A SunCam online continuing education course

Tiny Houses Part 3

Building Enclosure Design

by

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Course Description

This course is part three of a multi-part course series on designing tiny houses (houses 400 square feet or less in size). The majority of this multi-part course focuses on tiny houses mounted on trailers, which are often referred to as tiny houses on wheels (THOW). This third course focuses on building enclosure design: insulation, air sealing, roof assemblies, ventilation, exterior siding, doors, windows, and interior finishes. Over 60 figures and photos are included. The basis of this course came from my own research, planning, designing, and construction of a THOW I built myself.

Learning Objectives

After completing this course participants should be able to:

1. Understand the importance of climate zones as they relate to tiny house insulation and vapor retarder requirements.
2. Comprehend the differences between vented and unvented roof assemblies.
3. Recognize the code approved, and most commonly used, materials for THOW roofs and exterior siding.
4. Identify the most common interior finish materials used in THOW and why some materials used commonly for THOW are different than those used for tiny houses on foundations.

Introduction

Over the past few decades a small, but growing segment of the population has moved to smaller housing options. Cable TV shows like *Tiny House Nation* and *Tiny House Hunters* have increased the popularity and general population's awareness of "tiny living." This course is the third part of a multi-part course series on one of these alternatives – tiny houses. This course discusses both tiny houses on foundations (THOF) and tiny houses on wheels (THOW).

The first course in this series covered consulting engineering opportunities both with the house structures themselves and development of sites for tiny houses. It also discussed where tiny houses can be placed and the various construction and manufacturing standards THOW are built to, including a tiny house appendix in the 2018 International Residential Code (IRC). Finally, information on trailers, appliances, utility connections, floor plans, and lofts was presented.

The second course in this series went over specific structural design considerations for floor systems, walls, headers, and roof systems. Both prescriptive and engineered methodologies were included. How to structurally handle the mobile nature of THOW was also covered.

This third course focuses on the remaining building enclosure components: insulation, air sealing, roof assemblies, ventilation, exterior siding, doors, windows, and interior finishes.

Course four will discuss mechanical, electrical, and plumbing (MEP) systems with an emphasis on going off-grid or mobile with a tiny house. Course four's release is anticipated in early 2020.

The basis of these courses came from my own research, planning, designing, and construction of a THOW I have built myself.

A Brief Review

There is no universally accepted definition of a tiny house. For the purpose of this course we will define a tiny house as a dwelling unit 400 square feet or less.

All material and product costs or estimated costs in this course are in 2018 dollars. Some costs vary greatly from region to region. Also, mention of a specific product is not necessarily a recommendation of that product. While I have specified and personally used many of the products listed, others I have not. The purpose of listing products I have not used is to illustrate that products exist for a specific application. Please perform your own due diligence.

The Engineer's Role

Building codes govern THOF construction. Since meeting most requirements of building codes can be achieved through prescriptive means, THOF in many jurisdictions can be approved, permitted, and constructed without the assistance of any design professionals. Similar to larger, traditional home construction, the use of engineers for a THOF is most likely a voluntary one on the part of the client or builder.

Some production THOW builders and manufacturers like to promote and advertise that they have engineered plans produced, signed, and sealed by licensed professional engineers. In some cases it may even be a requirement depending on the certifications they are trying to achieve. Generally, building enclosure system design is more in the realm of architects and residential designers than engineers. Nevertheless, it is helpful for engineers to have a general understanding of these systems. Additionally, some of the typical materials used in THOF may not be suitable for THOW (due to the mobile nature of THOW) unless solutions are engineered to protect these materials from movement and excessive vibrations.

Drawings

The level of drawing detail required for a THOW is generally greater than for most other residential projects. See the section on "Drawings" in *Tiny Houses Part 1 – Planning and Design Considerations, Legality, and the Engineer's Role* for more information.

Weight Considerations

Some typical building enclosure materials are very heavy. As discussed in *Tiny Houses Part 1 – Planning and Design Considerations, Legality, and the Engineer's Role* overall house weight is critically important for THOW to ensure the weight on the axles doesn't exceed the total axle rating.

Construction and Manufacturing Standards

Due to the great variation and uncertainty in how states, counties, and municipalities classify THOW and the limitations these differences place on THOW moving around the country, some THOW builders have decided to go through the process to become a Recreation Vehicle Industry Association (RVIA) certified manufacturer. This certification means most states will classify THOW built by these manufacturers as RVs. This helps buyers obtain more traditional financing, and simplifies the insurance and DMV registration processes. However, at the same time, it limits legal full-time occupancy in the majority of locations since recreational vehicles are often only allowed for travel and temporary use. Some builders have decided not to pursue the RVIA certification for this or other reasons including the cost of certification and because they produce high end, customized projects as opposed to mass produced models. Many of the builders that don't have RVIA certification attempt to follow the local building code as much as possible. A third possible standard for use is the manufactured home standard. Almost universally either the RVIA certification or use of the local building code as closely as possible is chosen.

Building Codes

In the United States the International Code Council (ICC) is the dominate building code publisher. The ICC publishes a set of 15 codes called the I-Codes and revises them every three years. The most well-known of these codes are the International Building Code (IBC), the International Mechanical Code (IMC), the International Plumbing Code (IPC), and the International Residential Code (IRC).

Each state chooses whether to have or not have state-wide building codes. As of 2019, most states have chosen to adopt some of the ICC codes. In some instances states publish and title their own codes. Florida is one such example. The Florida Building Code took I-Code text and modified it. There were enough modifications the state deemed it better to produce a unique code instead of publishing a long list of additions, deletions, and changes to the model code. Additionally, jurisdictions at any level (county, city, town, etc.) may further adopt and/or amend model codes unless prohibited by law (state law for counties, county law for municipalities). Most states that adopt model codes don't automatically adopt the latest edition of the model codes and as a result it is common to be one or two code cycles behind the latest published editions.

The IRC "comprises all building, plumbing, mechanical, fuel gas and electrical requirements for one- and two-family dwellings and townhouses up to three stories." Since tiny houses and other small dwelling units meet these criteria, the IRC will be the building code referenced in this course. Specifically, the 2018 IRC edition was chosen for reasons expounded on in the following section. The 2018 IRC can be viewed online for free on the ICC website at https://codes.iccsafe.org/content/IRC2018.

2018 IRC Appendix Q

The IRC in 2018 added Appendix Q, entitled *Tiny Houses*. Just like the main text body of the IRC, this appendix would need to be adopted by the authority having jurisdiction for it to come into effect. A jurisdiction may choose to adapt the IRC with no appendices, all appendices, or some appendices. This course uses the 2018 IRC as its code reference because of this new appendix. If adopted, Appendix Q "relaxes various requirements in the body of the code as they apply to houses that are 400 square feet in area or less." The entire text of Appendix Q can be viewed at https://codes.iccsafe.org/content/IRC2018/appendix-q-tiny-houses. A more detailed discussion of construction and manufacturing standards, building codes, and 2018 IRC Appendix

Q can be found in *Tiny Houses Part 1 – Planning and Design Considerations, Legality, and the Engineer's Role*.

Building Enclosure Components

Climate Zone

Certain components of the building enclosure (for example windows, doors, insulation, net free ventilating area) cannot be selected, calculated, or designed properly without first knowing the applicable climate zone. The IRC divides the United States into eight numbered climate zones. Each of these climate zones is further divided by moisture regime (moist, dry, or marine). Moist zones are designated with an "A", dry zones with a "B", and marine zones with a "C". Moist zones are further classified as "warm-humid" or not. The climate zone of a THOF can be determined using either IRC Figure N1101.7, shown below in Figure 1, or from a list of states and counties in IRC Table N1101.7.

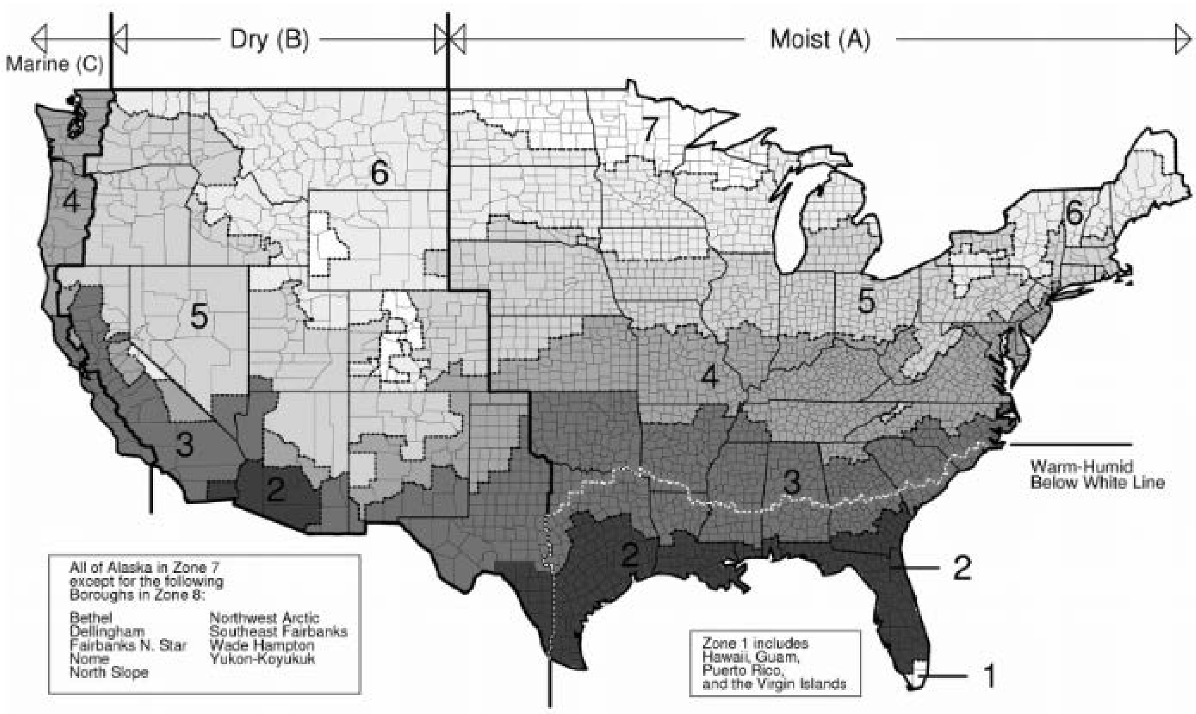


FIGURE N1101.7 (R301.1)
CLIMATE ZONES

Figure 1: IRC Figure N1101.7 (from 2018 IRC)

From Figure N1101.7 we can see both western Washington state and all of Kentucky are in climate zone 4. However, western Washington is zone 4C (marine) while Kentucky is zone 4A (moist). Likewise, almost the entire state of Alabama is in zone 3A, but only the southern portion of the state is in zone 3A and classified as "warm-humid" (below the white line shown on the figure).

Determining the climate zone for an often moved THOW can be a challenging. Traveling briefly through different climate zones and moisture regimes will likely not cause severe, long-term issues. Conversely a THOW designed for northern Montana, zone 6B (dry), and then permanently moved to "warm-humid" south Florida, zone 1A (moist), could be very problematic. Since engineers, architects, and designers have no control over the movement of a THOW after it is constructed, it is best to list the climate zone used for the design on the cover sheet of the drawings just like design criteria such as snow load, wind load, etc. are listed.

Insulation and Air Sealing

The IRC requires both insulation (IRC N1102.1.2) and the limiting of air leakage (IRC N1102.4) for a building thermal envelope.

Insulation

Up through the first half of the 20th century, a large percentage of houses in the United States were built with little to no insulation. My parents' current house, built in Oregon's climate zone 4C in the 1940s, had no wall, floor, or ceiling insulation when they bought it in the late 1980s. Fire wood, heating oil, and propane were so abundant and cheap until the 1970s that most people saw no pressing need to insulate the houses they were building or writing building codes for.

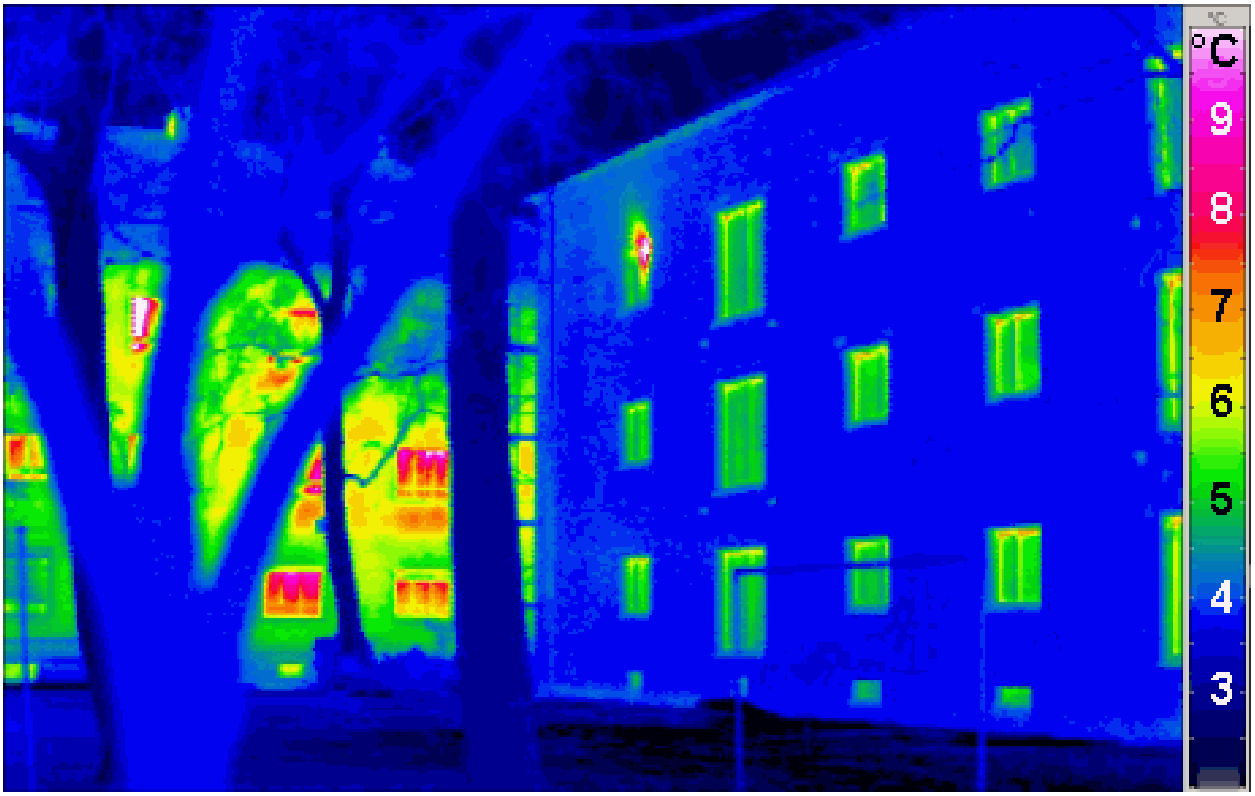
There are many different types of materials used for insulation. Thermal resistance (the ability of insulation, or any building material for that matter) is usually given as an R-value per inch of thickness. The higher the R-value the better the material is at resisting heat transfer. Two common building components that do not use R-value are windows and doors. Instead of R-value windows and doors use U-factor, or thermal transmittance. The lower the U-factor the better it is at resisting heat transfer. Generally U-factor is used for building components that integrally form a system (e.g. the frame and glazing together make up a window). To convert a U-factor to an approximate R-value take the reciprocal of the U-factor. Thus a window with a U-factor of 0.30 has an approximate R-value of 3.33 (since 1 divided by 0.30 is 3.33). This comparison of R-value and U-factor can be useful for understanding the relative resistance of heat flow between windows and their adjacent wall assemblies.

Table 1 shows the R-values of select common building and insulation materials. The table also indicates if each material is a potential air barrier (more on that in the next course section).

Material	R-Value per Inch or Material as Specified	Potential Air Barrier
Concrete	0.11	Yes
Mortar	0.20	Yes
Brick	0.20	Yes
Concrete Block	1.11 for 8" thick	Yes
Soft Wood	1.0 to 1.25	Yes
Plywood	1.25	Yes
Air space in wall (vertical)	1.35 for 3/4" space	N/A
Cotton (batt or roll)	3.5 to 3.7	No
Fiberglass (batt or roll)	3.2 to 3.8	No
Fiberglass (blown-in)	2.0 to 4.2	No
Mineral Wood (batt or blanket)	3.8 to 4.3	No
Mineral Wool (blown-in)	3.1 to 4.0	No
Cellulose (blown-in)	3.2 to 3.8	No
Extruded Polystyrene (XPS) rigid foam	4.0 to 5.4	Yes
Expanded Polystyrene (EPS) rigid foam	3.6 to 4.2	Yes
Polyisocyanurate rigid foam	6.5	Yes
Open-Cell polyurethane spray foam	3.5 to 3.6	Yes
Closed-Cell polyurethane spray foam	6.5	Yes

Table 1: R-Values of Common Insulation Materials (compiled from various reference sources)

Another concern related to insulation is thermal bridging. The Building Science Corporation defines a *thermal bridge* as "A material with higher thermal conductivity transferring heat through an assembly with substantially lower thermal conductivity. For example, a steel stud in a wall will transfer more heat than the surrounding insulation, reducing the overall thermal control of the system." Essentially any materials with differing R-values that extend all the way through a wall, floor, or ceiling assembly can create a thermal bridge. The R-value of a wood 2x4 stud is around R-3.5 (3.5 inches times an R-value of 1.0 per inch for soft wood) while the R-value of fiberglass insulation batts between the 2x4 studs is about R-13 (3.5 inches times an R-value of 3.7 per inch). The insulation provides nearly four times the resistance to heat transfer as the wood studs. Thermal camera images can show thermal bridging quite strikingly.



A thermal image of two adjacent buildings taken on a cold night. The building on the right was constructed using techniques to minimize thermal bridging and with very energy efficient windows. The building on the left behind the tree was not built using these same techniques. (Credit: Passivhaus Institut/Wikimedia Commons/CC BY-SA 3.0)

In the picture above, the building on the right has an exterior with the same temperature throughout except for the slightly warmer windows. The overall temperature difference on the building exterior is only 2 degrees Celsius. The building on the left has a much wider range of temperatures as shown by the differing colors. The overall temperature difference on this building exterior is 5 degrees Celsius. There are many ways to combat thermal bridging; the most common is installing sheets or blankets of insulation, typically rigid foam, over the entire exterior of the building's walls. This insulation over the exterior of a building is considered "continuous insulation" by the IRC.

Table 2 shows the IRC insulation requirements for ceilings, wood framed walls, floors, basements walls, slabs-on-grade, and crawlspace walls for each climate zone.

TABLE N1102.1.2 (R402.1.2)
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION *U*-FACTOR[b]	SKYLIGHT[b] *U*-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING *R*-VALUE	WOOD FRAME WALL *R*-VALUE	MASS WALL *R*-VALUE[i]	FLOOR *R*-VALUE	BASEMENT[c] WALL *R*-VALUE	SLAB[d] *R*-VALUE & DEPTH	CRAWL SPACE[c] WALL *R*-VALUE
1	NR	0.75	0.25	30	13	3/4	13			
2	0.40	0.65	0.25	38	13	4/6	13			
3	0.32	0.55	0.25	38	20 or 13 + 5[h]	8/13	19	5/13[f]		5/13
4 except Marine	0.32	0.55	0.40	49	20 or 13 + 5[h]	8/13	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.30	0.55	NR	49	20 or 13 + 5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.30	0.55	NR	49	20 + 5[h] or 13 + 10[h]	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.30	0.55	NR	49	20 + 5[h] or 13 + 10[h]	19/21	38[g]	15/19	10, 4 ft	15/19

For SI: 1 foot = 304.8 mm.

NR = Not Required.

a. *R*-values are minimums. *U*-factors and SHGC are maximums. Where insulation is installed in a cavity that is less than the label or design thickness of the insulation, the installed *R*-value of the insulation shall be not less than the *R*-value specified in the table.

b. The fenestration *U*-factor column excludes skylights. The SHGC column applies to all glazed fenestration.

Exception: In Climate Zones 1 through 3, skylights shall be permitted to be excluded from glazed fenestration SHGC requirements provided that the SHGC for such sky lights does not exceed 0.30.

c. "10/13" means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation on the interior of the basement wall. "15/19" means R-15 continuous insulation on the interior or exterior of the home or R-19 cavity insulation on the interior of the basement wall. Alternatively, compliance with "15/19" shall be R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home.

d. R-5 insulation shall be provided under the full slab area of a heated slab in addition to the required slab edge insulation *R*-value for slabs. as indicated in the table. The slab edge insulation for heated slabs shall not be required to extend below the slab.

e. There are no SHGC requirements in the Marine Zone.

f. Basement wall insulation shall not be required in warm-humid locations as defined by Figure N1101.10 and Table N1101.10.

g. Alternatively, insulation sufficient to fill the framing cavity providing not less than an *R*-value of R-19.

h. The first value is cavity insulation, the second value is continuous insulation. Therefore, as an example, "13+5" means R-13 cavity insulation plus R-5 continuous insulation.

i. Mass walls shall be in accordance with Section N1102.2.5. The second *R*-value applies where more than half of the insulation is on the interior of the mass wall.

Table 2: IRC Table N1102.1.2 Insulation and Fenestration Requirements by Component (from 2018 IRC)

The most commonly used residential insulation in the United States is probably fiberglass batts or rolls. Batts are pre-cut to standard lengths while rolls are continuous and require onsite cutting for every piece used. Table 3 shows the fiberglass batt or roll R-values that fit between common framing member sizes.

Framing Member	Typical Fiberglass Batt/Roll R-Value
2x4	R-13 or R-15
2x6	R-19 or R-21
2x8	R-25
2x10	R-30
2x12	R-38

Table 3: Typical Fiberglass R-Values for Common Framing Member Sizes

From Table 2's "Ceiling R-Value" column we see the minimum R-value in any climate zone is R-30 (zone 1). Table 3 shows to achieve R-30 with fiberglass batts or rolls requires the use of a 2x10 which is larger than what is structurally needed for THOW in most parts of the country. 2x6 ceiling or roof members are adequate for THOW spans and loads in much of the country. Using the materials with the highest R-value per inch, closed-cell polyurethane spray foam or polyisocyanurate rigid foam (often referred to as simply polyiso), requires just over 4.5 inches of insulation. Even in climate zones 4 through 8 the requirement for R-49 ceiling insulation can be met with closed-cell polyurethane spray foam or polyiso at a reasonable thickness of 7.5 inches. The biggest downside of these two insulation materials is their cost – often four to eight times that of fiberglass. Meeting IRC floor insulation requirements is easier than meeting the ceiling requirements. Half of the climate zones require R-19 or less, which can be achieved using fiberglass insulated 2x6 floor joists, which are the most common THOW floor joist size used. Also Table 2, foot note "g" doesn't require you to increase the size of floor joists just to meet the floor insulation requirements as long as you have at least R-19 in the floor assembly. With head space at a premium in THOW designers usually either bite the bullet and pay for the premium insulation to maintain head space and meet the code or they decide to insulate less than required by code.

Looking at the "Wood Frame Wall R-Value" column in Table 2 we see the minimum R-value in climate zones 1 and 2 is R-13 and in climate zones 3 to 5 it is R-20. Both R-13 and R-20 are achievable in a THOW at reasonable expense without losing too much floor space. Climate zones 6 to 8 are much more stringent as they require "20+5" or "13+10". "20+5" means R-20 minimum cavity insulation between the studs and continuous insulation with a minimum R-5 value. This continuous insulation requirement is meant to reduce thermal bridging. While possible in a THOW this IRC requirement is rarely, if ever, met.

IRC Table N1102.2.6 provides insulation values if metal framing members are used to frame a THOW or THOF instead of wood framing members. Due to the greater thermal bridging through metal compared to wood, this table requires both cavity insulation and continuous insulation for steel-framed structures in most climate zones.

Air Sealing

Traditionally houses have been built “leaky” or “to breath”. This means not much thought during design, or care during construction, was taken to keep air from easily and quickly moving from outside to inside houses, or vice versa. A “leaky” house’s greatest benefit is that when building components get wet those components are able to dry easily from either the outside or inside. For example, in a heating climate like Wyoming water that gets inside an exterior wall can be dried by the heat from a heating furnace during the winter or by the warm outside temperature during the summer. The lack of insulation in older homes actually helps accelerate this drying because heat quickly moves through the walls. The downsides of a “leaky” house are many: higher heating and cooling costs, discomfort due to drafts, infiltration of airborne pollutants into the home (from the exterior air, from the garage or nearby streets, from rodent occupied crawl spaces, etc.), a reduction in the effective R-value of insulation, and potential moisture/condensation/mold/rot issues, just to name a few. As a result, building codes have added minimum air sealing requirements.

IRC Table N1102.4.1.1 requires a continuous air barrier for the building thermal envelope. More specifically the table requires, among other items:

- Air sealing the space between window frames/doors jams and their framing members
- Air sealing around shafts and penetrations
- Air sealing between garages and conditioned spaces
- Recessed light fixtures installed in the building thermal envelope must be sealed
- An air barrier behind electrical/phone boxes on exterior walls (or the use of air-sealed boxes)

The IRC defines an *air barrier* as “one or more materials joined together in a continuous manner to restrict or prevent the passage of air through the *building thermal envelope* and its assemblies.” The IRC provides a technical definition for *building thermal envelope* but it is basically all building assemblies that separate the conditioned space from the unconditioned space (e.g. outside air, vented attic, garage)

Left: Air sealing the space between window frames and framing members with closed-cell polyurethane spray foam (Dupont Great Stuff Window & Door). The spray foam will be trimmed flush with the interior window plane later to allow for finish trim work to be installed.

Right: Air sealing around penetrations with closed-cell polyurethane spray foam (Dupont Great Stuff) where telecommunication wires go through the building thermal envelope

In Table 1 the term "potential air barrier" is used because some materials need to be a minimum thickness to act as an effective air barrier. Also, while some of the materials like plywood and rigid foam are suitable air barriers at most of their commonly used thicknesses, the seams of these materials must be properly sealed for them to act as continuous air barriers. Seam sealing can be accomplished using flashing tape, liquid-applied flashing, or canned spray foam depending on the substrate. Some materials are notoriously difficult to seal with flashing tapes.

IRC N1102.4.1.2 requires a dwelling unit to be tested (typically through a blower door test) and have an air leakage rate not exceeding five air changes per hour (ACH) in climate zones 1 and 2 and not exceeding three ACH in climate zones 3 through 8. One air change per hour means the equivalent of the entire air volume of the house is exchanged with outside air over the duration of one hour. This testing must occur at negative 50 pascals of internal house pressure. Typically, a blower door test result of three air changes per hour is written as 3.0 ACH_{50}, where the 50 refers to the 50 pascal pressure during testing. THOF will often require testing, though I've heard in many parts of the country inspectors are not yet enforcing air leakage testing, but it is unlikely most THOW will be tested. Still, due to the limited space for insulation in a THOW, proper air sealing is vitally important for improving thermal comfort.

Once a building gets very tight, there is no hard and fast rule due to the many influencing variables but likely 2.0 ACH_{50} or lower, building scientists recommend a dedicated ventilation system. Ventilation systems make sure the concentrations of undesirable gases, such as carbon dioxide, inside a building don't get too high. Also they control the source location and filter the air entering the house.

To further illustrate the relationship between insulation and air sealing consider the following example. Wearing a wool sweater (insulation) outside when the winter wind is blowing will likely not keep you warm by itself because the cold air is able to blow through the wool. Similarly, wearing a windbreaker jacket (air barrier) outside when it's cold is likely not going to keep you warm by itself because you quickly lose body heat. However, wearing a windbreaker over a wool sweater is likely to keep you warm because the windbreaker keeps the cold wind out and the sweater keeps your body heat from escaping quickly.

Vapor Retarders

The IRC defines three classes of vapor retarders:

- Class I (0.1 perm or less, considered impermeable): sheet polyethylene or non-perforated aluminum foil
- Class II (between 0.1 perm and 1 perm, considered semi-impermeable): kraft faced fiberglass
- Class III (between 1 perm and 10 perms, considered semi-permeable): latex or enamel paint

IRC R702.7 requires a Class I or Class II vapor retarder "on the interior side of frame walls in Climate Zones 5, 6, 7, 8, and Marine 4" with only three exceptions. Some building scientists are now recommending <u>not</u> using Class I vapor retarders in walls systems due to the increased potential for trapping water inside of walls. If your plan reviewer or inspector insists on a Class I or Class II vapor retarder in your wall system go with the Class II.

Advanced Framing

Another option to reduce thermal bridging is to use advanced framing techniques. Advanced framing is a platform framing method developed to use less material, less labor, and increase building energy efficiency compared to traditional platform framing used in most residential construction. Using less wood allows for more insulation in a given floor, wall, or roof assembly. Advanced framing uses some or all of the following techniques:

- 24 inch on-center stud spacing combined with fully sheathed exterior walls
- Corner and wall intersections using fewer studs
- Single member headers or box headers

- Elimination of headers in non-load bearing walls
- Reduction in number or elimination of jack studs and cripples in certain circumstances
- Single top plate (achieved by aligning/stacking floor joists, studs, and roof framing members)
- Increased use of metal hardware in place of extra lumber

Most, if not all, advanced framing techniques are easily adoptable for THOF construction; however, that is not the case for THOW. As explained in *Tiny Houses Part 2 – Structural Design*, using 24 inch stud spacing is not very practical and in some cases will increase the overall THOW weight. It is however, easy and practical to use single member headers, eliminate headers in non-load bearing walls, and reduce the number or eliminate jack studs in THOW. Utilizing these three techniques provides weight savings and increased energy efficiency compared to traditional framing techniques.

A window utilizing a single member header. This allowed sufficient space for insulating the header with expanded polystyrene rigid foam to reduce thermal bridging.

Ceiling Insulation and Air Barriers

The most commonly used types of ceiling insulation in THOF with vented roofs are blown-in fiberglass, blown-in cellulose, blown-in mineral wool, and fiberglass rolls. This is due to their low cost and the presence of adequate space in attics for a thick insulation installation. Rigid foam insulation and closed-cell polyurethane spray foam is common for both THOF and THOW with unvented roof assemblies. Vented THOW often use rigid foam or a combination of rigid foam and fiberglass or mineral wool batts. Ceiling air barriers are most often formed using rigid foam, gypsum board (using air-tight drywall methods), or closed-cell polyurethane spray foam.

Rigid expanded polystyrene (EPS) insulation used in a vented roof assembly. The EPS triples as a ventilation baffle, a portion of the ceiling insulation, and the ceiling air barrier. The 1" ventilation space is maintained between the roof sheathing and EPS by using 1" wide wood spacers nailed to the sides of the roof joists. Canned closed-cell polyurethane spray foam that also acts as an air sealer, is used to fill the gaps between the EPS, roof joists, and wall top plate to create the ceiling's air barrier. The electric boxes do not extend through the EPS; rather the spray foam fills the small gap between the boxes and EPS. Fiberglass insulation was later installed in the joist cavities and gypsum board was used as the ceiling finish for this THOW.

A THOW vented roof assembly with 1" thick EPS insulation (R-3.85) and 3.5" thick fiberglass roll insulation (R-13). The remaining 1" of the 2x6 roof joist height is used for a 1" ventilation air space. The total ceiling assembly is less than R-17, which is less than required by the IRC for climate zone 1.

Wall Insulation and Air Barriers

The most prevalent materials for wall insulation in THOF are probably fiberglass rolls/batts, rigid foam, or a combination of the two. Fiberglass rolls/batts, rigid foam, closed-cell polyurethane spray foam, or some combination is typical for THOW walls. Wall air barriers are most often structural sheathing (plywood or OSB), rigid foam, or interior gypsum board. The seams of structural sheathing are air sealed with either tape or a liquid-applied flashing while the seams of rigid foam are either taped or filled with spray foam. Some rigid foam materials are notoriously hard to tape even with exotic tapes specifically formulated for this purpose. Using gypsum board for a wall air barrier is more difficult than for a ceiling mainly because even after air-tight drywall methods are used it is almost guaranteed occupants will create a large number of holes in the wall for the purpose of hanging decorations.

Left: Fiberglass roll insulation in the walls of a THOW

Right: Rigid foam insulation (in this case EPS) for insulating the wheel wheels of a THOW. Later canned spray foam sealed the gaps.

Left: A structural insulated panel (SIP), which sandwiches rigid foam insulation between structural sheathing. No studs or joists are needed between the structural sheathing so thermal bridging is avoided. SIPs can be used as wall or roof assemblies. After installation proper air sealing between each SIP piece is critical. Some companies are now making THOW with SIPs.

Right: Spray foam behind a wall electrical box to insulate the small, hard to insulate area.

Structural sheathing serving double duty as the wall air barrier in a THOW. The air barrier is made continuous by taping the plywood's seams with a high-quality flashing tape (3M All Weather Flashing Tape 8067). Use a flooring "J" roller to ensure the tape adheres to the sheathing along its entire length.

Floor Insulation and Air Barriers

The most frequently used materials for floor insulation in both THOF and THOW are fiberglass rolls/batts, mineral wool batts, rigid foam, or some combination. Blown-in insulation of any kind is not used for THOW floors (or ceilings and walls for that matter) because blown-in insulation's effectiveness relies on the presence of air spaces throughout the insulation profile. Blow-in insulations would quickly settle due to road vibrations and lose much of their real world R-value. Floor air barriers are most often subfloor sheathing (plywood or OSB) or rigid foam with proper seam sealing. Occasionally a thin layer of spray foam may be used for an air barrier, but its use in floor systems is not as common since it is easier to meet building code minimum floor R-values even in THOW.

THOW floor insulation using a combination of two layers of 3/4" EPS (R-6 for the 1.5" total thickness) and 3.5" of fiberglass batts (R-13). The bottom layer of EPS runs underneath the floor joists to minimize thermal bridging and the seams of the two layers of EPS are offset from each other and taped. The total floor assembly is approximately R-19, which meets the IRC requirements for climate zones 1, 2, 3, 4A, and 4B.

Roof Assemblies

Options for roofs of THOF are essentially the same as for traditionally sized homes. Decisions regarding roof shape, roof covering material, roof slope, and ventilation are usually based on climate, overall architectural style, geographical fire hazard, cost, etc. These four major design considerations also apply to THOW; however, the decisions are more often based on maximizing loft height and transportability.

Roof Shape

The most common THOW roof shapes are gable and shed. Those with gable roofs often include dormers to provide both natural light and increase available loft space. Using a roof covering material that allows for a low roof slope means almost any roof shape can provide adequate loft ceiling height for most, if not all, of the loft area. If steeper roof slope is desired for aesthetic reasons or because of the roof covering material chosen, the shape of the roof becomes more critical. For example, shed roofs are a common choice for low slope roofs but may look strange and almost assuredly provide highly variable loft ceiling heights for high pitched roofs. Hip roofs perform very well in high wind areas and should also do well for THOW that move often. Refer to page 30 of the course material to see photos of shed, gable, and curved roof shapes.

Roof Covering Material and Roof Slope

Section R905 of the IRC includes 13 code approved roof covering materials for a THOF. Of those, metal roof paneling is the predominate material used for THOW. Table 4 lists these roof covering material categories and their respective minimum slopes.

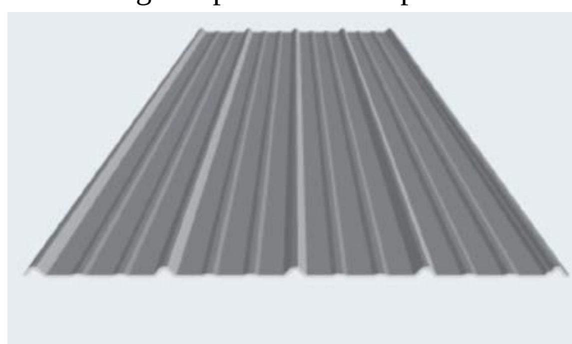
Material Category	Minimum Slope
Asphalt Shingles	2 : 12
Clay and Concrete Tile	2.5 : 12
Metal Roof Shingles	3 : 12
Mineral-Surfaced Roll Roofing	1 : 12
Slate Shingles	4 : 12
Wood Shingles and Shakes	3 : 12
Built-Up Roofs	Varies by Material
Coal-Tar Built-Up Roofs	0.125 : 12
All Other Built-Up Roofs	0.25 :12
Metal Roof Panels	Varies by Material
Lapped, Nonsoldered Seams without Applied Lap Sealant	3 : 12
Lapped, Nonsoldered Seams with Applied Lap Sealant	0.5 : 12
Standing Seam	0.25 :12
Modified Bitumen Roofing	0.25 : 12
Thermoset and Thermoplastic Single-Ply Roofing	0.25 : 12
Sprayed Polyurethane Foam Roofing	0.25 : 12
Liquid-Applied Roofing	0.25 : 12
Photovoltaic Shingles	2 : 12

Table 4: IRC Approved Roof Covering Materials and Minimum Slopes

The most common residential roof covering material in the United States, asphalt shingles, can be used for a THOW, but their use is uncommon. This is because asphalt shingles are only allowed for roof slopes of 2:12 (2 vertical units in 12 horizontal units) or steeper and they have greater susceptibly to damage during frequent movement compared to some other materials. For infrequent movement asphalt shingles are not a big issue – think of how many manufactured homes you've seen being moved down highways with their asphalt shingles remaining intact. If asphalt shingles are desired, specify an ASTM D7158, Class H or ASTM 3161, Class F rated shingle as they are designed to resist higher wind speeds. Alternatively, if aesthetics are not much of a concern, consider mineral-surfaced rolled roofing which is also an asphalt coated product but can be placed at the shallower slope of 1:12.

The other roof covering materials listed in the tables are not generally used for THOW due to various reasons. Clay and concrete tile, slate singles, metal roof shingles, and wood shingles and shakes have steeper minimum slopes and/or heavy weight. Built-up, modified bitumen, thermoset and thermoplastic, sprayed polyurethane foam, and liquid-applied roofing are more common to the commercial market, often require uncommon tools or skills, and generally don't have the aesthetics most people are looking for in a residential roof.

Metal roof panels are chosen because of their wind resistance and adequacy for shallow roof pitches. There are two seam types in the metal roof panel category: standing seam panels and lapped panels. The most common lapped panels are corrugated panels and rib panels.



Top Left: A 26 gauge standing seam metal roof panel. Standing seam roofs usually have to be ordered from a roofing supply company. The benefit is they come cut to length and the cut ends are primed with the exact same color as the roof.

Top Right: A rib style lapped panel. Panel width varies, but 36" is most common at big box stores.

Bottom: Corrugated galvanized steel lapped panel suitable for roofing or siding. Panel width varies, but 24" is most commonly available in big box stores.

Standing seam panels can be sloped as shallow as 0.25:12 (2%) by code. I've found standing seam panels installed even at 0.75:12 tend to have large water beads, greater than 1 inch in length, form and stand on them for some time after a rain storm is over (see photo below). I suspect the life of the panel coating may be shortened somewhat by this and/or it increases the likelihood of a leak around exposed fasteners. As a result I now design no shallower than 1:12.

A standing seam metal roof at 0.75:12 slope. Note the large water beads forming at the bottom of the panels.

If lapped, nonsoldered seamed panels do not have lap sealant applied, the minimum code approved slope is 3:12. With lap sealant, the minimum slope increases to 0.5:12. My experience has led me to use standing seam panels over lapped panels for two major reasons. First, there are fewer exposed fasteners in a standing seam roof compared to a lapped roof. It varies by manufacturer, panel width, and the fastener spacing for different wind design speeds, but an 8.5 feet wide THOW with a shed roof will likely have one-quarter to one-half as many exposed fasteners using standing seam compared to a lapped panel system. Most exposed fasteners on a standing seam system will be located above an overhang not a living space. The opposite is true of lapped panel systems. Eventually the washers on the exposed roofing screws will deteriorate resulting in leaks. In my opinion lapped systems have greater leak potential, likely have more actual leaks, and require more maintenance time when screw washers are replaced proactively. Second, the raised standing seams have very little chance of leaking compared to the lapped seams. Lap sealants of low quality are often used. All sealants tend to degrade over time and the low quality ones lose elasticity and crack much more quickly. Even with a high quality sealant it takes impeccable attention to detail to ensure a continuous, properly sized bead along the entire length of all seams. Leaks along the seams due to capillary action or negative pressure, while not nearly as frequent as fastener leaks, are a concern.

Standing seam metal roofs are available in scores of colors, multiple panel profiles (flat pan, accent ribs, striated, etc.), and different metals (galvanized steel, stainless steel, copper, lead, aluminum, zinc etc.). 26, 24, or 22 gauge galvanized steel with a G90 zinc coating meeting ASTM A653 is most common for THOW. Residential quality materials (panels, drip edge, flashing pieces, closures, butyl mastic tape, and fasteners) can be purchased for as little as $3.50 per square foot.

Some standing seam panel systems require special tools, but there are now many readily available “snap” together systems that don’t require a seamer tool. These systems can be installed using common carpentry tools plus aviation snips, a small hand seamer, rivet tool, and if desired for quicker installation a short metal folding tool. Any tradesperson who installs stock flashing or bends custom flashing will have some or all of these tools. Most installation will also benefit from the use of electric metal shears, though a circular saw can be used as well.

The majority of roof covering materials require an underlayment between the roof covering material and roof deck. IRC Tables R905.1.1(1), R905.1.1(2), and R905.1.1(3) provide cover underlayment types and underlayment application requirements. At shallower slopes some materials require a double layer of underlayment. For a standing seam metal roof the two most common underlayments are roofing felt or self-adhering modified bitumen underlayment. Roofing felt is much less expensive, but self-adhering underlayment has performance advantages. It self-seals around nail or screws used to attach the roof covering, helps protect the structure when ice dams melt, and lengthens the allowable time between roof sheathing and final roof covering installation. The material cost of roofing felt is around $0.10 per square foot compared to about $1.00 for self-adhering underlayment. Self-adhering underlayment is often called “peel-and-stick” or “ice and water shield”. For metal roofs be sure to use high temperature self-adhering underlayment. For example Grace Ice & Water Shield HT (for high temperature) instead of regular Grace Ice & Water Shield. Consult the metal roof manufacturer’s installation instructions for allowable underlayment options.

Ventilation

The last major roof consideration is whether a vented or unvented roof assembly will be used. Vented roof assemblies are outside of the conditioned living space while unvented roof assemblies are part of the conditioned living space. See Figure 2 for typical vented and unvented assemblies.

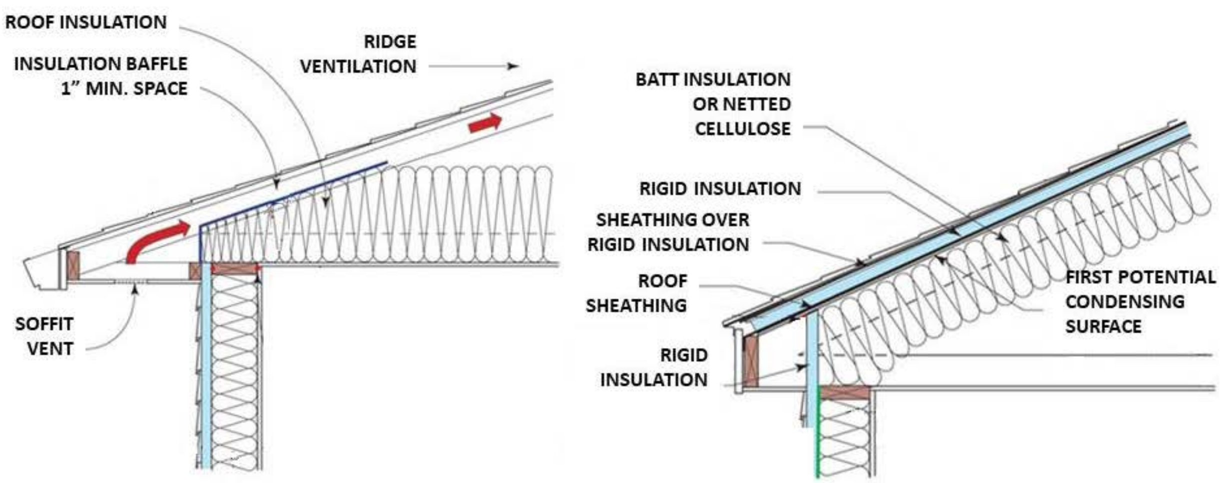


Figure 2: A typical vented roof assembly is shown on the left and a typical condensing surface temperature controlled unvented roof assembly is shown on the right. There is an alternate type of unvented roof assembly used in certain climate zones.

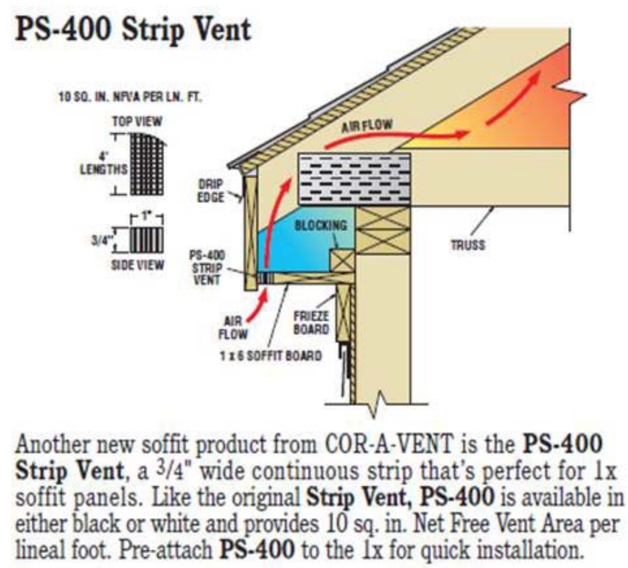
Both types of assemblies are allowed by IRC Section R806. The vast majority of homes in the United States have vented roofs. This is because older houses were built with little to no insulation, up until recently there were very few air-impermeable insulation products readily available, and unvented roofs were not allowed by building codes until recently. The primary purposes of vented assemblies are to:

- Prevent ice dam formation in cold climates by keeping the roof surface cold to minimize snow melt
- In cold climates, vent hot air escaping from the conditioned space from the roof/ attic space before it condensates on the roof sheathing
- In hot climates, roof venting releases air in the roof/attic space that is heated by the sun which reduces the temperature and/or cooling load of the conditioned space, however generally by no more than 10 degrees at best

Vented roofs are simpler, less expensive, and generally less prone to water vapor/condensation related problems if constructed improperly compared to unvented roofs. For all but the coldest three climate zones, IRC R806.2 requires a minimum net free ventilating area (NFVA) of 1 to 150 of the area of the vented space. A 2 foot wide rafter bay that is 8 feet long requires at least 16 square inches total NFVA per bay as shown in the below calculation.

$$Minimum\ NFVA = (2\ ft)(8\ ft)\left(\frac{1}{150}\right)\left(\frac{144\ in^2}{1\ ft^2}\right) = 16\ in^2$$

The IRC requires "not less than 40 percent and not more than 50 percent of the required ventilating area is provided by ventilators located in the upper portion of the attic or rafter space." This means for our example provide between 6.4 and 8 square inches of NFVA near the ridge or highest point of the roof of each rafter bay. The balance of between 8 and 9.6 square inches must be provided near the eave or soffit of each bay. The theoretical benefit behind having slightly less ventilation area at the high point of the roof is to slightly overpressure the attic or rafter space and reduce the exfiltration of air from the conditioned space into that area. "Not less than a 1-inch (25 mm) space shall be provided between the insulation and the roof sheathing" for a vented roof according to IRC R806.3.



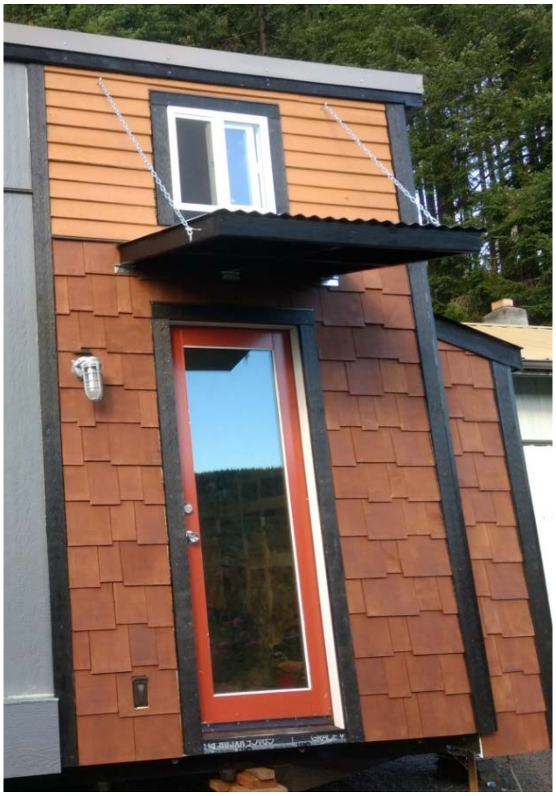
Cor-A-Vent PS-400 Strip Vent Product Information (from Cor-A-Vent S-400 Application Brochure)

Since a THOW is so narrow, almost all of the available width is used for living space resulting in very narrow roof overhangs, typically only a few inches. This leaves very little room for roof venting under overhangs or in soffits. One product that provides a solution is the Cor-A-Vent PS-400 strip vent, which is only 1 inch wide, but provides 10 square inches of NFVA per linear foot. In our example the PS-400 would provide about two and a half times the minimum ventilation required at both the high and low points of each rafter bay.

Installed Cor-A-Vent PS-400 strip vent in the overhang of a THOW

There are other potential ventilation solutions to narrow THOW overhangs, but many ventilation products providing above-roof deck ventilation are not for metal roofs, which as mentioned before are the prevalent roof covering material for THOW.

Of course, wider overhangs can be easily accommodated on both the front and back of the THOW and generally they should be designed wider to better protect the siding, doors, and windows from wind-blown rain. Strong consideration should be given to including removable or rollable awnings over doors and windows on the long sides of a THOW.



Removable, adjustable awning supported by hinges and chains

For a THOW the two biggest benefits of an unvented roof assembly are the greater amount of insulation, since no ventilation space is needed, and no need to fit vents into the narrow roof overhangs. If you choose to use an unvented roof assembly make sure to carefully research how to properly construct the assembly in your climate zone and make sure the assembly meets all building code requirements. A good introduction to unvented roof assemblies can be found online at the URL listed in the course references for Joe Lstiburek's article entitled "Understanding Attic Ventilation."

Siding Material

Material Options

The IRC uses the term "exterior wall coverings" for siding materials. For THOF, IRC Section R703 lists twelve exterior wall covering options including aluminum, stone and masonry veneer, wood, hardboard, particle board, wood structural paneling siding, wood shakes and shingles, exterior plaster, steel, vinyl, fiber cement, and exterior insulation finish systems. After removing the siding materials that are very heavy, brittle, or widely unavailable the following materials are left as easily viable options for a THOW: aluminum, wood, wood structural paneling siding, wood shakes and shingles, steel, vinyl, and exterior insulation finish systems. Refer to Table 5 for comparison of these materials.

Siding Material	Approximate Weight (lbs/ft^2)	Minimum Cost (per ft^2)	Comment
Aluminum	0.4	$1.50	Lap siding
Wood	0.5	$3.00	Weight varies by species/thickness
Wood Structural Paneling Siding	1.3 to 1.7	$0.85	Weight varies by product
Wood Shakes and Shingles	0.75 to 1.0	$2.25	Weight and cost depends on species and exposure chosen. Least wind resistant of the seven.
Steel	0.5	$1.25	Lap siding or corrugated panels
Vinyl	0.4	$1.00	
Exterior Insulation Finish Systems	Varies	$4.00	Small residential market share

Table 5: THOW Siding Material Options, Weights, and Costs

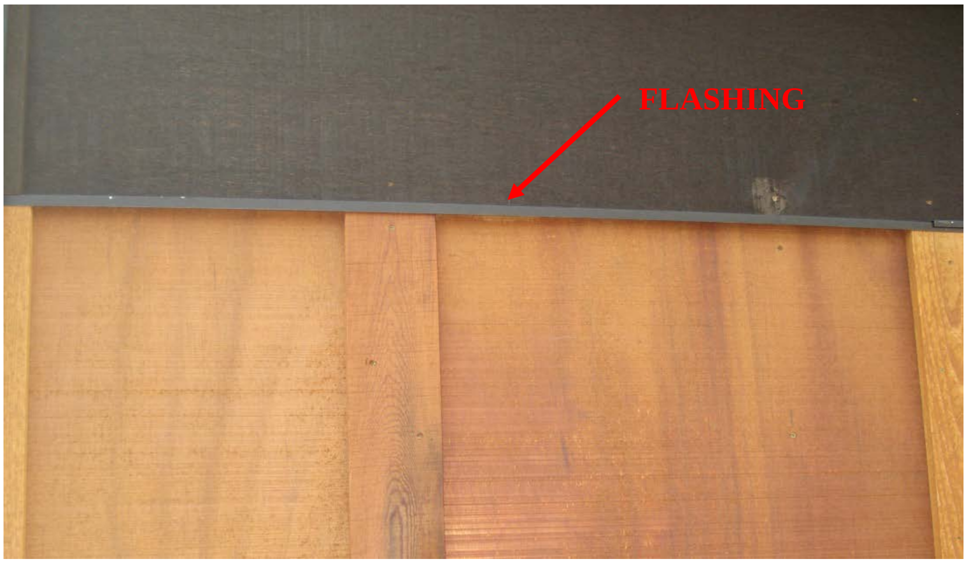
THOW using multiple siding materials including corrugated galvanized steel panels, LP SmartSide (a wood structural panel), cedar shingles, and cedar lap siding

THOW (in foreground) using multiple siding materials including painted corrugated steel panels, cedar shingles, Breckenridge siding panels, and faux board and batten siding

Left: THOW using tongue and groove wood siding and sheet metal for siding

Right: THOW using wood panel siding

Required siding fastener sizes and spacing are in IRC Table R703.3(1). Consider using screws instead of nails if the THOW will be moved regularly. Conversion from the required nail diameter to screw size (i.e. No. 6, No. 7, No. 8) can be accomplished using IRC Table R703.3(2). For simplicity stick with the same screw length as the nail length required even though screws have much greater withdrawal resistance. Flashing is required for all horizontal, non-lapped siding joints (see photo below).



Flashing between horizontal joints of two dissimilar siding materials

Water-Resistive Barriers

A water-resistive barrier (WRB) is required over the studs or wall sheathing of all exterior walls according to IRC R703.2. WRBs act as the second line of protection against water entering a house (the first line of protection is the exterior wall covering). Sometimes water will get past even the best products installed impeccably due to wind-driven rain, vapor diffusion, pressure differentials, or solar drive. Not only are WRBs required to be water-resistant, but they are also required to be vapor permeable. This vapor permeability allows water that gets into the exterior walls to evaporate and escape in the form of water vapor. When materials are able to dry quickly they are less likely to rot, corrode, and support mold growth. The WRB can be one layer of number 15 (often denoted as No. 15 or #15) asphalt felt installed horizontally and lapped in accordance with the code or an approved alternate material. House wraps, which are usually made of woven polypropylene or spun-bonded polyethylene, are the most commonly used approved alternate and are manufactured by many different companies. Tyvek's Home Wrap is probably the most recognizable brand.

Installed Tyvek Home Wrap used as a water-resistive barrier (WRB)

The biggest advantage to using asphalt felt is that it can absorb water and then release that water through evaporation. Also you should know its vapor permeance characteristics change when it is wet compared to when it is dry. When it is dry the permeance is around 5 perms (making it vapor semi-permeable) and when it is wet or the relative humidity is above 95% the permeance is over 60 perms (making it vapor permeable). House wrap permeance generally does not change with moisture content. The biggest disadvantage to using asphalt felt it is tears more easily than house wraps and becomes brittle if exposed to excessive sunlight. The material cost of No. 15 asphalt felt is between $0.05 and $0.10 per square foot compared to $0.08 to $0.12 per square foot for basic to mid-level residential house wraps.

Rain Screens

A rain screen (sometimes also called a drainage gap or drainage plane) is an air gap created between the WRB and the exterior wall covering/siding to create a capillary break and allow drainage and evaporation of water from both the siding and exterior wall framing or sheathing. Often the rain screen is created by attaching furring strips to the wall sheathing. Normally it is considered a best practice, but not a code requirement. At least one exception to this is the State of Oregon. Oregon residential code requires a minimum of 1/8 inch space between the WRB and exterior veneer, though there are multiple exceptions and alternatives allowed. Some WRBs have "built-in" drainage gaps, but most are around 1 millimeter (mm), slightly greater than 1/32 inch, which is significantly less than the 1/8 inch Oregon requirement. However it seems many Oregon code officials are allowing these types of drainage house wraps under the exception criteria. The Building Science Corporation's research indicates effective drainage can occur in spaces as narrow as 1/16 to 1/8 of an inch (2 to 3 mm), but that ventilation may require up to ¾ to 1 inch spaces. Depending on the local climate, designers need to weigh the benefits of a rain screen to the resulting loss of up to 2 inches of living space width in a THOW.

Doors and Windows

Doors

Every dwelling unit, for our purposes a tiny house, must have at least one egress door. This exterior egress door must have 32 inches or wider of clear width (with the door opened 90 degrees) and 78 inches or taller clear height (see IRC R311.2). THOW options include inswing doors, outswing doors, sliding doors, and garage doors. Generally outswing doors are used in hurricane prone areas so that both the locking mechanisms and door frame stop are able to resist door opening due to higher pressure outside compared to inside. For THOW applications the choice of an inswing or outswing exterior door is more likely based on the floor plan and whether an inswing will conflict with usable space just inside the entry. Keep in mind outswing exterior doors require larger landings outside the THOW so that occupants can open the door without having to back down entry steps (also a code requirement). This may cause some challenges for THOW that are moved often since a large staircase with landing may not be easily transportable or movable by hand. By code flashing is required above all exterior doors.

Besides swinging doors, other common options for interior tiny house doors are pocket doors, barn doors, and doors made of cloth or curtains. These door options are useful since they require almost no door clearance space and space is such a premium in a tiny house. Thought should be given before specifying any of these for a bathroom as noise and air transfers past them more easily than most swinging doors. A popular recent trend is to mount loft ladders onto barn doors. Be sure to specify barn door hardware rated for 300 pounds or more. Barn door hardware sold at big box stores is generally not that strong. Agriculture supply stores selling "real" barn door hardware are usually the go to source. All standard width interior door widths are acceptable but keep in mind an average sized man's shoulders come very close to touching the stops on a 24 inch wide door frame. Also doors leading to rooms below lofts may require custom doors shorter than 6 feet 8 inches tall due to the height of the loft above the finish floor. In some situations the way to avoid this is to run the loft floor joists in the direction and at on-center spacing that doesn't conflict with a standard door height.

Loft joists oriented and spaced to maximize door height. The wall top plate was not yet cut out of the doorway opening at the time of this photo. Also note the 2x6 tongue and groove decking used for the loft flooring and below loft ceiling.

Other door considerations include:

- Ensure door U-factors specified meet the minimum required by IRC Table N1102.1.2 or N1102.1.4 (both tables have the same values) for the climate zone (for THOW the most stringent climate zone it will remain in for a long period of time)
- Make sure doors selected meet the fenestration air leakage requirements given in IRC N1102.4.3 of not greater than 0.3 cfm per square foot for sliding glass doors and 0.5 cfm per square foot for swinging doors

Windows

The size and location of windows in tiny houses is extremely important due to the minimal floor area. Lots of windows make a room feel bigger, generally make the space feel more cheerful, allow plenty of natural light, and provide a connection between the indoors and outdoors. This connection is especially important in connecting indoor and outdoor living spaces such as a deck or patio. Lining up windows and doors creates long sight lines, provides cross ventilation, helps make the space feel bigger, creates connection to the outdoors, and provides natural cooling. Many designers limit the number and size of windows on the trailer tongue side of a THOW to minimize potential damage from rocks and other projectiles during towing. If windows are desired on this side simple solutions during transport include shutters, hurricane panels, and temporary plywood covers

There are a few minimum light and ventilation requirements for windows in IRC Section R303 that are easily met and usually exceeded in tiny houses. Habitable rooms (rooms used for living, sleeping, eating, or cooking functions) are required to have "an aggregate glazing area of not less than 8 percent of the floor area of such rooms." The glazing area is the area of glass, not the overall window area including the frame. For natural ventilation purposes the "openable area to the outdoors shall be not less than 4 percent of the floor area being ventilated." Windows, skylights, doors, and louvers are allowed to provide this required ventilation area. Bathrooms require aggregate glazing area of at least 3 square feet, half of which must be openable for natural ventilation, unless artificial light and an exhaust system are provided. I am unaware of any maximum glazing area percentage requirements in the IRC. There is a maximum percentage given in the International Energy Conservation Code, but it applies only to commercial building. That being said, the more glazing there is in a structure, the harder it is to meet the code requirements for heating and cooling.

Windows provide not only light and ventilation, but also can provide passive solar heating. Past experience from builders and occupants of passive solar houses has shown excessive daytime heating can occur even in very cold climate zones if too much glazing is provided. While it varies greatly by climate zone and even from site to site in a given region, a general guideline for planning purposes is to provide 25 percent or less glazing area on a south facing wall and 15 percent or less total glazing area over the remaining wall area (with the west facing walls receiving the least glazing of all). This can be challenging for a THOW that may oriented differently each time it is moved so keeping all walls below 15 percent might be a good compromise.

EXAMPLE:

A 320 ft^2 THOF consists of the following rooms and floor areas: living/dining room (94 ft^2), kitchen (70 ft^2), two bedrooms (60 ft^2 each), and bathroom (36 ft^2). The bathroom doesn't have an exhaust fan. The south and north exterior walls are each 20 feet long. The east and west exterior walls are each 16 feet long. Assume the heights of all walls are 10 feet. What are the minimum glazing areas? What are the minimum operable window areas for natural ventilation? What is the maximum glazing of the walls given this course's recommended criteria?

SOLUTION:

All the rooms listed except for the bathroom are habitable rooms by IRC definition. So the total habitable space is 284 ft^2. There are differing interpretations as to whether the code provision requires each and every habitable room to meet the 8 percent minimum glazing or if some rooms can have less than 8 percent and others have more than 8 percent as long as the total is 8 percent or greater. The 2012 IRC is clear that all habitable rooms must meet the requirement, but the language in the 2015 and 2018 IRC removed the term "all" making it appear to many that the individual room mandate has been removed. For the purposes of this example we will assume the 8 percent applies only to the total habitable room area.

$$Habitable\ Room\ Minimum\ Glazing\ Area = (284\ ft^2)(0.08) = 22.7\ ft^2$$
$$Habitable\ Room\ Minimum\ Natural\ Ventilation\ Area = (284\ ft^2)(0.04) = 11.4\ ft^2$$

The bathroom, regardless of size, requires at least 3 ft^2 of glazing and 1.5 ft^2 of ventilation area since there is no exhaust system.

$$South\ Wall\ Maximum\ Glazing\ Area = (20\ \ ft)(10\ ft)(0.25) = 50\ ft^2$$
$$East, West, and\ North\ Wall\ Total\ Maximum\ Glazing\ Area$$
$$= (16\ ft + 16\ ft + 20\ ft)(10\ ft)(0.15) = 78\ ft^2$$

Less than one-third of the 78 ft^2 glazing should be on the west wall to help reduce late afternoon heating. Let's say somewhere around 20 ft^2 on the west wall, 28 ft^2 on the north wall and 30 ft^2 on the east wall.

Other window considerations include:

- An *emergency escape and rescue opening* is required in every sleeping room. Refer to the section on lofts in *Tiny Houses Part 1 – Planning and Design Considerations, Legality, and the Engineer's Role* for more information.
- Generally keep your window seat/sill heights between 24 and 44 inches above the floor
- Use tempered glass in every location of a THOW even when non-tempered glass is allowed by code. Tempered glass is stronger than non-tempered glass. Also it is safer when it does break compared to non-tempered glass.

- Consider using laminated glass for a THOW that moves frequently, however this is generally quite expensive
- Ensure window U-factors specified meet the minimum required by IRC Table N1102.1.2 or N1102.1.4 (both tables have the same values) for the climate zone (for THOW the most stringent climate zone it will remain in for a long period of time)
- Ensure window solar heat gain coefficients (SHGC) specified comply with IRC Table N1102.1.2 or N1102.1.4 for the climate zone. SHGC is the ratio of the solar heat gain entering the space through the window as a percentage of the solar radiation that strikes its surface.
- Make sure windows selected meet the fenestration air leakage requirement given in IRC N1102.4.3 of not greater than 0.3 cfm per square foot
- Flashing is required above all exterior windows by code
- Due to narrow overhangs over THOW windows make sure to include window details in your drawings showing the window flashing, WRB placement, sill sloping, and liquid-applied or tape flashing. These details are even more critical than regular installations where deeper overhangs help protect windows from rain.

Figure 3: A National Fenestration Rating Council (NFRC) energy performance label showing the U-factor, SHGC, visible transmittance, and air leakage testing results for a fictitious window (from NFRC fact sheet). Energy performance label stickers should be on all new windows made in the United States.

Left: A vinyl window with its top and side nailing flanges covered with 6" wide Grace Vycor Plus self-adhered flashing. The bottom flange is not covered with self-adhered flashing so that any water that gets behind the window is not trapped. The window framing bottom member was covered with self-adhered flashing prior to window installation.

Right: Aluminum Z flashing (also called Z bar flashing or window cap flashing) installed above the window trim. Roofing nails are used to fasten the aluminum flashing to the studs or sheathing. The top leg of the flashing is then taped to the house wrap using a flashing tape (in this case 3M All Weather Flashing Tape 8067) so that any moisture that gets behind the siding above the window doesn't go behind the aluminum flashing.

THOW Exterior Storage

Many THOW have exterior storage cabinets that double as both extra storage space and as a mechanical room for the electric panelboard (IRC term for circuit breaker box or load center), propane tank(s), solar battery bank, water heater, etc. Usually the storage cabinet is constructed on the tongue of the trailer to utilize otherwise unused trailer space. Don't design or build cabinets so deep or wide that they unnecessarily compromise the turning radius of the trailer due to the back of the tow vehicle hitting the storage cabinet on tight turns.

Two examples of THOW exterior storage cabinets

Options for Accommodating THOW Wheel Wells

One situation most THOW designers must address is how to deal with the presence of a wheel well and its fender both on the exterior and interior of the structure. There are a few trailer manufactures that raise their trailer decks so that the wheels are entirely under the deck, though for headroom purposes this is usually only for a THOW without lofts.

Exterior

There are two main approaches to handle the wheel well on the exterior. The first is to provide flashing to transition from vertical siding to the horizontal top of the fender surface. Steel can be welded to the top of the fender by the trailer manufacturer to form an integral flashing with the trailer (see below photo). It is imperative the designer provides the trailer manufacturer the correct location to weld the flashing at so that it properly integrates with the exterior wall sheathing or WRB. Alternatively a custom flashing can be made from aluminum flashing rolls.

Steel welded perpendicular to the fender makes flashing integral to the trailer

The second approach is to totally cover the top of the fender so that its horizontal surface is not exposed to the elements at all. One photo below shows a THOW that located its exterior walls so the entire siding plane was outside of the wheel well. This approach requires the removal of some siding in the event of tire removal. If this approach is used, be aware of the finished width and if an oversized load permit is required during transportation. The second photo below shows the use of extra wide flashing, custom-made from aluminum flashing rolls to cover the top of the fender. With this approach only a small portion of siding is located outside the wheel well. Removal of the siding covering the wheel well is necessary for both trailer movement and tire removal, but it can be detached easily by removing a few screws.

Left : THOW with its entire siding plane outside of the wheel well

Right: THOW with extra wide flashing used to cover the top of the fender and extend siding partway down the wheel well.

Interior

There are many options for accommodating the projection of wheel wells into the interior of a THOW. Primarily the wheel wells are left projecting out or built-in furniture is constructed on top or around them (desks, couches, beds, bookcases, etc.). Whether left projecting or covered by built-ins the wheel wells are framed around with 2x2 lumber, insulated, and a finish covering of some sort is installed.

Left: Wheel well framed out and finished with painted gypsum board

Right: Wheel well interior construction in progress. Plywood was screwed to the top of the wheel well framing prior to installing the gypsum board so that people can sit or stand on it without breaking the gypsum board.

Interior Finishes

Interior wall, ceiling, and floor finish options for traditional homes and THOF are almost unlimited. Commonly used finish options for a THOW are more limited since weight and movement are major factors. Brittle materials are usually avoided or modified construction methods are necessary to avoid crack development.

Walls

Early THOW almost all used wood boards with tongue and groove or shiplap joints or wood paneling for their interior walls. Gypsum board (drywall) was not used because of its weight compared to wood and concerns over cracking of joints when moving the THOW. In recent years the use of gypsum board has become fairly common. Builders have developed their own methods to avoid or minimize cracks. Usually it entails some combination of caulking, flexible corner products (like CertainTeed No-Coat Corner or Trim-Tex Magic Corner), and drywall clips on both coplanar joints and corners. Most builders use both drywall adhesive and screws for their gypsum board and glue and nail wood paneling to the studs to help reduce fastener popping during towing.

Tongue & groove wood board walls

Painted wood wall paneling

Gypsum board (drywall) walls in a THOW

Architectural wall system in a THOW

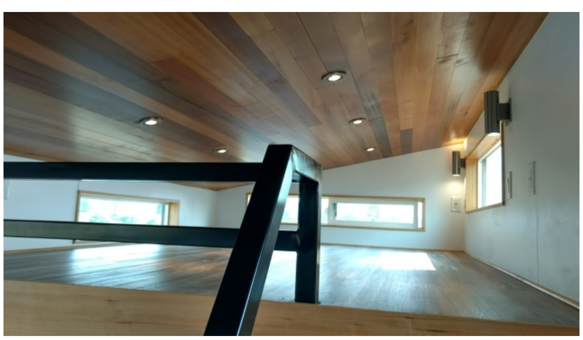
Left, Right Top, and Right Bottom: CertainTeed No-Coat Flexible Corner 325 for drywall

Ceilings

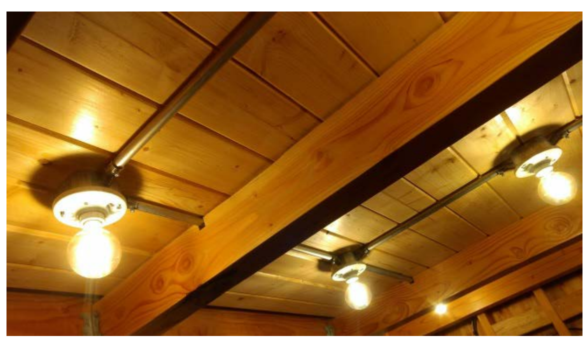
Most THOW ceilings are finished with tongue and groove (T&G) wood boards. T&G boards are not a very good air barrier and the ceiling air barrier is the most important air barrier in the entire house. Use a stand-alone air barrier if a vented roof assembly is used. A product such as CertainTeed's MemBrain or similar is preferable to a polyethylene sheet which can cause moisture problems in certain climate zones, especially those that heat during the winter and air condition during the summer. Wood panels are sometimes used, but additional ceiling framing is necessary to ensure the thin panels don't sag. This takes up valuable headroom so it seems to reduce paneling's popularity for this application. Gypsum board is now probably the second most common ceiling material behind T&G wood. When designing, require the use of drywall adhesive and screws for a THOW. Gypsum board can be a good air barrier if seams and light fixture box penetrations use air-tight drywall installation methods. With vented roof assemblies, specify air-tight drywall installation which uses minimal additional materials (high quality caulk for narrow gaps and spray foam for wide gaps) at all seams, edges, and penetrations. Alternatively, use a separate material such as rigid foam, for the air barrier (see page 16).

Painted wood ceiling paneling

Tongue & groove (T&G) wood board ceiling



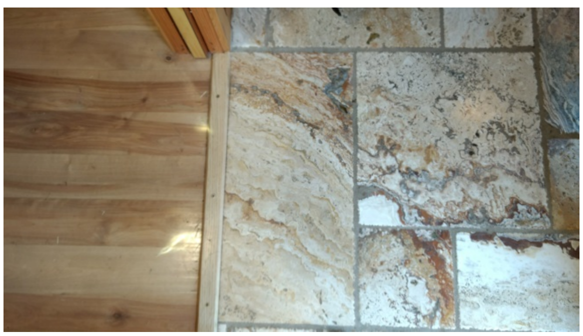
T&G wood board ceiling



2x6 T&G ceiling/loft floor

Floors

Early THOW mostly used vinyl floors in the bathrooms and wood floors everywhere else because of their light weight and pliability. In recent years the use of ceramic and porcelain tile has become somewhat common in the bathroom and kitchen areas. Builders are using uncoupling membranes and developing their own grout mixture concoctions to try and limit cracking. While much of the tile work I've seen seems to have stood up to occasional trailer movement I personally haven't inspected any THOW that moves frequently to see how the grout lines fared. Regardless, since un-cracked grout itself isn't waterproof, a water proofing system behind the tile is a must. Current THOW flooring options include hardwood flooring, engineered hardwood flooring, laminate wood flooring, bamboo, cork, vinyl tile, vinyl planks, sheet vinyl, carpet, carpet tiles, ceramic tile, and porcelain tile.



Wood and tile flooring in a THOW

Stone flooring in a THOW

Left: Wood 2x6 decking for loft flooring in a THOW

Right: Porcelain bathroom tile floor installation in a THOW during the tile laying process. Notice the orange colored uncoupling membrane (Schluter Systems Ditra) under the tile.

Interior Trim

Interior trim materials selected for THOW are usually wood (often finger-jointed pine) or medium-density fiberboard (MDF). MDF weighs more than wood, but trim contributes very little to overall THOW weight.

Five types of trim work in the loft of a THOW. Trim materials include MDF for the floor, corner, and ceiling trim; reclaimed cedar for the window side and top extensions; and MDF window stools.

Cabinets and Vanities

Kitchen cabinets and bathroom vanities are critical storage spaces for all tiny houses. Cabinets and vanities come in four categories: stock, Ready-to-Assemble (RTA), semi-custom, and custom. Stock cabinets are factory made, pre-assembled, and ready to pick up and install the same day from a big box or cabinet supply store. RTA cabinets are factory made but not factory assembled (think Ikea); sometimes RTA cabinets are available the same day but many suppliers require a short lead time. Semi-custom cabinets allow some level of customization; say choosing from a large selection of door styles and hardware for a given cabinet box. Usually semi-custom cabinets are available in more sizes (both width and height) than stock or RTA cabinets. Custom cabinets are exactly what they sound like; you choose the sizes, materials, finishes, and hardware.

Since space is at a premium in a tiny house custom cabinets seem ideal. They are built to the exact dimensions present without wasting potential storage space. For example if you have 75" between two walls you likely would use two 36" wide stock or RTA cabinets and a 3" filler to hide the 3" of dead space. With custom cabinets you can have a 36" wide cabinet and a 39" wide cabinet. Additionally, custom sink cabinets and bathroom sink vanities can be designed and built to accommodate the plumbing quirks introduced by THOW trailer frames. More on that in *Tiny Houses Part 4*. The rub is all kitchen cabinets are expensive, but custom cabinets are really, really expensive unless you build them yourself.

Cabinets are also heavy, especially if made from high-density fiberboard, a common material for RTA cabinets. What are some options to save on weight? Open shelving and large shelves are a good option as are curtains on cabinets instead of doors. I also recommend self-closing door hinges and drawer slides to keep doors and drawers closed during THOW movements. Additionally, their use eliminates loud slamming noises during kitchen use – something greatly appreciated if you live with others in such a small space.


Left: Custom kitchen cabinets made from pre-finished birch plywood. The upper cabinets are 16" deep instead of the typical 12" (to facilitate small appliance storage) and slightly shorter than typical (because of the loft above the kitchen). Due to the large kitchen window (seen on the left side of the photo) there was limited wall space for upper cabinets. A long shelf was used instead which allows for storage and limits obstruction of the window.

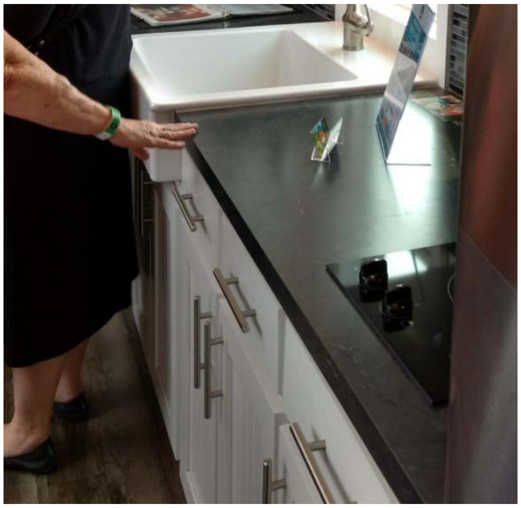
Right: Don't forget to include some drawers in the lower cabinets. Also make sure to utilize corner storage by installing a Lazy Susan, corner drawers, or other alternatives.


Left: Bathroom vanity in a THOW

Right: Over toilet storage cabinet in a THOW bathroom

Countertops and Tables

Wood and laminate countertops dwarf all competitors as the top material choices for THOW. Stainless steel is another good lightweight alternative. Very few THOW use natural stone countertops, such as granite, due to the high weight of these materials. When the countertop area is extremely small natural stone is occasionally used. Wood is almost always the top choice for THOW dining room tables.



Laminate countertop in a THOW

Wood countertop in a THOW

Built-In Furniture

Due to the limited storage area in THOW and THOF, built-in furniture is a common feature for both. Built-in furniture often includes bookcases, sitting areas (with storage under the cushions), foldable desks, foldable dining room tables, storage under staircases, etc.

Left: A built-in bookcases in the wall between the living area and bathroom of a THOW. The wall is two 2x4s thick. More storage space was built into the wall to the right of the bookcase and is accessible from the bathroom side of the wall.

Right: A full extension drawer in the bottom of the entry closet of a THOW. The drawer has dividers in it to facilitate shoe storage in the vertical position.

A desk in a THOW loft which folds down parallel to the wall to allow for more loft space when the desk is not in use

Conclusion

This course concentrated on the remaining building enclosure components not previously covered in the *Tiny Houses Part 1* and *Tiny House Part 2* courses, specifically insulation, air sealing, roof assemblies, ventilation, exterior siding, doors, windows, and interior finishes.

Remember there will be one more course in this series. Course four will focus on mechanical, electrical, and plumbing (MEP) systems with an emphasis on going off-grid or mobile with a tiny house. Look for course four's release in early 2020.

Write a Review

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