GROUND TO ROOF CONVERSION FACTORS

FOR SNOW LOADS

by

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Introduction

The purpose of this report is to present an analysis of snow load case history data, in order to determine the effect of various parameters on the ground-to-roof conversion factor. The ground-to-roof conversion factor is a ratio of the roof snow load to the ground snow load. The data was gathered by Don McLaughlin and George Duggan as part of their masters project at Rensselaer Polytechnic Institute. A paper describing the data collection procedure appears in this Conference Proceedings. In their project report the ground and roof snow load and their configurations were documented for 21 students located in the Troy, New York area, for the 1975-1976 winter season. Of the 21 structures considered in that report, roughly half of the roofs were flat, with the exposure level varying from fully exposed to relatively sheltered. The remaining roofs range from 5° to 60° in slope and all the sloped roofs were semi-sheltered. The thermal characteristics of the roof were represented by an estimated R value (resistance to heat flow). These estimated R values range from 4.25 to 15.88 for the structures in that study. Table 1 contains a listing of the slopes, exposure, and estimated R values for each of these structures.

The winter of 1975-76 was not a good season for snow in the Troy area. The total snow fall of 50.6 in. was below the historic average of 66.1 in. As seen in Table 2, of the four snow storms for which snow readings could be taken, only two had ground snow accumulation over 10 inches. Because of the relatively long time between snowfalls, the snow on both the ground and roof melted and/or evaporated before the next snowfall. Hence each storm has to be treated as a separate event; snow falling on a bare roof. This is unfortunate, since it eliminates the possibility of investigating the buildup and compaction of snow over a series of snow storms.

The specific parameters relating to the ground-to-roof conversion factor which are considered in this report are:

a) The exposure of the roof to wind;
b) Wind speed during and after the storm;
c) Slope of the roof;
d) Parapets and equipment on the roof.

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Data Reduction

The raw data which is analyzed in this report consists of average ground snow depth and ground snow density readings along with depth contours of the roof snow and roof snow density readings, for a number of days during the 75-76 winter. It should be noted that the roof density samples for sloped roofs were taken close to the edge of the roof for reasons of safety. Also, for light snowfalls a number of density samples were taken from drifts which may not accurately represent the actual average density. Presented in Table 3 are the average ground snow depth, the average ground snow density, and the range of the ground snow density sample readings, as well as the average depth, average density and density range for the roof snow. Also presented in Table 3 is the area of the roof, as a fraction of the total area, which had snow cover on the day of the readings. Thus, a sloped roof with one side bare and a uniform load of 8 inches on the other side is considered to have an average of 8 inches of snow and A_r is equal to 0.5. It should be noted that for some of the ground and roof density samples the range is relatively large in comparison to the average value. This fact, coupled with the errors induced by the sampling procedure prevent precise determination of ground-to-roof conversion factors. A further reduction of the data is presented in Table 4. Here the ground-to-roof conversion factors calculated using the average depth and density values for the roof and ground are tabulated. These conversion factors were calculated as follows

$$\text{Conversion factor} = P_r/P_g$$

where

$$P_r = \gamma_r \cdot h_r \cdot A_r$$

$$P_g = \gamma_g \cdot h_g$$

in the above relations h_r and h_g are the average roof and ground depths, γ_r and γ_g are the average roof and ground densities and A_r is the percentage of the roof covered by snow.

Wind Speed During and After the Storm

The most important parameter affecting the conversion factor is the wind speed during and after the storm. Two measures of wind speed were considered, the average wind speed and the fastest mile of wind. For the data analyzed in this report the fastest mile of wind proved the most consistent measure of the propensity of the wind to remove roof snow. The average conversion factor for the structures during each of the four snowfalls and the corresponding fastest mile of wind are presented in Table 5. As one would expect, as the wind increases, the amount of snow on the roof, measured by the conversion factor, decreases. This relationship is portrayed graphically in Figure 1.

Wind Exposure

One would expect that the exposure of a roof to the wind, (i.e., whether the roof is sheltered, semi-sheltered, or exposed) would have a major effect upon its roof's snow load. However, the results from an analysis of the case history data are ambiguous on this point. The vast majority of the buildings investigated in the aforementioned report, were classified by the data-gathers as either wind-swept, or semi-sheltered (few trees and obstructions). For the December 20th storm (fastest mile = 23 miles per hour) the average conversion factor for the semi-sheltered structures was 0.68 with the average conversion factor for the exposed structures being 0.54. But for the March 17 storm, (fastest mile = 38 mph) the average conversion factor for the semi-sheltered and exposed structures were both 0.37. In this regard it should also be noted that if the wind speeds were zero, one would expect the wind exposure would have little effect and the loads would be approximately the same.

The wind exposure rating of a roof, i.e., wind-swept, semi-sheltered, etc., is meant to gage the propensity of the wind to remove snow from the roof. Wind-swept roofs are expected to have a substantial portion of the load removed by wind action, while sheltered roofs are expected to have relatively little snow removed. Presently, the wind exposure rating is a rather subjective measure, defined in broad general terms. As seen from the results of this section, the correlation between these subjective ratings and the actual conversion factors is not good. It is expected that procedures will be developed in the future which will quantify the exposure rating in terms of tree height, effective windward area of trees, distance from the structure as well as parapets and roof equipment. Hopefully with this "better" measure of roof exposure, more precise statements about its effect can be made.

Parapets and Roof Equipment

Both parapets and roof equipment tend to prevent the wind from removing roof snow. The effect of parapets is shown in Table 6 which lists parapet height, the average conversion factors for the December 20 and March 17th storms for 6 structures which are classified as wind-swept and have no roof equipment. Note there is a trend towards increased conversion factors with increase in parapet height. Also note, the average conversion factor for five structures with parapets is 0.51 while the corresponding value for the one wind-swept structure with no parapets is 0.33.

Thermal Effects

As mentioned previously, the thermal characteristics of the roof were quantified by the R value (resistance to heat flow). Once the roofing material and insulation are known, the R value can be estimated by using handbooks and/or manufacturers literature. Unfortunately, for most of the single family homes in this study, McLaughlin, Murphy, Pawlowski, Kinns, Sorrel, and Ensel the attics were sealed and the type and thickness of the insulation could not be determined. For these homes the R value of 13 was assumed. The rest of the structures had R values ranging from between 9.2 and 15.9 except for Aloia, and unheated garage, which had an estimated R of 4.2 and a "sheltered" exposure.

Because actual roof heat flux readings were not taken and for a third of the structures an assumed value for R was recorded on the data sheets no analysis of thermal effects is presented herein.

Slope Effects

Intuitively, the slope of the roof should have an effect upon its snow load. To investigate this phenomenon the average conversion factor for the two heavy snowfalls, are plotted in Figure 2 against the slope of the roofs. The data for Fig. 2 is presented in Table 7. The March 3rd storm was neglected in this plot because that snowfall was light (4 in. average ground depth) and subtle differences in roofs depths were difficult to detect. As can be seen from the plot in Figure 2, there is a general trend towards lower conversion factors for roofs with steeper slopes but a concise relationships between these quantities is not apparent. It should also be noted in this regard that a portion of the Chapel and Cultural Center has a 60° slope and there was no accumulation of snow on that portion of that roof throughout the winter. This can serve as an upper bound for the effect of slope, i.e., if a roof has a slope steeper than 60°, snow loads do not have to be considered in the structural design.

Another aspect of slope roofs, particularly gable roofs, which is of importance, is the effect of aerodynamic shading when the wind blows perpendicular to the ridge. When a strong wind blows parallel to the ridge it can remove most or all of the snow from the roof (e.g., Pawlowski and Lis, March 17th), however, if the wind blows perpendicular to the ridge the windward side is unloaded while additional load is placed on the leeward side. The case histories record three instances in which the leeward side was completely unburdened of its load. (McLaughlin, Murphy and Kinns, March 17th). Table 8 records for these three structures the average ground depth, the average depth on the windward side of the roof, the maximum depth which in all cases is located immediately to the leeward side of the ridge, the average leeward depth and the minimum leeward depth, which in all cases is located at the eave. Note that the snow load distribution is similar in all three cases and is characterized by a uniform load on the leeward side of approximately 70% of the ground depth on top of which is added a triangular distribution, zero at the eave and equal to the average ground load at the ridge.

Conclusions and Recommendations

Snow load case histories were analyzed to determine the effect of various parameters on the ground-to-floor conversion factor. The data from these case histories is quite variable and also corresponds to snowfalls on bare roofs (i.e., no accumulation from storm to storm). Hence, exact relationships between the parameters cannot be drawn from this data alone. However, the following trends and tentative recommendations seem appropriate.

1. There is a good relationship between the roof snow load and the fastest mile of wind during and after the snowfall.
2. A more quantitative measure of the roof exposure rating is needed which includes the effect of parapets and roof equipment.

3. There is a trend towards decreased conversion factor with increasing slope.

4. For gable roofs the following load case should be considered, no load on the windward side and two loads on the leeward side. The first a uniform load of approximately 70% of the ground load to which is added a triangular distribution zero at the eave and equal to the ground snow load at the ridge.

	STRUCTURE	SLOPE	THERMAL RESISTIVITY (R)	EXPOSURE* RATING
1	McLaughlin	26°	13.0	2
2	Murphy	16°	13.0	2
3	Lis	23°	13.0	2
4	Pawlowski	27°	13.0	2
5	Kinns	12°	13.0	2
6	Sorrel	17°	13.0	2
7	Ensel	27°	13.0	2
8	Aloia	Flat	4.3	3
9	Berdar's	5°	13.5	2
10	Cohoes C.C.	Flat	12.9	2
11	MRC	Flat	15.9	1
12	Cogswell	Flat	14.2	1
13	Science Center	Flat	13.3	1
14	Comm. Center	Flat	13.5	1
15	Renss. Union	Flat	11.0	1
16	Chapel	Flat	11.3	2
17	Burdett	Flat	14.8	1
18	Bray	Flat	14.8	1
19	Sharp	Flat	15.0	1
20	Norton #29	Flat	9.2	1
21	Norton #20,28	Flat	9.2	1

* EXPOSURE RATING
1 - Exposed (wind-swept)
2 - Semi-sheltered (some trees or obstructions)
3 - Sheltered

TABLE 1 LIST OF STRUCTURES

TABLE 2 CLIMATOLOGICAL DATA FOR ALBANY, N.Y. (1975-76 Winter)

DATE OF STORM	SNOWFALL (in)	AVERAGE WINDS (MPH)	FASTEST SUSTAINED WIND (MPH)	GENERAL DIRECTION	COMMENTS
12/20/75 to 12/22/75	11.9	11.0	23.0	N/W	Light Snow
2/3/76	2.9	20.0	50.0	N/W	High Winds
3/2/76 to 3/3/76	3.6	10.0	13.0	S	Wet, Heavy Snow
3/17/76 to 3/18/76	10.0	16.0	38.0	N/W	Light Snow
Minor storms	22.2				

STRUCTURE	DATE	GROUND DEPTH (in)	AVERAGE ROOF DEPTH (in)	AVERAGE GROUND DENSITY ($\#/ft^3$)	AVERAGE ROOF DENSITY ($\#/ft^3$)	RANGE GROUND DENSITY ($\#/ft^3$)	RANGE ROOF DENSITY ($\#/ft^3$)	A_r
Renns. Union	12/23	9	5	11.2	11.4	1.9	5.0	1.0
"	1/14	8	2	24.4	25.8	1.2	8.8	0.25
"	2/4	3	2	13.1	13.3	0.0	2.3	1.0
"	3/17	9	5	10.4	11.1	1.0	1.8	0.75
Chapel	1/14	7	2	22.1	-	1.3	-	0.2
"	3/17	8	5	11.0	12.6	1.3	0.9	1.0
Burdett	12/23	9	7	9.9	9.0	0.6	1.25	1.0
"	2/4	3	6	12.8	13.0	2.5	2.0	0.2
"	3/17	9	9	8.5	7.8	1.0	2.5	1.0
Bray	12/23	9	4	11.5	15.0	0.8	2.6	0.8
"	2/4	3	2	13.5	13.3	1.0	1.5	0.05
"	3/17	9.5	4	10.1	9.5	0.5	2.6	0.4
Sharp	12/23	9	6	11.6	10.6	1.6	3.3	1.0
"	2/4	3	3	13.3	13.8	1.0	1.5	0.2
"	3/17	9	4	10.7	10.5	1.8	1.4	1.0
Norton (#20, 28)	2/4	3	1	12.0	12.8	3.1	1.9	1.0
"	3/17	9	2	10.2	9.6	0.6	4.9	0.5

TABLE 3 GROUND & ROOF SNOW DEPTHS AND DENSITIES (continues)

STRUCTURE	DATE	GROUND DEPTH (in)	AVERAGE ROOF DEPTH (in)	AVERAGE GROUND DENSITY ($\#/ft^3$)	AVERAGE ROOF DENSITY ($\#/ft^3$)	RANGE GROUND DENSITY ($\#/ft^3$)	RANGE ROOF DENSITY ($\#/ft^3$)	A_r
MRC	12/23	10	3	10.5	14.2	0.3	5.6	0.8
"	1/14	8	0	24.1	-	6.0	-	-
"	2/4	3	1	13.6	-	2.4	-	-
"	3/17	9	2	10.3	10.6	1.0	1.38	0.75
Cogswell	12/23	10	5	10.5	11.7	0.3	4.3	1.0
"	1/14	8	4	24.1	21.5	6.0	13.1	0.4
"	2/4	3	6	13.6	12.5	2.4	2.0	0.25
"	3/17	9	8	10.0	10.3	1.6	0.9	0.75
Science Cntr.	12/24	7	3	12.8	13.6	0.3	2.1	1.0
"	1/14	8	3	24.1	21.3	6.0	7.5	0.4
"	2/4	3	4	13.9	12.8	0.8	3.6	0.2
"	3/17	9	4	10.5	10.9	1.3	1.0	0.6
Comm. Center	12/24	7	4	12.8	12.6	0.3	3.5	1.0
"	1/14	9	1.5	22.4	-	2.3	-	1.0
"	2/4	3	2.5	14.3	14.3	0.6	1.5	0.25
"	3/17	9	1.5	10.7	10.1	1.8	0.8	0.75

TABLE 3 GROUND & ROOF SNOW DEPTHS AND DENSITIES (continues)

STRUCTURE	DATE	GROUND DEPTH (in)	AVERAGE ROOF DEPTH (in)	AVERAGE GROUND DENSITY ($\#/ft^3$)	AVERAGE ROOF DENSITY ($\#/ft^3$)	RANGE GROUND DENSITY ($\#/ft^3$)	RANGE ROOF DENSITY ($\#/ft^3$)	A_r
Sorrel	12/27	6	6	14.5	14.0	4.3	1.5	1.0
"	3/3	4	3.25	22.9	22.2	2.0	1.1	1.0
"	3/18	10	4.75	10.1	9.3	1.5	0.9	1.0
Ensel	12/27	8	4	16.1	14.8	1.9	0.9	1.0
"	3/3	4	3	22.9	22.1	1.6	1.5	1.0
"	3/18	10	4	10.8	10.1	1.8	0.9	0.5
Aloia	12/24	10	8	12.1	10.0	1.6	2.0	1.0
"	1/13	9	15	11.0	11.6	10.0	10.0	1.0
"	2/4	3.5	4	15.7	15.1	9.5	9.5	0.8
"	3/18	10	8	9.8	9.1	1.5	0.6	1.0
Berdar's	12/24	7	5	12.4	11.8	4.3	3.1	1.0
"	1/13	12	8	12.9	10.0	12.4	4.4	1.0
"	2/4	5	2.5	17.0	13.4	8.9	0.5	0.33
"	3/18	8	5	11.0	10.2	0.5	0.9	1.0
Cohoes C.C.	12/27	7	2	14.9	16.7	2.0	4.5	1.0
"	2/4	5	1	14.3	14.0	0.9	0.3	0.75
"	3/18	8	2.5	10.6	10.8	1.3	1.9	0.66

TABLE 3 GROUND & ROOF SNOW DEPTHS AND DENSITIES (Continues)

STRUCTURE	DATE	GROUND DEPTH (in)	AVERAGE ROOF DEPTH (in)	AVERAGE GROUND DENSITY (#/ft^3)	AVERAGE ROOF DENSITY (#/ft^3)	RANGE GROUND DENSITY (#/ft^3)	RANGE ROOF DENSITY (#/ft^3)	A_r
McLaughlin	12/22	10	13	12.6	10.2	1.2	2.4	0.75
"	12/27	6	6	14.1	12.8	1.9	0.6	0.75
"	3/3	4	3	20.4	19.9	2.5	2.1	1.0
"	3/18	10	10	10.8	11.1	1.8	1.6	0.5
Murphy	12/22	10	10	10.6	9.2	3.3	1.0	1.0
"	3/3	4	3	22.0	22.9	1.1	1.3	1.0
"	3/17	10	10	9.8	10.3	1.4	1.4	0.5
Lis	12/22	10	7	11.4	10.8	0.8	1.0	1.0
"	12/27	6	4	15.1	14.9	1.4	1.5	1.0
"	3/3	4	3	21.7	21.1	1.9	1.9	1.0
"	3/18	10	3	8.8	8.7	1.5	0.9	0.06
Pawlowski	12/22	10	7	11.4	9.9	0.8	0.9	1.0
"	12/27	6	4.5	15.1	15.7	1.4	1.4	1.0
"	3/3	4	3	21.7	21.4	1.9	2.0	1.0
"	3/18	10	4	8.8	9.6	1.5	0.6	0.12
Kinns	12/22	10	8	9.46	9.3	0.9	0.7	1.0
"	3/3	4	3	22.1	21.7	0.8	0.9	1.0
"	3/18	9	7	10.4	9.8	1.0	1.3	0.75

TABLE 3 GROUND & ROOF SNOW DEPTHS AND DENSITIES

DATE OF STORMS

STRUCTURE	12/20/75	2/3/76	3/3/76	3/17/76
McLaughlin	0.79	–	0.73	0.51
Murphy	0.87	–	0.78	0.53
Lis	0.67	–	0.73	0.02
Pawlowski	0.61	–	0.74	0.05
Kinns	0.78	–	0.74	0.55
Sorrel	0.97	–	0.79	0.44
Ensel	0.46	–	0.73	0.18
Aloia	0.67	0.88	–	0.74
Berdar's	0.68	–	–	0.58
Cohoes C.C.	0.32	0.14	–	0.21
MRC	0.32	–	–	0.17
Cogswell	0.56	0.46	–	0.68
Science Center	0.45	0.24	–	0.28
Comm. Center	0.56	0.21	–	0.12
Renss. Union	0.57	0.66	–	0.44
Chapel	–	–	–	0.71
Burdett	0.71	0.41	–	0.91
Bray	0.58	0.03	–	0.16
Sharp	0.61	0.21	–	0.44
Norton	–	0.35	–	0.10
Average	0.63	0.36	0.75	0.39

TABLE 4 GROUND-ROOF CONVERSION FACTORS

DATE OF STORM	FASTEST MILE OF WIND (MPH)	AVERAGE CONVERSION FACTOR
3/3/76	13	0.75
12/20/75	23	0.63
3/17/76	38	0.39
2/3/76	50	0.36

TABLE 5 AVERAGE CONVERSION FACTORS AND FASTEST MILE OF WIND

STRUCTURE	PARAPET HEIGHT (in.)	AVERAGE OF CONVERSION FACTORS for 12/20 & 3/17
Comm. Center	0	0.33
Bray	6	0.37
Renss. Union	14	0.50
Sharp	18	0.52
Burdett	20	0.81
Science Center	36	0.36

TABLE 6 CONVERSION FACTORS AND PARAPET HEIGHT FOR WIND-SWEPT STRUCTURES WITH NO ROOF EQUIPMENT

STRUCTURE	SLOPE	AVERAGE CONVERSION FACTOR FOR 12/20 & 3/17
Kinns	12°	0.66
Murphy	16°	0.70
Sorrel	17°	0.70
Lis	23°	0.34
McLaughlin	26°	0.65
Pawlowski	27°	0.33
Ensel	27°	0.33
Chapel	60°	0.00

TABLE 7 AVERAGE CONVERSION FACTORS AND SLOPES

STRUCTURE	AVERAGE GROUND DEPTH (in)	AVERAGE WINDWARD DEPTH (in)	MAXIMUM LEEWARD DEPTH (in)	AVERAGE LEEWARD DEPTH (in)	MINIMUM LEEWARD DEPTH (in)
McLaughlin	10	0	20	16	8
Murphy	10	0	18	12	6
Kinns	9	1	15	12	7
Average	9.66	0.33	17.6	13.3	7

TABLE 8 UNBALANCED LOADS - GABLE ROOFS

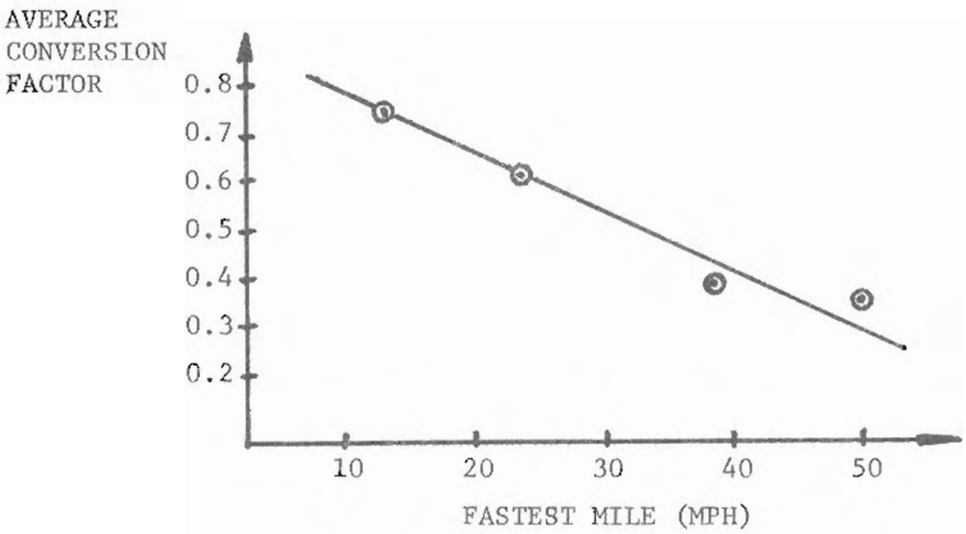

FIGURE 1 AVERAGE CONVERSION FACTORS VS FASTEST MILE OF WIND

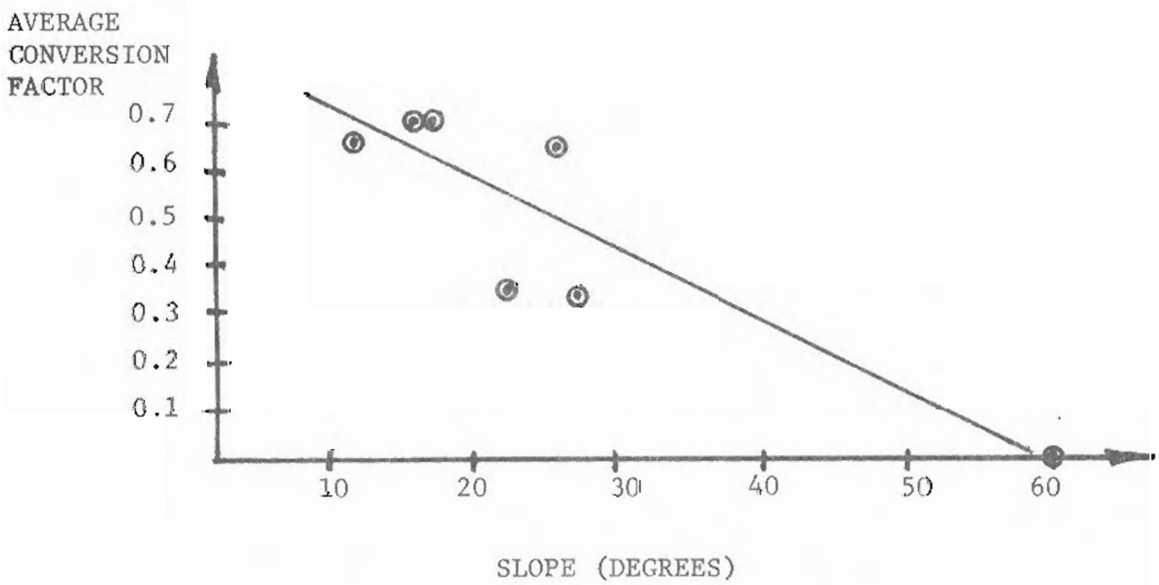

FIGURE 2 AVERAGE CONVERSION FACTOR VS SLOPE