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Deep Snow at Mt. Washington, Vancouver Island: Implications for the NBC

listed ✓

by Donald A. Taylor

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ABSTRACT

This paper presents results of the 1980-1992 survey of snow loads and densities on roofs in the deep snow areas of Mount Washington near Comox/Courtenay, Vancouver Island, British Columbia. At the ski village, as calculated from survey data, the 30-year return ground snow load is about 21 kPa (435 psf) at 1175 metres above sea-level. Recommendations are made for the design of buildings at Mt. Washington and the management of heavy snow on roofs.

INTRODUCTION

In the fall of 1980 the author organized a survey of snow loads on roofs and on the ground at Mt. Washington, a heavy snow load area on Vancouver Island (Fig. 1). Since then some existing buildings there have suffered structural damage (Fig. 2); furthermore, an expansion of the ski village is contemplated. Continued economic development for ski resorts like that at Mt. Washington requires that the estimates of design roof loads obtained from the National Building Code of Canada be adequate, but not overly conservative.

This paper presents results from an analysis of the data collected since 1980. It makes recommendations for the design of buildings in deep snow areas, in particular Mt. Washington, and for the management of heavy snow on roofs.

Snowfall at Mt. Washington

Mt. Washington gets its snow from three sources:

(1) The primary source is from synoptic westerly winds blowing over the Pacific towards Vancouver Island. These winds pick up a large amount of moisture, enough to supply rain to the west side of the Island's mountains as the humid air is forced to rise, as well as substantial snow to the whole expanse of peaks as far east as Mt. Washington (Fig. 3). Furthermore, these same winds, after picking up additional moisture over the Georgia Strait, supply rain and snow to the Coast Mountains on the mainland.

(2) A secondary source is from Arctic outbreaks: cold winds flowing out from the valleys and fiords on the west coast of the mainland pick up some moisture from Georgia Strait and displace warmer air upwards causing precipitation at Mt. Washington and fairly strong cold north to north-easterly winds.

(3) A tertiary source yielding a small amount of snow is from winds that blow through the Juan de Fuca Straight to the south of Vancouver Island. These winds circulate counterclockwise and flow, channelled between the ridge of mountains on Vancouver Island and the Coast Mountains on the mainland, until they hit Mt. Washington. It stands higher than most of the other mountains in the ridge of mountains on the island and is directly in the path of these winds.

The Ski Village

The ski runs and ski village are located on the south and southwest faces of the mountain and are therefore 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 metres 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 roof of the sewage treatment plant in the floor of the valley (at 1098 metres) 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. All vehicles are parked on the periphery of the village since the village roads are not plowed because of the very deep snow. The village roads are usable only by skiers, pedestrians, and the service vehicles -- snowcats and snowmobiles.

Buildings vary from single-storey chalets to three- and four-storey blocks of condominiums. Some roofs are flat while others are shed, gable and cruciform (intersecting gable) in plan. The single-storey buildings are almost buried during deep snow winters, and for this reason many structures have storage areas under them at ground level. Thus the living areas start at the second storeys and are accessed by outside stairs; as the snow accumulates fewer stairs are climbed! This avoids having to dig down to doorways and windows as the snow accumulates.

THE SNOW SURVEYS

The Ground Snow Survey - 30-year Return Ground Snow Loads

When development of the ski area began in 1979-80, no formal surveys of snow loads on the ground were being conducted. Observations had been taken for about 20 years at Forbidden Plateau, some 11 kilometres to the south, but local experience indicated that the loads at Mt. Washington were heavier. In any case, without observations the basic 30-year return ground snow load had to be estimated--and it appears that some estimates may have been too low.

The ground snow loads were obtained using two different approaches. In the first, the author analyzed the maximum snow depths recorded each year at the weather station, elevation 1175 metres, not far from the Day Lodge. Using a Gumbel extreme value distribution (Type I), the analysis described by Boyd (1961), and an average specific gravity (0.39) 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.

In the second approach, the Atmospheric Environment Service (AES) 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, and by their own observers (D. Etkin - private communication). Load-elevation relationships derived from the data were usually characterized by a constant load from sea-level to a particular (low) elevation, 250 m, and then a steeply rising load-elevation curve (linear or quadratic) above that. The relationship, derived by the author using the AES data for Mt. Washington, is:

[1] $S_s = -0.93 + 15.66 \times 10^{-3} \times [\text{elev(m)}] + 1.83 \times 10^{-6} \times [\text{elev(m)}]^2$ kPa

[2] and $S_r = 0.4 + 0.0008 \times [\text{elev(m)}]$ kPa below 250 m elevation

[3] or $S_r = 0.8$ kPa above 250 m

where S_r is the rain load associated with S_s.

Thus at 1175 m, as indicated in Table 2, the predicted value of 30-year return ground snow load is:

$S_s = 20.0$ kPa and $S_r = 0.8$ kPa.

Therefore $S_o = S_s + S_r = 20.8$ kPa and since the two analyses give close agreement, the AES values of $S_s = 20.0$ kPa and $S_r = 0.8$ kPa are recommended for the ski village (at 1175 m elevation) on Mt. Washington.

The 1990 National Building Code uses these figures as shown in the following summary of sentence 4.1.7.1.(1):

> *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*
>
> *[4]* $S = S_s (C_b C_w C_s C_a) + S_r$
>
> *where*
>
> S_s = *ground snow load in kPa with a 1-in-30 probability of exceedence per year*

S_r = *the associated rain load in kPa. However, the rain load at any location on a roof need not be taken greater than the load due to snow (i.e., $S_r \leq S_s [C_b C_w C_s C_a]$).*

C_b *is the basic roof snow load factor of 0.8.*

C_w *is the wind exposure factor.*

C_s *is the slope factor.*

C_a *is the accumulation factor.*

The Roof Snow Survey

Even if a good estimate of the 30-year return ground snow load had been available when the survey started, it would still have been important to determine whether the snow load factors in the National Building Code were appropriate for the design of roofs in deep snow areas like Mt. Washington. The survey, started in the autumn of 1980, was intended to do just that. In the first two years, measurements of snow depths and densities were taken on the roofs of the Day Lodge, and Condominium numbers 96, 89, 81. In the third year the observer took photographs but no measurements. Unfortunately this was the deepest snow year.

During the next year (1983-84) a new observer took measurements on the Day Lodge and Condos 95 and 81, and in 1984-85, on the Day Lodge and Condos 85 and 81. In the winter of 1985-86 he was injured skiing and was unable to find anyone to take the readings, so a year was lost again. A new observer was hired who recorded depths and densities on the Day Lodge and Condos 85 and 81 in 1986-87. The new observer took readings on the Day Lodge, the Maintenance Shop, the Recreational Vehicle (R.V.) Park Building, the Reception Building, the Sewage Treatment Plant and Condos 85 and 81. Readings were taken six times between December 27, 1987 and May 12, 1988; the same pattern of observations on the same roofs continued for another four winters until April 1992 as shown in Table 3. Throughout the ten winters in which observations were made, depths and densities (specific gravities) of ground snow were also recorded.

Initially, densities were sampled vertically through the snow pack using a one-metre-long tube sampler of inside diameter 51 mm. The sampler was too short to be practical in deep snow packs so the observer switched to a Federal Snow Sampler and a probe. The probe was used to get the snow depth to the roof surface. Then the sampler was twisted vertically downward and sections were screwed on as required until the sampler was stopped just short of the roof surface. Because the sampler had a smaller diameter (approx. 38 mm) than the shorter tube sampler, it was not as prone to dropping the sample while being withdrawn from the snowpack.

As shown in Table 3, the only two buildings surveyed every year in which measurements were taken were the Day Lodge (Fig. 4) and Condo 81 (Fig. 5). The Day Lodge is a two-level flat roof which, prior to 1989, had an upper level roof, in plan, 18 by 14.5 m and a lower level roof of 31 by 21 m surrounded by a 1 m high parapet. After 1989 the lower roof was expanded by the addition of a section 14 by 21 m (leaving the original parapet between the old and the new sections). The original and new lower roofs are about 13 m high and are surrounded on three sides by 1 metre parapets; the upper level is 2 m higher than the lower roof and is located against the northwest corner of the building. Only results for the lower roof are given. The ground elevation at the Day Lodge is about 1179 metres, and the building is exposed to the wind on all sides. Condo 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 partially sheltered by the trees. Its roof is an asymmetrical gable roof with the longest side facing northwest into the hill and sloping at 20°. The other side faces southeast and is too steep for observations. The approximate geometry of all the buildings surveyed is described in Table 4.

RESULTS OF SURVEY

Temperature and snow data

For the winter of 1986-87, Figure 6 presents the daily maximum temperature, snowfall, rainfall, snow depth on the ground, the specific gravity of snow, and the average snow load on the ground and on the roofs of the Day Lodge and Condos 81 and 85. Between November 1, 1986 and April 6, 1987, 989 cm of snow fell and, as Fig. 6 indicates, it accumulated to a maximum depth of 340 cm on the ground by February 4 and stayed well into April. Although ground snow was denser on January 12 when the first observations were made, the specific gravity of roof and ground snow differed little after February 1 and increased to an average value of about 0.47 on April 6. The ground snow load, on the other hand, peaked at about 12 kPa on February 12 and remained more or less constant into April. Roof snow loads peaked on February 12 also but decreased gradually thereafter. Maximum daily temperatures above 0°C with diminishing snowfalls caused the decrease. Unlike at most (lower) snow load areas of Canada, the heavy snow loads on roof and ground were of long duration. The ground load was at its maximum for at least two months, while the roof loads were within 16% of the maximum for 2-1/2 months. The large rainfall of 38 mm and 104 mm on the third and fourth of March seems to have had only a small influence on the roof snow loads and very little on the ground load. This is not surprising because the rain melts some snow, reducing the load, but some water is retained in the snow pack and this increases the load. The overall effect on the total load in a deep snow pack can be minimal.

The following is important background to Figs. 7 to 9: measurements of depths and specific gravities 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 specific gravity. The largest of these averages, for each roof, is the maximum average depth or load for that winter. Clearly this *'maximum'* is equal to or less than the actual maximum depth or load in spite of the effort to take readings when loads, in particular, are at their heaviest.

Specific Gravity of Roof Snow

In order to obtain a specific gravity of roof snow that could be used in design, only the specific gravities associated with the maximum annual average load for each roof were used (Table 5). These are plotted in Fig. 7. The circled points are those specific gravities corresponding to the maximum average load for each roof over the whole period of record. The straight line is the least squares fit of these particular (circled) specific gravities. It is clear from Fig. 7 that an appropriate specific gravity of roof snow for use in design should be about 0.4, corresponding to the mid-February/mid-March period of maximum roof loads (see Fig. 6).

Snow Loads: Recorded Data

The annual statistics of normalized snow depths and snow loads on the roofs of the Day Lodge and Condos 81 and 85 and on the ground are shown in Tables 6(a, b, c) and 7(a, b) and in Fig. 8, and for the Maintenance Shop, the Registration Building, the R.V. Park Building and the Sewage Treatment Plant in Fig. 9. Figures 8(a, b) and 9(a, b) show snow depths on ground and roof, respectively; 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 wet sticky snow that often falls at Mt. Washington, the influence of the wind is unmistakable. In some years, as shown in Figs. 8(c) and (d), the normalized loads and depths on Condo 81 exceed those on the flat roof of the 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 Condo 81 (Figs. 9(c, d)). In the winters of 1987-88 to 1991-92, measurements were taken on three roofs exposed to the wind (the R.V. Park Building, Condo 85, and the Sewage Treatment Plant), one sheltered (the Maintenance Shop) and three that were partially sheltered (the Day Lodge, only because of its 1 m high parapets, the Reception Building and Condo 81). The parapets on the 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 the Day Lodge is considered 'exposed' for design purposes. For each building site the average ratio of maximum average roof load to the 30-year return ground load calculated using the AES 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 to be used in describing wind exposure are given in the following section on "Prediction of design snow loads for ski village roofs".

Code Comparisons: Figures. 8(c, d) and 9(c, 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 8(e) and 9(e) show that even the heaviest average roof loads were only about 34% to 38% of the 30-year return ground snow load at the Day Lodge and Condo 81. Values of the ratio during years with ground snow loads approaching those predicted using the AES equation would be most interesting. However no observations were taken in the heavy snow year 1982-83 and this is unfortunate; comparison with the previous year would have been very useful.

PREDICTION OF DESIGN SNOW LOADS FOR SKI VILLAGE ROOFS

To make realistic predictions of design roof loads, the NBC's equation [4] with its factors C_b, C_W etc. requires verification for use at Mt. Washington. Then, results obtained using equation [4] need to be compared to the 30-year return loads derived from the data recorded in the survey.

Determination of the C_b and C_w factors

In order to use more of the data to improve predictions of 30-year return roof snow loads for the ski village, the data was 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, the last 5 years of data were used because readings were taken in this period on all the roofs in the survey. The mean value of the ratio *'maximum average roof load* to *maximum average ground load'* was calculated for the five roofs that have complete data sets, as shown in Table 8, to obtain a normalization factor for each of three different exposures: sheltered, partially sheltered, and exposed. These were further normalized by using the well sheltered Maintenance Shop as the basis, i.e. 1.00. The normalization factors are, in NBC terms, C_W

exposure factors. It can be seen in Table 8 that the values obtained for sheltered and exposed roofs ($C_w = 1.0$, and 0.72, respectively), are close to those used in the NBC (1.0 and 0.75, respectively). Because it was observed that snow was sliding off the metal roof of Condo 81 during the 5 years used for the normalization, a full correction for slope ($C_s = 0.89$) was made for Condo 81 as per 1990/1995 NBC rules.

The calculated exposure factors (Table 8) were applied to the annual maximum average roof loads for each of the roofs surveyed in the 10 years of record. The results are plotted in Fig. 10(a) before and in 10(b) after normalization. The average value of *'maximum average roof load/maximum average ground load'* applicable over the full range of ground snow loads in Fig. 10(a) 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 0.76 when a partial correction for slippery sloping roofs, more appropriate for predictions of design loads, is made for Condo 81 using the 1990 NBC slope-reduction formula. In any case the effect is small. A full correction would reduce the figure slightly to 0.75. Therefore the C_b factor in Equation [4] would be about 0.75, as shown in the following, which is 94% of the NBC recommended value of $C_b = 0.8$. In Equation [4]

$$S = (C_b\, C_w\, C_s\, C_a)\, S_s + S_r$$

Thus $\quad C_b\, C_w\, C_s\, C_a = S/S_s - S_r/S_s = S/S_s - 0.8/20 = S/S_s - 0.04$

But $\quad S/S_s = S/S_o \times S_o/S_s = S/S_o \times 20.8/20 = 1.04\, S/S_o$

Thus $\quad C_b\, C_w\, C_s\, C_a = 1.04\, S/S_o - 0.04$

Since $\quad C_w = C_s = C_a = 1.00$ (normalized),

then $\quad C_b = 1.04\, S/S_o - 0.04 = 1.04 \times 0.76 - 0.04 = 0.75$

Therefore Equation [4] becomes $S = (0.75\, C_w\, C_s\, C_a)\, S_s + S_r$

Predicted Loads: Comparisons with 1995 NBC Loads

With the C_b (=0.75) and C_w (=1.0 or 0.72) values determined, a comparison of the loads obtained using equation [4] with 1995 NBC values and with those predicted using the roof snow data collected in the survey is possible. As there are 10 years of records for the Day Lodge and Condo 81, and 7 years for Condo 85 - enough to do Gumbel extreme value predictions of the 30-year return roof snow loads (Boyd 1961) - these roofs were used for the comparison. For the four additional roofs observed during the last half of the survey there were only 5 sets of observations, too few to do an extreme value analysis. Furthermore the last 5 years, 1988 to 1992 inclusive, were not heavy snow years.

The proposed 1995 NBC rules give the following roof loads S (before adding the rain loads S_r):

Day Lodge $S = 0.8 \times 0.75 \times 1.00\ S_s = 12.1$ kPa
(NBC exposed)

Condo 81* $S = 0.8 \times 1.00 \times 1.00\ S_s = 15.7$ kPa
(NBC sheltered)

Condo 85 $S = 0.8 \times 0.75 \times 1.00\ S_s = 12.1$ kPa
(NBC exposed)

(*For Condo 81 $C_w = 1.0$, as per the 1990 and 1995 NBC rules, and C_s is also 1.0 because at predicted design load levels it cannot be assumed that the snow will have room to slide completely off the roof [Fig. 5]).

The loads obtained using equation [4], with $C_b = 0.75$ and C_w factors of 1.0 (sheltered) and 0.72 (exposed) and $C_s = 1.0$ for Condo 81, are listed below:

Day Lodge $S = 0.75 \times 0.72 \times 1.0\ S_s = 10.9$ kPa

Condo 81 $S = 0.75 \times 1.00 \times 1.0\ S_s = 14.7$ kPa

Condo 85 $S = 0.75 \times 0.72 \times 1.0\ S_s = 10.9$ kPa

The Gumbel predictions based on the survey data resulted in the following *average* roof loads with a 1-in-30 probability of exceedence per year (Fig. 11):

Day Lodge $S = 9.2$ kPa ($0.46\ S_s$)

Condo 81 $S = 10.8$ kPa ($0.55\ S_s$)

Condo 85 $S = 8.6$ kPa ($0.43\ S_s$)

The results are compared in Table 9. On average, the predicted 30-year return loads are about 72 % of the 1995 NBC design values less the corresponding rain load $S_r = 0.8$ kPa. They are some 79 % of the values obtained using equation [4] 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 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 very unlikely) and thus has to be added later to the snow portion of the design load.

In summary, equation [4] with $C_b = 0.75$ and $C_w = 1.0$ or 0.72, as above, would provide design loads for the roofs at Mt. Washington with some savings over the 1995 NBC recommended loads. Because the survey data is always equal to or less than the true maximum loads (i.e. annual maxima can be missed during observations), loads obtained using equation [4] are minimums. Further loads less than those recommended in the current design codes can only be used with the agreement of the (code) authorities having jurisdiction.

RECOMMENDATIONS FOR DESIGN AT MT. WASHINGTON

The following recommendations are offered to help designers avoid some of the problems already experienced at Mt. Washington.

Good design, especially in deep snow areas, must ensure that:

1. the design loads are safe and economical;
2. the area around the building is not made hazardous by falling cornices or sliding snow;
3. the snow is managed sensibly.

1. Safe and Economical Design Loads

The paper, to this point, has dealt with safe loads on the main areas of the roofs. This is the conventional concern of the designer but in deep snow areas there is much more:

a) At Mt. Washington cornices can be enormous, (Figs. 12, 13, 14) equal to the roof snow in depth and may extend horizontally as much as 2.5 metres beyond the edge of the roof and hang down a metre 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 (Fig. 2). In order to avoid problems due to cornices, the owner of one 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 metres of the edge of the roof (Fig. 15). Access is by a ladder inside the penthouse which extends down to the floor below inside the building.

b) With single snowfalls as deep as one metre, cohesive wet snow may accumulate uniformly on steep gable roofs without sliding. The tensile strength of the wet snow across the ridge allows the snow on one side 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 (Fig. 16).

c) Balconies should be designed for roof snow loads and loads due to falling cornices if they are not roofed over.

d) Railings should also be designed to take the forces from falling cornices.

e) Metal decking should not extend more than 1 to 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) Careful 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 (Paine and Bruch, 1985).

2. Sliding or Falling Snow

a) If cornices break off they could injure or kill; furthermore they have damaged building components such as balconies or stairways below, or attachments of power lines to the building (Fig. 17). Because they sometimes rotate about the eaves when they break off, they have also cracked windows (Fig. 18) and damaged siding.

b) Sliding snow may rip chimneys (Fig. 18), 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. 19), wiring etc. below. To prevent the retention of dangerous 'hats' of deep snow balanced at the ridges of roofs (Fig. 16) some roofs have been cleverly built (Fig. 20) to use the snow's own 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 jam in the valleys when it tries to slide (Fig. 21). The outstanding ribs on metal roofing will be flattened or even ripped where they impede sliding (Fig. 22). As well, snow held in a valley will substantially increase the load on the opposing roof surface.

3. Management of Heavy Snow

a) Power lines must be very carefully considered. At Mt. Washington some lines can be touched by children playing around the buildings because the wires and the attachments to the buildings are not far 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 (Fig. 23).
c) Parapets should be avoided to allow wind to remove snow.
d) A positive slope on flat roofs will avoid the ponding of melt and rain water. The flat roof of the Day Lodge once had a perforated plastic drainage pipe lying across it to aid drainage.
e) Chimneys and other protrusions should be located at the ridges to avoid being sheared off by sliding snow (Fig. 24).
f) Balconies that are roofed over will be protected from falling cornices; so will their railings (Figs. 25, 26).
g) If there is any flexibility in siting, buildings should be located to prevent sliding snow from landing on roads or walkways.
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.

RECOMMENDATIONS FOR INCLUSION IN THE 1995 NBC COMMENTARY ON SNOW LOADS

The following paragraph was recommended to the NBC Part 4 Committee on Structural Design for consideration and possible inclusion in the 1995 NBC Commentary on Snow Loads:

> *In deep snow areas of Canada, in particular the mountains and valleys of British Columbia, the following should be kept in mind (Taylor 1989, 1991):*
>
> *(a) Snow cornices can become very large and cantilever out over the edges of flat or sloping roofs a distance equal to the snow depth on the roof. This can occur in sheltered or completely calm areas and on*

the leeward side of roofs where there is wind. Cornices have been known to overload walls and columns, resulting in failures. In addition, cornices are a hazard if they break off. They can destroy balconies, stairs, porches, attachments of wires, etc., to the building and they could be very dangerous to people below.

(b) *When deep snow is deposited on slippery sloping roofs, it has been known to shear off vents, chimneys, aerials, wiring stacks, skylights and ventilators when it slides. It is a menace below when it falls. In addition, it may creep off the roof, rotating slowly at the eaves, and may even break windows if it hits the side of the building. Protrusions through the roof should be located at the ridge, or be especially protected against shearing forces due to the snow.*

(c) *Where a roof is L-shaped or has dormers, the snow on each slope will slide in the direction of the ribs or corrugations and jam in the valleys. If one slope is longer or steeper, the snow on this slope will predominate and may force the whole mass of snow to slide across the opposing corrugations on the other slope, resulting in a tearing or flattening of these corrugations. If the corrugations hold and the snow does not slide, the restraining load on the lower opposing slope may be very high.*

CONCLUSIONS

1. The ground snow load at elevation 1175 m at Mt. Washington is 20.8 kPa and is comprised of $S_s = 20.0$ and $S_r = 0.8$ kPa.

2. The 1995 NBC equation $S = (C_b C_w C_s C_a) S_s + S_r$ is appropriate for use in obtaining design snow loads for roofs at Mt. Washington.

3. For Mt. Washington the C_b factor in the equation in Conclusion 2. above is 0.75, thus flat roofs in *sheltered* locations at the ski village could, with the agreement of the authorities having jurisdiction, be designed for loads $S = 0.75\ S_s + S_r$.

4. For Mt. Washington the exposure factor, C_w, in the equation in Conclusion 2. above is 1.00 for sheltered roofs and 0.72 for exposed roofs, thus flat roofs in *exposed* locations at the ski village could, with the agreement of the authorities having jurisdiction, be designed for about $0.54\ S_s + S_r$.

5. The specific gravity of snow on roofs when loads are at their maxima is about 0.4. Such loads may be sustained for up to two months.

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 due to 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.

ACKNOWLEDGEMENTS

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Table 1. Annual Maxima Ground Snow Depths and Corresponding Specific Gravities (SG) at 1175 m Elevation

No.	Year	Date	Maximum Ground Depth (cm)	Corresponding SG (estimated)	Calculated Ground Load (kPa)
1	1980-81	3 Dec 80	103		
2	1981-82	13 Apr 82	395		
3	1982-83	31 Mar 83	391		
4	1983-84	14 Apr 84	269	~ 0.41 *	10.8
5	1984-85	28 Mar 85	254	~ 0.40 *	10.0
6	1985-86	27 Jan 86	206		
7	1986-87	4 Feb 87	340	0.35 *	11.7
8	1987-88	6 Apr 88	308	0.44 *	13.3
9	1988-89	5 Apr 89	290	0.35 *	10.0
10	1989-90	5 Feb 90	189	0.33	
11	1990-91	8 Feb 91	158	0.22	
12	1991-92	2 Feb 92	206	0.30	
		Average		0.35	

* Specific gravities corresponding to maximum measured snow depths at the 1175 m weather station. The specific gravities 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 SG corresponding to the 5 maximum ground loads was about 0.39.*

Table 2. Ground Snow Loads at Various Elevations Calculated Using AES Values

Elevation (m)	Site	S_s (kPa)	S_r (kPa)	$S_o = S_s + S_r$ (kPa)
250		3.1	0.6	3.7
1098	Sewage Treatment Plant	18.5	0.8	19.3
1173	Reception Building, Condo 81	19.6	0.8	20.4
1175	Weather Station	20.0	0.8	20.8
1179	RV Park, Condo 85, Day Lodge	20.1	0.8	20.9
1183	Maintenance Building	20.2	0.8	21.0
1590	Top of Mountain	28.6	0.8	29.4

Table 3. Number of Observation Per Winter

Year	Day Lodge	Condo					Maintenance Shop	Reception Building	Sewage Treatment Building	RV Park
		81	85	89	95	96				
1980-81	1	1	-	1	-	1	-	-	-	-
1981-82	3	4	-	2	-	3	-	-	-	-
1982-83	-	-	-	-	-	-	-	-	-	-
1983-84	6	6	-	-	6	-	-	-	-	-
1984-85	6	6	6	-	-	-	-	-	-	-
1985-86	-	-	-	-	-	-	-	-	-	-
1986-87	6	6	6	-	-	-	-	-	-	-
1987-88	6	6	6	-	-	-	6	6	6	-
1988-89	6	6	6	-	-	-	6	6	6	6
1989-90	4	4	4	-	-	-	4	4	4	4
1990-91	6	6	6	-	-	-	6	6	6	6
1991-92	5	5	5	-	-	-	5	5	5	5

Table 4. Geometry of Buildings Observed

Building	Elevation (m)	Length (m)	Width (m)	Roof Height (m)	Character-istics	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
Condo 81	1173	15.2	15.2	15	slope 20°	partially sheltered
Condo 85	1179	48.8	15.2	15	flat	exposed
Day Lodge	1179			13	flat (2 level)	exposed (but has 1 m high parapets)
upper roof		18.0	14.5			
exist. lower roof		31.0	21.0			
new lower roof		14.0	21.0			
overall new roof		45	21.0			
RV Park Building	1179	17.1	13.7	3.4	flat	exposed
Maintenance Building	1183	18.6	12.2	≈6	flat	sheltered

Table 5. Specific Gravity of Roof Snow at Maximum Annual Load[1] from Winters 1980-81 to 1991-92

Year		1980-	1981-	1982-	1983-	1984-	1985-	1986-	1987-	1988-	1989-	1990-	1991-
Building[2]	**Roof Value**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Day Lodge	SG	0.29	0.27	-	0.43	0.41	-	0.45	0.36	0.37	0.38	0.37	0.39
	Load (kPa)	1.5	4.7	-	4.2	4.1	-	7.0	4.8	5.6	3.8	4.4	6.3
	Date	Feb 20	Dec 25	-	Mar 24	Dec 30	-	Mar 22	Mar 27	Mar 25	Mar 18	Feb 3	Feb 23
Condo 81	SG	0.23	0.37	-	0.32	0.46	-	0.38	0.49	0.35	0.31	0.31	0.32
	Load (kPa)	1.0	7.8	-	5.1	5.8	-	5.6	4.6	4.9	2.8	1.8	2.8
	Date	Feb 20	Mar 5	-	Feb 24	Apr 17	-	Feb 15	Feb 28	Mar 25	Feb 17	Feb 3	Feb 23
Condo 85	SG	-	-	-	-	0.36	-	0.37	0.40	0.35	0.31	0.37	0.33
	Load (kPa)	-	-	-	-	3.0	-	6.8	3.5	4.2	2.8	2.9	4.3
	Date	-	-	-	-	Feb 19	-	Feb 15	Feb 28	Mar 25	Feb 17	Feb 3	Feb 23
Condo 89	SG	0.26	0.26	-	-	-	-	-	-	-	-	-	-
	Load (kPa)	1.6	2.6	-	-	-	-	-	-	-	-	-	-
	Date	Feb 20	Dec 25	-	-	-	-	-	-	-	-	-	-
Condo 95	SG	-	-	-	0.41	-	-	-	-	-	-	-	-
	Load (kPa)	-	-	-	6.0	-	-	-	-	-	-	-	-
	Date	-	-	-	Mar 24	-	-	-	-	-	-	-	-
Condo 96	SG	0.24	0.38	-	-	-	-	-	-	-	-	-	-
	Load (kPa)	1.3	8.7	-	-	-	-	-	-	-	-	-	-
	Date	Feb 20	Mar 5	-	-	-	-	-	-	-	-	-	-
Maint.	SG	-	-	-	-	-	-	-	0.42	0.34	0.29	0.33	0.30
	Load (kPa)	-	-	-	-	-	-	-	6.4	6.4	3.9	3.9	5.6
	Date	-	-	-	-	-	-	-	Apr 16	Mar 25	Feb 17	Feb 3	Feb 23
Reception	SG	-	-	-	-	-	-	-	0.40	0.36	0.27	0.33	0.32
	Load (kPa)	-	-	-	-	-	-	-	5.8	5.0	3.4	3.5	5.1
	Date	-	-	-	-	-	-	-	Mar 27	Mar 25	Feb 17	Feb 3	Feb 23
Sewage	SG	-	-	-	-	-	-	-	0.31	0.37	0.23	0.41	0.38
	Load (kPa)	-	-	-	-	-	-	-	1.0	2.5	1.6	1.7	1.6
	Date	-	-	-	-	-	-	-	Dec 27	Mar 25	Feb 3	Feb 3	Dec 15
RV Park	SG	-	-	-	-	-	-	-	0.30	-	-	-	-
	Load (kPa)	-	-	-	-	-	-	-	1.0	-	-	-	-
	Date	-	-	-	-	-	-	-	Jan 14	-	-	-	-

Notes: 1. ▨ Shaded areas indicate Maximum Load for each roof. 2. See Table 4.

Table 6 a). Snow depth and loads on roofs and ground from winters 1980-81 to 1991-92

Year	1980-81		1981-82		1982 -83	1983-84		1984-85			1985 -86
Building[1]	Day Lodge	Condo 81	Day Lodge	Condo 81	All[2]	Day Lodge	Condo 81	Day Lodge	Condo 81	Condo 85	All[2]
Ground Snow											
Max. Depth (cm)	61	61	225	375	390	239	272	199	200	198	205
Max. Load (kPa)	1.9	1.5	6.0	13.9	N/A	9.8	9.7	8.5	7.4	7.1	N/A
Roof Snow											
Max. Avg. Depth (cm)	54	44	163	215	N/A	130	164	123	127	85	N/A
Max. Avg. Load (kPa)	1.5	1.0	4.2	7.8	N/A	4.2	5.2	4.1	5.8	3.0	N/A
Ratios											
$\frac{\text{Max. Avg. Roof Depth}}{\text{Max. Avg. Ground Depth}}$	0.88	0.73	0.72	0.57	N/A	0.54	0.60	0.62	0.64	0.43	N/A
$\frac{\text{Max. Avg. Roof Load}}{\text{Max. Avg. Ground Load}}$	0.80	0.66	0.69	0.56	N/A	0.43	0.53	0.48	0.78	0.42	N/A
$\frac{\text{Max. Avg. Roof Load}}{\text{Load on Ground (same day)}}$	0.80	0.66	0.69	0.56	N/A	0.58	0.53	0.87	0.78	0.49	N/A
$\frac{\text{Max. Avg. Roof Load}}{S_o}$	0.07	0.05	0.20	0.38	N/A	0.20	0.25	0.20	0.28	0.14	N/A
$\frac{\text{Max. Avg. Ground Load}}{S_o}$	0.09	0.07	0.29	0.68	N/A	0.47	0.48	0.41	0.36	0.34	N/A

Notes:
[1] See Table 4
[2] Value of "Max. Depth" observed at Weather Station

Table 6 b). Snow depth and loads on roofs and ground from winters 1980-81 to 1991-92 (Continued)

Year	1986-87			1987-88			1988-89		
Building[1]	Day Lodge	Condo 81	Condo 85	Day Lodge	Condo 81	Condo 85	Day Lodge	Condo 81	Condo 85
Ground snow									
Max. Depth (cm)	302	317	317	251	272	263	258	269	254
Max. Load (kPa)	11.2	12.3	12.3	10.5	10.9	9.7	9.6	8.2	7.7
Roof snow									
Max. Avg. Depth (cm)	199	152	189	149	105	134	155	144	122
Max. Avg. Load (kPa)	7.0	5.6	6.8	4.8	5.3	3.5	5.6	4.9	4.2
Ratios									
$\frac{\text{Max. Avg. Roof Depth}}{\text{Max. Avg. Ground Depth}}$	0.66	0.48	0.60	0.59	0.39	0.51	0.60	0.53	0.48
$\frac{\text{Max. Avg. Roof Load}}{\text{Max. Avg. Ground Load}}$	0.63	0.46	0.55	0.46	0.49	0.36	0.58	0.60	0.54
$\frac{\text{Max. Avg. Roof Load}}{\text{Load on Ground (same day)}}$	0.63	0.46	0.57	0.46	0.52	0.37	0.65	0.60	0.54
$\frac{\text{Max. Avg. Roof Load}}{S_0}$	0.34	0.28	0.33	0.23	0.26	0.17	0.27	0.24	0.20
$\frac{\text{Max. Avg. Ground Load}}{S_0}$	0.54	0.60	0.59	0.50	0.53	0.46	0.46	0.40	0.37

Note: [1] See Table 4

Table 6 c). Snow depth and loads on roofs and ground from winters 1980-81 to 1991-92 (Continued)

Year	**1989-90**			**1990-91**			**1991-92**		
Building[1]	Day Lodge	Condo 81	Condo 85	Day Lodge	Condo 81	Condo 85	Day Lodge	Condo 81	Condo 85
Ground snow									
Max. Depth (cm)	185	193	191	181	143	153	228	230	214
Max. Load (kPa)	6.2	5.4	5.5	6.0	4.7	5.1	6.8	6.8	5.5
Roof snow									
Max. Avg. Depth (cm)	150	95	116	124	59	79	162	87	131
Max. Avg. Load (kPa)	3.8	2.8	2.8	4.4	1.8	2.9	6.3	2.8	4.3
Ratios									
$\frac{\text{Max. Avg. Roof Depth}}{\text{Max. Avg. Ground Depth}}$	0.81	0.49	0.61	0.68	0.41	0.52	0.71	0.38	0.61
$\frac{\text{Max. Avg. Roof Load}}{\text{Max. Avg. Ground Load}}$	0.62	0.53	0.51	0.74	0.38	0.56	0.93	0.40	0.77
$\frac{\text{Max. Avg. Roof Load}}{\text{Load on Ground (same day)}}$	0.62	0.59	0.69	0.93	0.38	0.59	0.93	0.40	0.84
$\frac{\text{Max. Avg. Roof Load}}{S_o}$	0.18	0.14	0.13	0.21	0.09	0.14	0.30	0.14	0.20
$\frac{\text{Max. Avg. Ground Load}}{S_o}$	0.30	0.26	0.26	0.29	0.23	0.25	0.32	0.33	0.27

Note: [1] See Table 4

Table 7 a). Snow depth and loads on roofs and ground from winters 1987-88 to 1991-92

Year	1987-88				1988-89				1989-90	
Building[1]	Maint.	RV Park	Recep.	Sewage	Maint.	RV Park	Recep.	Sewage	Maint.	RV Park
Ground snow										
Max. Depth (cm)	243	252	268	295	230	242	228	300	175	178
Max. Load (kPa)	9.4	10.9	10.8	11.2	8.6	9.0	8.5	11.2	5.8	6.1
Roof snow										
Max. Avg. Depth (cm)	201	33	152	39	193	10	142	68	151	53
Max. Avg. Load (kPa)	6.4	1.0	5.8	1.1	6.4	N/A	5.0	2.5	3.9	N/A
Ratios										
$\frac{\text{Max. Avg. Roof Depth}}{\text{Max. Avg. Ground Depth}}$	0.83	0.13	0.57	0.13	0.84	0.04	0.62	0.23	0.86	0.30
$\frac{\text{Max. Avg. Roof Load}}{\text{Max. Avg. Ground Load}}$	0.68	0.09	0.54	0.10	0.75	N/A	0.59	0.22	0.68	N/A
$\frac{\text{Max. Avg. Roof Load}}{\text{Load on Ground (same day)}}$	0.69	0.12	0.54	N/A	0.75	N/A	0.59	0.22	0.81	N/A
$\frac{\text{Max. Avg. Roof Load}}{S_o}$	0.30	0.05	0.29	0.06	0.31	N/A	0.25	0.13	0.19	N/A
$\frac{\text{Max. Avg. Ground Load}}{S_o}$	0.45	0.52	0.53	0.58	0.41	0.43	0.42	0.58	0.27	0.29

Note: [1] See Table 4

Table 7 b). Snow depth and loads on roofs and ground from winters 1987-88 to 1991-92 (Continued)

Year	**1989-90**		**1990-91**				**1991-92**			
Building[1]	Recep.	Sewage	Maint.	RV Park	Recep.	Sewage	Maint.	RV Park	Recep.	Sewage
Ground snow										
Max. Depth (cm)	178	170	154	155	130	143	200	190	223	163
Max. Load (kPa)	6.4	5.5	5.1	N/A	4.3	N/A	5.9	N/A	6.6	N/A
Roof snow										
Max. Avg. Depth (cm)	136	69	120	N/A	109	42	190	N/A	163	42
Max. Avg. Load (kPa)	3.4	1.6	3.9	N/A	3.5	1.7	5.6	N/A	5.1	1.6
Ratios										
$\frac{\text{Max. Avg. Roof Depth}}{\text{Max. Avg. Ground Depth}}$	0.76	0.41	0.78	N/A	0.84	0.30	0.95	N/A	0.73	0.26
$\frac{\text{Max. Avg. Roof Load}}{\text{Max. Avg. Ground Load}}$	0.52	0.29	0.76	N/A	0.82	N/A	0.94	N/A	0.77	N/A
$\frac{\text{Max. Avg. Roof Load}}{\text{Load on Ground (same day)}}$	0.69	0.55	0.85	N/A	0.82	N/A	0.94	N/A	0.77	N/A
$\frac{\text{Max. Avg. Roof Load}}{S_o}$	0.17	0.08	0.18	N/A	0.17	0.09	0.26	N/A	0.25	0.08
$\frac{\text{Max. Avg. Ground Load}}{S_o}$	0.32	0.28	0.24	N/A	0.21	N/A	0.28	N/A	0.32	N/A

Note: [1] See Table 4

Table 8. Equivalent Exposure Factors

Roof	Exposure	mean M.A.R.L.* / M.A.G.L.	Normalized	C_w (NBC)
Condo 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	1.0
Condo 81	Partially sheltered	0.539‡	0.71	1.0
Maintenance Shop	Sheltered	0.762	1.00	1.0

* M.A.R.L = Maximum Average Roof Load
M.A.G.L. Maximum Average Ground Load

‡ corrected for 20° slope

Table 9. Comparison of Predicted and Design Loads (loads in kPa)

Building	30-year load - from data	1995 NBC load	Equ [4] load	30-year load/ '95 NBC load %	30-year load/ Equ [4] load %
Day Lodge	9.2	12.1	10.9	76	84
Condo 81	10.8	15.7	14.7	69	73
Condo 85	8.6	12.1	10.9	71	79
			Avg.	72 %	79 %

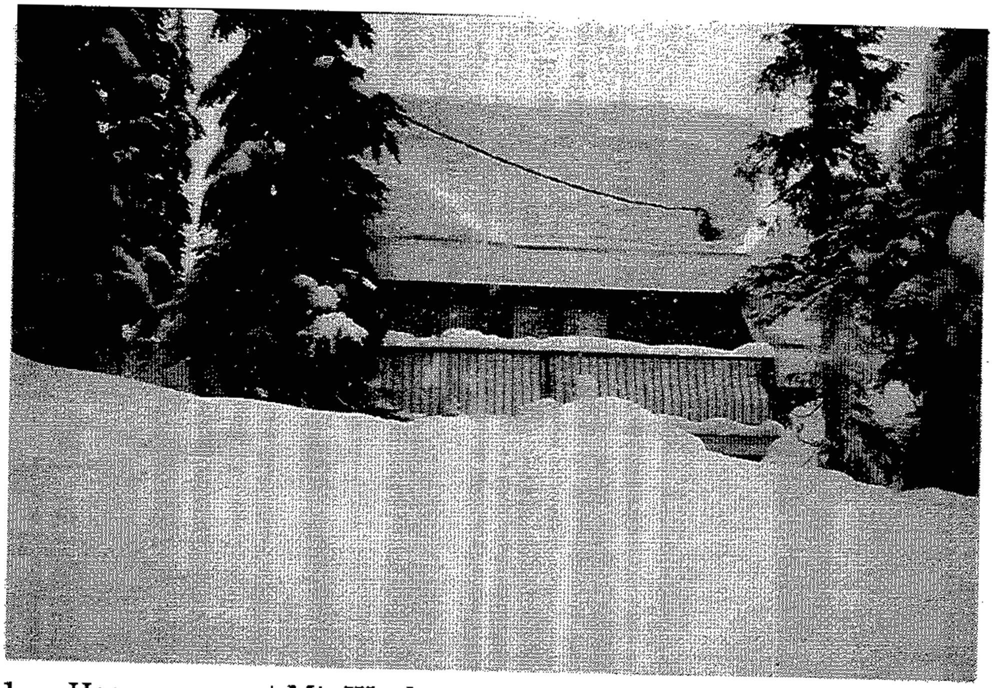

Figure 1. Heavy snow at Mt. Washington, April 2, 1983.

Figure 2. Crushing loads due to cornice (overhanging snow), March, 1982.

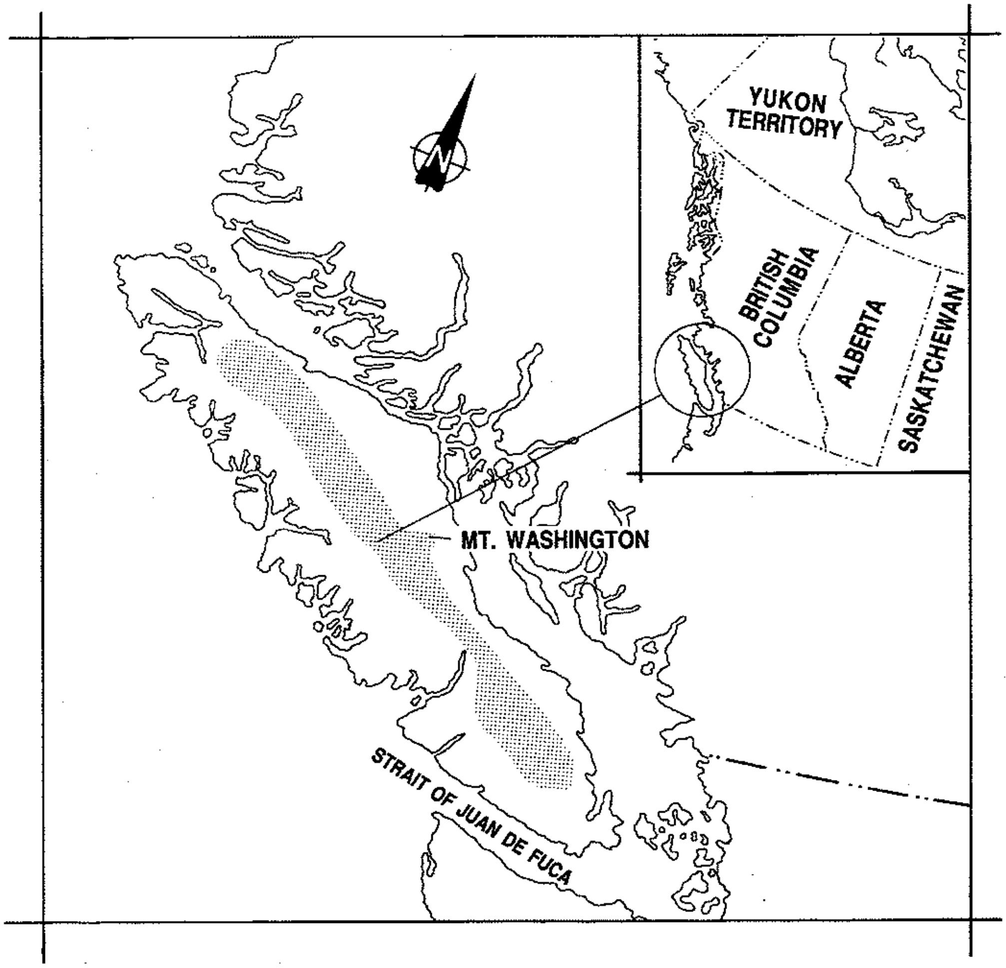

Figure 3. Map showing location of Mt. Washington, Vancouver Island.

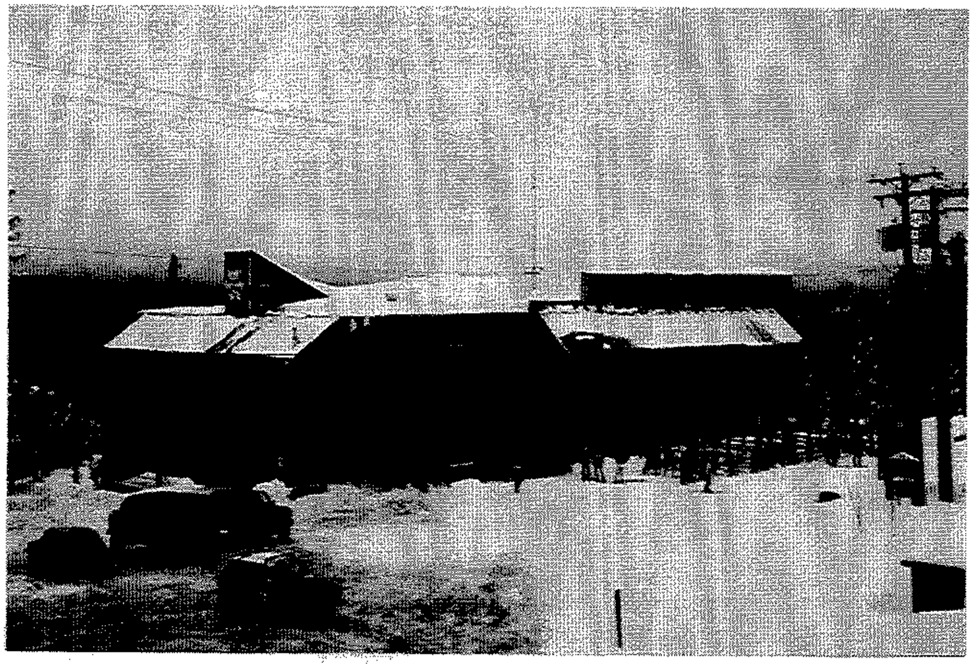

Figure 4. Day Lodge at Mt. Washington, January 14, 1988.

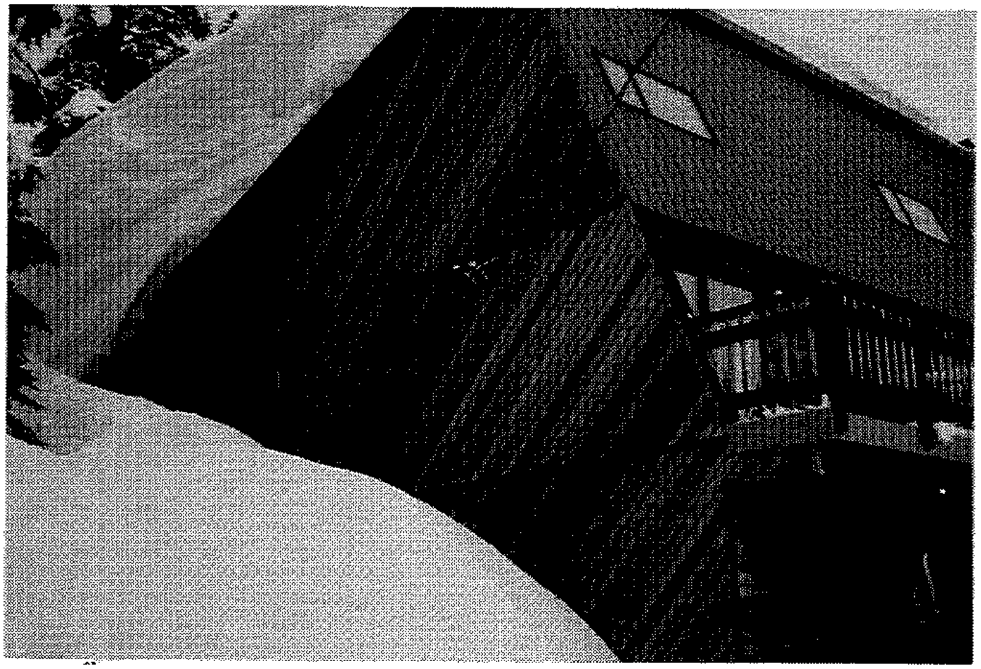

Figure 5. Condominium 81, April, 1983. Very deep snow cannot slide off because the roof slopes towards the hill.

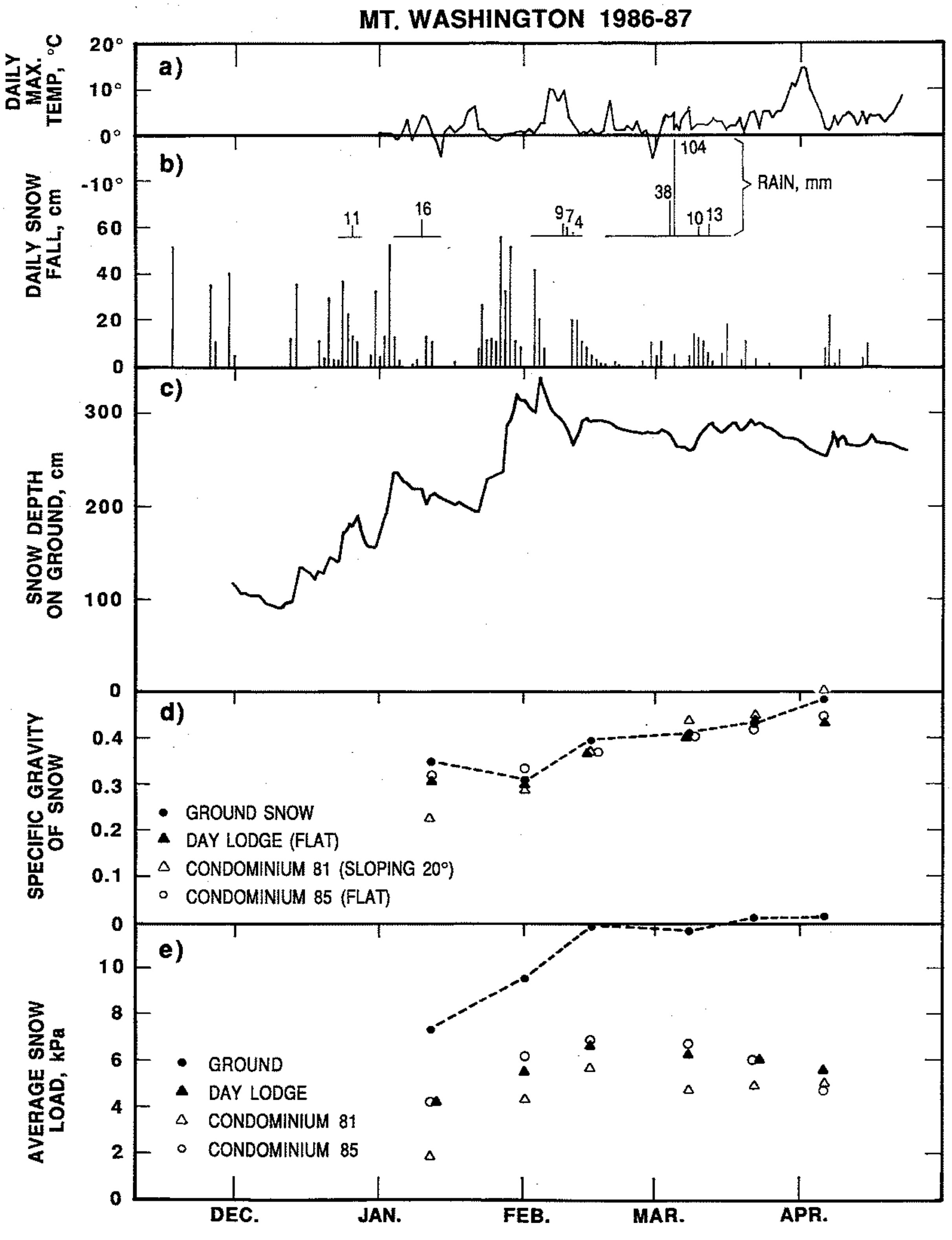

Figure 6. Temperature and snow data at the Mt. Washington ski village for winter of 1986-87.

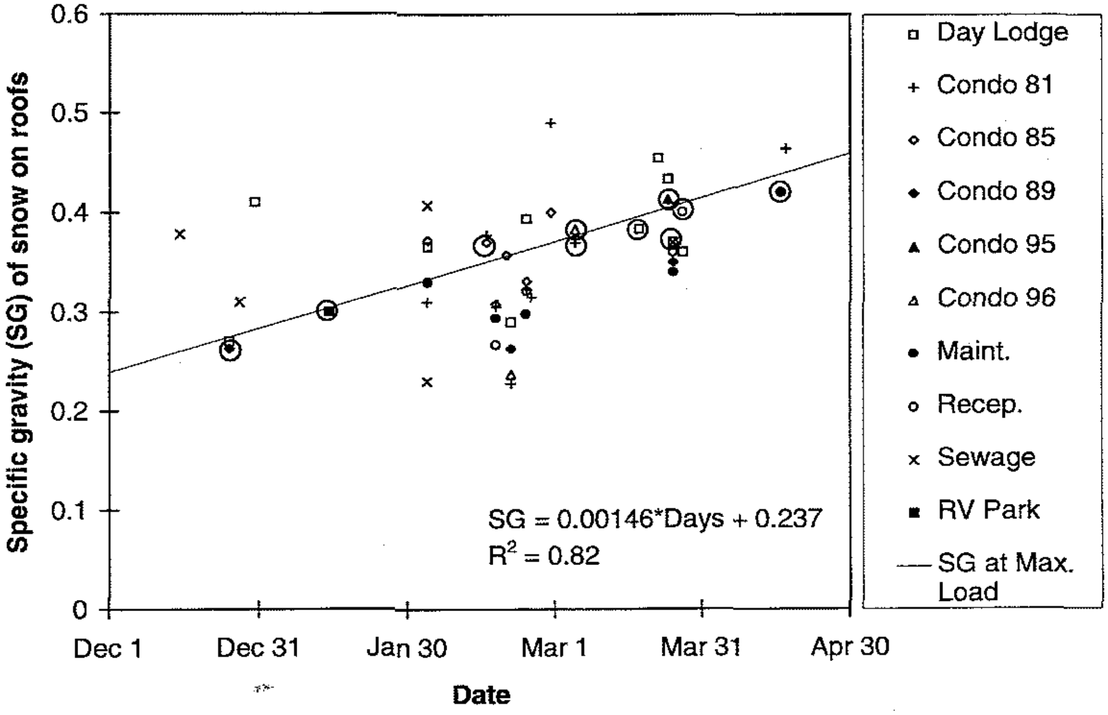

Figure 7. **Specific gravity (SG) of roof snow versus days from Dec. 1.**

The plotted points are SG's corresponding to the annual maximum average load for each roof surveyed. 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 (circled points only).

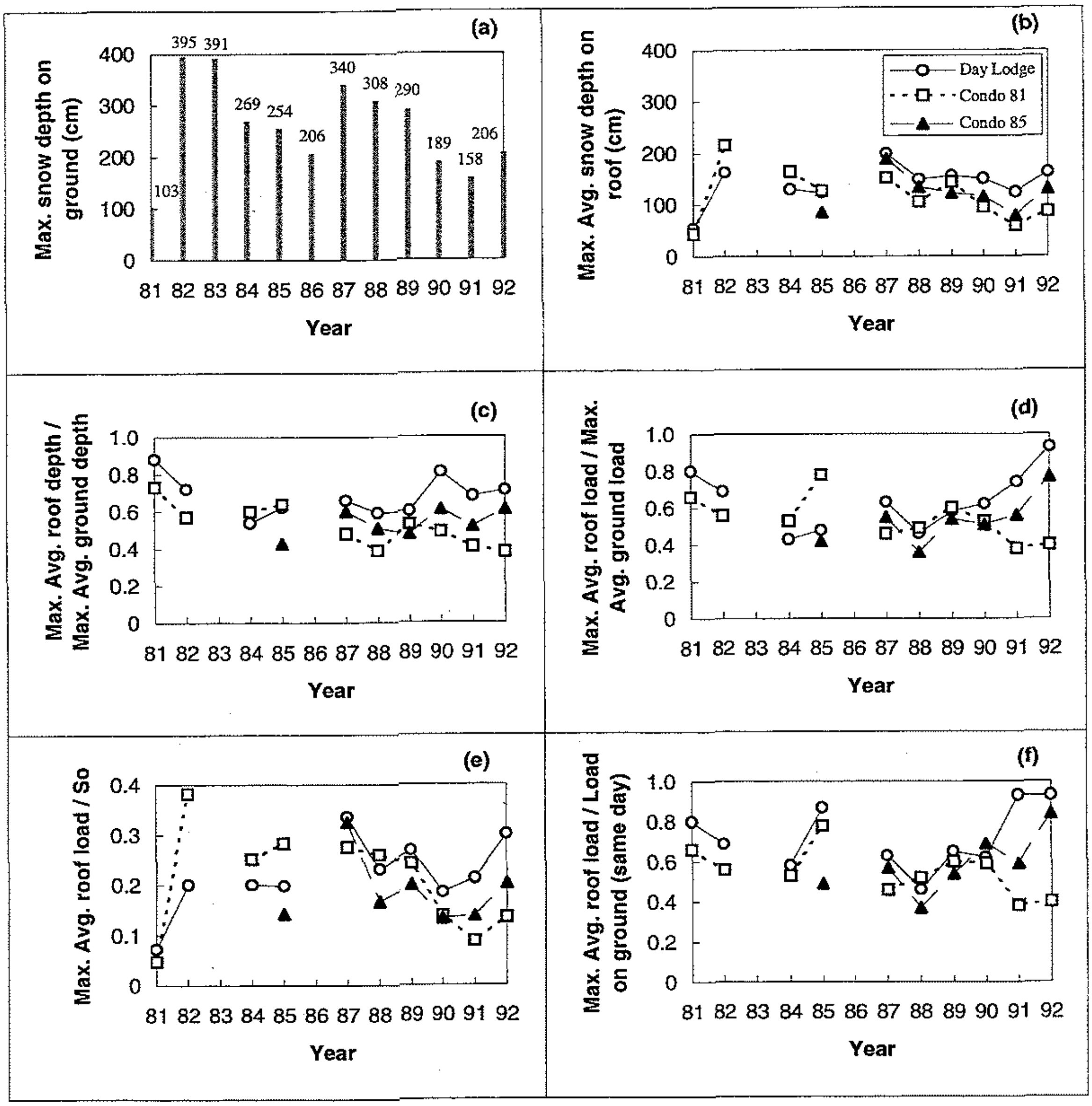

Figure 8. Snow depth and loads on roofs and ground from winters 1980-81 to 1991-92, inclusive.

No observations were recorded for winters 1982-83 and 1985-86 (Year 81 on the graphs denotes the winter of 1980-81, etc.). S_0, the ground snow load with a 1-in-30 probability of exceedance per annum is calculated using the AES data for each building site.

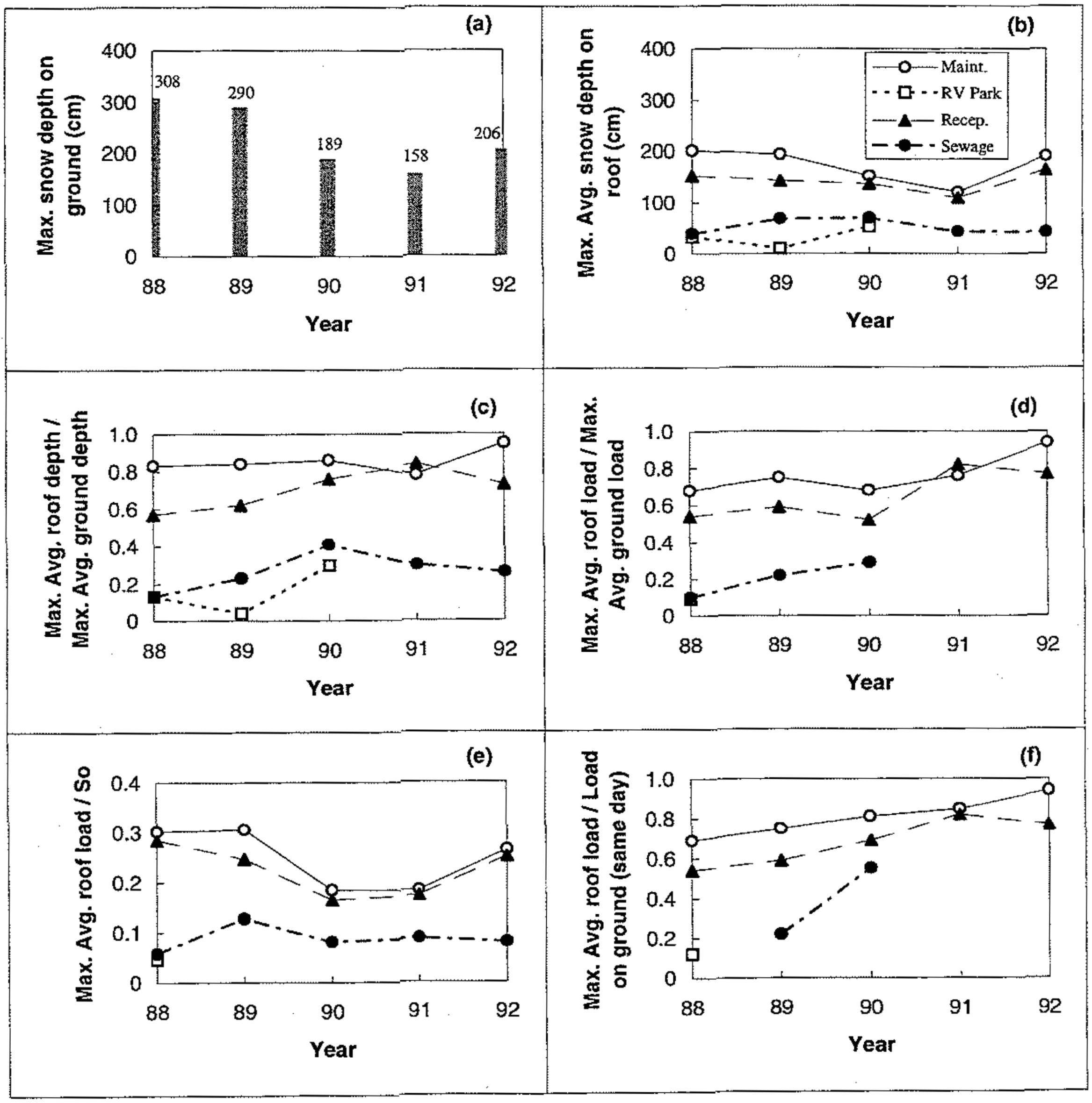

Figure 9. Snow depths and loads on roofs and ground for winters 1987-88 to 1991-92 inclusive.

See notes for Figure 8 caption.

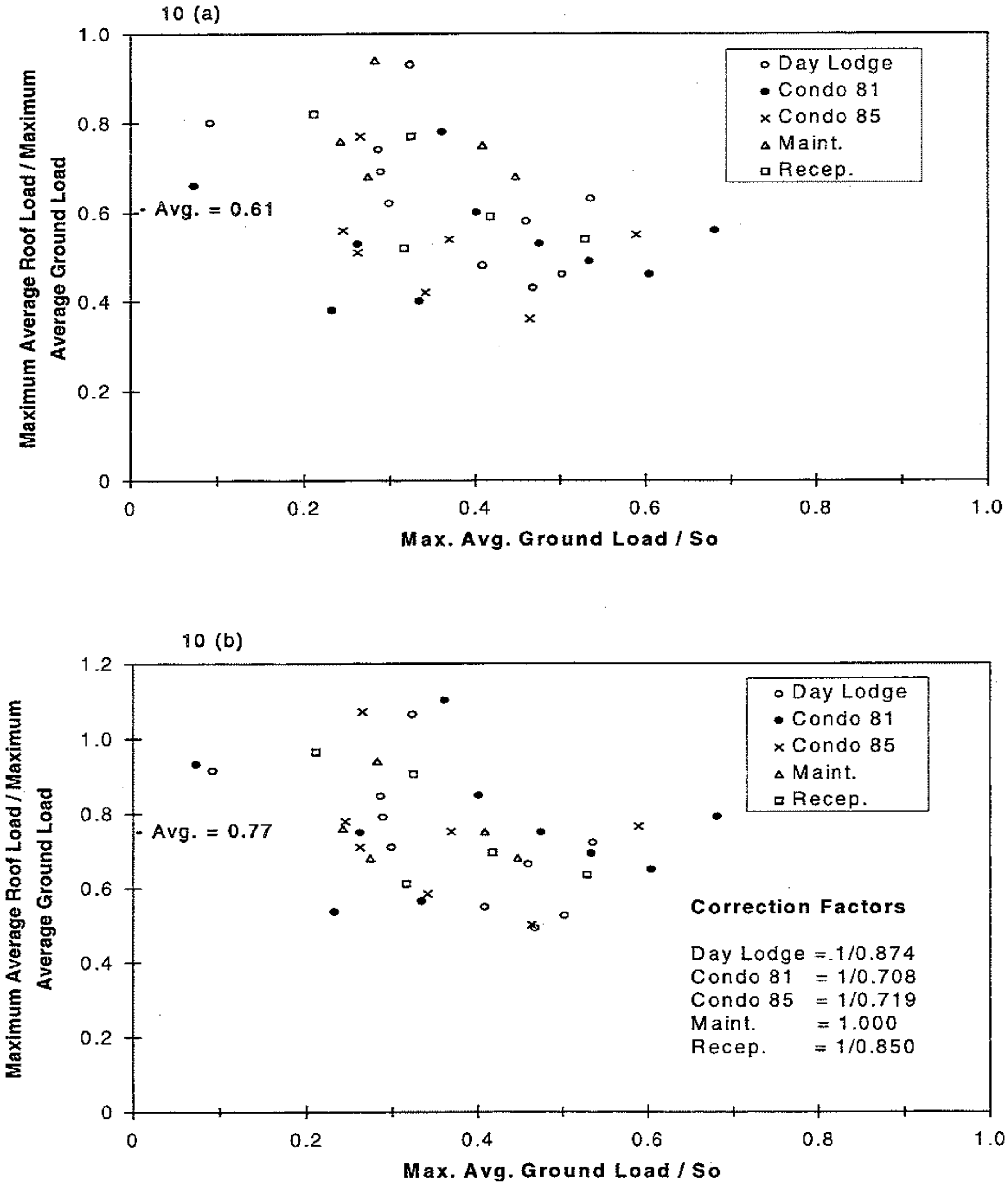

Figure 10. Normalized load data plotted to show the effect of the exposure corrections used to obtain the C_b factor.

Upper graph plotted prior to correction and lower graph after correction to obtain the C_b factor in equation [4].

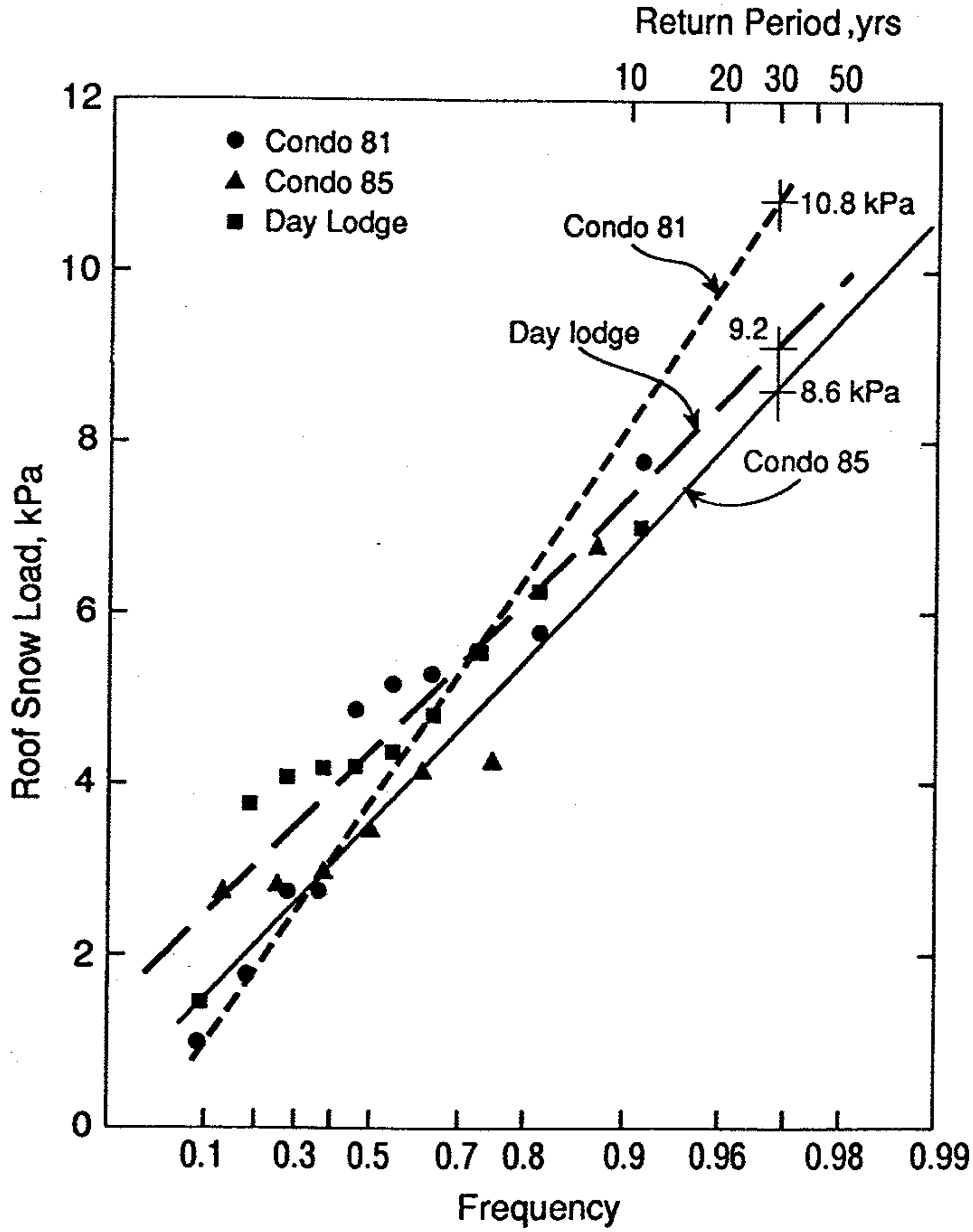

Figure 11. Predictions of 30-year return snow loads on roofs of Day Lodge, Condo 81, and Condo 85 using Gumbel plots.

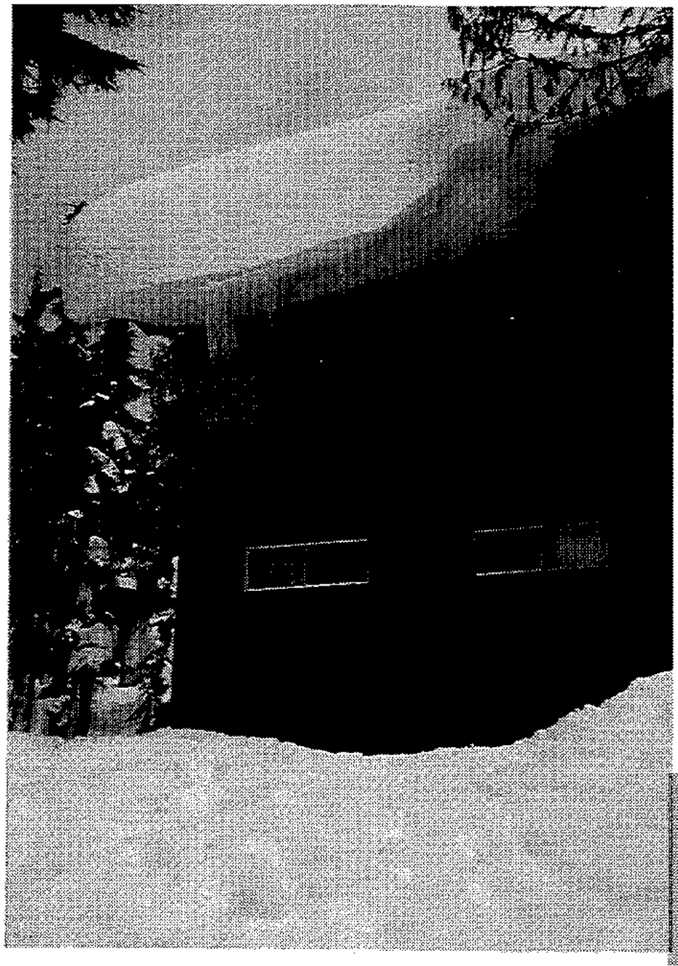

Figure 12. Heavy cornice,
January 14, 1988

Figure 13. Heavy cornice,
February 2, 1982

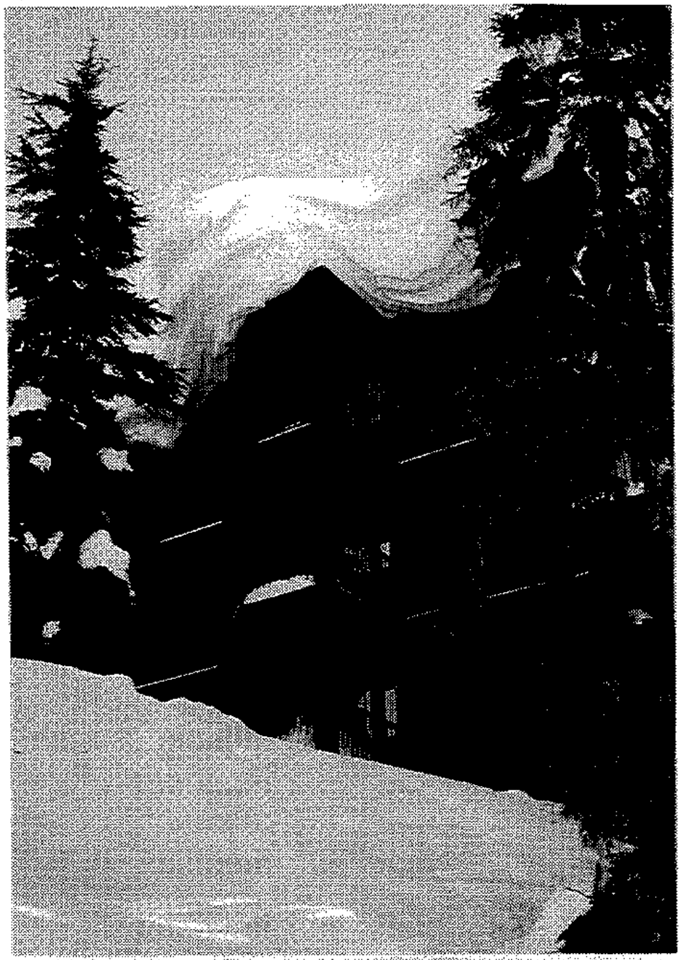

Figure 14. Heavy cornice,
February 2, 1982

Figure 15. Perimeter of flat roof cleared by snow blower kept on roof.

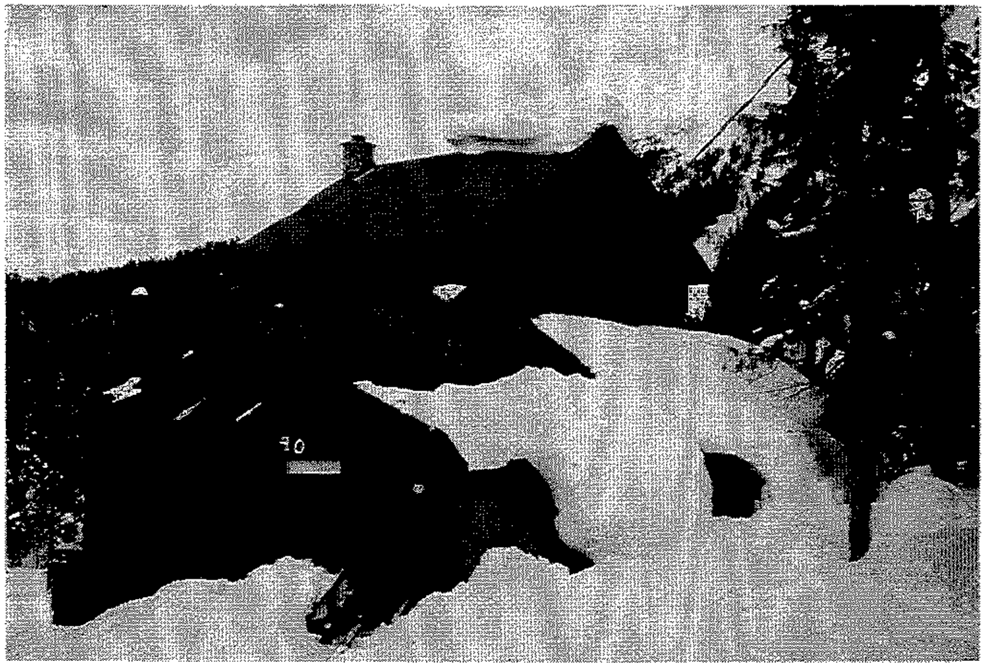

Figure 16. Slippery metal roof has shed snow. Notice "hat" of heavy snow at ridge posing danger below.

Figure 17. Power lines damaged due to falling cornices and sliding snow.

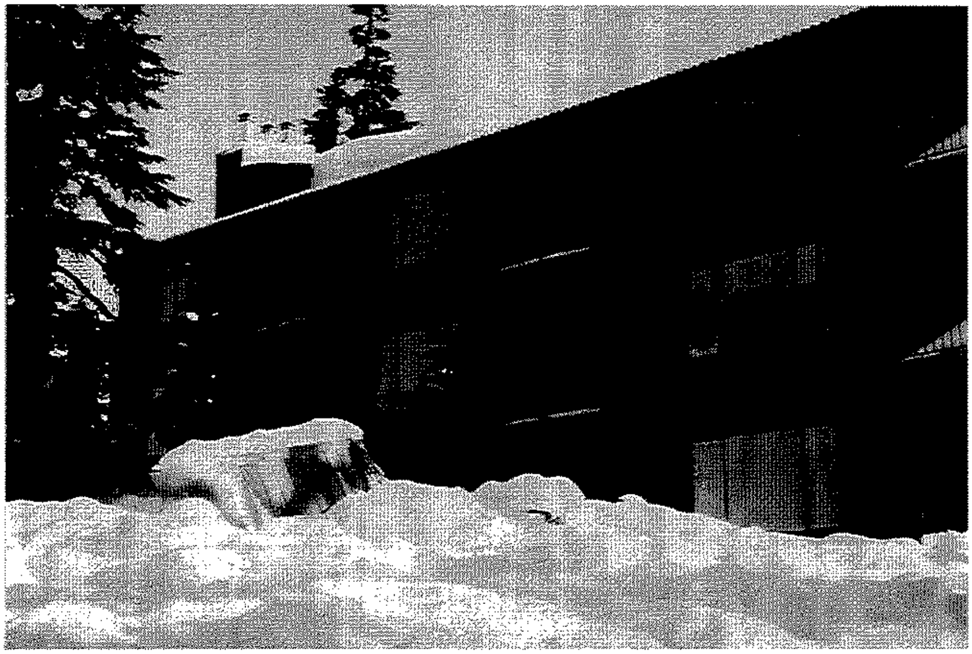

Figure 18. Sliding snow has swept chimney off roof (chimney in foreground) and broken window.

Figure 19. Railing around deck broken or removed to prevent breakage by sliding snow.

Figure 20. Roof designed to prevent 'hat' of snow from balancing at ridge. The special ridge will force the snow cover to crack and slide off.

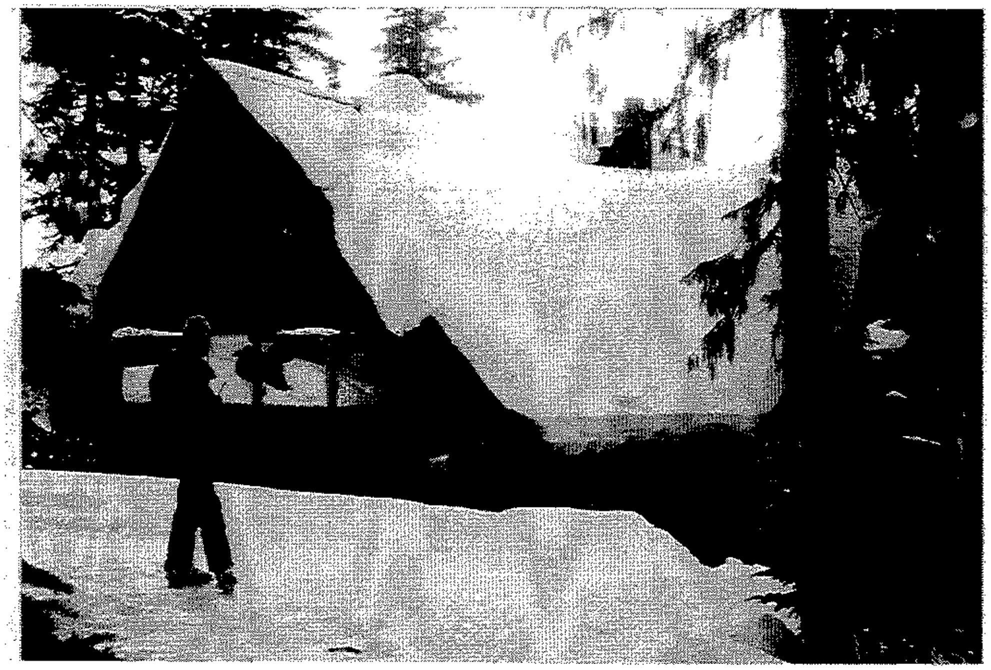

Figure 21. Snow trying to slide in two directions is jammed in the valley.

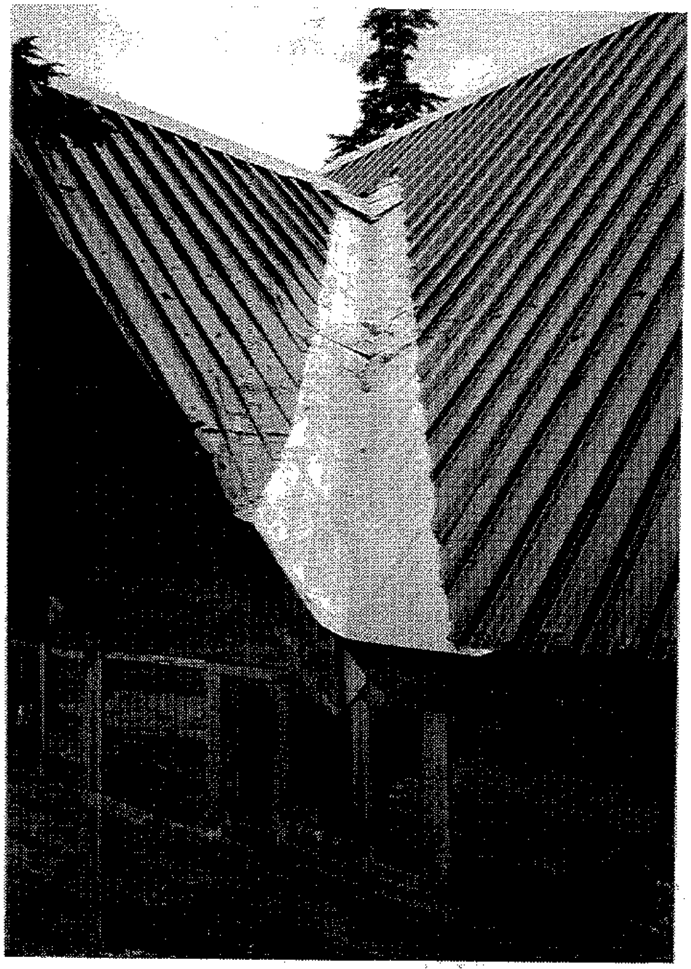

Figure 22. Snow sliding down the larger roof on right side has damaged metal roofing in valley as it moved downwards.

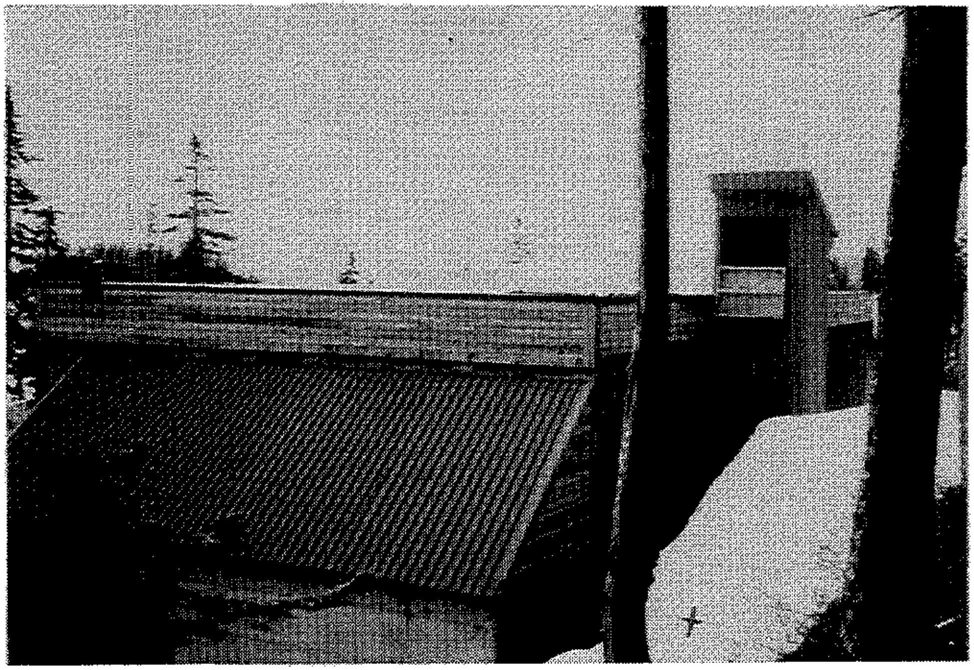

Figure 23. Wooden escape hatch at back door of building (against hill). Snow is usually very deep there. Note two door openings in hatch.

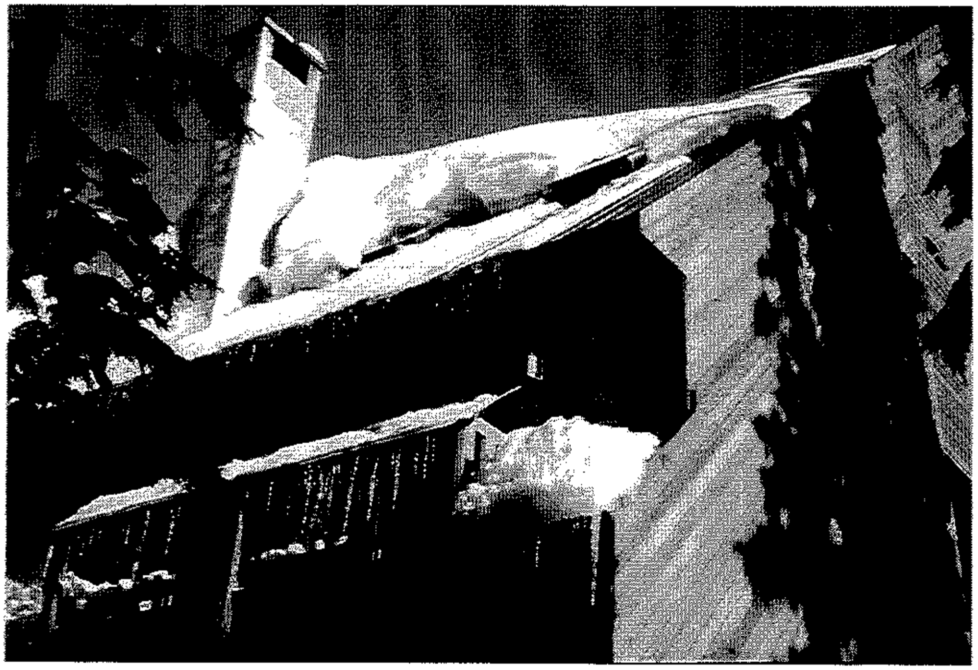

Figure 24. Chimney part way down roof slope is holding back sliding snow.

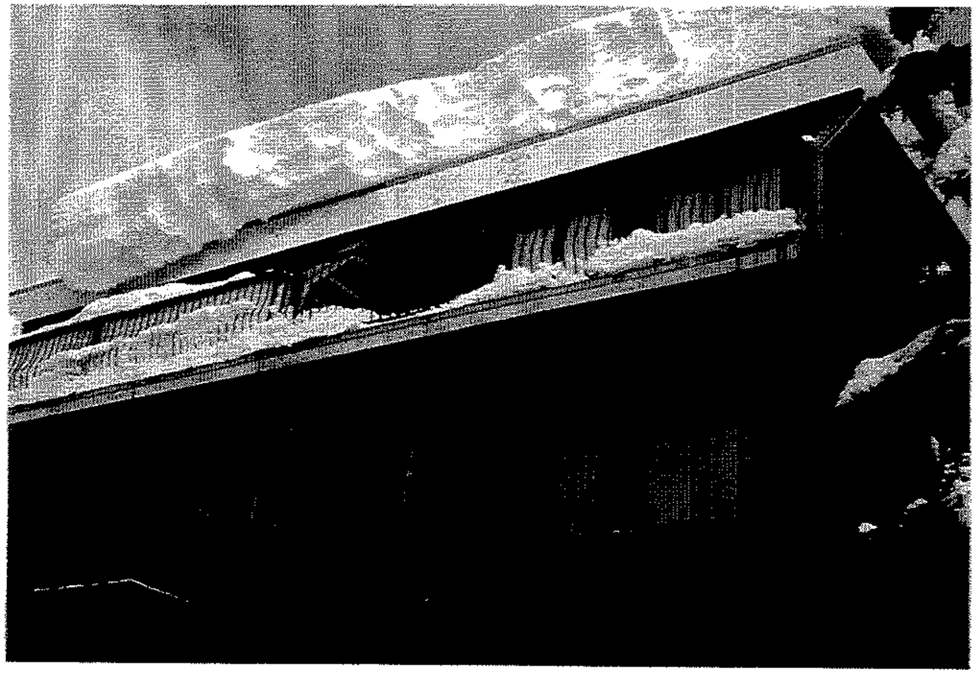

Figure 25. Overhanging snow falling into balconies is a danger to the structure and to people.

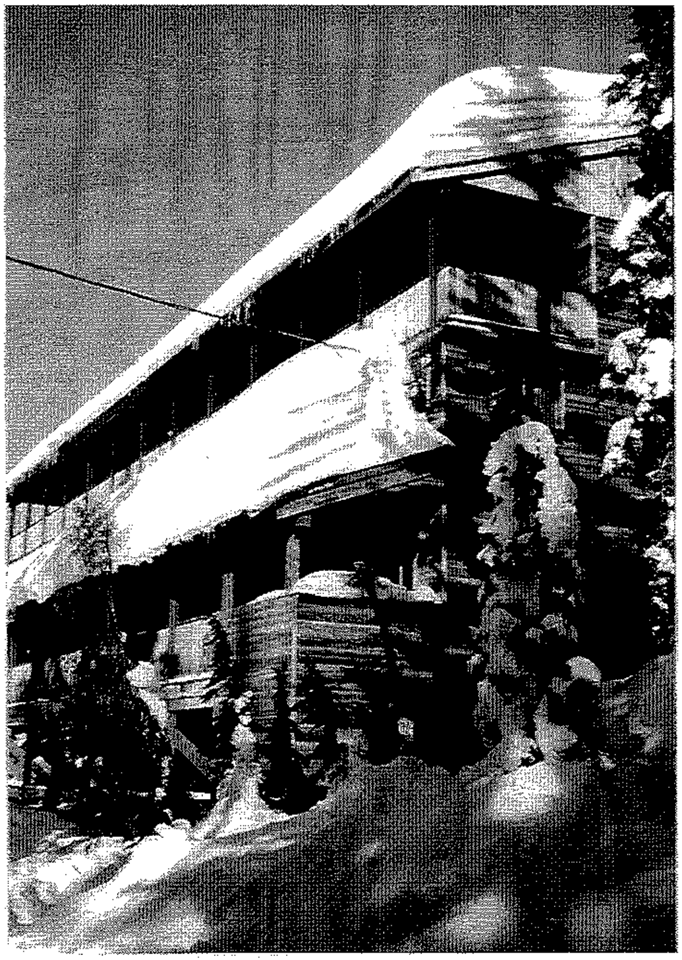

Figure 26. Balconies with roofs to keep snow out and risks low.