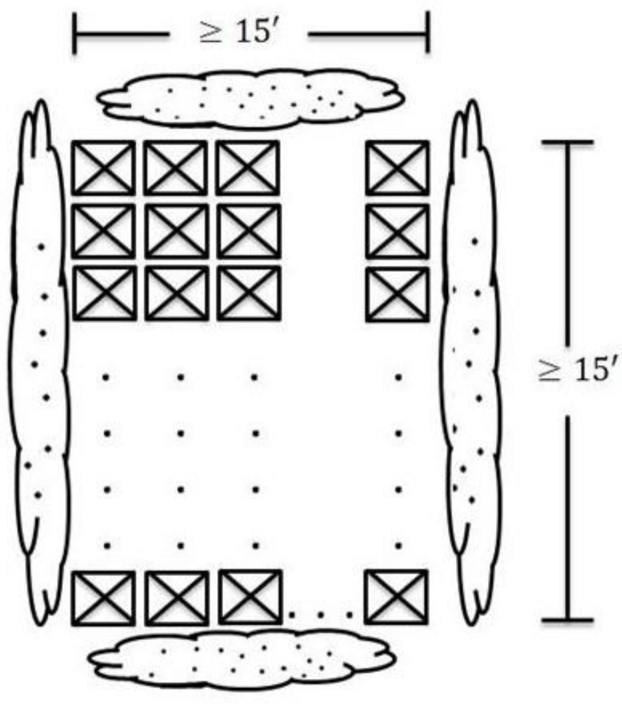



**Fig. 4-3. Drifts for Array of Flush Panels**

## 4.2 Snow Drift for Tilted Panels

### 4.2.1 Single Row of Tilted Panels

Similar to flush panels, one does not expect significant drift loads for roofs with buried or barely visible ($h_p \leq 1.2h_b$) tilted solar panels. However, because tilted panels are typically taller than flush panels, the space available for drift formation is larger, and the drift size may be controlled by the upwind fetch. That is, the drift height based on ASCE 7-10 Fig. 7-9 may be smaller than $h_c$. For such cases, the upwind fetch for a single row of visible tilted panels near the north or south edge of the roof would be roughly along the wind north-south dimension of the roof. For a single row of visible tilted panels near the center of the roof, the fetch would be about half the north-south roof dimension. That is, it is reasonable to treat a single row of tilted solar panels as RTUs with windward drifts on both sides, as sketched in Fig. 4-4. This leads to Recommendation #9.

**Recommendation #9–Drifts at Single Row of Tilted Panels:** For a single row of visible ($h_p \geq 1.2h_b$) Tilted panels, windward snow drifts based on the larger of the two north-south fetch distances should be applied each side of the row if the total east-west row width is 15 ft or greater. The windward drift on the north side of the panel has a right triangular shape, as sketched in Fig. 4-5. The windward drift on the south side has an isosceles triangular shape, as sketched in Fig. 4-6.

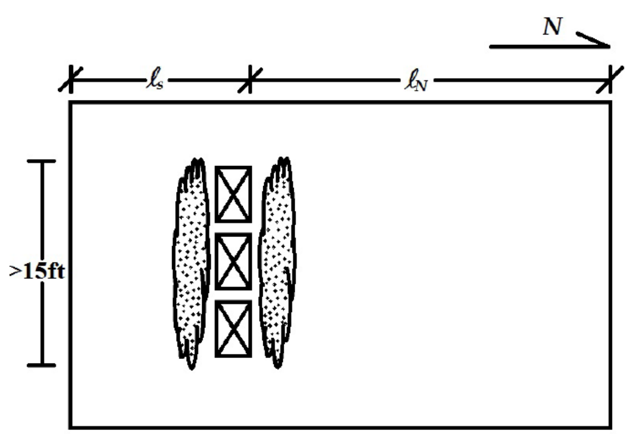



**Fig. 4-4. Windward Drifts Both North and South of Single Row of Tilted Solar Panels ($\ell_u$ taken as larger of $\ell_s$ and $\ell_n$)**

The windward drifts in Figs. 4-5 and 4-6 are functions of $h_{dw}$, the expected height of a windward drift, unconstrained by the space available for drift formation. As per the ASCE 7-10 provisions,

$$h_{dw} = 0.75h_d = 0.75\left[0.43(\ell_u)^{1/3}(p_g + 10)^{1/4} - 1.5\right],$$

that is, 75% of the drift height from ASCE 7-10 Fig. 7-9 for a given fetch distance and ground snow load.

The north side drifts in Fig. 4-5 follow directly from snow load provisions in ASCE 7-10 Sections 7.7.1 and 7.8. The south side drift in Fig. 4-6 is based on the expectation that the drift surcharge is largest at the southernmost edge of the panel. Also, note that the cross-sectional area of the south side drift unrestricted by space issues (i.e., $h_s = 0.707h_{dw} < h_c$ and $4h_s < L$) matches the cross-sectional area ($2h_{dw}^2$) of the north side unrestricted drift in Fig. 4-5a.

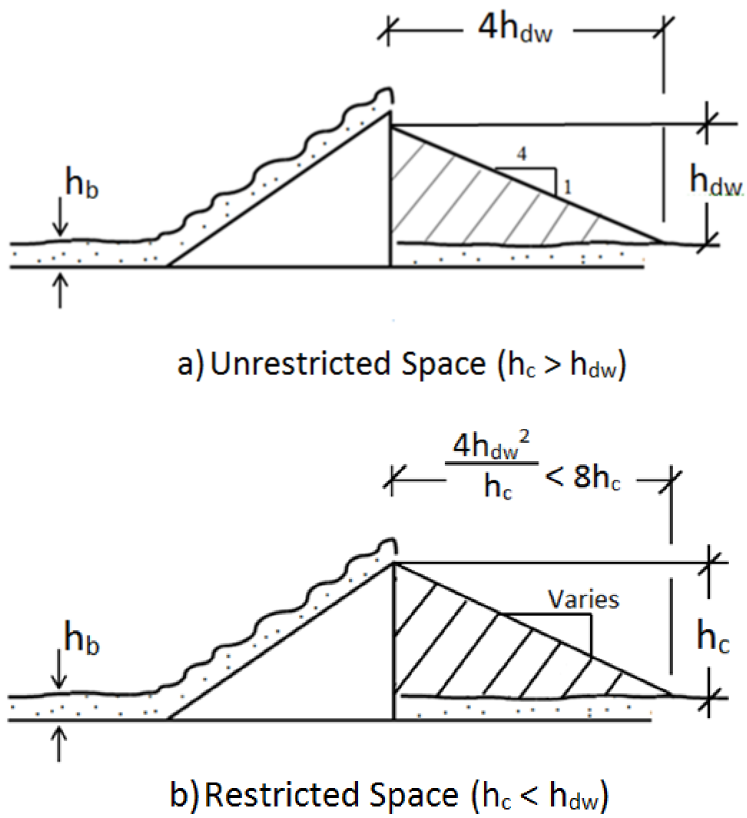



**Fig. 4-5. Windward Drifts at North Side of Tilted Panels**

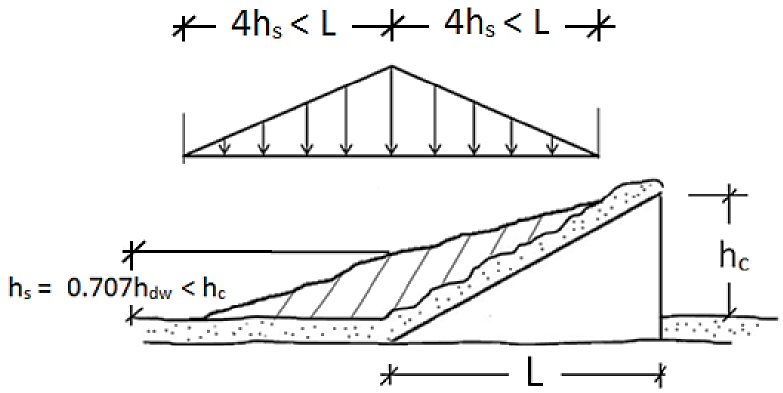


**Fig. 4-6. Windward Drift at South Side of Tilted Panel**

Both sketches show a straight back tilted-closed panel. Although some tilted-closed panels have a nonvertical back deflector plate and tilted-open panels do not have a back deflector plate, the drift surcharge based on a straight back assumption is expected to result in a conservative surcharge. This leads to Recommendation #10.

**Recommendation #10–Drifts for Tilted-Closed Panels:** For the purposes of determination of the drift surcharge, it is recommended that a vertical back deflector plate be assumed for all tilted-closed panels and all tilted-open panels.

### 4.2.2 Multiple Rows of Tilted Panels

Things become much more complex for multiple rows of tilted panels as indicated by the two theoretical observations presented as follows.

*Theoretical Observation #1*

The fetch for downwind panels is reduced because some of the upwind snow would be in the aerodynamic shade (shelter) region generated by the upwind panels and, hence, not susceptible to wind transport. For example, note that the aisle spacing between rows of tilted–closed solar panels in Fig. 1-2 is comparable to the height of the panels themselves. Also, as sketched in Fig. 2-5, the downwind wind shelter region is taken herein to $8h_c$. Hence, all of the snow in the aisle and most of the snow atop a particular tilted solar panel now would likely be sheltered by upwind rows of visible solar panels. Hence, the effective fetch distance for a row of solar panels located within a multiple row array would be different than that for a single row at the same location.

*Theoretical Observation #2*

The snow transport from wind exposed areas of the roof (e.g., solar panels occupying only a portion of the roof) would also be reduced, because some of the transported snow is captured at the upwind solar panels. That is, consider multiple rows of visible tilted solar panels downwind of an open roof area as sketched in Fig. 4-7. Furthermore, for simplicity, idealize each row of panels as a tall roof step. As such, there would only be leeward drifts, and the drift size would not be a function of the step size/space available for the drift formation. The snow transport at idealized Row A would be that due to the full upwind fetch $\ell_u = \ell_s$. However, because some of this snow now forms the drift at idealized Row A, there is less snow transport available for drift formation at idealized Row B. Laboratory tests suggest that the snow remaining at a roof step is typically about half the transported amount. Hence, one expects the drift at idealized Row A to be that for an upwind fetch $\ell_s$ using ASCE 7-10 Fig. 7-9. Because the amount of transported snow flowing over idealized Row B is half that for idealized Row A (half already captured at Row A), one expects that the total drift at Row B to be roughly half that for Row A. Following the same train of logic, one expects the total idealized Row C drift to be a quarter of that at idealized Row A (i.e., half of that at Row B), and the idealized Row D drift to be an eighth of that at idealized Row A. Hence, for the case of tall roof steps, the drifts are small to negligible at the fourth and all succeeding rows. The sum of all the drift would then be twice the size of the drift at Row A ($1 + ½ + ¼ + ⅛ \cong 2$).

These theoretical observations are based on the assumption that (a) the space available for drift formation at idealized Row A can accommodate the full ASCE 7-10 Fig. 7-9 drift, and (b) each idealized row is a roof step. As to the first assumption, if the space available for drift formation is limited, there would be a "full" or "equilibrium" drift at A and more snow transport for the downwind rows. In that case, the drifts at Rows B and C could also be full or equilibrium drifts, and there could be significant drifts at more downwind rows.

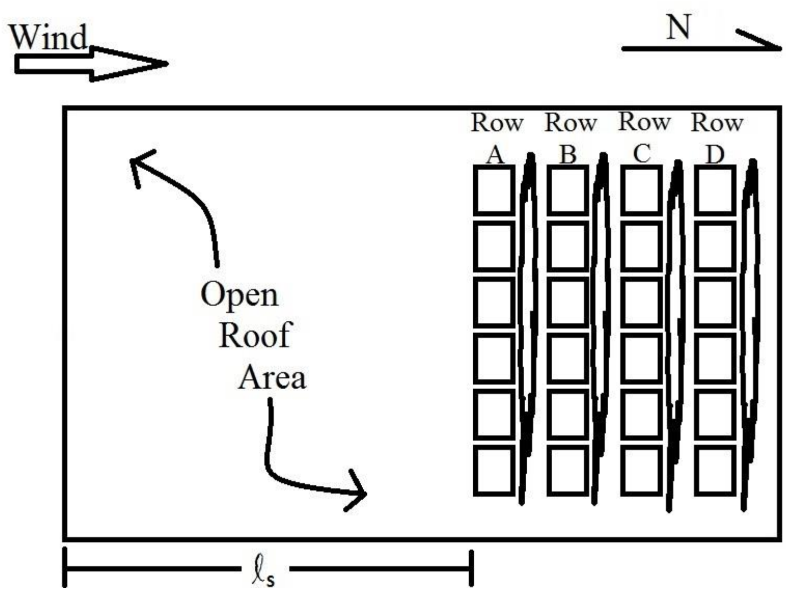



**Fig. 4-7. Plan View of Roof with Rows of Visible Tilted Solar Panels (idealized as roof steps) Downwind of an Open Roof Area. For roof geometry shown, upwind fetch $\ell_u = \ell_s$.**

As to the second assumption, titled panels are not roof steps. They are more like RTUs where one expects a drift on both the upwind and downwind sides. For the multiple rows of titled solar panels located as in Fig. 4-7, there is an "open roof" snow source area to the south, which when combined with wind out of the South would result in a *windward* snow drift immediately south of Row A, and leeward/windward combination drifts between Rows A and B, between Rows B and C, etc. For wind out of the north, in Fig. 4-7, there is no open roof area upwind of the rows of solar panels. Hence, based on Theoretical Observation #1, one does not expect snow drifts due to wind out of the north.

In summary, roof projections including a single row of solar panels do not fully extract all of the snow that is transported by wind over the upwind fetch. In the case of a single row of solar panels, snow that has not been captured at the row continues to be transported over the roof downstream of the row. For the case of multiple rows of panels, snow settles out at subsequent rows. Existing information indicates that the trapping efficiency at steps and gable roofs is about 50%. Hence, the total available snow flux is therefore about twice the amount of the snow drift surcharge as noted in Theoretical Observation #2. In the absence of trapping efficiency data specific to solar panels, it is conservatively recommended that the total available snow flux be taken as three times the single drift surcharge, namely $3(0.5 \cdot h_d \cdot 4h_d) = 6h_d^2$, where $h_d$ is the drift height determined from ASCE 7-10 Fig. 7-9. Drifts would not be required beyond the point where the cross-sectional areas of all the upwind drifts sum to $6h_d^2$. This leads to Recommendation #11.

**Recommendation #11–Drifts at Multiple (closely spaced) Rows of Tilted Panels:** Snow drifts are not required if the east-west dimension of the row is less than 15 ft. For multiple rows of closely spaced ($a < 8h_c$) visible tilted solar panels ($h_p > 1.2h_b$) adjacent to an open roof area, the windward and leeward drifts should be based on north-south upwind fetch for the open area. A windward drift as sketched in Fig. 4-6 is located at the panel row immediately adjacent to the open roof area. Leeward drift as sketched in Fig. 4-8 are located between the next rows until the sum of the drift areas exceeds $6h_d^2$.

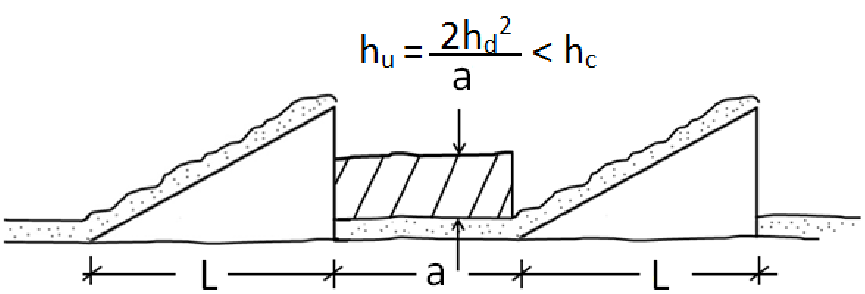



**Fig. 4-8. Leeward Drifts between Rows of Closely Spaced Solar Panels ($a < 8h_c$).**

Note that the leeward-like drift between the rows in Fig. 4-8 is quantified by a uniform surcharge over the aisle. This uniform surcharge is a simplification that applies to both wind out of the north or out of the south. That is, suggesting different inter-row drifts for different wind direction is considered to be unwarranted. Also, note that if there is space available, ($h_u < h_c$) the cross-sectional area of the drift is $2h_d^2$.

A roof with multiple closely spaced ($a < 8h_c$) rows of tilted panels with two open roof areas sketched in Fig. 4-9, the windward and leeward drifts for Row A and its immediate neighbors are to be based on the upwind fetch $\ell_s$. These drifts would be due to wind out of the south. Hence, the windward drift is as sketched in Fig. 4-6, whereas the inter-row drifts would be as sketched in Fig. 4-8. The windward and leeward drifts for Row Z and its immediate neighbors are to be based on the upwind fetch $\ell_N$ and wind out of the north. Hence, the windward drift for wind from the north would be as shown in Fig. 4-5, whereas the inter-row drifts would be as shown in Fig. 4-8.

The inter-row drifts in Fig. 4-8 are for closely spaced rows of tilted solar panels ($a < 8h_c$). This is the expected geometry for both tilted-closed panels, as shown in Fig. 1-2 and for tilted-open panels, as shown in Fig. 1-3. That is, in both figures the aisle spacing is comparable to the height of the panel.

For widely spaced rows of panels ($a > 8h_c$), one expects a leeward drift on one side of the aisle and a windward drift on the other. For this somewhat unexpected roof geometry, treating each row as its own single row is expected to be a conservative approach. This leads to Recommendation #12.

**Recommendation #12–Drift Loads at Widely Space Rows of Tilted Solar Panels:** Rows of solar panels are considered widely spaced if the aisle width, a is larger than $8h_c$. For this case, it is recommended that each row be treated as a single row (follow the suggested drifts in Recommendation #9), with the upwind fetch determined as in Fig. 4-4.

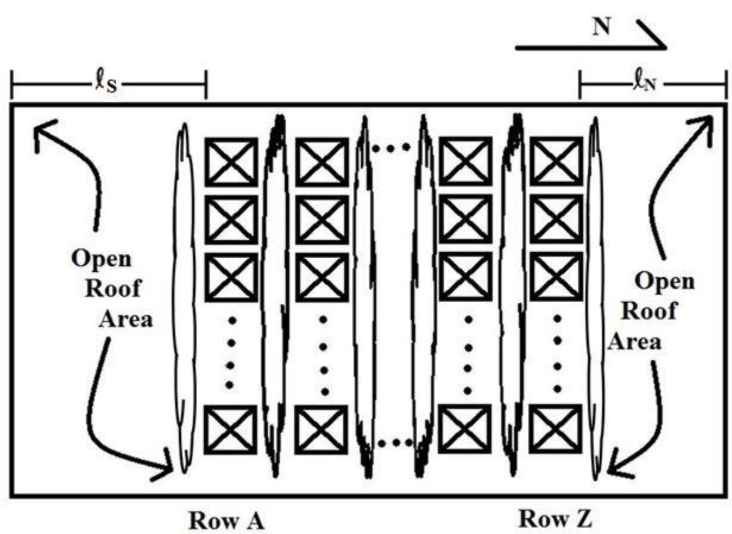
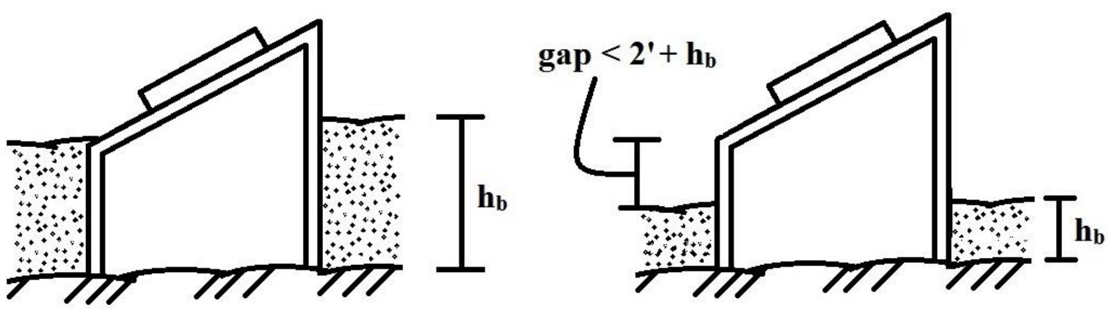



**Fig. 4-9. Plan View of Roof with Two Open Roof Areas and Multiple Rows of Viable Tilted Solar Panels.**

## 4.3 Snow Drift Loads for Elevated Panels

Based upon the proceeding, one expects no significant drifts if the elevated panel is completely buried or if the elevated solar panel is barely visible, $h_c < 1.2h_b$. Also, one expects no significant drift if the east-west width of the row is less than 15 ft. Finally, one expects no significant drifts if the panel is located well above the balanced snow depth $h_b$. For that case, wind flow below the panel prevents drift accumulation. However, snow may well slide from elevated panels, potentially reducing or closing the gap between the (new higher) snow surface and the bottom of the panel. Herein, for the purposes of determining drift loads for elevated panels, the location of the snow surface is taken as twice the balanced snow depth to account for the potential of sliding snow. That is, drifts at elevated panels are expected if (a) the north or upper edge is well above the balanced snow level and the south or sunward edge is below the balanced snow level ($h_c > 1.2h_b$), or (b) the south or sunward edge is less than 2 ft plus $h_b$, above the balanced snow level. Both of these conditions are sketched in Fig. 4-10. This leads to Recommendation #13.

**Recommendation #13–Elevated Panels-Wind Obstruction:** Elevated solar panels should be considered susceptible to snow drift loading if (a) the north or upper edge is above the balanced snow level ($h_p > 1.2h_b$) and the south or lower edge is below the balanced snow level, or (b) the South edge is less than 2 ft plus $h_b$ above the balanced snow depth as sketched in Fig. 4-10.




(a) Bottom Buried- Top Unburied ($h_c > 1.2h_b$)        (b) Small Gap

**Fig. 4-10. Elevated Solar Panels for which Drifting is Expected (snow atop solar panel not shown for clarity).**

That is, snow drift loading need not be considered for an elevated solar panel with its south edge more than 2 ft plus $h_b$ above the balanced snow surface or 2 ft plus $2h_b$ above the roof surface. Table 4-2 presents this 2 ft plus $2h_b$ value for the smallest, typical, and largest balanced snow layer for flat roofs and various ground snow loads.

**Table 4-2. 2 ft plus 2$h_b$ Distance for Smallest, Typical, and Largest Balanced Roof Loads**

| | *Ground Snow Load (psf)* | | | | | |
|---|---|---|---|---|---|---|
| | *10* | *20* | *30* | *40* | *50* | *60* |
| Smallest: $I_s$ = 0.8, $C_t$ = 0.85, $C_e$ = 0.7 | 29.2 in. | 33.5 in. | 37.3 in. | 40.6 in. | 43.4 in. | 45.9 in. |
| Typical: $I_s$ = 1.0, $C_t$ = 1.0, $C_e$ = 1.0 | 35.0 in. | 44.2 in. | 52.1 in. | 59.0 in. | 65.0 in. | 70.2 in. |
| Largest: $I_s$ = 1.2, $C_t$ = 1.35, $C_e$ = 1.2 | 44.6 in. | 61.8 in. | 76.6 in. | 89.5 in. | 101 in. | 110 in. |

Hence, if the bottom or south edge of an elevated solar panel is 5 ft (60 in.) above a "typical" roof surface, drift loads would need to be considered for a site with $p_g$ = 50 psf and higher (60″ < 65″) but need not be considered for a site with $p_g$ = 40 psf and lower (60″ > 59″).

Elevated solar panels are similar to tilted solar panels in relation to snow drifts. This leads to Recommendation #14.

**Recommendation #14–Snow Drift at Elevated Panels:** Snow drifts loading at a single row or multiple rows of drift susceptible elevated solar panels should be based on the corresponding procedures for tilted panels.

## 4.4 Solar Panels on Non–North-South Roof Bays

Tilted and elevated panels are usually orientated such that the light absorbing surfaces point nominally to the south. As such, wind out of the north or south can lead to snow drifts, whereas wind out of the east or west does not. Hence, the recommendation for tilted and elevated panels are presented in relation to north-south winds. This same approach is suggested for solar panel installations on non–north-south roof bays. That is, for the solar panel installation in Fig. 4-11, it is suggested that one consider drifts out of the project south and project north directions. For the geometry sketched in Fig. 4-11, the use of the perpendicular distance from the project north corner to the first row of panels for the upwind fetch for wind out of the project north direction is expected to be conservative and is recommended.

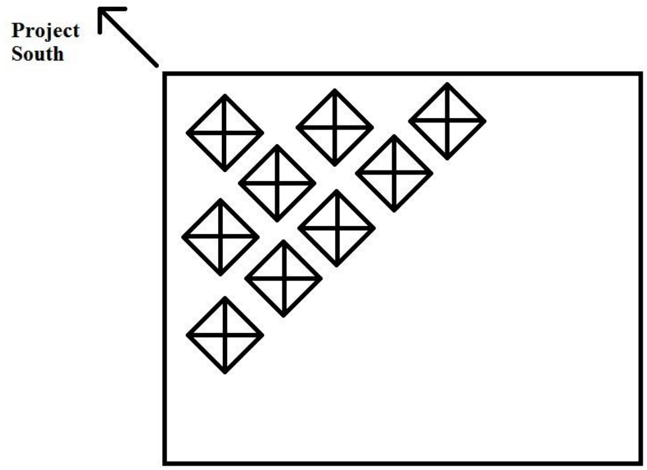



**Fig. 4-11. Roof Bay with a Non–North-South Orientation. Solar panels point in Project South direction.**

## 4.5 Drift Loads from/onto Solar-Paneled Roofs

The drift loads discussed thus far correspond to snow being transported from one roof level toward solar panels located on the same roof level. For a single row of tilted panels, they are similar to drift loads specified for roof projection (RTUs) in ASCE 7-10 Section 7.8. Similar to the ASCE 7-10 provisions, they are based on the wind direction that tends to maximize the size of the drift. That is, for a single row of tilted panels, wind nominally perpendicular to the row is considered.

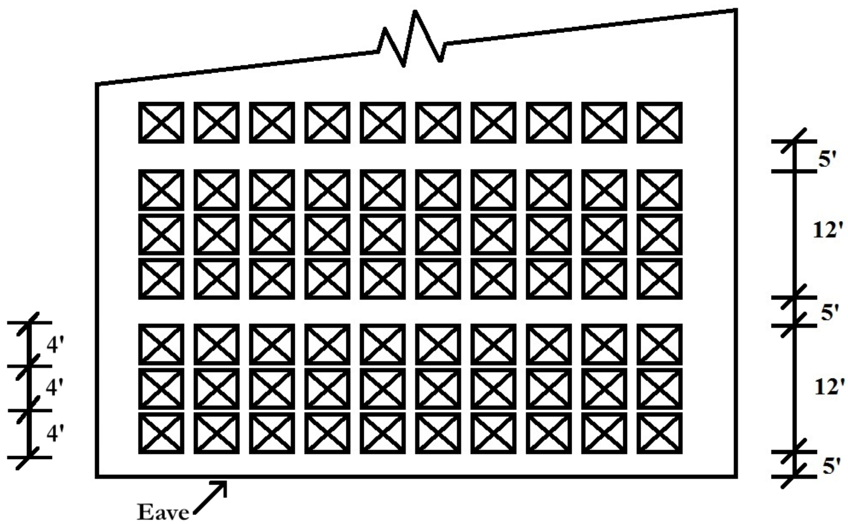
There are, of course, other drift load situations, such as snow drift loads at a roof step, snow drift at a parapet wall, and unbalanced loads due to across-the-ridge drifting on a gable roof. For all of these other situations, there could be solar panels on the roof area that serves as snow source or on the roof area where the snow deposition occurs. Taking the leeward roof step as an example, one expects that solar panels located on the lower level roof (deposition area) would not have a significant effect on the drift load. Conversely, the presence of solar panels on the upper level roof (snow source area) could conceivably influence the drift load that forms on the lower level roof. However, the influence is likely a function of the panel type, depth of the balanced snow atop the upper level roof, panel geometry (single panel, single row, etc.), orientation of any aisles with respect to the roof step (parallel to step, perpendicular to step) and the wind direction. Note that wind direction is expected to have a significant influence on the ability of a row of visible panels to act as a “snow fence.” That is, one expects a row of visible panels to act as a snow fence (snowdrift each side of row) for wind nominally perpendicular to the row. One expects the same row of visible panels to be ineffective as a snow fence (no snow drifts either side of row) for wind nominally parallel to the row. Finally, the efficiency or lack thereof for a row of panels at 45° to the wind is an open question. Given the lack of available observation, changes to the existing drift provision in ASCE 7-10 Sections 7.7 and 7.8 seem unwarranted at this time. Also, any solar panel related reduction in ASCE 7-10 Sections 7.7 and 7.8 drift loads may place the roof at risk should the panels be removed or changed in the future. This leads to General Recommendation B.

**General Recommendation B–Drift Loads from/onto Solar Paneled Roofs:** It is recommended that the presence of solar panels on either the snow source or snow deposition areas be neglected when drift loads are being determined using ASCE 7-10 Sections 7-7 and 7-8.

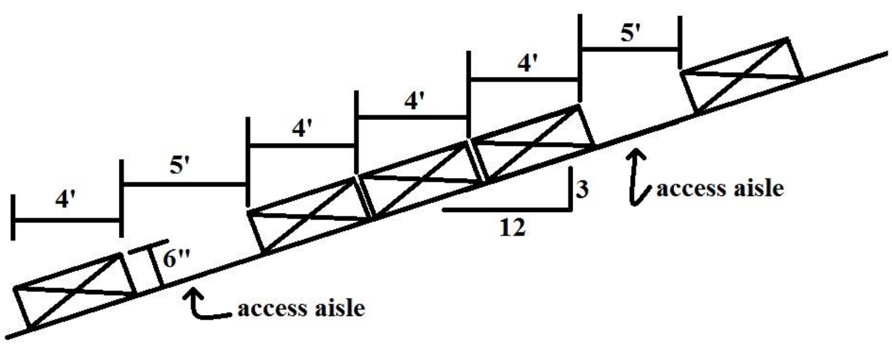
# Chapter 5
# EXAMPLE PROBLEMS

## 5.1 Example Problem #1: Flush Panels/Moderate Ground Snow Load

Determine all roof snow loads of interest for the solar panel geometry sketched in Fig. 5-1. The building has a monoslope metal roof with an unobstructed eave, a roof slope of 3 on 12 downward to the south and a bay size of 25 ft by 25 ft. It is a heated structure with an unventilated $R$ = 30 roof, partially exposed in Terrain Category C. It is of ordinary importance at a site with ground snow load $p_g$ = 25 psf.




a) Partial Plan View




b) Partial Elevator View

**Fig. 5-1. Plan and Elevation Views of Solar Paneled Roof in Example Problem #1.**

### 5.1.1 Balanced Roof Snow Load

The flat roof snow load from ASCE 7-10 Eq. (7.3-1) is

$$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$$

As per Recommendation #1, solar panels are to be conservatively neglected in the determination of the thermal factor $C_t$. Hence, because the structure is heated with an unventilated roof,

$$C_t = 1.0 \qquad \text{(ASCE 7-10 Table 7-3)}$$

Given the flush panel height of 6 in. as shown in Fig. 5-1 and the ground snow load of 25 psf, it seems likely that the panel will be buried under the balanced snow. This assumption will be checked later. As per this guideline document, buried solar panels do not influence the exposure factor $C_e$. Hence, for a partially exposed structure in Terrain C,

$$C_e = 1.0 \qquad \text{(ASCE 7-10 Table 7-2)}$$

The importance factor is taken as $I_s = 1.0$, based on risk category II (ordinary importance) and ASCE 7-10 Tables 1.5.1 and 1.5.2.

Hence, the flat roof snow load becomes

$$p_f = 0.7\ C_e\ C_t\ I_s\ p_g = 0.7\ (1.0)^3(25 \text{ psf}) = 17.5 \text{ psf}$$

As per the problem statement, the 5-ft-wide access aisle at the eave (low edge) of the roof is unobstructed and slippery (metal roof). However, for all other portions of the roof the presence of solar panels results in an obstructed roof in relation to snow sliding and the slope factor $C_s$ (see Fig. 2-2c). Hence, even for the eave bays, 80% (20 ft/25 ft) is sliding obstructed. As such, all bays are sliding obstructed as per Recommendation #3. Entering ASCE 7-10 Fig. 7.2 with 14° (3 on 12) slope, $C_t = 1.0$, and an obstructed surface

$$C_s = 1.\ 0$$

for all the roof. Hence, the balanced or sloped roof snow loads become from ASCE 7-10 Eq (7.4-1),

$$p_s = C_s\ p_f = 1.0\ (17.5 \text{ psf}) = 17.5 \text{ psf}$$

From ASCE 7-10 Eq. (7.7-1), the snow density is

$$\gamma = 0.13 p_g + 14 \leq 30 \text{ pcf}$$

or

$$\gamma = 0.13(25) + 14 = 17.25 \text{ pcf.}$$

Hence, the depth of the balanced roof snow load is

$$h_b = p_s/\gamma = 17.5 \text{ psf} / 17.25 \text{ pcf} = 1.01 \text{ ft} = 12.2 \text{ in.}$$

Note that as assumed, the 6-in. tall flush solar panels are "buried" in the balanced roof snow load. Hence, as per Recommendation #6 (sliding) and Recommendation #8 (drifting), neither sliding snow loads (see Section 3.1) nor snow drift loads (see Section 4.1) need to be considered.

The final consideration is the minimum snow loads for low-sloped roofs, $p_m$, in ASCE 7-10 Section 7.3.4. Because the monoslope roof in question has a slope (14°) that is less than 15°, $p_m$ must be considered. As $p_g$ (25 psf) is greater than 20 psf,

$$p_m = 20I_s = 20(1.) = 20 \text{ psf.}$$

As the minimum load is larger than the balanced roof loads of 17.5 psf, the design snow load is 20 psf over the whole roof, as sketched in Fig. 5-2.

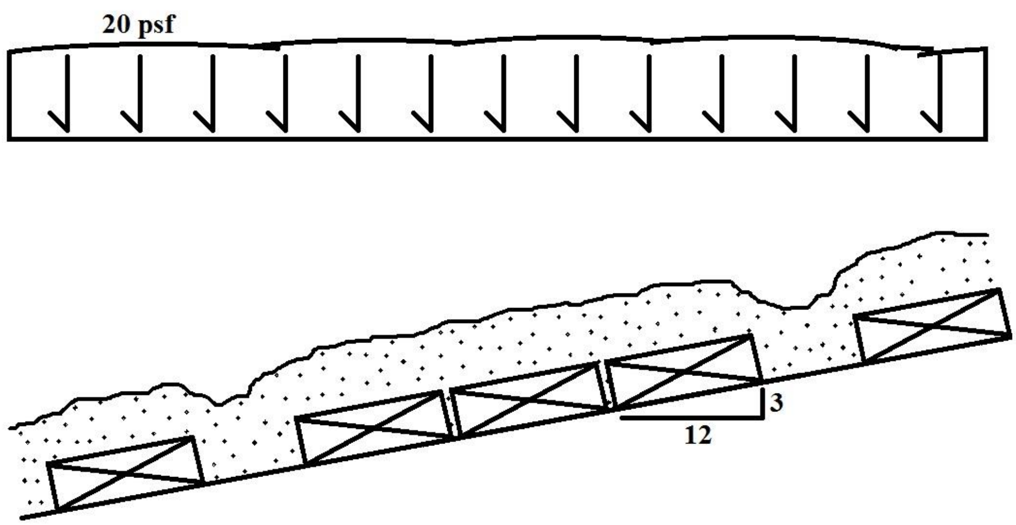



**Fig. 5-2. Design Snow Load for Example Problem #1.**

Depending on the structural configuration, it may be necessary to consider the effects of partial loading as specified in ASCE 7-10 Section 7.5. If necessary, this would be done with the balanced roof load of $p_s$ = 17 psf and not the minimum load of $p_m$ = 20 psf. Finally, as per the recommendations presented in the Introduction, if a lower level roof is located to the south of the solar paneled roof sketched in Fig. 5-1, the presence of solar panels on the upper (Fig. 5-1) roof should be conservatively neglected in the evaluation of the sliding loads (ASCE 7-10 Section 7.9) on the lower level roof.

## 5.2 Example Problem #2: Flush Panels/Low Ground Snow Load

This example is the same as Problem #1, except $p_g$ = 5 psf. As sketched in Fig. 5-3 there are a total of five 5-ft-wide access aisles and twelve 4-ft-wide solar panel rows.

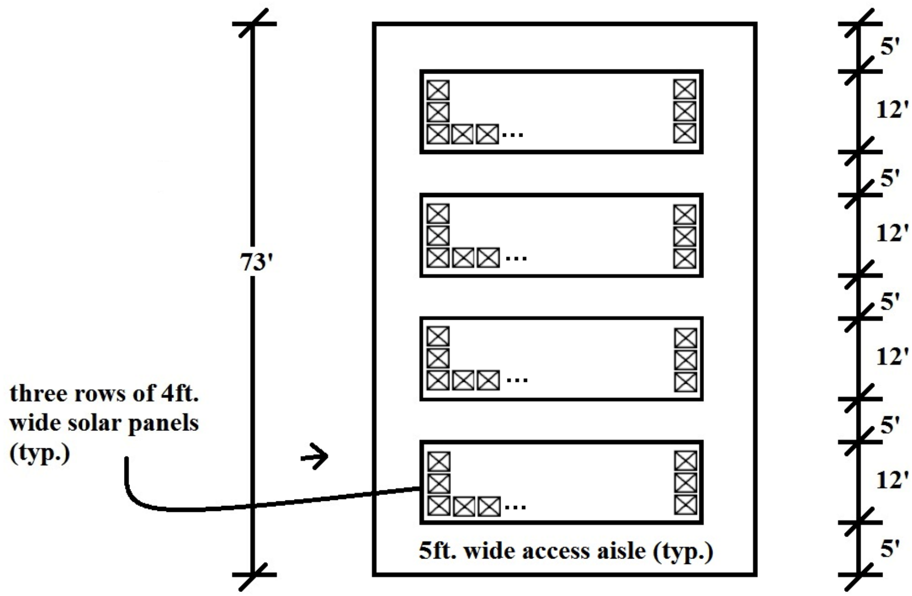



**Fig. 5-3. Full Plan View of Solar Paneled Roof in Example Problem #2.**

### 5.2.1 Balanced Roof Snow Load

As in Problem #1,

$$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$$

where $C_t$ = 1.0 and $I_s$ = 1.0. Given the flush panel height of 6 in. and the ground snow load of 5 psf, it is likely that the panel will be visible $h_p > h_b$ under the balanced roof snow load. This assumption will be checked later.

Using the *simple approach* in the guidelines, as the solar panels are visible and the roof without solar panels is partially exposed, the solar paneled roof is considered sheltered. Hence, for a sheltered structure in Terrain C,

$$C_e = 1.1$$

from ASCE 7-10 Table 7-2. So again, following the simple approach

$$p_f = 0.7\ (1.1)(1.0)^2\ (5) = 3.85 \text{ psf}$$

As in Problem #1, the slope factor $C_s$ = 1.0 for the roof. Hence,

$$p_s = 1.0\ (3.85) = 3.85 \text{ psf}$$

For a ground snow load of $p_g$ = 5 psf, the snow density is

$$\gamma = 0.13(5) + 14 = 14.65 \text{ psf}$$

and the balanced snow depth is

$$h_b = 3.85 \text{ psf}/14.65 \text{ pcf} = 0.263 \text{ ft} = 3.15 \text{ in.}$$

Note that the panel height $h_p$ = 6 in. is larger than the $h_b$ value; hence, the panels are visible as assumed.

The guidelines also contain an *alternate approach* to determine the exposure factor $C_e$. Consider a representative portion of the roof containing three rows of solar panels and a half aisle both upslope and downslope (Fig. 5-4).

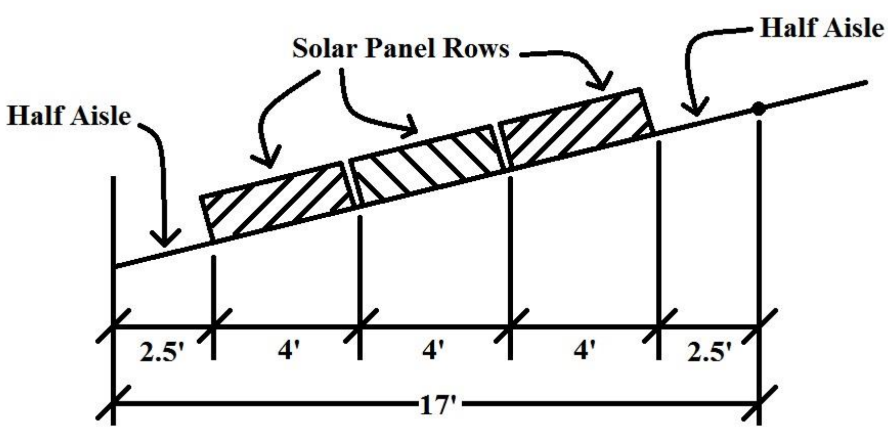



**Fig. 5-4. Representative Portion of Roof.**

As per the guidelines, the wind shelter region downwind of the wind obstructing solar panel is taken as having a horizontal extent of $8h_c$, where $h_c$ is the height difference between the balanced snow surface and the top of the panel. From the simple approach, $h_b$ is about 3 in., suggesting that $h_c = h_p - h_b$ = 6 in. – 3 in. = 3 in. For $h_c$ = 3 in., the wind shelter region would be $8h_c$ = 8(3 in.) = 24 in. = 2.0 ft. Hence, for $h_b \cong$ 3 in., the wind shelter region is 2.0 ft/17.0 ft = 12% of the area of the representative portion of the solar paneled roof. Note that one expects a much smaller wind shelter region upwind of the solar panels. Assuming that the upwind shelter region is comparable in size to the downwind shelter region, the total would be 24%.

Hence, because the portion of the roof that is sheltered is less than 25%, the original partially exposed structure remains partially exposed as per Recommendation #5 and

$$C_e = 1.0.$$

Hence, the flat roof load becomes

$$p_f = 0.7(1.0)^3(5) = 3.5 \text{ psf}$$

and the balanced or sloped roof snow load with $C_s = 1.0$ becomes

$$p_s = 1.0 \text{ (3.5 psf)} = 3.5 \text{ psf.}$$

As above, the snow density for the 5 psf ground snow load is

$$\gamma = 14.65 \text{ pcf}$$

and the depth of the balanced snow becomes

$$h_b = 3.5 \text{ psf} / 14.65 \text{ pcf} = 0.238 \text{ ft} = 2.86 \text{ in.}$$

Hence, the balanced roof snow load is 3.85 psf using the simplified approach (3.5 psf using the alternate approach).

The final uniform load consideration is the minimum snow load, $p_m$ in ASCE 7-10 Section 7.3.4

$$p_m = I_s\, p_g = 1.0(5 \text{ psf}) = 5 \text{ psf}$$

for sites with $p_g < 20$ psf. This controls and hence the uniform load case is as sketched in Fig. 5-5. As in Example Problem #1, depending on the structural configuration, it may be necessary to consider the partial loading provisions in ASCE 7-10 Section 7.5.

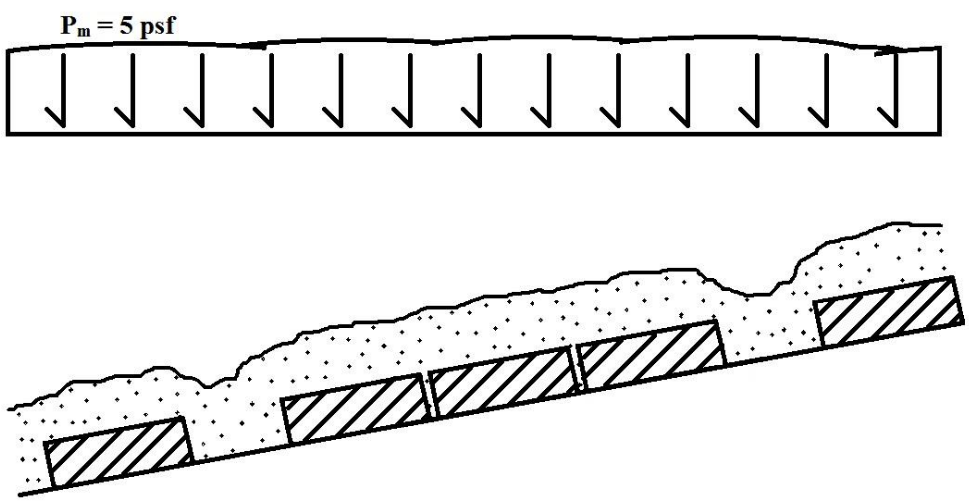



**Fig. 5-5. Uniform Load Case for Example Problem #2. Governing uniform load is minimum roof snow load from ASCE 7-10 Section 7.3.4.**

### 5.2.2 Sliding Snow Loads

Because the flush solar panels are visible and the roof slope is greater than ¼ on 12, as per Recommendation #6, the sliding load surcharge of $1.0p_fW_c$ is distributed over a downslope width of $W_c$ where $W_c$ is the width of the upslope panels.

Herein, we will use the flat roof load from the simple approach $p_f$ = 3.85 psf and the corresponding balanced or sloped roof snow load $p_s$ = 3.85 psf. As per the problem statement, the three solar panel rows are each 4 ft wide; hence, $W_c$ = 3(4 ft) = 12 ft and the sliding load case is as sketched in Fig. 5-6.

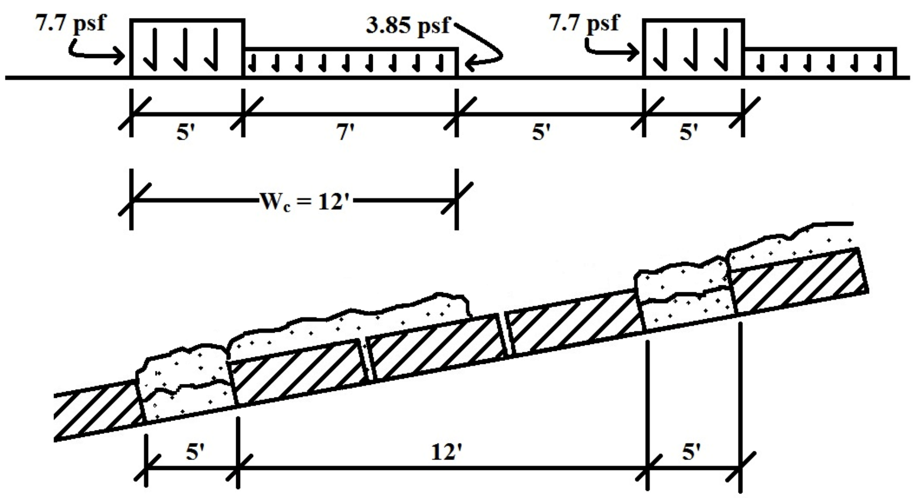



**Fig. 5-6. Sliding Load Case for Example Problem #2 (Simple Approach).**

In the aisles, we have the balanced load of 3.85 psf plus the sliding surcharge of 3.85 psf or a total of 7.7 psf. For the 7 ft of solar panel immediately upslope of the aisle we have the sliding surcharge of 3.85 psf, whereas for the 5 ft of solar panel immediately downslope of the aisle we have zero snow load. (Note: These loads are 7.0 psf, 3.5 psf, and zero, respectively, using the alternative approach for determination of the exposure factor.)

### 5.2.3 Drift Snow Load

Because the flush panels are visible, drift loads need to be checked. As per Recommendation #8, drift loads need to be considered if $h_c / h_b \geq 0.2$. Again using the simple approach, $h_b$ = 3.15 in., hence $h_c = h_p - h_b$ = 6 in. – 3.15 in. = 2.85 in. = 0.238 ft and $h_c / h_b$ =2.85 in. / 3.15 in. = 0.90 > 0.2. Hence, drift loads must be considered.

Again, as per Recommendation #8, the drift height is $h_c$ = 2.85 in. = 0.238 ft, and the horizontal extent is $8h_c$ = 8(2.85 in.) = 22.8 in. = 1.9 ft. The peak drift surcharge load then becomes $\gamma h_c$ = 14.65 pcf ×0.238 ft = 3.5 as sketched in Fig. 5-7.

The drifts sketched in Fig. 5-7 are based on north-south winds. East-west winds would result in the same 3.5-psf drift surcharge along the east and west edges of the solar panel arrays. Note in this regard that the 15-ft. minimum in ASCE 7-10 Section 7.8 applies to a single obstruction, not a series of closely spaced obstructions each with a width less than 15 ft.

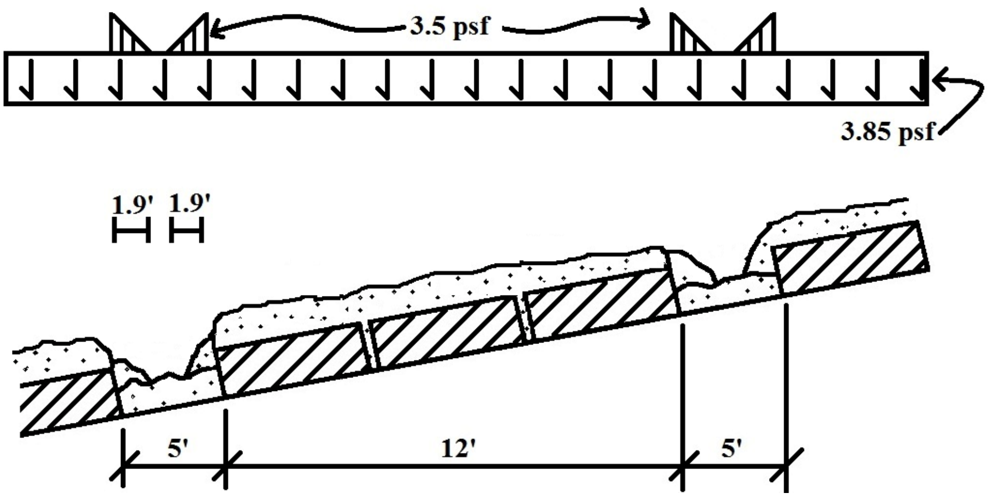



**Fig. 5-7. Drifting Snow Load Case for Example Problem #2 (Simple Approach).**

## 5.3 Example Problem #3: Flush Panels/Sliding Obstructed

Three rows of 4 ft × 5 ft solar panels are located on the 50 ft × 75 ft roof as shown on Fig. 5-8. The remainder of the roof is free of solar panels. Determine all roof snow loads of interest using the simple approach for the exposure factor. As in Example Problem #2, the ground snow load is $p_g$ = 5 psf, the roof slope is 3 on 12, and $C_t = I_s = 1.0$.

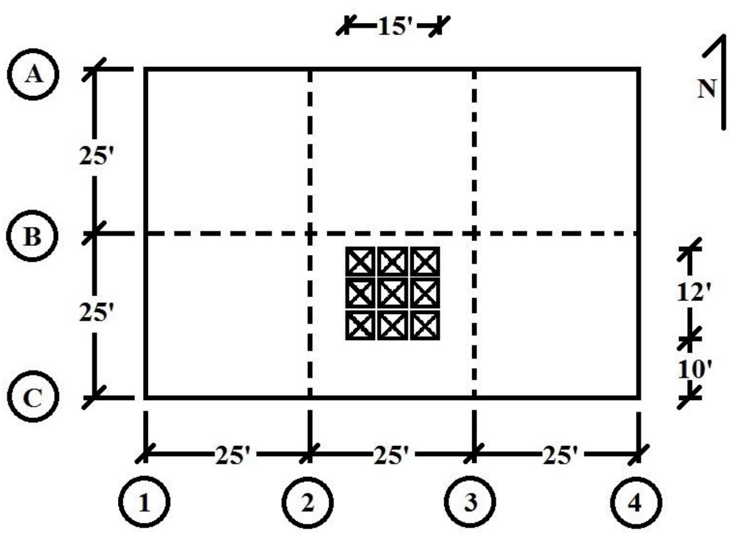



**Fig. 5-8. Plan View of Solar Paneled Roof for Example Problem #3.**

### 5.3.1 Balanced Roof Snow Load

As shown in Example Problem #2, using the simple approach, the exposure factor $C_e$ = 1.1 and the flat roof snow load $p_f$ = 3.85 psf.

As per Recommendation #3, the theoretical sliding obstructed area proceeds at a 45° angle from the lower corner of the solar panel array as sketched in Fig. 5-9.

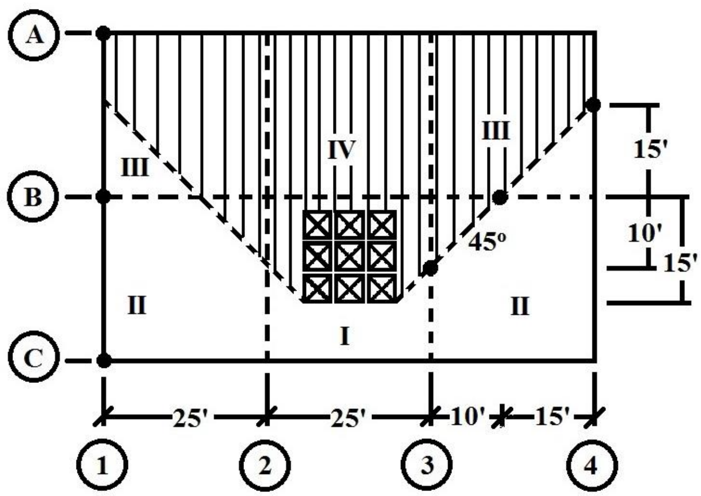



**Fig. 5-9 Sliding Obstructed Region.**

Furthermore, again as per Recommendation #3, a bay is considered obstructed if 25% or more of the area is obstructed.

Bay I: The total plan area of the bay is 25 ft × 25 ft = 625 $ft^2$. The obstructed area is more than 10 ft × 25 ft = 250 $ft^2$. Hence, since 250 $ft^2$ is more than 25% of 625 $ft^2$, Bay I is considered obstructed for sliding.

Bay II: The obstructed area is ½ (10 ft)(10 ft) = 50 $ft^2$. Because 50 $ft^2$ is only 8% of the total bay area of 625 $ft^2$, Bay II is considered not obstructed for sliding.

Bays III and IV: By inspection, the obstructed area of Bay III is more than half the total bay area, whereas all of Bay IV is obstructed. Hence, both Bay III and Bay IV are considered obstructed for sliding.

Therefore, the slope factor, $C_s$ for Bays I, III, and IV is based on an obstructed surface, $C_t$ = 1.0 and a 14° slope (3 on 12) or from ASCE 7-10 Fig. 7-2(a)

$$C_s = 1.0$$

and the balanced or sloped roof snow load is

$$p_s = C_s\, p_f = 1.0\ (3.85) = 3.85 \text{ psf}$$

for Bays I, III, and IV.

The slope factor for Bay II is based on an unobstructed slippery (metal) surface with $C_t = 1.0$ and a 14° slope or

$$C_s = 0.86$$

and

$$p_s = 0.86(3.85 \text{ psf}) = 3.3 \text{ psf}$$

The balanced snow loads are as sketched in Fig. 5-10.

However, as in Example Problem #2, the minimum roof load of $p_m = 5$ psf from ASCE 7-10 Section 7.3.4 controls. Hence, the governing uniform load is as sketched in Fig. 5-11. As in Example Problems #1 and #2, depending on the structural configuration, it may be necessary to determine the effects of partial loading.

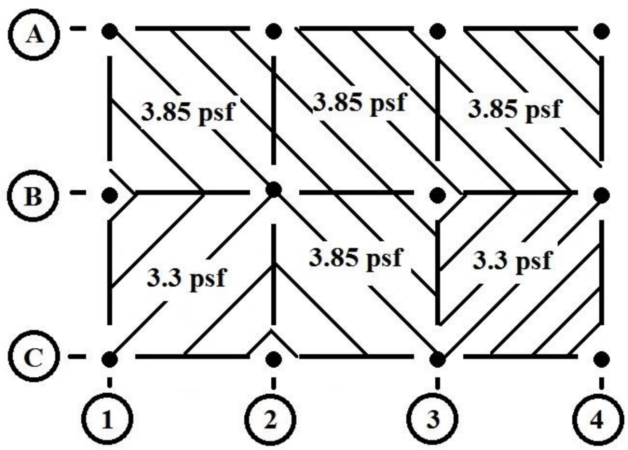



**Fig. 5-10 Balanced Roof Snow Load for Example Problem #3.**

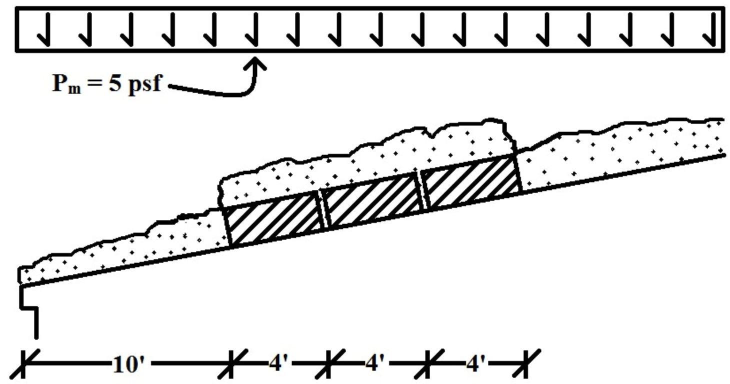



**Fig. 5-11. Uniform Load Case for Example Problem #3. Minimum load from ASCE 7-10 Section 7.3.4 Governs.**

### 5.3.2 Sliding Snow Loads

Because the panels are in Bay I, the sliding loads exist only in Bay I. As determined in Example Problem #2, the magnitude and horizontal extent of the sliding load surcharge are 3.85 psf and 12 ft respectively. Given that the downslope edge of the solar panels is 10 ft from the roof eave, the sliding loads over the 15-ft width (east-west direction) of the panel rows is as sketched in Fig. 5-12.

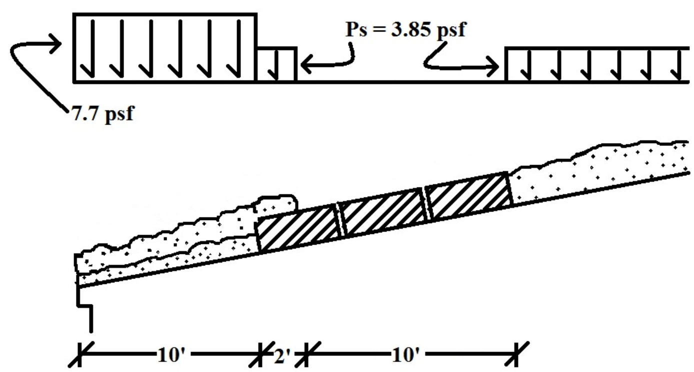



**Fig. 5-12. Sliding Snow Load Case at Solar Panels for Example Problem #3. Sliding loads Extend 15 ft in East-West Direction.**

### 5.3.3 Drift Snow Loads

As in Example Problem #2, drift loads need to be considered because the panels are visible and $h_c/h_b > 0.2$. Because the north-south extent of the panels (12 ft) is less than 15 ft, drift loads for east-west winds need not be considered. The east-west extent is 15 ft, so drift loads for north-south winds must be determined.

As in Example Problem #2, $h_d$ exceeds $h_c$ (0.237 ft), the intensity of the drift surcharge $p_d$ = 3.5 psf, and the horizontal extent $W$ = 1.9 ft. This drift load case is sketched in Fig. 5-13.

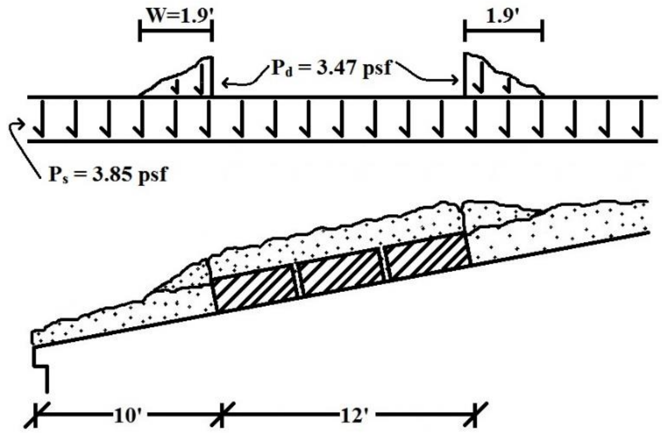



**Fig. 5-13. Drifting Snow Load Case for Example Problem #3. Drifts extend 15 ft in East-West Direction.**

## 5.4 Example Problem #4: Tilted-Closed Panels/Low Ground Snow Load

Determine all roof snow loads of interest for a 1-on-12 metal roof with unobstructed eaves. The building is heated, and the roof is unventilated with $R$ = 30 insulation. The site is fully exposed in terrain category B. The elevation view in Fig. 5-14 provides geometric details of the tilted-closed solar panels.

The panels cover the whole roof, with minimal exposed or open areas at the roof edges. The ground snow load $p_g$ = 10 psf and $I_s$ = 1.0. Use the simple approach to determine the exposure factor.

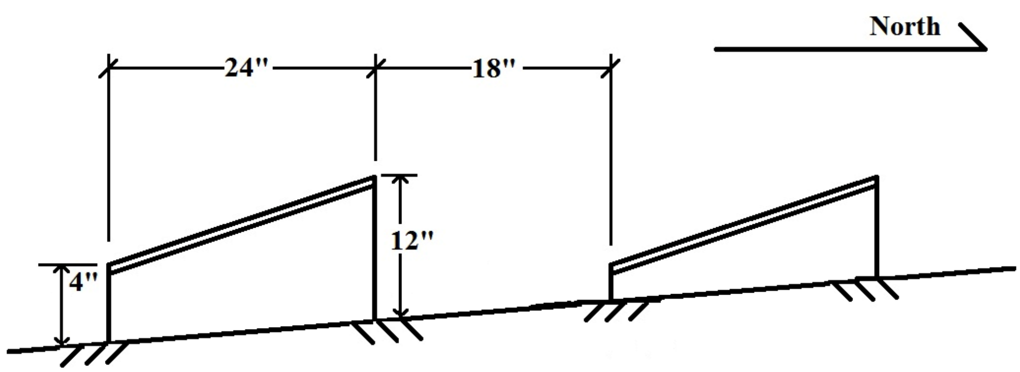



**Fig. 5-14. Partial Elevation View of Tilted-Closed Solar Panels in Example #4: View Looking West.**

### 5.4.1 Balanced Roof Snow Load

The flat roof snow load from ASCE 7-10 Eq. (7.3-1)

$$p_f = 0.7\ C_e\ C_t\ I_s\ p_g$$

As per Recommendation #1, the thermal factor, $C_t$, should be based on the roof condition without solar panels. Hence, for an unventilated roof for a heated facility,

$$C_t = 1.0$$

from ASCE 7-10 Table 7-3.

As the high point for the solar panel is a foot above the roof surface and the ground snow load is only 10 psf, it seems likely that the panels will be visible, that is, only partially buried. This assumption will be checked later. As per the simple or default approach in Recommendation #4, a roof with visible panels in a fully exposed location is considered to be partially exposed. Hence, from ASCE 7-10 Table 7-2, for a partially exposed structure in terrain category B

$$C_e = 1.0.$$

Hence, the flat roof snow load becomes

$$p_f = 0.7(1.0)^3(10\text{ psf}) = 7\text{ psf}$$

Because the solar panel rows extend across the whole roof, the roof is obstructed with respect to sliding snow. For a sliding obstructed roof with $C_t = 1.0$ and a slope of 1 on 12 (4.76°),

$$C_s = 1.0$$

as per ASCE 7-10 Fig. 7-2a.

Hence, the balanced or sloped roof snow load becomes

$$p_s = C_s\ p_f\ = 1.0(7\text{ psf}) = 7\text{ psf}$$

The snow density from ASCE 7-10 Eq (7.7-1) is

$$\gamma = 0.13p_g + 14 = 0.13(10) + 14 = 15.3\text{ pcf}$$

and the depth of the balanced snow is

$$h_b = p_s/\gamma = 7\text{ psf}/15.3\text{ pcf} = 0.458\text{ ft} = 5.5\text{ in.}$$

Hence, the solar panels are, in fact, visible.

For the uniform load case, the minimum roof load of ASCE 7-10 Section 7.3.4 needs to be checked. For $p_g < 20$ psf,

$$p_m = I_s\, p_g = 1.0(10 \text{ psf}) = 10 \text{ psf}$$

Hence, the governing uniform load case is 10 psf over the whole roof as sketched in Fig. 5-15. Depending on the structural configuration, it may necessary to investigate the effects of partial loads in ASCE 7-10 Section 7.5.

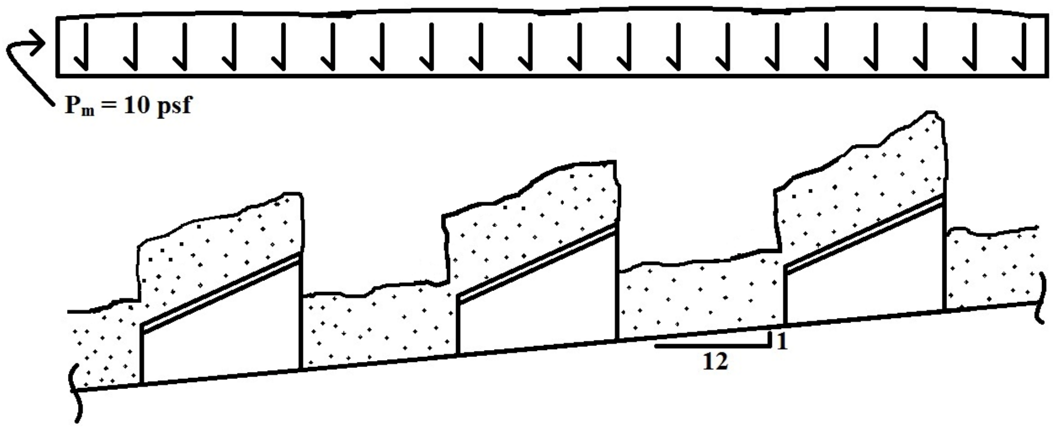



**Fig. 5-15. Uniform Load Case for Example Problem #4. Minimum Load from ASCE 7-10 Section 7.3.4 Governs.**

### 5.4.2 Sliding Snow Load

As per Recommendation #7, one needs to consider sliding snow loads for all visible tilted panels. The sliding load with intensity $p_f$ is placed atop the balanced load, which for this example has a depth of 5.5 in. The width of the sliding load surcharge is based upon geometry as sketched in Fig. 5-16.

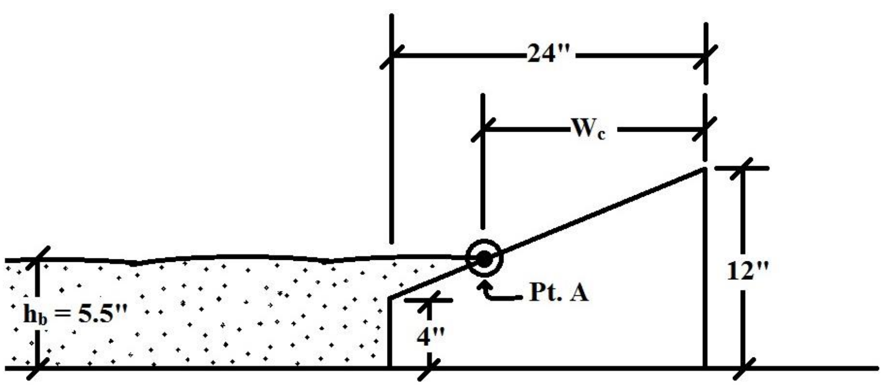



**Fig. 5-16. Location of Point A for Sliding Snow Surcharge.**

By similar triangles

$$1.5/(24 - W_c) = 8/24$$

or

$$W_c = 19.5 \text{ in. (say 20.0 in.)}$$

Hence, the sliding load surcharge of $p_f$ = 7 psf has a total horizontal extent of 20 in. The surcharge covers 4 in. (24–20) at the southern portion of the panel, and 16 in. of the aisle between panels, as sketched in Fig. 5-17.

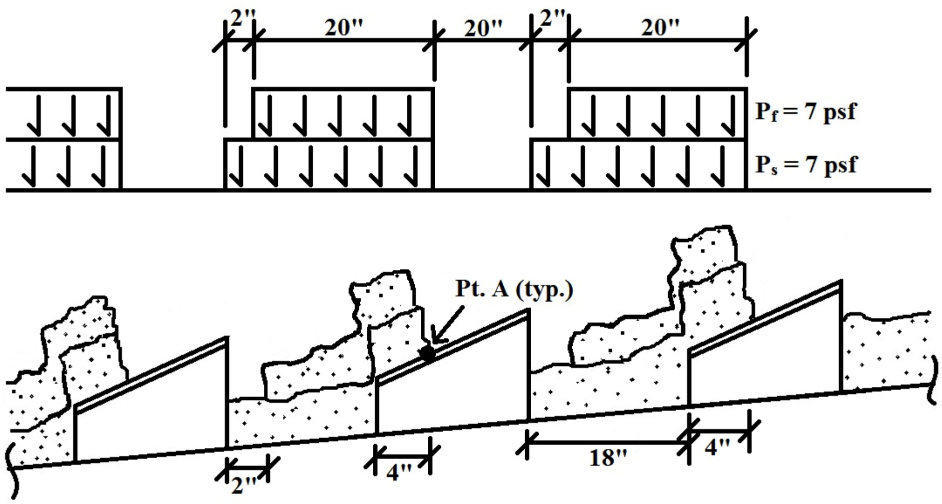



**Fig. 5-17. Sliding Snow Load Case for Example Problem #4.**

Notice in this case there is a 2-in. gap between the edge of the sliding load from an upslope panel and the upslope edge of the adjacent downslope panel. However, if the aisle between panels were only 12 in., then the sliding load moves 16 in. (12 + 4) until it reaches the adjacent downslope panel. In that case, the sliding load surcharge would be as sketched in Fig. 5-18.

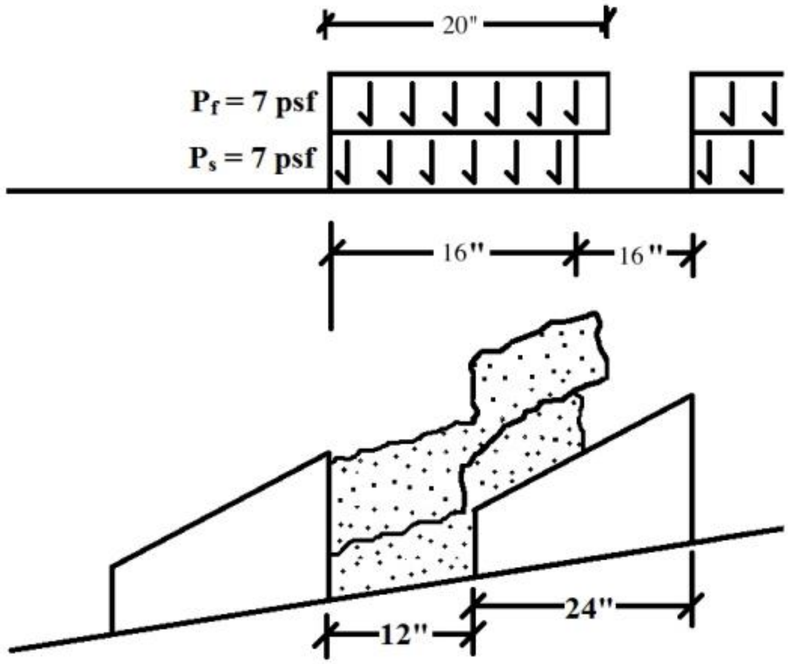



**Fig. 5-18. Sliding Snow Load Case for Narrow Aisle between Panels.**

As per the problem statement, the whole roof is covered by rows of tilted solar panels. As such, there are no open roof areas to the north or south of the solar panels and, hence, from Recommendation #11, there are no significant snow source areas for potential drifts. That is, the uniform snow load case in Fig. 5-15 and the sliding snow load case in Fig. 5-17 are the only snow loads cases of interest. Roof structural components need to be checked for each of these separate load cases. Depending on the structural configuration, the partial loading case in ASCE 7-10 Section 7.5 may also need to be checked.

## 5.5 Example Problem #5: Drifts/Single Row of Panels

Determine the snow drift surcharge loads for a single row of tilted-closed solar panels as sketched in Fig. 5-14, located as sketched in Fig. 5-19. As in Example Problem #4, $h_b$ = 5.5 in. and $p_g$ = 10 psf.

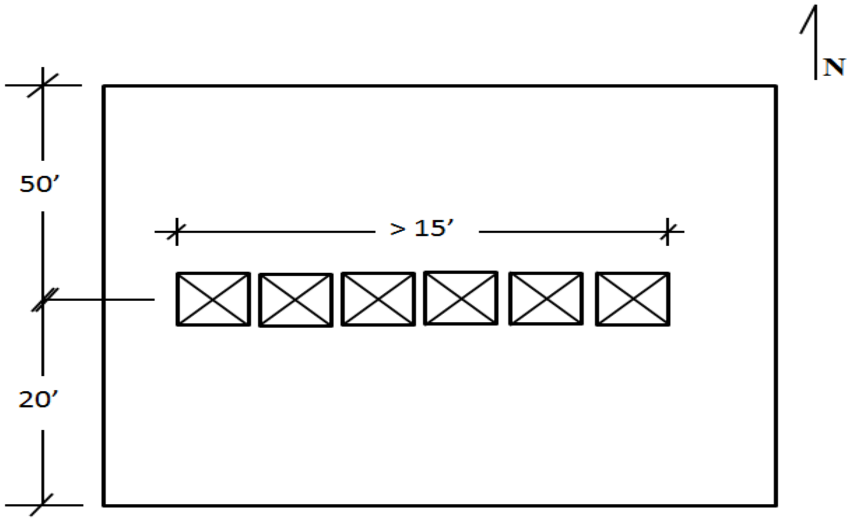



**Fig. 5-19. Location of Single Row of Solar Panels for Example Problem #5.**

As per Recommendation #9, drifts need to be considered, as $h_p$ = 12 in > 1.2 $h_b$ = 6.6 in., and the east-west row width is larger than 15 ft. The larger of the two north-south fetch distances is $\ell_u$ = 50 ft. Hence, the leeward drift height from ASCE 7-10 Fig. 7.9 is

$$\begin{aligned} h_d &= 0.43\sqrt[3]{\ell_u}\sqrt[4]{p_g+10}-1.5 \\ &= 0.43(50)^{1/3}(10+10)^{1/4}-1.5 \\ &= 1.85 \text{ ft} = 22.2 \text{ in.} \end{aligned}$$

The height of the corresponding windward drift is

$$h_{dw} = 0.75h_d = 0.75(22.2) = 16.65 \text{ in.} = 16.7 \text{ in.}$$

As per the Recommendation #9, there is a right triangular drift to the north of the row based on Fig. 4-5. Because $h_c = h_p - h_b = 12 - 5.5 = 6.5$ in. is less than $h_{dw}$ = 16.7 in., the restricted space drift in Fig. 4-5b applies. Specifically, the drift surcharge height is $h_c$ = 6.5 in., and the horizontal extent is the smaller of $8h_c$ = 52 in. or

$$\frac{h_{dw}{}^2}{h_c} = \frac{4(16.7)^2}{6.5} = 171 \text{ in.}$$

Hence, the horizontal extent of the drift is taken as 52 in.

Because $p_g$ = 10 psf, the snow density is 15.3 pcf and the peak surcharge load is

$$P = h_c\,\gamma = (6.5 \text{ in.})(15.3 \text{ pcf})/(12 \text{ in./ft}) = 8.3 \text{ psf}$$

This drift surcharge located immediately north of the single row of solar panels is shown in Fig. 5-20.

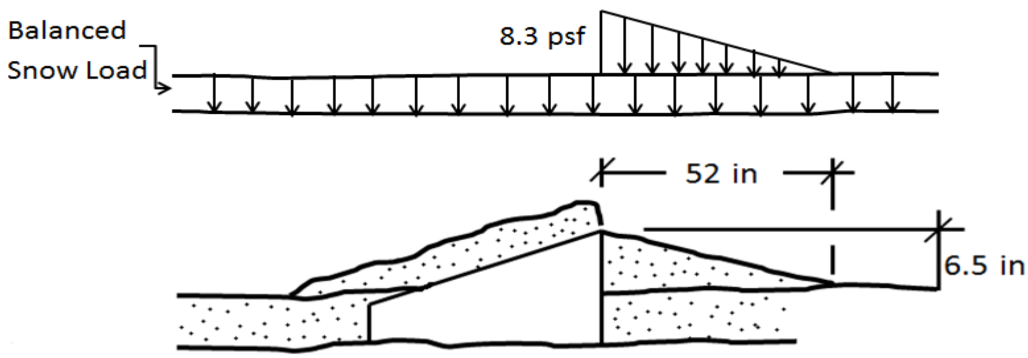



**Fig. 5-20. Drift Surcharge Load North of Single Row of Solar Panels in Example Problem #5.**

Again, as per Recommendation #9, the drift south of the solar panel row is based on Fig. 4-6. It is an isosceles triangle with a peak height

$$h_s = 0.707h_{dw} < h_c$$

$$h_s = 0.707(16.7) < 6.5$$

$$h_s = 11.8 < 6.5$$

$$h_s = 6.5 \text{ in.}$$

The horizontal extent of each half of the drift surcharge, again from Fig. 4-6, is the smaller of $4h_s = 4(6.5) = 26$ in. and the horizontal extent of the solar panel itself, $L = 24$ in from Fig. 5-14. Because the snow density is $\gamma = 15.3$ pcf, the peak surcharge load is $h_s\gamma = 6.5(15.3)/12 = 8.3$ psf, and the drift is as sketched in Fig. 5-21.

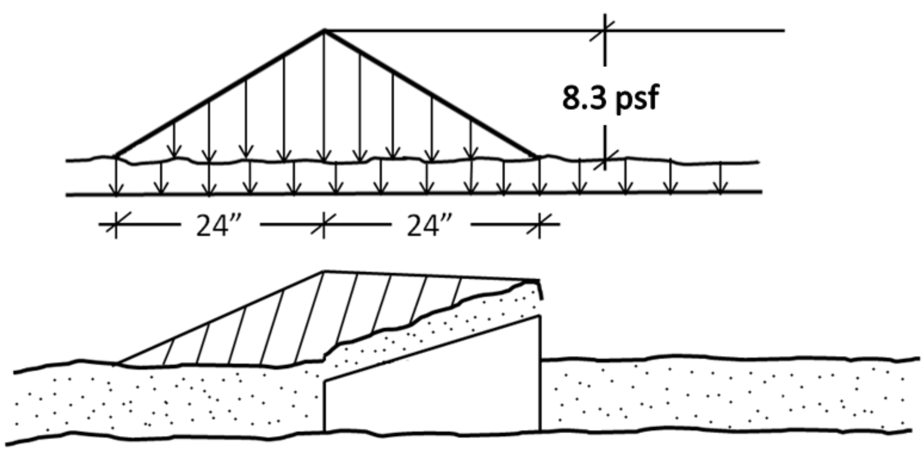



**Fig. 5-21. Drift Surcharge Load South of Single Row of Solar Panels in Example Problem #5.**

Note that the north side drift (Fig. 5-20) and the south side drift (Fig. 5-21) are part of the same balance roof load plus drift load case. No drift loads are needed to the east or west or the single row of panels since the solar panel width from Fig. 5-14 is only 24 in., which is less than 15 ft.

## 5.6 Example Problem #6: Drifts/Closely Spaced Multiple Rows

Similar to Example Problem #5, determine the drift surcharge loads for a multiple-row array of solar panels. The solar panel geometry is that shown in Fig. 5-14. That is, $h_p$ = 12 in., the horizontal extent of the panel $L$ = 24 in., with an aisle spacing of 18 in. There is a total of 40 rows of panels located on the roof as shown in Fig. 5-22. As in Example Problem #5, the balanced snow depth $h_b$ = 5.5 in., the space available for drift formation $h_c$ = 6.5 in., and the ground snow load $p_g$ = 10 psf. The extent of the open roof space to the east and west of the array is minimal.

As demonstrated in Example Problem #5, drifts must be considered. Furthermore, as the aisle spacing $a$ = 18 in. is less than $8h_c$ = 8(6.5) = 52 in., the solar panels are closely spaced and, hence, Recommendation #11 applies.

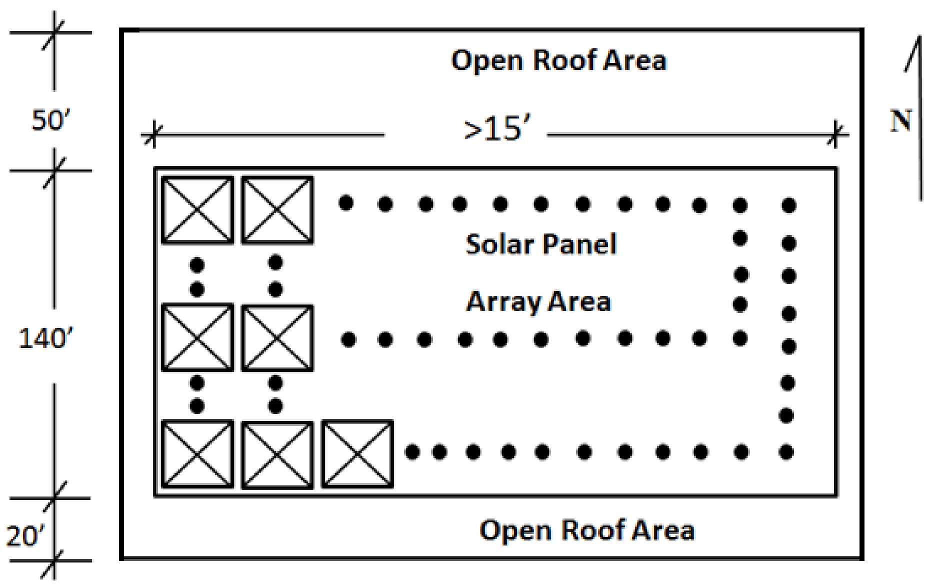



**Fig. 5-22. Roof Plan View for Example Problems #6 and #8.**

### 5.6.1 Drift Loads for South Wind

As per Recommendation #11, the drift surcharge loads for the solar panels toward the south of the array are based on an upwind fetch distance of 20 ft. From ASCE 7-10 Fig. 7.9, the leeward drift height for an upwind fetch of 20 ft in a region with $p_g$ = 10.0 psf is

$$
\begin{aligned}
h_d &= 0.43(\ell_u)^{1/3}(p_g + 10)^{1/4} - 1.5 \\
&= 0.43(20)^{1/3}(10 + 10)^{1/4} - 1.5 \\
&= 0.96 \text{ ft} = 11.6 \text{ in.}
\end{aligned}
$$

and the windward drift height is

$$h_{dw} = 0.75h_d = 0.75(11.6) = 8.7 \text{ in.}$$

The expected area of the leeward drift is

$$A_d = ½\,(h_d)(4h_d) = 2h_d^2 = 2(11.6)^2 = 268 \text{ in.}^2.$$

The drift to the south of the southern row of the solar panel is a windward drift, specifically a isosceles triangular drift as sketched in Fig. 4-6. The central drift height, $h_s$, is the smaller of 0.707 $h_{dw}$ = 0.707 (8.7) = 6.1 in. = 0.51 ft and $h_c$ = 6.5 in = 0.54 ft. The drift surcharge load is then $P = \gamma\, h_s$= 15.3(0.51) = 7.8 psf. The horizontal extent of each half of the drift is the smaller of $4h_s$ = 4(6.1 in.) = 24.4 in. or the horizontal extent of the solar panel $L$ = 24 in. This windward drift to the south of the array is shown in Fig. 5-23. Note that the cross-sectional area of this windward drift is ½ (6.1)(48)= 146 in.$^2$.

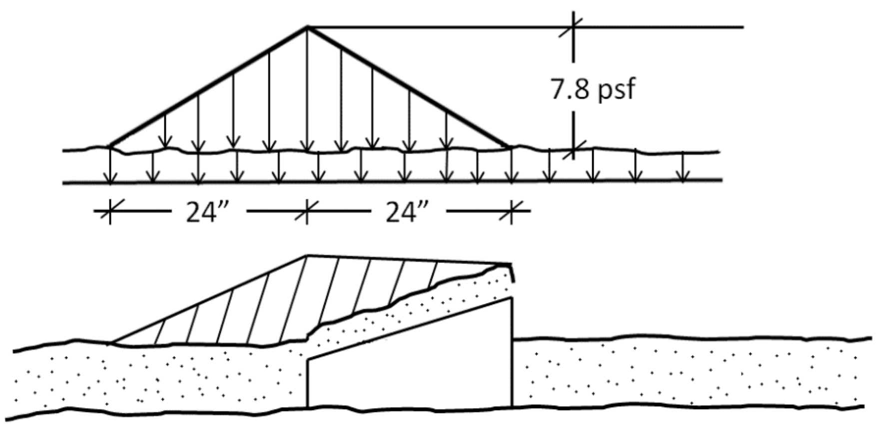



**Fig. 5-23. Windward Drift Surcharge South of Southern Row of Solar Panels in Example Problem #6.**

The drift surcharge between closely spaced rows at the southern portion of the array is based on Fig. 4-8. The horizontal extent of the rectangular drift is the aisle spacing $a$ = 18 in. The drift height $h_u$, again from Fig. 4-8, is

$$h_u = (2h_d^2/a) < h_c = 2(11.6)^2/18 < 6.5 = 14.95 < 6.5$$

$$h_u = 6.5 \text{ in.}$$

Hence, the uniform inter-row drift surcharge load is

$$P = h_u \gamma = (6.5)(15.3)/12 = 8.3 \text{ psf.}$$

This inter-row drift is sketched in Fig. 5-24. Note that the cross-sectional area of this inter-row drift is (6.5)(18) **=** 117 in.$^2$. As per Recommendation #11, the number of such inter-row drifts is based on providing a total drift surcharge area of $6h_d^2 = 6(11.6)^2 = 807$ in$^2$.

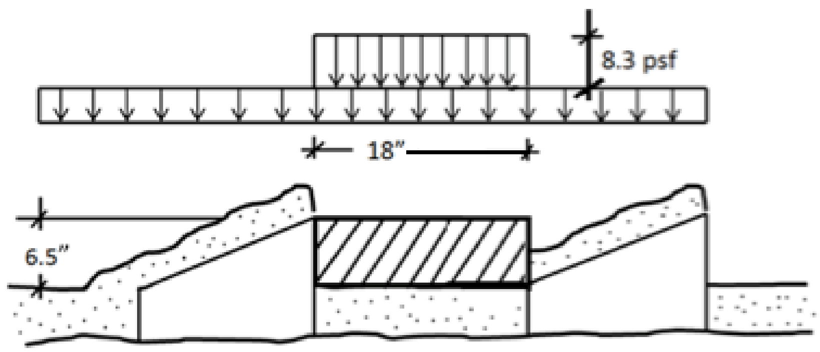



**Fig. 5-24. Inter-row Drift Surcharge at Southern Portion of Solar Panel Array in Example Problem #6**.

Because the windward drift to the south of the array (Fig. 5-23) provides 146 in.$^2$, and each inter-row drift provides 117 in.$^2$, the number of inter-row drifts is

$$n = (807 - 146) / 117 = 5.65 \text{ or } 6.$$

Hence, there are a total of seven individual drift surcharge loads at the southern portion of the array; one windward drift (Fig. 5-23) and six inter-row drifts (Fig. 5-24).

### 5.6.2 Drift Loads for North Wind

As per Recommendation #11, the drift surcharges loads at the northern portion of the solar panel array are based on wind out of the north acting over a fetch distance of 50 ft. From Example Problem #4, the corresponding windward drift is sketched in Fig. 5-20. The height is 6.5 in. and was controlled by the space available $h_c$. The horizontal extent is 52 in., and it also was controlled by the space available ($8h_c$). The cross-sectional area of this north of the array windward drift was (6.5)(52)/2 = 169 in.$^2$

In relation to the inter-row drifts at the northern portion of the array, recall from Example Problem #5 that for a upwind fetch of 50 ft and a ground snow load $p_g$ = 10 psf, $h_d$ = 22.2 in., and $h_{dw}$ = 16.6 in. Hence, from Fig. 4-8, the horizontal extent of the inter-row drift is the aisle spacing $a$ = 18 in. Also, the height of the rectangular inter-row drift surcharge is

$$h_u = (2h_d^2/a) < h_c = 2(22.2)^2/18 < 6.5 = 54.8 < 6.5$$

$$h_u = 6.5 \text{ in.}$$

This inter-row drift is sketched in Fig. 5-24. It has a cross-sectional area of 117 $\text{in.}^2$ as determined previously. As per Recommendation #11, the required number of such northern end inter-row drifts is based on a total drift surcharge area of $6h_d^2 = 6(22.2)^2 = 2{,}957 \text{ in.}^2$, the area of 169 $\text{in.}^2$ for the windward drift, and 117 $\text{in.}^2$ for each of the inter-row drifts:

$$n = (2{,}957 - 169) / 117 = 23.8 \text{ or } 24.$$

Hence, there are a total of 25 individual drift surcharges at the northern end of the solar panel array: one windward drift (Fig. 5-20) and 24 inter-row drifts (Fig. 5-24). That is, for the balanced plus drift load case there are only nine aisles (39 – 6 – 24 = 9) without an inter-row drift surcharge.

When locating tilted-solar panels on a roof, it is advantageous to keep the fetch distance for open roof areas to a minimum.

## 5.7 Example Problem #7: Drifts/Full Closely Spaced Panels

Determine the drift surcharge loads for Example Problem #6, except there are now 20 rows of solar panels and 19 inter-row aisles as sketched in Fig. 5-25.

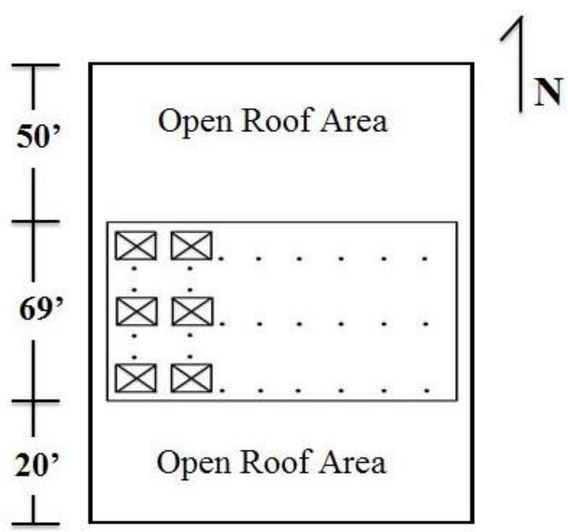



**Fig. 5-25. Roof Plan View for Example Problem #7.**

Recall that in Example Problem #6, the 20-ft upwind fetch to the south required are a windward drift (Fig. 5-23) and six inter-row drifts (Fig. 5-24) to reach the recommend total drift area of 807 $\text{in.}^3$ Whereas for the 50-ft upwind fetch to the north, one needs one windward drift (Fig. 5-20) and 24 inter-row drifts (Fig. 5-24) to reach the recommended total drift area of 2,957 in.$^2$ Note that all these inter-row drifts were governed by the space available for drift formation $h_c$. Specifically, the height of the inter-row drift height (6.5 in.) was controlled by $h_c$, and the horizontal extent was the aisle width. Hence, the space available for drift formation at each aisle is full.

Similarly, as noted previously, the height and horizontal extent of the windward drift at the north end of the array (Fig. 5-20) were both controlled by the space available for drift formation. Hence, this drift is also full. The only drift in Example Problem #6 that is not full is the windward drift at the south end of the array. For that drift, the height of the isosceles triangle was based on $0.707h_{dw}$ = 6.1 in. as opposed to the space available $h_c$ = 6.5 in., whereas the horizontal extent was controlled by the horizontal extent $L$ of the solar panel itself. As such, a full windward at the south end would have a peak load of (15.3)(6.5)/12 = 8.3 psf. The cross-sectional area of this full windward drift is ½ (6.5)(24 + 24) = 156 in.$^2$. This drift happens to be identical to that sketched in Fig. 5-21.

Hence, although Recommendation #11 requires a total drift cross-sectional area of 2,957 in$^2$ for wind out of the north, there is only room for 156 in$^2$ (full south), 19 × 117 = 2,223 in.$^2$ for 19 full inter-row drifts and 169 in$^2$ for the full north drift. This totals to 2,548 in.$^2$ Hence, a little over 400 in.$^2$ of snow flux for wind from the north bypasses all the aerodynamic shade regions.

## 5.8 Example Problem #8: Drifts/Widely Spaced Multiple Rows

Determine the drift loads for the solar panel array geometry sketched in Fig. 5-22. The exposure factor $C_e$, the thermal factor $C_t$, the importance Factor $I_s$, and the slope factor $C_s$ are all equal to 1.0. The ground snow load $p_g$ = 20 psf and the individual panel geometry is as sketched in Fig. 5-26.

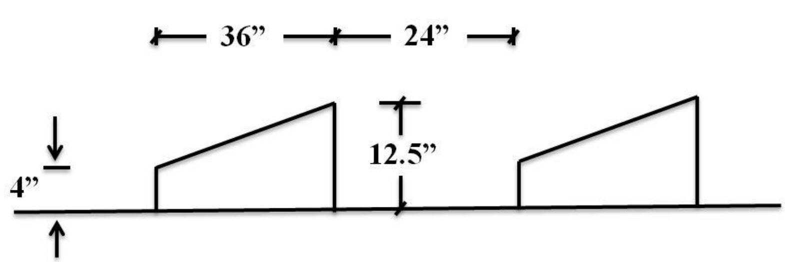



**Fig. 5-26. Solar Panel Geometry for Example Problem #8.**

The flat roof snow load from ASCE 7-10 Eq. (7.3-1) is

$$p_f = 0.7C_e\, C_t\, I_s\, p_g.$$

As per the problem statement $C_e = C_t = I_s = C_s$ =1.0; hence,

$$p_f = 0.7(1.0)^3(20) = 14 \text{ psf}$$

and the sloped roof or balanced snow load is

$$p_s = C_s\, p_f = 1.0(14) = 14 \text{ psf.}$$

From ASCE 7-10 Eq. (7.7-1), the snow density is

$$\gamma = 0.13 p_g + 14 \leq 30 \text{ pcf}$$

or

$$\gamma = 0.13(20) + 14 = 16.6 \text{ pcf}$$

and the depth of the balanced roof snow is

$$h_b = p_s / \gamma = (14 \text{ psf}) / (16.6 \text{ pcf}) = 0.84 \text{ ft} = 10.1 \text{ in.}$$

Note that from Fig. 5-26, $h_p$ = 12.5 in., which is larger than $1.2h_b$ = 1.2(10.1) =12.1 in. Hence, from Recommendations #11 and #12, one needs to consider drift loads. Furthermore, the space available for drift formation $h_c = h_p - h_b$ = 12.5 – 10.1 = 2.4 in. is comparatively small, whereas the aisle width from Fig. 5-26 is comparatively large. Specifically, the aisle spacing (24 in.) is larger than $8h_c$ = 8(2.4) = 19.2 in. Hence, from Recommendation #12, the rows of solar panels are considered widely spaced, and it is recommended that each row be treated as a single row (i.e., follow the suggested drifts in Recommendation #9). For the southernmost row of panels, the upwind fetch distance to the south is 20 ft, whereas the controlling upwind fetch is 190 ft to the north. For the northernmost row, the controlling fetch distance of 160 ft is to the south. The controlling upwind fetch distance for all other rows is somewhere between 160 and 190 ft.

For the smaller upwind fetch of 160 ft and a ground snow load of 20 psf, the height of the corresponding windward drift is

$$\begin{aligned} h_{dw} &= 0.75\left[0.43(\ell_u)^{1/3}(p_g + 10)^{1/4} - 1.5\right] \\ &= 0.75\left[0.43(160)^{1/3}(20 + 10)^{1/4} - 1.5\right] \\ &= 2.95 \text{ ft} \end{aligned}$$

However, because $h_{dw}$ for the smallest upwind fetch is larger, actually much larger than the space available for drift formation ($h_c$ = 2.4 in.) the windward drift on the north side of each row (Fig. 4-5) and the windward drift on the southside at each row (Fig. 4-6) are controlled by the space available for drift formation. Specifically, as per Fig. 4-5b, the height of the space restricted drift of the north side is $h_c$ = 2.4 in and the peak surcharge is $h_c\,\gamma$ = 2.4(16.6)/12 = 3.3 psf. From the same figure, the horizontal extent of the north side drift is by inspection $8h_c$ = 19.2 in. This north side drift is sketched in Fig. 5-27.

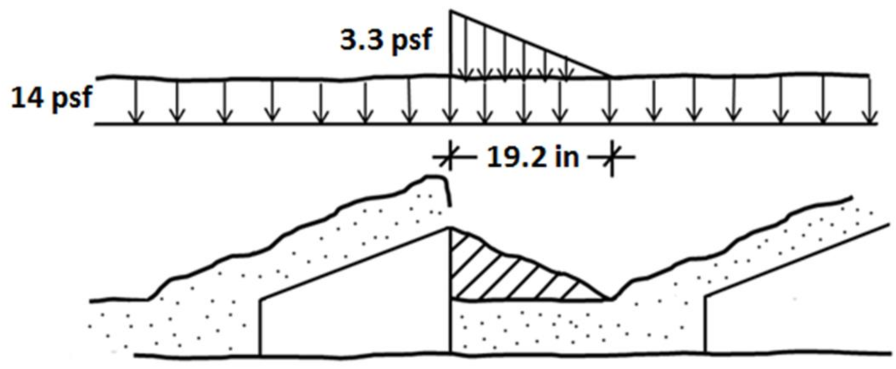



**Fig. 5-27. Windward Space Restricted Drift on Northside of Each Row in Example Problem #8.**

Similarly, as per Fig. 4-6, the space restricted windward drift to the south of each row is an isosceles triangle with height $h_s = h_c = 2.4$ in., peak load $\gamma\ h_c = 3.3$ psf and a total horizontal extent of $2(4h_s) = 8(2.4$ in.$) = 19.2$ in. This south drift is sketched in Fig. 5-28.

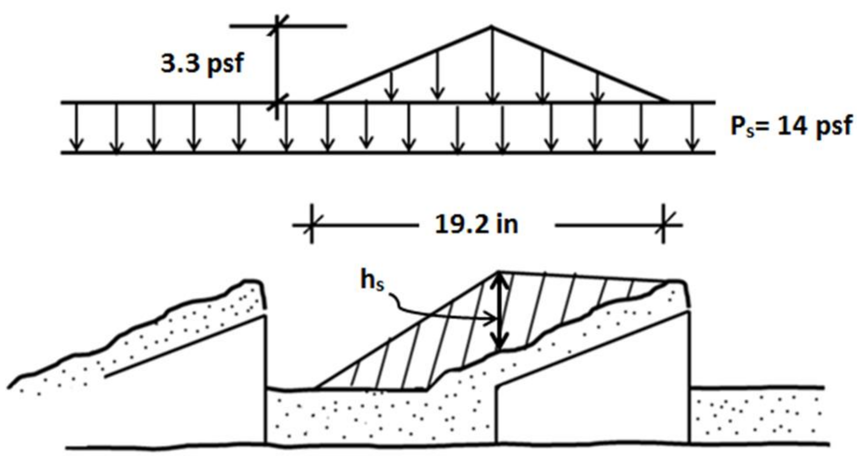



**Fig. 5-28. Windward Space Restricted Drift on Southside of Each Row in Example Problem #8.**

Note that for the arguably typical solar panel geometry sketched in Fig. 5-26, there is a very limited range of ground snow loads for which the rows are considered widely spaced. If the ground snow load were 25 psf or greater in this example problem, the solar panels would either be buried ($h_b > h_p$) or the space available for drift formation would be too small to worry about ($h_c < 0.2h_b$). In either case, drift loads need not be considered. If, conversely, the ground snow load were 15 psf or smaller, $h_c$ would be large enough that the panels would be considered closely spaced. That is, as suggested in Section 4.2.2 in relation to multiple rows of solar panels, widely spaced rows are not common.

## 5.9 Example Problem #9: Drifts/East-West Edges

Determine the drift loads at the east and west edges of the tilted-closed solar panel array sketched in Fig. 5-29. The panel geometry is that sketched in Fig. 5-14. The ground snow load $p_g$ = 10 psf and as in Example Problem #4, $C_t = C_s = C_e = I_s = 1.0$.

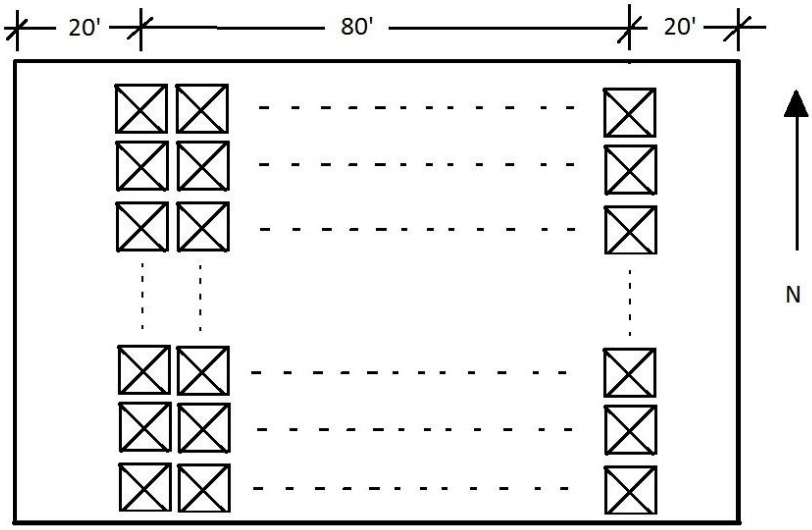



**Fig. 5-29. Roof Plan for Example Problem #9.**

As determined in Example Problem #4, the depth of the balanced roof snow load $h_b$ = 5.5 in. and the snow density $\gamma$ = 15.3 pcf.

### 5.9.1 Drifts at East and West Edges

For wind out of the west, the fetch for potential drifts at the eastern edge of the solar panel array consist of 20 ft of open roof area and 80 ft of sloping to the south solar panel surface. That is, for western wind, each row of panels is nominally a long slender roof top unit (RTU) having a north-south plan dimension of 2 ft and an east-west plan dimension of 80 ft. Again, for western wind, snow originally atop this RTU could well lead to leeward drifts at the eastern edge of the solar panel row.

As per the provisions for roof projections in ASCE 7-10 Section 7.8, a windward drift based on the larger of the two fetch distances (that is, 100 ft to the west, 20 ft to the east) is prescribed.

$$
\begin{aligned}
h_{dw} &= 0.75\left[0.43(\ell_u)^{1/3}(p_g+10)^{1/4}-1.5\right] \\
&= 0.75\left[0.43(100)^{1/3}(10+10)^{1/4}-1.5\right] \\
&= 2.04 \text{ ft}
\end{aligned}
$$

Note the $h_{dw}$ is larger than the space available for drift formation, which varies, because the solar panel surface slopes downward to the south. The largest available space is at the north edge, $h_c = h_p - h_b = 12 - 5.5 = 6.5$ in., which will be used to determine the drift surcharge.

Using the space available of $h_c = 6.5$ in., the horizontal extent in the east-west direction is 8 (6.5) = 52 in. = 4.34 ft. The peak drift load is $h_c\gamma = 6.5(15.3)/12 = 8.29$ psf.

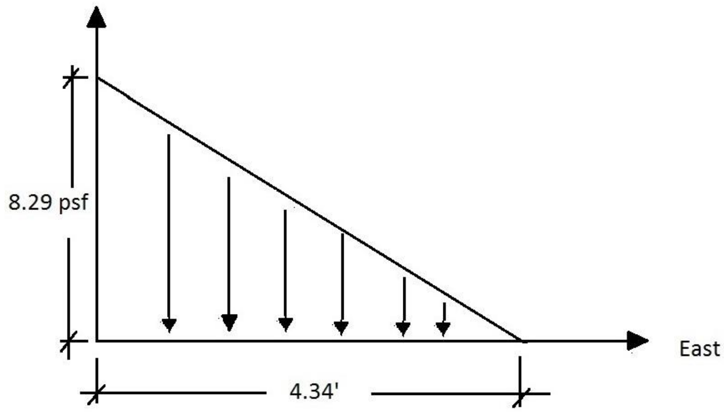



**Fig. 5-30. Drift Surcharge at East Edge of Solar Panel Array in Example Problem #9.**

This 8.29 psf drift surcharge is located at the east edge of the solar panel array as sketched in Fig. 5-30. Note that

1. The 15 ft bound for the width of a roof projection in ASCE 7-10 Section 7.8 corresponds to a single, standalone, roof projection. The width of the drift at such a single roof projections would be nominally 15 ft of less. Such “comparatively small” drifts have not resulted in structural performance problems in the past, and the ASCE 7-10 load standard has allowed structural engineers to neglect them. However, the multiple rows of solar panels correspond to a number of closely spaced roof projections and, as such, snow drift loads should be considered.
2. For the arguably common solar panel geometry in Fig. 5-14, the drift surcharge loads at the east edge of the solar panel row was directly related to the space available for drift formation. For such “close to the roof” panel geometries, one gets drifts only for comparatively low values of the ground snow load. For example, for the thermal, exposure, slope, and importance factors in Example Problems #9, drift loads need not be considered for ground snow loads of 20 psf and larger, as per Recommendation #9.
3. Due to the symmetry of the solar panel array, the same 8.29 psf drift surcharge would also occur at the west edge of the solar panel array.

Note that one does not expect a drift in the aisle between rows of solar panels for wind exactly out of the east or west. However, an aisle drift is considered likely for wind at a small angle with respect to true east or west wind. The drift surcharge suggested is simple to determine and considered reasonably conservative.

# REFERENCES


ASCE. (2013). *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI 7-10, Third Printing, Reston, VA.

Cattaneo, L., Harris, J., Reinhold, T., Simiu, E., and Yancey, C. (1981). *Wind, Earthquake, Snow, and Hail Loads on Solar Collectors*, Report NBSIR 81-2199, National Bureau of Standards, Gaithersburg, MD.

Corotis, R., Dowding, C., and Rossow, E. (1979). *Snow and Ice Accumulation at Solar Collector Installations in the Chicago Metropolitan Area*, Report NBS GCR 79-181, National Bureau of Standards, Gaithersburg, MD.

Irwin, P., Gamble, S., and Lepage, M. (1984). S*now and Wind Loads Resulting from Roof Mounting of Solar Collectors*, Report Coll-17-D, National Research Council Canada, Ottawa.

O'Rourke, M. (1979). *Snow and Ice Accumulation Around Solar Collector Installations,* Report NBS-GCR 79-180, National Bureau of Standards, Gaithersburg, MD.