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Deep snow in British Columbia: survey implications for the National Building Code of Canada

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Abstract: This article presents an overview of results from the 1980–1992 survey of snow loads and densities on roofs in deep snow areas of British Columbia with particular emphasis on results from an extensive survey at the ski village on Mt. Washington, Vancouver Island, where the 30-year return ground snow load is 21 kPa. The article makes recommendations for the design of buildings in deep snow areas and, of particular importance to designers, shows for the first time that the National Building Code of Canada (NBCC) procedure for obtaining design snow loads works for such areas. It also shows that the density of roof snow at high loads is about 400 kg/m^3 (one third higher than average NBCC values) and that NBCC recommended roof loads at elevations above the tree line may be excessive. The article also makes suggestions for the management of deep snow on roofs based to a great extent on experience from Mt. Washington.

Key words: snow survey, loads, deep snow, density, snow management, roofs, codes, design.

Résumé : Cet article présente une revue des résultats d'une étude de 1980 à 1992 des charges et densités de neige sur les toits dans des régions de neige profonde en Colombie Britannique, avec une attention particulière aux résultats d'une étude intensive au village de ski du Mont Washington, le de Vancouver où la charge de neige au sol pour une période de retour de 30 ans est de 21 kPa. L'article fait des recommandations pour la conception de bâtiments dans les régions de neige profonde et, d'une importance particulière aux concepteurs, montre pour la première fois que les procédures du Code National du Bâtiment (CNB) pour obtenir les charges de neige sont valables dans ces régions. L'article montre aussi que la densité de neige de toit à des charges élevées est d'environ 400 kg/m^3 (plus élevée d'un tier que les valeurs moyennes du CNB) et que les charges recommandées par le CNB à des élévations au delà de la hauteur d'arbre peut être excessive. L'article fait aussi des suggestions pour la gestion de neige profonde sur les toits basées largement sur l'expérience acquise au Mt. Washington.

Mots clés : étude de neige, charges, neige profonde, densité, gestion de neige, toits, codes, conception.
[Traduit par la Rédaction]

Introduction

Between 1956 and 1966 the Institute for Research in Construction of the National Research Council conducted a general cross-Canada survey of snow loads on roofs with many volunteer observers from British Columbia participating. Following this, a survey of snow on two-level flat roofs was conducted from 1966 to 1981. Although observations were obtained from many areas, few were received from British Columbia. Consequently, with the assistance of the Building Standards Branch in Victoria, the author started a survey of snow loads on roofs in British Columbia, which ran from 1980 to 1992, to assess whether the National Building Code (NBCC 1995*b*) procedure for obtaining design snow loads was appropriate for use in deep snow areas of the province.

Survey results for regions with deep snow are presented in Part I of this article where they are compared with NBCC recommended design loads. Part II deals with special problems that arise in deep snow areas. These relate to building maintenance and human safety and can be addressed by good management of snow on and around buildings. Experience with such problems, though derived from many locations, is illustrated with examples and photographs from Mt. Washington on Vancouver Island and is given in the form of recommendations to avoid such problems. The problems and solutions have, however, wide applicability to deep snow areas of western North America.

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Written discussion of this article is welcomed and will be received by the Editor until August 31, 1997 (address inside front cover).

Part I — The snow surveys

Survey locations

Data were collected during the regular surveys of snow on roofs at Mt. Washington, Rogers Pass, and Whistler. In addition, on a less regular basis, observations were taken at 25 locations around the province (on the itineraries of avalanche technicians), including Castlegar, Cranbrook, Duffy Lake, Fernie, Field, Kootenay Pass, Manning Park, Monashee Pass, Glacier, Golden, Revelstoke, Sparwood, Trout Lake, and the following ski areas: Galena (CMH Camp), Kamloops (Tod Mt.), Kelowna (Big White), Nancy Green Park, Nelson

Table 1. Annual maxima ground snow depths and corresponding densities at 1175 m elevation.

No.	Year	Date	Maximum ground depth (cm)	Corresponding density (estimated) (kg/m^3)	Calculated ground load (kPa)
1	1980–1981	1980-12-03	103		
2	1981–1982	1982-04-13	395		
3	1982–1983	1983-03-13	391		
4	1983–1984	1984-04-14	269	~ 410*	10.8
5	1984–1985	1985-03-28	254	~ 400*	10.0
6	1985–1986	1986-01-27	206		
7	1986–1987	1987-02-04	340	350*	11.7
8	1987–1988	1988-04-06	308	440*	13.3
9	1988–1989	1989-04-05	290	350*	10.0
10	1989–1990	1990-02-05	189	330	
11	1990–1991	1991-02-08	158	220	
12	1991–1992	1992-02-02	206	300	
Average				350	

*Densities corresponding to maximum measured snow depths at the 1175 m weather station. The densities were estimated from values measured at approximately the same elevations (from 1173 to 1183 m) on, or nearly on, the dates of maximum snow depths. The average density corresponding to the five maximum ground loads was about 390 kg/m^3.

(Whitewater), Penticton (Apex Mt.), Rossland (Red Mt.), and Vernon (Silver Star).

Within this province-wide survey, an intensive study was conducted at the ski village on Mt. Washington, Vancouver Island (near Comox/Coutenay), with financial support from the Province. Emphasis in Part I is on the Mt. Washington data, although a summary of the overall survey results is given (Taylor 1991).

Details of the Mt. Washington ski village

The ski village at Mt. Washington is located on the south and southwest faces of the mountain and is exposed mainly to winds ranging from the southwest to southeast directions. Only those roofs rising above the shoulders of the mountain are exposed to winds from the northerly directions. The building sites range from about 1100 to 1185 m above sea level. The valley that runs westward from the east ridge of the mountain is swept by strong east winds which keep the low flat roof of the sewage treatment building in the floor of the valley (at 1098 m) relatively clear of snow. Tall trees are plentiful among the buildings, but any roofs protruding above the trees or above sheltering ridges also show evidence of snow removal by the wind. Buildings vary from single-storey chalets, which are almost buried during deep snow winters, to three- and four-storey blocks of condominiums. Some roofs are flat while others are shed, gable and cruciform (intersecting gable) in plan.

The ground snow survey: 30-year return ground snow loads

At all locations surveyed, observations were made of snow on roofs and ground to enable the results to be compared with NBCC recommended design values. When development of the ski area at Mt. Washington began in 1979–1980, no data from surveys of snow loads on the ground were available. By 1992 there were enough to make an estimate of the 30-year return ground snow load which is needed in the NBCC procedures for deriving design snow loads on roofs. The annual maximum snow depths recorded at the weather station (elevation 1175 m), not far from the ski lodge (Day Lodge), were used. Using the Gumbel extreme value (type I) analysis, as described by Boyd (1961) and as used in the NBCC since 1960, and an average density (390 kg/m^3) corresponding to the five highest ground snow loads with known densities obtained from the survey (Table 1), the 30-year return snow depth was calculated to be 526 cm and the corresponding load, S_s, to be 20.1 kPa. The standard error of the depth (100 cm), the coefficient of variation (19%), and the correlation coefficient ($R^2 = 0.96$) were calculated using the methods described by Newark et al. (1989) of the Atmospheric Environment Service.

Atmospheric Environment Service (AES) also made an estimate of the 30-year return ground snow load for their service to designers using the National Building Code (NBCC 1995*a*). They used observations of ground snow loads versus elevation at a number of mountains throughout south and central British Columbia taken by P. Schaerer and colleagues at the National Research Council (Claus et al. 1984), and by their own observers (D. Etkin, private communication) to give the following:

$$S_s = 20.0 \text{ kPa (at 1175 m elevation)}$$

and

$$S_r = 0.8 \text{ kPa (above 250 m elevation)}$$

where S_r is the rain load associated with the 30-year return snow load S_s. The two approaches give about the same answer, therefore the AES values of $S_s = 20.0$ kPa and $S_r = 0.8$ kPa were used to give a total load $S_o = S_s + S_r = 20.8$ or 21 kPa for elevation 1175 m on Mt. Washington. In the preamble to the tables of climatic factors in Appendix C of NBCC (1995*a*) it states that although the S_s and S_r values are given to the nearest 0.1 kPa, values of S_s typically have an uncertainty of about 20%.

Table 2. Geometry of buildings observed.

Building	Elevation (m)	Length (m)	Width (m)	Roof height (m)	Characteristics	Exposure
Sewage treatment plant	1098	33.3	17.0	3.3	Flat	Exposed
Reception building	1173	19.2	8.6	17.7	Flat	Partially sheltered
Condominium 81	1173	15.2	15.2	15.2	Slope 20°	Partially sheltered
Condominium 85	1179	48.8	15.2	15.0	Flat	Exposed
Day Lodge	1179			13.0	Flat (2 level)	Exposed (but has 1 m high parapets)
Upper roof		18.0	14.5			
Existing lower roof		31.0	21.0			
New lower roof		14.0	21.0			
Overall new roof		45.0	21.0			
RV park building	1179	17.1	13.7	3.4	Flat	Exposed
Maintenance building	1183	18.6	12.2	≈6	Flat	Sheltered

Fig. 1. Day Lodge at Mt. Washington, January 14, 1988.

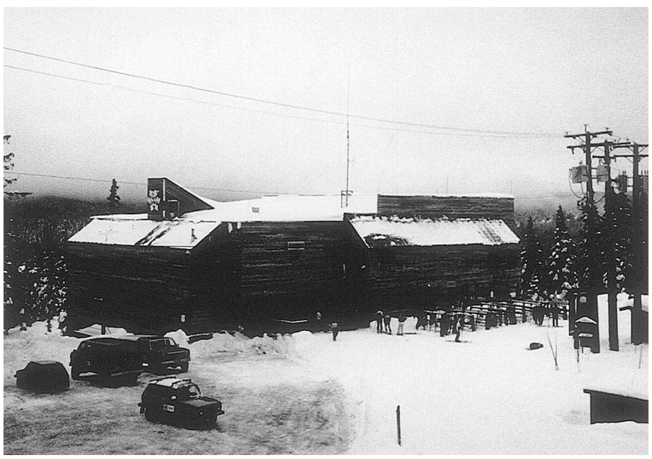


Fig. 2. Condominium 81, April 1983. Very deep snow cannot slide off because the roof slopes towards the hill.

The 1995 National Building Code uses S_s and S_r as described in sentence 4.1.7.1.(1) below to obtain design roof loads:

The specified loading, S, due to snow accumulation on a roof or any other building surface subject to snow accumulation shall be calculated from the formula:

$$[1] \quad S = S_s(C_b C_w C_s C_a) + S_r$$

where S_s (in kPa) is the ground snow load with a 1-in-30 probability of exceedence per year, and S_r (in kPa) is the associated rain load. C_b, C_w, C_s, and C_a are the basic roof snow load factor of 0.8, the wind exposure factor, the slope factor, and the accumulation factor respectively.

The roof snow survey

The province-wide survey was aimed at determining whether the NBCC procedure for deriving design snow loads was adequate for deep snow regions (S_o > 5 kPa). Rogers Pass and Whistler have S_o values of 10 kPa near the mid to low end of the range; Mt. Washington has S_o values of 21 kPa near the upper end. Snow loads were not measured; rather, depths and densities were measured. Densities were obtained by sampling vertically through the snow pack using a "Federal" snow sampler of inside diameter 38 mm and a probe. The probe was used to measure the snow depth to the roof surface. Then the aluminum sampler tube was twisted vertically downward and sections were screwed on as required until the sharp cutting edge of the sampler was stopped just short of the surface. The sampler was withdrawn, the snow core within measured and weighed, and the density calculated.

Measurements at Mt. Washington were taken between 1980 and 1992 on the roofs of the buildings described in Table 2. Two winters were missed, 1982–1983 (the deepest snow year) and 1985–1986, due to observer's injuries. The only two buildings surveyed at Mt. Washington every year in which measurements were taken were Day Lodge (Fig. 1) and Condominium 81 (Fig. 2). Day Lodge, at elevation 1179 m, is a fully exposed two-level flat roof for which only results for the lower roof, 44 m by 21 m, are given. Condominium 81 is 15 m by 15 m in plan and is further along the treed slope at 1173 m elevation. Because it is about three stories high, it is only partially sheltered by the trees. Its roof has an asymmetrical gable with the longest side facing northwest into the hill and sloping at 20°. The other side faces southeast and is too steep for observations.

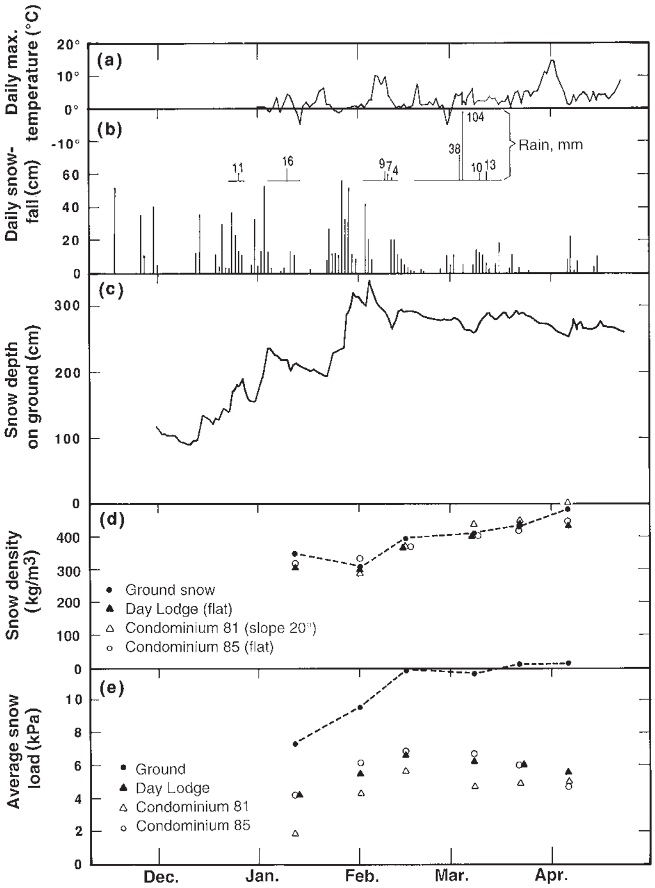


Fig. 3. Temperature and snow data at the Mt. Washington ski village for winter of 1986–1987.

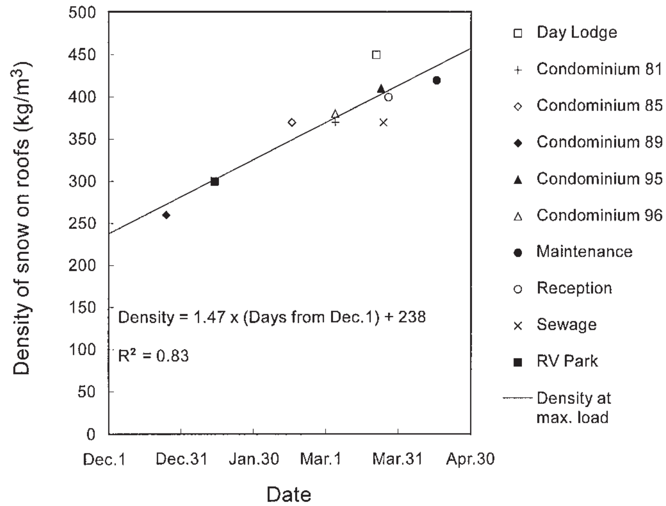


Fig. 4. Density of roof snow versus days from December 1. The straight line is fitted by least squares to those points that correspond to the maximum average load over the whole period of record for each roof surveyed.

Results of surveys

Mt. Washington survey

Temperature and snow data

Figure 3 is presented to show the daily snow and weather data at 1175 m elevation on Mt. Washington for 1986–1987, a heavy snow year. Between November 1, 1986, and April 6, 1987, almost 10 m of snow fell and, as indicated in Fig. 3, it accumulated to a maximum depth of 340 cm on the ground by February 4 and stayed well into April. The density of roof and ground snow differed little after February 1 and increased to an average on April 6 of about 470 kg/m^3, which is far above the NBCC value of about 300 kg/m^3. Unlike at most areas of Canada where the loads are less, the high snow loads on roof and ground were of long duration, with design implications for wood structures and glass skylights because the strength of both is affected by load duration. The ground load was at its maximum for at least 2 months; and the roof loads were close to the maximum for 2½ months. The large rainfalls of 38 and 104 mm on March 3 and 4, respectively, seem to have had only a small influence on the roof snow loads and very little on the ground load. This is likely because the rain melts some snow, reducing the load, but some water is retained in the snow pack which increases the load.

The information plotted in Figs. 4, 6, and 7 was obtained in the following manner: Measurements of depths and densities were made up to six times per winter and, for each roof on each observation day, a spatial average of the snow depths was calculated. An average load was calculated from the measured density. The largest of these averages, for each roof, is the maximum average depth or load for that winter. This "maximum" is equal to or less than the actual maximum depth or load because it is not practical to sample often enough to obtain the true maximum.

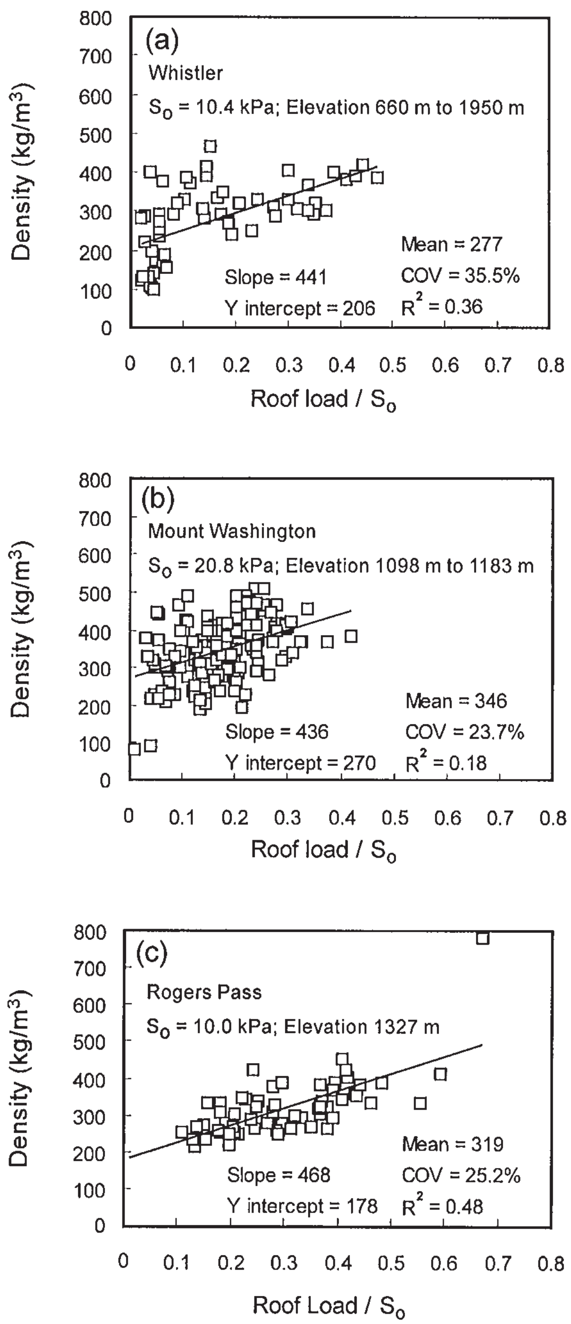
Density of roof snow

The densities of roof and ground snow are important to designers for estimating loads on complicated roof shapes that are not covered by the NBCC Commentary on Snow Loads (NBCC 1995*c*). Further, NBCC Committees need densities for development of the Code; for example, to determine whether the density given in the NBCC (306 kg/m^3) in lieu of better local information is adequate for deep snow regions of British Columbia.

Close correlation between snow density and snow load is not expected. For example, a thin layer of ice remaining on a roof has very high density but does not weigh much. It is, nevertheless, prudent to use densities that correspond to the highest loads because there is a (weak) relationship between density and load.

To obtain a density of roof snow at Mt. Washington that applies to high (close to design) snow loads, only the densities associated with the maximum average load for each roof over the whole period of record were used. These are plotted in Fig. 4, with the straight line being a least squares fit. It can be seen in Fig. 4 that an appropriate density of roof snow for use in design is about 400 kg/m^3, corresponding to the period of maximum roof loads between mid-February and mid-March (Fig. 3). A comparison of all the data from Mt. Washington, Whistler, and Rogers Pass (Fig. 5) shows that for high loads at the three locations the average snow density is approximately 400 kg/m^3, one third higher than the normal value recommended in the NBCC. The product of the average snow

Fig. 5. Data on the variation of roof snow density with non-dimensionalized roof loads at the regular survey locations: Whistler, Mt. Washington, and Rogers Pass.



density at the higher load levels and the 30-year return snow depth gives the 30-year return load.

Roof snow loads
The annual statistics of normalized snow depths and snow loads on the roofs of buildings at Mt. Washington, Day Lodge, and Condominiums 81 and 85 and on the ground are shown in Fig. 6, and for the Maintenance Shop, the Registration Building, the R.V. Park Building, and the Sewage Treatment Plant in Fig. 7. Figures 6*a* and 7*a* show snow depths on ground, and Figs. 6*b* and 7*b* on roof; their relative magnitudes correspond approximately. This gives support for the use of ground snow loads as a basis for design roof loads at Mt. Washington.

Effects of wind: In spite of the fact that at Mt. Washington snowfalls may be wet, this is not always the case and, consequently, the influence of the wind is unmistakable. In some years, as shown in Figs. 6*c* and 6*d*, the normalized loads and depths on Condominium 81 exceeded those on the flat roof of Day Lodge, and vice versa. This probably indicates the influence of the different wind exposures of the two roofs and of sliding and drainage from the sloping roof of Condominium 81. In the winters of 1987–1988 to 1991–1992, measurements were taken on three roofs exposed to the wind (R.V. Park Building, Condominium 85, and Sewage Treatment Plant), one sheltered (Maintenance Shop) and three that were partially sheltered (Day Lodge, only because of its 1 m high parapets, Reception Building, and Condominium 81) (Table 2). The parapets on Day Lodge produce some wind shelter under normal conditions but at design load levels of 10 kPa or more; the depth of snow was more than twice the height of the parapets. Thus Day Lodge is considered “exposed” for design purposes.

The average ratio of maximum average roof load to the 30-year return ground load calculated using the Atmospheric Environment Service equation was 0.25 for the sheltered, 0.23 for the partially sheltered (or 0.24 for the sheltered and partially sheltered taken together), and 0.14 for the exposed roofs. The derivation of factors for wind exposure is given in a following section.

Code comparisons: Figures 6*c*, 6*d* and 7*c*, 7*d* also show that the ratio of the maximum average roof load to the maximum average ground load (or indeed, to the ground load on the same day that the roof load is a maximum) reached a value of 0.8. The design value from the National Building Code of Canada is also 0.8 for roofs not entirely exposed to the wind on all sides. An important point, however, is that the 0.8 (and greater) values did not occur in the heaviest snow years. Figures 6*e* and 7*e* show that even the heaviest average roof loads were only about 34– 38% of the 30-year return ground snow load at Day Lodge and Condominium 81. This is not unexpected in a survey of only 12 winters.

Effects of elevation — all roofs: Figure 8 shows the normalized roof snow loads plotted against elevation, for all locations in the province-wide survey. Maximum loads are as high as $0.7S_o$ at elevations up to about 1350 m, but drop considerably at higher elevations. There are a number of reasons for the reduction above about 1350 m: shelter offered by the trees decreases (near tree line); the buildings observed are primarily at ski hills where they tend to be very exposed; temperatures tend to be lower at high elevations, resulting in less rain and less dense snow; and S_o values increase markedly at high elevations.

NBCC predictions

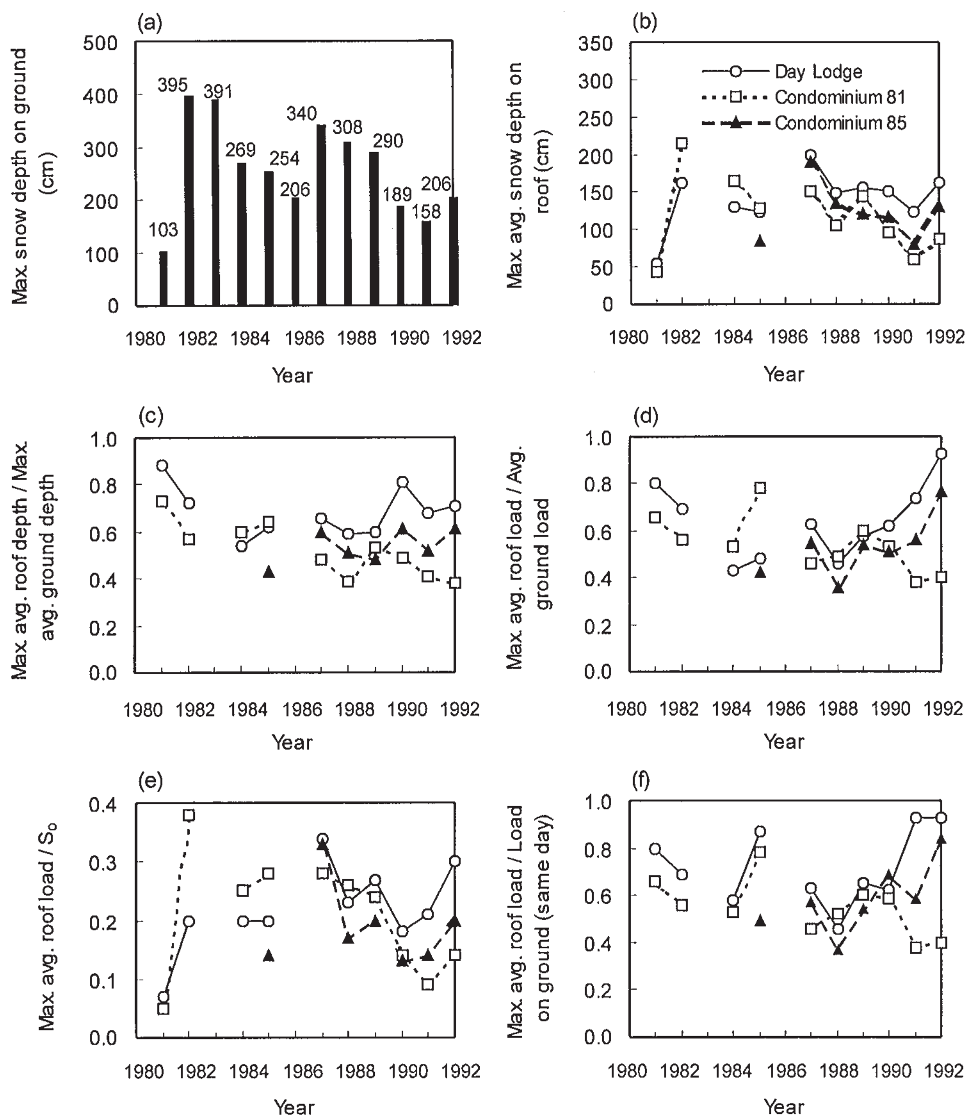
To make realistic predictions of design roof loads, eq. [1] of NBCC (1995) with its factors C_b, C_w, C_s, and C_a requires verification for use in deep snow regions like Mt. Washington. Then, results obtained using eq. [1] should compare favourably

Table 3. Equivalent exposure factors.

Roof	Exposure	Mean MARL/MAGL*	Normalized	C_w (NBCC)
Condominium 85	Exposed	0.548	0.72	0.75
Day Lodge	Exposed (with parapets)	0.666	0.87	0.75
Reception	Partially sheltered	0.648	0.85	1.00
Condominium 81	Partially sheltered	0.539‡	0.71	1.00
Maintenance Shop	Sheltered	0.762	1.00	1.00

* MARL, maximum average roof load; MAGL, maximum average ground load.
‡ Corrected for 20° slope.

Fig. 6. Snow depth and loads on roofs and ground from winters 1980–1981 to 1991–1992, inclusive. No observations were recorded for winters 1982–1983 and 1985–1986 (Year 1981 on the graphs denotes the winter of 1980–81, etc.). S_o, the ground snow load with a 1-in-30 probability of exceedence per annum, is calculated using the Atmospheric Environment Service data for each building site.



with the 30-year return loads derived from the data recorded in the survey.

In order to use more of the data to improve predictions of 30-year return roof snow loads for the Mt. Washington ski village, the data were reduced to a common base. This was done by removing the effect of elevation, by dividing by the elevation-dependent S_o (= $S_s + S_r$), and by an approximate approach to removing the effects of exposure. To normalize the data for different exposures, data of the last 5 years were used because readings were taken in this period on all the roofs

Fig. 7. Snow depths and loads on roofs and ground for winters 1987–1988 to 1991–1992 inclusive. (See notes for Fig. 8 caption.)

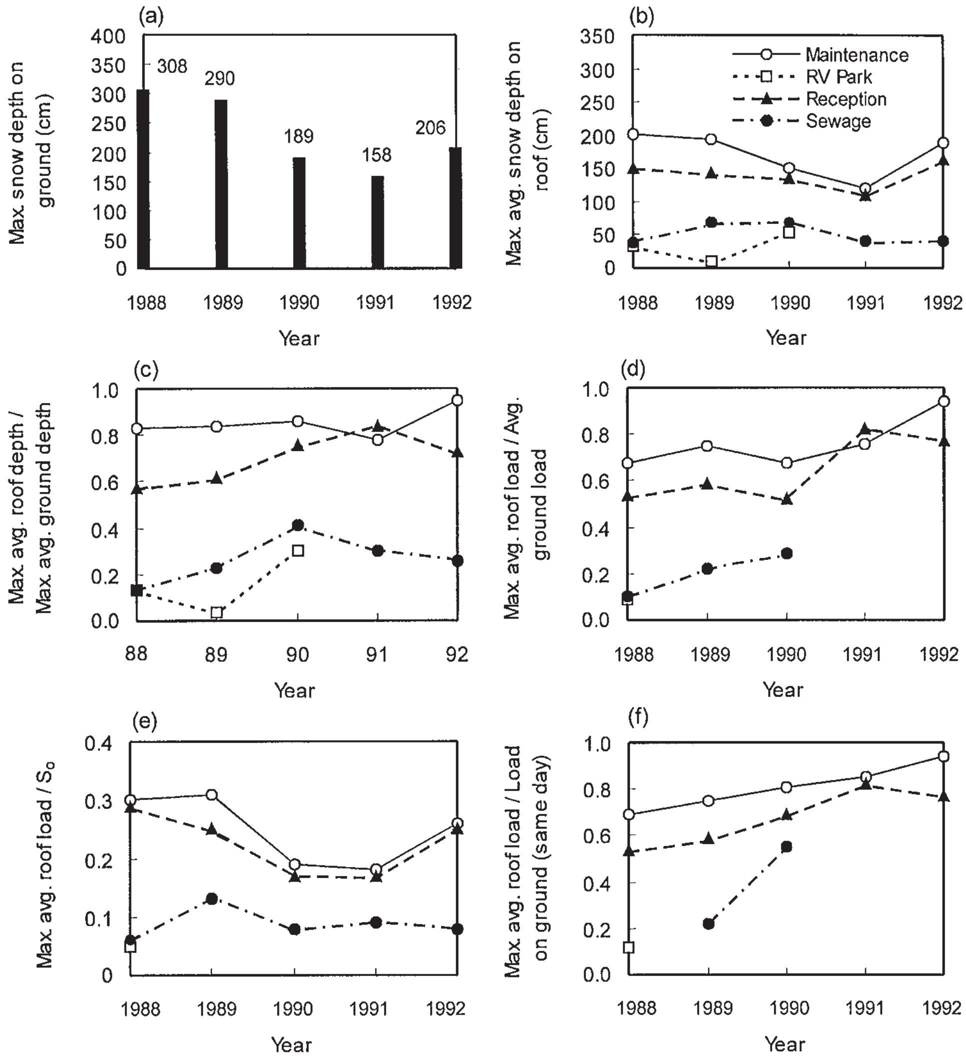


Table 4. Comparison of predicted and design loads (loads in kPa).

Building	30-year load from data	1995 NBCC load	Eq. [1] load	30-year load/ 1995 NBCC load (%)	30-year load/ eq. [1] load (%)
Day Lodge	9.2	12.1	10.9	76	84
Condominium 81	10.8	15.7	14.7	69	73
Condominium 85	8.6	12.1	10.9	71	79
Average				72	79

in the survey. The mean value of the ratio of maximum average roof load to maximum average ground load was calculated for the five roofs with complete data, as shown in Table 3, to obtain a normalization factor for each of three different exposures: sheltered, partially sheltered, and exposed. These were further normalized by using the ratio for the well-sheltered Maintenance Shop as the reference value, i.e., 1.00. The normalization factors are, in NBCC terms, C_w exposure factors. It can be seen in Table 3 that the values obtained for sheltered and exposed roofs ($C_w = 1.0$ and 0.72, respectively) are close to those used in the NBCC (1.0 and 0.75, respectively). Because it was observed that snow was sliding off the metal roof of Condominium 81 during the 5 years used for the normalization, a full correction for slope ($C_s = 0.89$) was made for Condominium 81 as per 1995 NBCC rules.

The calculated exposure factors (Table 3) were applied to

Fig. 8. The effect of elevation above sea level on nondimensionalized roof snow loads. Above the tree line there is a large reduction in roof loads.

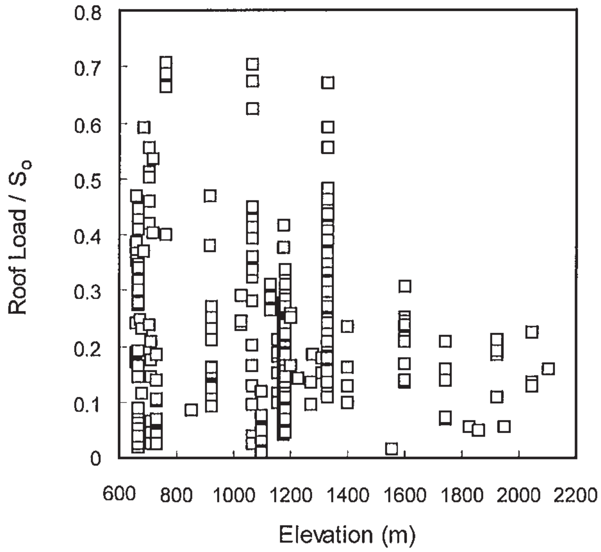
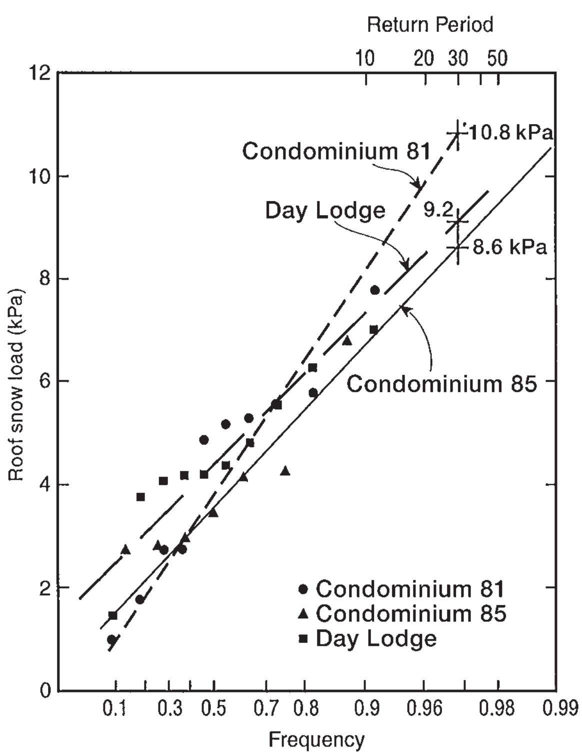


Fig. 9. Predictions of 30-year return snow loads on roofs of Day Lodge, Condominium 81, and Condominium 85 using Gumbel plots.



the annual maximum average roof loads for each of the roofs surveyed in the 10 years of record. The average value of the ratio of maximum average roof load to maximum average ground load applicable over the full range of ground snow loads is 0.61 before normalization. This increases to 0.77 when the correction is applied to remove the effect of exposure, and decreases slightly to 0.75 when a correction for slippery

Fig. 10. Heavy cornice, January 14, 1988.

sloping roofs, more appropriate for predictions of design loads, is made for Condominium 81 using the 1995 NBCC slope-reduction formula. Therefore the C_b factor in eq. [1] is approximately 0.75, as shown in the following, which is 94% of the NBCC recommended value of $C_b = 0.8$.

Comparisons with 1995 NBCC loads

With the C_b (= 0.75) and C_w (= 1.0 or 0.72) values determined, a comparison of the loads obtained using eq. [1] with 1995 NBCC values and with those predicted using the roof snow data collected in the survey will help assess the viability of the NBCC procedure. As there are 10 years of records for Day Lodge and Condominium 81, and 7 years for Condominium 85, which are enough to do Gumbel extreme value predictions of the 30-year return roof snow loads (Boyd 1961), these roofs were used for the comparison (Fig. 9). The standard error, coefficient of variation, and correlation coefficient (R^2) were 1.4 kPa, 15%, and 0.88 respectively for Day Lodge; 2.0 kPa, 18%, and 0.91 respectively for Condominium 81; and 1.6 kPa, 18%, and 0.87 respectively for Condominium 85 (Newark et al. 1989). For the four additional roofs observed during the last half of the survey, there were only 5 years of observations (1988 – 1992), which were too few for an extreme value analysis and, as well, they were not high snow years.

The results are compared in Table 4. On average, the 30-year return loads predicted using the Gumbel extreme value procedure are about 72% of the 1995 NBCC design values less the corresponding rain load, S_r, of 0.8 kPa. They are some 79% of the values obtained using eq. [1] with $C_b = 0.75$ and $C_w = 0.72$ for exposed roofs (S_r not considered). The rain load S_r is equivalent to the transient rain passing through the snowpack during a rainstorm at the time when the snow load

Fig. 11. Power lines damaged due to falling cornices and sliding snow.

is reaching its 30-year return value. This water is not retained in a snow sampler when density readings are taken (if observations are taken in the rain, which is unlikely) and thus has to be added later to the snow portion of the design load.

In summary, eq. [1] with $C_b = 0.75$ and $C_w = 1.0$ (or 0.72), as above, gives design loads for roofs at Mt. Washington which are some 20–30% less than those recommended in the 1995 NBCC, which have an uncertainty of about 20% (NBCC 1995*a*). Because the survey data are always equal to or less than the true maximum loads (i.e., annual maxima can be missed during observations), loads obtained using eq. [1] are minima. Also, because of the short period of observations, the difficulty of getting good data, and loads above $0.7S_o$ were obtained at other locations in the province, there seems to be little reason to depart from NBCC procedures for obtaining design loads. An exception might be for buildings constructed in exposed locations above the tree line, but more data would need to be collected for such locations before appropriate factors could be developed for eq. [1].

Part II — Recommendations for design in deep snow areas

During the 12 years in which the province-wide survey was under way, problems due to the deep snow were observed which were related more to design inadequacies for managing deep snow. Similar problems with aspects of building in deep snow areas were being identified by designers, building owners, and other researchers from Canada, U.S.A., Japan, and other parts of the world at the same time. Since many of the problems were documented at Mt. Washington, photographs taken at the ski village are used to support recommendations to help designers anticipate them.

Good design, especially in deep snow areas, should ensure that (*i*) the design loads are safe; (*ii*) the area around buildings is not made hazardous by falling cornices or sliding snow; and (*iii*) the snow is managed sensibly.

Safe design loads

Safe loads on the main areas of the roofs are the conventional concern of the designer. However, in deep snow areas there are additional concerns:

(a) At Mt. Washington, as in other deep snow areas, cornices can be enormous, equal to the roof snow in depth (Fig. 10), and have been known to extend horizontally as much as 2.5 m beyond the edge of the roof and hang down 1 m or so. The extra weight exerted by cornices on the edge of the roof or the columns or walls beneath has been more than some could carry. To avoid problems due to cornices, one owner of a flat-roofed building keeps a snow blower in a small penthouse (with a roll-up door) on the roof to remove the snow within about 1.5 m of the roof edge. Access to the inside of the penthouse is by a ladder which extends down through the roof to a staircase in the top floor.

(b) With single snowfalls as deep as 1 m, cohesive wet snow may accumulate uniformly on steep gable roofs without sliding. The tensile strength of the wet snow allows the snow on one side of the ridge to anchor that on the other. The substantial loads that can be held on the roof should be considered in design as should the inevitable avalanching of this snow off the roof when the snow cracks at the ridge.

(c) If balconies are not roofed over, they should be designed for roof snow loads, including sliding snow, and for loads due to falling cornices.

(d) Railings should be designed to take the impact from falling cornices.

(e) Metal decking should not extend more than 1–2 cm beyond the structural decking under it. The heavy snow will bend the metal and damage or make it look unsightly.

(f) Windows and doors should be installed properly with no shims above them; otherwise, vertical shortening or bending of the building components will break the glass or jam the doors.

(g) Consideration should be given to earthquake design of the buildings accounting for the heavy snow loads and their long duration. Sliding of deep snow off the roof may also result in significant dynamic loads applied to the building.

Sliding or falling snow

(a) If cornices break off they could injure or kill; furthermore, they could damage building components, such as balconies or stairways below, or attachments of power lines to the building (Fig. 11). Because they sometimes rotate about the eaves when they break off, they could also crack windows (Fig. 12) and damage siding.

(b) Sliding snow may rip chimneys (Fig. 12), escape hatches, toilet vents, aerials, wiring stacks, skylights, ventilators, and other protrusions off the roof and may also be very dangerous to people, vehicles, stairways, balconies (Fig. 13), wiring, etc. below. To prevent the retention of dangerous "hats" of deep snow balanced at the ridges of roofs, some roofs have been cleverly built (Fig. 14) to use the snow's own

Fig. 12. Sliding snow has swept chimney off roof (chimney in foreground) and broken window.

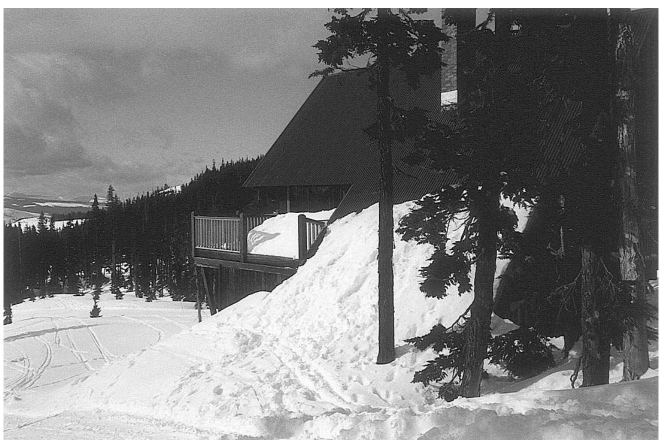


Fig. 13. Railing around deck broken or removed to prevent breakage by sliding snow.

weight to shear through the snow thickness at the ridge, allowing it to slide off.

(c) Where there is a dormer or where the roof is made from intersecting gables, the snow will slide down the corrugations on the intersecting metal roofs as if on rails and jam in the valleys. Outstanding ribs or corrugations on metal roofing will be flattened or even torn where they impede sliding (Fig. 15). As well, snow held in a valley will substantially increase the load on the opposing roof surface.

Management of deep snow

(a) Power lines must be very carefully considered. At Mt. Washington some lines could, at one time, be touched by children playing around the buildings, because the wires and the attachments to the buildings were not high enough above the snow surface.

(b) Building entrances and exits should be on the gable ends and should be reached by stairs. Where an exit (fire exit) cannot be placed above the snow level, a hatch should be built to permit escape at various levels depending on the snow depth.

(c) Parapets should be avoided to allow wind to remove snow.

Fig. 14. Roof designed to prevent "hat" of snow from balancing at ridge. The special ridge will force the snow cover to crack and slide off.

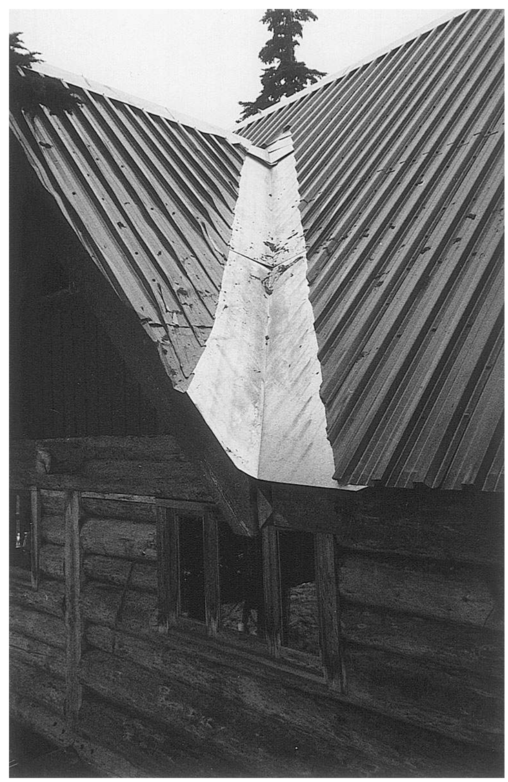


Fig. 15. Snow sliding down the larger roof on right side has damaged metal roofing in valley as it moved downwards.

(d) A positive slope on flat roofs will avoid the ponding of melt and rain water due to exaggerated deflections.

(e) Chimneys and other protrusions should be located at the ridges to avoid being sheared off by sliding snow (Fig. 16).

(f) Balconies that are roofed over will be protected from falling cornices; so will their railings (Fig. 17).

(g) If there is any flexibility in siting, buildings should be located to prevent sliding snow from landing on roads or walkways.

Fig. 16. Chimney partway down roof slope is holding back sliding snow.

Fig. 17. Overhanging snow falling into balconies is a danger to the structure and to people.

(h) One-storey buildings may have problems. Safe entry and exit may be difficult to achieve; it may be necessary to dig down to doorways. On a one-storey building with a sloping roof, the snow will not be able to slide entirely off the roof. Windows may also be below ground snow level.

(i) Large roof overhangs are desirable for keeping cornices and falling snow away from walls, doors, and windows; however, structural support of big overhangs is difficult and expensive to achieve. Columns may be required.

Conclusions

1. The NBCC procedure for calculating design roof loads using eq. [1], $S = S_s(C_b C_w C_s C_a) + S_r$, is appropriate for use at Mt. Washington, though it appears to give loads that are as much as 20% overconservative.

2. At some survey locations (but not at Mt. Washington), roof loads as high as $0.7S_o$ were obtained. These are close to NBCC loads of $0.8S_s$.

3. At sites above 1350 m elevation, maximum roof loads seem to be only about half those at lower elevations ($0.7S_o$).

4. Without special studies to establish the elevation effect, there is little evidence to reduce design roof loads in the surveyed areas of British Columbia except perhaps at Mt. Washington.

5. The density of snow on roofs in deep snow areas is about 400 kg/m^3, some 33% higher than the general value recommended for use in Canada (300 kg/m^3).

6. Designers must consider the extra loads on roofs due to overhanging cornices. The influence of the loads on walls and columns will be exaggerated because of the cantilever action of the cornice.

7. The safe management of deep snow on roofs and around buildings should be part of the building design.

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