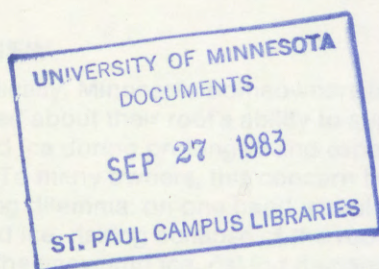
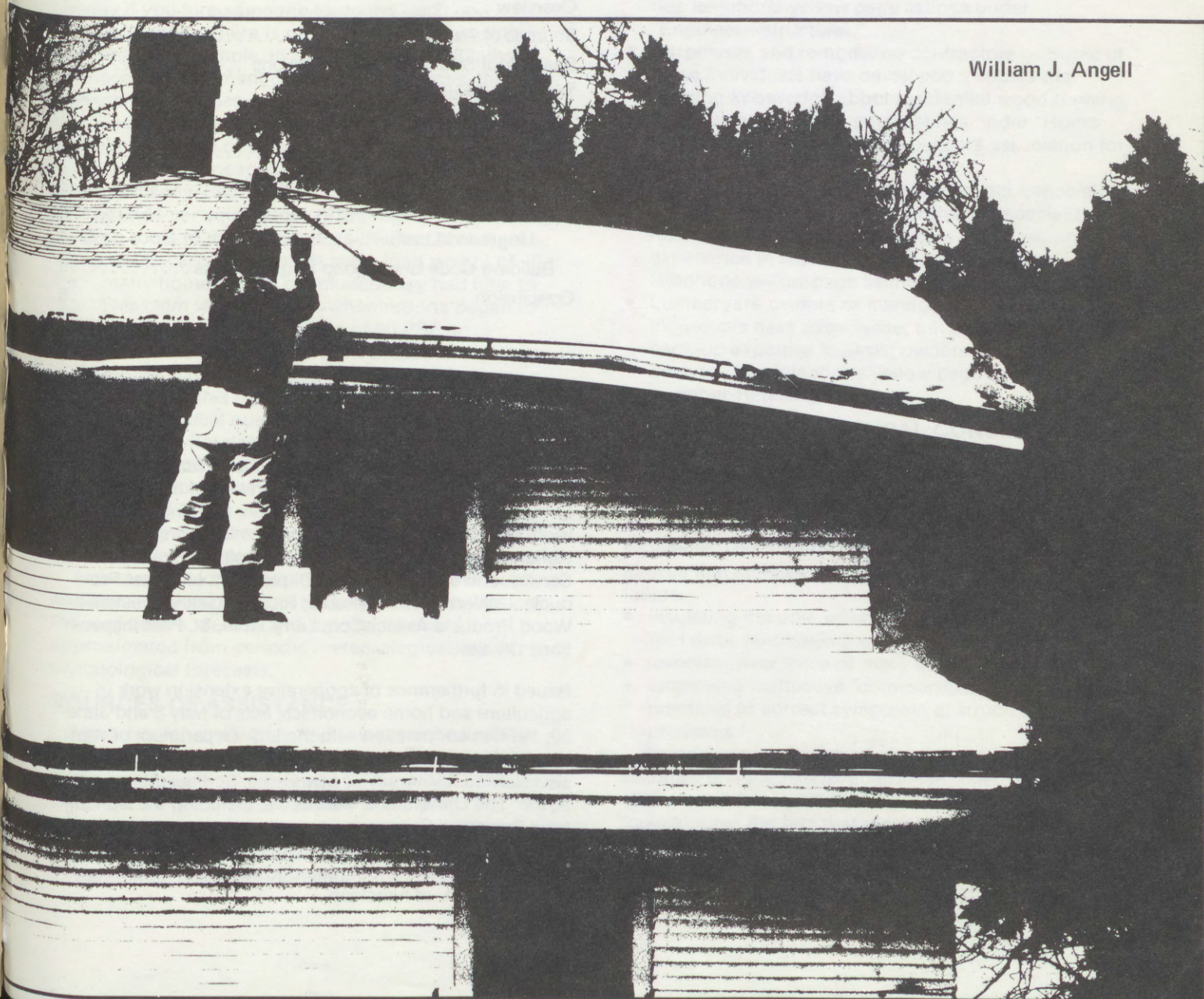


Residential Roof Snow Load Concerns



William J. Angell



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OVERVIEW

Periodically, Minnesota homeowners become concerned about their roof's ability to support tons of snow and ice during prolonged and especially moist winters. To many owners, this concern becomes a frustrating dilemma: on one hand, should you leave the snow and ice, risking collapse of the roof; or should you remove the snow and ice, risking damage to brittle shingles and personal injury or incurring expense and liability if you hire someone to do the job?

Unfortunately, there is no simple solution to this dilemma. For example, in early February 1982, the Minnesota Department of Natural Resources, the University of Minnesota, and the National Weather Service issued a joint summary of snow depth/moisture content from field observer reports. The summary revealed that Minneapolis-St. Paul had 21 to 26 inches of ground snow depth with a possible weight range of 4 to 9 pounds per square foot (PSF). Since the relatively modern roofs in the Minneapolis-St. Paul area were designed to carry a minimum snow load weight of 40 PSF, many homeowners concluded they had little to fear. This calm was shattered when reports began to surface of snow loads in excess of 60 PSF on commercial buildings and of the collapse of institutional, garage, carport, and patio roofs.

The intent of this report is to introduce homeowners to the three critical questions that must be answered to determine to what degree they should be concerned about snow load weight conditions on their roof:

1. How much snow and ice (moisture) weight is on the roof?
2. What is the "dead" weight of roofing materials?
3. What is the strength of roof structural members?

Answers to a fourth pertinent question, how much additional moisture weight is likely to accumulate on the roof before melting and runoff, may be approximated from periodic meteorological and climatological forecasts.

SOURCES OF ASSISTANCE

Many homeowners may find themselves unable to answer those questions, especially those related to structural determination. Owners who desire assistance may find the following sources to be helpful:

- Local building official or housing inspector — Although these individuals seldom have schedules that permit extensive consultation, building or

housing inspectors may be able to offer impartial advice and referral. See municipal or county telephone listings. (In rural areas lacking building or housing code enforcement, County Farmers Home Administration supervisors may fulfill a similar role.)

- Structural engineers — These individuals generally have the greatest academic preparation in structural analysis, although this ability may be limited in respect to residential wood framing considerations. See telephone yellow page listings under "Engineers-Structural."
- Carpenters and remodeling contractors — Some of these individuals have developed a substantial working knowledge about residential wood framing. See telephone yellow page listings under "Home Builders" for the area home builders association for referral.
- Architects — Some of these individuals, especially architectural engineers and architects specializing in residential remodeling, may have academic and field experience in residential wood framing. See telephone yellow page listings under "Architects."
- Lumberyard owners or managers — Many of these individuals have experience, training, and access to back-up expertise to assist owners in structural analysis. See telephone yellow page listings under "Lumber-Retailing."

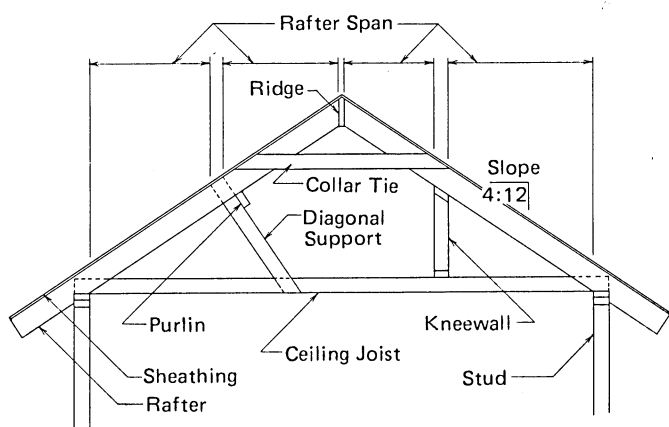
BASIC ROOF STRUCTURAL CONSIDERATIONS

Roofs are subjected to the greatest load, temperature, and moisture extremes of any component of the home. The roof may be the most "under-built" portion of and older home and thus, the most vulnerable to structural problems. This situation is intensified by common abuses that increase the vulnerability to structural failure:

- insulating the attic without providing for adequate roof deck ventilation (i.e. underside of sheathing);²
- reroofing over three or more layers of shingles;
- employing ineffective "commonsense" construction practices to correct symptoms of structural problems.³

Some owners of older homes and contractors rationalize: If the roof structure has lasted all of these years, it will last indefinitely . . . Unfortunately, this logic ignores the fact that older home roofs were not insulated or minimally insulated. Without insulation, roof snow melted faster and roofs carried snow loads

Figure 1. Common Roof Components



for very brief periods. With the addition of insulation, roof snow loads accumulate to new and perhaps excessive weight levels. Furthermore, most older home roof decks have not been adequately ventilated as attic insulation has been added. This situation promotes ice-dam water back-up and condensation favorable for deterioration of roof structural members and fastener holding ability.

If you are unfamiliar with common roof structural components, refer to figure one. In effect, the rafter and ceiling joist structure form a basic truss. This rafter/joist combination may also involve a "collar beam" or "collar tie" to stabilize the thrust mechanics of loading by tension; a vertical support, known as a "kneewall;" or a diagonal support designed to transfer a portion of roof loads to interior load-bearing partitions. In new construction, an engineered truss of interconnected diagonal members may be found.

If kneewalls or diagonal supports/purlins are not present, rafter span is measured from the ridge to the exterior stud wall. If kneewalls and diagonal supports are placed over load-bearing walls or joists designed to carry snow loads, rafter span is measured from the ridge to the intermediate support and from that support

to the exterior stud wall (or to the next load-bearing partition). Collar ties are not considered when measuring spans.

Roof structural failure generally begins with rafter deflection or rafter spread. Deflection results when horizontal loads (such as snow and ice buildup) cause wood fibers to bend. Eventually, deflection will cause rafters to rupture in the center third of the span or at weak points, such as notches or knots on the top or bottom edge of the rafter. Rafter spread results from the failure of mechanical ties, such as nails, to hold ceiling joists, top plates, and studs together or, occasionally, failure in the ceiling joist itself. Unless rafter spread is stabilized, roof collapse will eventually occur.

Rafter deflection and spread represent initial stages of structural failure. These problems should be corrected or stabilized with the assistance of a knowledgeable contractor, engineer, or architect.⁴

TECHNICAL SECTION

In this section, information and procedures are outlined that may help the homeowner estimate the strength of roof structural members and existing load conditions. Many owners may wish to retain professional assistance (see page one) to make or to verify this technical assessment.

Measuring Roof Snow and Ice Weight

Depth of snow is not a critical factor. Rather, the weight of accumulated snow/ice moisture content is important. Water content of snow may range from 3 percent for a very dry snow (30 inches of snow equals 1 inch of water), to 20 percent for compacted, settled snow, to approximately 100 percent for ice. Water per inch of depth weighs 5.2 pounds per square foot. Thus, a modern roof designed to carry a snow load of 40 pounds per horizontal square foot is designed to support an equivalent of approximately 8 inches of ice or 3½ feet of compacted or settled snow or, theoretically,⁵ 20 feet of very dry snow, or a combination of these amounts.

The only practical and accurate way to determine the snow/ice weight on your roof is to collect representative samples of snow/ice from *your* roof.⁶ These samples should be melted and either weighed or measured.

To obtain samples of roof snow, you may wish to use a 3-pound coffee can (6 inches in diameter). The can may be repeatedly thrust into a vertical core of the snow blanket (see figure three), with snow content emptied into a pail each time the can fills. After the snow is melted, the coffee can samples, if weighed, should be multiplied by 5.1 to determine pounds per square foot. If the coffee can samples are measured by inches of liquid depth, the inches of liquid in the coffee can are multiplied by 5.2 to determine weight per square foot. For example, if . . .

- your melted samples weigh 4 pounds, your roof snow load is approximately 20 pounds per square foot ($4 \times 5.1 = 20.4$); or if
- your melted samples, in the 6-inch diameter coffee can, have a cumulative depth of 4 inches, your roof snow load is approximately 21 pounds per square foot ($4 \times 5.2 = 20.8$).

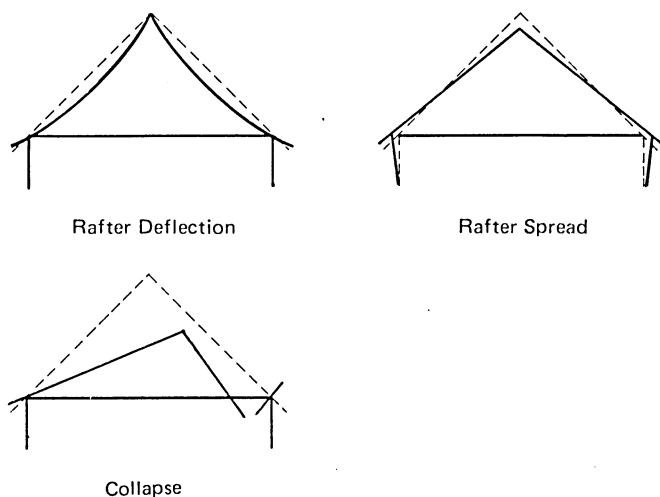


Figure 2. Roof Structural Failure

Do not compact snow when sampling. Remove can samples after each fill. Bottom may be cut from can.

Since it may be impossible to obtain representative samples of ice at the bottom of the roof snow blanket without damaging shingles, you may wish to estimate the average thickness of the ice, multiply the thickness by 5.2 per square foot, and add this result to snow moisture weight. In most cases, ice thickness is greatest at the lowest edges of the roof, especially in lower valleys if present. Therefore, ice thickness from these areas should not be assumed to be representative of the entire roof deck.

Snow samples from valleys or other roof areas susceptible to drifting or blow-off should not be assumed to be representative. Generally, the most representative samples can be drawn from the center third of roof planes. These areas are also usually the most important for determination of rafter strength capabilities.

However, in some cases you should be concerned about snow/ice loads on these specific areas of the roof:

- overhangs, especially large overhangs projecting several feet from horizontal supports, that have substantial ice buildup;
- multilevel roofs, where a lower roof is subject to sliding or drifting snow or accumulation of snow melt; and
- valleys subject to substantial snow or ice accumulation due to drifting, sliding, or melting.

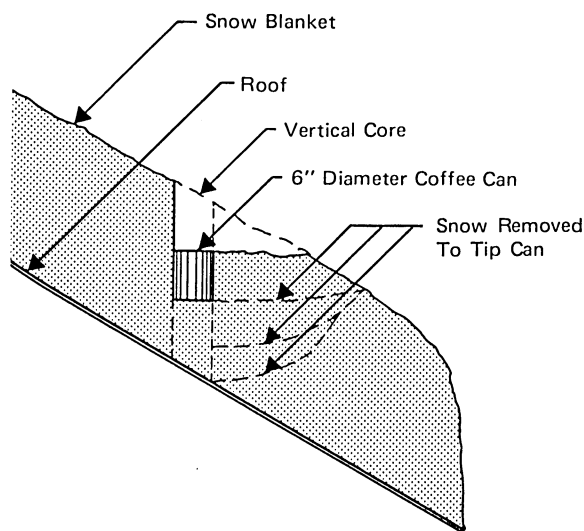


Figure 3. Snow Sampling Technique

Measuring Roof Dead Weight

Another variable affecting your roof's snow-bearing capacity is roof dead weight, or the weight of all the roofing materials (sheathing, roofing paper, felt, shingles, or built-up membrane). According to state and national "model" building codes,⁷ roof rafters or trusses in new Minnesota homes are assumed to carry 10 pounds of roofing material per horizontal square foot. While this assumed weight is well within the realm of reality of new construction practices, multiple application of additional layers of roofing over the life of a dwelling may exceed dead weight assumptions and thus reduce snow load capabilities. Figure four shows how to estimate the dead load weight of your roof.

Figure 4.

Approximate Roofing Dead Weight Calculations

Material	Approximate Weight in PSF by Slope ⁸									
	0:12 (flat)		3:12 (11¼°)		6:12 (22¼°)		9:12 (33 1/3°)		12:12 (45°)	
	Item	Cum.	Item	Cum.	Item	Cum.	Item	Cum.	Item	Cum.
initial sheathing, roofing paper, and shingles	4	4	4	4	4	4	5	5	6	6
additional layer over existing roofing layer	3	7	3	7	3	8	4	8	4	10
additional layer over two existing roofing layers	3	10	3	10	3	11	4	12	4	14
½" sheetrock ceiling	2	12	2	12	2	13	2	14	3	17
TOTAL	-	12	-	12	-	13	-	14	-	17

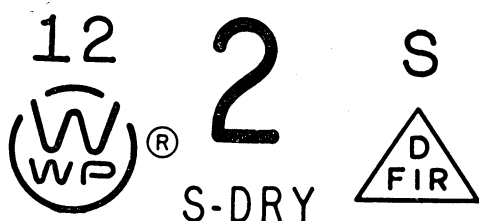
If the combination of roofing materials on your roof exceeds the assumed 10 pounds of dead load, your roof's snow load capabilities are reduced by an equal number of PSFs. For example, if you have a 6:12 roof with three layers of shingles and a sheetrock ceiling carried by your rafters, the roof dead weight is 13 PSF ... or 3 PSF over assumed dead weight.

Estimating Roof Structural Strength

In most cases, structural strength of an existing roof is the most difficult variable to define. There are several reasons this situation exists.

- Foremost, in the majority of older homes as well as in many new homes built in areas lacking building code enforcement, lumber is not graded according to structural properties and thus is subject to substantial variation.
- Second, the majority of lumber used in new construction has been visually graded by an experienced, but human, eye (see figure five) and thus is subject to variations in human judgment.⁹
- Third, mechanical- or machine-tested structural lumber (see figure six) used for modern roof trusses is rated conservatively in respect to maximum load capabilities.¹⁰
- Finally, roof structural members may have been destroyed, modified, or weakened by notching, rotting, deteriorated fasteners, or insect damage.

Figure 5.



Example of grade stamp for visually rated and graded lumber.

In homes with graded lumber, estimating roof structural strength is easier and more accurate. In the next two subsections, the process of determining structural properties will be outlined.

1. **Graded Lumber** — Grade stamps provide the most accurate basis to determine structural properties of roof lumber members. If your home has rafter lumber with a grade stamp, note the following information.

a. *from the grade stamp ...*

- species of lumber. For example, figure five identifies douglas fir while figure six reflects hem fir.
- grade or stress rating. For example, figure six identifies a machine stress rating of: 1650 pounds per square inch (PSI) extreme fiber stress in bending (f) or the maximum stress in bending before wood fiber would separate — a measure of strength; and 1.4 million PSI modulus of elasticity (E) — a measure of stiffness.

Figure five identifies a number 2 grade of visually rated douglas fir. (E and f values are given in span tables for visually rated lumber.)

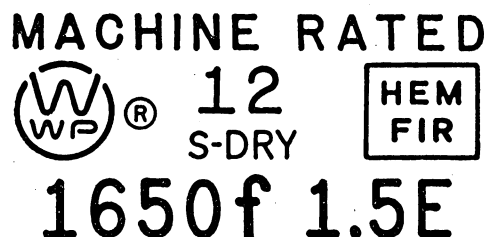
b. *from attic observation ...*

- the horizontal rafter span between the ridge and exterior walls and/or supports such as vertical kneewalls or diagonal supports and purlins built over load-bearing joists, walls, or beams (see figure one).
- the slope of the rafters (see figure one).
- the distance, on center, between the rafters.
- any strength reduction items such as notching, rotting, or insect attack.

With this information, you may refer to span tables (see figure eight), available at lumberyards or through engineers, building inspectors, architects, or carpenters. These tables enable you to estimate the PSF snow load capacity of your roof.

2. **Ungraded Lumber** — Unfortunately, species and grade information is not readily available for homes built without graded lumber — as is the case with older homes as well as some new homes built without building code review. In these situations, it is difficult, at best, to definitely estab-

Figure 6.



Example of grade stamp for machine-tested lumber (used in roof trusses).

lish several critical variables without on-site assessment by an experienced, knowledgeable carpenter, contractor, or building inspector. These variables include:

- a. *species of wood used for rafters.* Species is important to the structural properties of rafters, as illustrated by the following allowable fiber stress ratings for snow loading for *equal grades* of lumber:¹¹
 - No. 2 douglas fir, commonly used in new construction = 1900f for 2x4 and 1670f for over 2x4.
 - No. 2 hemlock/fir (species group), also known as "hem fir" and commonly used in new construction = 1550f for 2x4 and 1320f for over 2x4.
 - No. 2 red or white pine, commonly used in older construction¹² = 1260f for 2x4 and 1090f for over 2x4.
 - No. 2 cottonwood, used in some older construction = 950f for 2x4 and 800f for over 2x4.
- b. *strength reduction characteristics of rafters due to natural occurrences.* These factors include:
 - grain slope or "cross graining" (see figure seven). For example, in comparison to straight grain lumber, an average grain slope of vertical

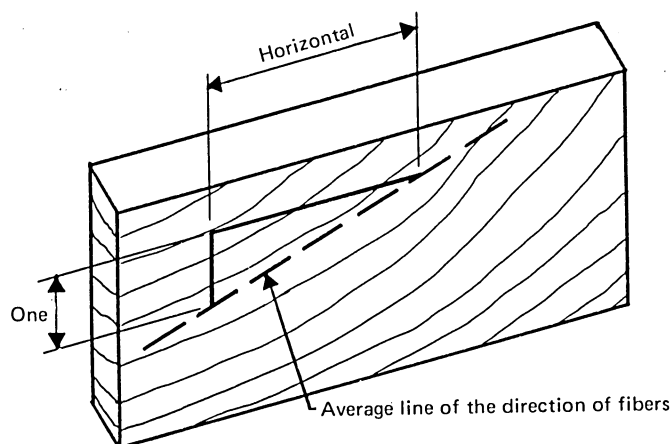


Figure 7. Grain Slope

rise by horizontal run will reduce elasticity (E) to the following amounts:¹³

1:20 grain slope = 96 percent or commonly rated as a "select structural" grade, all other factors equal

1:10 grain slope = 89 percent or commonly rated as a No. 1 grade

1:5 grain slope = 67 percent or commonly rated as a No. 2 grade

- knots. Knots reduce strength since they interrupt the grain slope and cause localized cross-graining. Knots or knot holes located at a lower vertical edge of a rafter may further reduce proportionate strength by approximately the knot's depth into the rafter.

c. *strength addition characters of older "full-dimension" lumber.* For example, older framing lumber was larger than today's "nominal-dimension" lumber. Currently a 2x4 is actually 1½ x 3½ inches, a 2x6 is actually 1½ x 5½ inches, and a 2x8 is actually 1½ x 7¼ inches. Thus, a full-dimension rafter of the same species, grade, and moisture content may have 10 to 15 percent greater strength than nominal-dimension lumber listed in current span tables. Since this difference is similar to the snow load stress difference between red and white pine, often used in older construction, and hem fir, often used in new construction and listed in most span tables, an owner of a home with full-dimension red or white pine rafters may simply wish to assume that the rafters are similar to an equal grade of hem fir.

Assuming that rafter species and grade have been accurately estimated and that rafters are free of notching, rotting, or insect damage, you can refer to a span table similar to that in figure eight to determine design snow load capabilities of your roof. For example, if you have a roof with a 6:12 pitch and single layer of shingles that is carried by No. 2 — 2x6 hem fir rafters, 16 inches on center, and the horizontal span of the rafter is 11½ feet from the exterior wall to the ridge, your roof has a designed capacity to carry 30 PSF of snow (and ice).

Figure 8.

For Nominal No. 2 Dimension Hem Fir or Full-Dimension Red or White Pine
(7 PSF Dead Load, Roof Slope over 3:12)¹⁴

Rafter Span by Distance On Center by Snow Load

Rafter Size	16" O.C.			24" O.C.		
	20 PSF	30 PSF	40 PSF	20 PSF	30 PSF	40 PSF
2x4	9'3"	7'11"	7'0"	7'6"	6'5"	5'8"
2x6	13'6"	11'6"	10'3"	11'0"	9'5"	8'4"
2x8	17'9"	15'2"	13'6"	14'6"	12'5"	11'0"
2x10	22'8"	19'5"	17'2"	18'6"	15'10"	14'1"

Building Code Snowload Requirements

Minimum building code requirements for structural capabilities of roofs vary according to geographic snow load variations and types of structures. In Minnesota, the maximum 50-year average or mean snow load, measured on the ground, ranges from less than 20 PSF in the far northwest portion of the state to over 50 PSF in the extreme northeast section (see figure nine).

Reflecting this pattern, the State Building Code establishes a 40-PSF minimum roof snow load capability for homes in the northeastern sixth of the state, including the Minneapolis-St. Paul metropolitan areas. In the balance of the state, a 30-PSF minimum requirement is used.

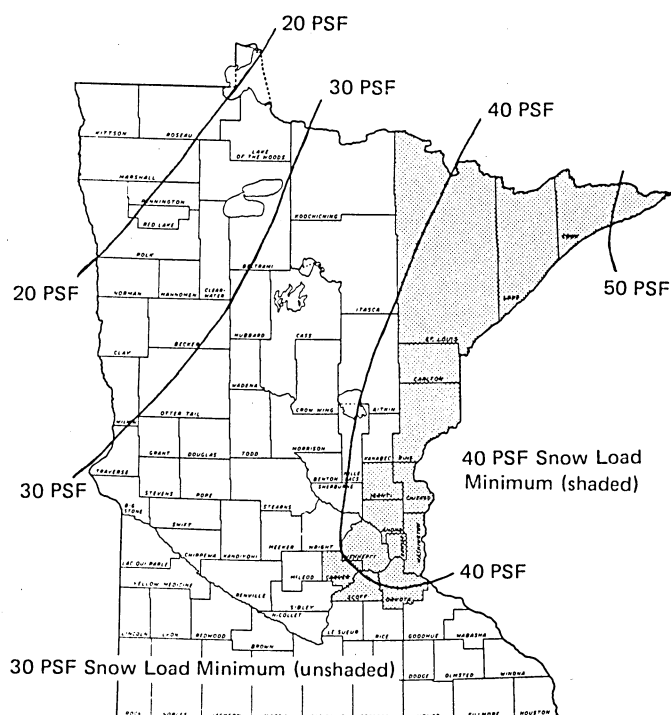


Figure 9. 50-Year Mean Ground Snow Load and State Building Code Minimum Snow Load Requirement for Homes

There are, however, some important variations to these requirements:

- First, detached accessory structures, such as garages, may have lower snow load requirements. For example, in the 14 Minnesota counties having a 40-PSF snow load requirement under the State Building Code, detached structures may have a 30-PSF design. For this reason, detached structures may be earlier victims to snow and ice buildup.
- Second, agricultural structures are exempt from State Building Code standards and thus, may be more vulnerable to widespread snow load failure than nearby residences.

- Third, under federal standards, which supersede state requirements, mobile homes must have a minimum 30-PSF snow load capability. This factor may make some mobile homes, especially double-wide mobile homes with "conventional roofs," more vulnerable to snow load failure.
- Finally, in many areas of the state, local residents have voted not to enforce a building code. In these areas, an unknown proportion of new construction fails to meet building code requirements.

The State Building Code considers not only rafter species, grade, size, spacing, and span in respect to snow load, but also roof slope (see figure ten). For example, a higher pitched roof tends to shed more snow than a flatter roof and thus may have a lower minimum snow load requirement. Although not considered at this time, the State Building Code may also in the future consider roof exposure to the wind, as outlined in other model codes. For example, if a roof is exposed to the wind, greater amounts of snow may be blown off the roof and thus, lower minimum snow load requirements may be reasonable. Thus, whereas a roof with a slope less than 6:12 may have a minimum 40- (or 30-) PSF snow load requirement, a 12:12 sloped roof exposed to wind may have a minimum 20-PSF requirement.

Figure 10.

Roof Slope and Wind Exposure Adjustments to Minimum Code Snow Load Requirements¹⁵

Roof Slope	Allowed Currently by Section of Minnesota*		Proposed Wind Exposure Allowances* (Not Currently Allowed)	
	40 PSF Counties	30 PSF Counties	40 PSF Counties	30 PSF Counties
0:12 (0° or flat)	40 PSF	30 PSF	30 PSF	23 PSF
3:12 (11¼°)	40	30	30	23
6:12 (22½°)	38	28	29	21
9:12 (33 1/3°)	27	20	20	15
12:12 (45°)	20	20	15	15

*See figure nine: 40-PSF section includes shaded counties. Under the current State Building Code, snow load requirements may be reduced 1 PSF for each degree of slope over 20°, to a minimum requirement of 20 PSF.

CONCLUSION

Concern about roof snow/ice loads affecting Minnesota homes is justified. Whether the snow/ice load on a particular roof merits snow/ice removal or roof structural modification must be determined by on-site analysis of three items: 1) amount of seasonal snow/ice accumulation, 2) roof dead weight, and 3) roof snow load design capacity.

Owners who desire on-site analysis may wish to retain a knowledgeable carpenter, engineer, or architect.

FOOTNOTES

¹ This paper is based upon a survey of literature and professional opinions identified in subsequent footnotes. Currently, the University of Minnesota does not have funds to provide one-to-one consultation, to carry out research on roof structural design, nor to test construction materials and practices. For further information or assistance, obtain the references or contact the sources cited in this paper.

² For more information, obtain "Preventing Ice Dams on Minnesota Homes" (F FS 12), available free to Minnesota residents through county extension offices.

³ For example, "kneewalls" or diagonal supports are frequently installed (to stabilize rafters) over ceiling joists not designed to carry additional loads. Also, rafters are occasionally notched and thus weakened.

⁴ Additional information about older home construction and common defects is found in *Evaluating Structural and Exterior Components* . . . (Bulletin 411), available to Minnesota residents through county extension offices.

⁵ In reality, as snow accumulates, compaction of lower portions of the snow blanket occurs. Likewise, wind and drifting contribute to compaction.

⁶ Ground samples may not accurately reflect weight conditions on a roof since drifting, melting, and slide-off conditions are not the same.

⁷ *One and Two Family Dwelling Code*, Interstate Printers and Publishers, Danville, Ill., 1975. (This publication contains standardized requirements compiled from four national model building codes, one of which has been adopted by statutory reference as the Minnesota State Building Code. In many rural areas of the state, there is no building code enforcement due to rejection by resident voters.)

⁸ These values are rounded to the nearest pound and thus, may not be additive in the cumulative (i.e. "cum") column. *Construction Materials: Principles, Materials, & Methods* by Schmidt, John L., Lewis, Walter H., and Olin, Harold B., American Savings and Loan Institute Press, Chicago, Ill., 1970.

⁹ op. cit. *Construction Materials* . . . : 201-27. This source claims that ". . . tests have shown that at least half of the visually graded lumber is at least twice as strong as its assigned stress rating."

¹⁰ op. cit. *Construction Materials* . . . : WF 201-3.

¹¹ *Design Values for Joists and Rafters*, National Forest Products Associations, Washington, D.C. 1980.

¹² According to Charles Nelson, Architectural Historian with the Minnesota Historical Society, native white pine or red pine, also known as Norway pine, were extensively used for older residential construction in Minnesota. However, other native regional species may also be found including aspen, cottonwood, oak, tamarack, and walnut.

¹³ op. cit. *Construction Materials* . . . : 201-22.

¹⁴ *Simplified Span Tables for Light Frame Construction*, West Coast Lumber Inspection Bureau, Portland, Ore., 1971. These spans are identical or very similar to those presented in *Part II Building Inspection Manual*, The North Star Chapter, International Conference of Building Officials, c/o State Building Code Division, Minnesota Department of Administration, St. Paul, Minn., 1982.

¹⁵ *The Basic Building Code*, Building Officials and Code Administrators International, Inc., Chicago, Ill., 1975: 198, 470.