THE INFLUENCE OF WINDWARD PARAPETS ON THE HEIGHT OF LEEWARD SNOW DRIFTS AT ROOF STEPS

by

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Abstract

The American Society of Civil Engineers (ASCE) has developed standards for the design of snow loads that occur on buildings and structures. These standards are published in the *Minimum Design Loads for Buildings and Other Structures*, or ASCE 7, and are based on the findings of case studies and other scientific tests. However, design guidance on the possible reduction of leeward snow drifts at the junction of a roof parapet and a moderately sized roof step is limited and not specifically addressed in the ASCE 7. Therefore, a literature review and parametric study were performed to evaluate possible leeward snow drift reduction that could occur at the junction of parapets and roof steps. Leeward drift reduction was estimated using the Fetch Modification Method, the Direct Reduction Method, and the Simplistic Reduction Method for parapets with heights of 30 in. and 48 in. with upwind snow fetch distances from 100 to 300 ft and ground snow loads from 20 to 50 psf. More drift reduction was seen with the 48 in. parapets than with the 30 in. parapets. The Fetch Modification Method and the Direct Reduction Method gave relatively similar reductions across the range of upwind fetch distances, while the Simplistic Reduction Method gave larger reductions overall. Reductions in height for the Fetch Modification Method were between 0.25 ft and 0.42 ft, while the Direction Reduction Method returned 0.08 to 0.63 ft and the Simplistic Reduction Method returned 1.61 to 3.09 ft. Due to the large magnitude of reduction estimated by the Simplistic Reduction Method, the method was considered unconservative. From the results of the Fetch Modification Method and Direct Reduction Method, it could be suggested that parapets 30 in. or 48 in. tall could only provide a small amount of leeward drift reduction, roughly 7% to 8% of the original leeward drift height. Further research should be done to expand the heights of parapets examined and to incorporate testing and full scale observations to verify the reduction of the leeward drift.

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Dedication

This is dedicated to all the family, friends, and professors who have encouraged me throughout my college career and during the writing of this report. Thank you.

Chapter 1 - Introduction

Drift snow is snow that has been transported by the wind and deposited at obstructions such as buildings, parapets, mechanical equipment, and changes in roof geometry. Drifting snow generally causes large loads at relatively concentrated locations on buildings and other structures when compared to flat snow loads that blanket an entire roof area. Therefore many researchers have attempted to increase understanding of snow drift behavior and develop equations practicing engineers can use to determine snow drift loads. The American Society of Civil Engineers (ASCE) standard *Minimum Design Loads for Buildings and Other Structures*, or ASCE 7, is the accepted code standard for determining the loads imposed on structures by snow drifts in the United States. The ASCE 7-10 snow provisions cover snow drifting in Chapter 7; Section 7.7 specifically covers drifts on lower roofs, known as leeward drifts, and Section 7.8 covers drifts at roof projections and parapets, known as windward drifts. Leeward drifts can be generally described as drifts forming downwind of an obstacle, and windward drifts can be described as drifts forming upwind of an obstacle.

The ASCE 7 provides guidance to engineers who must design structures for the increased load caused by leeward and windward drifts. However, when building geometries are irregular or other special cases, the ASCE 7 may not provide appropriate representations of drifts that form in these locations. The ASCE 7 acknowledges this lack of representation and encourages designers to seek water flume or wind tunnel testing in order to determine drifting requirements for their structures (ASCE, 2010). Testing can be expensive and time-consuming, however, and may not be an option for the engineer. In some conditions, such as possible reduction of a leeward roof step drift due to an upwind parapet, the ASCE 7 directs readers to outside sources because the ASCE 7 does not contain significant information regarding potential reduction of a leeward drift, other than presenting standard drift design equations that could be adapted.

This thesis reviews the behaviors of drifts, explains how these behaviors are described in the ASCE 7, presents past leeward drift reduction research, and expands on research conducted on leeward drift reduction by comparing what will be called the Fetch Modification Method by O'Rourke (2010), and two other methods, the Direct Reduction Method and the Simplistic Reduction Method. All three methods are used to examine a range of ground snow loads and upwind fetch distances for two parapet heights. Calculations and results for each individual method are presented and discussed.

Chapter 2 - Literature Review

Before proposing to reduce a leeward drift due to a parapet at a roof step, drift behavior at roof steps and parapets and the development of these behaviors must be understood. Leeward drift reduction is not specifically addressed in the ASCE 7-10 code body; even the standard's commentary references outside studies for information on the subject. Therefore, examination of the study *Snow Drifts at Windward Roof Steps* (O'Rourke and De Angelis, 2005) and O'Rourke's (2010) book, *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-10*, is necessary in order to fully understand and advance the topic of leeward drift reduction due to a parapet.

ASCE 7-10 Drift Properties

ASCE 7-10 snow drift provisions stem from the examination of snow and its drifting patterns on buildings since the 1980s when researchers assembled and analyzed a database of 347 snow drift case histories. The case histories originate from a variety of sources including technical literature, failure reports written by practicing engineers, and failure investigations by insurance companies (O'Rourke et al., 1985). These case histories spanned from the winter of 1958-59 to the winter of 1981-82, including cases from Canada, the southeast United States, the Midwest, the coastal Northeast, and upstate New York. These studies defined attributes of snow drifts on roofs that were adapted for use in the ASCE 7. Some of the major attributes observed were drift shape, height, and length, as well as the density of the drift snow. The density equation in the ASCE 7-10, Equation 3-3 ($\gamma = 0.13p_g + 14 \leq 30$ pcf), which was originally developed by Speck in 1984, produces densities similar to Tabler's independently developed equation in 1994, Equation 2-1.

$$\gamma = 522 - \frac{304}{1.485h_g}\left[1 - e^{-1.485h_g}\right] \quad \text{(EQ 2-1)}$$

Where: γ = density of drifted snow (kg/m^3)

h_g = snow depth (m)

e = base of natural logarithms

The major studies upon which leeward snow drift provisions in the ASCE 7-10 are based include *Analysis of Snow Loads Due to Drifting on Multilevel* Roofs by Speck (1984), *Snow Loads on Two-Level Flat Roofs* by Taylor (1984), *Drift Snow Loads on Multilevel Roofs* by O'Rourke et al. (1985), and *Proposed Code Provisions for Drifted Snow Loads* by O'Rourke et al. (1986).

Drift Shape

O'Rourke (1985) observed a major attribute of snow drifts to be the shape the drifts take when they form. Observations were made by examining the database of 347 case histories previously mentioned. A majority of the case histories, 206 out of 347 cases, occurred in the winters of 1977-78 and 1978-79. Structural failure, either full collapse, partial collapse, or excessive deflection, was noted in 43% of all case histories. Of the "case histories involving structural failure, 75% occurred in the New England coastal area or in the Illinois/Wisconsin area" (O'Rourke et al., 1985). Results from this database showed that drift shape is determined by wind direction and the location of drift formation on the structure. Leeward drifts, drifts that form in the aerodynamic shade of an upwind obstacle (Figure 2-1), are approximately triangular drifts that fill in the intersecting corner of the roof step and lower roof. The triangular shape is shown in Figure 2-2. Windward drifts however, or drifts that form on the upwind side of an obstacle (Figure 2-1), are quadrilateral drifts in which the peak of the drift forms a distance away from the intersection of the lower roof and roof step. The distance of the drift peak away from the step is due to the fact that, when the drift is relatively short compared to the step, wind creates a vortex as it impinges on the top of the step, blowing snow away from the step. The quadrilateral shape of the windward drift changes as the drift becomes taller, thus reducing the distance between the drift peak and the top of the step. Once the distance between the drift peak and top of the step becomes small enough, the wind no longer impinges on the step and travels over the step. When this occurs, the windward drift fills in and becomes nominally triangular, similar to a leeward drift (O'Rourke et al., 1985).

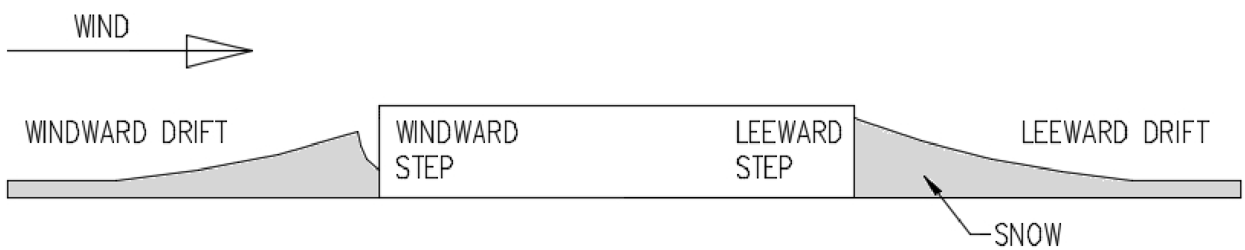

Figure 2-1 – Drifts Formed at Windward and Leeward Steps

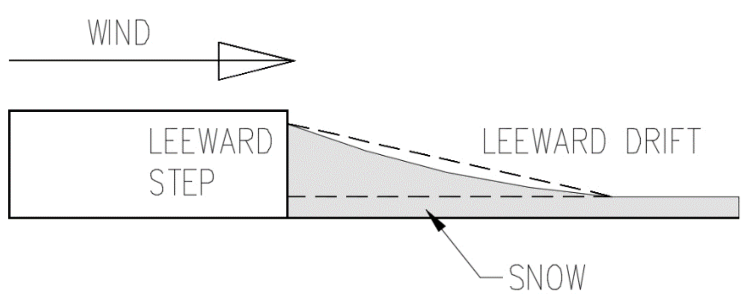

Figure 2-2 – Nominally Triangular Drift

The ASCE 7-10 describes both leeward and windward drifts as triangular, but it does not include provisions for the quadrilateral shape that windward drifts could take when they form. The ASCE 7 does not include provisions for quadrilateral drifts because examination of the case history database used by O'Rourke in 1985 revealed that the triangular shape is the predominate drift shape, regardless of the drift being leeward or windward. The triangular drift shape was determined when the number of cases histories for each drift shape for a given direction of the monthly fastest mile wind, either leeward, windward, or lateral, was graphed. The graph showed that for any wind direction, case histories largely had drifts that were triangular, rather than quadrilateral. Leeward drift loads were also found to be generally larger than drift loads for quadrilateral windward drifts because leeward drifts were, on average, longer and taller. These observations make triangular drifts more important in terms of load magnitude, resulting in the exclusion of quadrilateral drifts from the ASCE 7.

Drift Height

Drift height is based on an empirical equation developed by O'Rourke, Speck, and Stiefel in their 1985 study of drift snow on multilevel roofs. The equation, Equation 2-2, contains input parameters of upper roof length, lower roof length, roof step height, and ground snow load.

$$H_d = 1.22\ln(L_u) + 1.51\ln(H_r) + 1.03\ln(P_g + 10) + 0.36\ln(L_l) - 9.28 \quad \text{(EQ 2-2)}$$

Where: H_d = predicted measured height of snow drift (ft)

H_r = height of the roof step (ft)

L_u = length of the roof upwind of the drift (ft)

P_g = measured ground snow load (psf)

These parameters were chosen because they are known to the design engineer and because they are strongly correlated to drift load characteristics such as drift height, cross-sectional area of the drift, and peak drift height. In order to determine potential input parameters, simple correlation analyses were performed to eliminate parameters that did not show strong correlation with drift load characteristics. A simple correlation analysis, or a simple linear correlation, measures the degree to which two variables vary together. Speck (1984) found two parameters, the length of the upper roof and the roof elevation difference (roof step), to most strongly influence drift characteristics. After narrowing the list of potential input parameters using simple linear correlations, multiple linear regression was used to determine the relationship between the input parameters and the drift load characteristics. Multiple linear regression is a statistical method used to relate two or more explanatory variables (input parameters) and a response variable (a drift load characteristic) by fitting a linear equation to a set of observed data ("Multiple Linear Regression," n.d.). In order to determine the final set of input parameters, O'Rourke, Speck, and Stiefel set the criteria that "a parameter would not enter the relationship unless the change in the coefficient of multiple determination was significant at the 90% level" (O'Rourke et al., 1985). The coefficient of determination, or the coefficient of multiple determination as used by O'Rourke et al., reports the amount of variation of one variable directly related to, or accounted for, by variation in the other variable. Accuracy of the final relation, Equation 2-2, was tested by plotting predicted drift heights against measured drift heights for all 347 case histories. The plot is shown in Figure 2-3.

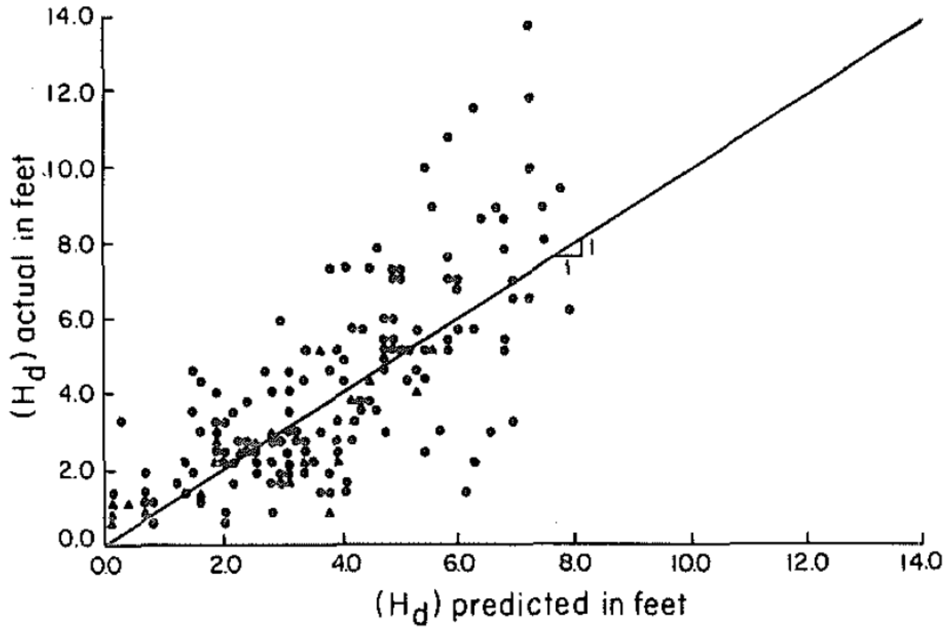

Figure 2-3 – Scatterplot of Measured Drift Height versus Predicted Drift Height, with permission of ASCE

The accuracy of Equation 2-2 had to be tested because it was determined from the case histories that, out of the 347 histories, had total peak loads greater than 30 psf. The slope of the least squares straight line through the origin and the points was determined to be 1.006 and the standard error of the estimate was 1.72 ft. This was taken by O'Rourke, Speck, and Stiefel as sufficiently accurate at predicting drift heights from lower load levels. In Equation 2-2 the drift height was bounded by the roof step height, and the drift length was taken as four times the drift height and bounded by the length of the lower roof since the 1985 study focused on leeward drifts. Despite accurate estimations of measured drift loads, Equation 2-2 was not used in ASCE 7 because it did not yield 50-yr mean recurrence interval (MRI) loads for drifts because the equation is a relation between roof geometry, the measured ground snow load, and the measured drift loads where the ground snow load was not the 50-yr MRI value. Drifts require a combination of wind and snow to form, meaning that the joint probability of wind and snow must be evaluated and quantified before an estimation method for 50-yr MRI drift loads could be suggested. The joint probability of wind and snow was not evaluated and quantified in O'Rourke et al. (1985); therefore Equation 2-2 does not estimate 50-yr MRI drift loads.

Proposed Code Provisions for Drifted Snow Loads by O'Rourke et al. (1986) presents the simplification of the drift height relation and modification of the relation to yield approximately 50-yr MRI loads. The simplification presented in this study uses the empirical log-log form, Equation 2-3, of Equation 2-2 found in O'Rourke et al. (1985) and eliminates the length of the lower roof and the height of the roof step from the simplified relationship.

$$H_d = 0.083(H_r)^{0.50}(L_u)^{0.31}\left(p_g + 10\right)^{0.26}(L_l)^{0.10} \qquad \text{(EQ 2-3)}$$

Where: H_d = predicted measured height of snow drift (ft)

H_r = height of the roof step (ft)

L_u = length of the roof upwind of the drift (ft)

p_g = measured ground snow load (psf)

The length of the lower roof was eliminated because it had less influence on drift size than the length of the upper roof and ground snow load. The roof step height was eliminated because it was considered when limiting the maximum drift height to the height of the roof step. Substitution of the powers on the remaining two input variables, L_u and p_g, of Equation 2-3 with cube and fourth roots, respectively, yielded the basic form of the simplified equation. In order to determine the constants to use in the simplified equation, O'Rourke, Tobiasson, and Wood tested many values and ultimately determined that the values of 0.61 and 2.2 provided "the best fit between the measured drift height and the value predicted by the equation" (O'Rourke et al., 1986). Equation 2-4 is the resulting simplified equation.

$$h_d = 0.61\sqrt[3]{\ell_u}\,\sqrt[4]{p_g + 10} - 2.2 \qquad \text{(EQ 2-4)}$$

Where: h_d = predicted measured height of snow drift (ft)

ℓ_u = length of the roof upwind of the drift (ft)

p_g = measured ground snow load, (psf)

The unmodified equation, Equation 2-4, which uses the measured ground snow load to predict the measured drift height, is similar to the equation used in the ASCE 7-10, Equation 2-5, to determine drift heights. The simplified equation, Equation 2-4, does not as accurately predict measured drift heights as Equation 2-2, but the difference in accuracy between the two sets of equations is not drastic. In order to quantify the difference in accuracy between Equation 2-2 and Equation 2-4, the measured drift height was plotted against the predicted drift height by each equation. The standard error of the estimate was then determined for each plot, returning 1.72 ft for Equation 2-2 and 1.90 ft for Equation 2-4, where a smaller value means the equation more accurately predicted measured drift heights. Even though Equation 2-4 was based empirically on a database containing a large amount of small ground loads, it is appropriate for case histories with high ground loads.

O'Rourke, Tobiasson, and Wood sought the simplified equation to use established 50-yr MRI ground snow loads and to be able to predict an appropriate 50-yr MRI drift height because engineers would be using 50-yr MRI ground snow loads during design and to provide conservative design estimates of drift heights without being overly conservative. Inserting the 50-yr MRI ground snow load into Equation 2-4 produced drift loads with MRIs greater than 50 years, prompting modification of the equation to predict 50-yr MRI heights. The unmodified equation did not produce 50-yr MRI heights because the probability of having all conditions met for drift formation, a snow source and wind with proper velocity, was lower than the probability of the occurrence of snow (O'Rourke et al.,1985). Therefore, O'Rourke, Tobiasson, and Wood multiplied Equation 2-4 by a multiplication factor less than one. Different multiplication factors were tried, and the percentage of case histories was recorded in which the design drift load was larger than the measured value. The modification factor was determined to be 0.7 based on the researchers' knowledge of the database and their collective engineering judgement since 0.7 produced a conservative percentage (68%) of design drift loads exceeding their measured drift counterparts. Using the value 0.7 takes into consideration "that not all drifts in the data base can be classified as large design-type drifts" (O'Rourke et al., 1986) by being larger than 0.53, which makes Equation 2-4 produce design drift loads similar to measured drift loads on average. After the 0.7 modification factor was applied to Equation 2-4, the resulting equation was Equation 2-5, as is found in ASCE 7-10.

$$h_d = 0.43\sqrt[3]{\ell_u}\,\sqrt[4]{p_g + 10} - 1.5 \qquad \text{(EQ 2-5)}$$

Where: h_d = height of snow drift (ft)

ℓ_u = length of the roof upwind of the drift (ft)

p_g = ground snow load, (psf)

In the 1985 study, Equation 2-5 was proposed to be used with Equation 3-3, the density of the drift snow (Speck, 1984), and the 50-yr MRI ground snow load, in addition to taking the drift length as four times the drift height to determine the drift surcharge load and the drift's cross-sectional area.

Equation 2-5 determines the drift height for leeward drifts but not windward drifts because the studies performed by O'Rourke in 1985 and 1986 focused on larger, more common triangular drifts and not quadrilateral drifts. In order to determine the height of windward drifts, O'Rourke and El Hamadi (1987) examined quadrilateral drifts in detail. They found that quadrilateral drift heights, or windward drift heights, were approximately half as tall as the drift heights produced by Equation 2-5. This finding was accepted for many years, but more recent research by O'Rourke and De Angelis (2002) determined that windward drift heights were more appropriately described by multiplying Equation 2-5 by a three-quarters factor. The research by O'Rourke and De Angelis in 2002 showed that previous editions of the ASCE 7, before 1995, were flawed because the provisions assumed that windward drifts were always quadrilateral. O'Rourke and De Angelis (2002) briefly investigated the aerodynamics of windward drifts and determined that windward drifts may start out quadrilateral due to impinging wind, but as the drift height increases and the wind no longer impinges, the windward drift becomes approximately triangular. O'Rourke and De Angelis (2002) examined five case histories to determine if the change from the half to three-quarters factor in the ASCE-98 produced representative windward drift heights. The case histories were chosen because the predominate wind direction during drift formation was known, allowing straightforward distinction between leeward and windward drifts. For the chosen case histories, the upwind fetch ranged from 65 to 570 ft, with four out of five case histories having fetches larger than 350 ft. The observed ground snow load ranged from 11 to 40 psf, while the 50-yr ground snow load ranged from approximately 26 psf, based on ground snow depth and the snow density relation used in ASCE-98, to 53 psf. Analysis of the case studies provided sufficient evidence to justify the increase of the half factor to a three-quarters factor in the ASCE-98. This research validated the use of Equation 2-6 to determine windward drift heights.

$$h_d = 0.75[0.43\sqrt[3]{\ell_u}\,\sqrt[4]{p_g + 10} - 1.5] \qquad \text{(EQ 2-6)}$$

Where: h_d = height of snow drift (ft)

ℓ_u = length of the roof upwind of the drift (ft)

p_g = ground snow load, (psf)

Drift Slope

The length and slope of snow drifts, which are significant attributes, are necessary in order to fully describe a drift. Drift length is discussed in the analysis performed by O'Rourke, Speck, and Stiefel in 1985. The study observed that many codes in use during 1985 used direct relations between drift length and drift height. The study also found that the case history database supported a relationship between the two parameters. In order to obtain the relationship between drift length and drift height, drift length was plotted against drift height for 101 case histories that contained both measurements. The correlation coefficient and the slope of the regression line were then determined: the correlation coefficient was high, 0.804, and the slope of the regression line was 0.228, or 1:4.4. Other subsets of data from Speck (1984) and O'Rourke et al. (1985) were tested, such as a subset in which the same plot of drift length versus drift height was made using case histories that each had a total peak load greater than 30 psf. For all subsets tested, the correlation coefficients commonly exceeded 0.80, and the average slopes ranged from 1:3.6 to 1:6.9 (Speck, 1984). The study found that drift slope was approximately 1:4 when drift height was more than 6 in. shorter than the roof step height and the lower roof length was long enough to not influence drift length. However, when drift height was almost equal to the roof step height or when total peak load was less than 30 psf, drift slopes averaged 1:5 or 1:6. This slope flattening was attributed to the 1:4 drift profile filling, causing additional snow to build up at the toe of the drift. The flatter slope observations were supported by other studies, (Finney, 1939) and (Tabler, 1975), in which snow drift behavior was examined using wind tunnels and topographical catchments, respectively. More recently Tabler (1994) found that snow drifts take on a 1:6 slope in relation to drifts onto road surfaces. With the observations from the 347 case histories and studies performed by other researchers, O'Rourke (1985) concluded that drifts fill in, yielding a slope of 1:6, as the difference between drift height and roof step diminished. In addition, the drift became sufficiently streamlined, thereby preventing additional snow build up.

The maximum slope in the ASCE 7-10 is 1:8, not 1:6. ASCE 7-10 Section 7.7.1 states that, when the drift is full, $h_d \geq h_c$, the width of the drift, w, is $4h_d^2/h_c$ with a maximum of $8h_c$, and the drift height is h_c, where h_c is the clear distance between the balanced snow load and upper roof, as shown in Figure 3-2. According to the ASCE 7-10 commentary for Section 7.7:

> [The] drift width relation is based upon equating the cross-sectional area of [a height-limited triangular] drift (i.e., $1/2h_c \times w$) with the cross-sectional area of a triangular drift where the drift height is not limited by h_c (i.e., $1/2h_d \times 4h_d$) as suggested by Zallen (1988). The upper limit of drift width is based on studies by Finney (1939) and Tabler (1975) that suggest that a 'full' drift has a rise-to-run of about 1:6.5, and case studies (Zallen 1988) that show observed drifts with a rise-to-run greater than 1:10 (p. 432).

O'Rourke clarifies the reason for a 1:8 maximum slope in *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-10*, where he explains that the maximum slope was chosen because significant additional accumulation is not expected on an aerodynamically streamlined drift, or a drift with a rise-to-run of approximately1:8.

Leeward Drift Reduction

Previous research on leeward drift reduction at a roof step with a parapet is limited, potentially because the relative inefficiency of windward drifts for capturing snow or because engineers conservatively ignore parapets' reducing effects on leeward drifts. As many engineers note, the ASCE 7-10 code does not include provisions for calculating the possible reduction of leeward drifts due to parapets, but guidance on the subject is available in O'Rourke's book, *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-05* (2005). Because the 2005 guide contains the same information as the 2010 *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-10*, this thesis references the 2010 guide. Although the guide contains limited information about reducing leeward drifts, the Frequently Asked Questions (FAQ) section in the guide addresses this subject.

Before examining the information in O'Rourke's guide, however, the study referenced in the guide, *Snow Drifts at Roof Steps in Series* by O'Rourke and Kuskowski (2005), which develops a method for determining snow drift heights at roof steps in series, must be examined. O'Rourke and Kuskowski considered a structure with three roof levels, A, B, and C, where each level was at a lower height than the previous level, and the roofs had lengths of ℓ_A, ℓ_B, and ℓ_C, respectively, as shown in Figure 2-4 from O'Rourke's and Kuskowski's study (2005).

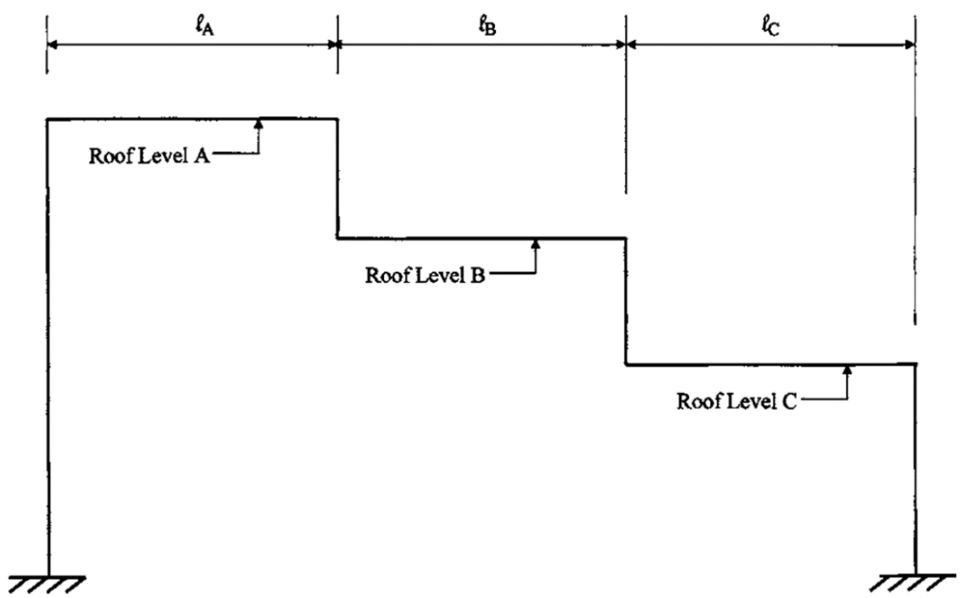

Figure 2-4 – Roof Steps in Series, with permission of ASCE

In this structure with three roof levels, leeward drifts were initially considered with wind blowing from roof A towards roof C, creating leeward drifts on roof B and roof C. The snow source area on roof A caused the leeward drift on roof B, where the height of the drift was directly calculated per ASCE 7-05 using Equation 2-7. ASCE 7-05 was referenced because it was the current code at the time O'Rourke and Kuskowski performed their study.

$$h^L_{B/A} = 0.43\sqrt[3]{\ell_A}\,\sqrt[4]{p_g + 10} - 1.5 \qquad \text{(EQ 2-7)}$$

Where: $h^L_{B/A}$ = leeward drift height on roof B due to snow originally on roof A (ft)

ℓ_A = length of roof A (ft)

p_g = 50-yr MRI ground snow load (psf)

The width of the drift was considered to be four times the drift height since the study only considered conditions when the drift height was not constrained. The cross-sectional area of the drift on roof level B due to snow on roof A was then described by Equation 2-8.

$$A^L_{B/A} = 2\left(h^L_{B/A}\right)^2 \qquad \text{(EQ 2-8)}$$

Where: $h^L_{B/A}$ = leeward drift height on roof B due to snow originally on roof A (ft)

$A^L_{B/A}$ = cross-sectional area of the leeward drift on roof B due to snow originally on roof A (ft^2)

Equation 2-8 is a simplified triangular area equation in which both side lengths are a multiple of the drift height.

Because a leeward drift occurs due to the snow source area upwind of the drift, the leeward drift on roof C contains a combination of snow from roof A and roof B. In other words, the drift on roof C had an upwind fetch between ℓ_B and $\ell_A + \ell_B$. However, the fetch could not be $\ell_A + \ell_B$ because a portion of the snow originally on roof A was captured in the drift on roof B. The contribution of snow originally on roof B to the drift on roof C was then Equation 2-9.

$$A^L_{C/B} = 2\left(h^L_{C/B}\right)^2 \qquad \text{(EQ 2-9)}$$

Where: $h^L_{C/B} = 0.43\sqrt[3]{\ell_B}\,\sqrt[4]{p_g + 10} - 1.5$ (EQ 2-10)

$A^L_{C/B}$ = cross-sectional area of the leeward drift on roof C due to snow originally on roof B without considering the effects of sheltering afforded by roof A (ft^2)

Calculation of the contribution of snow on roof A to the drift on roof C was accomplished by modifying the increase in drift size that occurred when the fetch length increased from ℓ_B to $\ell_A + \ell_B$. This modification accounted for the amount of snow from roof A that became trapped in the drift on roof B, thereby requiring the modification factor to be related to the snow source area on roof A and the relative size of the drift on roof B. O'Rourke used Equation 2-4 to determine the percentage of snow in the upwind fetch area that became trapped in the leeward case history drifts. The percentage was calculated by comparing the cross-sectional area of the drifts to the cross-sectional area of the fetch snow area, which was the product of the fetch distance and the snow depth, determined by dividing the ground snow load by the snow density, as described in Equation 3-3. Percentages ranged from 20% to 40%, so the study used a conservative value of 25%. The contribution of snow originally on roof A to the drift on roof C was then described with Equation 2-11.

$$A^L_{C/A} = \left[A^L_{C/A+B} - A^L_{C/B}\right](1 - 0.25) \qquad \text{(EQ 2-11)}$$

Where: $A^L_{C/A+B} = 2\left(h^L_{C/A+B}\right)^2$ (EQ 2-12)

$h^L_{C/A+B} = 0.43\sqrt[3]{\ell_A + \ell_B}\,\sqrt[4]{p_g + 10} - 1.5$ (EQ 2-13)

$A^L_{C/A}$ = cross-sectional area of the leeward drift on roof C due to snow originally on roof A (ft^2)

The first term of Equation 2-11 is the increase in drift size when the fetch distance increased from ℓ_B to $\ell_A + \ell_B$. The second term in the equation is the modification factor intended to account for the drift at roof B capturing a portion of the snow originally from roof A. The total drift on roof C was then the sum of snow contributions from roof B and roof A, as described by Equation 2-9 and Equation 2-11.

O'Rourke used a similar approach applied to the fetch distance to determine the size of the leeward drift on roof C, as shown in Equation 2-14, where the effective fetch distance for the leeward drift on roof C is a portion of ℓ_A plus the entire length ℓ_B.

$$effective\ fetch = \beta_L \ell_A + \ell_B \qquad \text{(EQ 2-14)}$$

Where: β_L = modification factor for two leeward drifts in series

The leeward drift height on roof C can then be described as Equation 2-15.

$$h_C^L = 0.43\sqrt[3]{\beta_L \ell_A + \ell_B}\,\sqrt[4]{p_g + 10} - 1.5 \qquad \text{(EQ 2-15)}$$

O'Rourke developed a table of leeward drift modification factors with various combinations of ground snow load (p_g), roof length (ℓ_B), and ratio ℓ_A/ℓ_B. The ground snow load was tested for 10, 30, and 50 psf, the roof length ℓ_B was tested for 25 and 500 ft; and the ratio of the two roof lengths was tested for 5, 1, and 0.2. Values in the table ranged from 0.7 to 0.75, with the modification factor decreasing slightly when the ground snow load or roof length increased. This trend was expected because doubling the fetch distance or ground snow load for an unreduced leeward drift yielded a value less than doubling in the drift area, when using Equation 2-5 and taking the drift slope as 1:4.

For windward drifts created on roofs B and C when the wind blows from roof C towards roof A, a similar length reduction approach to that for leeward drifts was used to estimate the windward drift on roof B due to snow originally on roof B and C, as shown in Figure 2-5.

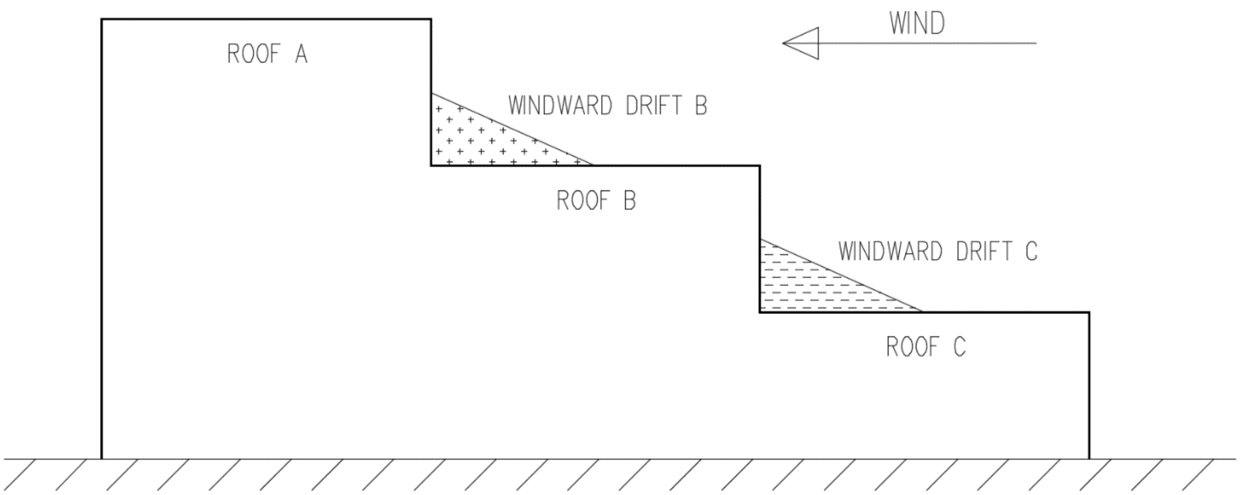

Figure 2-5 – Windward Drifts in Series

The main difference between a windward drift and a leeward drift is that the drift height is three-quarters the height of a leeward drift. Therefore, the contribution of snow originally on roof B to the windward drift on roof B was described by Equation 2-16.

$$h^W_{B/B} = 0.32\sqrt[3]{\ell_B}\,\sqrt[4]{p_g + 10} - 1.125 \qquad \text{(EQ 2-16)}$$

The area of this drift was then described by Equation 2-17, where the drift is considered not to be full, resulting in a slope of 1:4 similar to the leeward drifts.

$$A^W_{B/B} = 2\left(h^W_{B/B}\right)^2 \qquad \text{(EQ 2-17)}$$

The contribution of the snow on roof C to the windward drift in B was described as Equation 2-18, which is similar to Equation 2-11.

$$A^W_{B/C} = \left[A^W_{B/B+C} - A^W_{B/B}\right](1 - 0.14) \qquad \text{(EQ 2-18)}$$

Where: $A^W_{B/B+C} = 2\left(h^W_{B/B+C}\right)^2$ (EQ 2-19)

$$h^W_{B/B+C} = 0.32\sqrt[3]{\ell_B + \ell_C}\,\sqrt[4]{p_g + 10} - 1.125 \qquad \text{(EQ 2-20)}$$

$A^W{}_{B/C}$ = cross-sectional area of the windward drift on roof B due to snow originally on roof C (ft^2)

Instead of using 25% like in Equation 2-11, Equation 2-18 uses 14% because the windward drift height was three-quarters the height of a leeward drift, making the area of the windward drift 56%, or 0.75^2, of the leeward drift. Use of 0.56×0.25 yielded the value of 0.14 used in Equation 2-18. Equation 2-21, which was similar to Equation 2-15, was used to describe drift height of the windward drift on roof B in terms of an effective upwind fetch.

$$h_B^W = 0.32\sqrt[3]{\beta_W \ell_C + \ell_B}\,\sqrt[4]{p_g + 10} - 1.125 \qquad \text{(EQ 2-21)}$$

Results for the windward modification factor were tabulated in a table exactly similar to the table made for the leeward modification factor, where the windward modification factor ranged from 0.83 to 0.86. A slight decrease in the windward modification factor was observed when either the ground snow load or the roof length were increased, similar to the leeward modification factor. O'Rourke and Kuskowski (2005) summarize the results and recommend a leeward modification factor of approximately 0.75 and a windward modification factor of 0.85.

In FAQ #10 of O'Rourke's *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-10*, O'Rourke described a leeward roof step drift with a parapet at the step, as shown in Figure 3-1, as having drifts at roof steps in series. Using findings from O'Rourke & De Angelis (2005) and because the upwind drift is windward, O'Rourke used the windward modification factor, 0.85, to reduce the fetch of the upper roof. This was done because the upper roof was analogous to roof A in Figure 2-3 when the wind blew left to right. The two roofs are similar because the upper roof in Figure 3-1 had a roof step, the parapet, that separated the upper roof from the lower roof, or roof C in Figure 2-3. Since the windward and leeward drifts were adjacent to each other, as in Figure 3-4, O'Rourke considered the length between the two drifts, the length of roof B in Figure 2-3, as zero. Summing the length of the upper roof and the length between drifts resulted in the effective fetch length. The leeward drift height was then calculated using Equation 2-5, where ℓ_u was replaced with the effective fetch length. For FAQ #10, the leeward drift height was 3.75 ft when considering the effects of the parapet; the leeward drift height was 4.05 ft when ignoring the effects of the parapet, such as in a design office.

The method presented by O'Rourke in FAQ #10 is the only complete method known to the author of this thesis that addresses the expected size of the leeward roof step drift with a parapet. A less complete method is presented in FAQ #7, in which O'Rourke investigates mitigating the size of a leeward drift using a parapet at the roof step by considering that a designer may assume, unrealistically, that a parapet would capture all the snow blown towards it. A parapet capturing all of the snow blown towards it is unrealistic, however, since water flume tests have shown that reasonably sized parapets have less than 100% trapping efficiency. With the assumption that the parapet captures all of the snow blown towards it, a windward drift was calculated with an upwind fetch of 150 ft, a parapet wall height of 5 ft, a ground snow load of 25 psf, a snow density of 17.3 pcf, a clear height of 4 ft, and $C_e = C_t = I_S = 1.0$. Figure 2-6 illustrates these conditions.

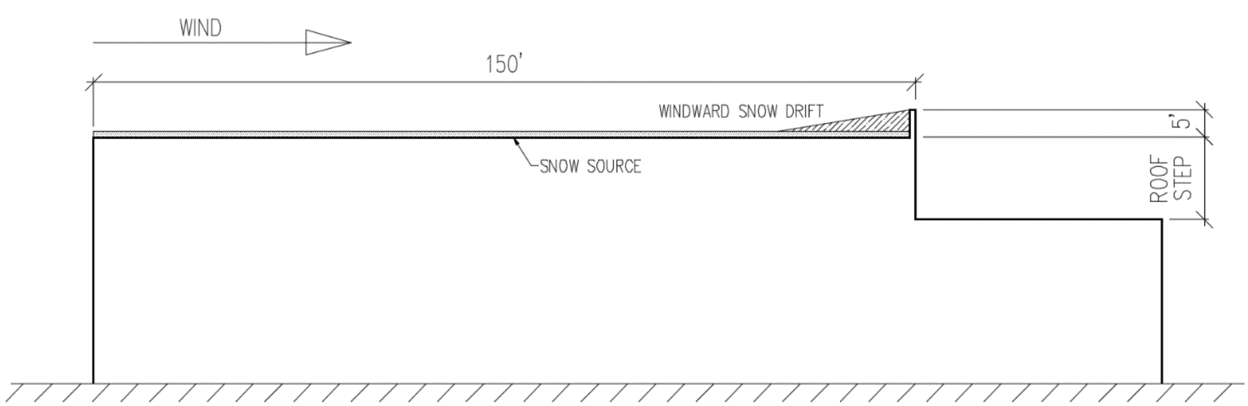

Figure 2-6 – Example Problem Setup

Snow density was calculated per ASCE 7-10, but the height and width of the windward drift were not calculated per ASCE 7-10. O'Rourke assumed the drift filled the entire clear height, 4 ft, and that the drift formed with a slope of 1:6. The drift was not calculated using ASCE 7-10 equations because the drift was considered to be full due to the assumption that the parapet wall trapped all blowing snow. Use of ASCE 7-10 equations would have resulted in a drift shorter than the clear height, 3 ft drift versus a 4 ft clear height, with a slope of 1:4, thereby failing to adhere to the assumption that the parapet captures all of the snow blown towards it. The drift calculated according to FAQ #7 and the drift calculated according to ASCE 7-10 are shown in Figure 2-7.

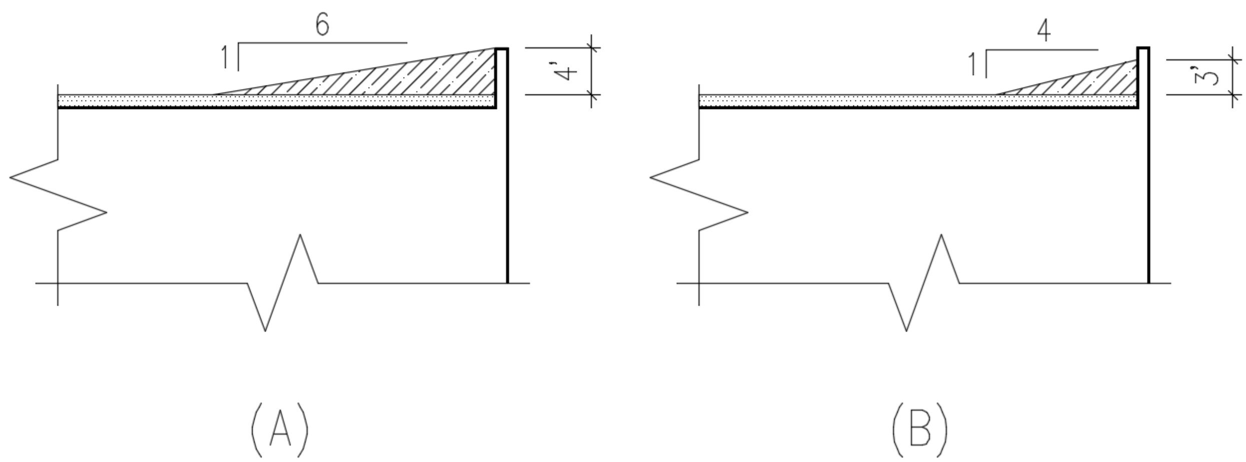

Figure 2-7 – Example Problem Results: (A) Windward Drift Determined using FAQ #7; (B) Windward Drift Determined using ASCE 7-10 Procedures

A slope of 1:6 was used because it is the aerodynamically streamlined slope observed in previous research of snow drifts on roofs (O'Rourke et al., 1985; Speck, 1984). The cross-sectional drift area was then compared to the cross-sectional area of the upwind snow source, which is described as the depth of the balanced snow times the upwind fetch, in order to determine the amount of upwind snow the parapet captured. According to O'Rourke's findings, approximately 32% of the source snow was captured, leaving 68% of the snow to potentially cause a leeward drift. Although O'Rourke's example does not continue, it influences the Direct

Reduction Method because the method uses the same way of determining the windward drift cross-sectional area as the example.

Chapter 3 - Parametric Study

A parametric study was performed to determine the reduction capabilities a parapet has on a leeward drift using the Fetch Modification Method, the Direct Reduction Method, and the Simplistic Reduction Method. The ASCE 7-10, Chapter 7, *Snow Loads*, was used as the referenced standard for current design equations and procedures relating to snow drifts. The three methods incorporated, in some form, the equations presented in ASCE 7-10 Chapter 7 with variations in order to achieve the reduced leeward drift. The ASCE 7-10 was used because the 2016 edition was not yet published at the time of this study.

Typical Scenario and Parameters

The typical scenario for this parametric study considered a significantly sized building with a change in roof elevation between a long, upper roof and a short, lower roof, as shown in Figure 3-1. The leeward drift from the upper roof without a parapet was considered to govern over a windward drift on the lower roof. A reduction of the leeward snow drift was desired and it was considered that a parapet was placed at the roof step or was already present.

The building in the scenario was similar to a typical big-box store with long, flat roofs that are kept warm and have parapets at the perimeter of the structure. A roof step was present on one side of the building and the lower roof has a relatively short roof in comparison to the main building. Both the upper and lower roofs had an exposure factor, C_e, and thermal factor, C_t, equal to 1.0. The building had no single specific geographical location, but it was considered to be in an area within the United States in which the ground snow load, p_g, is between 20 psf and 50 psf. The snow importance factor, I_s, was equal to 1.0 because the building was classified as a risk category II structure.

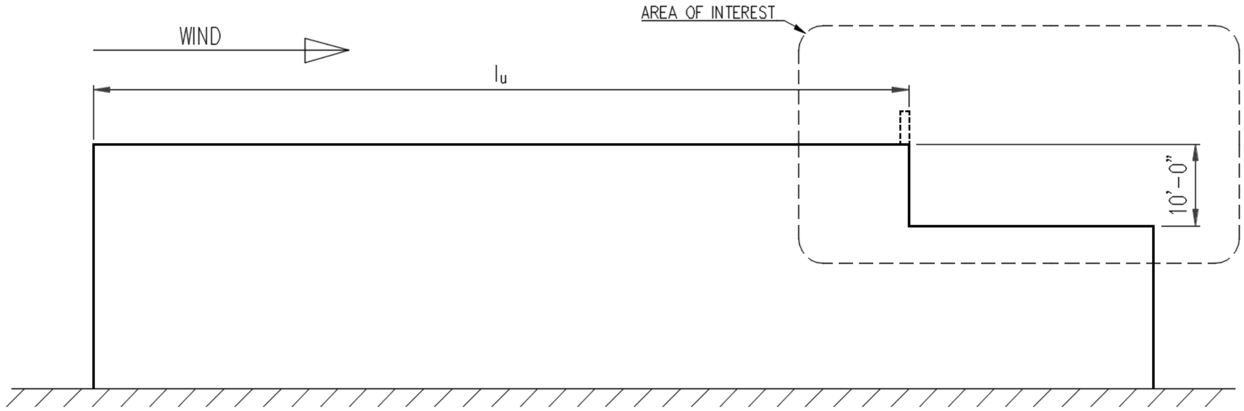

Figure 3-1: Typical Building Section

Windward and leeward drifts were examined with three changing parameters: ground snow load (p_g), upwind fetch (l_u), and parapet height. Ground snow load was tested for values ranging between 20 psf and 50 psf in increments of 5 psf. The lower bound of the ground snow load was within the range of ground snow loads recorded in the original database of 347 case studies, generally 25 psf and lower. Any ground snow loads lower than that range raised the question of how long snow would stay on the roof after a snow event and whether or not a significant drift would develop to need some form of drift reduction measures. The upper bound for ground snow load chosen incorporated a large portion of the contiguous United States and provided large amounts of snow for drifting. The upwind fetch, l_u, on the windward drift was considered to be between 100 ft and 300 ft with 50 ft increments. A length of 100 ft represented a sizable roof, while the upper limit of 300 ft was imposed because the database of case studies examined in (O'Rourke et al., 1985) had fetch distances less than 350 ft. The two parapet heights examined were the minimum parapet height according to Section 705.11.1 of the 2012 IBC, 30 in., and a parapet height of 48 in., in order to exceed the current minimum height of 42 in. for fall protection according to OSHA standard number 1926.502.

The height of the roof step and the length of the lower roof were held constant during the analysis. The roof step height was taken as 10 ft to allow for large leeward drift accumulation and to create a large enough difference in height in which neither leeward nor windward drifts would have drift heights as tall as the roof step, meaning that either drift was already at its peak height and could not take advantage of the presence of a parapet to grow taller. The length of the lower roof was not specifically defined and not needed in the calculations because it was considered to be at least as long as the leeward drift accumulating on it but short enough to cause the accumulating windward drift to be smaller than the leeward drift. The lower roof length was defined as such because investigation of whether or not the leeward drift could be reduced would be unnecessary if the design engineer determined that a windward drift was governing on a particular roof step. Windward drifts should not govern for the minimum length of the lower roof because the lower roof would have an exceptionally short fetch distance compared to the distance used for leeward drifts and because windward drift height is multiplied by a factor of 0.75 when it is determined. No investigation was made regarding how long the lower roof must be in order to cause a governing windward drift; the design engineer must check the windward drift condition.

General Calculations

The three methods used to determine drift reduction shared a general set of calculations that followed procedures set forth in the ASCE 7-10. Shared calculations included the flat snow load on upper and lower roofs, leeward drift without a parapet, the windward drift on the parapet, and each drift's respective cross-sectional area. These calculations provided a baseline value of the leeward drift with which each reduction method could be compared, as well as measurements needed by each reduction method to perform the reduction calculation.

The flat roof snow load from ASCE 7-10 Section 7.3 was calculated using Equation 3-1.

$$p_f = 0.7C_e C_t I_s p_g \qquad \text{(EQ 3-1)}$$

Where: p_f = snow load on flat roofs (psf)

C_e = exposure factor, from ASCE 7-10 Table 7-2

C_t = thermal factor, from ASCE 7-10 Table 7-3

I_s = snow importance factor, from ASCE 7-10 Table 1.5-2

p_g = ground snow load, from ASCE 7-10 Fig. 7-1 and Table 7-1 or site-specific analysis (psf)

For the scenario in this study, the exposure, thermal, and snow importance factor were all considered to be equal to unity, and the ground snow load ranged from 20 psf to 50 psf in increments of 5 psf. The minimum snow load check of ASCE 7-10 Section 7.3.4 was performed and shown in the calculations for completeness, but it did not affect the drift calculations since the minimum snow load need not be used when determining or in combination with drift loads.

The unreduced leeward drift was determined using the procedure in ASCE 7-10 Section 7.7.1 and neglecting the presence of the windward parapet, as shown in Figure 3-2. The drift height equation can be found in ASCE 7-10 Figure 7-9, as shown here as Equation 3-2.

$$h_d = 0.43\sqrt[3]{\ell_u}\,\sqrt[4]{p_g + 10} - 1.5 \qquad \text{(EQ 3-2)}$$

Where: h_d = height of snow drift (ft)

l_u = length of the roof upwind of the drift (ft)

p_g = ground snow load (psf)

The upwind length or fetch, l_u, was the full length of the upper roof, and the clear height, h_c, and the drift width, w, were results of the conditions and dimensional limitations defined in Section 7.7.1.

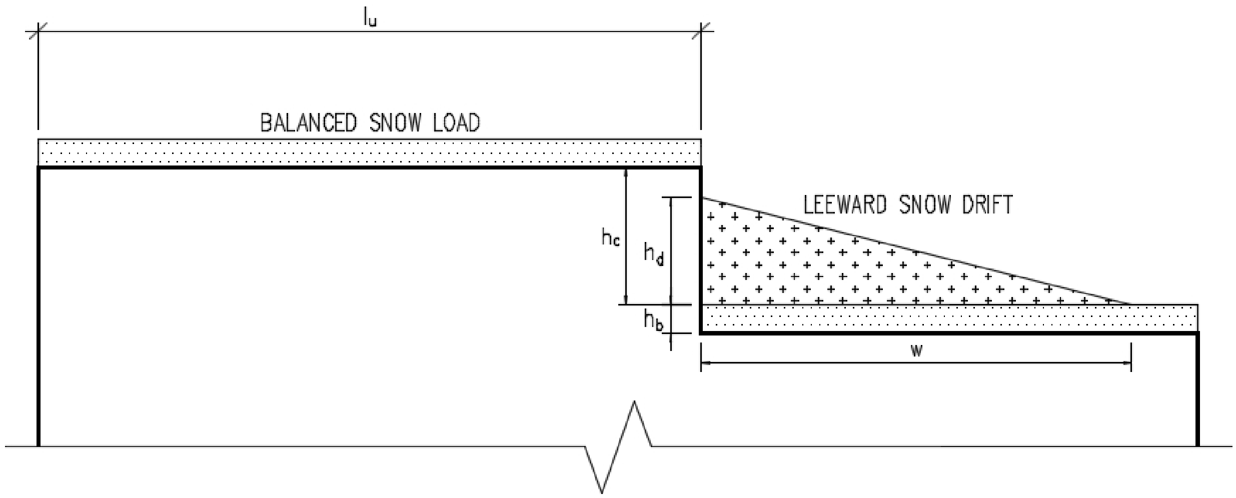

Figure 3-2: Leeward Snow Drift

The general calculations determined the height of the balanced snow load, h_b, by dividing the flat roof snow load, p_f, by the snow density, γ, given by Equation 3-3.

$$\gamma = 0.13p_g + 14 \text{ but not more than 30 pcf} \qquad \text{(EQ 3-3)}$$

Where: γ = snow density (pcf)

p_g = ground snow load (psf)

The height of the balanced snow load is defined by Chapter 7.7 of the ASCE 7-10 as the balanced sloped roof snow load, p_s, divided by the snow density, where the balanced sloped roof snow load is given by Equation 3-4.

$$p_s = C_s p_f \qquad \text{(EQ 3-4)}$$

Where: p_s = sloped roof (balanced) snow load (psf)

C_s = slope factor, from ASCE 7-10 Figure 7-2

p_f = snow load on flat roofs (psf)

The slope factor was considered to be equal to unity in the typical scenario because the roof was considered to be flat, or having a slope less than or equal to 5° as defined in the ASCE 7-10. With the slope factor equal to unity, p_f was equal to p_s, allowing direct calculation of the balanced snow height from the flat roof snow load.

The windward drift onto the parapet was calculated similarly to the leeward drift according to the procedure defined in ASCE 7-10 Section 7.7.1. The only difference in calculations was that the drift height was multiplied by a factor of 0.75. The windward drift is shown in Figure 3-3. All calculation sets contained a general calculation section in which the windward drift height was calculated per ASCE7-10. The Direct Reduction Method, however, uses a different method for determining the windward drift height than the ASCE 7-10. That unique method is explained in the method's respective section.

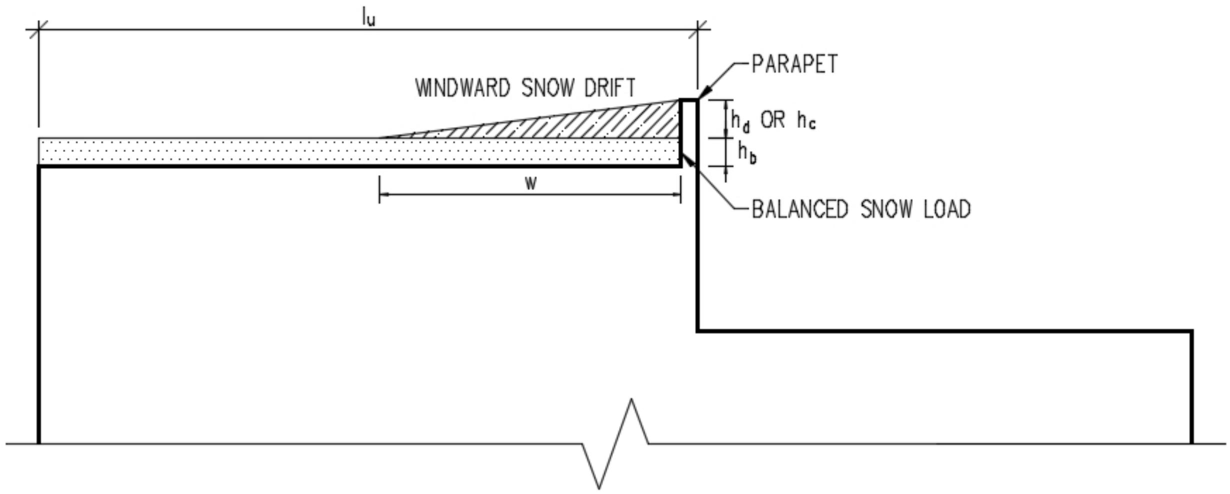

Figure 3-3: Windward Snow Drift

Fetch Modification Method

The Fetch Modification Method to reduce leeward drift was used by Michael O'Rourke in FAQ #10 of *Snow Loads: Guide to the Snow Load Provisions of ASCE 7-10*. O'Rourke's method was based on research done in (O'Rourke & Kuskowski, 2005), where a fetch modification factor, β, is applied to upwind fetch distances of the leeward or windward drift in order to reduce the size of the respective drift. Specifics of the research were discussed in Chapter 2. The Fetch Modification Method was used to determine the reduced leeward drift height because it has a rational basis from previous work and it provides a relatively conservative reduction.

Determination of leeward drift size using the Fetch Modification Method is identical to the general calculations with the exception that an effective fetch distance is used instead of the full upwind fetch distance. Using O'Rourke's and Kuskowski's research and the fact that the upwind drift is a windward drift, the effective fetch distance can be described by Equation 3-5.

$$\ell_{eff} = \beta_W \ell_u + \ell_{Between} \qquad \text{(EQ 3-5)}$$

Where: ℓ_{eff} = effective fetch distance (ft)

ℓ_u = length of the roof upwind of the drift, from Figure 3-3 (ft)

$\ell_{Between}$ = fetch distance between drifts (ft)

β_W = windward fetch modification factor, from (O'Rourke & Kuskowski, 2005)

Because the windward and leeward drifts were adjacent to each other, the fetch distance between them was zero and the effective length became the windward upwind fetch multiplied by the windward modification factor, 0.85, from (O'Rourke & Kuskowski, 2005). The reduced height of the leeward drift was calculated by substituting Equation 3-5 into Equation 3-2, yielding

Equation 3-6, which describes the reduced drift height of the leeward drift calculated via the Fetch Modification Method, as shown in Figure 3-4.

$$h_d = 0.43\sqrt[3]{\ell_{eff}}\,\sqrt[4]{p_g + 10} - 1.5 \qquad \text{(EQ 3-6)}$$

Where: h_d = reduced height of leeward snow drift (ft)

ℓ_{eff} = effective fetch distance (ft)

p_g = ground snow load (psf)

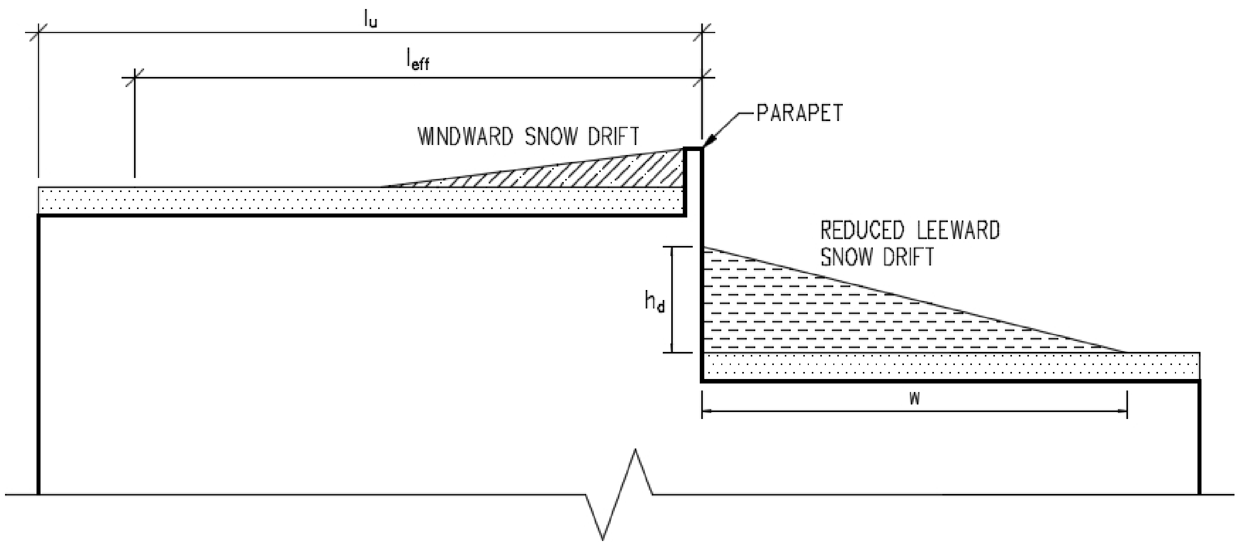

Figure 3-4: Reduced Leeward Drift by the Fetch Modification Method

Direct Reduction Method

The Direct Reduction Method is similar to the Fetch Modification Method in that it uses an effective fetch distance to calculate reduced leeward drift height. However, the Direct Modification Method directly determines the new fetch length instead of using a fetch modification factor. Direct calculation of the effective fetch length was done by idealizing the windward drift at the parapet as a full drift with a 1:6 slope at all times, removing the triangular cross-sectional area of the drift from the cross-sectional area of the upwind snow, and then calculating the new length of the fetch, as shown in Figure 3-5.

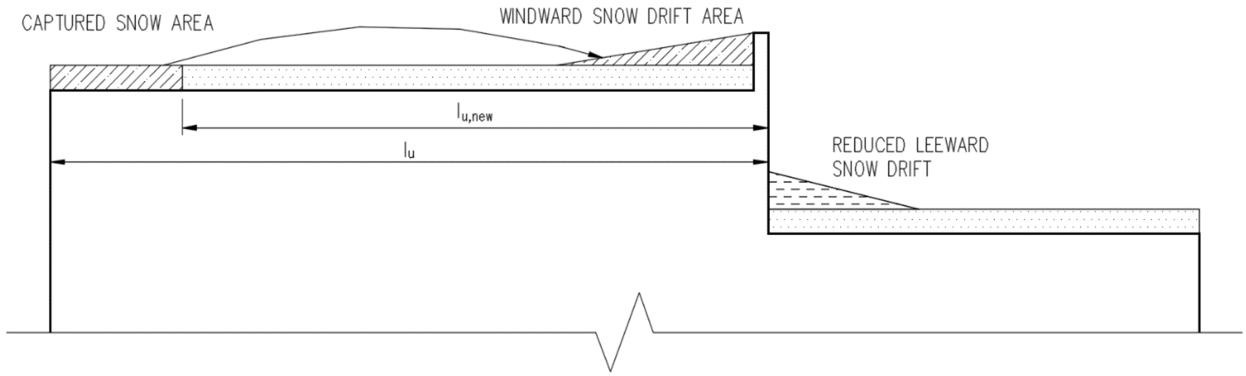

Figure 3-5: Determination of $\ell_{u,new}$

The way the leeward drift reduction was calculated is a key distinction between the Fetch Modification Method and Direct Reduction Method because the Fetch Modification Method was based on equations from (O'Rourke & Kuskowski, 2005), where all drifts have a 1:4 slope, meaning that the drifts have yet to become full and the drift heights are unconstrained. The Direct Modification Method, however, considers that the windward drift height may be constrained and that the drift has become full, yielding the shallower slope of 1:6. The windward drift was been constrained to a slope of 1:6 because that slope was used by O'Rourke in FAQ #8 of (O'Rourke, 2010) to reasonably determine the largest area of snow a windward parapet could capture assuming, unrealistically, that the parapet would capture all the snow blown towards it. The slope of the full drift in this parametric study and in FAQ #8 was 1:6 due to the nature of full drifts observed during the analysis of 347 case histories that were "consistent with those of Finney [Finney, 1939] and Tabler [Tabler, 1975], who studied the process of drifting using wind tunnels and topographical catchments, respectively" (O'Rourke et al., 1985, p. 298). More recently, (Tabler, 1994) also found full drifts to assume a 1:6 slope in relation to snow drifting onto road surfaces.

The procedure for determining the new fetch distance stemmed from the comparison of areas of the captured snow to total upwind snow in FAQ #8, in which the percentage of captured snow to total upwind snow is defined as the amount of snow the parapet prevented from contributing to the leeward drift; the remaining snow then contributed to the leeward drift. The Direct Modification Method in this study similarly involved subtracting the captured snow area from the upwind snow area, leaving the remaining snow to contribute to the leeward drift. The captured snow area at the parapet was a triangular area described by Equation 3-7.

$$A_W = \frac{1}{2}(h_c)(6h_c) \qquad \text{(EQ 3-7)}$$

Where: A_W = cross-sectional area of windward drift (sf)

h_c = clear height from the top of the balanced snow load to the top of the parapet (ft)

When the area obtained from Equation 3-7 was subtracted from the upwind snow area, or the balanced snow depth multiplied by the upwind fetch distance, the upwind fetch area was reduced. The new upwind fetch distance, $\ell_{u,new}$ in Figure 3-5, was the reduced upwind fetch area divided by the balanced snow load. With the new, or effective, fetch distance, the reduced height of the leeward drift was calculated using Equation 3-6.

Simplistic Reduction Method

The Simplistic Reduction Method differs from the Fetch Modification Method and Direct Reduction Method because it does not reduce the upwind area in order to calculate the reduced leeward drift height based on an effective upwind fetch. Instead, the Simplistic Reduction Method subtracts the cross-sectional area of the windward drift from the cross-sectional area of the leeward drift and then determines the drift geometry. For example, when considering a structure like the structure in Figure 3-1 without a parapet, the snow that ends up in the leeward drift was from the upper snow source area. This drifted snow was transported via three methods: creep, saltation, and suspension. A physical study by Kobayashi (1972) determined that the primary method of snow transportation was saltation, or “the movement of snow particles by a ‘skipping’ or ‘jumping’ action along the snow surface” (Pomeroy & Brun, 2001), occurring at approximately 0.01–0.1 m (0.4–4 in.) (Tominaga et al., 2011). Kobayashi’s findings were based on wind speeds less than 10 m/s (~22 mph) at the 1 m (~3.3 ft) level. Typical winds at roof elevations, however, are more accurately described by wind measurements taken at the 10 m level (~33 ft). Despite the difference in height for measuring wind speeds, 1 m versus 10 m, the assumption was made that saltation is the dominant mode of transportation of snow along the roof surface. Snow moved by creeping, rolling, or sliding along the surface occurred below ~0.01 m and was considered with saltation as in previous studies (Tominaga et al., 2011). Suspended snow constituted the remaining transported snow. As snow was transported via creep, saltation, and suspension, some snow eventually became trapped in the leeward roof step, constituting the leeward drift.

When considering the same roof with a parapet at the roof step, a parapet of either 30 in. or 48 in. was taller than the height of snow transported by saltation and creep. Therefore, the parapet trapped some of the snow transported by saltation and creep until the windward drift, formed by the trapped snow, grew tall enough to allow snow to pass the parapet. The remaining snow passing the parapet by all three methods of transport constituted the leeward drift. All snow trapped by the parapet, then, was assumed to have originally been a part of the leeward drift if the parapet had not been present. With this assumption, the cross-sectional area of the windward drift when the parapet was present was subtracted from the cross-sectional area of the leeward drift when the parapet was not present, therefore calculating the cross-sectional area of the reduced leeward drift when the parapet was present.

Calculation of the reduced leeward drift height using the Simplistic Reduction Method is straightforward. First, the leeward and windward parapet drift heights were calculated using Equation 2-5, with the 0.75 factor applied to the windward drift. The windward drift area was then subtracted from the leeward drift area in order to determine the reduced leeward drift area, $A_{Reduced\ Drift}$. The reduced leeward drift area was then used in Equation 3-8 with the unreduced leeward drift height, $h_{d\ no\ parapet}$, and width, $w_{no\ parapet}$, to determine the dimension reduction factor, x.

$$A_{Reduced\ Drift} = \frac{1}{2}(x)(h_{d\ no\ parapet})(w_{no\ parapet}) \qquad \text{(EQ 3-8)}$$

Where: $A_{Redcued\ Drift}$ = cross-sectional area of the reduced leeward drift (sf)

$h_{d\ no\ parapet}$ = unreduced leeward drift height (ft)

$w_{no\ parapet}$ = unreduced leeward drift length (ft)

x = dimension reduction factor

The square root of the dimension reduction factor, $\sqrt{x}$, was then used in Equation 3-9 and 3-10 to determine the reduced leeward drift height, $h_{d\ reduced}$, and reduced leeward drift length, $w_{reduced}$. The dimension reduction factor was used to preserve the slope of the unreduced leeward drift while still reducing the dimensions of the unreduced leeward drift that produce the appropriate reduced drift triangular area, $A_{Reduced\ Drift}$.

$$h_{d\ reduced} = \sqrt{x}(h_{d\ no\ parapet}) \qquad \text{(EQ 3-9)}$$

$$w_{reduced} = \sqrt{x}(w_{no\ parapet}) \qquad \text{(EQ 3-10)}$$

Where: $h_{d\ reduced}$ = reduced leeward drift height (ft)

$w_{reduced}$ = reduced leeward drift length (ft)

Chapter 4 - Parametric Study Results

Calculations, in the form of Microsoft Excel tables, for the parametric study are located in Appendix A, while graphical results are presented in this chapter. The set of calculations and results apply to a 30 in. parapet with a fetch distance of 100 ft. Tables of calculations are labeled in this chapter for explanation purposes; they are not labeled in Appendix A. Observations are made for the result graphs in the example set, and overall observations are discussed in Chapter 5.

Calculations and Results: 30 in. Parapet, 100 ft Fetch

Table 4-1 – General Flat Roof Snow Load Calculations

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Table 4-1 shows input parameters of ground snow load (p_g), exposure factor (C_e), thermal factor (C_t), and importance factor (I_s). The density (γ), minimum snow load (p_m), flat snow load (p_f), and flat snow load with rain on snow load surcharge ($p_{f(rain)}$) are calculated in Table 4-1.

Table 4-2 – General Windward Drift Calculations per ASCE 7-10

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
2.5	1.66	0.84	1.96	YES	100	1.66	2.38	13.25	OKAY	27.5
2.5	1.49	1.01	1.46	YES	100	1.49	2.52	11.88	OKAY	25.6
2.5	1.33	1.17	1.13	YES	100	1.33	2.64	10.61	OKAY	23.8
2.5	1.18	1.32	0.89	YES	100	1.18	2.75	9.43	OKAY	21.9
2.5	1.04	1.46	0.71	YES	100	1.04	2.86	8.33	OKAY	20.0
2.5	0.91	1.59	0.58	YES	100	0.91	2.95	7.30	OKAY	18.1
2.5	0.79	1.71	0.46	YES	100	0.79	3.04	6.34	OKAY	16.3

Table 4-2 calculates drift height at the parapet using the procedure set forth by the ASCE 7-10. Drift parameters in this table are referenced by other tables when a specific reduction method needs information regarding the windward drift.

Table 4-3 – General Leeward Drift Calculations

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	3.17	3.17	12.68	OKAY	52.6
10.0	9.0	3.35	3.35	13.42	OKAY	57.9
10.0	8.8	3.52	3.52	14.08	OKAY	63.0
10.0	8.7	3.67	3.67	14.68	OKAY	68.1
10.0	8.5	3.81	3.81	15.23	OKAY	73.1
10.0	8.4	3.94	3.94	15.74	OKAY	78.1
10.0	8.3	4.05	4.05	16.22	OKAY	83.1

Table 4-3 calculates the leeward drift that would occur at the roof step if no parapet was present. This table uses ASCE 7-10 procedures to determine leeward drift parameters.

Table 4-4 – Calculations for the Fetch Modification Method

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	85.0	2.92	2.92	11.70	OKAY	48.6	92.2	0.25	4.1
0.85	85.0	3.10	3.10	12.39	OKAY	53.5	92.4	0.26	4.4
0.85	85.0	3.25	3.25	13.02	OKAY	58.3	92.5	0.26	4.7
0.85	85.0	3.40	3.40	13.59	OKAY	63.0	92.6	0.27	5.1
0.85	85.0	3.53	3.53	14.11	OKAY	67.7	92.6	0.28	5.4
0.85	85.0	3.65	3.65	14.59	OKAY	72.4	92.7	0.29	5.7
0.85	85.0	3.76	3.76	15.05	OKAY	77.1	92.8	0.29	6.0

Table 4-4 is the calculation table for the Fetch Modification Method developed by O'Rourke and Kuskowski (2005). This table calculates leeward drift height using an upwind fetch that was multiplied by the modification factor. Drift height reduction and drift load reduction were also calculated.

Table 4-5 – Calculations for the Direct Reduction Method

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
90.2	9.2	3.01	3.01	12.06	OKAY	50.0	95.0	0.90	0.16	2.6
93.5	9.0	3.25	3.25	12.99	OKAY	56.0	96.8	0.93	0.11	1.9
95.5	8.8	3.44	3.44	13.77	OKAY	61.6	97.8	0.95	0.08	1.4
96.8	8.7	3.61	3.61	14.46	OKAY	67.0	98.5	0.97	0.06	1.0
97.8	8.5	3.77	3.77	15.07	OKAY	72.3	99.0	0.98	0.04	0.8
98.4	8.4	3.91	3.91	15.63	OKAY	77.5	99.3	0.98	0.03	0.6
98.9	8.3	4.03	4.03	16.14	OKAY	82.7	99.5	0.99	0.02	0.4

Table 4-5, which is the calculation table for the Direct Reduction Method, uses an effective upwind fetch, $\ell_{u,new}$, to determine leeward drift height. Drift height reduction and drift load reduction were also calculated.

Table 4-6 – Calculations for the Simplistic Reduction Method

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.0	20.1	3.17	12.68	9.13	0.4542	2.14	8.55	67.39	35.47	1.03	17.2
8.8	22.5	3.35	13.42	13.68	0.6078	2.62	10.46	77.96	45.11	0.74	12.8
7.0	24.8	3.52	14.08	17.73	0.7157	2.98	11.91	84.60	53.30	0.54	9.7
5.6	26.9	3.67	14.68	21.37	0.7934	3.27	13.07	89.08	60.63	0.40	7.4
4.3	29.0	3.81	15.23	24.65	0.8503	3.51	14.04	92.21	67.41	0.30	5.7
3.3	31.0	3.94	15.74	27.64	0.8923	3.72	14.87	94.46	73.79	0.22	4.3
2.5	32.9	4.05	16.22	30.37	0.9236	3.90	15.59	96.10	79.88	0.16	3.2

Table 4-6, which is the calculation table for the Simplistic Reduction Method, subtracts the cross-sectional area of snow captured at the parapet directly from the cross-sectional area of snow of the leeward drift. Geometry of the leeward drift was then determined, and drift height reduction and drift load reduction were also calculated.

Table 4-7 – Drift Cross-Sectional Area Calculations

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.0	11.0	8.2	20.1	84.3
8.8	8.8	6.6	22.5	101.4
7.0	7.0	5.3	24.8	117.3
5.6	5.6	4.2	26.9	132.1
4.3	4.3	3.3	29.0	145.8
3.3	3.3	2.5	31.0	158.7
2.5	2.5	1.9	32.9	170.7

Table 4-7 calculates the cross-sectional areas for the windward drift per ASCE 7, the windward drift used by the Fetch Modification Method, the windward drift used by the Direct Reduction Method, the leeward drift without considering a parapet, and the upwind snow source area based on the full length of the upwind fetch distance.

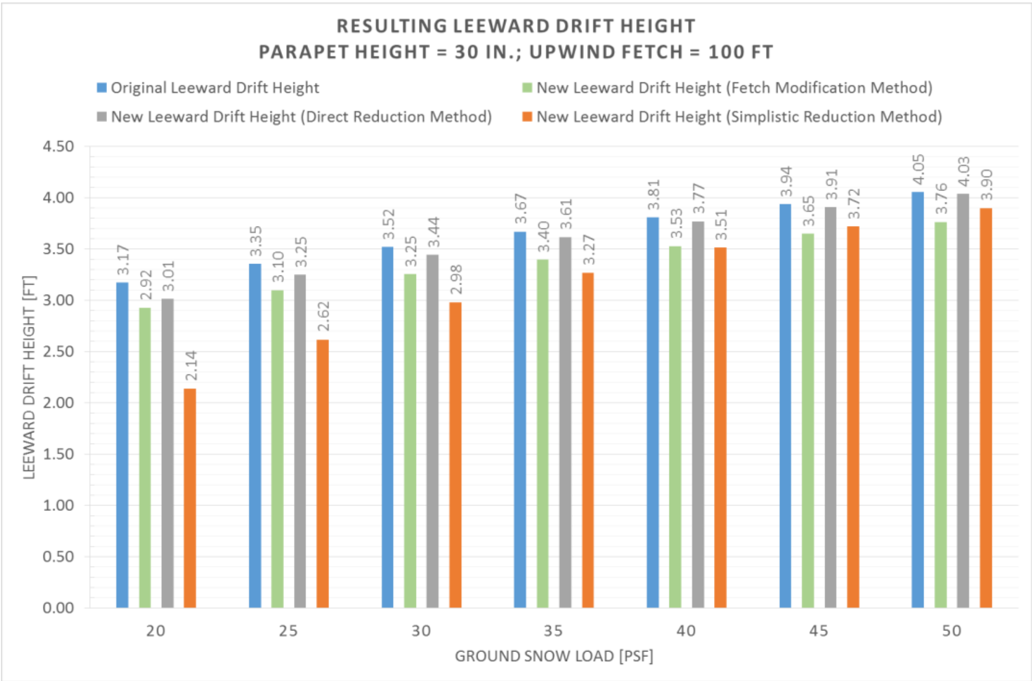

Figure 4-1 – Resulting Leeward Drift Height: 30 in. Parapet, 100 ft Fetch

Figure 4-1 compares leeward drift height calculated using the ASCE 7 while ignoring the parapet with resulting leeward drift heights calculated by the Fetch Modification Method, Direct Reduction Method, and Simplistic Reduction Method for a 30 in. parapet with an upwind fetch of 100 ft. As ground snow load increased, the unreduced leeward drift and the reduced leeward drifts also increased in height for each reduction method. As shown in Figure 4-1, the Simplistic Reduction Method results in the greatest drift height reductions, especially at lower ground snow loads. The Fetch Modification Method provided small reductions, and the Direct Reduction Method provided the least reduction.

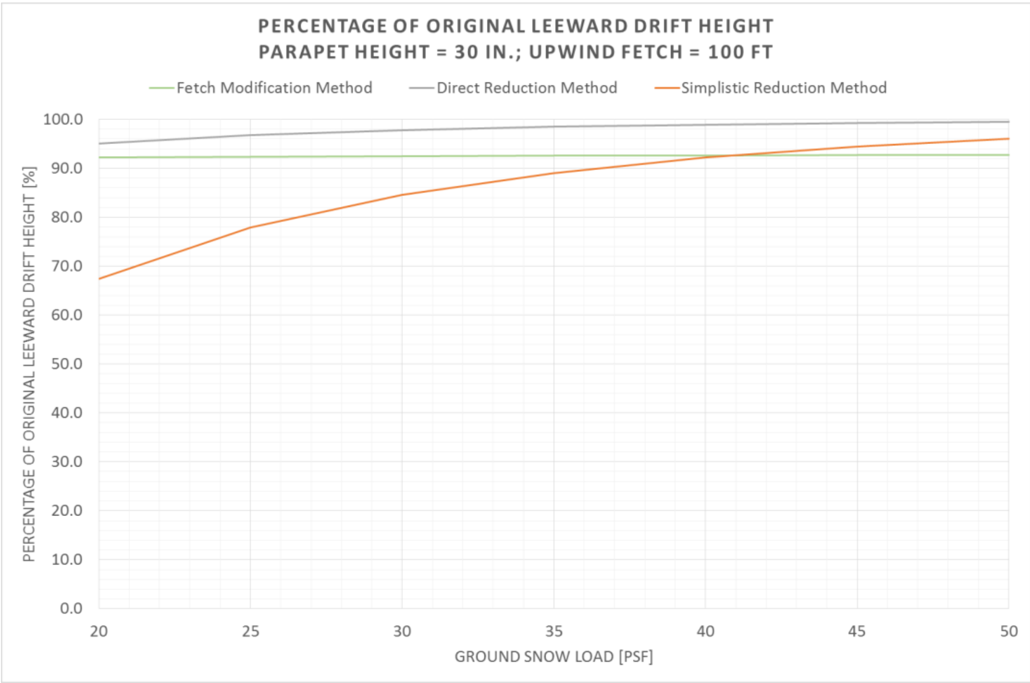

Figure 4-2 – Percentage of Original Leeward Drift Height: 30 in. Parapet, 100 ft Fetch

Figure 4-2 graphs what percentage of the unreduced leeward drift height the reduced leeward drift height was for each method. This graph can be interpreted as showing how much a particular method reduced the original leeward drift, as a percentage of the original drift height. For example, with a ground snow load of 20 psf, the Fetch Modification Method yielded a reduced leeward drift height that was approximately 92% of the unreduced leeward drift height, meaning that the Fetch Modification Method yielded an approximate 18% drift height reduction. Graphing the reduced leeward drift height as a percentage of the unreduced leeward drift height is useful because the values can be compared across all scenarios, demonstrating how each reduction method performs as parameters change. A comparison of the magnitude of reduction, found in Figure 4-3, between scenarios is less informative than the percentage of reduction because it is unknown how much of the unreduced leeward drift the amount of reduction was. Figure 4-2 shows trends similar to trends in Figure 4-1. One similar trend is that the Simplistic Reduction Method provided generally greater reductions than the Fetch Modification Method or the Direct Reduction Method. Another repeating trend is that the Direct Reduction Method resulted in minimal leeward drift reduction. In addition, the Direct Reduction Method produced reduced leeward drifts between 95% and 99.5% the height of the unreduced leeward drift, as compared to 92.2%-92.8% from the Fetch Modification Method and 67.4%-96.1% for the Simplistic Reduction Method.

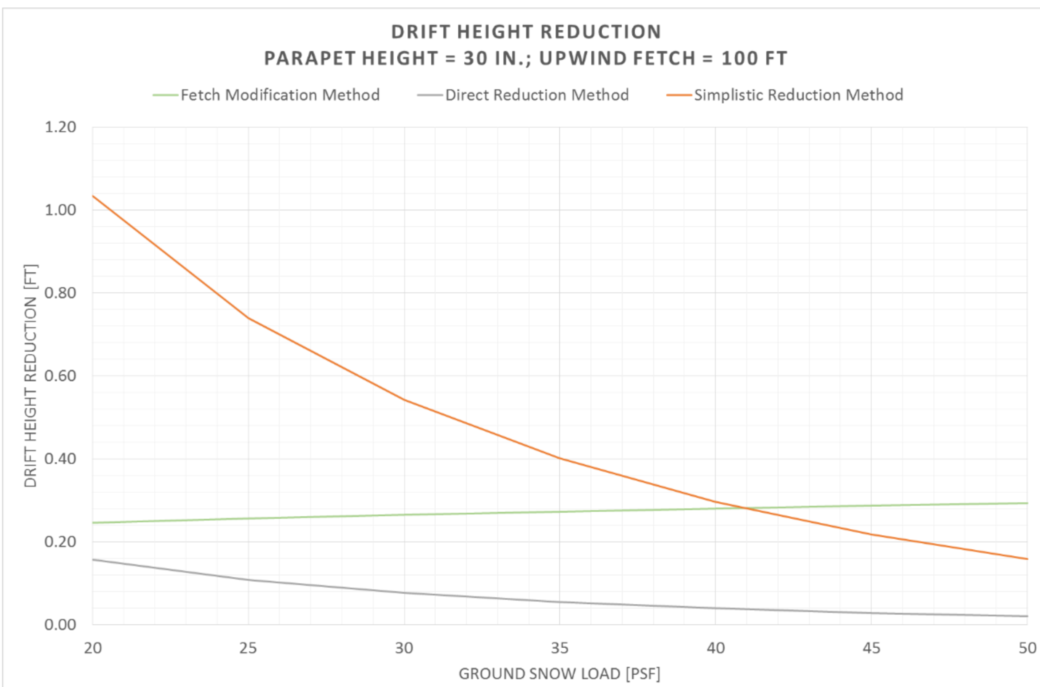

Figure 4-3 – Drift Height Reduction: 30 in. Parapet, 100 ft Fetch

Figure 4-3 shows the amount of leeward drift height reduction as the ground snow load increased for each reduction method, overall demonstrating the trends of reduction amounts of the leeward drift from each reduction method. According to Figure 4-3, as the Direct Reduction Method and the Simplistic Reduction Method decreased reduction of the leeward drift, the Fetch Modification Method increased leeward drift reduction. As the ground snow load increased in Figure 4-2, the percentage of unreduced leeward drift became greater, or the percentage reduction of the leeward drift became lesser, for all three methods.

Parametric Study Results

Below are the results of the parametric study in graphical form.

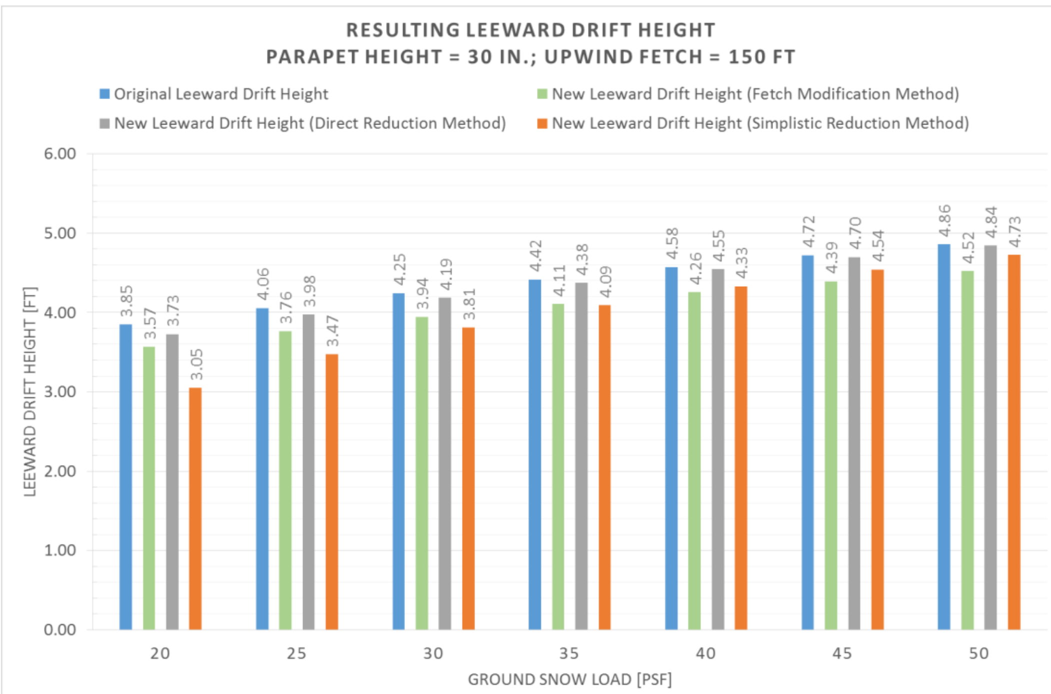

Figure 4-4 – Resulting Leeward Drift Height: 30 in. Parapet, 150 ft Fetch

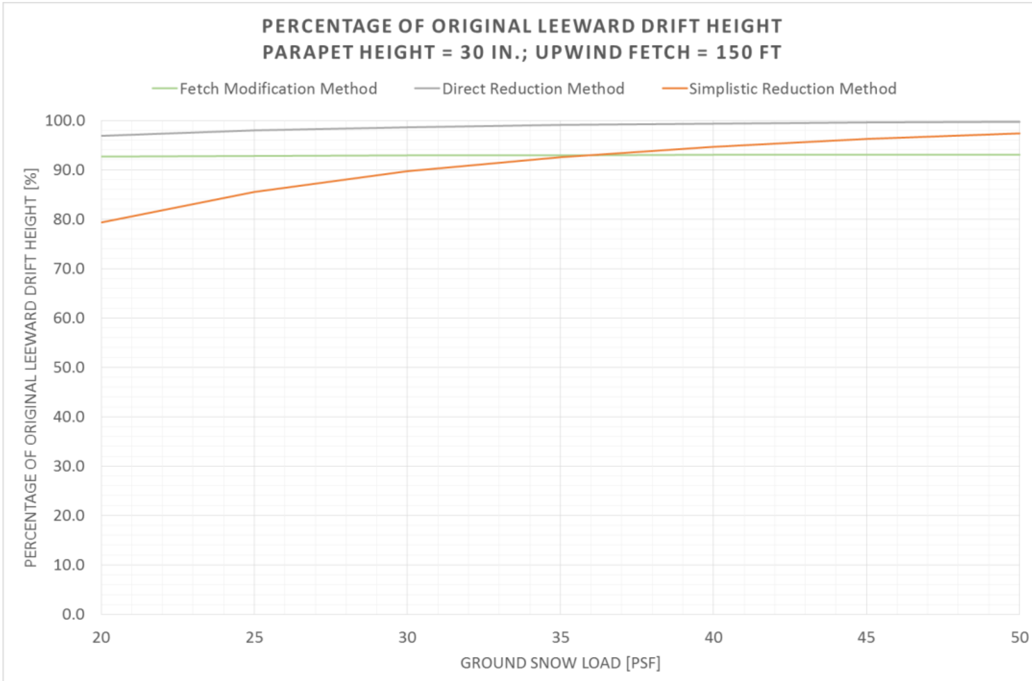

Figure 4-5 – Percentage of Original Leeward Drift Height: 30 in. Parapet, 150 ft Fetch

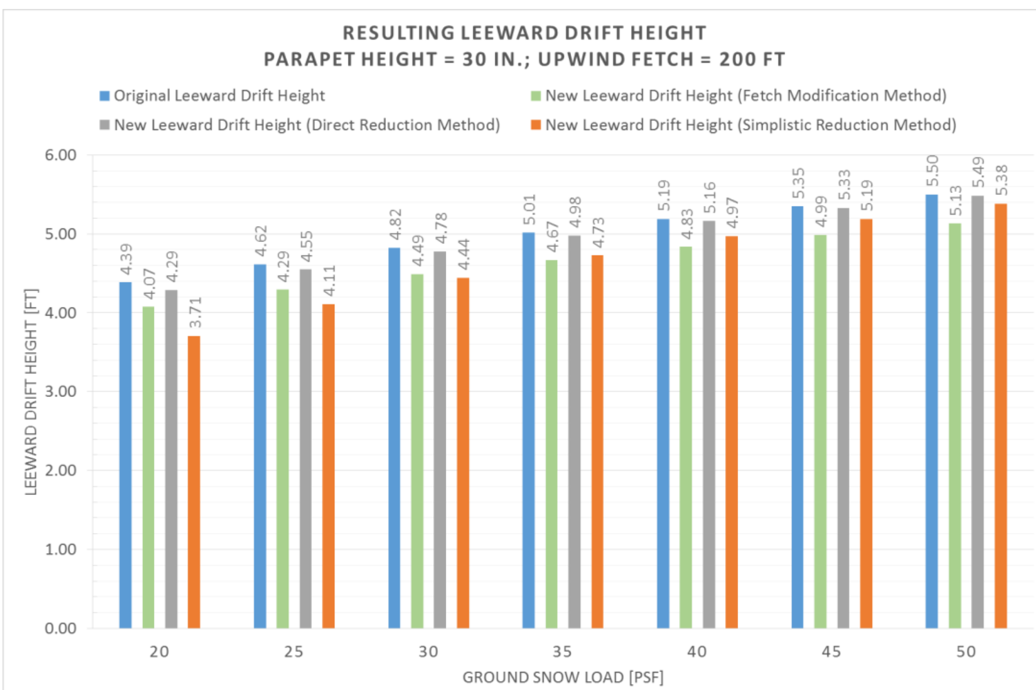

Figure 4-6 – Resulting Leeward Drift Height: 30 in. Parapet, 200 ft Fetch

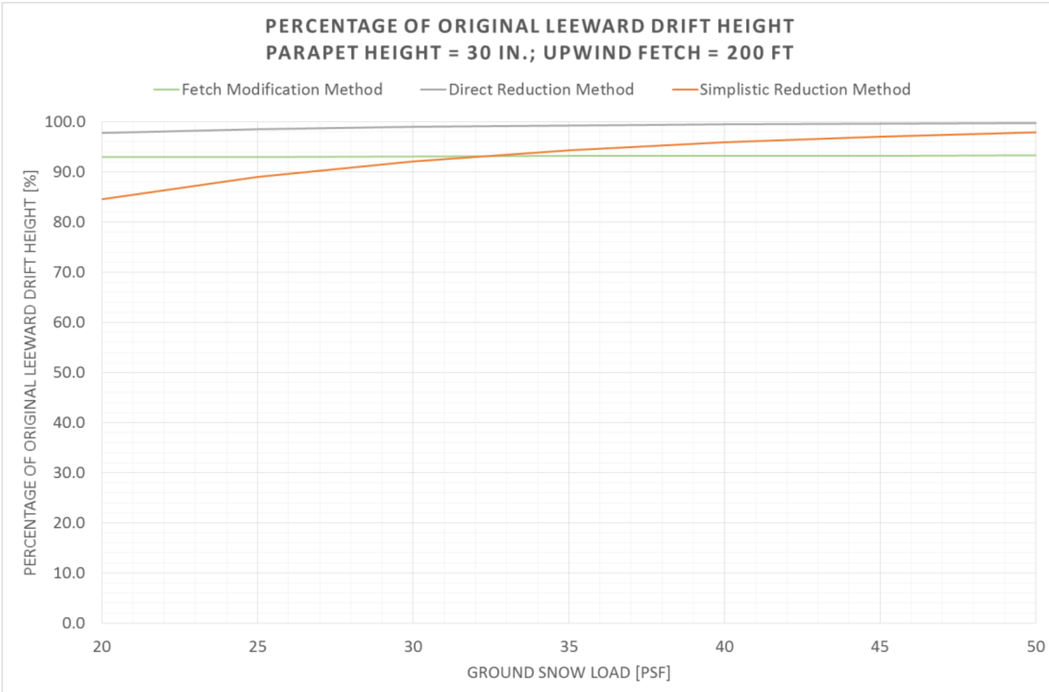

Figure 4-7 – Percentage of Original Leeward Drift Height: 30 in. Parapet, 200 ft Fetch

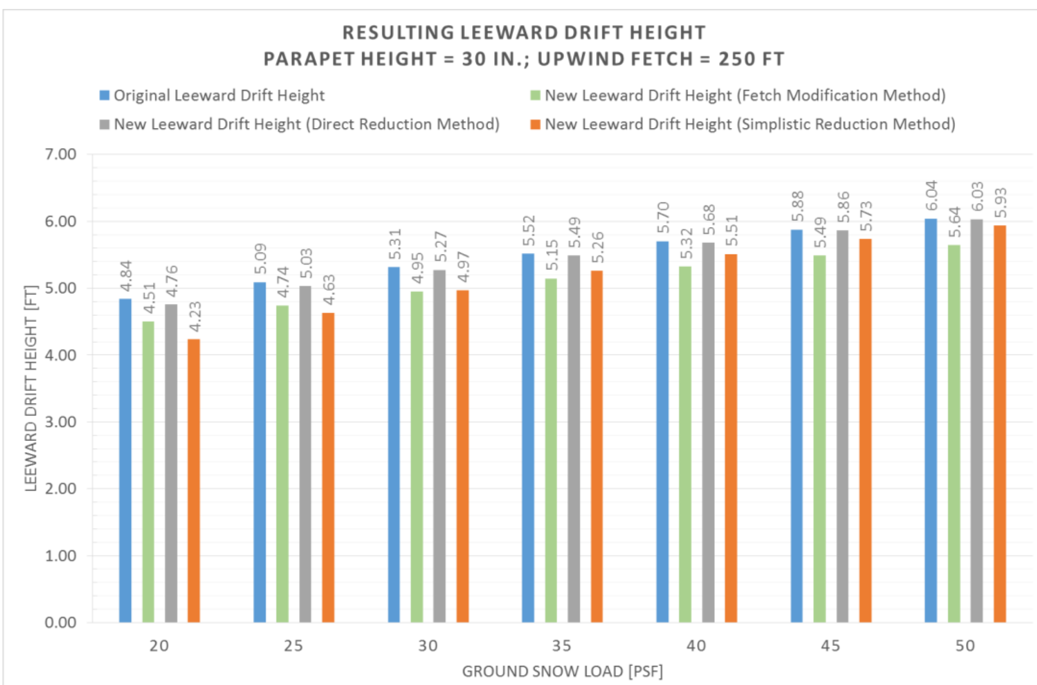

Figure 4-8 – Resulting Leeward Drift Height: 30 in. Parapet, 250 ft Fetch

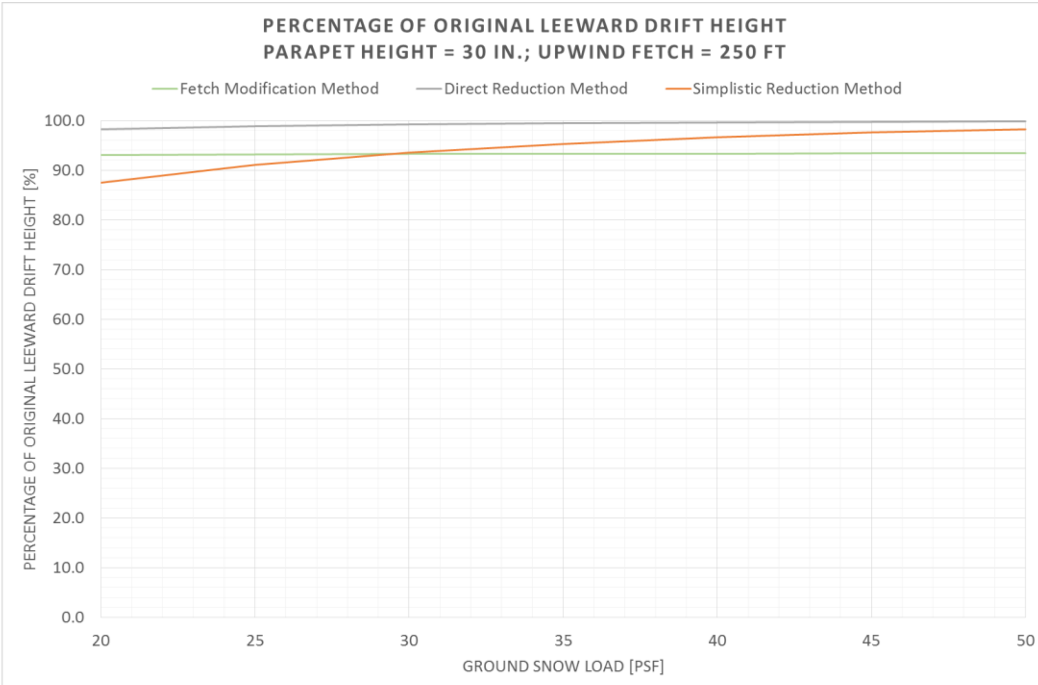

Figure 4-9 – Percentage of Original Leeward Drift Height: 30 in. Parapet, 250 ft Fetch

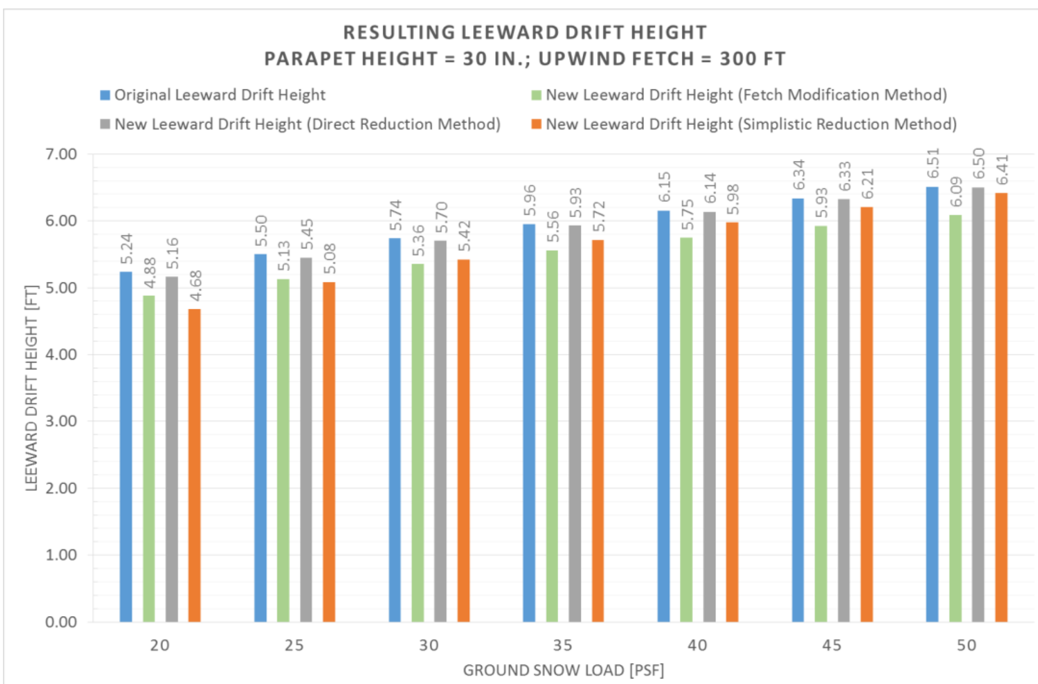

Figure 4-10 – Resulting Leeward Drift Height: 30 in. Parapet, 300 ft Fetch

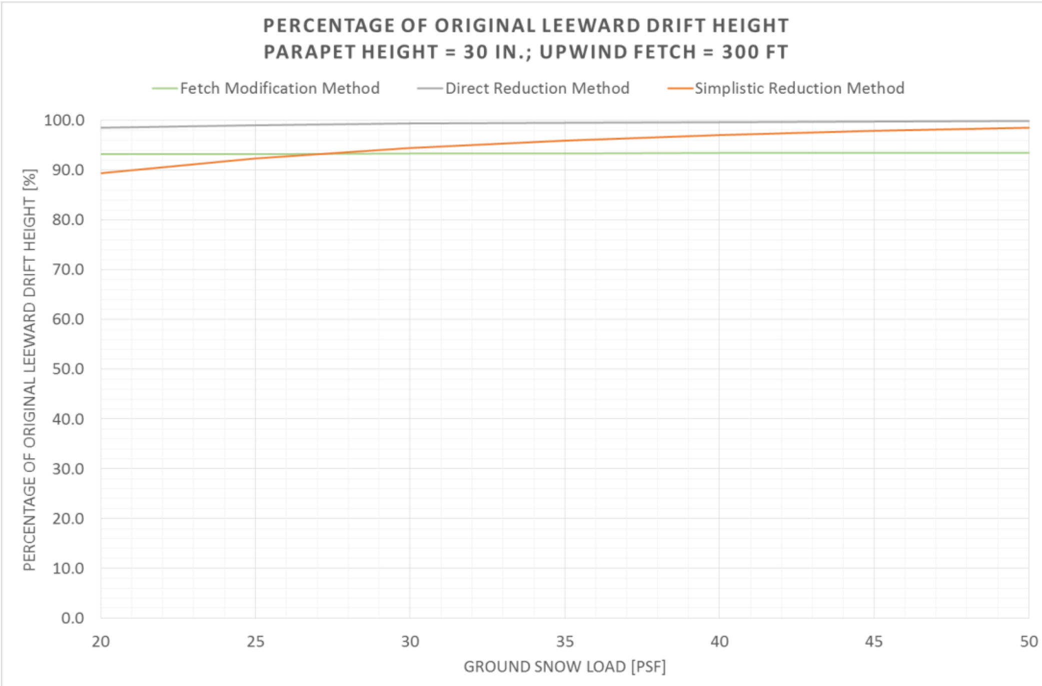

Figure 4-11 – Percentage of Original Leeward Drift Height: 30 in. Parapet, 300 ft Fetch

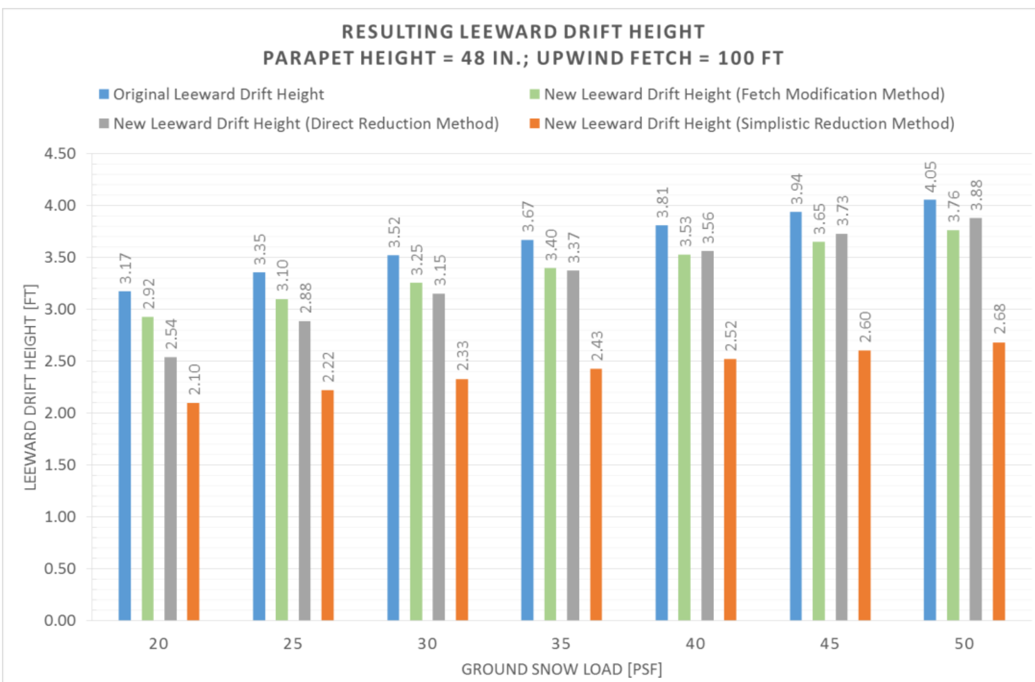

Figure 4-12 – Resulting Leeward Drift Height: 48 in. Parapet, 100 ft Fetch

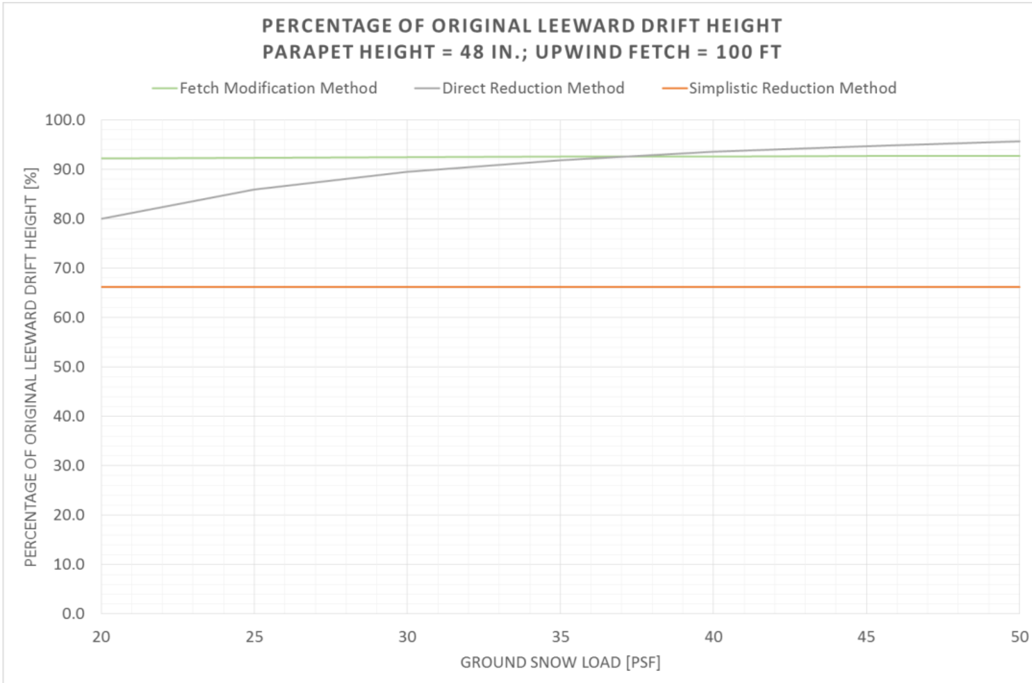

Figure 4-13 – Percentage of Original Leeward Drift Height: 48 in. Parapet, 100 ft Fetch

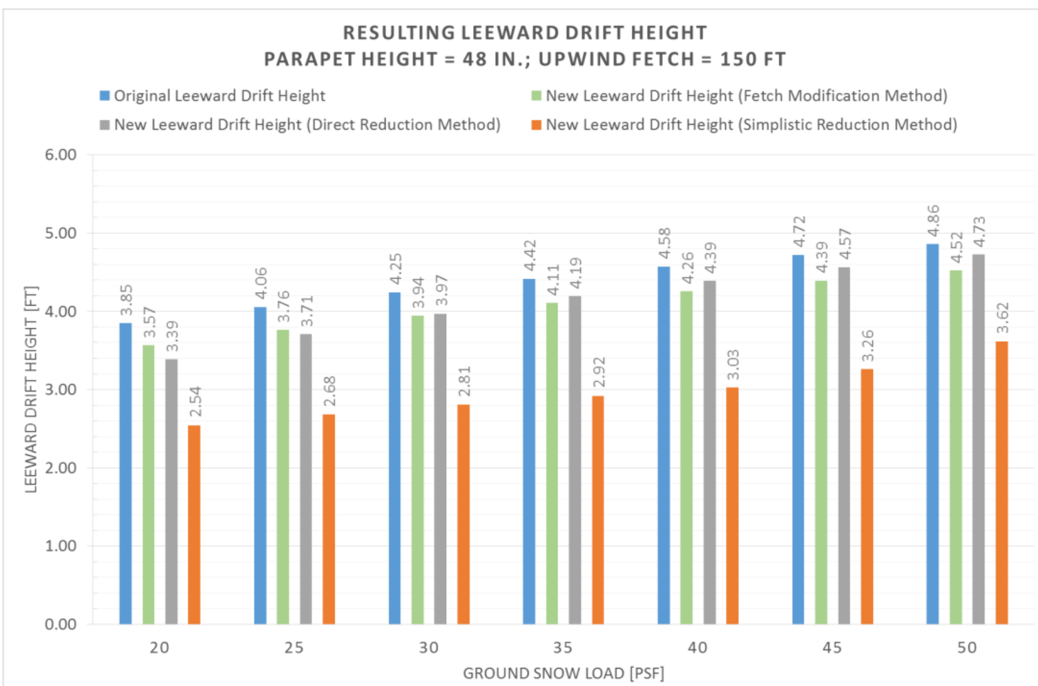

Figure 4-14 – Resulting Leeward Drift Height: 48 in. Parapet, 150 ft Fetch

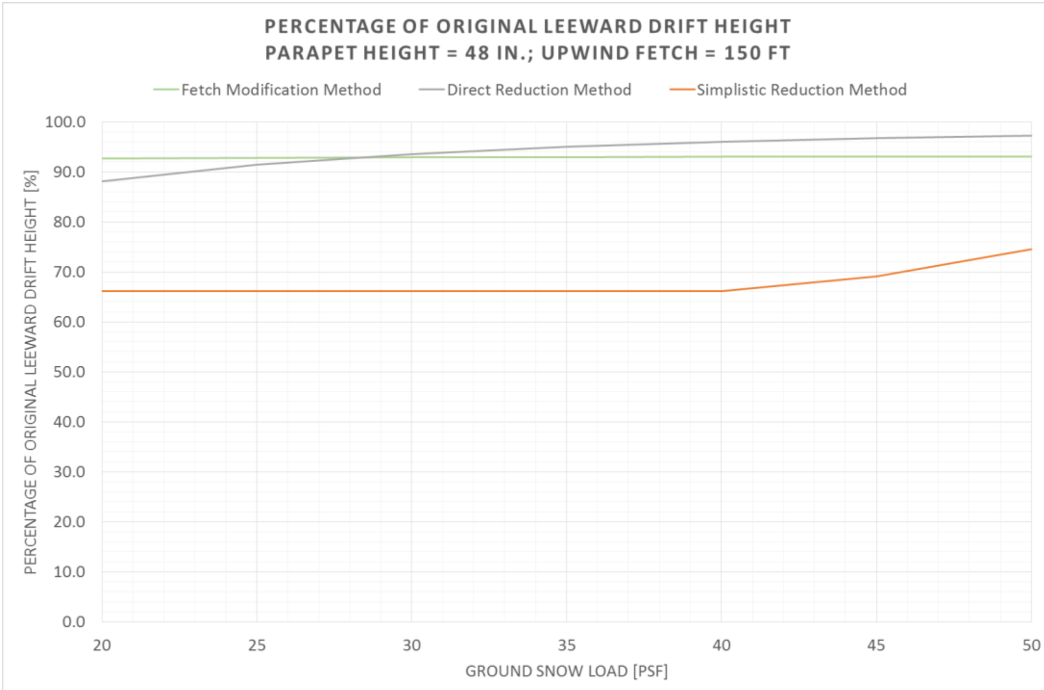

Figure 4-15 – Percentage of Original Leeward Drift Height: 48 in. Parapet, 150 ft Fetch

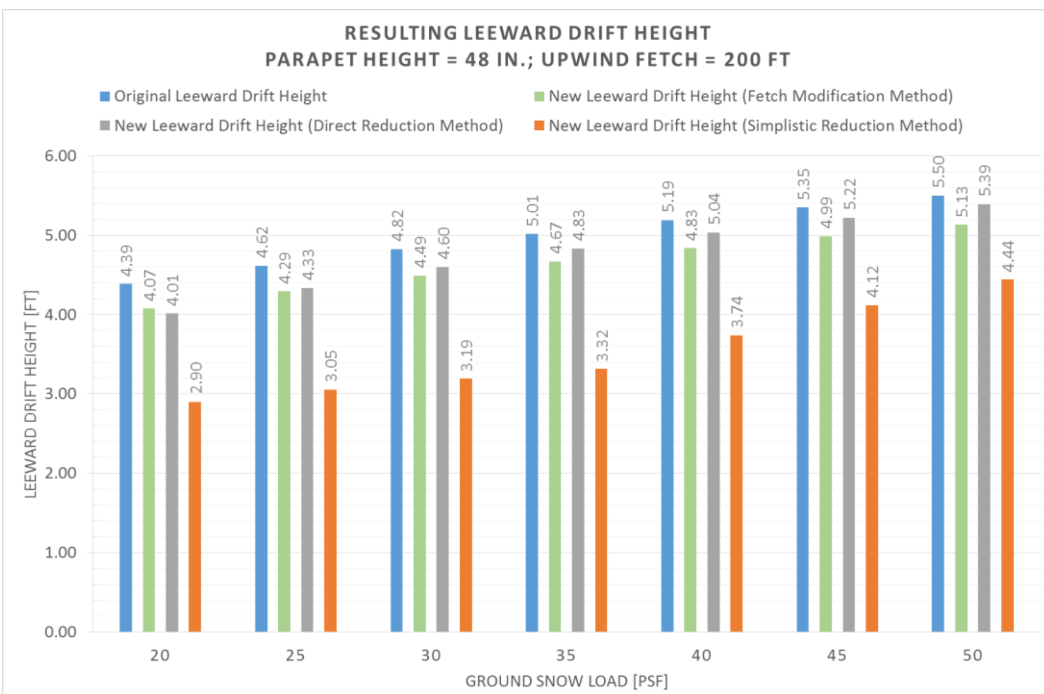

Figure 4-16 – Resulting Leeward Drift Height: 48 in. Parapet, 200 ft Fetch

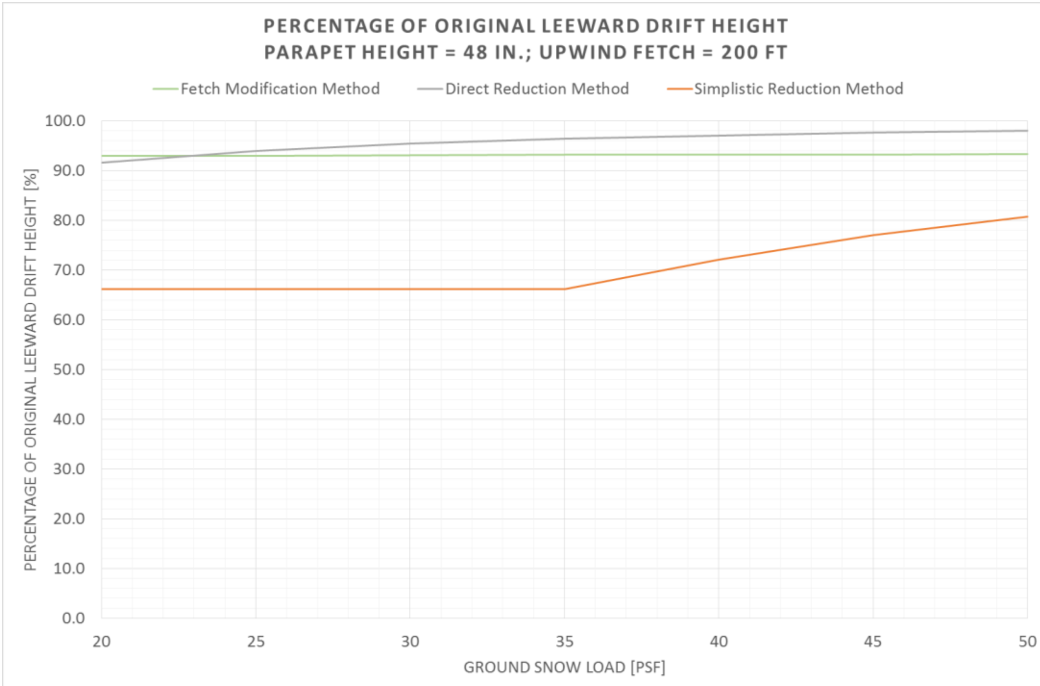

Figure 4-17 – Percentage of Original Leeward Drift Height: 48 in. Parapet, 200 ft Fetch

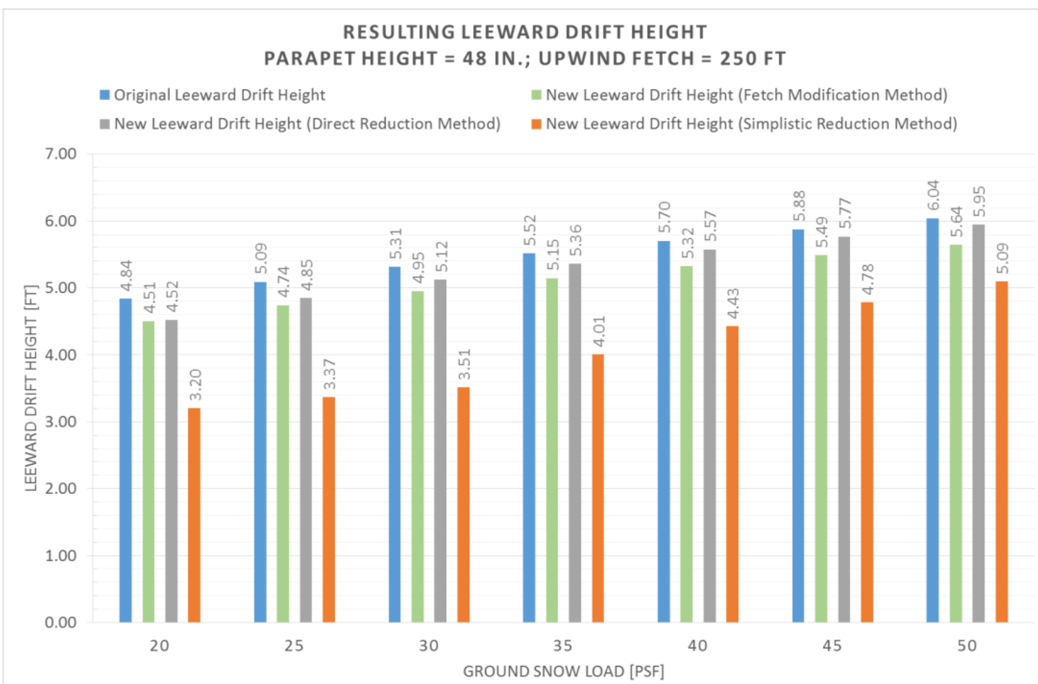

Figure 4-18 – Resulting Leeward Drift Height: 48 in. Parapet, 250 ft Fetch

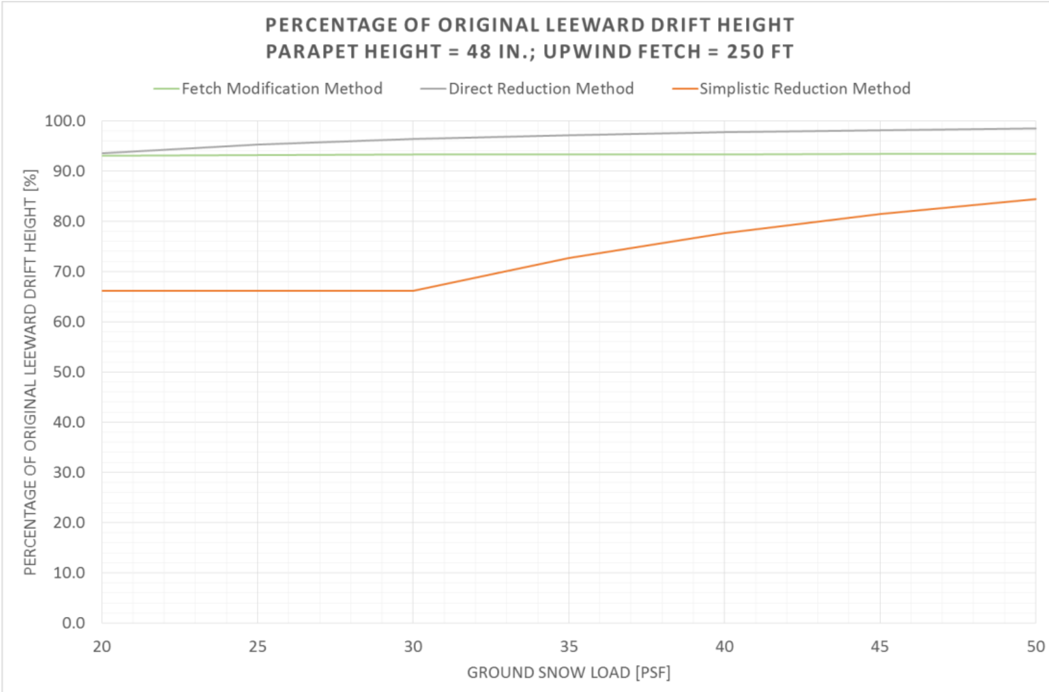

Figure 4-19 – Percentage of Original Leeward Drift Height: 48 in. Parapet, 250 ft Fetch

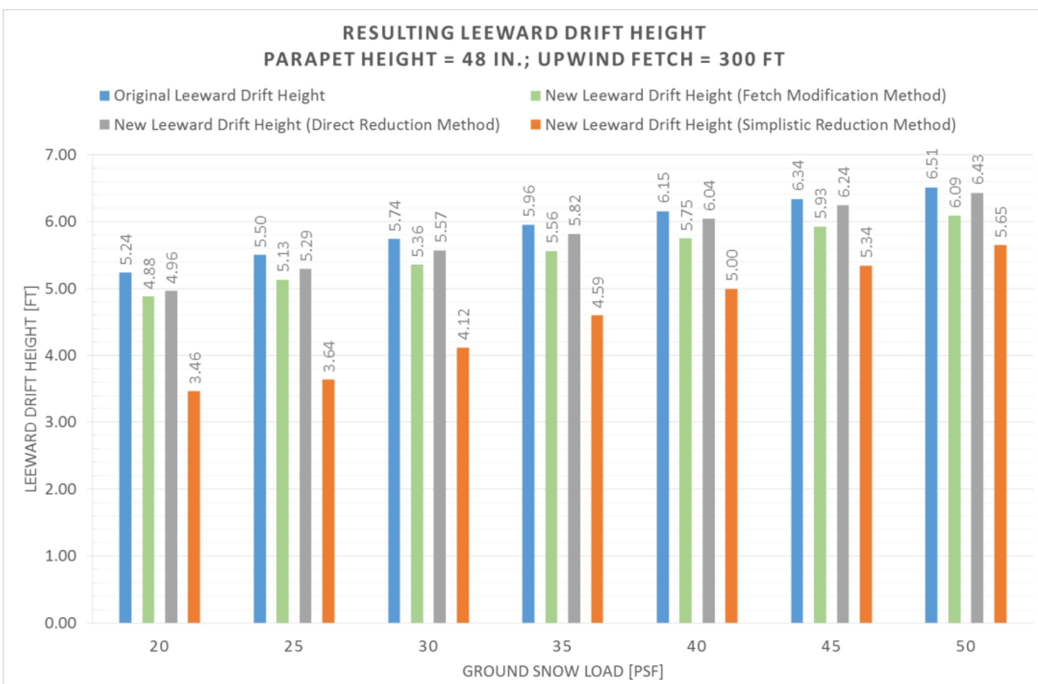

Figure 4-20 – Resulting Leeward Drift Height: 48 in. Parapet, 300 ft Fetch

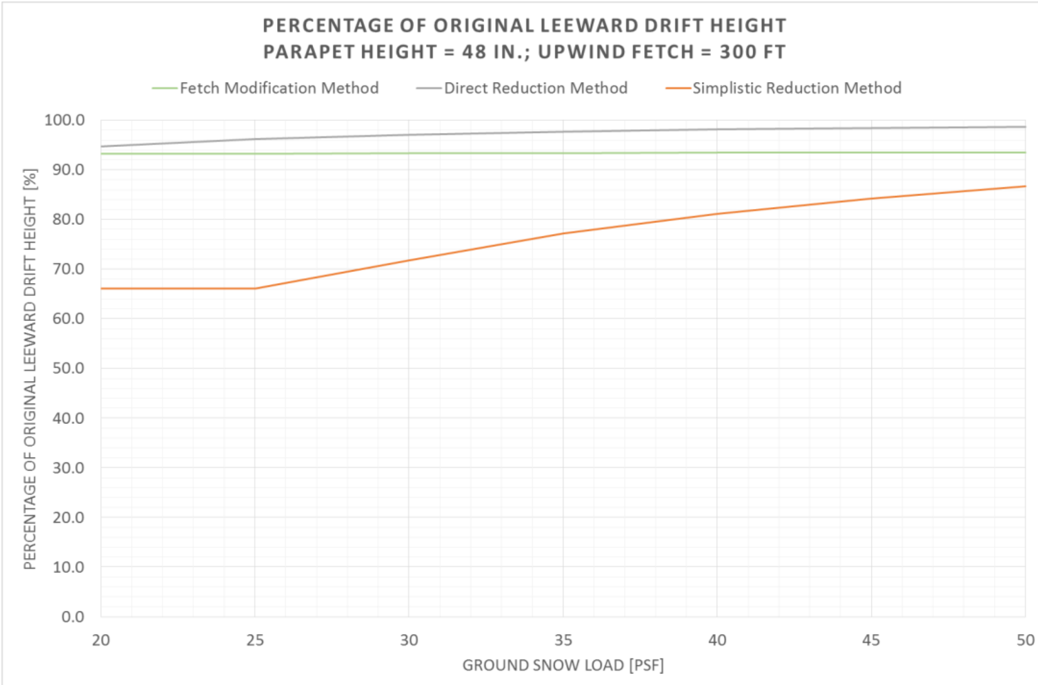

Figure 4-21 – Percentage of Original Leeward Drift Height: 48 in. Parapet, 300 ft Fetch

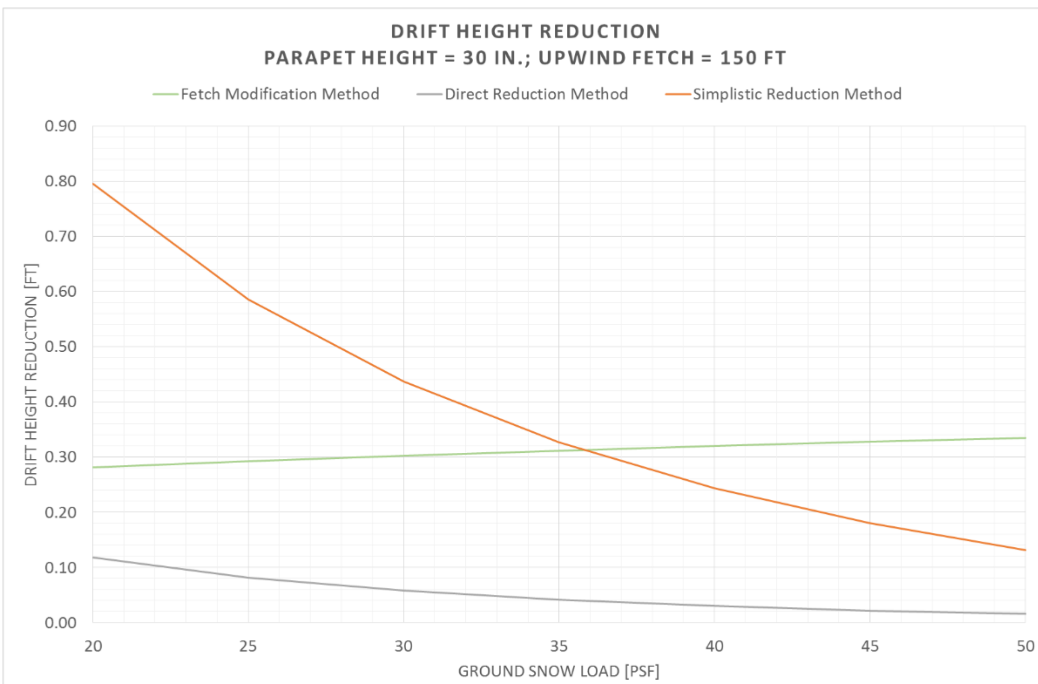

Figure 4-22 – Drift Height Reduction: 30 in. Parapet, 150 ft Fetch

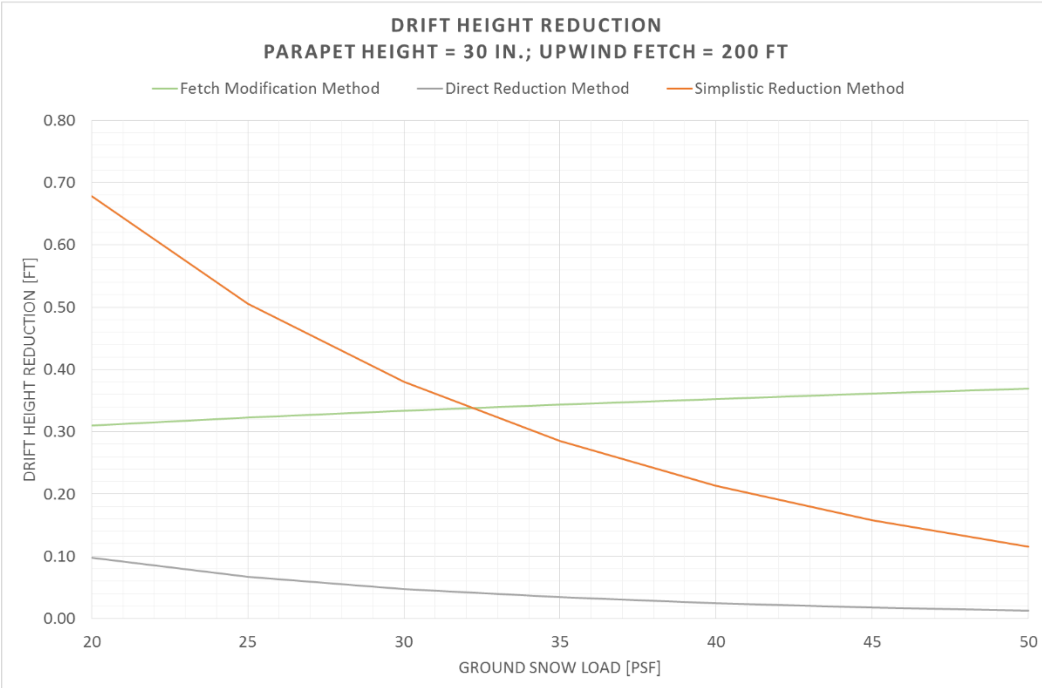

Figure 4-23 – Drift Height Reduction: 30 in. Parapet, 200 ft Fetch

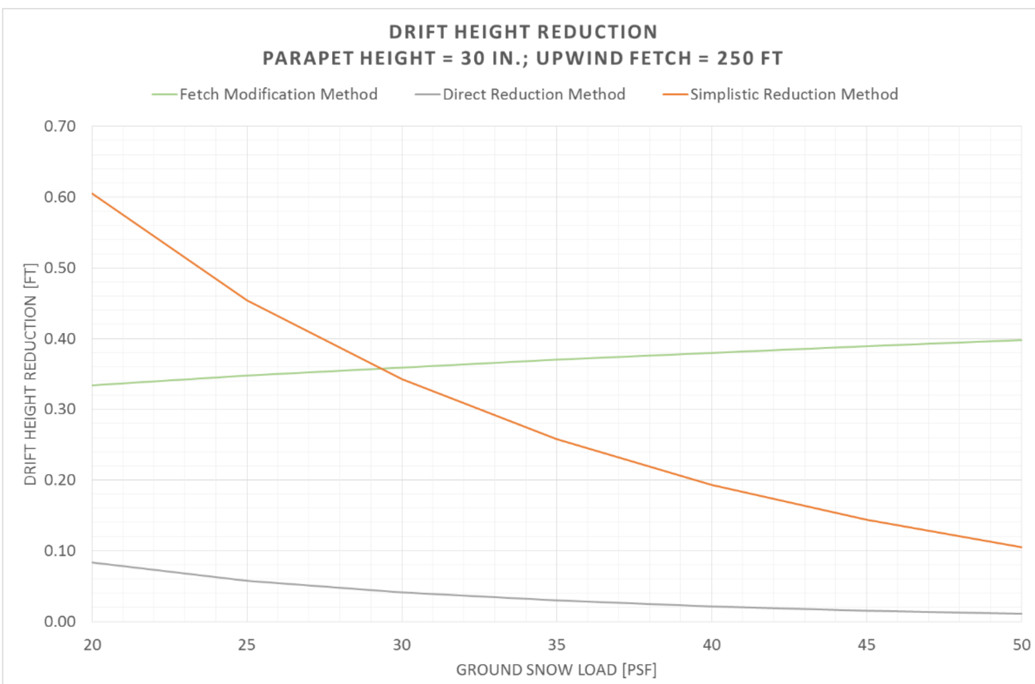

Figure 4-24 – Drift Height Reduction: 30 in. Parapet, 250 ft Fetch

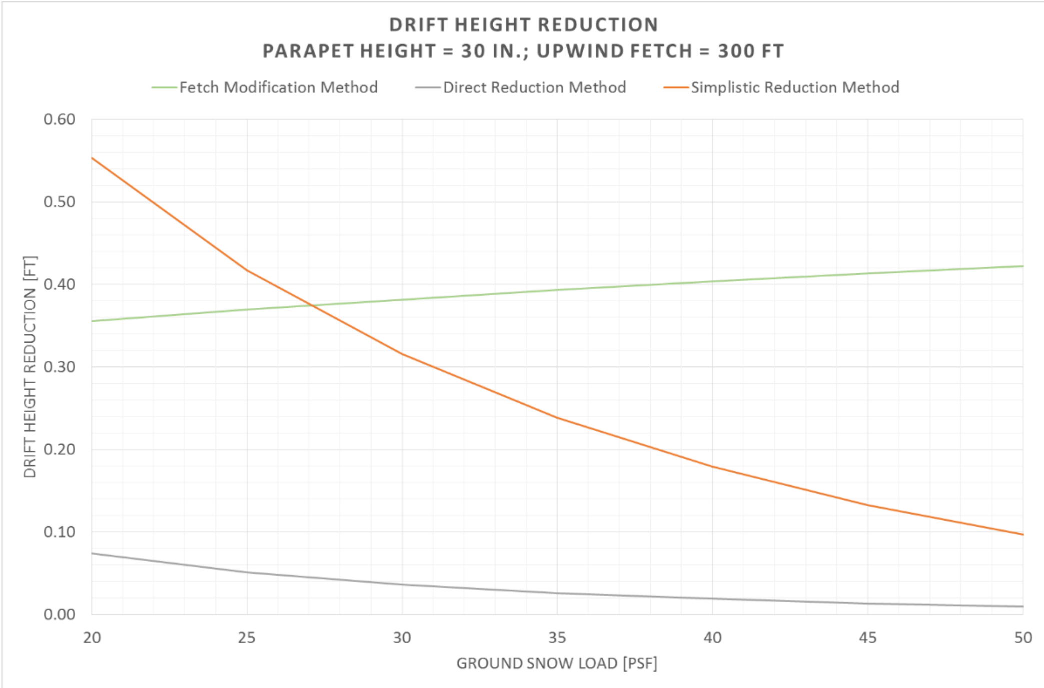

Figure 4-25 – Drift Height Reduction: 30 in. Parapet, 300 ft Fetch

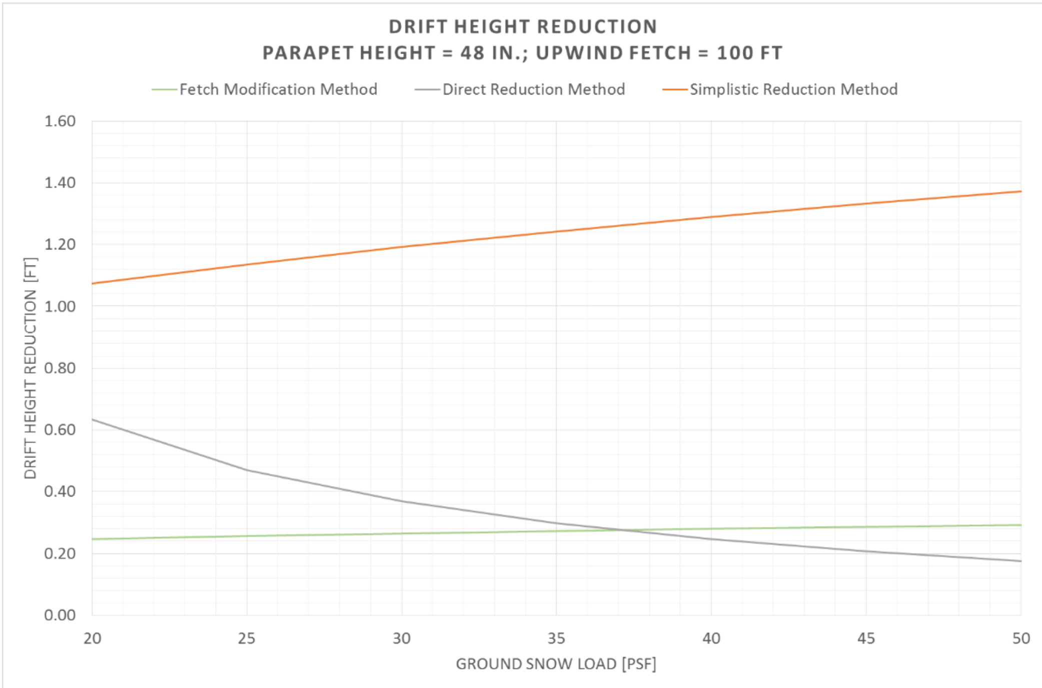

Figure 4-26 – Drift Height Reduction: 48 in. Parapet, 100 ft Fetch

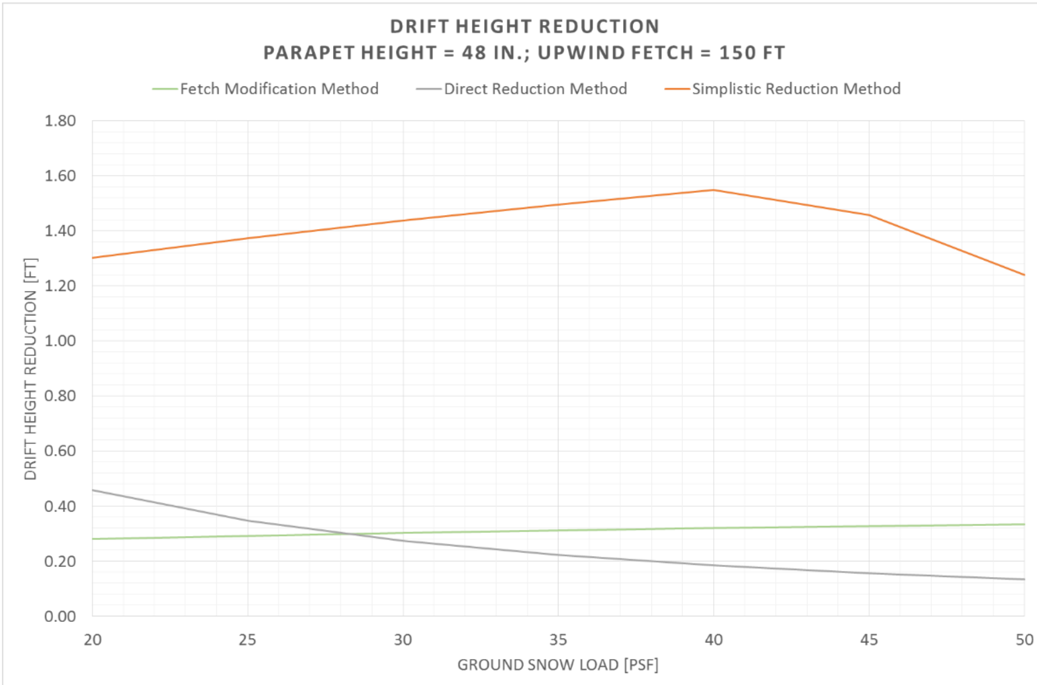

Figure 4-27 – Drift Height Reduction: 48 in. Parapet, 150 ft Fetch

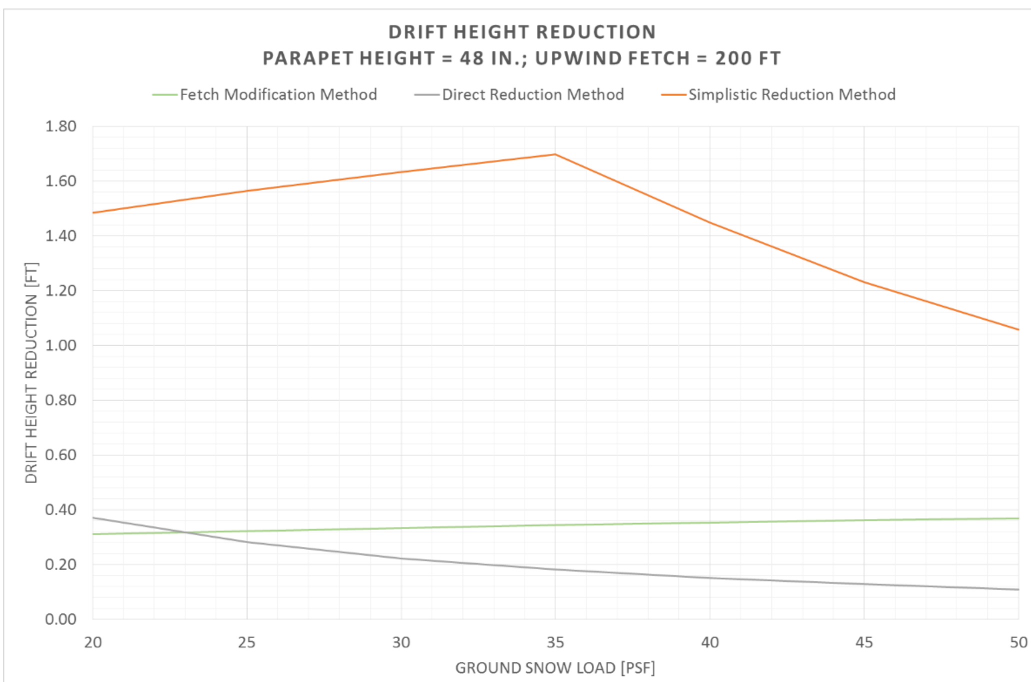

Figure 4-28 – Drift Height Reduction: 48 in. Parapet, 200 ft Fetch

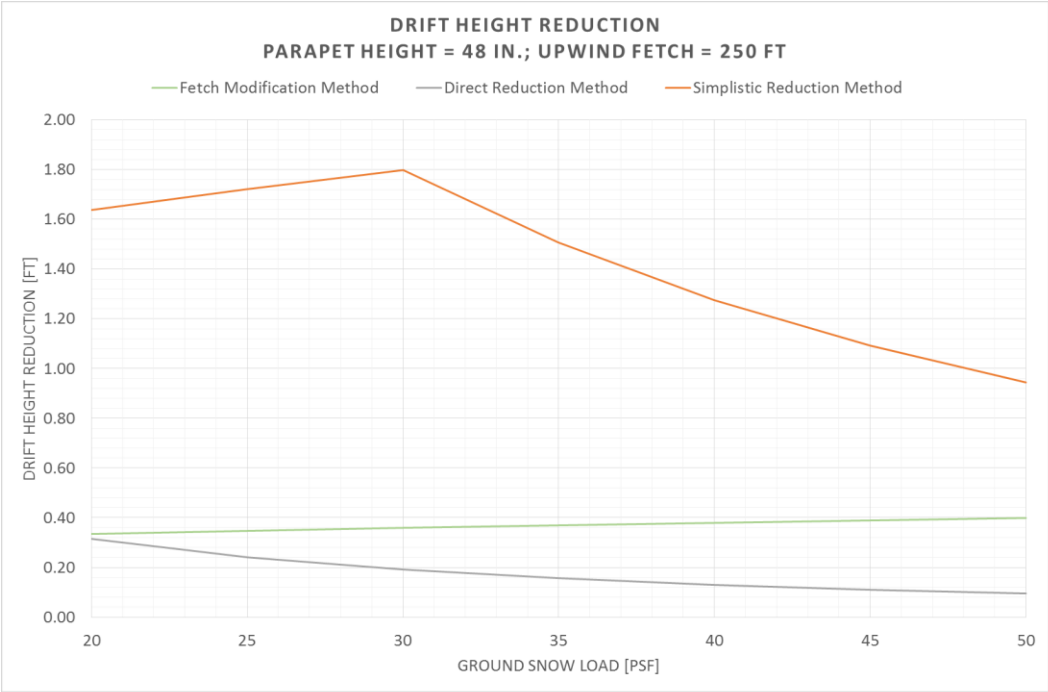

Figure 4-29 – Drift Height Reduction: 48 in. Parapet, 250 ft Fetch

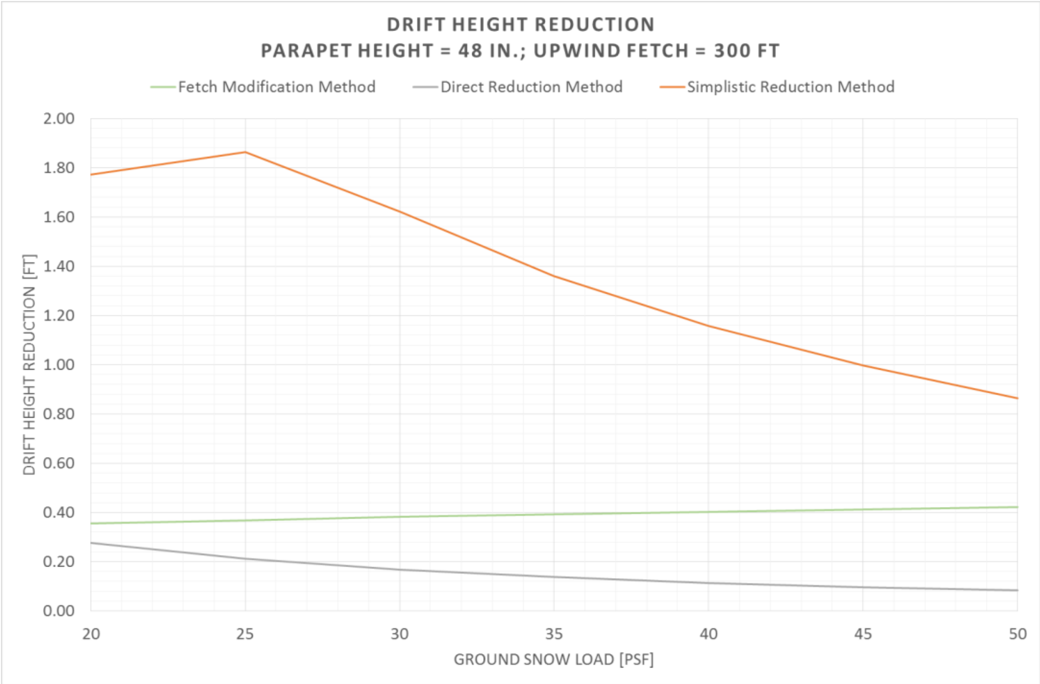

Figure 4-30 – Drift Height Reduction: 48 in. Parapet, 300 ft Fetch

Chapter 5 - Discussion of Results

30 in. Parapet Results

According to Figures 4-2, 4-5, 4-7, 4-9, and 4-11, the percentage of original leeward drift height increased as the ground snow load or the upwind fetch increased. These results could also mean that as the ground snow load or upwind fetch increased, leeward drift reduction decreased. The Fetch Modification Method predicted reduced leeward drift heights ranging from 92.2% of the unreduced leeward drift height to 93.5%, the Direct Reduction Method predicted a range of 95%-99.8%, and the Simplistic Reduction Method predicted a range of 67.4%-98.5%. Therefore, the Fetch Modification Method predicted a leeward drift height reduction of 6.5%-7.8%, compared to 0.2%-5% and 1.5%-32.6% reductions predicted by the Direct Reduction Method and Simplistic Reduction Method, respectively. The reason for this behavior is related to the amount of reduction in leeward drift height estimated by each method, as graphed in Figures 4-3, 4-22, 4-23, 4-24, and 4-25. These figures show that for the Direct Reduction Method and the Simplistic Reduction Method, estimated leeward drift reductions decrease as the ground snow load or upwind fetch increased. On the other hand, the Fetch Modification Method estimated increasing leeward drift reductions as the ground snow load or upwind fetch increased. The behavior in Figures 4-3, 4-22, 4-23, 4-24, and 4-25 can be explained by how each method reduces the leeward drift height. The Direct and Simplistic Reduction Methods both rely directly on the cross-sectional area of the windward drift to reduce the cross-sectional area of the snow source or the leeward drift, respectively, while the Fetch Modification Method uses the β_w factor which does not rely on the windward drift being calculated.

As ground snow load increased in the Direct Reduction Method, the windward drift's cross-sectional area decreased due to decreasing clear height as an increasing amount of balanced snow built up on the roof. Continuing to decrease the cross-sectional area of the windward drift caused less area to be subtracted from the upwind snow source, resulting in decreased leeward drift reduction. As the fetch distance increased, windward drift cross-sectional area did not increase because the clear height did not change, thereby yielding identical windward drift for each fetch. Since the windward drift cross-sectional area did not increase and the cross-sectional area of the upwind snow source increased with fetch distance, the Direct Reduction Method reduced the upwind fetch less as the fetch distance increased, consequently reducing the leeward drift less as well.

In the Simplistic Reduction Method, as the ground snow load increased, the windward drift's cross-sectional area also decreased because the clear height decreased as snow built up on the roof. Therefore, less area was able to be subtracted from the leeward drift, thereby reducing the amount the leeward drift was reduced each time the ground snow load was increased. As the fetch distance increased, the windward drift cross-sectional area did not increase because the clear height did not change and the drift was already full. However, the unreduced leeward drift's cross-sectional area increased with increased fetch distance. Since the windward drift's static cross-sectional area was directly subtracted from the increasing cross-sectional area of the leeward drift, overall leeward drift reduction decreased as the fetch increased.

The Fetch Modification Method predicted consistent leeward drift height reductions as the ground snow load increased or the fetch distance increased because the modification factor reduced each fetch distance equally. Since the cross-sectional area of the windward drift was not directly used to reduce the leeward drift or the upwind snow source area, the varying relative sizes of each cross-sectional area were eliminated, producing a steady prediction of leeward drift height reduction.

48 in. Parapet Results

According to Figures 4-13, 4-15, 4-17, 4-19, and 4-21, the percentage of original leeward drift height increased as the ground snow load or upwind fetch increased, similar to the behavior observed with the 30 in. parapet. The Simplistic Reduction Method, however, had a constant value of 66.14% across all ground snow load values when the fetch distance was 100 ft. As the fetch distance increased, the percentage value increased for greater values of ground snow load, but even with a 300 ft fetch, ground snow loads of 20 psf and 25 psf had a leeward drift height predicted to be 66.14% of the unreduced leeward drift height.

The Fetch Modification Method predicted reduced leeward drift heights ranging from 92.2% of the unreduced leeward drift height to 93.5%, identical to the 30 in. parapet data. The Direct Reduction Method had a range of 80%-98.7%, and the Simplistic Reduction Method had a range of 66.14%-88.72%, meaning that the Fetch Modification Method predicted a reduction of leeward drift height of 6.5%-7.8%, compared to 1.3%-20% and 11.3%-33.9% reductions predicted by the Direct Reduction Method and Simplistic Reduction Method, respectively. The reduction percentages increased for both the Direct and the Simplistic Reduction Methods when the parapet height increased. The increased reduction was expected since the windward drift developed a larger cross-sectional area at the 48 in. parapet than the 30 in. parapet, further reducing the leeward drift. The increasing percentage values in Figures 4-13, 4-15, 4-17, 4-19, and 4-21 were attributed to the same trend as seen for the 30 in. parapets in Figures 4-2, 4-5, 4-7, 4-9, and 4-11. That is, the increasing percentage values related to the amount of reduction in leeward drift height estimated by each method. Reduction amounts are graphed in Figures 4-26, 4-27, 4-28, 4-29, and 4-30, demonstrating that for the Direct Reduction Method, estimated leeward drift reductions decreased as the ground snow load or upwind fetch increased. On the other hand, the Fetch Modification Method estimated increasing leeward drift reductions as the ground snow load or upwind fetch increased. The Simplistic Reduction Method exhibited both increasing and decreasing leeward drift reductions as the ground snow load and fetch distance increased. The behavior exhibited by each method, shown in Figures 4-26, 4-27, 4-28, 4-29, and 4-30, pertains to how each method reduced the leeward drift height. The Direct and Simplistic Reduction Methods both depended on the cross-sectional area of the windward drift, while the Fetch Modification Method did not, as explained for the 30 in. parapet. Drift height reduction behaviors for the Direct Reduction Method and the Fetch Modification Method for a 48 in. parapet were identical to drift height reduction behaviors for a 30 in. parapet. The only new behavior observed occurred for the Simplistic Reduction Method, which was that for various values of ground snow load, the leeward drift reduction increased as the ground snow load increased.

In the Simplistic Reduction Method, as the ground snow load increased, the amount of leeward drift reduction initially increased and then began to decrease after various ground snow load values became large enough for various upwind fetches. When the leeward drift reduction increased, the windward drift's cross-sectional area increased because as the ground snow load increased, the slope of the drift flattened, from roughly 1:4 to 1:8. Flattening the slope increased the drift width and increased the windward drift's cross-sectional area even though the drift height decreased due to the decreasing amount of clear height. Although the unreduced leeward drift's cross-sectional area increased, the windward drift's cross-sectional area increased proportionately to produce a reduced leeward drift with a height that was 66.14% of the unreduced leeward drift height, as seen in Figures 4-13, 4-15, 4-17, 4-19, and 4-21. When the leeward drift reduction decreased, the windward drift's cross-sectional area decreased because the drift reached the maximum slope of 1:8. As the ground snow load increased, the clear height decreased as the balanced snow height on the roof increased, consequently decreasing the drift height. Since the drifts had the same 1:8 slope, the width and the cross-sectional area decreased as the height decreased. Increasing the fetch distance caused the transition from increasing leeward drift reductions to decreasing leeward drift reductions to occur at lower ground snow loads, as seen in Figures 4-26, 4-27, 4-28, 4-29, and 4-30, because as the fetch distance increased, more snow accumulated in the windward drift than would have accumulated at a shorter fetch distance with an identical ground snow load. Since more snow became trapped by the windward parapet, the drift became full and the slope of the drift became 1:8 at low values of ground snow load. Once the slope of the windward drift was 1:8, leeward drift reductions decreased.

General Discussion

In general, the Fetch Modification Method provided a steady, conservative height reduction (approximately 3–5 in.) for the leeward drift. The Direct Reduction Method provided a wider range of height reduction (approximately 0–7.5 in.) for the leeward drift and was more conservative than the Fetch Modification Method. The Direct Reduction Method was generally more conservative than the Fetch Modification Method because the drift height reduction for the Direct Reduction Method was often less than the drift height reduction for the Fetch Modification Method. The Simplistic Reduction Method provided large reductions in leeward drifts heights that were inconsistent with the other two methods (approximately 1–22 in.). For the 30 in. parapet the Simplistic Reduction Method resulted in reduced leeward drift heights ranging from much less than the Fetch Modification Method, approximately 9 in. shorter, to reduced heights between results of the Fetch Modification Method and Direct Reduction Method. For the 48 in. parapet, however, the Simplistic Reduction Method consistently resulted in reduced leeward drift heights that were shorter than the Fetch Modification Method. Due to the inconsistency and larger reductions in leeward drift height than the Fetch Modification Method, the Simplistic Reduction Method was considered to be unconservative. Reductions for the Simplistic Reduction Method were the most unconservative at low values of ground snow loads, combined with short fetch distances, and a 48 in. parapet. Tables 5-1 through 5-4 contain the minimum, maximum, and mean drift height reductions and drift load reductions for 30 in. and 48 in. parapet heights.

Table 5-1 – General Drift Height Reduction Measures: 30 in. Parapet Height

Upwind Fetch	Drift Height Reduction								
	Method #1			Method #2			Method #3		
(FT)	Min. (FT)	Max. (FT)	Mean (FT)	Min. (FT)	Max. (FT)	Mean (FT)	Min. (FT)	Max. (FT)	Mean (FT)
100	0.25	0.29	0.27	0.02	0.16	0.07	0.16	1.03	0.48
150	0.28	0.34	0.31	0.02	0.12	0.05	0.13	0.80	0.39
200	0.31	0.37	0.34	0.01	0.10	0.04	0.12	0.68	0.33
250	0.33	0.40	0.37	0.01	0.08	0.04	0.10	0.60	0.30
300	0.36	0.42	0.39	0.01	0.07	0.03	0.10	0.55	0.28
Overall	0.25	0.42	0.34	0.01	0.16	0.05	0.10	1.03	0.36

Table 5-2 – General Drift Load Reduction Measures: 30 in. Parapet Height

Upwind Fetch	Drift Load Reduction								
	Method #1			Method #2			Method #3		
(FT)	Min. (PSF)	Max. (PSF)	Mean (PSF)	Min. (PSF)	Max. (PSF)	Mean (PSF)	Min. (PSF)	Max. (PSF)	Mean (PSF)
100	4.09	6.00	5.05	0.42	2.61	1.23	3.24	17.17	8.62
150	4.68	6.87	5.78	0.32	1.97	0.93	2.69	13.21	6.88
200	5.15	7.57	6.37	0.26	1.62	0.77	2.37	11.26	5.96
250	5.55	8.15	6.86	0.23	1.39	0.66	2.15	10.04	5.36
300	5.90	8.66	7.29	0.20	1.23	0.58	1.99	9.18	4.93
Overall	4.09	8.66	6.27	0.20	2.61	0.84	1.99	17.17	6.35

Table 5-3 – General Drift Height Reduction Measures: 48 in. Parapet Height

Upwind Fetch	Drift Height Reduction								
	Method #1			Method #2			Method #3		
(FT)	Min. (FT)	Max. (FT)	Mean (FT)	Min. (FT)	Max. (FT)	Mean (FT)	Min. (FT)	Max. (FT)	Mean (FT)
100	0.25	0.29	0.27	0.18	0.63	0.34	1.07	1.37	1.23
150	0.28	0.34	0.31	0.13	0.46	0.25	1.24	1.55	1.41
200	0.31	0.37	0.34	0.11	0.37	0.21	1.06	1.70	1.44
250	0.33	0.40	0.37	0.09	0.31	0.18	0.94	1.80	1.43
300	0.36	0.42	0.39	0.08	0.28	0.16	0.86	1.86	1.38
Overall	0.25	0.42	0.34	0.08	0.63	0.23	0.86	1.86	1.38

Table 5-4 – General Drift Load Reduction Measures: 48 in. Parapet Height

Upwind Fetch	Drift Load Reduction								
	Method #1			Method #2			Method #3		
(FT)	Min. (PSF)	Max. (PSF)	Mean (PSF)	Min. (PSF)	Max. (PSF)	Mean (PSF)	Min. (PSF)	Max. (PSF)	Mean (PSF)
100	4.09	6.00	5.05	3.62	10.53	6.17	17.82	28.14	23.02
150	4.68	6.87	5.78	2.73	7.63	4.57	21.62	29.74	26.13
200	5.15	7.57	6.37	2.24	6.15	3.72	21.68	31.48	26.60
250	5.55	8.15	6.86	1.93	5.23	3.18	19.36	32.19	26.09
300	5.90	8.66	7.29	1.70	4.59	2.80	17.73	32.13	25.08
Overall	4.09	8.66	6.27	1.70	10.53	4.09	17.73	32.19	25.38

Chapter 6 - Conclusion

The reduction of a leeward roof step drift due to a parapet was investigated using three methods for estimating reduced leeward drifts. According to the results, the recommendation was made that engineers should use the Fetch Modification Method developed by O'Rourke and Kuskowski (2005). The Fetch Modification Method produced consistent, conservative reductions as compared to results from the Simplistic Reduction Method in which the reduction of the leeward drift varied in magnitude across the range of ground snow loads, upwind fetch lengths, and parapet heights. As a result of this variance, the Simplistic Reduction Method produced unconservative reductions. The Direct Reduction Method produced reductions that varied less in magnitude than reductions in the Simplistic Reduction Method, leading to results that were generally more similar to reductions produced using the Fetch Modification Method. In general, the Direct Reduction Method produced reductions that were less than the Fetch Modification Method and were considered to be very conservative.

This study contained the following limitations:

- All three methods have not been verified with testing or case studies. The Fetch Modification Method was based on a study by O'Rourke and Kuskowski (2005), which used relations such as drift height and cross-sectional area from ASCE 7, but the 2005 study did not perform testing or observations. Full-scale observations or experimental tests may show different reductions than any method in this study.
- The effect of wind speed or direction were not taken into account. Variations in wind speed or direction could affect the amount snow captured, or not captured,

by the parapet, as well as introduce other means of transporting snow around the parapet.

- Snow wetness and cohesion between snow particles was not taken into account. Variations in either could result in a change in the likelihood for snow to drift. For example, wet snow is less likely to drift, if at all, compared to fresh snow.
- Duration of a snow event was not taken into account, potentially changing leeward drift reduction results by altering the fullness of the windward or leeward drift. For example, if a snow storm lasted long enough to completely fill the windward space at the parapet and to fully develop the leeward drift as calculated per ASCE 7 while ignoring the presence of the parapet, then the leeward drift would not have been reduced at all and the parapet would have been completely ineffective.
- Only two parapet heights and one roof step height were examined, thereby limiting representation of results if taller parapet heights were examined. Examination of taller parapets than the ones presented herein may result in increased drift reductions.

This study compared three methods for estimating the reduction of a leeward roof step drift due to a parapet. The Fetch Modification Method developed in O'Rourke and Kuskowski (2005) was re-examined for more fetch distances and ground snow loads, and the Direct Reduction Method and the Simplistic Reduction Method were introduced. The study compared all three methods across a large range of ground snow loads, reasonable fetch distances for a big-box store structure, and reasonable parapet heights for those stores. The results showed that the

Fetch Modification Method was appropriately conservative for estimating reductions of the leeward drift. Despite only small reductions in leeward drift, roughly 7% to 8% reduction in leeward drift height, the leeward drift height reduction may be beneficial to engineers by reducing the load of the leeward drift.

Further research into the reduction of leeward drifts due to upwind parapets is recommended. Studies should be done to verify the reductions observed using any of the three reduction methods. The studies should include the effects of wind speed, wind direction, snow particle cohesion, and snow wetness in order to fully understand the transportation of snow towards and past the parapet as well as the formation of a leeward drift due to the presence of a parapet. A larger range of parapet heights and roof step values should also be examined during testing to increase understanding their effect on reducing the leeward drift.

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Appendix A - Parametric Study Calculations

Calculations done in the parametric study are shown below. These calculations were done in Excel and are organized by sets of tables starting with the 30 in. parapet and a 150 ft fetch.

30 in. Parapet, 150 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
2.5	1.66	0.84	1.96	YES	150	1.66	2.89	13.25	OKAY	27.5
2.5	1.49	1.01	1.46	YES	150	1.49	3.04	11.88	OKAY	25.6
2.5	1.33	1.17	1.13	YES	150	1.33	3.18	10.61	OKAY	23.8
2.5	1.18	1.32	0.89	YES	150	1.18	3.31	9.43	OKAY	21.9
2.5	1.04	1.46	0.71	YES	150	1.04	3.43	8.33	OKAY	20.0
2.5	0.91	1.59	0.58	YES	150	0.91	3.54	7.30	OKAY	18.1
2.5	0.79	1.71	0.46	YES	150	0.79	3.64	6.34	OKAY	16.3

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	3.85	3.85	15.39	OKAY	63.9
10.0	9.0	4.06	4.06	16.23	OKAY	70.0
10.0	8.8	4.25	4.25	16.98	OKAY	76.0
10.0	8.7	4.42	4.42	17.67	OKAY	81.9
10.0	8.5	4.58	4.58	18.30	OKAY	87.8
10.0	8.4	4.72	4.72	18.89	OKAY	93.7
10.0	8.3	4.86	4.86	19.43	OKAY	99.6

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	127.5	3.57	3.57	14.26	OKAY	59.2	92.7	0.28	4.7
0.85	127.5	3.76	3.76	15.06	OKAY	64.9	92.8	0.29	5.1
0.85	127.5	3.94	3.94	15.77	OKAY	70.6	92.9	0.30	5.4
0.85	127.5	4.11	4.11	16.42	OKAY	76.2	92.9	0.31	5.8
0.85	127.5	4.26	4.26	17.02	OKAY	81.7	93.0	0.32	6.2
0.85	127.5	4.39	4.39	17.58	OKAY	87.2	93.1	0.33	6.5
0.85	127.5	4.52	4.52	18.09	OKAY	92.7	93.1	0.34	6.9

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
140.2	9.2	3.73	3.73	14.91	OKAY	61.9	96.9	0.93	0.12	2.0
143.5	9.0	3.98	3.98	15.90	OKAY	68.6	98.0	0.96	0.08	1.4
145.5	8.8	4.19	4.19	16.75	OKAY	75.0	98.6	0.97	0.06	1.0
146.8	8.7	4.38	4.38	17.50	OKAY	81.2	99.1	0.98	0.04	0.8
147.8	8.5	4.55	4.55	18.18	OKAY	87.3	99.3	0.99	0.03	0.6
148.4	8.4	4.70	4.70	18.80	OKAY	93.3	99.5	0.99	0.02	0.4
148.9	8.3	4.84	4.84	19.37	OKAY	99.3	99.7	0.99	0.02	0.3

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.0	29.6	3.85	15.39	18.62	0.6291	3.05	12.21	79.32	50.65	0.80	13.2
8.8	32.9	4.06	16.23	24.09	0.7319	3.47	13.88	85.55	59.87	0.59	10.1
7.0	36.1	4.25	16.98	29.01	0.8047	3.81	15.23	89.70	68.17	0.44	7.8
5.6	39.0	4.42	17.67	33.47	0.8575	4.09	16.36	92.60	75.88	0.33	6.1
4.3	41.9	4.58	18.30	37.53	0.8963	4.33	17.33	94.67	83.17	0.24	4.7
3.3	44.6	4.72	18.89	41.26	0.9252	4.54	18.17	96.19	90.16	0.18	3.6
2.5	47.2	4.86	19.43	44.70	0.9468	4.73	18.91	97.30	96.92	0.13	2.7

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.0	11.0	8.2	29.6	126.5
8.8	8.8	6.6	32.9	152.2
7.0	7.0	5.3	36.1	176.0
5.6	5.6	4.2	39.0	198.1
4.3	4.3	3.3	41.9	218.8
3.3	3.3	2.5	44.6	238.0
2.5	2.5	1.9	47.2	256.1

30 in. Parapet, 200 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
2.5	1.66	0.84	1.96	YES	200	1.66	3.29	13.25	OKAY	27.5
2.5	1.49	1.01	1.46	YES	200	1.49	3.46	11.88	OKAY	25.6
2.5	1.33	1.17	1.13	YES	200	1.33	3.62	10.61	OKAY	23.8
2.5	1.18	1.32	0.89	YES	200	1.18	3.76	9.43	OKAY	21.9
2.5	1.04	1.46	0.71	YES	200	1.04	3.89	8.33	OKAY	20.0
2.5	0.91	1.59	0.58	YES	200	0.91	4.01	7.30	OKAY	18.1
2.5	0.79	1.71	0.46	YES	200	0.79	4.12	6.34	OKAY	16.3

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	4.39	4.39	17.54	OKAY	72.8
10.0	9.0	4.62	4.62	18.47	OKAY	79.6
10.0	8.8	4.82	4.82	19.30	OKAY	86.4
10.0	8.7	5.01	5.01	20.05	OKAY	93.0
10.0	8.5	5.19	5.19	20.75	OKAY	99.6
10.0	8.4	5.35	5.35	21.39	OKAY	106.2
10.0	8.3	5.50	5.50	21.99	OKAY	112.7

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	170.0	4.07	4.07	16.30	OKAY	67.6	92.9	0.31	5.2
0.85	170.0	4.29	4.29	17.18	OKAY	74.1	93.0	0.32	5.6
0.85	170.0	4.49	4.49	17.96	OKAY	80.4	93.1	0.33	6.0
0.85	170.0	4.67	4.67	18.68	OKAY	86.6	93.1	0.34	6.4
0.85	170.0	4.83	4.83	19.34	OKAY	92.8	93.2	0.35	6.8
0.85	170.0	4.99	4.99	19.95	OKAY	99.0	93.2	0.36	7.2
0.85	170.0	5.13	5.13	20.52	OKAY	105.2	93.3	0.37	7.6

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	$β_e$ Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
190.2	9.2	4.29	4.29	17.15	OKAY	71.2	97.8	0.95	0.10	1.6
193.5	9.0	4.55	4.55	18.20	OKAY	78.5	98.5	0.97	0.07	1.2
195.5	8.8	4.78	4.78	19.10	OKAY	85.5	99.0	0.98	0.05	0.9
196.8	8.7	4.98	4.98	19.91	OKAY	92.4	99.3	0.98	0.03	0.6
197.8	8.5	5.16	5.16	20.65	OKAY	99.1	99.5	0.99	0.02	0.5
198.4	8.4	5.33	5.33	21.32	OKAY	105.8	99.7	0.99	0.02	0.4
198.9	8.3	5.49	5.49	21.94	OKAY	112.5	99.8	0.99	0.01	0.3

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.0	38.5	4.39	17.54	27.48	0.7146	3.71	14.83	84.53	61.53	0.68	11.3
8.8	42.6	4.62	18.47	33.80	0.7929	4.11	16.44	89.05	70.91	0.51	8.7
7.0	46.5	4.82	19.30	39.50	0.8487	4.44	17.78	92.13	79.55	0.38	6.8
5.6	50.3	5.01	20.05	44.70	0.8893	4.73	18.91	94.30	87.69	0.29	5.3
4.3	53.8	5.19	20.75	49.47	0.9193	4.97	19.89	95.88	95.49	0.21	4.1
3.3	57.2	5.35	21.39	53.87	0.9417	5.19	20.76	97.04	103.02	0.16	3.1
2.5	60.5	5.50	21.99	57.96	0.9584	5.38	21.53	97.90	110.36	0.12	2.4

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.0	11.0	8.2	38.5	168.7
8.8	8.8	6.6	42.6	202.9
7.0	7.0	5.3	46.5	234.6
5.6	5.6	4.2	50.3	264.2
4.3	4.3	3.3	53.8	291.7
3.3	3.3	2.5	57.2	317.4
2.5	2.5	1.9	60.5	341.5

30 in. Parapet, 250 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
2.5	1.66	0.84	1.96	YES	250	1.66	3.63	13.25	OKAY	27.5
2.5	1.49	1.01	1.46	YES	250	1.49	3.82	11.88	OKAY	25.6
2.5	1.33	1.17	1.13	YES	250	1.33	3.98	10.61	OKAY	23.8
2.5	1.18	1.32	0.89	YES	250	1.18	4.14	9.43	OKAY	21.9
2.5	1.04	1.46	0.71	YES	250	1.04	4.28	8.33	OKAY	20.0
2.5	0.91	1.59	0.58	YES	250	0.91	4.41	7.30	OKAY	18.1
2.5	0.79	1.71	0.46	YES	250	0.79	4.53	6.34	OKAY	16.3

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	4.84	4.84	19.36	OKAY	80.3
10.0	9.0	5.09	5.09	20.35	OKAY	87.8
10.0	8.8	5.31	5.31	21.25	OKAY	95.1
10.0	8.7	5.52	5.52	22.06	OKAY	102.3
10.0	8.5	5.70	5.70	22.81	OKAY	109.5
10.0	8.4	5.88	5.88	23.51	OKAY	116.7
10.0	8.3	6.04	6.04	24.16	OKAY	123.8

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	212.5	4.51	4.51	18.02	OKAY	74.8	93.1	0.33	5.5
0.85	212.5	4.74	4.74	18.97	OKAY	81.8	93.2	0.35	6.0
0.85	212.5	4.95	4.95	19.81	OKAY	88.7	93.2	0.36	6.4
0.85	212.5	5.15	5.15	20.58	OKAY	95.5	93.3	0.37	6.9
0.85	212.5	5.32	5.32	21.29	OKAY	102.2	93.3	0.38	7.3
0.85	212.5	5.49	5.49	21.95	OKAY	108.9	93.4	0.39	7.7
0.85	212.5	5.64	5.64	22.57	OKAY	115.7	93.4	0.40	8.1

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
240.2	9.2	4.76	4.76	19.02	OKAY	78.9	98.3	0.96	0.08	1.4
243.5	9.0	5.03	5.03	20.12	OKAY	86.8	98.9	0.97	0.06	1.0
245.5	8.8	5.27	5.27	21.08	OKAY	94.4	99.2	0.98	0.04	0.7
246.8	8.7	5.49	5.49	21.95	OKAY	101.8	99.5	0.99	0.03	0.6
247.8	8.5	5.68	5.68	22.73	OKAY	109.1	99.6	0.99	0.02	0.4
248.4	8.4	5.86	5.86	23.45	OKAY	116.3	99.7	0.99	0.02	0.3
248.9	8.3	6.03	6.03	24.11	OKAY	123.6	99.8	1.00	0.01	0.2

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.0	46.8	4.84	19.36	35.87	0.7657	4.23	16.94	87.50	70.30	0.60	10.0
8.8	51.8	5.09	20.35	42.96	0.8296	4.63	18.54	91.08	79.95	0.45	7.8
7.0	56.4	5.31	21.25	49.40	0.8752	4.97	19.88	93.55	88.96	0.34	6.1
5.6	60.9	5.52	22.06	55.29	0.9086	5.26	21.03	95.32	97.53	0.26	4.8
4.3	65.1	5.70	22.81	60.71	0.9333	5.51	22.04	96.61	105.79	0.19	3.7
3.3	69.1	5.88	23.51	65.74	0.9517	5.73	22.93	97.56	113.81	0.14	2.9
2.5	72.9	6.04	24.16	70.43	0.9655	5.93	23.74	98.26	121.65	0.10	2.2

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.0	11.0	8.2	46.8	210.8
8.8	8.8	6.6	51.8	253.6
7.0	7.0	5.3	56.4	293.3
5.6	5.6	4.2	60.9	330.2
4.3	4.3	3.3	65.1	364.6
3.3	3.3	2.5	69.1	396.7
2.5	2.5	1.9	72.9	426.8

30 in. Parapet, 300 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
2.5	1.66	0.84	1.96	YES	300	1.66	3.93	13.25	OKAY	27.5
2.5	1.49	1.01	1.46	YES	300	1.49	4.13	11.88	OKAY	25.6
2.5	1.33	1.17	1.13	YES	300	1.33	4.30	10.61	OKAY	23.8
2.5	1.18	1.32	0.89	YES	300	1.18	4.47	9.43	OKAY	21.9
2.5	1.04	1.46	0.71	YES	300	1.04	4.62	8.33	OKAY	20.0
2.5	0.91	1.59	0.58	YES	300	0.91	4.75	7.30	OKAY	18.1
2.5	0.79	1.71	0.46	YES	300	0.79	4.88	6.34	OKAY	16.3

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	5.24	5.24	20.95	OKAY	86.9
10.0	9.0	5.50	5.50	22.01	OKAY	94.9
10.0	8.8	5.74	5.74	22.96	OKAY	102.7
10.0	8.7	5.96	5.96	23.82	OKAY	110.5
10.0	8.5	6.15	6.15	24.62	OKAY	118.2
10.0	8.4	6.34	6.34	25.36	OKAY	125.8
10.0	8.3	6.51	6.51	26.05	OKAY	133.5

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	255.0	4.88	4.88	19.53	OKAY	81.0	93.2	0.36	5.9
0.85	255.0	5.13	5.13	20.53	OKAY	88.5	93.3	0.37	6.4
0.85	255.0	5.36	5.36	21.43	OKAY	95.9	93.3	0.38	6.8
0.85	255.0	5.56	5.56	22.25	OKAY	103.2	93.4	0.39	7.3
0.85	255.0	5.75	5.75	23.00	OKAY	110.4	93.4	0.40	7.7
0.85	255.0	5.93	5.93	23.70	OKAY	117.6	93.5	0.41	8.2
0.85	255.0	6.09	6.09	24.36	OKAY	124.8	93.5	0.42	8.7

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
290.2	9.2	5.16	5.16	20.65	OKAY	85.7	98.6	0.97	0.07	1.2
293.5	9.0	5.45	5.45	21.80	OKAY	94.0	99.1	0.98	0.05	0.9
295.5	8.8	5.70	5.70	22.81	OKAY	102.1	99.4	0.98	0.04	0.7
296.8	8.7	5.93	5.93	23.72	OKAY	110.0	99.6	0.99	0.03	0.5
297.8	8.5	6.14	6.14	24.54	OKAY	117.8	99.7	0.99	0.02	0.4
298.4	8.4	6.33	6.33	25.30	OKAY	125.6	99.8	0.99	0.01	0.3
298.9	8.3	6.50	6.50	26.01	OKAY	133.3	99.8	1.00	0.01	0.2

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.0	54.8	5.24	20.95	43.87	0.7999	4.68	18.73	89.43	77.75	0.55	9.2
8.8	60.5	5.50	22.01	51.71	0.8542	5.08	20.34	92.42	87.71	0.42	7.2
7.0	65.9	5.74	22.96	58.84	0.8931	5.42	21.70	94.50	97.09	0.32	5.6
5.6	70.9	5.96	23.82	65.37	0.9216	5.72	22.87	96.00	106.06	0.24	4.4
4.3	75.8	6.15	24.62	71.42	0.9427	5.98	23.90	97.09	114.73	0.18	3.4
3.3	80.4	6.34	25.36	77.03	0.9585	6.21	24.82	97.90	123.19	0.13	2.6
2.5	84.8	6.51	26.05	82.29	0.9704	6.41	25.66	98.51	131.49	0.10	2.0

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.0	11.0	8.2	54.8	253.0
8.8	8.8	6.6	60.5	304.3
7.0	7.0	5.3	65.9	352.0
5.6	5.6	4.2	70.9	396.2
4.3	4.3	3.3	75.8	437.5
3.3	3.3	2.5	80.4	476.1
2.5	2.5	1.9	84.8	512.2

48 in. Parapet, 100 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < 8h_c	p_d (PSF)
4	3.16	0.84	3.74	YES	100	2.38	2.38	9.51	OKAY	39.5
4	2.99	1.01	2.94	YES	100	2.52	2.52	10.06	OKAY	43.4
4	2.83	1.17	2.41	YES	100	2.64	2.64	10.56	OKAY	47.2
4	2.68	1.32	2.03	YES	100	2.68	2.75	11.31	OKAY	49.7
4	2.54	1.46	1.74	YES	100	2.54	2.86	12.83	OKAY	48.8
4	2.41	1.59	1.52	YES	100	2.41	2.95	14.44	OKAY	47.9
4	2.29	1.71	1.34	YES	100	2.29	3.04	16.14	OKAY	47.0

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < 8h_c	p_d (PSF)
10.0	9.2	3.17	3.17	12.68	OKAY	52.6
10.0	9.0	3.35	3.35	13.42	OKAY	57.9
10.0	8.8	3.52	3.52	14.08	OKAY	63.0
10.0	8.7	3.67	3.67	14.68	OKAY	68.1
10.0	8.5	3.81	3.81	15.23	OKAY	73.1
10.0	8.4	3.94	3.94	15.74	OKAY	78.1
10.0	8.3	4.05	4.05	16.22	OKAY	83.1

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	85.0	2.92	2.92	11.70	OKAY	48.6	92.2	0.25	4.1
0.85	85.0	3.10	3.10	12.39	OKAY	53.5	92.4	0.26	4.4
0.85	85.0	3.25	3.25	13.02	OKAY	58.3	92.5	0.26	4.7
0.85	85.0	3.40	3.40	13.59	OKAY	63.0	92.6	0.27	5.1
0.85	85.0	3.53	3.53	14.11	OKAY	67.7	92.6	0.28	5.4
0.85	85.0	3.65	3.65	14.59	OKAY	72.4	92.7	0.29	5.7
0.85	85.0	3.76	3.76	15.05	OKAY	77.1	92.8	0.29	6.0

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
64.6	9.2	2.54	2.54	10.15	OKAY	42.1	80.0	0.65	0.63	10.5
73.6	9.0	2.88	2.88	11.54	OKAY	49.7	86.0	0.74	0.47	8.1
79.6	8.8	3.15	3.15	12.60	OKAY	56.4	89.5	0.80	0.37	6.6
83.7	8.7	3.37	3.37	13.49	OKAY	62.5	91.9	0.84	0.30	5.5
86.7	8.5	3.56	3.56	14.24	OKAY	68.4	93.5	0.87	0.25	4.7
89.0	8.4	3.73	3.73	14.91	OKAY	74.0	94.7	0.89	0.21	4.1
90.8	8.3	3.88	3.88	15.51	OKAY	79.5	95.6	0.91	0.18	3.6

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
11.3	20.1	3.17	12.68	8.80	0.4375	2.10	8.39	66.14	34.82	1.07	17.8
12.7	22.5	3.35	13.42	9.85	0.4375	2.22	8.88	66.14	38.28	1.14	19.6
13.9	24.8	3.52	14.08	10.84	0.4375	2.33	9.31	66.14	41.67	1.19	21.3
15.1	26.9	3.67	14.68	11.78	0.4375	2.43	9.71	66.14	45.02	1.24	23.0
16.3	29.0	3.81	15.23	12.68	0.4375	2.52	10.07	66.14	48.35	1.29	24.7
17.4	31.0	3.94	15.74	13.55	0.4375	2.60	10.41	66.14	51.67	1.33	26.4
18.5	32.9	4.05	16.22	14.39	0.4375	2.68	10.73	66.14	54.98	1.37	28.1

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
11.3	11.3	29.9	20.1	84.3
12.7	12.7	26.7	22.5	101.4
13.9	13.9	24.0	24.8	117.3
15.1	15.1	21.5	26.9	132.1
16.3	16.3	19.4	29.0	145.8
17.4	17.4	17.5	31.0	158.7
18.5	18.5	15.8	32.9	170.7

48 in. Parapet, 150 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
4	3.16	0.84	3.74	YES	150	2.89	2.89	11.54	OKAY	47.9
4	2.99	1.01	2.94	YES	150	2.99	3.04	12.41	OKAY	51.5
4	2.83	1.17	2.41	YES	150	2.83	3.18	14.35	OKAY	50.6
4	2.68	1.32	2.03	YES	150	2.68	3.31	16.39	OKAY	49.7
4	2.54	1.46	1.74	YES	150	2.54	3.43	18.53	OKAY	48.8
4	2.41	1.59	1.52	YES	150	2.41	3.54	19.30	OKAY	47.9
4	2.29	1.71	1.34	YES	150	2.29	3.64	18.34	OKAY	47.0

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	3.85	3.85	15.39	OKAY	63.9
10.0	9.0	4.06	4.06	16.23	OKAY	70.0
10.0	8.8	4.25	4.25	16.98	OKAY	76.0
10.0	8.7	4.42	4.42	17.67	OKAY	81.9
10.0	8.5	4.58	4.58	18.30	OKAY	87.8
10.0	8.4	4.72	4.72	18.89	OKAY	93.7
10.0	8.3	4.86	4.86	19.43	OKAY	99.6

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	127.5	3.57	3.57	14.26	OKAY	59.2	92.7	0.28	4.7
0.85	127.5	3.76	3.76	15.06	OKAY	64.9	92.8	0.29	5.1
0.85	127.5	3.94	3.94	15.77	OKAY	70.6	92.9	0.30	5.4
0.85	127.5	4.11	4.11	16.42	OKAY	76.2	92.9	0.31	5.8
0.85	127.5	4.26	4.26	17.02	OKAY	81.7	93.0	0.32	6.2
0.85	127.5	4.39	4.39	17.58	OKAY	87.2	93.1	0.33	6.5
0.85	127.5	4.52	4.52	18.09	OKAY	92.7	93.1	0.34	6.9

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
114.6	9.2	3.39	3.39	13.55	OKAY	56.2	88.1	0.76	0.46	7.6
123.6	9.0	3.71	3.71	14.84	OKAY	64.0	91.5	0.82	0.35	6.0
129.6	8.8	3.97	3.97	15.89	OKAY	71.1	93.6	0.86	0.27	4.9
133.7	8.7	4.19	4.19	16.78	OKAY	77.8	95.0	0.89	0.22	4.1
136.7	8.5	4.39	4.39	17.56	OKAY	84.3	96.0	0.91	0.18	3.6
139.0	8.4	4.57	4.57	18.26	OKAY	90.6	96.7	0.93	0.16	3.1
140.8	8.3	4.73	4.73	18.90	OKAY	96.9	97.3	0.94	0.13	2.7

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
16.6	29.6	3.85	15.39	12.95	0.4375	2.54	10.18	66.14	42.24	1.30	21.6
18.5	32.9	4.06	16.23	14.40	0.4375	2.68	10.73	66.14	46.29	1.37	23.7
20.3	36.1	4.25	16.98	15.77	0.4375	2.81	11.23	66.14	50.27	1.44	25.7
22.0	39.0	4.42	17.67	17.07	0.4375	2.92	11.69	66.14	54.20	1.50	27.7
23.6	41.9	4.58	18.30	18.32	0.4375	3.03	12.11	66.14	58.11	1.55	29.7
23.3	44.6	4.72	18.89	21.30	0.4777	3.26	13.05	69.11	64.78	1.46	28.9
21.0	47.2	4.86	19.43	26.19	0.5547	3.62	14.47	74.48	74.18	1.24	25.4

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
16.6	16.6	29.9	29.6	126.5
18.5	18.5	26.7	32.9	152.2
20.3	20.3	24.0	36.1	176.0
22.0	22.0	21.5	39.0	198.1
23.6	23.6	19.4	41.9	218.8
23.3	23.3	17.5	44.6	238.0
21.0	21.0	15.8	47.2	256.1

48 in. Parapet, 200 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\ (rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
4	3.16	0.84	3.74	YES	200	3.16	3.29	13.71	OKAY	52.4
4	2.99	1.01	2.94	YES	200	2.99	3.46	16.06	OKAY	51.5
4	2.83	1.17	2.41	YES	200	2.83	3.62	18.52	OKAY	50.6
4	2.68	1.32	2.03	YES	200	2.68	3.76	21.10	OKAY	49.7
4	2.54	1.46	1.74	YES	200	2.54	3.89	20.33	OKAY	48.8
4	2.41	1.59	1.52	YES	200	2.41	4.01	19.30	OKAY	47.9
4	2.29	1.71	1.34	YES	200	2.29	4.12	18.34	OKAY	47.0

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	4.39	4.39	17.54	OKAY	72.8
10.0	9.0	4.62	4.62	18.47	OKAY	79.6
10.0	8.8	4.82	4.82	19.30	OKAY	86.4
10.0	8.7	5.01	5.01	20.05	OKAY	93.0
10.0	8.5	5.19	5.19	20.75	OKAY	99.6
10.0	8.4	5.35	5.35	21.39	OKAY	106.2
10.0	8.3	5.50	5.50	21.99	OKAY	112.7

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	170.0	4.07	4.07	16.30	OKAY	67.6	92.9	0.31	5.2
0.85	170.0	4.29	4.29	17.18	OKAY	74.1	93.0	0.32	5.6
0.85	170.0	4.49	4.49	17.96	OKAY	80.4	93.1	0.33	6.0
0.85	170.0	4.67	4.67	18.68	OKAY	86.6	93.1	0.34	6.4
0.85	170.0	4.83	4.83	19.34	OKAY	92.8	93.2	0.35	6.8
0.85	170.0	4.99	4.99	19.95	OKAY	99.0	93.2	0.36	7.2
0.85	170.0	5.13	5.13	20.52	OKAY	105.2	93.3	0.37	7.6

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
164.6	9.2	4.01	4.01	16.06	OKAY	66.6	91.6	0.82	0.37	6.2
173.6	9.0	4.33	4.33	17.34	OKAY	74.8	93.9	0.87	0.28	4.9
179.6	8.8	4.60	4.60	18.40	OKAY	82.4	95.4	0.90	0.22	4.0
183.7	8.7	4.83	4.83	19.32	OKAY	89.6	96.4	0.92	0.18	3.4
186.7	8.5	5.04	5.04	20.14	OKAY	96.7	97.1	0.93	0.15	2.9
189.0	8.4	5.22	5.22	20.88	OKAY	103.6	97.6	0.94	0.13	2.5
190.8	8.3	5.39	5.39	21.56	OKAY	110.5	98.0	0.95	0.11	2.2

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
21.6	38.5	4.39	17.54	16.83	0.4375	2.90	11.60	66.14	48.15	1.48	24.6
24.0	42.6	4.62	18.47	18.65	0.4375	3.05	12.21	66.14	52.67	1.56	27.0
26.2	46.5	4.82	19.30	20.36	0.4375	3.19	12.76	66.14	57.12	1.63	29.2
28.3	50.3	5.01	20.05	21.99	0.4375	3.32	13.26	66.14	61.51	1.70	31.5
25.8	53.8	5.19	20.75	27.97	0.5198	3.74	14.96	72.09	71.80	1.45	27.8
23.3	57.2	5.35	21.39	33.91	0.5928	4.12	16.47	76.99	81.74	1.23	24.4
21.0	60.5	5.50	21.99	39.45	0.6523	4.44	17.76	80.77	91.04	1.06	21.7

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
21.6	21.6	29.9	38.5	168.7
24.0	24.0	26.7	42.6	202.9
26.2	26.2	24.0	46.5	234.6
28.3	28.3	21.5	50.3	264.2
25.8	25.8	19.4	53.8	291.7
23.3	23.3	17.5	57.2	317.4
21.0	21.0	15.8	60.5	341.5

48 in. Parapet, 250 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
4	3.16	0.84	3.74	YES	250	3.16	3.63	16.69	OKAY	52.4
4	2.99	1.01	2.94	YES	250	2.99	3.82	19.52	OKAY	51.5
4	2.83	1.17	2.41	YES	250	2.83	3.98	22.46	OKAY	50.6
4	2.68	1.32	2.03	YES	250	2.68	4.14	21.43	OKAY	49.7
4	2.54	1.46	1.74	YES	250	2.54	4.28	20.33	OKAY	48.8
4	2.41	1.59	1.52	YES	250	2.41	4.41	19.30	OKAY	47.9
4	2.29	1.71	1.34	YES	250	2.29	4.53	18.34	OKAY	47.0

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	4.84	4.84	19.36	OKAY	80.3
10.0	9.0	5.09	5.09	20.35	OKAY	87.8
10.0	8.8	5.31	5.31	21.25	OKAY	95.1
10.0	8.7	5.52	5.52	22.06	OKAY	102.3
10.0	8.5	5.70	5.70	22.81	OKAY	109.5
10.0	8.4	5.88	5.88	23.51	OKAY	116.7
10.0	8.3	6.04	6.04	24.16	OKAY	123.8

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	212.5	4.51	4.51	18.02	OKAY	74.8	93.1	0.33	5.5
0.85	212.5	4.74	4.74	18.97	OKAY	81.8	93.2	0.35	6.0
0.85	212.5	4.95	4.95	19.81	OKAY	88.7	93.2	0.36	6.4
0.85	212.5	5.15	5.15	20.58	OKAY	95.5	93.3	0.37	6.9
0.85	212.5	5.32	5.32	21.29	OKAY	102.2	93.3	0.38	7.3
0.85	212.5	5.49	5.49	21.95	OKAY	108.9	93.4	0.39	7.7
0.85	212.5	5.64	5.64	22.57	OKAY	115.7	93.4	0.40	8.1

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
214.6	9.2	4.52	4.52	18.10	OKAY	75.1	93.5	0.86	0.31	5.2
223.6	9.0	4.85	4.85	19.39	OKAY	83.6	95.3	0.89	0.24	4.1
229.6	8.8	5.12	5.12	20.49	OKAY	91.7	96.4	0.92	0.19	3.4
233.7	8.7	5.36	5.36	21.44	OKAY	99.4	97.2	0.93	0.16	2.9
236.7	8.5	5.57	5.57	22.29	OKAY	107.0	97.7	0.95	0.13	2.5
239.0	8.4	5.77	5.77	23.07	OKAY	114.5	98.1	0.96	0.11	2.2
240.8	8.3	5.95	5.95	23.78	OKAY	121.9	98.4	0.96	0.09	1.9

Leeward Drift - Simplistic Reduction Method											
Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
26.3	46.8	4.84	19.36	20.49	0.4375	3.20	12.80	66.14	53.14	1.64	27.2
29.1	51.8	5.09	20.35	22.66	0.4375	3.37	13.46	66.14	58.06	1.72	29.7
31.7	56.4	5.31	21.25	24.69	0.4375	3.51	14.06	66.14	62.90	1.80	32.2
28.7	60.9	5.52	22.06	32.14	0.5281	4.01	16.03	72.67	74.36	1.51	28.0
25.8	65.1	5.70	22.81	39.21	0.6028	4.43	17.71	77.64	85.02	1.28	24.5
23.3	69.1	5.88	23.51	45.78	0.6628	4.78	19.14	81.41	94.97	1.09	21.7
21.0	72.9	6.04	24.16	51.92	0.7117	5.09	20.38	84.37	104.45	0.94	19.4

Cross-Sectional Areas				
Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
26.3	26.3	29.9	46.8	210.8
29.1	29.1	26.7	51.8	253.6
31.7	31.7	24.0	56.4	293.3
28.7	28.7	21.5	60.9	330.2
25.8	25.8	19.4	65.1	364.6
23.3	23.3	17.5	69.1	396.7
21.0	21.0	15.8	72.9	426.8

48 in. Parapet, 300 ft Fetch

Flat Roof Snow Load							
p_g (PSF)	C_e	C_t	I_s	γ (PCF)	p_m (PSF)	p_f (PSF)	$p_{f\,(rain)}$ (PSF)
20	1.00	1.00	1.00	16.6	20	14.0	19
25	1.00	1.00	1.00	17.25	20	17.5	NONE
30	1.00	1.00	1.00	17.9	20	21.0	NONE
35	1.00	1.00	1.00	18.55	20	24.5	NONE
40	1.00	1.00	1.00	19.2	20	28.0	NONE
45	1.00	1.00	1.00	19.85	20	31.5	NONE
50	1.00	1.00	1.00	20.5	20	35.0	NONE

Windward Drift (per ASCE 7-10, 1:4-1:8 slope basis)										
Parapet Height (FT)	h_c (FT)	h_b (FT)	h_c / h_b	Apply Drift?	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
4	3.16	0.84	3.74	YES	300	3.16	3.93	19.55	OKAY	52.4
4	2.99	1.01	2.94	YES	300	2.99	4.13	22.81	OKAY	51.5
4	2.83	1.17	2.41	YES	300	2.83	4.30	22.61	OKAY	50.6
4	2.68	1.32	2.03	YES	300	2.68	4.47	21.43	OKAY	49.7
4	2.54	1.46	1.74	YES	300	2.54	4.62	20.33	OKAY	48.8
4	2.41	1.59	1.52	YES	300	2.41	4.75	19.30	OKAY	47.9
4	2.29	1.71	1.34	YES	300	2.29	4.88	18.34	OKAY	47.0

Leeward Drift (No Parapet)						
Roof Drop (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	w < $8h_c$	p_d (PSF)
10.0	9.2	5.24	5.24	20.95	OKAY	86.9
10.0	9.0	5.50	5.50	22.01	OKAY	94.9
10.0	8.8	5.74	5.74	22.96	OKAY	102.7
10.0	8.7	5.96	5.96	23.82	OKAY	110.5
10.0	8.5	6.15	6.15	24.62	OKAY	118.2
10.0	8.4	6.34	6.34	25.36	OKAY	125.8
10.0	8.3	6.51	6.51	26.05	OKAY	133.5

Leeward Drift - Fetch Modification Method									
β	l_u (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
0.85	255.0	4.88	4.88	19.53	OKAY	81.0	93.2	0.36	5.9
0.85	255.0	5.13	5.13	20.53	OKAY	88.5	93.3	0.37	6.4
0.85	255.0	5.36	5.36	21.43	OKAY	95.9	93.3	0.38	6.8
0.85	255.0	5.56	5.56	22.25	OKAY	103.2	93.4	0.39	7.3
0.85	255.0	5.75	5.75	23.00	OKAY	110.4	93.4	0.40	7.7
0.85	255.0	5.93	5.93	23.70	OKAY	117.6	93.5	0.41	8.2
0.85	255.0	6.09	6.09	24.36	OKAY	124.8	93.5	0.42	8.7

Leeward Drift - Direct Reduction Method										
$l_{u,new}$ (FT)	h_c (FT)	h_d (FT)	h_d No Limit (FT)	w (FT)	$w < 8h_c$	p_d (PSF)	% of Original Height	β_e Effective Mod. Factor	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
264.6	9.2	4.96	4.96	19.84	OKAY	82.3	94.7	0.88	0.28	4.6
273.6	9.0	5.29	5.29	21.16	OKAY	91.3	96.2	0.91	0.21	3.6
279.6	8.8	5.57	5.57	22.28	OKAY	99.7	97.1	0.93	0.17	3.0
283.7	8.7	5.82	5.82	23.27	OKAY	107.9	97.7	0.95	0.14	2.6
286.7	8.5	6.04	6.04	24.16	OKAY	116.0	98.1	0.96	0.11	2.2
289.0	8.4	6.24	6.24	24.97	OKAY	123.9	98.5	0.96	0.10	1.9
290.8	8.3	6.43	6.43	25.71	OKAY	131.8	98.7	0.97	0.08	1.7

Leeward Drift - Simplistic Reduction Method

Cross-Sectional Area of Windward Drift (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	h_d No Parapet (FT)	w No Parapet (FT)	Cross-Sectional Area of Reduced Leeward Drift w/ Parapet (SF)	x Dimension Reduction Factor	h_d Reduced (FT)	w Reduced (FT)	% of Original Height	p_d (PSF)	Drift Height Reduction (FT)	Drift Load Reduction (PSF)
30.9	54.8	5.24	20.95	24.00	0.4375	3.46	13.86	66.14	57.50	1.77	29.4
34.1	60.5	5.50	22.01	26.48	0.4375	3.64	14.56	66.14	62.77	1.86	32.1
32.0	65.9	5.74	22.96	33.91	0.5148	4.12	16.47	71.75	73.71	1.62	29.0
28.7	70.9	5.96	23.82	42.22	0.5952	4.59	18.38	77.15	85.23	1.36	25.2
25.8	75.8	6.15	24.62	49.92	0.6589	5.00	19.98	81.17	95.92	1.16	22.2
23.3	80.4	6.34	25.36	57.08	0.7102	5.34	21.37	84.27	106.04	1.00	19.8
21.0	84.8	6.51	26.05	63.77	0.7521	5.65	22.59	86.72	115.76	0.86	17.7

Cross-Sectional Areas

Cross-Sectional Area of Windward Drift, Code (SF)	Cross-Sectional Area of Windward Drift - Fetch Modification Method (SF)	Cross-Sectional Area of Windward Drift - Direct Reduction Method (SF)	Cross-Sectional Area of Leeward Drift, No Parapet (SF)	Cross-Sectional Area of Upwind Snow Source (SF)
30.9	30.9	29.9	54.8	253.0
34.1	34.1	26.7	60.5	304.3
32.0	32.0	24.0	65.9	352.0
28.7	28.7	21.5	70.9	396.2
25.8	25.8	19.4	75.8	437.5
23.3	23.3	17.5	80.4	476.1
21.0	21.0	15.8	84.8	512.2

Appendix B - Copyright Permission Letter

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Gmail **Christopher Goodale <cgoodalemail@gmail.com>**

RE: ASCE Photo Use Permission

1 message

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Figure 6 - Scattergram of Actual Drift Height versus Predicted Drift Height

From: O'Rourke, M. J., Speck Jr, R. S., & Stiefel, U. (1985). Drift snow loads on multilevel roofs.

Journal of Structural Engineering, 111(2), 290-306.

Figure 2 - Roof steps in series

From: O'Rourke, M., & Kuskowski, N. (2005). Snow drifts at roof steps in series. Journal of Structural

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To whom it may concern,

I am a Master's student at Kansas State University in the Department of Architectural Engineering and Construction Science. I would like permission to use the following figures in my thesis, titled, "THE INFLUENCE OF WINDWARD PARAPETS ON THE HEIGHT OF LEEWARD SNOW DRIFTS AT ROOF STEPS."

Figure 6 - Scattergram of Actual Drift Height versus Predicted Drift Height

From: O'Rourke, M. J., Speck Jr, R. S., & Stiefel, U. (1985). Drift snow loads on multilevel roofs. Journal of Structural Engineering, 111(2), 290-306.

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Thank you!

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