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Snow Loads on Two-Level Flat Roofs

by D.A. Taylor

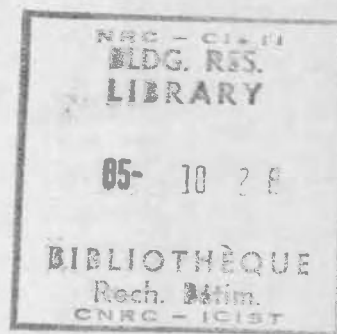
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RÉSUMÉ

Entre 1967 et 1982, dans le cadre d'une étude réalisée à l'échelle nationale, on a mesuré les charges de neige sur les toitures-terrasses à deux niveaux de cinq bâtiments situés à Ottawa. Les premiers résultats indiquent que la densité moyenne de la neige est de 0,295, soit environ 15% de plus qu'au sol (0,257) alors que les valeurs recommandées dans le Code national du bâtiment sont respectivement de 0,245 et 0,20. Les congères de neige et les charges correspondantes étaient conformes aux recommandations du Code. Les longueurs des congères étaient inférieures au double de la différence de hauteur entre les deux niveaux de toit.

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SNOW LOADS ON TWO-LEVEL FLAT ROOFS

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ABSTRACT

Between 1967 and 1982, snow loads were recorded on five two-level flat-roofed buildings in Ottawa as part of a Canada-wide survey. Preliminary analysis of the data indicates that the average snow density on flat roofs is 0.295, about 15% higher than that on the ground, 0.257, while the recommended values in the National Building Code of Canada are 0.245 and 0.20 respectively. The sizes of the snow drifts and the drift loads were within the design recommendations of the Code. The lengths of drifts were less than twice the difference in elevation between the upper and lower roofs.

INTRODUCTION

The "triangular" snow drifts that form at the junction between high- and low-level flat roofs must be properly accounted for in structural design. Currently there are some doubts concerning the adequacy of the height and length of such drifts specified by building codes. The density of snow in drifts is also in question. Is it higher than that generally recommended for design? Field studies by the Division of Building Research (DBR), National Research Council of Canada, provide some of the answers.

In 1956 DBR started a Canada-wide survey of snow loads on roofs. Many roof shapes including single- and two-level flat roofs were observed regularly for 10 winters and others less formally on a "case history" basis whenever very deep snow was encountered. As a result of this early research, average design snow loads in the National Building Code of Canada (NBC) were reduced, saving millions of dollars annually. Further, specific design information on drift loads was included in the NBC to avoid local collapses in heavily loaded areas.

SURVEY OF TWO-LEVEL FLAT ROOFS

In 1967 DBR decided to study industrial flat-roofed warehouses or production facilities with office annexes having lower roofs. Buildings at eight locations across Canada were chosen for study. The survey continued at five locations, some until 1982, and encompassed about 40 roofs in all. An overwhelming amount of work is required to interpret the measurements, many of which were taken under poor conditions of snow, rain, wind, and very cold temperatures. The results presented in this paper are only a preliminary look at the data obtained from a small sample: five two-level flat roofs in Ottawa, all within a mile of each other in an industrial park.

Formation of Drifts

When wind encounters a sharp-edged building obstructing its flow, a large separation bubble forms at the upstream or windward edge of the roof as shown in Figure 1. Snow that lands in the bubble area or that was deposited there before the wind started, may be carried upstream if the velocity is high enough. The flow over the bubble attaches itself to the roof surface further along (if the roof is long enough) and snow landing in the region of reattached flow is carried downstream by turbulent diffusion (Isyumov 1971). It

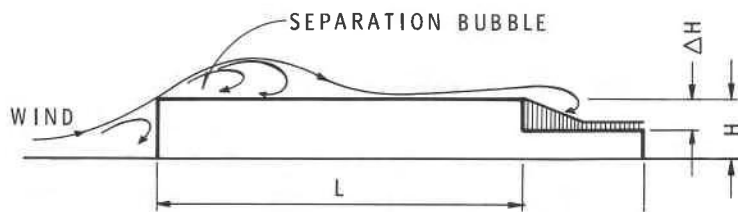


Figure 1. Wind flow patterns over roof showing separation bubble

is deposited finally in the region of the low speed wake, below the upper roof. If, however, the upper roof is too short, the separation bubble will be too large for reattachment of the flow, the snow will be dispersed and little will be deposited in a drift on the lower roof. Drifts that do form are shaped and reshaped by winds blowing from many directions during and after storms, although eventually sun, wind, rain and high temperatures will "set" the surface of the snow, largely preventing further erosion.

Except in unusual circumstances, ground snow does not blow onto a roof in significant quantities unless the wind is of sufficient speed and duration to cause a ramp-like drift (Figure 2) at the upstream wall, allowing snow to travel up the ramp to the roof (Taylor 1979; Templin and Schriever 1982).

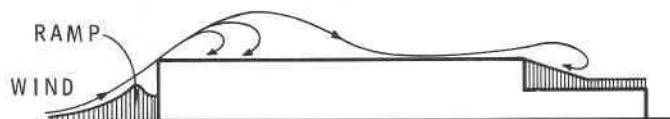


Figure 2. Snow drifts on roof. A drift may form on the windward side of the building which acts as a ramp for ground snow to gain access to the roof

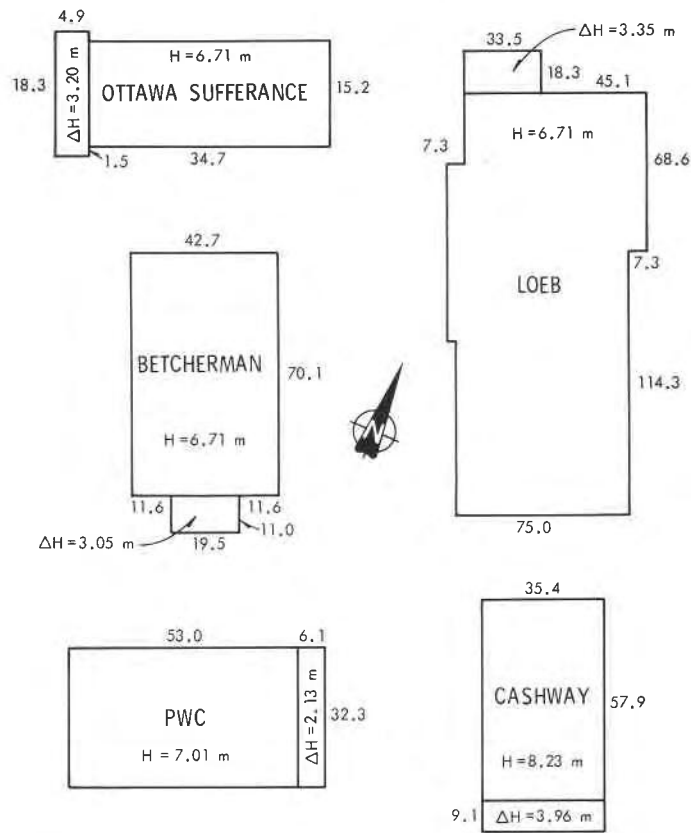
Orientation and Geometry of Roofs in the Survey

The five roofs in the survey are shown in Figure 3 in their proper orientation to true North. Prevailing winter winds are E, ENE and W, WNW; the "Loeb" building does not, therefore, collect high drifts because the prevailing winds sweep across the low roof towards the high. The buildings vary from 35 m (114 ft) to 183 m (600 ft) in length. The heights of the uppermost roofs vary from $H = 6.71$ m to 8.23 m (22 to 27 ft) above grade, while the difference in roof elevations, ΔH , varies from 2.13 m to 3.98 m (7 to 13 ft).

Measurements of Depths and Densities

As noted before, snow is deposited in drifts on the lower level of two-level roofs, at the junction between the high and the low (Figure 4) (Taylor 1980). The usual measurements taken on roofs to describe such drifts are depth profiles at a number of sections through the drifts, and densities. While the majority of densities were measured in the drifts, depths were also taken over the upper and lower roofs. Both depths and densities are used to compute the loads needed by designers. Aerodynamicists, on the other hand, generally assume that snow is a homogeneous mass of constant density. They are more interested in the depth profiles when they model snow drifting on roofs in wind tunnels or water flumes.

Measurements of depth and density were taken with metre sticks and sampling tubes. Prior to 1978 densities were obtained by taking samples horizontally (from a vertical section cut through the full depth), using an 86-mm (3.4 in.) 250-mL tube. The samples were placed in closed containers and weighed in the laboratory. During the winter of 1977-78, however, a vertical tube sampler, MSC type 1, was introduced. One m (40 in.)



DIMENSIONS ARE IN METRES

Figure 3. Plan view of buildings showing sizes and orientations to true north. Note that the scales are different from building to building



Figure 4. Photo of large 'triangular' drift on Ottawa Sufferance, mid-January 1978

long and 70 mm (2.78 in.) in diameter, this tube is inserted vertically into the snow with a careful twisting action, allowing the sharp cutting teeth to penetrate crust and ice layers. When the cutting edge reaches a plate inserted to protect the roof covering, the sample is removed and weighed on location. Such measurements were made after major snowstorms or at monthly intervals if more than 15 cm (6 in.) of snow were present; corresponding measurements of ground snow were taken at the same time.

Because there are few data available on snow densities on roofs, the results from this survey are important. There would be more except that good density measurements, especially through layers of new and old snow, ice at any level, and slush and water at the roof surface, are particularly time consuming and difficult to obtain. On the other hand, depth measurements are relatively easy to take unless there are thick ice layers in the snow pack or at the roof surface. As a result there are many more data on depths than densities available in DBR files of field surveys. Statistical analysis of densities or, preferably, specific gravities, are needed for prediction of loads for NBC purposes and for investigations of failures when only depths are available. The specific gravities of roof and ground snow are shown in Figures 5 and 6 respectively. The scatter is large (coefficient of variation = 0.25 (ground) and 0.28 (roof)), but there is a useful correlation (0.69 ground and 0.49 roofs) between increased specific gravity and the date. Although the correlation is significant, it does not provide any precise way of estimating densities. It is noteworthy that the average specific gravity measured on these roofs in Ottawa is 0.295, about 15% greater on average than for ground snow (0.257). The average values as shown in Figures 5 and 6 are reached by about February 6 and they exceed the NBC values by about 20% for roof snow and 28% for ground. The differences between roof and

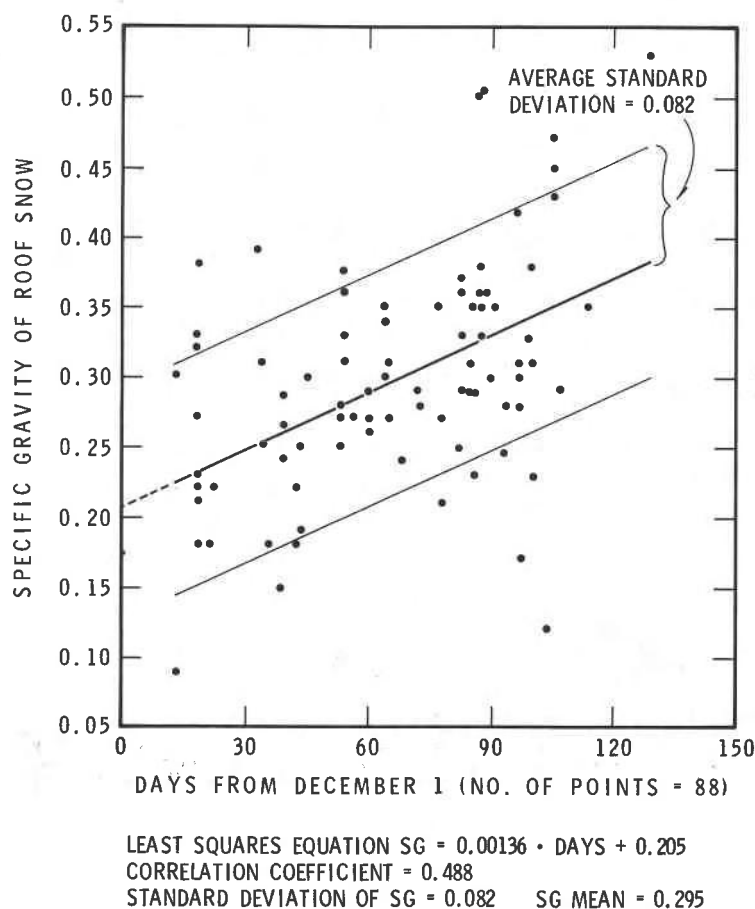


Figure 5. Specific gravity, SG, of roof snow on two-level flat roofs in Ottawa versus the date (number of days from Dec. 1)

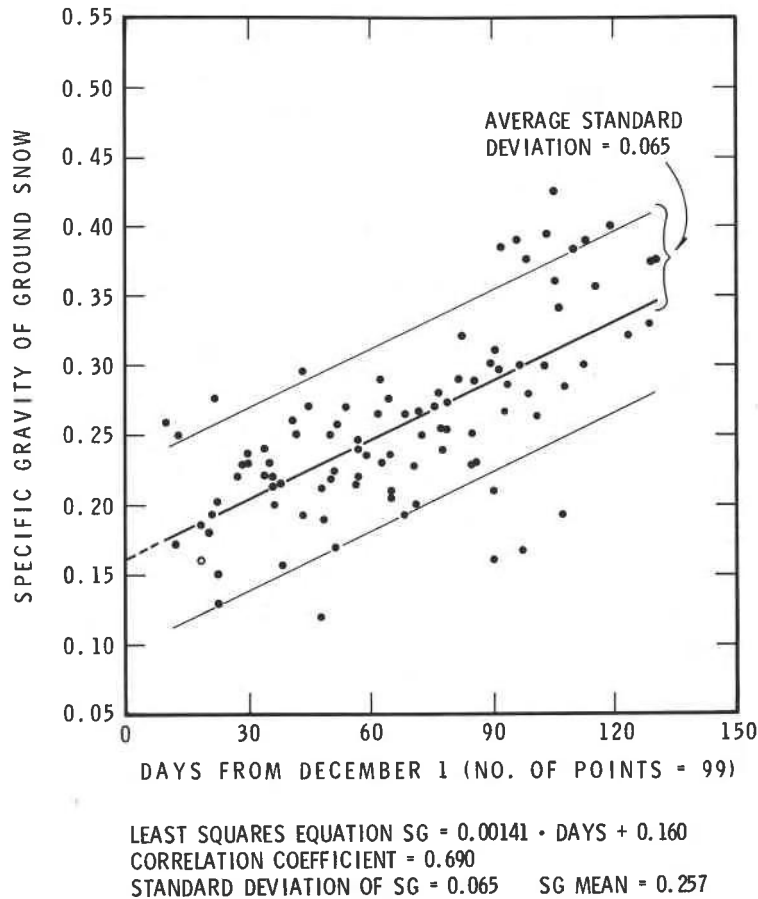


Figure 6. Specific gravity, SG, of ground snow in Ottawa versus the date (number of days from Dec. 1)

ground occur, in part, because of heat loss through the roofs and because of ice layers, and slush and water at the roof surface unable to drain away. This denser material increases the average specific gravity of the overall snow cover, although the deeper the snow, the less important a relatively thin, heavy layer becomes. It is interesting to note, as well, that the specific gravity was poorly correlated with snow depth.

Duration of Surveys

Depths and densities have to be measured for a number of years to give confidence that the heaviest drifts observed are near enough to the maxima to give the degree of safety required in structural design. Figure 7 illustrates that at least five years of observations were required on some roofs, whereas one had only a single high load in 12 years. As a general rule, surveys are conducted for five to 10 years, usually 10; this one continued at some locations, including Ottawa, for up to 15 years. To the best of the author's knowledge this is the longest and most comprehensive survey conducted on such roofs.

Load Profiles

Load profiles (not depths) for the five or six years having the highest measured loads are shown in Figures 8a to 8e. On each of these the design load recommended by the National Building Code of Canada (1985) is also indicated. The only measured loads significantly above those in the Code occurred in 1982 on the PWC building (Figure 8c).

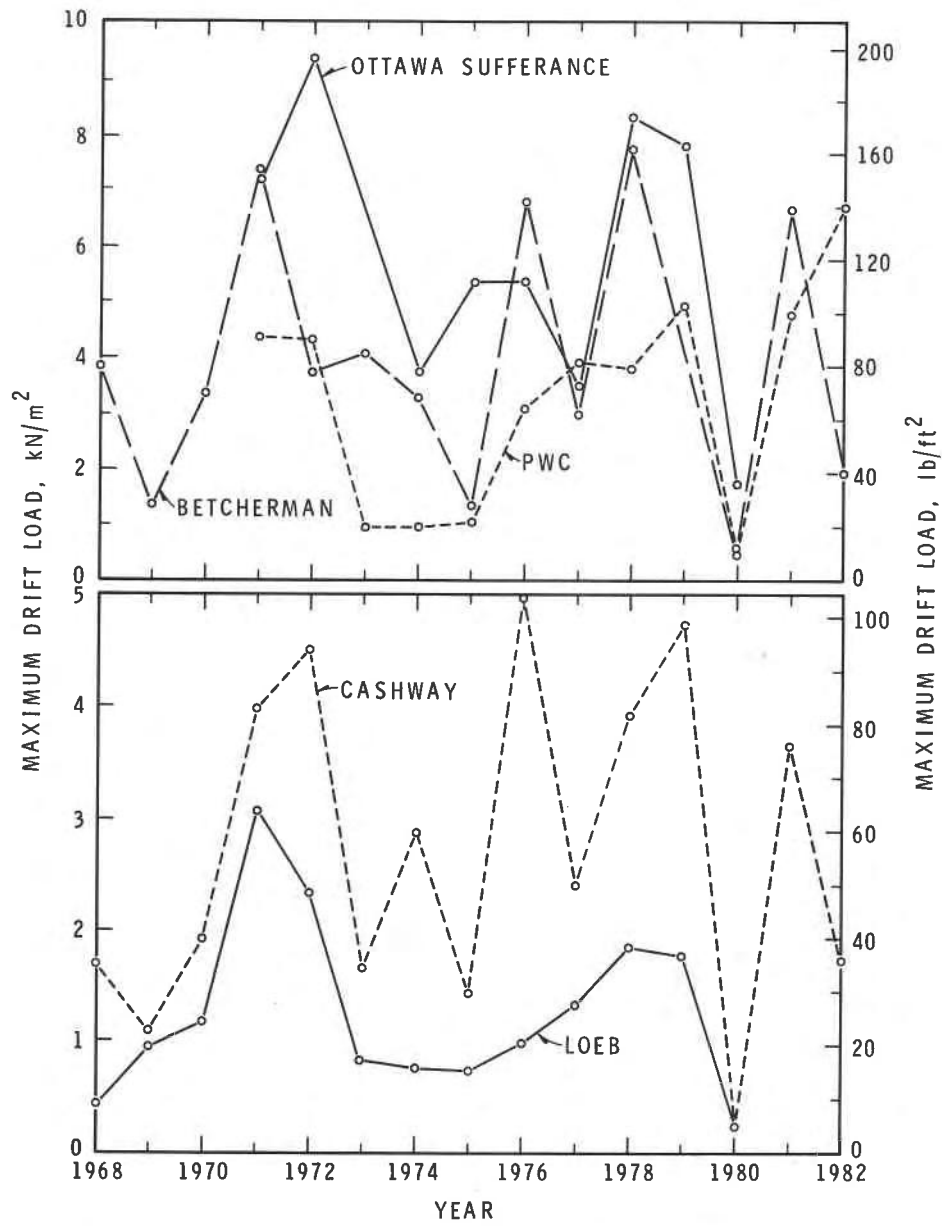


Figure 7. Variation of the annual maximum drift load on five two-level flat roofs in Ottawa

Figures 8a-8e. Drift load profiles on lower roofs of five two-level flat roofs in Ottawa (the x axis is the full length of the lower roof)

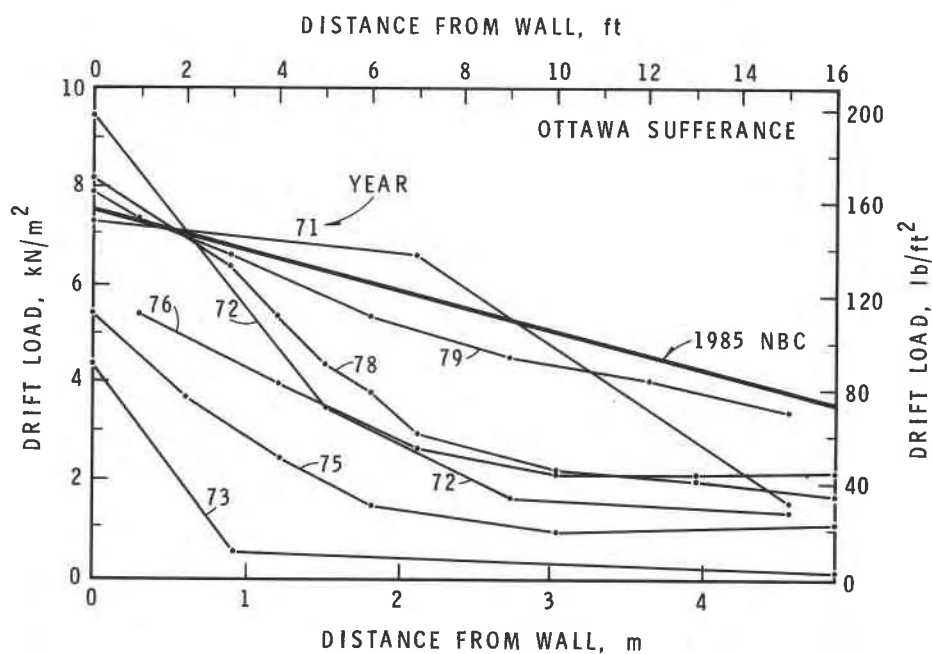


Figure 8a

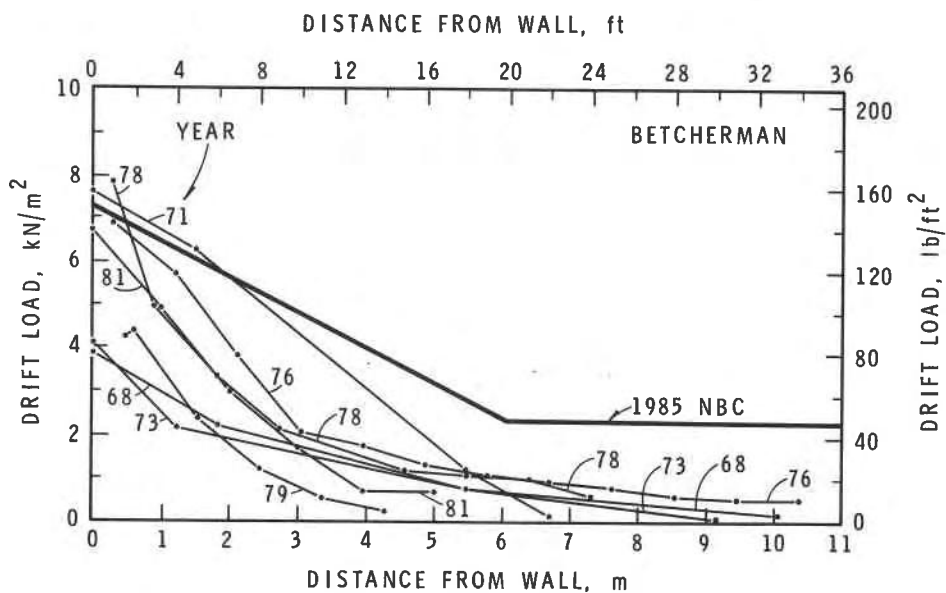


Figure 8b

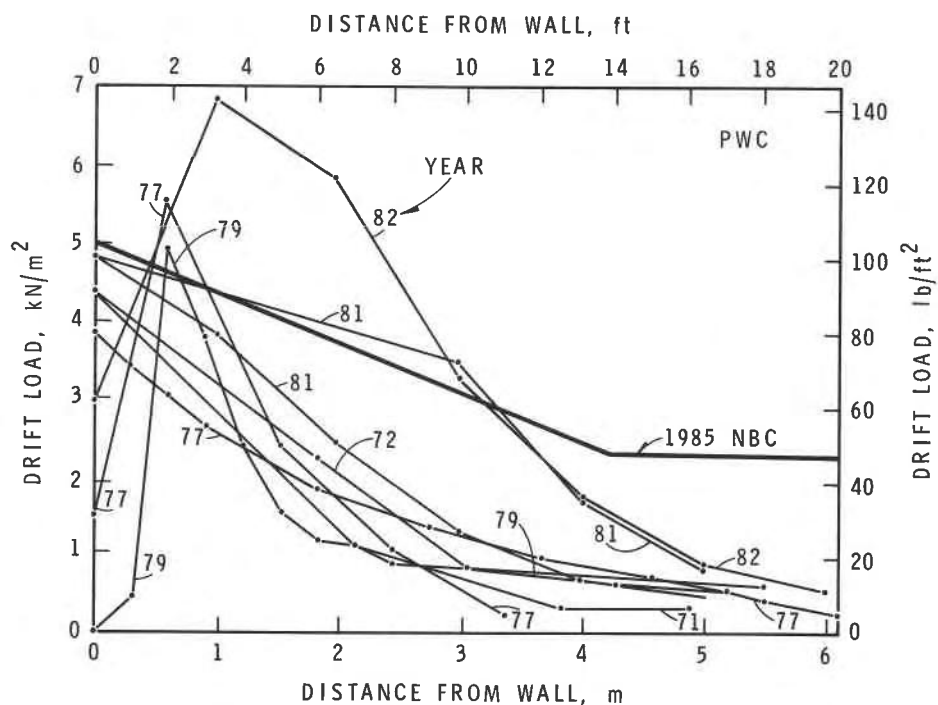


Figure 8c

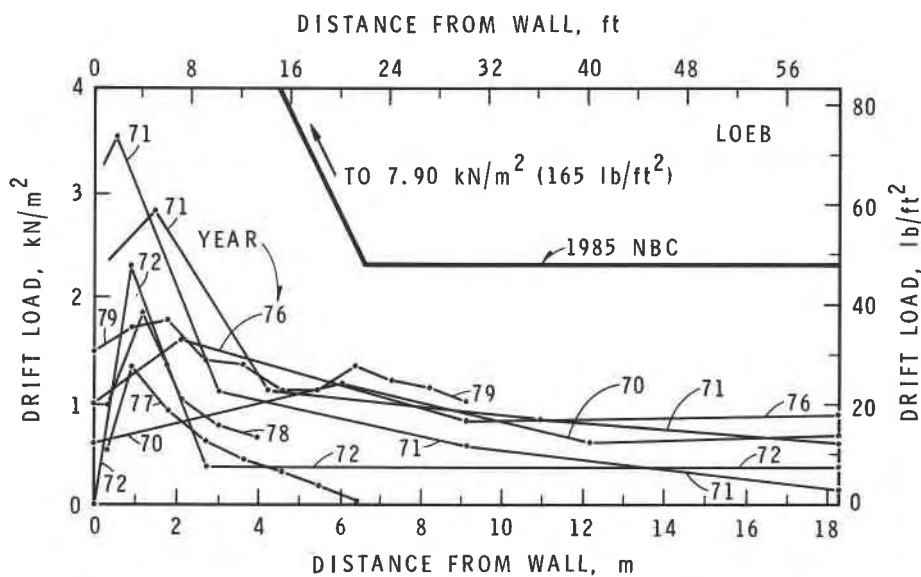


Figure 8d

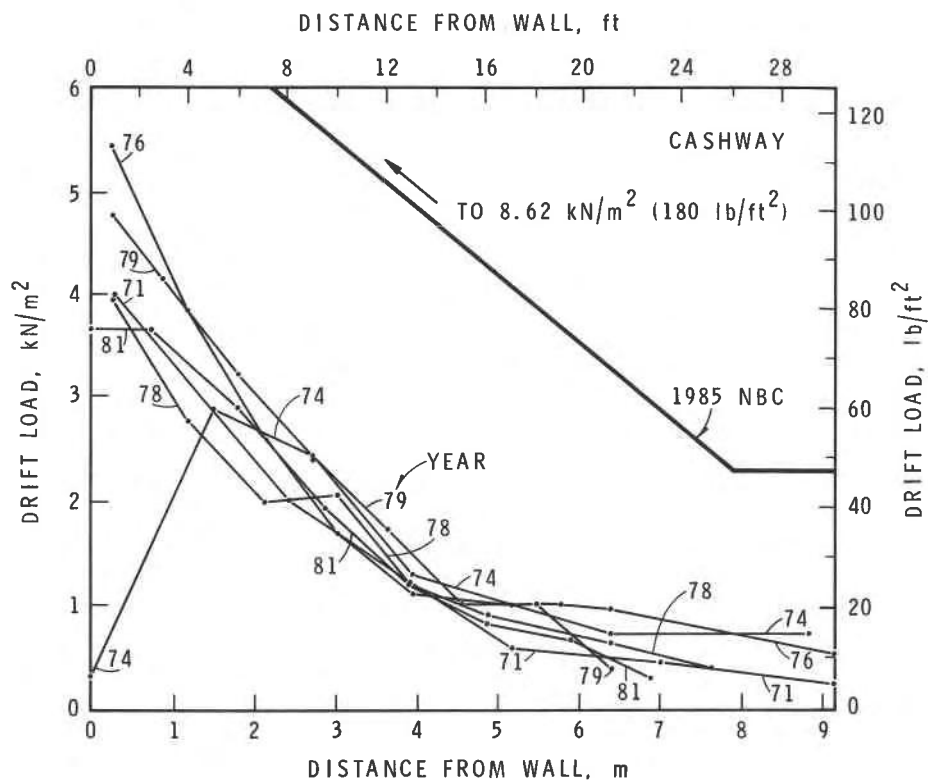


Figure 8e

Although they are not given here, the depths measured on this roof are less than 12% larger than those obtained using the NBC loads and the Code's specific gravity of 0.245. Hence, the snow causing the increase in load must have had a specific gravity greater than the "design" value of 0.245. It did indeed -- 0.36! Although the overload, as high as 57%, is significant and serves as a warning, it is perhaps unwise now to increase the design load, as the overload occurred only once during 12 years of observations. Use of the average measured drift density of 0.295 would have reduced it to about 30%. It is of interest that this load occurred on the roof that had the lowest change in elevation ($\Delta H = 2.1$ m (7 ft)). The author is aware of another case, apart from this survey, where there was a small ΔH and a structural failure due to a large overload from an excessively long drift. Such cases emphasize the need not only for more field data but also for fundamental research on drifting, perhaps using wind tunnels or water flumes*, and a careful examination of the design density of snow in drifts.

Drift Dimensions

In this survey there was no instance of the drift length L_d exceeding the value recommended in the NBC, i.e., $3 \text{ m} < (L_d = 2 \cdot \Delta H) < 9 \text{ m}$. Occasionally the length of a drift was greater than twice its height but these were drifts much smaller than "design" size. Because of the difficulty in deciding where a drift ends, a procedure like that used in the NBC was employed to determine its length: the end of the drift was considered to be at the point where the drift intercepted a "fictitious" uniform snow depth on the lower

*Research using a wind tunnel has been underway at DBR for three years. Two papers now in preparation will be submitted to the Journal of Industrial Aerodynamics:

- 1) da Matha Sant'Anna, F. Snow Drifts on Flat Roofs - Part I, Analytical Approach.
- 2) da Matha Sant'Anna, F. and D.A. Taylor. Snow Drifts on Flat Roofs - Part II, Wind Tunnel and Field Measurements.

roof of 80% of the average depth of ground snow, h_g , measured on the same day. In contrast, for this purpose the NBC uses 80% of the depth of the 30-year return ground snow load, S_o , computed using a specific gravity of 0.245.

Figure 9, showing the non-dimensional lengths of the drifts thus obtained versus the non-dimensional heights, was plotted from the five or six deepest or longest drifts recorded on each of the five roofs. There is a great deal of scatter, part of it due to the different orientations of the buildings. Buildings with different orientations will be affected differently by each snowstorm. Indeed a storm that deposits a drift on one roof may tend to scour one on another. An equation describing the upper limit of the data was derived (Figure 9). It predicts an upper limit of the maximum drift length L_d to be as follows:

$$L_d = 0.54 \cdot \Delta H + 2.2h^*$$

where h^* = the drift height less 80% of the average depth of ground snow on that day and ΔH is the difference in roof elevations.

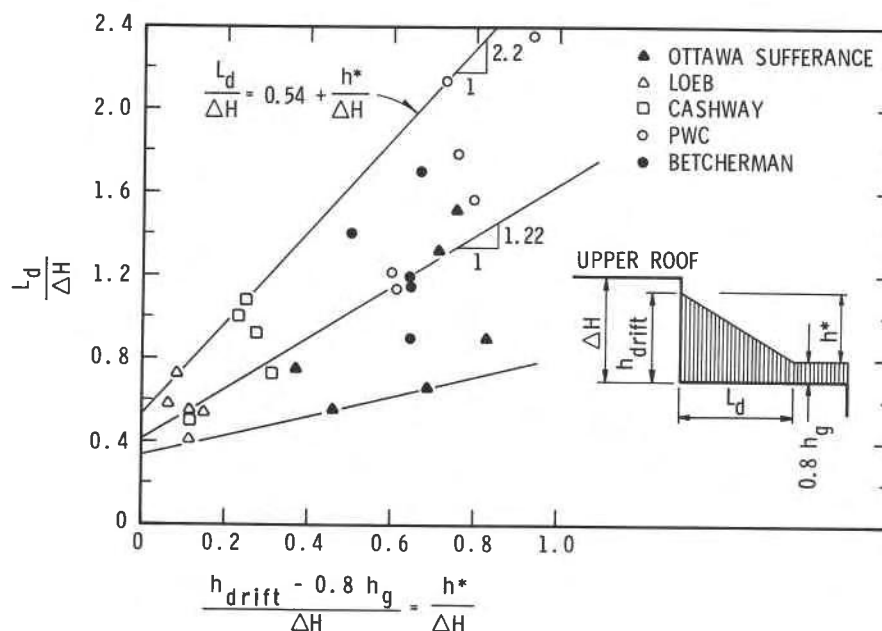


Figure 9. Graph of non-dimensional length of drift, $\frac{L_d}{\Delta H}$, versus non-dimensional height of drift, $\frac{h^*}{\Delta H}$, for the five or six years having the highest and longest drifts

The predicted drift lengths are not much larger than recommended values in the NBC. For example, if "design" values of the maximum drift height are taken from the NBC for Ottawa (30-year return ground load, S_o , of 2.9 kPa (60 psf), density of 2.4 kN/m³ (15.3 pcf), maximum drift height = $3 \times 2.9/2.4 = 3.63$ m (11.9 ft)), and if it is also assumed that the maximum drift height = ΔH , then $L_d = 2.15 \Delta H$, which is only slightly greater than the NBC value of $L_d = 2.0 \Delta H$. Further, if ΔH is 5 m, L_d increases only to $2.32 \Delta H$, some 16% higher than $2.0 \Delta H$ and 29% greater than the NBC limit of 9 m ($3 < L_d = 2 \Delta H < 9$ m).

In any event, it is premature to use an equation derived from such a small sample of the available data as other factors are probably influential. For example, the results of wind tunnel modelling of snow drifting on two-level flat roofs using fine sawdust as the "snow" indicate that the length of drift and indeed its maximum height should be a function of the L/H ratio (where L is the length of the upper roof in the direction of the

wind and H the height of the upper roof above the ground). However, this ratio is less and less important for L/H ratios greater than about 5 and all these roofs are beyond L/H = 5. Moreover, for these roofs in Ottawa, there is very little variation in H so the dependence of the drift length or maximum height on H cannot be determined from the field data alone. When the main body of the data from the rest of Canada is analyzed, the influence of L and H and the ratio L/H may be clearer.

SUMMARY

From a preliminary analysis of the data on snow drifts on five two-level flat roofs in Ottawa, it is apparent that:

1. The density of snow averaged over the winter was 15% higher on the roofs than on the ground, i.e., the mean specific gravity on roofs was 0.295 and that on the ground was 0.257. The specific gravity on roof and ground increased on average about 0.00138 per day from the first day of December.
2. There is no convincing reason to call for a reduction in the design loads. A case could be made, however, for a reduction based on orientation of the building but this is not allowed in the National Building Code except under special conditions.
3. The length of snow drifts as specified in the Code seems to be adequate for the Ottawa area, especially for those buildings in which the difference in elevation, ΔH , between upper and lower roofs is about one storey - 3 to 4 m (10 to 13 ft).
4. Roofs with low ΔH require more study. Such a relatively small volume of snow is required to fill in the Code-sized drift that although there were no observations of such in Ottawa, there is reason to be concerned that the drift length recommended in the Code may be exceeded.
5. Field studies take too long for a systematic study of factors affecting, for example, drift lengths. Modelling of snow drifting on roofs in a wind tunnel or water flume, or analytical models may provide some answers. Field measurements will still be required to confirm their validity.

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