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TechSpecs
A builder's blueprint for construction technologies
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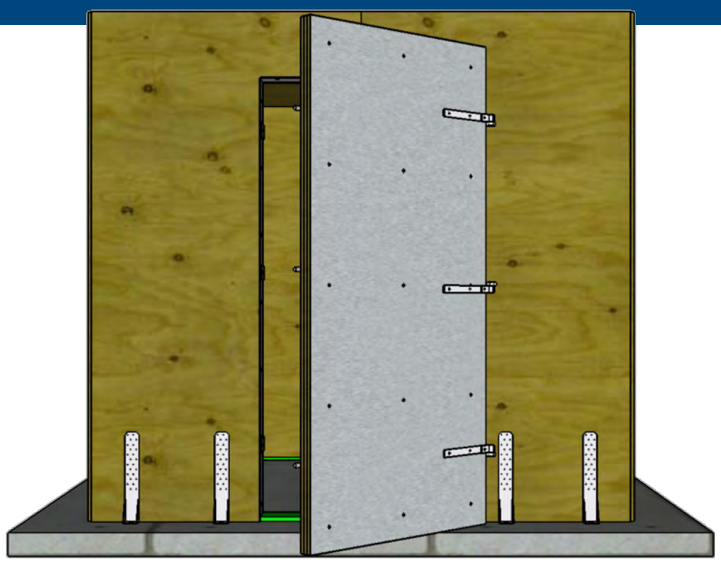
The Wood Tornado Shelter: A Cost-Effective Retrofit Solution

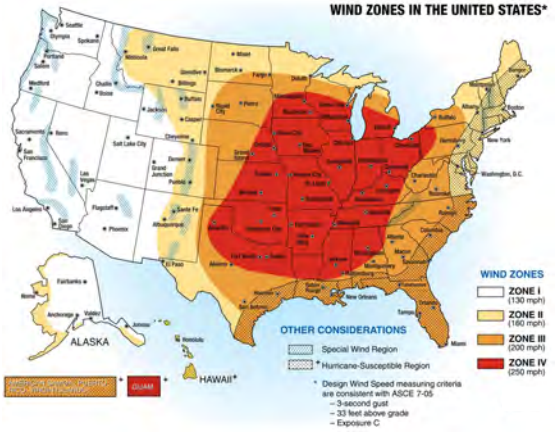


Why A Tornado Shelter?

The United States experiences more tornado activity than any other country in the world. These storms cause billions of dollars worth of damage and on average claim the lives of 60 Americans every year. Because of this, the Federal Emergency Management Agency (FEMA) recommends that Americans living in tornado-prone areas of the country (red and orange on the map) strongly consider buying or building a shelter in which to take cover during these sudden storms.

Engineers at the USDA's Forest Products Laboratory (FPL) have developed a residential shelter room that meets industry safety standards *and* can be built in an existing home by advanced Do-It-Yourselfers, which can result in a substantial cost saving to the homeowner.

A tornado shelter is a fortified structure that provides protection in extreme weather events. This TechSpec presents an overview of a new residential tornado shelter design. It includes information on the design details, construction sequence, materials and tools, implementation considerations, and a brief discussion on costs. This information is intended to help residential remodelers and homeowners with advanced Do-It-Yourself experience or a semiprofessional construction background ("prosumers") install this tornado shelter in an existing home.



How Much Does A Tornado Shelter Cost?

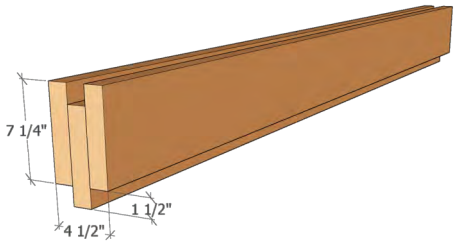
There are many variables that go into the final price of an installed shelter. The estimated cost of the 8 ft. x 8 ft. tornado shelter presented here is between $3,000 and $4,000. However, the following must be considered when budgeting for one:

- Costs of materials will vary widely between local markets around the country and costs can fluctuate seasonally or in response to other market factors.
- Permitting and inspection requirements and costs will need to be included, and can also vary from location to location.
- Labor costs, if any, and tool rental fees, if not owned.

Siting the Tornado Shelter

The first decision when retrofitting a home with a tornado shelter om is choosing the location. The shelter must be anchored to the foundation, so it will need to be constructed in the basement, the garage, or another location that has a reinforced concrete slab. The slab must be reinforced and a minimum of 4 in. thick to provide sufficient anchoring capacity. The shelter should be located in an easily accessible location that can be reached quickly and must be built under cover as it is not designed to be water proof. ***A shelter should not be situated below ground if the home is located in an area with a risk of flooding.***

Flood water

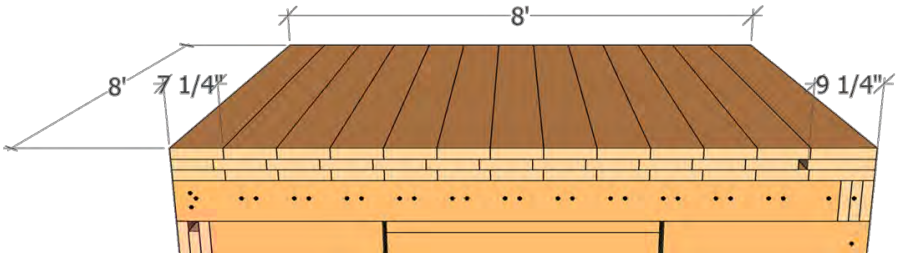


Overall Construction

The shelter is constructed by assembling nail-laminated lumber beams that are stacked log cabin style to form the walls. The roof panel is also constructed of these laminated beams. After the walls are assembled, plywood sheathing is nailed and glued to the interior and exterior of the room.

Beam Geometry and Construction

Each beam is composed of three 2x8s, with the middle board offset by 1-1/2 in. to form a tongue-and-groove configuration. Nails and construction adhesive keep the three pieces of lumber together in the pattern shown in the diagram above.



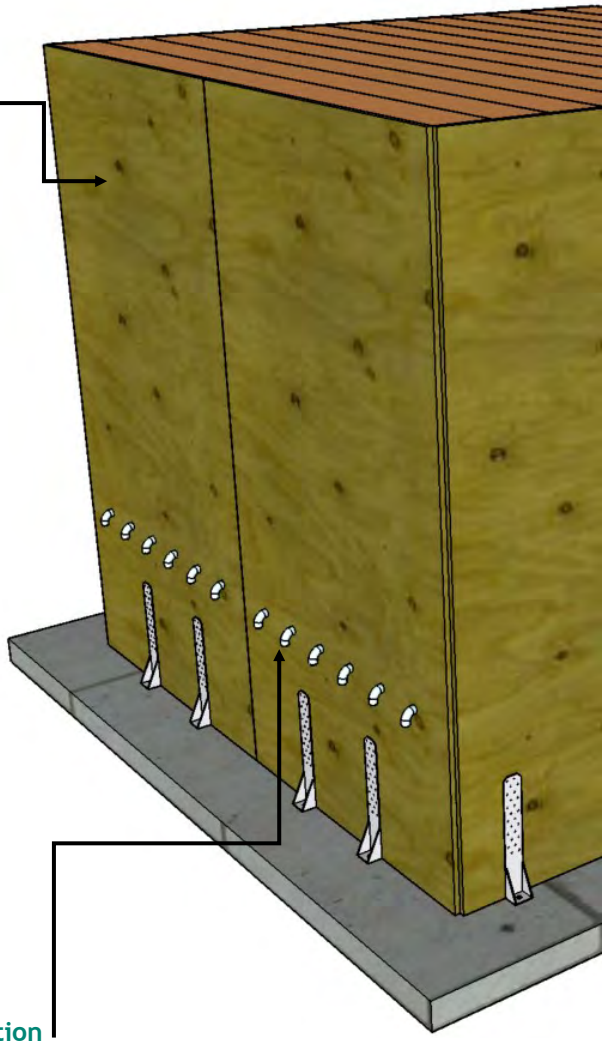
Roof Panel

The roof panel will measure 8 ft. by 8 ft. to sit over the exterior perimeter of the walls. It is composed of 13 triple-board beams that are 8 ft. long. The first twelve beams are made with 2x8 boards for a combined length of 87 in. The final beam is made using custom-cut 2x10 boards. The roof beams are installed one at a time using 8-inch long wood screws driven up at a 45° angle through the beams below on the walls' exterior surface. Note that the exterior sheathing extends over the roof beams and helps tie the roof to the walls.

Dimensional Lumber Board	Nominal		Actual	
	Thickness	Width	Thickness	Width
1x6	1 in.	6 in.	3/4 in.	5-1/2 in.
2x8	2 in.	8 in.	1-1/2 in.	7-1/4 in.
2x10	2 in.	10 in.	1-1/2 in.	9-1/4 in.

Sheathing

Two 4x8 sheets of 23/32 in. C-D Exposure 1 plywood are attached to the exterior and interior of each wall, and on the interior of the roof panel. The plywood sheets are attached with construction adhesive and nails. This sheathing provides added protection against windborne projectile impact. Plywood can be installed on the roof exterior if accessible.



Wall and Roof Panel Cross Section

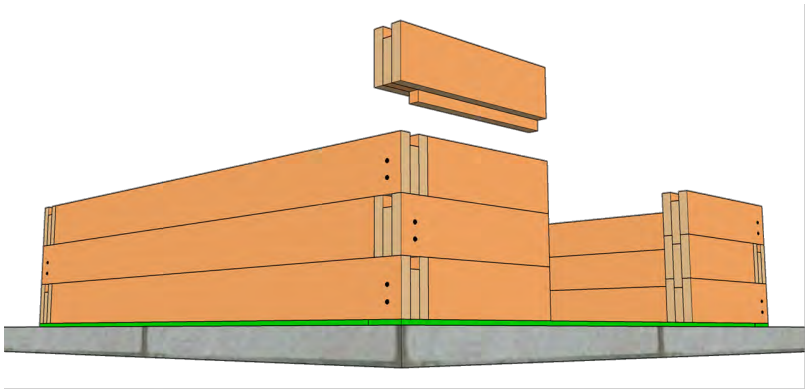
This diagram shows the cross section of the wall and roof construction. The tongue of one beam fits into the groove of the beam below. The top and bottom of the wall must be flat therefore the middle board of the bottom beam and the outer boards of the top beam have been rip-cut to 5-3/4 in height. Twelve individual beams are stacked up to create the non-entrance walls, and the beams are joined together using construction adhesive and screws at the corners. The height of the walls can be varied depending on site height limitations (e.g., basement or garage ceiling) by adding or subtracting layers of beams. The walls sit on preservative-treated 1x6s for decay protection.

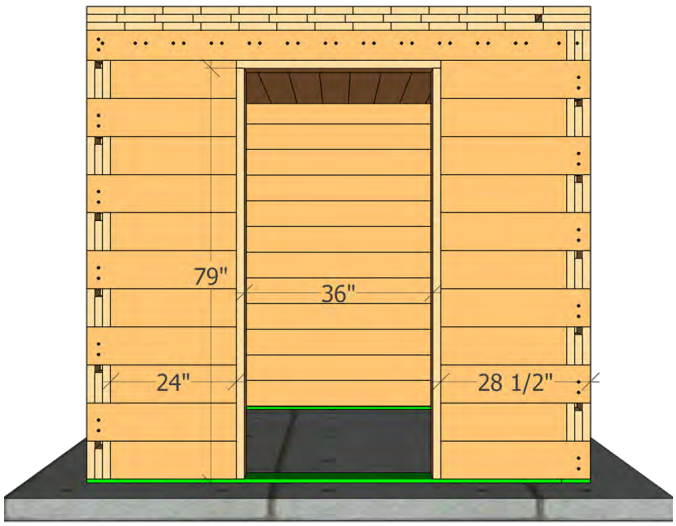
Ventilation

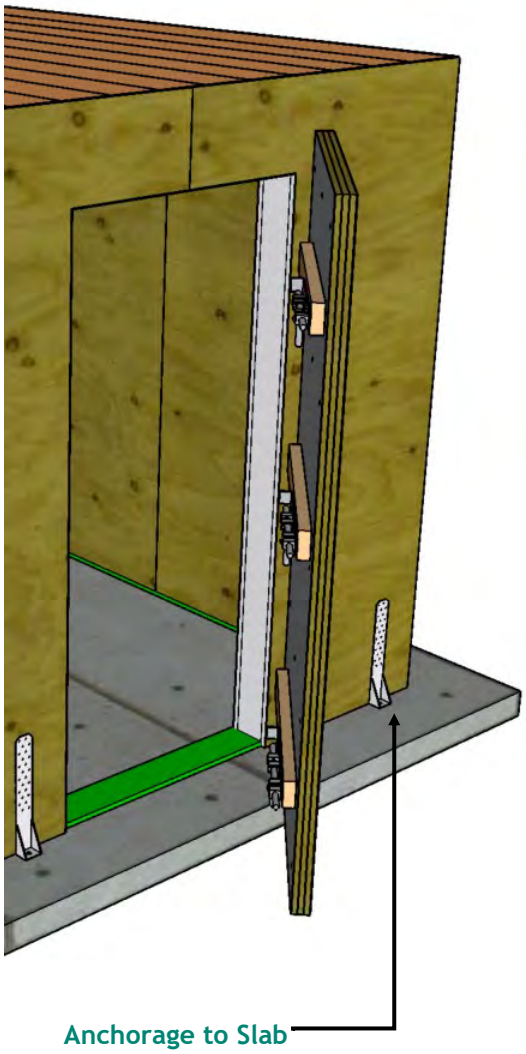
The interior of the room measures 7 ft. by 7 ft. providing nearly 50 sq. ft. of interior floor space, which allows for a recommended occupancy of 9 people. Twenty-four 1-in. diameter holes are drilled through the walls to provide natural ventilation; 12 holes along the top of one wall and twelve along the lower portion of the opposite wall. A PVC elbow is installed in each ventilation hole for protection against windblown debris.

Interlocked Room Corners

The individual beams are stacked one at a time so that the corners interlock like a log cabin. Therefore, the walls of the room go up one layer (or course) at a time. For the corners to fit correctly, a 4-1/2 in. notch is cut out of the end of the 'tongue'. This allows the end of the top beam to be flush with the adjacent wall surface. The corners are then reinforced using 8 in. long wood screws as shown.





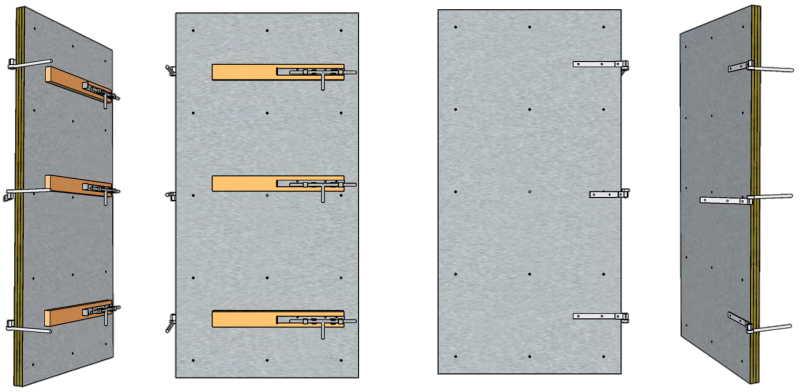


Entrance Wall

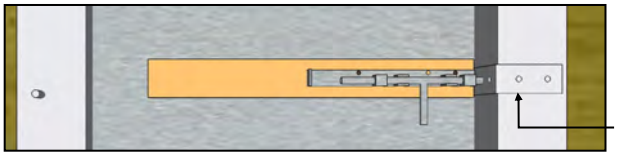
The entrance wall has a 36 in. x 79 in. opening made possible by 11 layers of alternating 24 in. and 28-1/2 in. beams topped with one full-length beam above the opening. The shorter 24 in. beams accommodate the ends of the beams of the adjacent walls, while creating an even surface for the door jambs. The interior and exterior plywood sheathing for this wall must be cut to fit around the opening prior to installation.

Door Geometry, Construction, Hardware, Hanging

The door is made up of five individual layers: three sheets of 23/32 in. thick plywood sandwiched between two 18-gauge sheet metal skins. The steel door skins help prevent penetration by windborne projectiles and help dissipate the impact energy. The door is an overlay outward swinging door that measures 42 in. by 84 in. The five layers are held together by 15 bolts (3/8 in. diameter). The door is attached to the walls using three bolt hooks and hinge straps. The bolt hooks are drilled straight through the wall, and the hinge straps are attached to the exterior of the door using bolts. On the door's interior, three slide bolt/latches are mounted on 2x4 offsets to provide the locking mechanism. Custom 14-gauge steel angles are installed on the entrance header and jambs, and three heavy angles are attached on one jamb to reinforce the slide bolts when



Interior **Exterior**

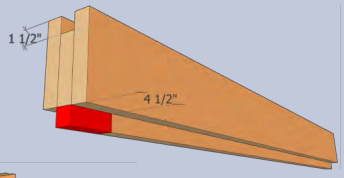


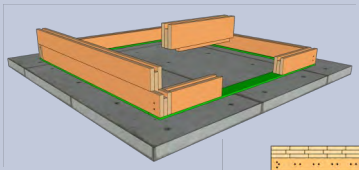
From room interior: to lock the door, slide each bolt through reinforcing heavy angle

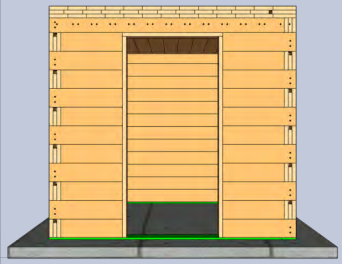
Anchorage to Slab

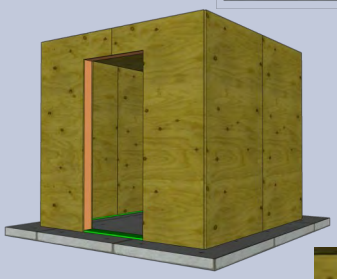
The room is anchored to the slab using sixteen tension ties installed around the perimeter. Each tension tie is connected to the shelter walls using 16d nails and secured to the slab using 5/8 in. diameter concrete anchor bolts and concrete epoxy. The anchor bolt manufacturer's installation instructions must be followed carefully as these connections are vital in resisting the high forces produced by tornado winds.

Construction Sequence

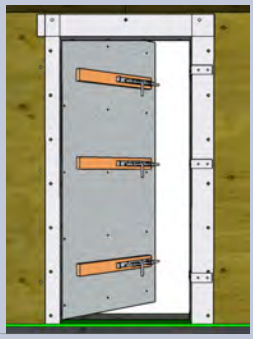


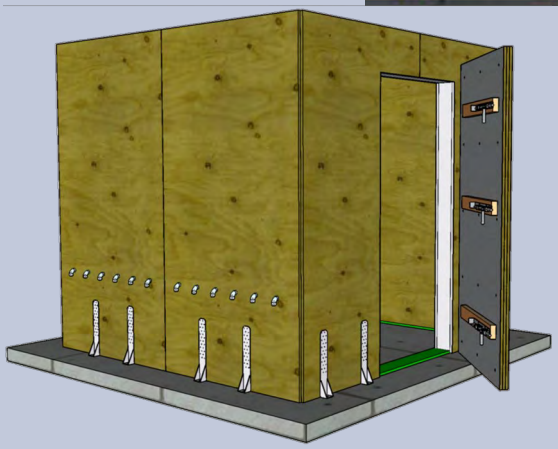






View from → inside shelter (note custom angles along entrance header and both jambs)





The Wood Tornado Shelter is built in eight phases

Phase 1: Cutting the lumber. All of the boards that make up the beams in the walls are cross-cut to specific length, depending on where the beam will be installed. Some boards are rip-cut to a different width to provide flat surfaces in key locations: bottom and top perimeter of the wall, header above the room entrance, and the roof panel perimeter

Phase 2: Constructing the beams. The triple beams that make up the walls and roof consist of three same-length 2x8 boards held together with construction adhesive and nails. The middle board is offset by 1-1/2 in. so that each beam has a groove on the top and a tongue on the bottom (unless the middle beam was rip-cut to make a flat top or bottom).

Phase 3: Building the walls. The shelter walls are built one course at a time. The first course (five beams) is laid on top of preservative-treated 1x6 boards. A 4-1/2 in. notch is cut from the end of the tongue of each second course beam and they are laid on top of the first course beams so that the tongue of each top beam fits into the groove of the beam below. This is repeated for the remaining courses. The beams alternate from course to course so that the corners interlock in a log cabin fashion. Each corner is reinforced with two 8 in. screws and adhesive.

Phase 4: Installing the roof beams. Twelve roof beams are installed one by one. The final roof beam is custom made from 2x10s to fit the remaining gap so that the roof panel measures 8 ft. by 8 ft. (the edges of the roof are flush with the walls below). The roof beams are permanently attached to the walls with 8 in. wood screws driven up at 45° through the walls below.

Phase 5: Attaching the sheathing. Sheets of plywood are attached to the exterior and interior of each wall, to the interior ceiling, and to the top of the roof if accessible. The exterior sheathing must overlap the roof beams to help tie the roof to the walls. The sheathing is attached using construction adhesive and 16d nails.

Phase 6: Building and hanging the door. The 42 in. x 84 in. outswing door is made from two sheet metal skins surrounding three sheets of plywood, held together with fifteen bolts. Three latches/slide bolts installed on the interior are used to lock the room when occupied. Three hinges attached to the door exterior are used to hang the door on three corresponding bolt hooks installed through the thickness of the wall. Custom sheet metal angles are installed on the entrance header and jambs, and three heavy angles reinforce the holes where the slide bolts lock.

Phase 7: Providing ventilation. Natural ventilation is provided by drilling 24 holes into the two walls on either side of the entrance wall; 12 ventilation holes are drilled at the top of one wall and 12 are drilled on the lower portion of the opposite wall. The holes are 1 in. diameter. A PVC elbow is installed in each ventilation hole for protection against windblown debris.

Phase 8: Anchoring the room. The shelter is anchored to the slab beneath it using 16 tension ties around the perimeter; four ties per wall. An anchor bolt and epoxy secure each tension tie to the slab.

Materials and Tools

The Wood Tornado Shelter design was developed so that it can be built using common tools and materials. The major materials needed are lumber (182 boards, mostly 2x8s), plywood sheathing, two 18-gauge cold-rolled steel door skins, hardware for mounting and locking the door, three custom 14-gauge steel angles, and the tension ties for anchoring the room. Advanced DIYers may already own most of the tools used in the room's construction (circular saw, nail gun, power drill, etc.), but they may need to rent or purchase a hammer drill and other tools. A detailed Construction Guide, which contains a full list of required tools and materials, as well as fully-illustrated step-by-step instructions, is available.