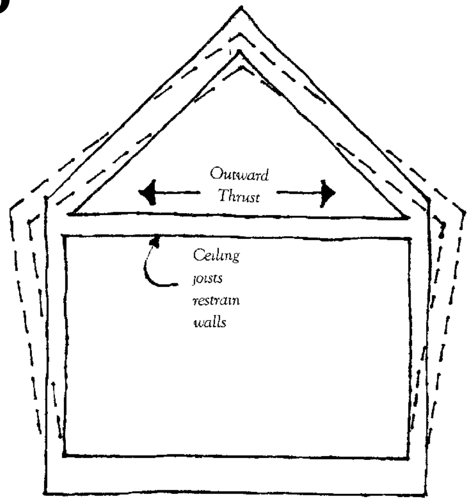
ROOFS:
STRUCTURAL BASICS

A *cluster of sheds can create visual interest while maintaining structural simplicity*



In a gable roof, the outward thrust of the rafters will force the walls out at the top unless restrained by ceiling joists. A structural ridge is another solution.

by Paul Hanke

In Japanese the word for roof and the word for house are the same, indicating the importance of this element in creating shelter. Moreover, what we call a roof is really a *system,* consisting of many components that must work together effectively to provide trouble-free service.

Design Loads: How Much is Enough?

How much load must a roof be able to support? This is crucial for the designer and builder to know, especially in snow country. It is generally assumed that a 40-pound-per-square-foot (psf) live load (snow) plus a 100-psf dead load (the weight of the materials themselves) is sufficient in New England. However, if you consult the snow-load map of the Vermont code, you'll find that 40-psf live load is the bare minimum—applicable only to the "banana belt" along Lake Champlain. In mountainous areas the design load for snow ranges up to 60 psf—the equivalent of nine feet of waterlogged snow, according to Hank Spies of the University of Illinois Small Homes Council. A snow map of Maine shows loads up to 80 psf in northern regions, while Hartford, Connecticut—site of the infamous Civic Center roof collapse—has a snow-load factor of a mere 30 psf.

On the other hand, codes may allow (or require) some modifications. For instance, steep pitches and roofs in windy, unsheltered locations may qualify for some reduction in snow loading, while those in protected forest areas may need a slight increase in design load.

Moreover, roofs of earth-sheltered houses might have to support not only the maximum snow load plus a drifting factor, but the weight of one or two feet of earth (at 120 pounds per cubic foot) plus a dead load (150 pounds pcf for concrete construction) and perhaps a pedestrian or vehicular load as well. This can total several times the design load for a conventional roof. For this reason I usually recommend that earth-shelter enthusiasts use bermed walls and a conventional roof structure with heavier-than-normal insulation to get the desired thermal performance.

Two other factors influence the structural design of a roof: configuration and outward thrust.

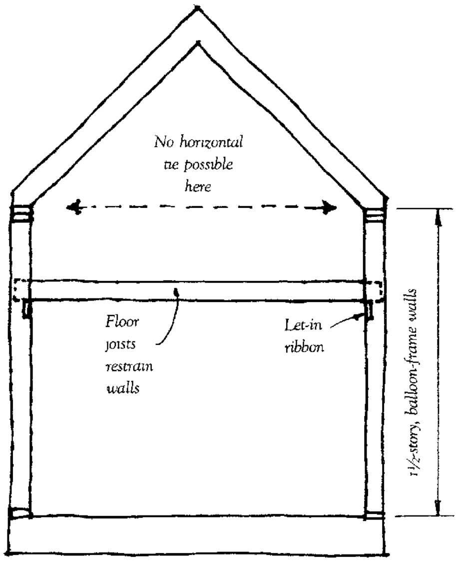
Sheds and Gables

Roofs come in a variety of types—from the simple shed to the doubly curved hyperbolic paraboloid (hypar, for short). To a great degree the shape of a roof determines the visual character of a building.

A shed—or single pitched—roof is the simplest type, both structurally and visually. The supporting members rest directly on supporting walls or girders. Sheds can cluster to form complex shapes (see illustration) while keeping construction relatively simple.

Next in complexity is the common gable roof. When framed with stick or heavy-timber construction, the roof beams or rafters lean against each other and create an outward thrust which, if not attended to, can force the walls out at the top and cause structural failure.

There are three ways to control thrust. The first is the addition of horizontal ceiling joists to the system. These members tie the walls together and resist the thrust force. For 1 1/2-story construction (see illustration), the second-floor joists fill this role, but the bearing walls *must be* balloon framed. Otherwise the upper knee walls will act as if they were hinged at the bottom, and will tip outward. (Diagonal braces tied back to the floor joists, or very wide structural top plates, are alternative solutions.)

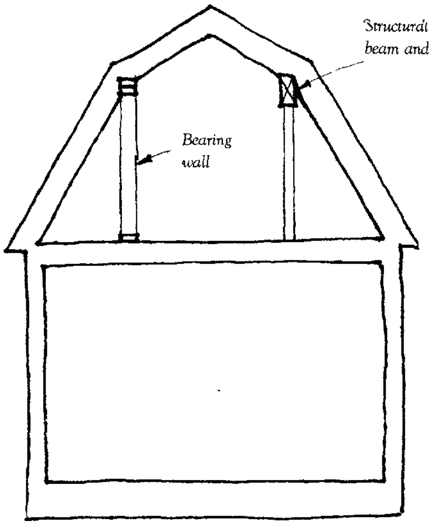


In 1 1/2-story houses, balloon framing is typically used to control outward thrust. In this case, the second-floor joists run by the studs and provide a horizontal tie.

The second thrust-control method is truss construction. Because they are composed entirely of triangles, trusses have no outward thrust.

Finally, a structural ridge, such as a glulam beam, may be used. In this case the structure is reduced to two simple sheds parked next to each other and, as noted above, sheds have no thrust. The ridge beam must be supported at the ends by posts and as necessary along its length.

A gambrel roof has two pitches—steeper on the lower portions and flatter on the top—which increases usable second-floor area. (The style is rumored to have developed as a tax dodge during a time in French history when space in the attic wasn't taxed.) Construction may consist of a trussed upper section or a supporting beam or header under the intersection of the two roof planes (see illustration). If the ends of the roof—in addition to the sides—are pitched in, the style is called mansard.



The doubly pitched gambrel roof may be supported under the joint with either a girder or a bearing wall.

Saltbox roofs are asymmetrical, with one long and one short side. This style originated as a rear shed addition to a two-story gable-roofed dwelling. It is well suited to passive-solar design since it can present a full two stories to the sun and a long, sloping roof and low wall to the winter winds. A garrison-style overhang at the second floor can provide summer shading for the downstairs windows.

Hips, Valleys, and Dormers

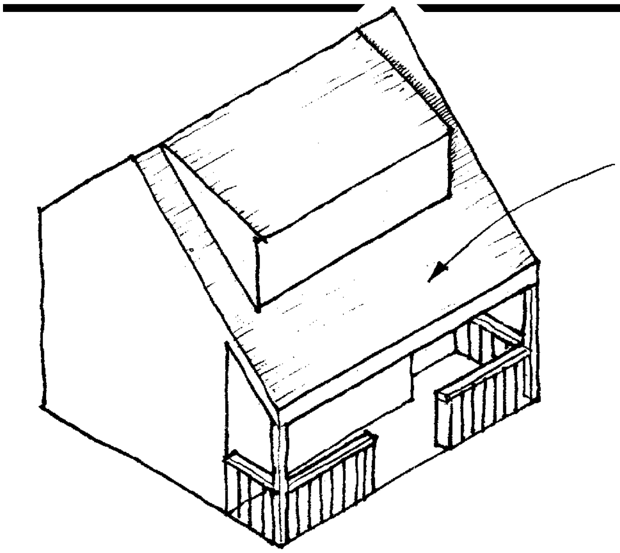
Hips and valleys present unique structural problems. Hip rafters act in some cases as structural beams, and must be doubled or tripled. In addition, valley rafters may be subjected to increased loading as snow and ice slide off adjacent roofs and collect in the valley, especially on shady north and east exposures.

Dormers are typically shed or gable style, although more complex ones are among the real jewels of New England architecture. Small dormers may interrupt roof framing with little impact on the structure, requiring only the doubling of rafters at each side and heading off the jacks above and below.

A large shed dormer that covers almost the entire length of a building can play havoc with a structure, Cutting a giant hole in a roof may eliminate any control of outward thrust on one or both sides of the building, except near the gable ends, where the end-wall sheathing provides bracing anyway. In addition, the flatter pitch of the dormer roof can hold snow longer, exacerbating the load condition. The solution is either a return to smaller dormers or the use of a structural ridge.

Finally, don't forget the appearance when considering a dormer. Big shed dormers with little surrounding roof look like phony second stories, and invariably look out of scale on the buildings. If several smaller dormers can't be used, leave a wider strip of roof at each side, and perhaps hold the peak slightly below the main ridge to scale down the monster so it looks like a dormer instead of a second story.

An equally effective way to scale down a large shed dormer is to extend the main roof out over a lower porch (see illustration). However, an attached shed or porch, especially on the north side, can be the recipient of unwelcome piles of snow and ice, to the extent that the rafters may need to be sized up.



A large shed dormer can visually overpower a gable roof. One solution is to extend the main roof, such as over a porch.

On all roofs, you must consider where snow and ice will fall when they leave the roof. At my apartment, massive chunks of ice and snow fall two stories, without warning, directly onto the main entry porch. This dangerous condition could easily be remedied by building a small gable roof to protect the porch and divert the snow from the steps. If this were done, however, the rafters would have to be designed twice as strong as normal (i.e., double width or 1.4 times as deep) to allow for the impact load falling from above. This is particularly important where one-story greenhouses are added under the eaves of 1 1/2- and two-story houses.

Rafters

During the latter half of the 1800s, stick building became the major method of construction throughout the U.S., replacing the earlier timber-frame methods. Today we can choose from rafters, traditional timber framing, modern plank-and-beam framing, or roof trusses to solve our roof framing problems.

Rafter construction is familiar to virtually everyone in the trades, although it takes a high level of skill to cut complex roofs. *(Roof Framing,* written by Marshall Gross and reviewed in the May 1985 issue of *NEB,* is a definitive reference on this subject.) Relatively small rafters typically 16 or 24 inches on center are covered with plywood or waferboard sheathing. Spaced ("skip") sheathing may be used instead of solid sheathing under roofing materials such as wood, metal, and Onduline where load conditions permit. Where support is necessary under the edges of the sheathing between bays, use plywood clips, since blocking would obstruct the air space in vented roofs.

Rafters must be sized for the load, spacing, and span of the job in question. The span is always measured horizontally—not along the slope of the roof. (See *Span Tables for Joists and Rafters,* reviewed in the February 1987 issue.) Deflection limits for roofs are typically 1/240 of the span for slopes of less than 3 in 12 and 1/180 for steeper pitches, since we can tolerate more deflection in a roof than in a floor.

Sheet goods used for sheathing will have a span rating, such as 32/16 or 48/24, as part of the grade stamp. The first number in each pair tells the maximum roof span in inches. The second number gives the floor-span rating.

Another interesting bit of information included in the grade stamp is the exposure classification ("Exterior," "Exposure 1" or "Exposure 2"). Exterior-grade panels are intended for continuous weather exposure. Exposure 1 panels are for use where long construction delays might occur. Exposure 2 panels will withstand only high humidity or moderate leakage in a protected application. These little-known facts of product specification may explain a lot of curled sheathing in the field.

Plank and Beam vs. Timber Framing

Modern plank-and-beam roof construction is a descendant of timber framing, where relatively heavy roof beams substitute for lighter rafters. The beams are spaced farther apart than rafters—typically 6, 7, or 8 feet on center. They may run across the house (a la rafters) or longitudinally. A network of posts provides support.

Decking for plank-and-beam roofs is typically 2x6 T&G planking spanning two or three bays. Insulation is laid on top of the deck, so the wood decking remains visible from below. Readers can get further information from the informative NFPA booklet *Plank-and-Beam Framing for Residential Buildings* (National Forest Products Assn., 1250 Connecticut Ave. NW, Washington, DC 20036, $2).

Timber-frame roofs are similar to plank-and-beam construction, but use old-fashioned mortise-and-tenon joints to hold the structural parts together. There has been a strong revival of this method of building, as witnessed by the formation of the Timber Framer's Guild, reported on in the September 1986 issue. Timber-frame roofs are often covered by stressed-skin panels or by structural planking with rigid insulation board.

Trusses

Roof trusses are, to my mind, a miracle of engineering. By the magic of triangulation, they transfer all forces and loads to exterior bearing walls—totally eliminating outward thrust and the need for interior bearing walls in the process. From an engineering standpoint, trusses are very efficient—that is, they use very small pieces of lumber in a carefully designed way to carry heavy loads or span wide distances. In addition, trusses are often more economical than stick construction for simple roof configurations, due primarily to reduced labor costs.

Trusses are typically factory engineered for the specified load, span, and spacing. Styles and pitches have been devised for just about every conceivable application. These include Cape-style trusses that allow limited attic-storage capacity, raised-heel trusses that allow a full depth of insulation out to the eaves, trusses for superinsulated houses, hip trusses, and more.

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Parallel-chord trusses can be used for flat roofs, where deep units can accommodate wide spans and heavy loads. They can also be installed at a pitch to create cathedral ceilings.

Several cautions are in order with trusses. First, consider site access—can you get a truck with 60-foot-long monsters up the driveway? Related to this is height—trusses over 12 feet or so may be too big for highway transportation. Also, trusses must be handled only *on edge* during handling and erecting. Laid flat they have little strength, and can be easily damaged.

You may also have to increase header size over openings in bearing walls, since trusses can transfer twice as much load as the equivalent rafter/joist construction. Most important, trusses need temporary diagonal bracing until the sheathing is applied to prevent domino-like collapses of the type we occasionally read about (but never personally experience, I hope). Sheathing for trusses is the same as for rafters.

Finally, there is the question of cutting trusses. By their nature, trusses are structural *units*, and all of the relatively flimsy members act together. Cutting any one of them is inviting disaster. Yet people have cut chords or webs to make room for ducts, pull-down stairs, or wide skylights.

If you absolutely must cut a truss, you must then treat the top and bottom chords as conventional rafters and joists and size them appropriately—perhaps requiring bearing at mid-span. If this advice is ignored, major structural problems may result (see "CFPS" in the May 1985 issue).

On the other hand, an article in the July 1981 issue of *Popular Science* described a method for cutting trusses and providing a box frame around the opening to do the job of the cut members. This was followed up in November by a piece that defended the concept in the face of intense reader reaction (both pro and con). The author cited field investigation as evidence that the method works, but advised caution and professional consultation before undertaking such a venture. That's my advice, too.

Conclusion

Whatever kind of roof you choose, remember that the materials, style, and structure create a system that works to provide comfort, protection, and beauty. Select the right combination, and both you and your clients will be satisfied. ■

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