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A SunCam online continuing education course

Tiny Houses Part 4

Mechanical, Electrical, and Plumbing Systems

by

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Course Description

This course is part 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 fourth course focuses on mechanical, electrical, and plumbing (MEP) systems. Over 50 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 basic components that make up each MEP system.
2. Size various MEP system components in accordance with building code requirements.
3. Identify key differences between designing and installing MEP systems in THOW and traditionally built dwellings.
4. Comprehend the importance and impact of selecting various energy sources for mechanical equipment and appliances.

Introduction

Over the past few decades a small, but growing segment of the population has moved to smaller housing options. This course is the fourth part of a multi-part course series on one of these alternatives – tiny houses. The course discusses both tiny houses on foundations (THOF) and tiny houses on wheels (THOW) and focuses on mechanical, electrical, and plumbing (MEP) systems. The basis of these courses came from my own research, planning, designing, and construction of a THOW I 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 2020 dollars. Some costs vary greatly from region to region. 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 Related to MEP Design

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. Potential engineering design services requested for tiny house MEP systems include sizing heating, cooling, and ventilation systems; designing propane systems; laying out and sizing plumbing systems; designing site utilities including water storage, water quality treatment systems, distribution piping, pumps, and septic systems; calculating electrical service loads; designing alternating current and direct current electrical systems; and designing solar photovoltaic and solar thermal hot water systems.

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 moving THOW 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 recreational vehicles (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 RVs 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 codes as much as possible. A third possible standard for use is the manufactured home standard.

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).

The 2018 IRC is referenced in this course and is viewable online for free on the ICC website at https://codes.iccsafe.org/content/IRC2018. Additionally, the National Electrical Code (NEC) has been adopted by all 50 states and is the commercial, industrial, and residential standard for electrical design and installation in the United States. The NEC is published by the National Fire Protection Association (NFPA) and is also called NFPA 70. NFPA 70A, the *National Electric Code Requirements for One- and Two-Family Dwellings* contains excerpts from NFPA 70 and uses the same chapter and paragraph designation system as NFPA 70. This shorter code (250 pages compared to 900 pages) does not include the commercial and industrial provisions of the full NEC. NFPA documents are viewable online for free after creating an account profile at https://www.nfpa.org. The electrical chapters of the IRC are based on NFPA 70 and the IRC lists the corresponding NEC section in parenthesis or brackets after each sentence or paragraph. For the sake of using a single source, this course will primarily reference the IRC electrical chapters.

Part 1 of this series provides a more detailed discussion of building codes and manufacturing standards.

Mechanicals and Appliances

This section of the course covers appliances, common heating and cooling systems, ventilation and exhaust considerations, and propane systems in tiny houses.

Appliances

During the planning stage, designers and clients need to decide what appliances to include and the appliance energy sources as these decisions greatly influence mechanical design, electrical design, off-grid suitability, and THOW mobility. A THOW will likely require tradeoffs, as only the longest trailer lengths will be able to accommodate all the appliances a traditional house has.

THOW most commonly use electric and liquid propane (LP) appliances. 2-way and 3-way appliances are able to run on multiple energy sources. The most common 2-way appliances run on LP and 120 volt alternating current (AC) while the most common 3-way appliances run on LP, 120 volt AC, and 12 or 24 volt direct current (DC). All tiny houses, but especially THOW and off-grid THOF can use either normal sized house appliances, RV appliances, or boat appliances. Many RV and boat appliances are 2-way appliances since they are transitory by nature. Off-grid tiny houses and frequently moved THOW are more likely to utilize a combination of gas and DC electric appliances. Make sure to secure appliances in a manner to ensure they don't tip during THOW movement. Table 1 shows appliance energy source options.

Appliance	Electric (AC)	Electric (DC)	Propane	Natural Gas	Comment
Refrigerator	X	X	X	X	
Range	X		X	X	
Cooktop	X		X	X	
Microwave	X	X			
Dishwasher	X				
Washing Machine	X	X			Hand operated options exist
Dryer	X		X	X	Two alternatives...a clothes line or drying rack!
Washer/Dryer Combos	X	X	X	X	Gas combos usually use electricity for washing
Water Heater (Tank)	X	X	X	X	Solar hot water is a fifth potential source
Water Heater (Tankless)	X		X	X	

Table 1: Common Appliance Energy/Fuel Source Options

Refrigerators

Electric refrigerators powered by AC are the dominant refrigerator type in the United States. They are readily available, come in all sizes (typically between 3 and 35 ft^3 in volume), and are inexpensive compared to DC electric and gas refrigerators.

Electric refrigerators powered by DC are available in 12, 24, and 48 volt models. They come in limited sizes, usually between 1 and 16 ft^3 in volume. They have more insulation than standard AC refrigerators.

Gas refrigerators are available in both LP and natural gas models. Many of them come with a conversion kit to allow use of either fuel. They come in a wide variety of sizes, usually between 2 and 22 ft^3 in volume. Gas refrigerators require direct venting to outside the house so it is easiest and least costly to locate them near exterior walls.

Ranges, Cooktops, and Microwaves

Ranges, which consist of both an oven and stove combined into a single appliance, are in nearly every single-family house in the United States. Both AC electric and gas ranges are widely available in widths 20 inches and wider, with 30 inches being the most common in single-family homes. Tiny houses often utilize ranges 20 to 24 inches wide with four stove burners on top.

Cooktops, which consist of stove burners and no oven compartment, are also commonly used in tiny houses. They may be built into a countertop or moveable, plug-in varieties. They usually consist of two to four burners.

Gas ranges and cooktops do not require dedicated venting, but many people choose to install exhaust hoods over these gas appliances. Igniter options for various models include AC electric, batteries, and matches.

Occupants who still want the option of baking or broiling, but don't want to dedicate the space necessary for ranges often choose to use an air fryer or toaster oven in conjunction with a cooktop. A limited variety of DC electric microwaves are available. Camping, boat, and trucking suppliers are your best bet for sourcing.

Dishwashers

Due to limited kitchen cabinet space most THOW don't have dishwashers in them, but appliances as narrow as 18 inches are available. Installing the rough-in plumbing for future dishwasher installation involves only a few extra pipe fittings and may be a good idea for designers to include in their plans. This would require the base cabinet next to the kitchen sink to be easily removable if an occupant ever decided to remove the cabinet and replace it with a dishwasher.

Washing Machines and Dryers

Quite a few THOW 20 feet and longer include clothes washers and dryers. Washer/dryer combination appliances are popular for space saving reasons. Both vented and ventless dryer and washer/dryer combos are sold.

Most ventless dryers are condensation dryers and require either a condensate drain or a manually emptied tray. The drying time per load is longer (usually 90 to 120 minutes), but ventless dryers use less energy and are less damaging to clothes. Ventless dryers are common in Europe, apartments built prior to the advent of the ducted dryer, and other places that limit easy installation of ducting to the outside. The smallest volume vented and ventless dryers run on 120 volts, while the larger dryers of both kinds use 240 volts. Heat pump dryers are a third option to consider and are even more energy efficient than condensation dryers. Smaller THOW often utilize small, manually operated washing machines for washing and clothes lines or drying racks for drying.

A ventless washer/dryer combo in a THOW

A portable, hand-operated washing machine

Water Heaters

A tankless, or on-demand, propane water heater installed in a THOW. This water heater model plugs into a 120 volt electrical receptacle to power the flame igniter. Models with battery powered flame igniters are also readily available.

There are two major initial decisions you must make regarding water heaters. The first is whether to use a tank water heater or a tankless (on-demand) water heater. The second is whether to select electricity or gas (LP or natural gas) as your energy source. Any combinations of these options are readily available. Generally, tankless water heaters are more energy efficient and supply unlimited durations of hot water. The drawback of an electric tankless unit is the high current it pulls when in use, usually 40 to 150 amps. As a result, tankless electric units are not practical for a THOW. The drawbacks of a gas tankless unit are the required clearances between the unit and combustible materials and the need for an exhaust vent which also must be located minimum distances from windows and other air intakes. Models that vent through sidewalls and floors are available. The issue of clearances to combustibles can be mitigated to a large extent by using non-combustible coverings in the vicinity of the water heater. Many tankless models have a minimum flowrate threshold before they kick on. This means if you open a faucet to get a trickle of hot water you might get a trickle of cold water instead. The majority of THOW use tankless water heaters.

A concern for both tank and tankless water heaters is exposure to freezing temperatures. If there is not room in a THOW for the water heater in the conditioned space, then specify an outdoor rated unit (if the THOW is not used in freezing temperatures an outdoor rated unit is probably not required, but the warranty will likely be voided). Outdoor rated on-demand units are readily available. I'm not aware of outdoor rated tank water heaters, but placing "regular" tanks outside of

A propane on-demand hot water heater exhaust vent installed in a THOW

conditioned spaces is common in warmer and temperate climates (at least up to climate zone 4C), especially in older houses built before mechanical rooms became commonplace. In colder climates an insulated enclosure is a possible solution, but even then, there will still be an energy penalty. Most electric tank water heaters run on 240 volts.

Manuals and instructions provided by the water heater manufacturer will include required clearances to combustible materials; exhaust vent clearance and placement requirements; and information on necessary pressure relief valves (PRV), drain valves, air relief valves, water and gas shutoff valves, etc.

Some manufacturers prohibit the connection of plastic plumbing piping to certain models they sell. Most all builders ignore this as plastic piping is almost exclusively used in THOW. Contact the company's technical department to see if they can expand on that prohibition; for example, maybe it's acceptable if the plastic pipe is separated from the water heater by a certain length of copper pipe. If not, this may be another instance where the manufacturer would likely void the warranty. Water heaters in THOW are usually located in the bathroom or outside storage cabinet.

Some less expensive tankless gas water heaters use a fixed rate of gas regardless of the water usage flowrate. The amount of gas is manually adjustable, but it's not practical to adjust constantly as you use different plumbing fixtures or more than one fixture at a time. I found this out the hard way. When I built our THOW, we hadn't yet bought the property we'd be moving it to. Since I was unsure if our eventual property would have an electric service or not, I decided to go with an inexpensive propane water heater. My thinking was if we did end up having grid power, I'd probably switch to a small electric tank water heater if the tankless propane one wasn't up to par. It would still be cheaper and more environmentally friendly than buying a top-of-the-line tankless propane one since electric utilities in the area produce 80% or more of their electricity from hydroelectric dams. It took quite some time to get an acceptable propane rate dialed in, but we still can't get just the right temperature of water at all the fixtures. My advice is to avoid these types of tankless water heaters and instead get one that automatically adjusts the rate of gas to maintain a constant water temperature regardless of water flowrate.

Two additional options for THOF water heaters are heat pump water heaters and domestic solar thermal hot water systems. Heat pump water heaters currently are available in few models smaller than 50 gallons so they are usually too big for THOW. The standard collector of a domestic solar hot water system is too heavy to practically use with a THOW, but smaller ones may be available.

Heating and Cooling Systems

The biggest challenge related to heating and cooling a THOF is finding equipment for such a small space. And while the physical size of the equipment may be a challenge, I'm mostly talking about the capacity of readily available units. Since most traditional homes are many times larger, there just isn't much demand for smaller heating and cooling units. In recent years European and some domestic manufacturers have expanded offerings in the United States, which is helpful. RV and boat suppliers are sometimes a good option. Oversized units turn on and off (cycle) more frequently, which reduces equipment life and increases maintenance costs. Additionally, they are more prone to large temperature differences between rooms, negatively impact humidity control, and generally cost more both upfront and to operate.

An additional challenge for heating and cooling a THOW is its potentially mobile nature. One month it may be in the beautiful Pacific Northwest and the next month parked by one of 10,000 lakes in Minnesota. Even within the same city a change in parking location and directional orientation could have significant implications. Sited on a property with northern exposure and lots of shade from trees may make a THOW comfortable in the summer. Moving it a few blocks to a cleared lot with southern exposure and its large expanse of windows facing south will increase your afternoon inside temperature significantly. In other words, shading and passive solar heating will naturally affect the small space and can be used to your advantage.

Table 2 shows heating and cooling equipment regularly used in tiny houses. The table shows whether the equipment supplies heating only, heating and cooling, and the fuel sources readily available for each type of equipment.

Equipment	Heating	Cooling	Electric (AC)	Electric (DC)	Propane	Natural Gas	Wood Product	Comments
Wall Heaters	X		X					
Baseboard Heater	X		X					Not typical in THOW due to limited wall space
Propane Heater	X				X			Only use vented models
"Mini" Gas Fireplace	X				X	X		
"Mini" Wood Stove	X						X	Can also use for cooking
Pellet Stove	X						X	Can also use for cooking
Wall/Window Unit	X+	X	X					+ Not all have built-in heaters
Air-Source Heat Pump (also known as a mini split)	X	X	X	X				Dual fuel models exist. They use propane in extreme cold temperatures when heat pumps wouldn't work or work efficiently.

Table 2: Common Heating and Cooling Equipment Options

Residential heating and cooling loads for each room and the total residence are usually calculated using the Air Conditioning Contractors of America (ACCA) Manual J procedures. Individual equipment and appliances are then selected in accordance with ACCA Manual S (see IRC Section M1401.3). Finally, ducts are sized using ACCA Manual D.

The Manual J method estimates required heating and cooling loads by taking into account outdoor temperatures, inside design temperatures, window and glass door characteristics (U-factors, SHGC values, area, exposure direction, and shading), insulation R-values, roof color, roof material, building envelope volume, air tightness, internal appliance and occupant heat loading, and more. Manual J calculations are usually completed using purchased software. Cool Calc offers a web based Manual J interface, which is ACCA approved, and a free account at https://www.coolcalc.com/. If you want to print the Manual J report and submit to a building department a small fee is required.

Loads from Manual J are the amounts of heating and cooling the building needs. Matching of individual equipment using Manual S to the loads calculated by Manual J takes into account factors like equipment efficiency, the differences between the conditions the equipment was tested at and your building design conditions, etc. So Manual S tells you the capacity of

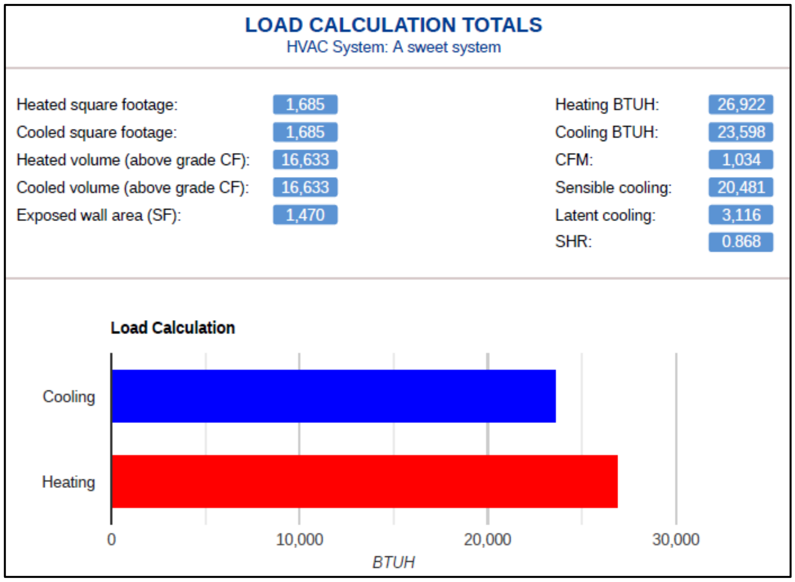


Figure 1: Excerpt from Sample Manual J Report from a 1,685 ft^2 house (from coolcalc.com)

equipment to heat and/or cool after trying to make conditions as equivalent as possible. It's not supposed to be as simple as calculating a 2,800 watt heating load and selecting a 3,000 watt heater since that's the next standard size larger than the load. But the thing is, pretty much every commonly used THOW heating and cooling option, with the exception of heat pumps, isn't going to have easily obtainable information necessary for a Manual S.

Certainly designers should use Manual J and Manual S, or more sophisticated methods, for designing a THOF system. But what method is appropriate for a THOW? Isn't the recommended room size range on a manufacturer's product data sheets good enough? You'll get various opinions depending on who you ask. In my opinion, if you know enough about the design location's climate to estimate where in the room size range you likely fall, then you'll probably be ok. In most cases, even if you perform detailed calculations to find how much heating and cooling is required, you'll end up having to pick an oversized unit because there just aren't that many small capacity options available. Throw in the movability aspect and in the end most THOW designers don't perform Manual J calculations. If it makes you more comfortable, do the Manual J and then make your mechanical engineer friends cringe by using those loads to directly select your equipment.

Table 3 summarizes the typical capacity range and costs of heating and cooling equipment frequently used in tiny houses. Typically, electrical heating equipment sizes are given in watts (W) or kilowatts (kW) while gas heating uses British Thermal Units per hour (BTU/hr). Cooling equipment capacities are usually given in BTU/hr for small units and tons of refrigeration for larger units. Central heating and air conditioning units are not included in the table since they are too large for tiny houses. Central electric furnaces are 10 kW and larger (~34,000 BTU/hr), central natural gas and liquid petroleum furnaces are 45,000 BTU/hr and larger. Standard central air conditioning units are 1.5 tons (18,000 BTU/hr) and larger.

Equipment	Capacity	Cost	Comments
Wall Heater	375 W - 4,500 W [1.3K - 15.4K BTU/hr]	$50 - $450	120 V and 240 V models available
Baseboard Heaters	500 W - 2,500 W [1.7K - 8.5K BTU/hr]	$40 - $100	120 V and 240 V models available
Propane Heater	10K - 24K BTU/hr	$300 - $800 for 10K BTU	
"Mini" Gas Fireplace	5K - 7K BTU/hr	$1,000+	
"Mini" Wood Stove	3,000 W - 5,000 W [10.3K - 17K BTU/hr]	$600 - $1,000	
Pellet Stove	10K - 30K BTU/hr	$1,000 - $4,000	
Wall/Window Unit	5K - 25K BTU/hr	$150 - $1,000	120 V and 240 V models available
Air-Source Heat Pump	9K - 36K BTU/hr	$800 - $1,500 for 9K BTU	120 V and 240 V models available

1,000 W = 3,412 BTU/hour

1 ton refrigeration = 12,000 BTU/hour

Table 3: Common Heating and Cooling Equipment Sizes and Cost

Left: THOW air-source heat pump, also known as a mini-split. This is the indoor unit (evaporator).

Middle: A mini-split outdoor unit (condenser)

Right: An electric wall heater (Cadet Com-Pak Twin Wall Heater Model #CSTC302TW) in a THOW. The heater has two heaters and two fans behind a single grill. It is a 240 volt heater rated at 3,000 watts so it pulls a maximum of 12.5 amps. Its fits in a 2x4 framed wall.

In Table 3 you may have noticed the equipment using electricity comes in both 120 volt and 240 volt models. The highest wattage models using 120 volts are usually somewhere around 1,500 watts. Producing the same wattage using 240 volts instead of 120 volts means only half as many amps are required. A 3,000 watt wall heater using 240 volts pulls a maximum of 12.5 amps. If you could find that same heater in a 120 volt version it would pull a maximum of 25 amps. When you get to the electrical section of this course you will see it is extremely useful to keep amperages low due to the standard electrical connections available for THOW.

The location of any of the equipment mentioned must be planned carefully due to the inherent limited space in a tiny house. All electric and gas heaters, fireplaces, and stoves have manufacturer required minimum distances to combustible surfaces (walls, furniture, etc.). There are ways to reduce these distances using galvanized sheet metal and/or other materials (see IRC Section M1306). Wall/window units project a considerable distance outside a THOW's exterior wall and heat pumps have an outside unit which must be mounted securely during THOW movement. Additionally, heat pump indoor units are fairly large (usually three to four feet long).

As always there are tradeoffs. Many rural properties have a lifetime supply of wood, but wood stoves take a relatively long time to heat a space. Propane heaters use fossil fuel, but make going off-grid much simpler and less expensive compared to solar. No one heating or cooling system is ideal for all circumstances.

Manual J results for my 20' long THOW located in the Pacific Northwest show a 5,050 BTU/hr (1,480 watts) total heating load and a 5,250 BTU/hr (0.4 tons) total cooling load to maintain a summer indoor temperature of 75°F and a winter indoor temperature of 70°F. Moving that same THOW to northern Minnesota and rerunning the Manual J gives a 10,500 BTU/hr (3,075 watts) heating load and a 4,050 BTU/hr (0.3 tons) cooling load. This helps quantify what we already know, a lot more heating load is needed in Minnesota than in coastal Oregon or Washington. For this specific THOW about twice as much heating load is needed. The Manual J for this simple building took about two hours to complete when entering in detailed information on windows and doors. Changing the design location took only minutes.

Manual J results for a 2018 IRC code-compliant 380 ft^2 THOF located in the same Pacific Northwest location showed a 6,300 BTU/hr (1,850 watts) heating load and a 6,300 BTU/hr (0.5 tons) cooling load to maintain the same indoor temperatures as the previous THOW modeling. Even though the THOF is over double the square footage as the THOW, the heating and cooling loads only increased by 25% and 20%, respectively. This is primarily due to the massive increase in insulation R-values required by the building code.

Let's go back to my Pacific Northwest THOW and its calculated heating load of 1,480 watts. I ended up selecting a 3,000 watt electric wall heater and opted to just open windows and use a ceiling fan for cooling purposes. I probably could have picked a heater half that size and been ok, especially given that we don't use the THOW during the winter. Much of the cooling load calculated came from heat generated by cooking appliances so an easy work around is to grill outside on the hottest days. We have substantial shade from large Douglas fir trees. In the end, there are only a few days a year it is uncomfortable in our tiny house. On a related note, most permanent housing stock in that area doesn't have any form of air conditioning either.

Looking back at Table 3, you will see typical THOW loadings are far less than the capacities of most of these "small" units.

Passive Solar

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 be oriented differently each time it is moved so keeping all walls below 15 percent might be a good compromise. On a side note, Manual J does not take into account passive solar gains when determining the heating load.

Ceiling Fans

Ceiling fans don't actually cool the air in a room, but they do make humans feel cooler by circulating it. Many THOW have one in their main living area. Select a fan that is wall-controlled or remote-controlled if installed in an area with high ceilings. Otherwise, chains on chain-controlled fans are hard to reach or get in the way if extension chains are added.

Ventilation and Exhaust

According to the IRC, ventilation is the "natural or mechanical process of supplying conditioned or unconditioned air to, or removing such air from, any space." A mechanical exhaust system removes air from a space by using mechanical means. By these definitions, exhaust systems are a subset of ventilation.

Ventilation

In THOW, open windows and natural air leakage are the main sources of ventilation. Mechanical supply ventilation systems are uncommon in THOW, but could be present in a tightly constructed THOF. If needed, whole house mechanical ventilation requirements are given in IRC M1505.4.

Kitchen and Bathroom Exhaust Systems

The IRC calls range hood exhaust systems "domestic cooking exhaust" (IRC M1503.2). The minimum intermittent exhaust rate allowed for kitchens is 100 cubic feet per minute (CFM) per IRC Table M1505.4.4. Intermittent simply means fans that are turned on and off as opposed to running continuously. Exhaust fans over electric ranges act to primarily remove odors, smoke, and grease, while fans over gas ranges also remove combustion byproducts. For both LP and natural gas these byproducts are mostly carbon dioxide and water vapor. Incomplete combustion due to an incorrect ratio of propane and air results in carbon monoxide, as well as other compounds, as additional byproducts. These combustion byproducts are why exhaust fans are more common for gas ranges than electric ranges. Most kitchen range hoods have variable fan speed settings to allow for multiple exhaust rates. Based on the typical size propane range in a THOW, an exhaust fan with a maximum rate of 320 CFM or less should be sufficient. If you select a fan rated for more than 400 CFM check IRC Section M1503.6 to see if dedicated makeup air is required.

Using an oversized kitchen fan will certainly remove combustion byproducts faster, but it comes with an energy penalty. A typical 20' long THOW has a volume of around 1,800 ft^3, so running a 100 CFM fan for 18 minutes exhausts the equivalent of its entire interior air volume. The exhausted conditioned air is replaced by unconditioned makeup air from the outdoors which then requires heating or cooling to reach the desired indoor temperature.

Since my wife and I only live in our THOW during the summer and fall months, I chose not to install a range hood even though we have a propane range. We open a window or two each time we cook and have a carbon monoxide/natural gas/propane alarm that plugs in and has an emergency battery backup. If we lived in it year-round I would have definitely installed a kitchen exhaust system.


Left: A kitchen range hood in a THOW

Right: A Broan through-wall fan used primarily for bathrooms (from manufacturer's website)

According to the IRC, 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. So, by code you have two options: a window or a mechanical exhaust fan.

50 CFM bathroom exhaust fans are the smallest standard sized fans available and the lowest intermittent rate allowed by the IRC. They should be adequate for bathrooms 375 ft^3 or smaller, which is most tiny house bathrooms. Walls and ceilings in THOW have limited room for fan ducts, so through-wall fans are a possible solution. Due to limited room in THOW walls and ceilings for fan ducts, through-wall fans are a possible solution. Using an oversized bath fan will certainly remove moisture laden air faster, but just like kitchen exhaust systems, it comes with an energy penalty.

Since we only live in our THOW during warmer months, I chose not to install a bathroom exhaust fan and instead put in a 2' by 2' slider window, which provides 2 ft^2 of ventilation when fully open. It works, but I imagine if we lived in it year round I'd want mechanical exhausting to avoid having to open the bathroom window when it's cold outside. I've also noticed greater than normal condensation on the toilet tank. This is likely due to a combination of very cold well water and elevated humidity levels in the bathroom after showering.

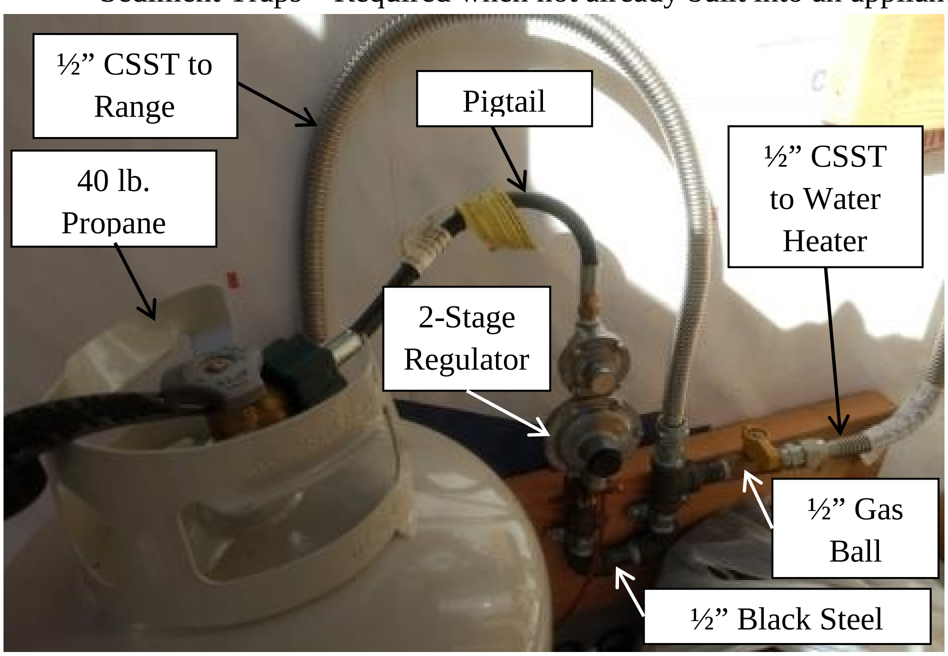
Exhaust Openings

Care must be taken when locating all exhaust openings (for gas appliances, clothes dryers, kitchen/bath exhausts) to keep them far enough away from windows, doors, and mechanical air intake openings. Refer to appliance installation instructions and IRC M1504.3 for more details.

Propane Systems

The major components of propane systems are tanks, regulators, piping/tubing, shutoff valves, and sediment traps.

- Tanks – Standard propane tank sizes are 20 pounds (holds 4.5 gallons and costs about $40), 40 pounds (9 gallons, ~ $90), and 100 pounds (23 gallons, ~ $140).
- Regulators – Before selecting a regulator you need to know the inlet pressure requirements of all proposed or installed appliances. Our THOW water heater required 14" of water column (wc) pressure or less and our range needed between 6" and 14" wc. I selected a regulator with an outlet pressure of 11" wc.
- Piping/Tubing – Black steel pipe and copper tubing are the most commonly used materials for propane conveyance in THOW. Corrugated Stainless Steel Tubing (CSST) is often used just before an appliance due to its flexible nature (see IRC Section G2413).
- Shutoff Valves – A shutoff valve is required within 6 feet of each appliance (see IRC Section G2420).
- Sediment Traps – Required when not already built into an appliance (see IRC G2419.4).



A portion of a propane system in a THOW

Sediment trap for propane water heater

Propane pipe bonding

Most THOW store their propane tank or tanks in an exterior storage cabinet on the front or back of the trailer. Some THOW use the plastic propane covers common to RV travel trailers. Multiple propane tanks allow for uninterrupted service and make refilling a tank less time urgent. Both manual and automatic changeover valves are sold to switch from one tank to the other.

If a tiny house has any fuel-fired appliances it needs to have a carbon monoxide alarm (see IRC R315.2.1). Our tiny house has both a propane water heater and a propane range with four stovetop burners and an oven. We cook with the range one to two meals a day. We have to refill our 40 pound propane tank about every six weeks. At $2.00 per gallon it costs about $18 to fill.

Plumbing

This plumbing section discusses four subsystems of a residential plumbing system as defined by the IRC: potable water service, potable water distribution, drain-waste-vent (DWV), and building sewer. Water distribution and DWV piping are located within a building while water service and building sewer piping are located outside a building and within the limits of the privately owned property. It is necessary to differentiate between these subsystems because the building code requirements are different inside and outside of buildings. Before going in-depth about these four subsystems let's talk briefly about plumbing fixtures.

Plumbing Fixtures

THOW often have a bathroom sink, shower, toilet, and kitchen sink. Some have a bathtub instead of a shower. A few have outdoor showers. Others have a kitchen sink, but no separate bathroom sink. Most people prefer a two-bowl kitchen sink for handwashing dishes since dishwashers are fairly uncommon.

The most common materials used for THOW plumbing fixtures are:

- Sinks – Stainless steel, porcelain, and composite are most common
- Showers – Prefabricated fiberglass or acrylic shower units dominate
- Bathtubs – Porcelain enameled steel, acrylic, and fiberglass are used for their light weight
- Shower/Bathtub Surrounds (walls covering above tub or shower basin) – Prefabricated fiberglass or acrylic shower units, acrylic sheets, corrugated or non-corrugated galvanized steel, aluminum sheets, or stainless steel sheets are all used


Left: Stainless steel drop-in sink in a THOW. The backsplash is an acrylic sheet painted on its backside.

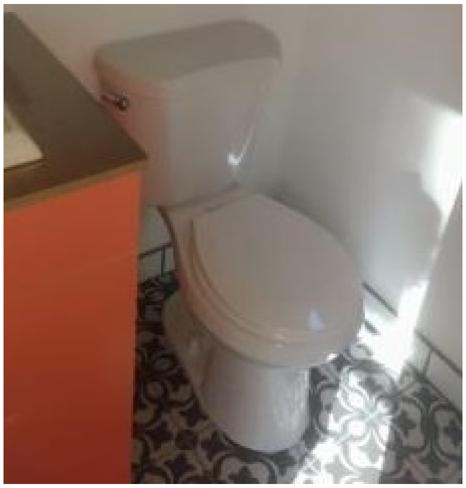
Right: Porcelain farmhouse style sink in a THOW


Left: Corrugated galvanized steel shower surround in a THOW

Right: Porcelain enameled steel bathtub with aluminum tub surround in a THOW

Both traditional flush toilets and composting toilets are common in tiny houses. Of course, flush toilets need a water supply and somewhere to discharge wastewater such as a sewer connection or septic tank. Basic flush toilets start at around $100.

Composting toilets aren't flushed with water. The user covers the new waste with bulking material such as sawdust, sphagnum peat moss, or coconut fibers. Alternately, many models have a handle the user (or an electronic motor) turns to mix the existing bulking material with the new waste. The liquid portion of waste is either evaporated through the ventilation system or diverted to a separate container. The urine diverting style toilets require removal and disposal of urine on a regular basis, which means a method for properly disposing it is needed. Oxygen supplied by the ventilation system keeps the bacteria breaking down the waste doing so in aerobic conditions. Usually, a minimal amount of electricity is needed to power the vent fan. Depending on use, the composted solid waste and bulking materials must be removed from the compost chamber every few weeks or months. While a composting toilet may eliminate the need for black water disposal, a gray water disposal method is still needed for the other plumbing fixtures. This course's wastewater section will discuss black and gray water in more detail. Composting toilets cost anywhere from $900 to several thousand dollars.



Left: Wall-Mounted flush toilet in a THOW

Middle: Floor-Mounted flush toilet in a THOW

Right: Composting toilet without urine diversion (Sun-Mar Excel). This model costs around $1,800. (Credit: RDavey1314/Wikimedia Commons/CC-BY-SA3.0)

Water Supply System

Potable Water Service

A water service connects a building to its drinking water source. Drinking water sources may include municipal water systems, wells, rainwater harvesting storage tanks, etc. The IRC requires a minimum water service pipe size of 3/4" diameter and lists 18 different acceptable materials (see IRC Table P2906.4). Of these, the most commonly used materials for new residential water services are chlorinated polyvinyl chloride (CPVC) pipe, copper tubing, high-density polyethylene pipe (HDPE), and polyvinyl chlorine (PVC) pipe. The code also requires all buried water service piping to have a minimum working pressure rating of 160 psi at 73°F. This is important to know because piping with various wall thicknesses is sold for other plumbing purposes. Examples of this include HDPE irrigation pipe (sometimes rated below 50 psi) and DWV PVC pipe intended for non-pressure systems. All drinking water system components must meet the NSF 61 standard.

CPVC piping used in a THOW. The metal nail guards provide protection from accidental puncturing of the pipes when the wall covering is installed.

Copper piping used in a THOW. This is the only THOW I've seen that used copper. The builder used push-to-connect fittings as opposed to soldering joints and fittings.

Potable Water Distribution

Municipal water providers often refer to the large diameter water mains throughout their service areas as water distribution systems; however, these systems are totally different than the systems referred to by the same name in the IRC. A water distribution system as defined by the IRC is the potable water system located within a building. Typically, the smallest pipe size used is 3/8" diameter and the IRC lists 12 different acceptable materials (see IRC Table P2906.5). Of these, the most commonly used materials for new water distribution piping are CPVC pipe, copper pipe or tubing, and cross-linked polyethylene (PEX) tubing.

Commonly used water distribution piping comes in two different sizing conventions: copper tube size (CTS) and iron pipe size (IPS). CPVC and copper use the CTS convention. Galvanized pipe, a very common water pipe material in the past, uses the IPS convention. PEX and polyethylene pipe are commonly sold in both conventions. CTS is outside diameter controlled, meaning the outside diameter stays the same while the inside diameter changes as wall thickness changes to facilitate smaller or greater pipe pressure ratings. This means a 1/2" CPVC pipe in a house has a nominal 1/2" inside diameter, but it is really only about 0.489" in diameter. IPS is inside diameter controlled (most of the time), meaning the inside diameter stays constant while the outside diameter increases as wall thickness increases or decreases. 1" diameter galvanized steel has an actual 1" inside diameter.

PVC is not one of the 12 acceptable materials for inside buildings because of its greater expansion and pressure capacity derating at higher temperatures compared to other materials. Codes do not even allow cold water pipes inside residences to use PVC pipe (likely to avoid the potential of mistakenly connecting cold water piping to hot water piping sometime in the future). The code requires water distribution piping to have a minimum pressure rating of 100 psi at 180°F.

According to the IRC, the way to size water distribution piping is to:

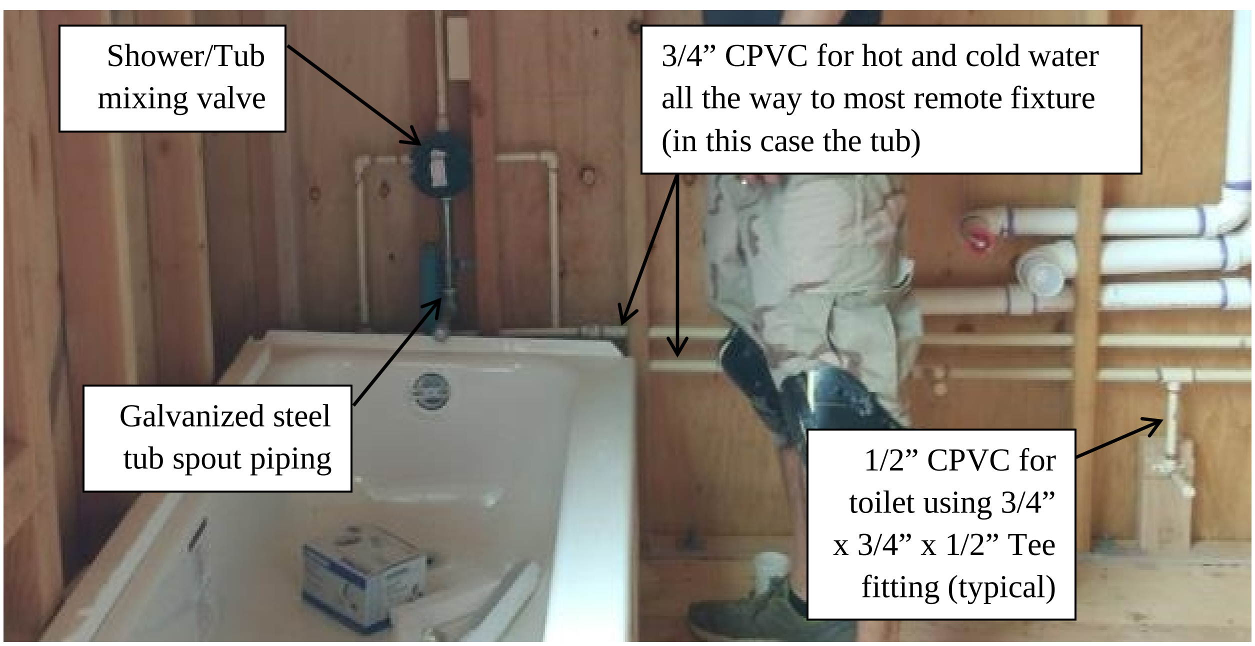
1. Layout your proposed piping paths between plumbing fixtures throughout the building.
2. Find the water supply fixture unit (w.s.f.u.) values for each fixture or fixture group using IRC Table P2903.6.
3. For each pipe segment sum the w.s.f.u. values that are supplied by that pipe segment.
4. Convert the w.s.f.u. values for each pipe segment into a gallon per minute demand using IRC Table P2903.6(1).
5. Find out the minimal available water pressure at the water service connection to the water supply (typically obtained from the water supplier or when using a well the pressure tank pressure setting).
6. Determine the "most hydraulically remote" fixture, as defined by IRC Appendix P, and lookup its minimum flowrate and minimum pressure in IRC Table P2903.1.
7. Determine pipe diameters using the steps presented in IRC Appendix P or "design methods conforming to acceptable engineering practice" approved by the building official to ensure the minimum pressure at the "most hydraulically remote" fixture is maintained. Acceptable methods must take into account friction losses along pipe

lengths; minor friction losses due to meters, valves, fittings, etc; and static pressure loss due to elevation change.

The above procedure is certainly necessary for large buildings, but tiny houses at maximum consist of a bathroom, kitchen, and laundry facilities. Additionally, when a THOW is moved around, the minimum available water pressure changes from location to location. I usually recommend the following for a THOW:

1. Use 3/4" diameter water distribution pipe throughout the entire THOW for both cold and hot water.
2. Use 1/2" diameter pipe to supply each individual plumbing fixture except use 3/4" diameter pipe for connections to hose bibbs.

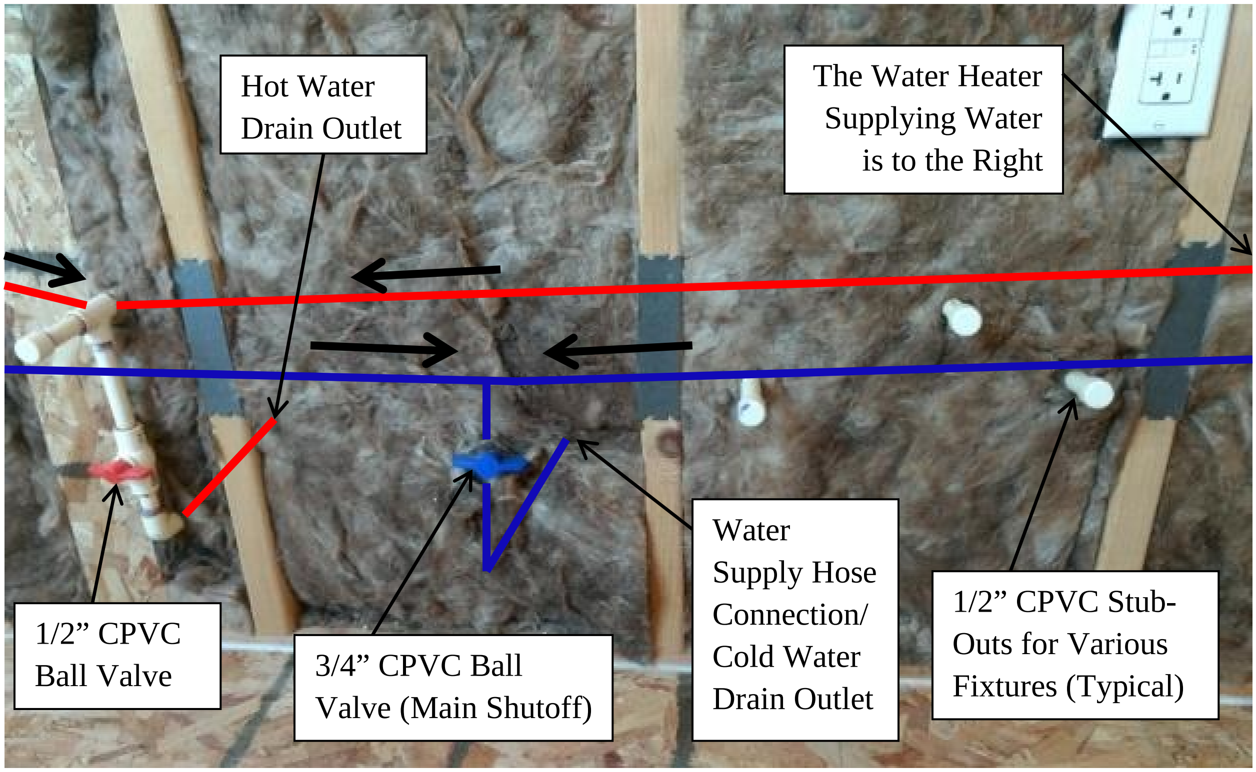
Using primarily 3/4" diameter pipe results in higher pressures at plumbing fixtures, but wastes more hot water and increases wait times for hot water to reach plumbing fixtures. Tiny houses with limited water heating capacities should limit the amount of 3/4" diameter hot water piping and/or place the water heater close to the bathroom.



Bathroom rough-in plumbing in a THOW

Most tub spouts require connection to either a galvanize steel or copper pipe as CVPC and PEX do not provide the required rigidity if someone grasps the spout to help them get out of the tub.

Tiny houses not used in the winter may benefit from sloping the water supply piping to allow for draining and winterization (see photo below). Any remnants of water remaining in the pipes will have room to expand if frozen and will not cause damage to pipes. Alternatively, some designs don't rely on sloped pipes and gravity. Instead, they include a fitting for connecting an air compressor to force water out of the supply piping before the first freeze.



The hot water and cold water pipes each slope to a low point in this seasonally used THOW. The 3/4" cold water ball valve is normally open while the 1/2" hot water ball valve is normally closed. Each autumn the water supply is turned off, the hose is disconnected, and the hot water valve is opened. Both hot and cold water drain out by gravity onto the ground. Both valves are then closed for the winter.

Testing

After rough-in is completed, water supply systems need testing. If tested by water, the system should be tested at a pressure not less than the working pressure of the system. If tested by air, use a pressure of at least 50 psi. The duration of both the water and air pressure tests is 15 minutes or longer. In general plastic piping may not be tested by air with the exception of some PEX piping (if allowed by the manufacturer). Just as with any residential dwelling, install a main shutoff valve to allow isolation of the building piping when repairs are necessary. Connect the water supply (usually a hose for a THOW) and expel air from the system by opening all exterior hose bibbs or other fixtures. After all air is expelled turn off the hose bibb valve, attach a pressure gauge to it, and then reopen the hose bibb valve to allow water to enter the gauge. Finally, close the main shutoff valve to isolate the test area. The final inspection may consist of only a visual inspection to look for leaks after all interior finishes are completed and the final connections are made to fixtures using braided supply connectors. Completing another pressure test is recommended, and in some municipalities may be required, to ensure nails or screws did not puncture pipes and all final connections are watertight. Refer to IRC P2503.7 and P2503.9 for testing and gauge requirements.

Sizing Water Heaters

Selecting a tankless/on-demand water heater requires knowing two inputs: hot water flow demand and temperature rise. Temperature rise is how much the incoming cold water must be heated to reach the desired hot water temperature.

Procedures for sizing tank water heaters are different and include considerations like tank volume, first hour delivery flowrate, and recovery rate.

EXAMPLE:

A THOW is being designed with off-grid and mobility considerations in mind. As a result, an on-demand propane water heater will be used. The occupants anticipate using one or two plumbing fixtures at any given time (kitchen sink, bathroom sink, or shower). Based on occupant input, the hot water heater will be set to 120°F. The THOW will spend a portion of each summer traveling around the country. During these travels, a water tank exposed to the air will be the primary water source. During the late spring and early fall the THOW will be parked at a rural property and connected to a well so the water tank will not be utilized. It is anticipated the coldest temperature the water storage tank will be exposed to when hot water is desired is 60°F. The ground water temperature at the property is no colder than 53°F during the applicable autumn and spring periods (interactive soil temperature maps are available online). The water heater will be installed in an external, unconditioned storage cabinet so it is expected to be subject to occasional freezing temperatures. The engineer is looking at Rheem water heaters as a potential option. What models would work for this application?

SOLUTION:

Two pieces of information are necessary to properly size most on-demand hot water heaters: hot water flow demand and temperature rise. Using IRC Table P2903.6 we find the hot water w.s.f.u. values for a kitchen sink, bathroom sink, and shower are 1.0, 0.5, and 1.0, respectively. The controlling w.s.f.u. value of 2.0 (kitchen sink plus shower) converts to a 5.0 gallons per minute (gpm) demand using IRC Table P2903.6(1). The 5.0 gpm value is too high for this fixture combination because from IRC Table P2903.2 we know that new sink and new shower head maximum flow rates are 2.2 gpm and 2.5 gpm, respectively (for w.s.f.u. values 4 and lower I recommend simply using IRC Table P2903.2 values instead of converting from w.s.f.u. values to gpm). As a result, we should use 4.7 gpm as the hot water flow demand. The largest temperature rise required for this scenario is 67°F (120°F minus 53°F).

Most on-demand water heater manufacturers provide sizing charts or tables similar to the one shown in Figure 2. According to the sizing chart, a 4.7 gpm demand requiring a 67°F temperature rise can be met using either of the two highlighted models in this water heater line. Both of these highlighted models are available in outdoor rated versions according to their product sheet.

	Temperature Rise (° F)								
Model Number	35°	45°	50°	60°	67°	70°	80°	90°	100°
RTGH-95 Water Flow (GPM)	9.5	8.5	7.7	6.4	5.7	5.5	4.8	4.3	3.8
RTGH-90 Water Flow (GPM)	9.0	7.7	6.9	5.8	5.2	4.9	4.3	3.8	3.5
RTGH-84 Water Flow (GPM)	8.4	6.7	6.0	5.0	4.6	4.3	3.8	3.3	3.0
RTGH-68 Water Flow (GPM)	6.6	5.1	4.6	3.8	3.4	3.3	2.9	2.6	2.3

Above estimates are for sizing purposes only.

Figure 2: Sizing Table for Rheem Prestige RTGH On-Demand Water Heaters (from rheem.com)

Wastewater

Drain-Waste-Vent (DWV)

A DWV system is the piping and fittings located within a building which are responsible for removing black and gray water from fixtures. Most states classify wastewater from toilets and kitchen sinks with garbage disposals as black water and wastewater from showers, bathtubs, bathroom sinks, kitchen sinks without garbage disposals, and laundry appliances as gray water. The largest difference between states is usually how they classify kitchen sink and dishwasher wastes. The drain portion of the system removes black and gray water while the vent portion allows air to enter the system which aids in faster draining. The presence of air in the drain system also helps prevent the siphoning of water from fixture traps so sewer odors stay isolated in the DWV system.

In residential applications DWV piping is between 1¼” and 4” diameter. The IRC lists different acceptable materials (see IRC Tables P3002.1(1) and P3002.1(2)) for above-ground and underground applications. Of these, the two most commonly used materials for new residential (and tiny house) DWV systems are acrylonitrile butadiene styrene (ABS) and PVC. Both are acceptable for above-ground and underground applications. Schedule 40, DR 22, and DR 24 ABS and PVC piping in IPS sizes are allowed for DWV applications. Dimension Ratio (DR) is the average outside pipe diameter divided by the minimum pipe wall thickness. Schedule 40 has the thickest pipe walls while DR 24 has the thinnest pipe walls. ABS dominates in some areas of the country, while PVC rules other places. Both are available in many regions. You can usually determine the most common material in your area by walking down the plumbing aisles of a store and seeing which material has the greater variety of 3” and 4” DWV fittings.

An ABS drain pipe under a THOW

PVC drain and vent pipes under a THOW

Every plumbing fixture is required to have its own trap. Additionally, to avoid clogging, double trapping a fixture is prohibited. Double bowl kitchen sinks may have a separate trap for each bowl or both bowls may share a single trap. Fixtures with integral (built-in) traps, like toilets, should only use their integral trap. Figure 3 shows minimum trap sizing for common fixtures.

TABLE P3201.7
SIZE OF TRAPS FOR PLUMBING FIXTURES

PLUMBING FIXTURE	TRAP SIZE MINIMUM (inches)
Bathtub (with or without shower head and/or whirlpool attachments)	1 1/2
Bidet	1 1/4
Clothes washer standpipe	2
Dishwasher (on separate trap)	1 1/2
Floor drain	2
Kitchen sink (one or two traps, with or without dishwasher and food waste disposer)	1 1/2
Laundry tub (one or more compartments)	1 1/2
Lavatory	1 1/4
Shower (based on the total flow rate through showerheads and bodysprays) Flow rate: 5.7 gpm and less More than 5.7 gpm up to 12.3 gpm More than 12.3 gpm up to 25.8 gpm More than 25.8 gpm up to 55.6 gpm	 1 1/2 2 3 4

For SI: 1 inch = 25.4 mm, 1 gallon per minute = 3.785 L/m.

Figure 3: IRC Table P3201.7 (from 2018 IRC)

Isometric drawings are usually included on plumbing plans to better illustrate the overall configuration of DWV systems. Two typical bathroom DWV isometric drawings are shown in Figure 4. In Figure 3 "LAV" stands for lavatory (sink) while "WC" is an acronym for water closet (toilet).

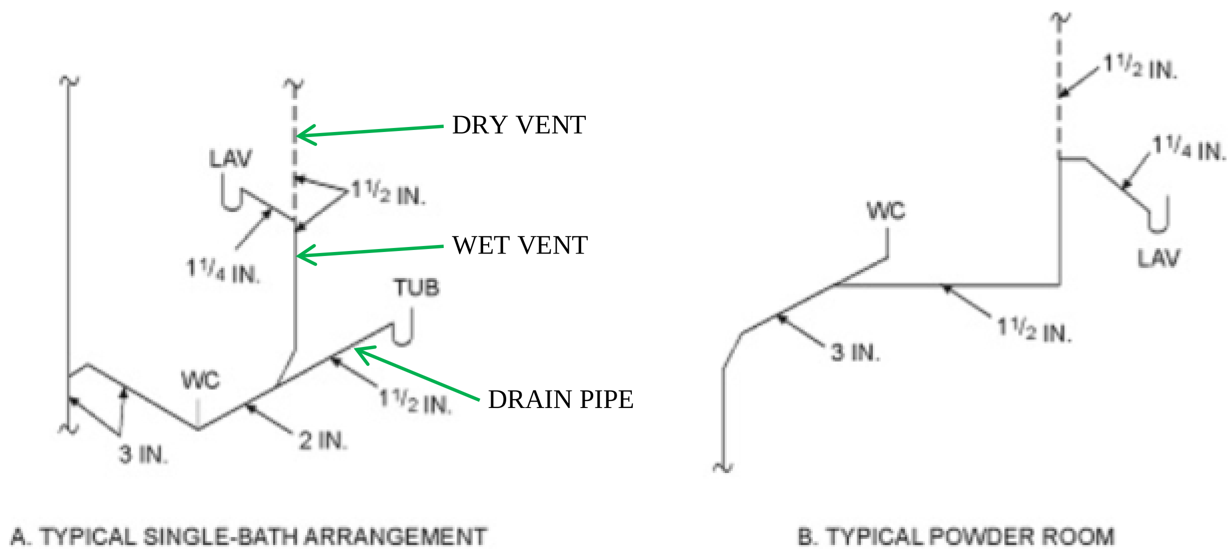


Figure 4: Two typical bathroom DWV isometric drawings (from 2018 IRC Appendix N)

There are two ways to provide air, or venting, to a given drain pipe. The first type is a "dry vent" where only air is present in the pipe (the pipe serves only as a vent pipe). The second type is a "wet vent" where both air and wastewater are present (the pipe serves as both a drain pipe and a vent pipe). Figure 4 labels one example of a dry vent and one example of a wet vent. The wet vent in Figure 4 serves as both a drain for the lavatory and a vent for the tub.

Plumbing codes give the maximum allowable distance from each fixture trap (specifically the weir of the trap) to its vent fitting. The allowable distance increases as the drain pipe trap diameter increases. IRC Table P3105.1 provides these maximum distances.

Vent piping may extend through the roof or a building sidewall. In most instances roof penetrating vents are required to extend the greater of 6" above the roof or 6" above the anticipated snow level on the roof. Due to height restrictions related to transportation of THOW sidewall vents are often the vent type of choice. Be careful not to locate them too close to windows or air intakes, though it is very difficult to meet the IRC P3103.5 distance requirements to such openings. You may notice neither of the two photos below meet the code requirements.

Left: Copper vent piping through a THOW sidewall. Copper is code approved, but uncommon due to cost.

Right: PVC vent piping (painted black) through a THOW sidewall

There are many different venting configurations allowed by building codes. Quite a few are irrelevant to tiny houses since there are so few plumbing fixtures in a tiny house. Additionally, there are quite a few nuances to the exact configuration, distances between fixtures, and sizing of vent piping which are not covered in this course; however, an example THOW DWV system is presented at the end of this section.

Sometimes the physical location of a plumbing fixture makes venting the fixture out through the roof or a sidewall very difficult. In these instances the use of an air admittance valve (AAV) may be warranted. An AAV is a small device designed to allow air into a vent system when necessary, but keeps air and associated odors from escaping. Many, but not all building codes or municipalities allow AAV installation. IRC Section P3114 covers where and how they may be used. The IRC requires each plumbing system to have not less than one vent extending to the outdoors. This means the exclusive source of venting for a plumbing system cannot be AAVs.

THOW trailers create two potential complications for DWV systems. Axle(s) are located at a lower elevation than the main trailer framing and may impede the running of drain lines from one end of the trailer to the other end. There are at least three obvious solutions to this complication:

1. Locate all plumbing on one side of the axle(s).
2. Run plumbing under the axle(s) and accept less clearance between the ground and plumbing.
3. Use more than one drain discharge location. For example, if the kitchen is located at the front of the trailer and the bathroom at the back, have a separate drain discharge wastewater from each room.

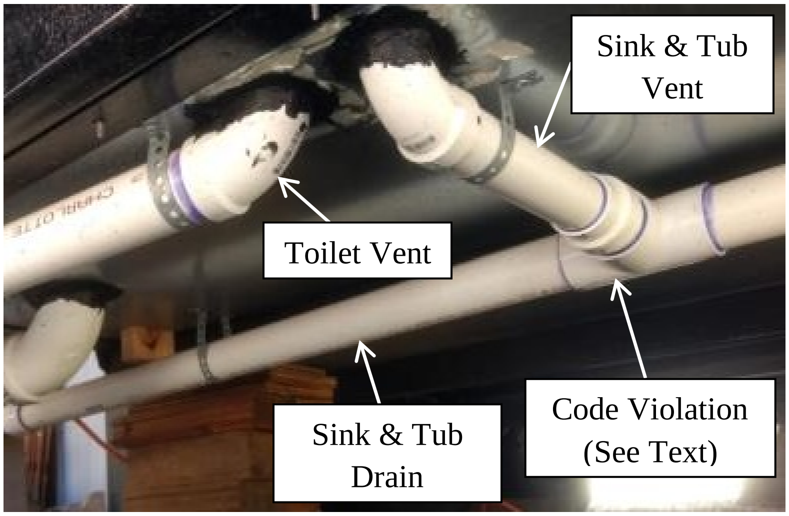
One of the benefits of solution #3 is it can be easily expanded to include three separate discharge locations: a black water discharge for the toilet, a gray water discharge for the remainder of the bathroom, and a gray water discharge for the kitchen. This provides the opportunity to use the gray water effluent for re-use purposes and reduces the volume of black water treatment needed since the two waste streams aren't mixed. The negative for highly mobile THOW is the need for additional sewer hoses to transport wastewater from multiple discharge points.

The second potential complication arises due to the location of major trailer structural members. In a typical house the drain pipes from sinks and bathtubs run through penetrations in the bottom plate of wall framing. Sinks are plumbed this way because the vent piping is also located in the wall, which makes for an easy connection of the two pipes. The reason for bathtubs is slightly different. Because the tub's overflow drain pipe is located in the wall it is easy to connect the primary tub drain to the overflow drain with a tee connection.

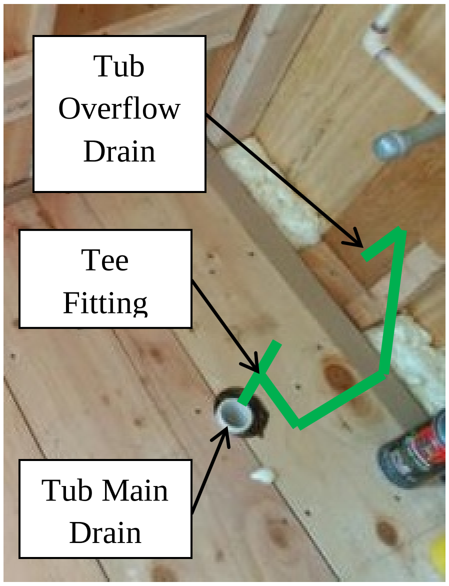
If these plumbing fixtures are located along THOW exterior walls, the drain lines can't follow the typical path through the bottom of the wall plate without drilling a large hole through the trailer's main perimeter structural member. Any such hole would severely weaken the trailer, especially on the left and right sides. Don't do it! Potential workarounds to this issue include:

Drain pipe (left) and two vent pipes (middle, right) located inside the bathroom vanity of a THOW.

1. Place sinks and tubs along interior walls, first making sure the trailer axle isn't directly below the drain location.
2. Connect sink drain and vent pipes inside of vanities and base cabinets instead of walls which allows drains to avoid hitting the trailer structural members (see photos this page).
3. Route the bathtub main drain vertically through the floor and run the tub overflow drain towards the main drain using multiple fittings. Connect the overflow drain to the main drain using a tee fitting (see photo next page).



The DWV system directly below the bathroom vanity shown in the above photo. Note the trailer's structural members (upper left corner of photo in black) that the pipe penetrations avoid.



Bathtub main drain and future overflow drain (green lines) configured to avoid making a penetration through the trailer perimeter structure member

The photo on the previous page of the DWV system under the trailer has an intentional code violation. Dry vent pipes are supposed to be connected to drain pipes or wet vents "above the centerline", meaning at a 45° or greater angle from horizontal. Connections as lesser angles are more prone to having the air path temporarily obstructed when wastewater is flowing in the drain pipe. While this greater rotation certainly could be done, it would dramatically reduce the clearance between the ground and drain pipe. As installed, the intersection of drain and vent pipe has a greater potential for clogging so a cleanout was installed upstream of this intersection to allow easy access for cleaning out any clogs or obstructions.

The bathtub main and overflow drain connection are not visible once the tub is installed so the piping is drawn in on the photo on this page. A circuitous configuration is shown because the shape of the hollow underneath cavities of a tub often prevents a more straight-line route.

EXAMPLE:

Figure 5 shows the isometric drawings of proposed DWV systems for a THOW. Determine the IRC required sizing of all fixture traps, drain pipes, and vent pipes. The kitchen group consists of a kitchen sink only (without garbage disposal). There is no dishwasher, but water supply lines have been roughed in to allow for adding a dishwasher in the future.

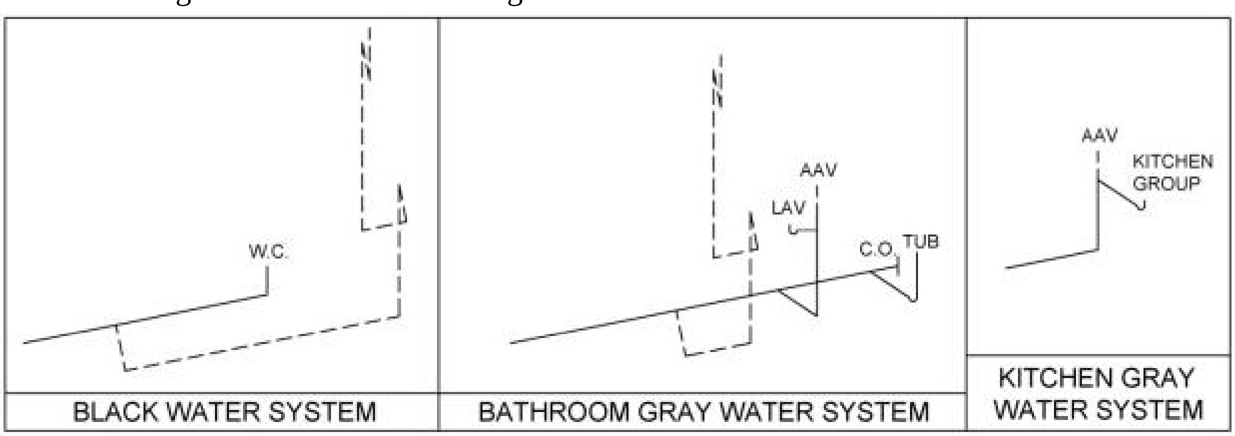


Figure 5: DWV Sizing Example Isometric Layout

SOLUTION:
IRC Table P3201.7 (provided earlier in the course text) gives the following minimum diameter trap sizes: 1½" for tubs, 1¼" for lavatories (sinks), 1½" for kitchen groups. Water closets (toilets) have an integral trap built into them. The IRC assigns a drainage fixture unit (d.f.u.) value for each plumbing fixture in IRC Table P3004.1.

TYPE OF FIXTURE OR GROUP OF FIXTURES	DRAINAGE FIXTURE UNIT VALUE (d.f.u.)
Bathtub (with or without a shower head or whirlpool attachments)	2
Clothes washer standpipe	2
Dishwasher	2
Kitchen sink	2
Lavatory	1
Shower stall	2
Water closet (1.6 gallons per flush)	3
Full-bath group with bathtub (with 1.6 gallon per flush water closet, and with or without shower head and/or whirlpool attachment on the bathtub or shower stall)	5
Half-bath group (1.6 gallon per flush water closet plus lavatory)	4
Kitchen group (dishwasher and sink with or without food-waste disposer)	2

Figure 6: Partial Reproduction of IRC Table P3004.1 (from 2018 IRC)

Size drain pipes based on their drainage fixture unit (d.f.u) loads. The size of drainage pipe may not be reduced in size in the direction of wastewater flow. The following drain pipe sizing procedure is copied verbatim from IRC P3005.4.

1. Draw an isometric layout or riser diagram denoting fixtures on the layout.
2. Assign d.f.u. values to each fixture group plus individual fixtures using Table P3004.1.
3. Starting with the top floor or most remote fixtures, work downstream towards the building drain accumulating d.f.u. values for fixture groups plus individual fixtures for each branch. Where multiple bath groups are being added, use the reduced d.f.u. values in Table P3004.1, which take into account probability factors of simultaneous use.
4. Size branches and stacks by equating the assigned d.f.u values to pipe sizes shown in Table P3005.4.1.
5. Determine the pipe diameter and slope of the building drain and building sewer based on the accumulated d.f.u. values, using Table P3005.4.2.

The black water system consists of a single toilet served by a horizontal fixture branch. IRC Table P3004.1 shows a toilet (water closet) discharges 3 d.f.u. Table P3005.4.1, shown below, states a 1½" pipe horizontal fixture branch can handle 3 d.f.u.; however, footnote b states water closets are prohibited from connecting to all pipes smaller than 3" diameter. As a result, a 3" drain pipe is required. Table P3005.4.2, also provided below, shows a 3" pipe carrying 3 d.f.u. can be installed a minimum slope of 1/8 inch per foot.

TABLE P3005.4.1
MAXIMUM FIXTURE UNITS ALLOWED TO BE CONNECTED TO BRANCHES AND STACKS

NOMINAL PIPE SIZE (inches)	ANY HORIZONTAL FIXTURE BRANCH	ANY ONE VERTICAL STACK OR DRAIN
1¼[a, b]	—	—
1½[b]	3	4
2[b]	6	10
2½[b]	12	20
3	20	48
4	160	240

For SI: 1 inch = 25.4 mm.

a. 1¼-inch pipe size limited to a single-fixture drain. See Table P3201.7.
b. Water closets prohibited.

Figure 7: IRC Table P3005.4.1 (from 2018 IRC)

TABLE P3005.4.2
MAXIMUM NUMBER OF FIXTURE UNITS ALLOWED TO BE CONNECTED TO THE BUILDING DRAIN, BUILDING DRAIN BRANCHES OR THE BUILDING SEWER

DIAMETER OF PIPE (inches)	SLOPE PER FOOT		
	1/8 inch	1/4 inch	1/2 inch
1½[a, b]	—	Note a	Note a
2[b]	—	21	27
2½[b]	—	24	31
3	36	42	50
4	180	216	250

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

a. 1½-inch pipe size limited to a building drain branch serving not more than two waste fixtures, or not more than one waste fixture if serving a pumped discharge fixture or food waste disposer discharge.
b. No water closets.

Figure 8: IRC Table P3005.4.2 (from 2018 IRC)

The bathroom gray water system consists of two fixtures. IRC Table P3004.1 shows a lavatory discharges 1 d.f.u. and a tub 2 d.f.u. The tub is the most remote fixture so size that drain pipe first. Table P3005.4.1 shows a 1½" horizontal branch pipe can handle the 2 d.f.u. from the tub, which matches the size of the tub trap. The 1¼" lavatory trap may connect to a 1¼" pipe. Once the lavatory drain joins the flow from the tub, the total flow is 3 d.f.u. Table P3005.4.1 shows a 1½" horizontal branch pipe can handle this combined flow. The pipe is upsized to 2" for reasons explained during the discussion on vent piping. Based on Table P3005.4.2, all of the 1½" and 2" pipe in this gray water system must be installed at a minimum slope of 1/4 inch per foot. The same minimum slope applies to the 1¼" pipe.

The kitchen gray water system consists of one kitchen group. IRC Table P3004.1 shows a kitchen group discharges 2 d.f.u. (the same as a kitchen sink by itself). Table P3005.4.1 shows a 1½" horizontal pipe can handle the 2 d.f.u. from the kitchen group. For the sake of keeping the discharge of this gray water system the same size as the first gray water system, which will ease connecting the two with site utilities, a 2" pipe is selected instead. Based on Table P3005.4.2, the 2" pipe in this gray water system should be installed at a minimum slope of 1/4 inch per foot.

Now that the d.f.u. values and drain pipe sizes have been determined we can move on to sizing the vent piping. The minimum vent pipe size is 1¼" diameter. Also, an individual vent cannot be less than one-half the diameter of the drain served (see IRC P3113.1). Additionally, there are various tables in the IRC for sizing different types of vent pipes.

The black water system consists of one fixture only so its vent is an individual vent. Some plumbing codes in the United States require a 1½" vent in this situation and others require a 2" vent. IRC P3113.1 allows for a 1½" vent, which is half the size of the 3" drain pipe. Due to the intentional code violation related to the rotation of the vent pipe/drain pipe connection fitting under the trailer (mentioned in a photo and in the text just prior to this sizing example, but also present in this black water system) the vent pipe sizing is increased to 2" to hopefully maintain the air path.

The bathroom gray water system consists of two vents: an AAV for the lavatory and an individual vent for the tub. The largest drain pipe in the system is 2". One half of a 2" drain pipe is 1", but that is less than the minimum vent pipe size of 1¼" diameter. Instead of a 1¼" vent pipe a 1½" vent is chosen to try and mitigate potential issues with two IRC code provisions that were not adhered to. As mentioned previously, dry vent pipes are supposed to be connected to drain pipes or wet vents 45° or greater angle from horizontal. Also, except for toilets, the vent pipe connection to a fixture drain (in this case the tub drain) is prohibited from being below the weir trap of that fixture. Both code provisions are given to help maintain an unobstructed air path when wastewater is flowing in the drain pipe. To help maintain this air path both the drain and vent pipes are upsized one standard pipe diameter from the code minimum.

The kitchen gray water system consists of a 1½" or 2" drain pipe. States and individual inspectors may disagree on whether the sink and future dishwasher are one or two fixtures. I support the single-fixture side of the debate, mainly because they share a common trap. In my opinion they could not share a trap if they are separate fixtures, as this is not one of the listed code exceptions. Additionally, the sink is rarely used simultaneously when the dishwasher is draining. Depending on interpretation, the vent for this system should be sized as an individual or common vent. Sizing as an individual vent requires a 1¼" diameter vent pipe. One half of a 2" drain pipe is 1", but that is less than the minimum vent pipe size of 1¼" diameter. It should be noted the use of an AAV in this application is an IRC code violation since there is no vent extending to the outdoors for this plumbing system. Since the kitchen sink is against a load bearing wall and has a window spreading beyond the horizontal extends of both sides of the sink base cabinet it was decided to use an AAV instead of drilling large diameter holes through multiple load bearing studs to allow for an outdoor vent.

Figure 9 shows the DWV isometric with final sizing for the example.

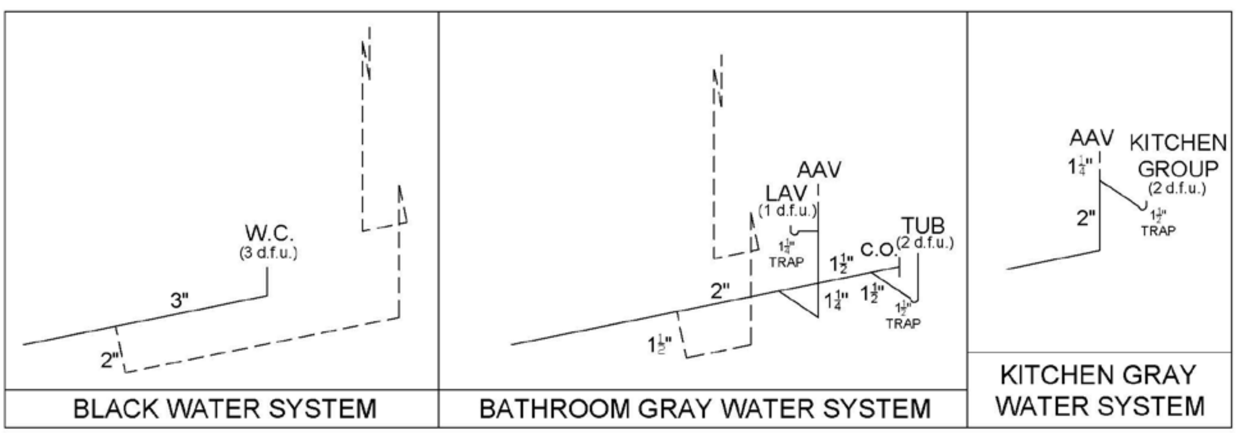


Figure 9: Solutions for DWV Sizing Example

Plumbing fixtures may share the same vent piping, known as a common vent, as long as certain conditions exist. One of the most important is the proximity of the fixture drains to the vent/drain connection point (again see IRC Table P3105.1 for maximum distances). Due to the small size of THOW the maximum distances are almost never an issue. Use IRC Table P3107.3 to size common vents.

Building Sewer

The building sewer is the piping and fittings outside of a building connecting the DWV system inside the building to the municipal sewer system, a septic tank, or some other on-site sewage disposal system.

Residential building sewer piping is usually 3" or 4" in diameter. Smaller piping is possible as well; for example, connecting an outdoor grilling station with a sink to the primary building sewer leaving a house. The IRC lists different acceptable materials (see IRC Tables P3002.2). Of these, the most commonly used materials for new construction are ABS and PVC. Just like with DWV pipe, Schedule 40, DR 22, and DR 24 ABS and PVC piping in IPS diameters are allowed for building sewers. The IRC also allows sewer and drain diameter sized ABS and PVC pipes (think of the green PVC pipe seen at many construction sites).

Size building sewer pipes the same way as drain pipes in DWV systems – sum up the total d.f.u. values for a building and use IRC Table P3005.4.2 to determine the diameter and slope. Building sewers are usually the same size as the largest drain pipe leaving a tiny house unless additional buildings are connected to the building sewer or the building sewer pipe slope is reduced enough to require a larger size pipe.

To ease the removal of clogs or blockages in both drain pipes and building sewers the installation of cleanouts are useful and in certain situations required. See IRC P3005.2 for more information on required locations.

Testing

After rough-in is completed, DWV systems need testing. If tested by water, fill the system with water to a point five or more feet above the highest fitting or the highest point of the system. The test duration is 15 minutes minimum and check for leaks by visual inspection. If tested by air, use a pressure of 5 psi which must be maintained for 15 minutes to pass inspection. In general plastic piping can't be air tested according to the IRC; however, inspectors often allow it. After setting all plumbing fixtures and filling their traps with water, the final water tightness test occurs by filling each fixture with water and then opening the drain. Traps and fixture connections are visually inspected for leaks. Refer to IRC P2503.5 for complete testing requirements.

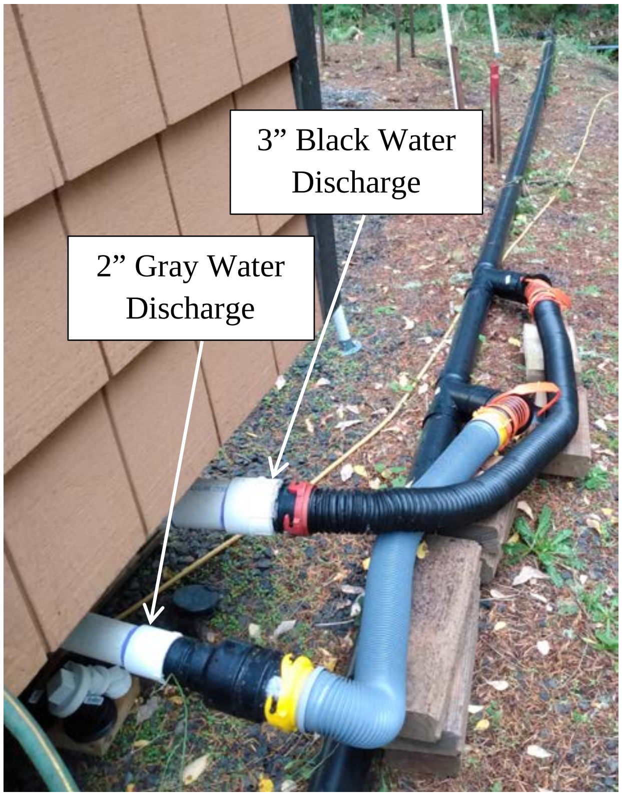
Notching and Drilled Holes in THOW Studs

In typical home construction water supply piping and DWV piping are installed after framing is complete. All non-flexible piping (pretty much everything other than PEX) is installed by notching studs. The IRC prohibits notches in exterior and bearing wall studs from exceeding 25 percent of the stud width. For space saving reasons almost all THOW are built with 2x4 stud walls. To meet the code, this means notching is limited to no more than a 7/8" width. This is sufficient for some water supply piping, but certainly not for DWV pipes. The IRC allows drilled holes in the studs to be 40 percent or less of the stud width (1.4" for a 2x4) or if the stud is doubled up, 60 percent of the stud width (2.1" for a 2x4). Since structurally it is best to remove material from the center rather than edge of a stud, avoid notches altogether in a THOW and used drilled holes instead. This means drilling holes and installing rigid water supply pipes before attaching wall sheathing.

CPVC water supply piping placed in walls prior to wall sheathing installation. The piping extending past the front of the trailer will be cut and connected to pipes not yet installed in the front wall.

PEX tubing is flexible enough to install after framing is completed and as a result it is now the go to material for THOW water supply piping. Place any DWV system piping that crosses studs into non-load bearing walls only. Drilled holes for 1¼" and 1½" DWV pipe through doubled up studs is likely the only prescriptive code compliant option. Larger DWV pipes need to go under the trailer to avoid structurally weakening walls. Place restrictions on notches and details on large drilled holes in the drawing details.

Plumbing Utility Connections



3” diameter RV hoses with “bayonet” style connections connect this THOW to ABS piping that discharges to a septic tank. The gray and black water from the THOW is mixed since the septic system can treat both.

Even if a composting toilet is selected, a THOW still needs a gray water sewer connection and potable water connection for sinks and showers. If a flush toilet is used either separate gray and black water sewer connections will be needed or a combined gray and black water sewer connection. Most of the time a designer will choose to make all utility connections more like a traditional house (e.g. all hard piped) or, if the THOW is going to be mobile or placed in an RV park or resort, use RV utility connection components. Most campground, trailer parks, and RV parks provide a hose bibb with a male connection that a drinking water hose can be connected to. Drinking water hoses are usually white, blue, or white and blue in color. All three common hose sizes (1/2”, 5/8”, and 3/4” inside diameters) have the same size fitting on the end and will connect to a standard 3/4” hose bibb.

Electrical

The electrical system of a tiny house can be anywhere in the spectrum from a system in a traditional house to a system nearly identical to a commercially manufactured RV.

This photo shows a 3-wire service just prior to the electric meter. Downstream of the meter is a 200 amp main circuit breaker panelboard. The hot wires are 4/0 AWG aluminum.

Traditional houses have lights and receptacles that use AC electricity. Often appliances and heating/cooling systems are also run off of AC, though it is also common to have a number of appliances and the heating system powered by a different fuel source, most commonly natural gas. RVs usually use AC electricity for plug loads (receptacles) and cooling systems (if present), DC electricity for lighting, and 2-way or 3-way appliances that run off multiple sources (most commonly propane and 120 volt AC). RV heating systems are usually propane based unless an electric heat pump is used for heating and cooling.

Where in the energy source spectrum a specific tiny house design strategy falls is highly dependent on available utilities, whether it will be used off-grid, and, in the case of THOW, whether it will be mobile or highly mobile. But first, let’s look at the basic components of a typical residential electrical system.

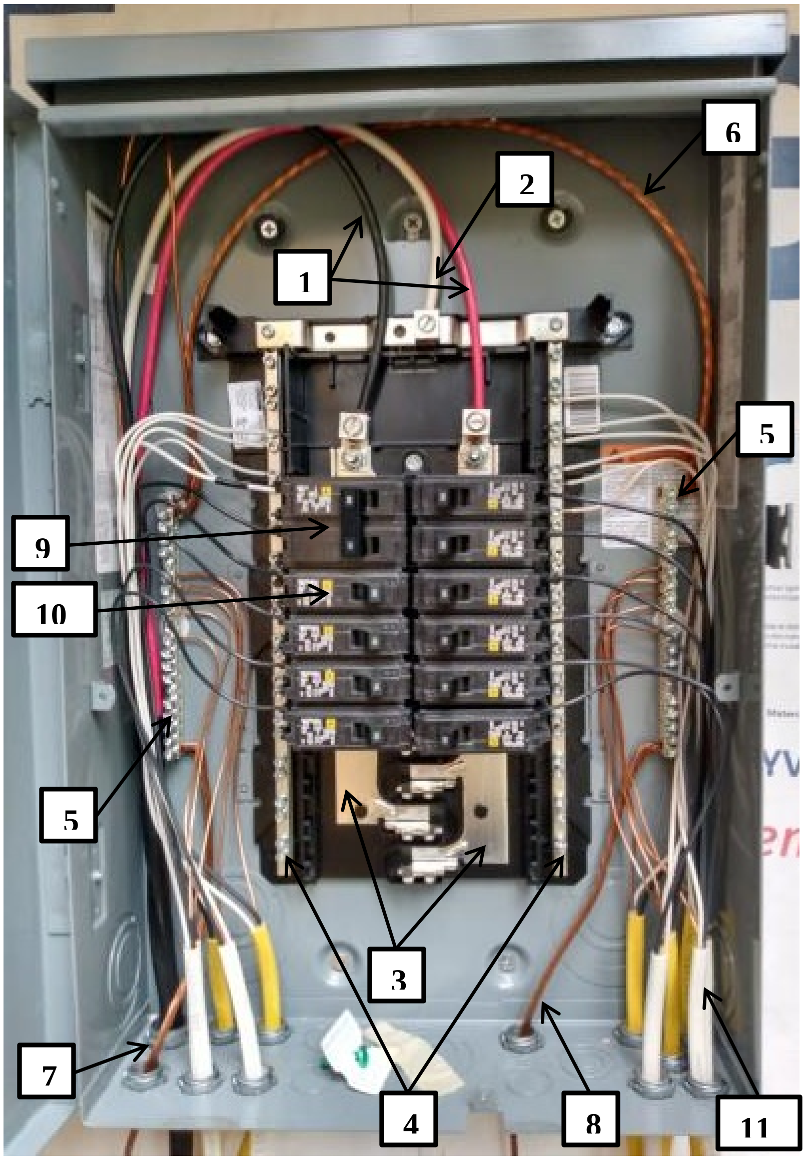
Electrical Services and Panelboards

Most new homes are served by a 3-wire service comprised of two hot wires each carrying 120 volts and one neutral wire. The service wires go through an electric meter used to measure power consumption and then to a main service panel. Main service panels are often called fuse boxes, breaker boxes, or load centers. Fuses and fuse boxes were phased out of new residential construction by circuit breakers and breaker boxes in the 1960s. The IRC and NEC refer to service panels as panelboards. Panelboards distribute power to individual circuits. Individual circuits may provide either 120 volts and/or 240 volts to connected devices such as receptacles and light fixtures. A 120 volt circuit uses a single-pole circuit breaker, which connects to only one of the two hot bus bars in the panelboard. 240 volt or 120/240 volt circuits are created by using 2-pole breakers, which connect to both hot bus bars in the panelboard. Each hot bus bar carries 120 volts since each bus bar is connected to a separate 120 volt hot service wire. Both single-pole and 2-pole breakers come in a variety of amperages. The most common residential single-pole breakers are 15 amps and 20 amps, which are used for lighting and receptacle circuits. The most common residential 2-pole breakers are 15 amps (for small tank wall heaters and small water heaters); 20 amps (for most wall heaters and some tank water heaters); 30 amps (for clothes dryers and most tank water heaters); and 40, 50, and 60 amps (for various size electric ranges, central air conditioning, and electric furnaces).

A main circuit breaker panelboard has a main circuit breaker and individual branch circuit breakers. The main circuit breaker acts as a single disconnect for all branch circuits. A main lug panelboard has individual branch circuit breakers, but no main circuit breaker integral to the panelboard. Main lug panelboards are often used as subpanels located "downstream" of a main circuit breaker panelboard. This means all main lug panelboard branch circuits and hot bus bars can still be disconnected from power, but it is accomplished by turning off the subpanel feeder breaker located in the "upstream" main circuit breaker panelboard. A stand-alone THOF would normally use a main circuit breaker panelboard, while a THOW could use either type of panelboard. In most instances, a THOW would not be required to use a main circuit breaker panelboard since THOW are usually connected to a circuit with an "upstream" circuit breaker.

Panelboards are typically installed in THOW exterior storage cabinets or within the THOW living space. Do not install panelboards in bathrooms.

The photo on the next page shows the main components of a main lug panelboard.



KEY
1. Hot Service Wires
2. Neutral Service Wire
3. Hot Bus Bars
4. Neutral Bus Bars
5. Grounding Bus Bars
6. Grounding Bus Bar Bonding Jumper Wire
7. Grounding Conductor Connected to THOW Trailer and Ground Rod
8. Conductor for Bonding Propane System Piping
9. 2-Pole Breaker (20 Amp, 240 Volt for Wall Heater)
10. Single-Pole Breaker (10 Total)
11. Branch Circuit (11 Total)

125 Amp Main Lug Panelboard (Square D Homeline Model #HOM2040L125PRB) in a THOW. The service load was less than 50 amps, but a panelboard with bus bars rated for greater amperage was selected simply because it had space for a greater quantity of breakers. Two separate grounding bus bars (Square D Model #PK18GTACP) were added since this main lug panelboard acts as a subpanel. Per code, subpanel grounding bus bar(s) and neutral bus bar(s) are not bonded together like in main circuit breaker panelboards.

Calculating Service Loads and Sizing Service Wires

Next, let's look at an example for an entirely AC electric powered house and how to determine the service load for such a house.

EXAMPLE:

A THOF has 380 square feet of floor area, two 20 amp small appliance kitchen circuits, one 20 amp laundry circuit for the washing machine, one 12.5 kilowatt (kW) range, one 1,200 watt (W) dishwasher, one 5,000 W clothes dryer, one 4,500 W water heater, and two separately controlled fan-forced in-wall 3,000 W heaters units. Power information is from appliance nameplates. What is the minimum total service load amperage?

SOLUTION:

IRC Table E3602.2 provides the step-by-step procedure for determining the minimum dwelling electrical service load. Table 4 is a condensed and slightly reorganized version of the IRC table.

Step	Loads and Procedure
1	3-volt amperes per ft^2 of floor area for general lighting and general use receptacle outlets
2	1,500 volt-amperes multiplied by total number of 20-ampere-rated small appliance and laundry circuits.
3	The nameplate volt-ampere rating of all fastened-in-place, permanently connected or dedicated circuit-supplied appliances such as ranges, ovens, cooking units, clothes dryers not connected to the laundry branch circuit and water heaters.
4	Subtotal of Steps 1, 2, and 3.
5	Apply demand factor to Step 4 subtotal: The minimum subtotal shall be 100% of the first 10,000 volt-amperes plus 40% of any portion in excess of 10,000 volt-amperes.
6	Add the largest of the following to the Step 5 demand factor adjusted subtotal:
	100% of the nameplate rating(s) of the air-conditioning and cooling equipment.
	100% of the nameplate rating(s) of the heat pump where a heat pump is used without any supplemental electrical heating.
	100% of the nameplate rating of the electric thermal storage and other heating systems where the usual load is expected to be continuous at the full nameplate value.
	100% of the nameplate rating of the heat pump compressor and 65% of the supplemental electric heating load for central electric space-heating systems.
	65% of the nameplate rating(s) of electric space-heating units if less than 4 separately controlled units.
	40% of the nameplate rating(s) of electric space-heating units of 4 or more separately controlled units.
7	Subtotal of Steps 5 and 6.
8	The minimum total load in amperes shall be the Step 7 subtotal divided by 240 volts.

Table 4: Reorganized and condensed version of IRC Table E3602.2

Recalling the equation P = IV, power (in watts) equals current (in amps) times voltage (in volts); therefore a volt-ampere (VA) is the same as a watt. Electrical engineers will rightly point out this equation is an oversimplification when talking about AC circuits in general, but for this application, both electricians and electrical engineers would do the same. Demand factors are allowed because it is unlikely all electrical devices and appliances in a house would be used at full load simultaneously. Additional reductions from demand factors may be applicable in some circumstances and can be found in the NEC.

For our example house the calculations for each step would be:

Step 1: *(3 VA per ft²)(380 ft²) = 1,140 VA*
Step 2: *(1,500 VA per circuit)(3 circuits) = 4,500 VA*
Step 3: *12,500 VA + 1,200 VA + 5,000 VA + 4,500 VA = 23,200 VA*
Step 4: *1,140 VA + 4,500 VA + 23,200 VA = 28,840 VA*
Step 5: *10,000 VA + (28,840 VA - 10,000 VA)(0.4) = 17,536 VA*
Step 6: *(0.65)(3,000 VA)(2 heater units) = 3,900 VA*
Step 7: *17,536 VA + 3,900 VA = 21,436 VA*
Step 8: *21,436 VA ÷ 240 volts = 89.3 amps*

Select a 3-wire, 100 amp minimum service size and 100 amp minimum panelboard since that is the next largest standard size available and because 100 amps is the smallest service allowed for a dwelling (see IRC E3602.1 or NEC 230.79(C)).

Table 5 compares the minimum total service load of our example 380 ft^2 THOF (House 1) to four other hypothetical houses. House 2 is a fully electric 20' long THOW with two lofts. House 3 is the same size as House 2, but uses a propane range and does not have laundry appliances. House 4 is the same as House 3, but utilizes a propane water heater instead of an electric one. House 5 is a traditional 2,000 ft^2 fully electric house. For simplicity, IRC Table E3602.2 was used for all five calculations. It would probably be most appropriate to use IRC Table E3704.2(1) for the THOW service load calculations since this table is for sizing feeder loads and the service load is less than 100 amps (see IRC E3602.2.1). To show both IRC tables result in similar service loads most of the time, I also calculated House 3's service load using IRC Table E3704.2(1). The result was 49.9 amps, which is within 5% of the value shown in Table 5.

Step	Description	House 1	House 2	House 3	House 4	House 5
1	Building Area (ft^2)	380	270	270	270	2,000
	General Lighting / Receptacle Loads (VA)	1,140	810	810	810	6,000
2	Small Appliance Circuits (VA)	3,000	3,000	3,000	3,000	4,500
	Laundry Circuits (VA)	1,500	1,500	0	0	1,500
3	Range (VA)	12,500	12,500	0	0	12,500
	Dishwasher (VA)	1,200	1,200	1,200	1,200	1,440
	Clothes Dryer (VA)	5,000	5,000	0	0	5,000
	Water Heater (VA)	4,500	4,500	4,500	0	5,500
4	**Subtotal (VA)**	**28,840**	**28,510**	**9,510**	**5,010**	**36,440**
5	Apply Demand Factor (VA)	17,536	17,404	9,510	5,010	20,576
6	Largest Heating / Cooling Load with Demand Factor Applied, if Applicable (VA)	3,900	1,950	1,950	1,950	15,000
7	**Subtotal (VA)**	**21,436**	**19,354**	**11,460**	**6,960**	**35,576**
8	**Min. Load (Amps)**	**89.3**	**80.6**	**47.8**	**29.0**	**148.2**

Table 5: Comparison of Service Loads for Hypothetical Houses

The first thing to notice when looking at Table 5 is a mobile, all electric THOW (House 2) is, for all intents and purposes, impractical. This is due to two reasons. First, the largest hookups most campgrounds, trailer parks, and RV parks provide are 50 amps. Our hypothetical House 2 requires slightly greater than an 80 amp service and an electric range by itself usually requires a 40 or 50 amp circuit. Second, solar photovoltaic panels covering the entire THOW roof area would provide nowhere near the required power. With current solar panel technology, the maximum wattage achievable per square foot is around 20 watts. The 20’ THOW roof area would be about 170 square feet, so the very best case scenario (which is totally unreasonable to expect) would be to produce 3,400 watts at peak production time. If that peak production lasted for six hours a day (again unlikely) we’d produce 20,400 watts. Let’s then assume we use the peak power, 19,354 watts, for just one hour during the day. Our best case production for the entire day produces only barely enough power for our highest one hour of use. Certainly the remaining hours of the day would have significantly less power use per hour (the dryer and heater wouldn’t run all day long), but the power needed for the remaining 23 hours is not trivial. Of course, a THOF could use a large ground-mounted photovoltaic array to power itself.

The next thing to notice from Table 5 is by using a propane range and eliminating laundry appliances a THOW could be powered by a 50 amp service (House 3). Many RV parks have onsite laundry facilities as washers and dryers are not that common in RVs. A 30 amp service could also be used for a THOW if additionally a propane water heater is used instead of an electric water heater (House 4). Further service load reductions are possible by using a non-electric heating source like propane or wood, though using anything smaller than a 30 amp service would likely result in observable light fixture dimming when high amperage appliances (like microwaves and hairdryers or when the refrigerator compressor kicks on) are used. That is unless the lights and/or appliances are DC powered. DC lights or appliances require an AC to DC converter unless they are powered directly from batteries charged by solar panels. One item of note – the 3 volt-amperes (watts) per square foot general lighting/receptacle loading factor has been in electrical codes for decades and has not changed even with the widespread use of LED lighting. So, while using LED lights will certainly help reduce your service load, they will not reduce the prescriptive code compliant service load.

Finally, for comparison sake, House 5 shows what size service a traditional 2,000 ft^2 fully electric house might require (150 amp or 200 amp services are typical). Hopefully Table 5 illustrates quantitatively, why using propane as an energy source is so common for a THOW.

Going back to the House 3 calculations, what size service wires are needed to supply the panelboard for a 47.8 amp or 49.9 amp service load? The answer can be found using IRC Table E3705.1. Assuming copper wires and a conductor temperature rating of 60°C (ratings are often printed on the wire's insulation jacket), IRC Table E3705.1 shows an 8 AWG conductor can carry 40 amps maximum and a 6 AWG conductor can carry 55 amps maximum. We will assume the ambient air temperature is 86°F (30°C) and no ambient temperature correction factor from IRC Table E3705.2 is necessary. As a result, select 6 AWG conductors for both hot wires and the neutral. There are ways to potentially reduce the size of the neutral, but that is beyond the scope of this course. Using IRC Table E3908.12 to size the ground wire for this THOW panelboard, we select a 10

An aluminum lug attached to steel trailer frame. The ground wire passes through the lug.

AWG, or larger, bare copper wire.

In addition to grounding the panelboard using a ground wire and ground rod, a THOW should also ground its trailer frame. This grounding can be accomplished by removing paint from a small area of the steel trailer frame and attaching an aluminum lug. The ground wire from the panel board is attached to the lug before terminating at the ground rod.

Circuits, Receptacles, Lighting, and Other General Considerations

Early THOW used a minimal number of circuits. I've seen designs using four total circuits that were broken up by what location they served: one circuit each for receptacles and lights on the front, back, left, and right of the house. While this approach certainly minimizes the amount of wiring needed and allows for a very small panelboard, it neglects many other considerations. For instance, almost all large plug loads could be on a single circuit instead of being spread over multiple circuits. Also, if a single circuit breaker trips, all lights might go out at the same time. It almost certainly will not meet code.

I recommend designing circuits pretty much like you would for a traditional house. The performance will be much better and the material cost not all that different. The panelboard may cost $80 to $100 instead of $20 to $40. The total cost of circuit breakers might be $40 extra. Cable and wires will run you an additional $40 to $60. If space for the panelboard is a concern, use space saving circuits breakers, like slimline or tandem breakers, to run the same number of circuits in a smaller load center.

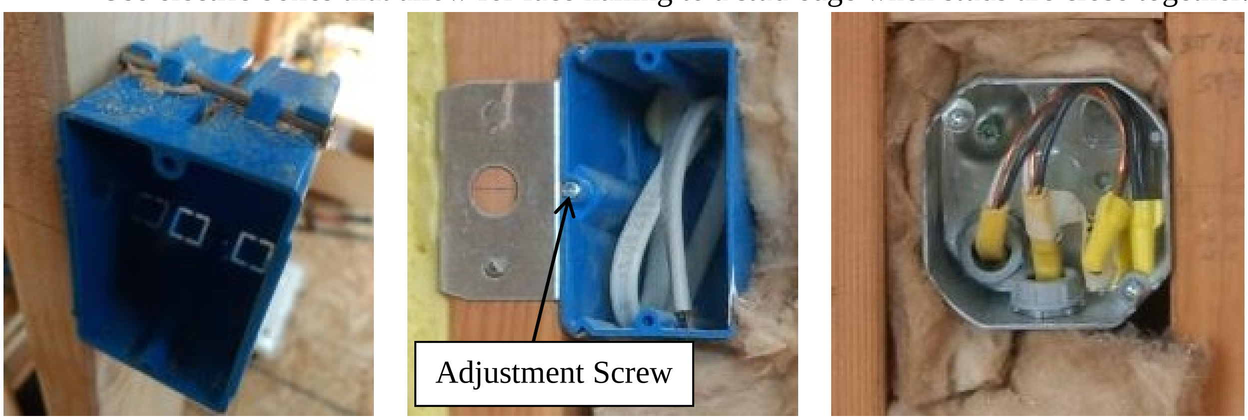
The following is a summary of major code requirements and personal recommendations to assist with tiny house electrical design:

- At minimum two 20 amp small appliance branch circuits are required. Generally, receptacles for these circuits are located in the kitchen (see IRC E3703.2 or NEC 210.11(C)(1)). Spacing of receptacles serving wall-mounted counters "shall be installed so that no point along the wall line is more than 600 mm (24 in.) measured horizontally from a receptacle outlet in that space", which in most applications means no more than 48 inches between receptacles (see IRC E3901.4.1 or NEC 210.52(C)(1)). These same sections of code also require a receptacle over all counters wider than 12 inches.
- At minimum one 20 amp bathroom branch circuit is required (see IRC E3703.4 or NEC 210.11(C)(3)). At least one receptacle is required within 3 feet of the outside edge of each sink (see IRC E3901.6 or NEC 210.52(D)).

- If a laundry area is present, at minimum one 20 amp laundry branch circuit is required in that area (see IRC E3703.3 or NEC 210.11(C)(2)).
- In essentially all rooms except bathrooms, receptacles must be spaced so that "no point measured horizontally along the floor line in any wall space is more than 1.8 m (6 ft) from a receptacle outlet", which in most applications means no more than 12 feet between receptacles (see IRC E3901..2.1 or NEC 210.52(A)(1)). This requirement is based on a typical 6-foot long electrical device's cord length. In a tiny house, spacing will normally be much closer than this. I space receptacles no further than about 5 feet apart and often have them only 3 to 4 feet apart. This helps limit cords stretching all over the place.
- With limited exceptions, 15 amp and 20 amp receptacles require ground-fault circuit-interrupter (GFCI) protection when located outdoors, in bathrooms, and in kitchens when meant to serve countertop surfaces (see IRC Section E39002 or NEC 210.8). GFCI receptacles or GFCI circuit breakers may provide the required GFCI protection. Use weather resistant (WR) GFCI receptacles for outdoors.
- At minimum one outdoor receptacle is required at both the front and back of each dwelling (see IRC E3901.7 or NEC 210.52(E)). One outdoor receptacle may be sufficient for a THOW.
- At least one switch-controlled light or switch-controlled receptacle is required in every habitable room, kitchen, and bathroom (see IRC E3903.2 or NEC 210.70(A)(1)). Switch-controlled receptacles are not allowed in kitchens and bathrooms.
- Use a dedicated circuit for each permanent appliance like an air conditioner, heat pump, heater (or group of heaters), and dishwasher.
- Remember to include receptacles behind or near most propane and natural gas appliances. Even though the primary energy source is gas, many appliances have igniters that require a small amount of electricity to operate. Appliances with battery powered ignition are also available.
- An exterior light is required for each grade-level exterior door (see IRC E3903.3). From personal experience, I'd recommend placing the fixture a few feet from the door since, especially in very rural areas, large numbers of insects are attracted to the light. If the fixture is too close to the entry door the insects often fly inside when the door opens, since they see even brighter lights inside.
- Smoke alarms are required in each sleeping room, outside each sleep area (e.g. a hallway outside bedroom(s)), and on each story of a dwelling (see IRC Section R314). In most cases smoke alarms require connection to the building wiring and a battery backup. Use photoelectric smoke alarms instead of ionization smoke alarms for tiny houses.

Photoelectric smoke alarms can be closer to cooking appliances and are less likely to give false alarms near cooking appliances.

- Consider placing receptacles for night lights on the wall at slightly below the loft floor elevation near sleeping loft ladders. This makes climbing down ladders in the dark safer.
- Require 3-way switches at the top and bottom of each loft staircase or ladder so lights can be turned on or off from both floor levels.
- Choose a ceiling fan with a remote control or provide separate wall controls for both the fan light and fan speed. Fan chain controls are hard to reach on high ceilings (or are often in the way if extension chains are added).
- Use electric boxes that allow for face nailing to a stud edge when studs are close together.



Left: A 1-gang, 18 in^3 plastic electric box (Carlon Model #B118A) used for many switches and receptacles.

Middle: A 1-gang, 21 in^3 adjustable plastic electric box (Carlon Model #B121ADJ) used for switches and receptacles when limited space exists between studs. This model is face nailed to the stud edge instead of side nailed to the stud width like the more commonly used B118A. An additional handy feature is the ability to adjust the depth of the box after the wall covering is installed by turning the adjustment screw. Each B121ADJ costs about $2.80 compared to $0.30 for each B118A.

Right: A 1-gang metal octagonal electric box (Raco Model #8125) used to provide greater stability for adjustable reading/task light fixtures and also for surface mounted ceiling lights.

- Select track lights or exposed conduits/boxes for illuminating the underside of lofts. Ceiling finishes can go over loft beams, but this reduces head room in an already low ceiling space.

Left: Exposed electric boxes and conduit on the underside of a THOW loft floor. The light fixtures are lamp holders without pull chains (Leviton Model # R50-49875-000) with vintage Edison LED G25 light bulbs.

Right: A track lighting fixture on the underside of a THOW loft floor.

- Provide wall-mounted task lighting for reading on couches or in beds since there is limited room for end tables and night stands in tiny houses. Specify metal electrical boxes for these lights so they are sturdy when adjusted.
- Install receptacles in wheel well frame out areas when furniture will be placed against that wall.
- Use low-profile LED light fixtures in loft spaces instead of recessed can lights. The low-profile LEDs use regular ceiling electrical boxes, but only extend approximately one inch below the ceiling, so they don't impede the loft headroom. They also allow for more insulation and better air sealing than recessed cans. Finally, they don't cause potential issues with shallow roof framing members in THOW. Recessed cans are usually between 5.5 inches and 7.5 inches deep, so they are impossible or problematic to use with 2x6 and 2x8 roof framing members.

Left: A flexible gooseneck, wall-mounted, 3 watt LED reading light in a THOW. The light has an on/off switch located on the lamp base and was hardwired to the electrical circuit to avoid the clutter of a cord.

Middle: A receptacle located in a THOW's wheel well frame out. A couch back would cover the wall area so placing the receptacle as shown made accessing the receptacle possible after furniture placement.

Right: A low-profile LED light fixture (GM Lighting Model #S4-3080-WH) in a THOW loft.

Telecommunications

Many THOW have little to no hardwired telecommunication (telecom) infrastructure due to the widespread proliferation of cell phones, smartphones, Wi-Fi, and Bluetooth devices. Most commonly installed is coaxial cable for internet, cable, and over-air TV. Less commonly installed are Ethernet/data, telephone, and audiovisual wiring like speaker wire and HDMI cables.

The following cable and connector types should be sufficient for inside a tiny house:

- Coaxial: RG6 cable with F-connectors
- Ethernet/data: Cat-5E with RJ45 connectors
- Telephone: Cat-5 or Cat-5E with RJ11 connectors

The use of Keystone wall plates and Keystone jacks/couplers allows for multiple types of wiring and jacks in the same box (see below photo). Each jack will likely homerun to a single location like a THOW exterior storage cabinet or an exterior telecom center/box. Multiple centers/boxes could also be used. Homerun means a single cable runs from the jack to the connection point of the telecom provider, not from one jack to another jack of the same type, before ending at the telecom provider connection point.

Left: The orange 1-gang plastic electric box (Carlon Model #SC100A) has both Cat-5E cable for an Ethernet/data jack and Cat-5 cable for a telephone jack

Right: A wall plate with three Keystone jacks (1 each for telephone, Ethernet/data, and coaxial)

Electrical Plan Drawings

Residential electrical drawings, and tiny house drawings, typically include the following:

- Electric Plan – Floorplan(s) showing locations and types of light fixtures, receptacles, switches, junction boxes, panelboard, hardwired electrical components such as heaters, branch circuits, and smoke alarms.
- Drawing Legend
- Electrical Notes – Common code requirements, project requirements departing from industry norms, prohibitions on notching studs, etc.
- Panelboard Schedule – Figure showing circuit numbers, description of loads, breaker amps and number of poles, wire size, panel type (main circuit or main lug), panelboard voltage (120 or 120/240), minimum panel bus capacity in amps, NEMA enclosure type, etc.
- Lighting Fixture Schedule – Figure showing fixture type; bulb quantity, wattage, bulb shape, bulb base type for each fixture; bulb color; fixture mounting height; etc.
- Telecommunication Plan – If applicable, floorplan(s) showing locations of coaxial, data, and telephone jacks; speakers; speaker wiring; and other audiovisual components.

Figure 10 shows the first floor of a THOW electric plan and its drawing legend.

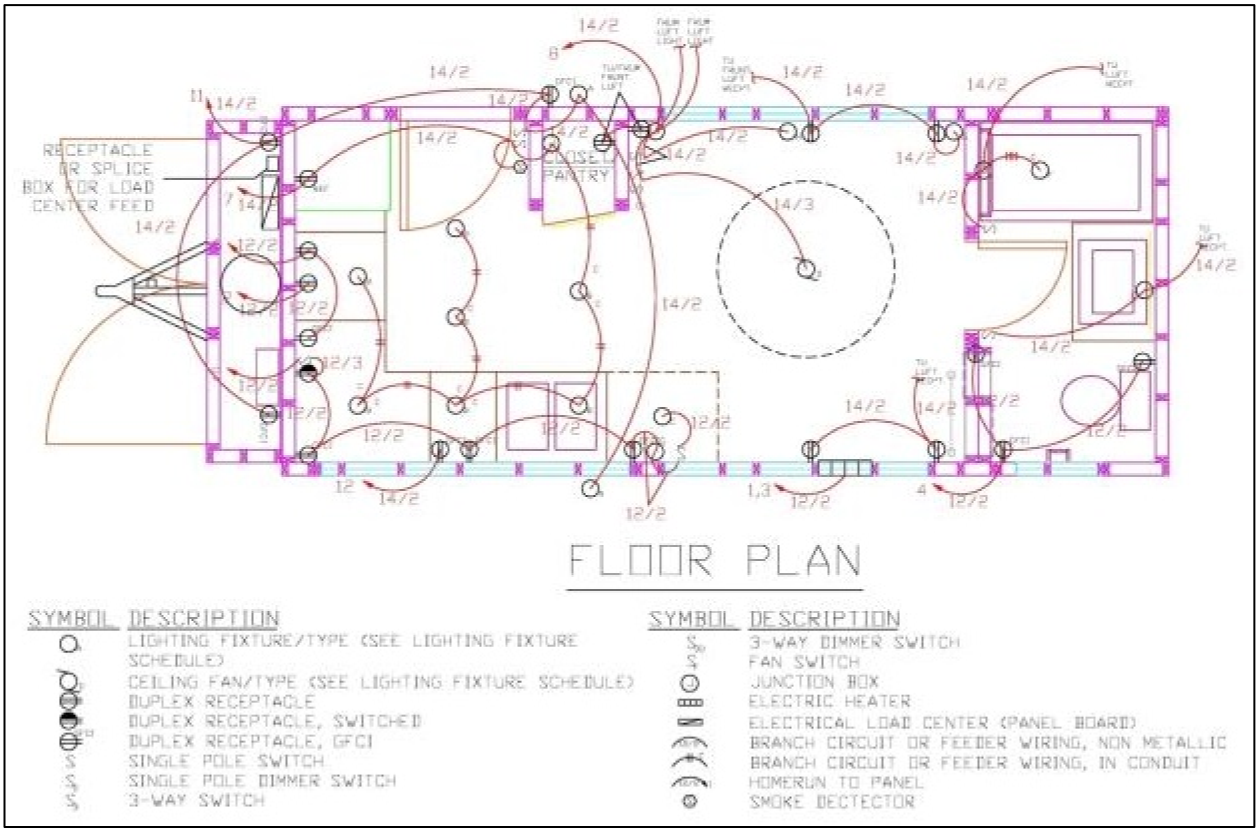


Figure 10: First floor electrical plan for a THOW

Solar Photovoltaics

People who install solar photovoltaics (PV) on traditional housing stock usually do it for one or more of the following reasons:

- Economics – smaller monthly utility bills, as a hedge against increasing future electricity prices, government subsidies (tax credits, tax deductions, rebate, incentives), etc.
- Environment Considerations – a desire to use a renewable energy source for their home
- Energy Independence – a desire to have power during outages, disconnect from the grid

One note on environmental considerations; always check your utility's power supply generation information first. The electric utility supplying power to the property our THOW is located on produces 85% of its power with hydroelectric, 10% with nuclear, 2% with wind and other renewables, and only 3% with natural gas and coal. The environmental impact from manufacturing solar panels, batteries, and other solar PV system components would likely dwarf the environmental impact of such a small amount of natural gas and coal.

From an economic standpoint using solar PV also makes little sense in our case. We've never used more than 150 kilowatt hours (kWh) in a month and our highest monthly bill has been $25. $15 of the $25 was the monthly base charge just for having an electric service and the remainder was the energy usage charge at a rate of 7.2 cents per kWh, which is a phenomenally low rate per kWh. In addition to the above three reasons, THOW owners often have a fourth major reason to use solar PV – mobility freedom. People who frequently move their THOW and don't always stop where they can plug into the grid can certainly produce enough power from solar PV to supply small plug loads and lighting loads.

The intent of this course is not to cover how to design a solar PV system for a tiny house. SunCam already has a five-part course on designing, installing, inspecting, and evaluating solar systems. Also, the fifth tiny house course in my series will go through case studies related to off-grid and mobile THOW design. A solar PV system sizing will be included in at least one of the case studies.

Electrical Utility Connections

Most campgrounds, trailer parks, and RV parks provide either or both 30 amp and 50 amp receptacles. The 30 amp receptacles usually provide 120 volts and the most common receptacle type is a NEMA TT-30R. The 50 amp receptacles provide 240 volts and the most common receptacles type is a NEMA 14-50R.

Left: An RV resort electrical hookup with the 50 amp receptacle on the left (where the cord is plugged in), 30 amp receptacle in the middle, and 20 amp convenience receptacle on the right

Right: A NEMA 14-50R receptacle. A NEMA 14-50P plug fits into this receptacle.

Typically a 50 amp or 30 amp RV power cord is used to connect a THOW to a power source, but of course at a permanent location a THOW could be hardwired. 50 amp cords are made with two 6 gauge hot wires, one 6 gauge neutral wire, and an 8 gauge ground wire. Three 10 gauge wires (one hot, one neutral, and one ground) are inside most 30 amps cords. It's recommended to perform a voltage drop calculation using the calculated service load for 30 amp, 120 volt cords/services over 50 feet in length and 50 amp, 240 volt cords/services over 150 feet in length.

Conclusion

This course concentrated on tiny house mechanical, electrical, and plumbing systems. Mechanical systems discussed included appliances, common heating and cooling systems, ventilation and exhaust considerations, and propane systems. Potable water service, potable water distribution, drain-waste-vent, and building sewer were covered in the plumbing section. Finally, an overview of a residential electrical system was given as well as major code requirements and personal recommendations to assist with tiny house electrical design.

One more tiny house course is forthcoming. In this upcoming course case studies in going off-grid or mobile with a tiny house will be presented. Completion of the course is expected in 2021.

Write a Review

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