A SunCam online continuing education course

Tiny Houses Part 5

Highly Mobile and Off-Grid Case Studies

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). This fifth course presents case studies related to highly mobile tiny houses on wheels (THOW) and off-grid tiny houses, whether THOW or tiny houses on foundations (THOF). Prior to the case studies, a "toolbox" of flowcharts, methods, and products is given to help show possible solutions for tiny house water, wastewater, and energy needs. Six examples and five case studies are included. Much of the basis of this course came from my own research, planning, designing, and construction of a THOW I built myself and the subsequent search for a property to place it on. This course is intended as a stand-alone course, meaning you can take it without having taken previous courses in the series. Certain topics and background are covered in greater detail previously in the series, so when appropriate, I make reference to other courses.

Learning Objectives

After completing this course participants should be able to:

1. Understand what potential solutions exist for a tiny house's water source(s), wastewater treatment or disposal system(s), and energy source(s).
2. Identify what solutions are feasible for a variety of situations or given scenarios.
3. Size an off-grid solar photovoltaic system array and battery bank.
4. Apply "toolbox" information and calculation methods to case studies and/or real life.

Introduction

Over the past few decades a small, but growing segment of the population has moved to smaller housing options. This course is the fifth 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 possible options for tiny house water, wastewater, and energy needs. The basis of this course came from my own research, planning, designing, and construction of a THOW I built myself and the subsequent search for a property to place it on.

The Engineer's Role and Building Standards

There is no universally accepted definition of a tiny house. For the purpose of this course series, 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 2021 or 2022 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

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 related to this course include sizing heating, cooling, and ventilation systems; designing propane systems; laying out and sizing plumbing systems; designing site utilities including rainwater harvesting, 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 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 codes called the I-Codes and revises them every three years. The 2018 International Residential Code (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. Part 1 of this course series provides a more detailed discussion of building codes and manufacturing standards.

Toolbox

Before looking at specific case studies, this course develops a "toolbox" of flowcharts, methods, and products to show potential solutions and help narrow down potential solutions. This toolbox covers possible water sources, wastewater treatment and disposal options, and potential energy sources.

When this course discusses a "highly mobile" THOW, it is referring to a THOW that moves often between different properties or campsites. "Often" is a relative term, but if the THOW moves semi-annually or more frequently, consider it highly mobile. When referring to "off-grid" locations, we are talking about locations where one or more of the standard utilities (electricity, water, and wastewater) are not available from a centralized utility provider. Off-Grid tiny houses must rely on privately-owned sources or treatment methods integral to the tiny houses or located on the property they are sited on. More commonly, off-grid means a structure is not provided electricity from a power grid, but this course uses the first, broader definition.

Water Sources

Potential drinking water sources include community water systems, private wells, bulk water deliveries, springs, surface waters (lakes, streams, etc.), rainwater harvesting, and treated graywater. All of these, other than a community water system, would be considered off-grid sources. Rainwater harvesting and bulk water deliveries require water storage tanks, bladders, or cisterns. Some of the other sources may also require storage facilities depending on the circumstances; for example, a low production well or seasonal stream. Some sources may also require water quality treatment for health reasons, aesthetics, or taste preferences.

Figure 1 is a flowchart to help determine an appropriate water source for a tiny house and its specific circumstances.

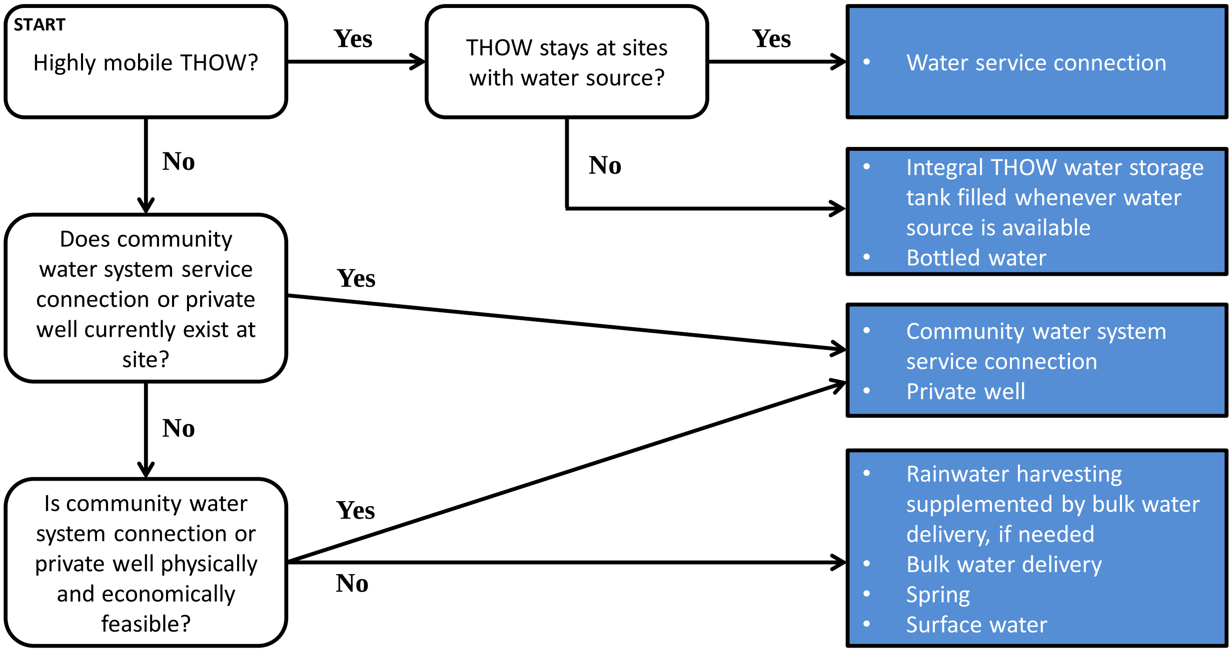


Figure 1: Water Source Selection Flowchart

Estimating Water Consumption

Obviously, the amount of water used must be known or properly estimated to ensure a given source is adequate to provide what will be consumed. Individual people use significantly different amounts of water. Likewise, an individual sometimes has widely different usages from day to day; for example, laundry day might be the largest consumption day of the week.

Study results differ, but recent reporting for U.S. water usage range from 60 to 80 gallons per person per day. Table 1 presents U.S. water usage data from a study published in 2016 by the Water Research Foundation entitled *Residential End Uses of Water, Volume 2*. The leak volumes given in the table are for leaks on the "customer side" meaning the report number doesn't include distribution system leakage, which is quite high for some utilities. Likely a large percentage of the leak volume is due to toilet flapper leakage. Whether leakage should be included in the daily demand calculation for a tiny house household will be determined on a case-by-case basis. The table's average per person water use does not include outdoor uses, most notable, irrigation uses. Historically, average per person irrigation use has been quite high in the U.S. Additionally, Table 1 provides the maximum IRC fixture flow rate or volume for toilets, showers, and sinks.

Fixture	Average Daily Indoor Per Person Water Use (gallon)	Maximum IRC Fixture Flow Rate or Quantity
Toilet	14.2	1.6 gallon per flush (gpf)
Shower	11.1	2.5 gallon per minute (gpm) at 80 psi
Sink Faucet	11.1	2.2 gallon per minute (gpm) at 60 psi
Clothes Washer	9.6	N/A
Leaks	7.9	N/A
Other	2.5	N/A
Bathtub	1.5	N/A
Dishwasher	7.0	N/A
Total	**64.9**	**N/A**

Table 1: Average Daily Indoor Per Person Water Use and Maximum Fixture Flow Rates (from the Water Research Foundation and 2018 IRC)

Per person or per household water demand can be based on the average water use information in Table 1, historical occupant use taken from past water bills, or calculated by using the maximum fixture flow rates in Table 1. If potable water will be used for irrigation purposes, such as watering a vegetable garden, add the estimated daily irrigation volume to the total indoor use calculated using the table. For example, one person living in a THOW might use the following water each day.

$$\begin{aligned}
&Daily\ Use = Toilet\ Use + Shower\ Use + Sink\ Use \\
&Daily\ Use = (1.6\ gpf)(5\ flushes) + (2.5\ gpm)(10\ minutes) + (2.2\ gpm)(5\ minutes) \\
&Daily\ Use = 44\ gallons
\end{aligned}$$

In off-grid situations where water production is low, potential ways to decrease potable water use include using lower flow plumbing fixtures, sailor/combat showers (turning off the shower while lathering up), and reusing gray water for toilet flushing.

The same Water Research Foundation study found average daily per person hot water use in the U.S. is currently between 15 and 20 gallons. This information is helpful for sizing tank hot water heaters. Maximum fixture flow rates in Table 1 are a combination of mixed hot and cold water, so they are not necessary the best way to estimated total hot water usage.

Community Water Systems

If available, getting your water from a community water system or similar water utility might be the way to go. If a THOW is parked at a camp site, RV resort, or backyard, likely the only item necessary to connect to the existing water source is a drinking water hose connected to a hose bibb. If a water main exists in the street adjacent to the site then water service piping, a water meter, and sometimes a backflow prevention assembly or dual check (not technically a backflow prevention assembly) would normally be required. Additionally, most utilities charge a connection fee or impact fee which is often based on the water meter size. These fees often vary between $3,000 and $5,000 for a typical 3/4" residential water meter and service connection. The thinking behind such fees is that after enough new customers connect to the system, the treatment plant and distribution system will require expansion or enlargement. In theory the fee money is saved for these large capital expenditures. Impact and connection fees are usually in addition to the cost of the water meter, other materials, labor to install the water service, permit fees, and inspection fees. If a water main is not already present in an adjacent street, the cost of extending the main is likely cost prohibitive for a single residence.

Private Wells

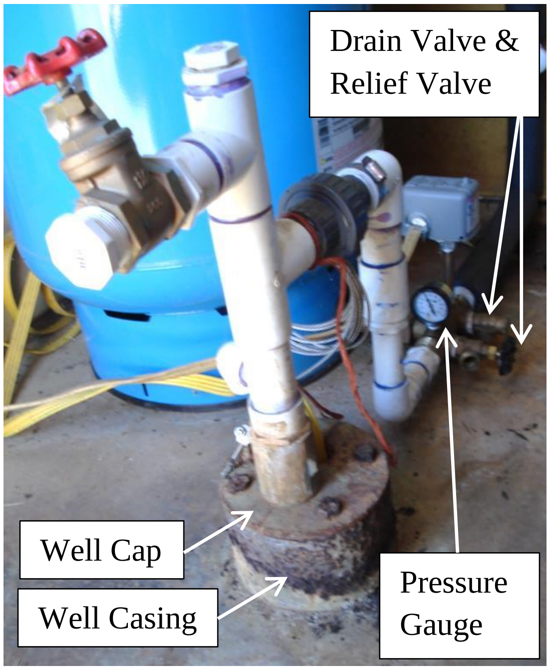
Private water wells are extremely common in rural areas and are the second most common residential water source in the U.S. behind community water systems. According to the U.S.

Environmental Protection Agency (EPA), over 13 million households use private water wells. Many additional people are supplied water from wells owned by their community water system.

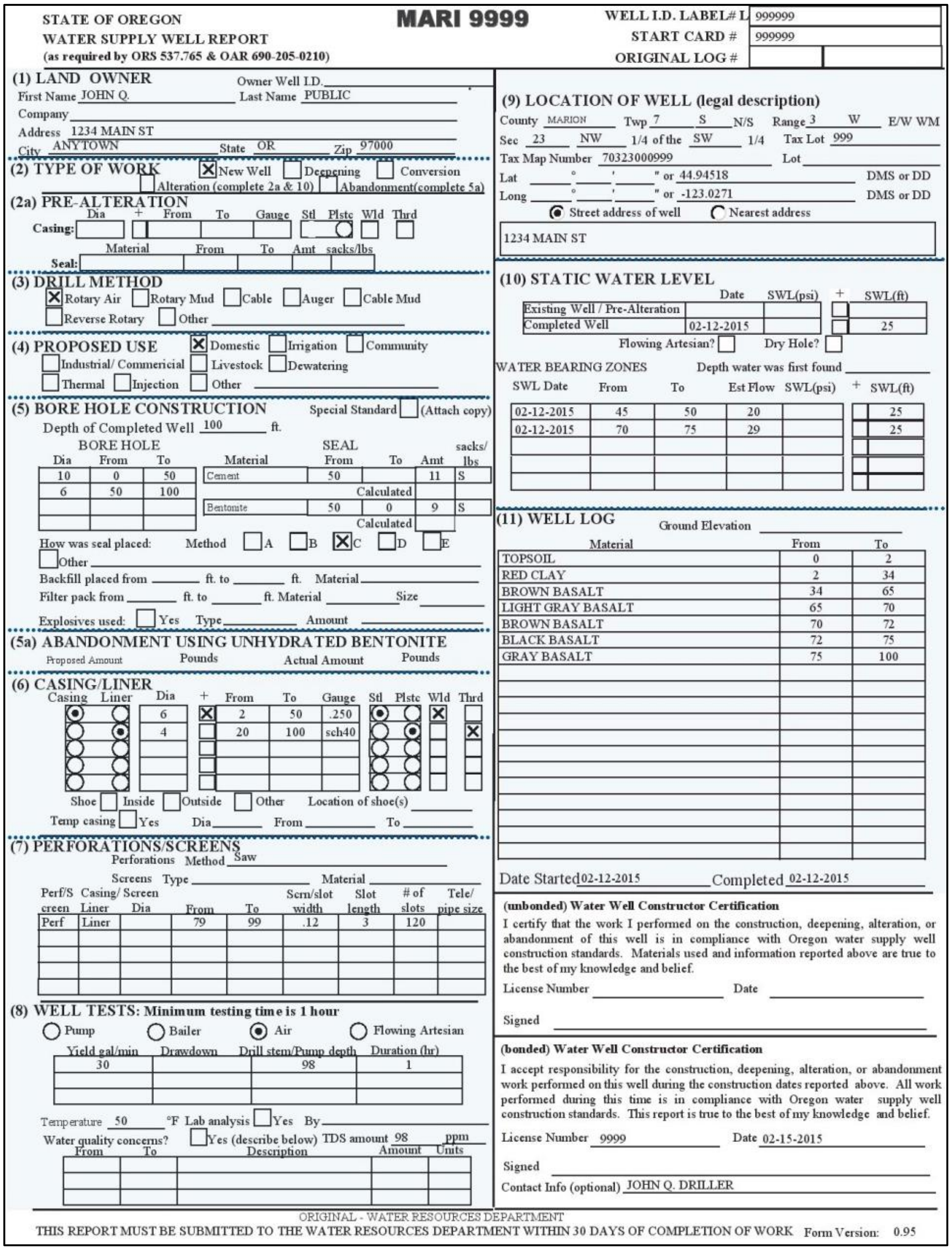
Now days, most wells are drilled instead of dug or driven. Well drillers typically install the major below-grade well components such as the well casing, well screen, and submersible pump (if desired). Significant above-grade components include the well cap, pressure tank, pump controller, check valve, drain valve, relief valve, pressure gauge, and pressure switch. See the below photos with most of these components labelled. In colder climates, the above-grade components are often inside a well house or pump house to keep them from freezing.

Left: An 81 gallon Flexcon Industries Flex2Pro H2P80 pressure tank in a well house. Pressure tanks store water and keep the water under pressure so that well pumps don't have to kick on each time water is used.

Below: The well cap and adjacent components



While it is impossible to know exactly how deep a new well will need to be to get an acceptable yield (a stable, sustainable water flow rate), an estimate often can be made by evaluating water well reports from nearby existing wells and topographic maps. Well reports are submitted to state environmental agencies by well drillers after wells are constructed. Many states make these well reports available online, so obtaining them for adjacent properties is fairly easy. Well reports often include information such as well diameter, well depth, casing material/depth, static water level, well water yield, soil log information, etc.



STATE OF OREGON
WATER SUPPLY WELL REPORT
(as required by ORS 537.765 & OAR 690-205-0210)

MARI 9999

WELL I.D. LABEL# L 999999
START CARD # 999999
ORIGINAL LOG #

(1) LAND OWNER
Owner Well I.D.
First Name JOHN Q. Last Name PUBLIC
Company
Address 1234 MAIN ST
City ANYTOWN State OR Zip 97000

(2) TYPE OF WORK ☒ New Well ☐ Deepening ☐ Conversion ☐ Alteration (complete 2a & 10) ☐ Abandonment(complete 5a)

(2a) PRE-ALTERATION

	Dia	+	From	To	Gauge	Stl	Plstc	Wld	Thrd
Casing:		☐				○	○	☐	☐

	Material	From	To	Amt	sacks/lbs
Seal:					

(3) DRILL METHOD
☒ Rotary Air ☐ Rotary Mud ☐ Cable ☐ Auger ☐ Cable Mud
☐ Reverse Rotary ☐ Other

(4) PROPOSED USE ☒ Domestic ☐ Irrigation ☐ Community
☐ Industrial/ Commericial ☐ Livestock ☐ Dewatering
☐ Thermal ☐ Injection ☐ Other

(5) BORE HOLE CONSTRUCTION Special Standard ☐ (Attach copy)
Depth of Completed Well 100 ft.

BORE HOLE

Dia	From	To
10	0	50
6	50	100

SEAL

Material	From	To	Amt	sacks/ lbs
Cement	50		11	S
		Calculated		
Bentonite	50	0	9	S
		Calculated		

How was seal placed: Method ☐ A ☐ B ☒ C ☐ D ☐ E
☐ Other
Backfill placed from ft. to ft. Material
Filter pack from ft. to ft. Material Size
Explosives used: ☐ Yes Type Amount

(5a) ABANDONMENT USING UNHYDRATED BENTONITE
Proposed Amount Pounds Actual Amount Pounds

(6) CASING/LINER

Casing	Liner	Dia	+	From	To	Gauge	Stl	Plstc	Wld	Thrd
●	○	6	☒	2	50	.250	●	○	☒	☐
○	●	4	☐	20	100	sch40	○	●	☐	☒
○	○		☐				○	○	☐	☐
○	○		☐				○	○	☐	☐
○	○		☐				○	○	☐	☐

Shoe ☐ Inside ☐ Outside ☐ Other Location of shoe(s)
Temp casing ☐ Yes Dia From To

(7) PERFORATIONS/SCREENS
Perforations Method Saw
Screens Type Material

Perf/Screen	Casing/ Liner	Screen Dia	From	To	Scrn/slot width	Slot length	# of slots	Tele/ pipe size
Perf	Liner		79	99	.12	3	120	

(8) WELL TESTS: Minimum testing time is 1 hour
○ Pump ○ Bailer ● Air ○ Flowing Artesian

Yield gal/min	Drawdown	Drill stem/Pump depth	Duration (hr)
30		98	1

Temperature 50 °F Lab analysis ☐ Yes By
Water quality concerns? ☐ Yes (describe below) TDS amount 98 ppm

From	To	Description	Amount	Units

(9) LOCATION OF WELL (legal description)
County MARION Twp 7 S N/S Range 3 W E/W WM
Sec 23 NW 1/4 of the SW 1/4 Tax Lot 999
Tax Map Number 70323000999 Lot
Lat ° ' " or 44.94518 DMS or DD
Long ° ' " or -123.0271 DMS or DD
● Street address of well ○ Nearest address
1234 MAIN ST

(10) STATIC WATER LEVEL

	Date	SWL(psi)	+	SWL(ft)
Existing Well / Pre-Alteration			☐	
Completed Well	02-12-2015		☐	25

Flowing Artesian? ☐ Dry Hole? ☐

WATER BEARING ZONES Depth water was first found

SWL Date	From	To	Est Flow	SWL(psi)	+	SWL(ft)
02-12-2015	45	50	20		☐	25
02-12-2015	70	75	29		☐	25
					☐	
					☐	
					☐	

(11) WELL LOG Ground Elevation

Material	From	To
TOPSOIL	0	2
RED CLAY	2	34
BROWN BASALT	34	65
LIGHT GRAY BASALT	65	70
BROWN BASALT	70	72
BLACK BASALT	72	75
GRAY BASALT	75	100

Date Started 02-12-2015 Completed 02-12-2015

(unbonded) Water Well Constructor Certification
I certify that the work I performed on the construction, deepening, alteration, or abandonment of this well is in compliance with Oregon water supply well construction standards. Materials used and information reported above are true to the best of my knowledge and belief.
License Number Date
Signed

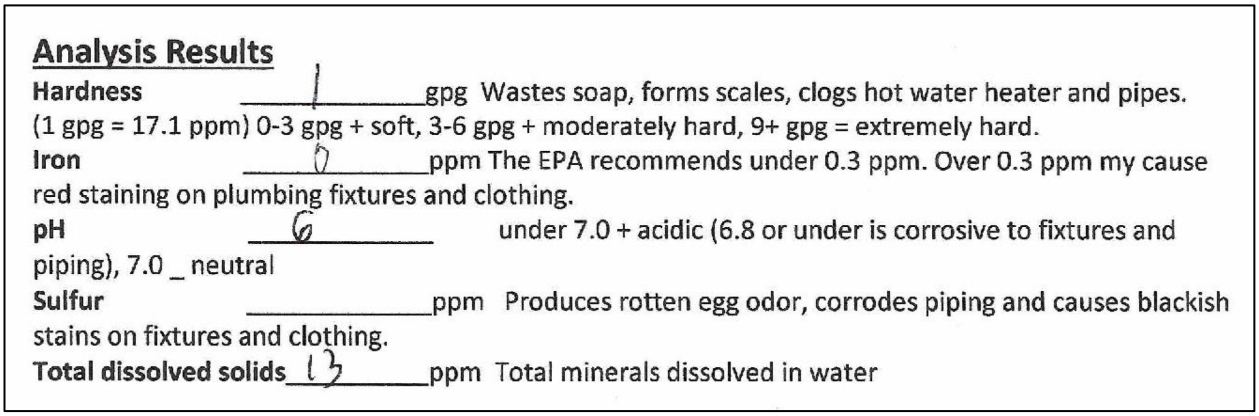
(bonded) Water Well Constructor Certification
I accept responsibility for the construction, deepening, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon water supply well construction standards. This report is true to the best of my knowledge and belief.
License Number 9999 Date 02-15-2015
Signed
Contact Info (optional) JOHN Q. DRILLER

ORIGINAL - WATER RESOURCES DEPARTMENT
THIS REPORT MUST BE SUBMITTED TO THE WATER RESOURCES DEPARTMENT WITHIN 30 DAYS OF COMPLETION OF WORK Form Version: 0.95

Figure 2: Fictitious Sample Well Report (from the Oregon Water Well Owner's Handbook).

The cost for drilling a well is highly variable, but $25 per foot could be used for initial cost estimates. Contacting a local well driller for a per foot price is best, as costs can vary from $15 to $60 per foot. The costs of a pump, pressure tank, etc. are all in addition to the well construction cost.

Many well drilling and well supply companies offer free water quality testing for some of the most basic chemical parameters such as hardness, total dissolved solids, iron, sulfur, and pH. They provide these testing services for free with the hope well owners will buy treatment systems from them. In some states there is required testing for specific well water contaminants prior to any land sales. Generally, this type of testing must be completed by a state certified laboratory. Additionally, labs will test for pretty much any water quality measure or contaminant an owner or potential owner is willing to pay for.



Analysis Results

Hardness 1 gpg Wastes soap, forms scales, clogs hot water heater and pipes. (1 gpg = 17.1 ppm) 0-3 gpg + soft, 3-6 gpg + moderately hard, 9+ gpg = extremely hard.

Iron 0 ppm The EPA recommends under 0.3 ppm. Over 0.3 ppm my cause red staining on plumbing fixtures and clothing.

pH 6 under 7.0 + acidic (6.8 or under is corrosive to fixtures and piping), 7.0 _ neutral

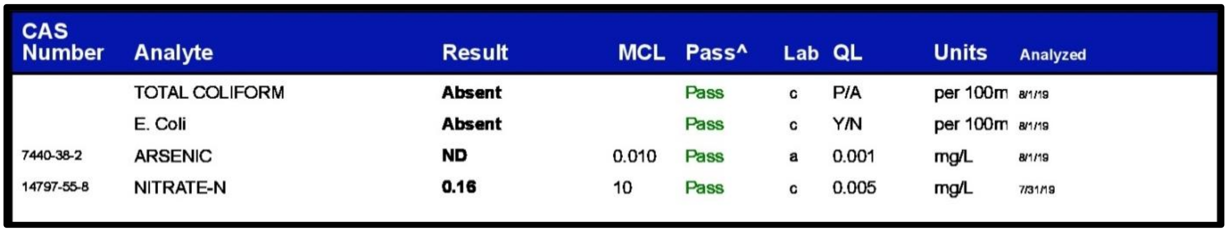
Sulfur ______ ppm Produces rotten egg odor, corrodes piping and causes blackish stains on fixtures and clothing.

Total dissolved solids 13 ppm Total minerals dissolved in water

Figure 3: Excerpt from water testing results performed by a well drilling company. Common acronyms shown in these results include grain per gallon (gpg) and parts per million (ppm).

Figure 3 results show the water is very "soft", iron is essentially non-existent, pH is on the acidic side, and total dissolved solids (TDS) are very low. The EPA recommends less than 500 ppm for TDS. For optimum taste, an extremely low TDS may not be ideal. A pH below 6.5 may result in a bitter metallic taste for certain people (I can't taste a difference between 6 and 7 pH). The only water treatment some people may desire for the above results is calcite neutralizer system for the pH. This may be for taste or concerns about corrosion to fixtures, appliances, and piping.

Figure 4 is an excerpt from water testing results performed by a certified lab. Testing for the contaminants was required per state law prior to sale of the property. MCL stands for maximum contaminant level and ND means not detected above reporting limit.



CAS Number	Analyte	Result	MCL	Pass^	Lab	QL	Units	Analyzed
	TOTAL COLIFORM	**Absent**		Pass	c	P/A	per 100m	8/1/19
	E. Coli	**Absent**		Pass	c	Y/N	per 100m	8/1/19
7440-38-2	ARSENIC	**ND**	0.010	Pass	a	0.001	mg/L	8/1/19
14797-55-8	NITRATE-N	**0.16**	10	Pass	c	0.005	mg/L	7/31/19

Figure 4: Excerpt from Laboratory Water Testing Results

Common water quality treatment systems for wells include water softening to reduce hardness and other positively charged TDS, filters (particulate and/or activated carbon) to remove particulates, and calcite neutralizers to raise pH from acidic to neutral.

Water softening systems are composed of three primary components: a mineral tank (sometimes called a resin tank), a control valve, and a brine tank. Softeners primarily remove dissolved calcium and magnesium (which are the main causes of "hard" water) since they are usually most abundant, but other cations like potassium, sodium, and dissolved iron are also removed.

Left: An Evolve water softener control valve connected to the top of a mineral tank.

Right: A Water-Right brine tank that supplies brine to the Evolve control valve. Brine is produced by salt added periodically to the brine tank.

Left: Pentair Pentek Big Blue filter primarily for large particulate removal. In this well's water quality treatment system, this filter is first, then a water softener system, and finally a second filter (see below photo).

Below: A string wound polypropylene yarn filter to remove smaller particulates. This filter was white when installed. It is now reddish-brown due to rust it has removed. The filter should be replaced.

Reverse osmosis (RO) systems remove virtually all TDS regardless if they are composed of cations or anions. As a result, RO remove the most commonly found TDS in water such as calcium, magnesium, potassium, sodium, nitrates, chlorides, and sulfates. Most of us are used to some minerals in our water, so RO treated water may taste "bad" in the opinion of many people. Reintroducing some minerals through means such as blending RO water with non-RO water is a common practice in many water treatment plants. Alternative methods are available for single residences with individual RO systems.

Water storage tanks may be necessary for low producing wells. A second pressure tank or inline pump may be required when wells are located a long distance away or at a much lower elevation than a residence. Well pumps can be powered by solar photovoltaic systems in off-grid applications. Our well uses around 1.5 kWh per day and is grid-tied, but even in northern locations it could be supported by 40 square feet of solar panels and a fairly small battery bank.

Bulk Water Delivery

In instances where all previously mentioned water sources are unavailable, impractical, or have prohibitively expensive upfront costs, bulk water delivery may be an option. In many rural and urban areas, companies will deliver water to your location by the tanker truck load for purposes such as drinking water, pond/pool filling, dust control, construction related work, etc.

Cost for bulk water delivery varies greatly depending on geographic region, and most importantly, how far the truck must drive to get to your location. A typical cost in the area our tiny house is located is around $300 for a 3,000 gallon truckload of potable water. At this price, bulk water delivery costs $0.10 per gallon compared to less than $0.01 per gallon for the electricity to operate my private well or receive water from a community water system.

Manufactured storage tanks for potable water range in size from less than 100 to over 15,000 gallons. Approximate costs for above-ground tanks in sizes from 1,000 to 5,000 gallons are in the ballpark of $0.65 to $1.00 per gallon. Tanks over 10,000 gallons usually cost more per gallon than mid-sized tanks, so consider using multiple mid-size tanks instead of one large one. Underground tanks are usually more expensive than above-ground tanks. Water bladders are an alternative to storage tanks. The mid-range bladder sizes (3,000 to 5,000 gallons) are competitive with above-ground tank costs and the very largest bladders are often more economical than tanks ($0.50 to $0.60 per gallon).

The elevation of water storage compared to the elevation of water use, typically the tiny house, determines what infrastructure is needed in addition to the storage tank. If the water storage tank can be located at an elevation high enough above the tiny house to provide adequate water pressure, only the tank and related piping, fittings, and valves are needed. Otherwise a pressure tank, and possibly an additional pump, would be needed to provide sufficient pressure for household uses.

EXAMPLE #1:

On a large, rural property a water storage tank can be easily placed on a hilltop near the selected tiny house location. The top of the hill can be accessed by an old logging road, so bulk water delivery trucks can easily offload water into the tank. The elevation difference between the bottom of the water storage tank and the tiny house floor elevation is 105 feet. The highest fixture in the tiny house is a showerhead located five feet higher than the tiny house floor elevation. Convert the pressure head to pressure in pounds per square inch (psi) for the worst case static pressure scenario (when the storage tank is almost empty and the highest fixture is being used). Neglect pipe friction losses because static pressure is being calculated. Assume the specific weight of water is 62.4 lb/ft^3.

SOLUTION:

Recalling from fluid mechanics or hydraulics courses that:

$$P = \gamma h \quad (Equation\ 1)$$

Where: P = Pressure
γ = Specific weight of the fluid
h = Pressure head

Use Equation 1 and an appropriate conversation factor so that units are consistent.

$$P = \gamma h = (62.4\ \frac{lb}{ft^3})(105\ ft - 5\ ft)(\frac{1\ ft^2}{144\ in^2}) = 43.3\ psi$$

The 43.3 psi is the worst static pressure case since you would experience three to four psi higher pressure when the tank is full and a lower fixture, such as a sink, is in use. Generally, 40 psi is considered low, but sufficient for household use. For most people the ideal range is 45 to 60 psi, while a residence over 80 psi would typically have a pressure reducing valve installed to reduce the high water pressure. In this example, a pressure tank would not be necessary since we calculated 43.3 psi; however, if the elevation difference was only 60 feet instead of 105 feet, the static pressure at the tiny house would only be 23.8 psi and a pressure tank would be needed.

In summary, the upfront capital cost for bulk water delivery is probably the lowest of all alternatives, but the ongoing cost per gallon of water is at the higher end of all options.

Bulk water deliveries can also be used as a supplemental water supply source when a primary source such as a spring, surface water, or rainwater harvesting system is no longer sufficiently supplying adequate water during a drought or dry stretch.

Springs and Surface Waters

Springs, which are essentially groundwater flowing directly onto the ground surface at a given point, may be a viable water source. Springs can flow intermittently or continuously. Lakes and streams are two common types of surface water. Seasonal (intermittent) springs and streams would require water storage capacity for use as a year-round water source. Generally, surface water requires more water quality treatment than groundwater/sub-surface water.

Rainwater Harvesting

Rainwater harvesting is the process of collecting rainwater and storing it for future use. A few states don't allow rainwater harvesting at all, strictly limit the collection volume, or require a permit, because they believe it violates existing water rights of other property owners. Some states only allow rainwater collection from your roof. Most states have no significant laws or regulations against rainwater harvesting and many of these states encourage the practice. The Pacific Northwest National Laboratory published a report entitled *Rainwater Harvesting State Regulations and Technical Resources*. This report attempts to summarize each state's regulation or lack thereof and provides a website link to many states' relevant regulations or technical resources. This report is from 2019, but is a good starting point for your own research purposes, so it has been included in the references at the end of this course. The American Rainwater Catchment Systems Association (ARCSA) website may also be a helpful resource.

Water collected by rainwater harvesting can be used for potable or non-potable purposes. The most common non-potable use is irrigation. Providing water for livestock and pets, toilet flushing, and clothes washing are probably the next most common non-potable uses.

The Oregon Department of Consumer and Business Services' Building Code Division provides a free publication on their website called *Oregon Smart Guide Rainwater Harvesting*. This 20-page document provides a good overview of rainwater harvesting. Figure 5 shows the common major components of a potable residential rainwater harvesting system. An off-grid tiny house would not require the RP device (a reduced pressure principal assembly that is a type of backflow prevention assembly) or water meter shown, since this figure shows a house connected to a community water system.

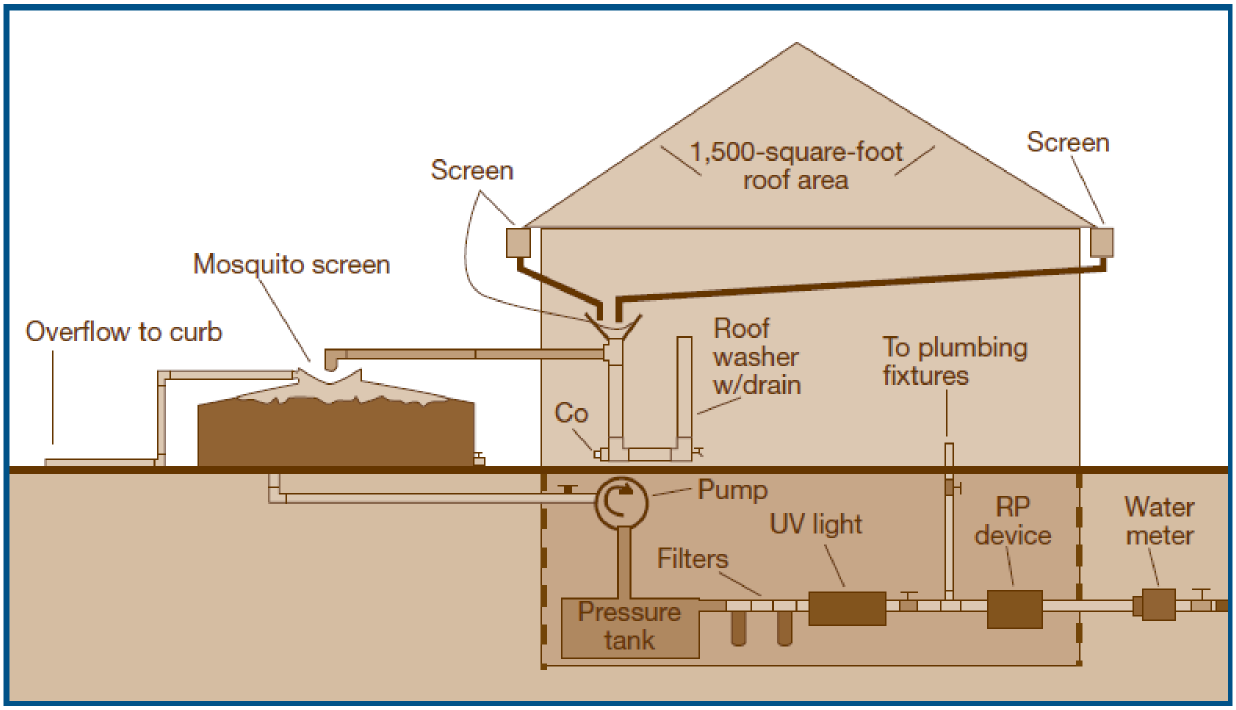


Figure 5: Major Components in a Potable Residential Rainwater Harvesting System (from the Oregon Department of Consumer & Business Services' Building Code Division)

Additionally, *Oregon Smart Guide Rainwater Harvesting* recommends a "five micron or less fiber cartridge filter followed by a three micron or less activated charcoal filter" and then goes on to state, "After filtering, the water must be disinfected by either chemical injection, ozone generators, or by a UV light" and "UV light systems should be listed to the ANSI/NSF 55 standard for Class A UV water treatment systems" to further give specifications for the filters and UV light components shown in the above figure. Appendix M of the 2008 Oregon Building Code provides even more in depth technical requirements for the entire harvesting system, including required components not shown in Figure 5, such as a first-flush diverter. If chosen, chemical injection would most likely be through chlorination. Full rainwater harvesting system kits, partial kits, and individual components are commercially available.

The Texas Water Development Boards' *The Texas Manual on Rainwater Harvesting* is an even more detailed publication that includes system component descriptions and photos, available material types for different components, water quality treatment options, sizing procedures, cost ranges for components and their operating costs, case studies, and more.

Many state and trade organization rainwater harvesting publications show sample storage sizing calculations using historical yearly or monthly precipitation data. Often average precipitation data is used, but sometimes median precipitation data is used instead. Median data tends to be more conservative, meaning it usually results in a larger calculated storage volume. I prefer using historical daily precipitation data when sizing rainwater harvesting systems used as the primary potable water source for a residence. Monthly data is probably sufficient for non-business irrigation purposes. Decades ago the daily precipitation method would not have been practical, but the precipitation data is now readily available in useable formats online and a basic spreadsheet can perform the tens of thousands of necessary calculations with ease. Of course, using historical precipitation data affords no guarantee about future precipitation amounts or distribution patterns.

Regardless of the time step (day, month, or year) selected, the calculations are the same. For each time step a mass balance equation is written for change in storage volume.

$$\Delta V = 7.48 A_c \frac{P}{12} \eta - C \quad (Equation\ 2)$$

Where: ΔV = Volume change, in gallons
A_c = Catchment area, in ft^2
P = Precipitation, in inches
η = Collection efficiency, in decimal form representing a percentage
C = Consumption, in gallons

The 7.48 coefficient converts cubic feet to gallons and the divisor of 12 converts inches of precipitation to feet of precipitation. Collection efficiency accounts for first-flush losses, evaporation, splash-out, etc. The storage available for use the next day is simply the previous day's storage plus the volume change, which can be either positive or negative. Obviously, there must be limits on available storage as it can never be below zero or more than the size of the storage tank or bladder volume.

The free software provided with this course (Excel spreadsheet) can be used for all examples and case studies. Relevant monthly and daily precipitation data for this course has been preloaded into the spreadsheet. Precipitation data for other locations is available from the National Oceanic and Atmospheric Administration's website (https://www.ncdc.noaa.gov/cdoweb/datatools/findstation). The rainwater harvesting formulas in the software utilize Equation 2 and have been pre-programed to limit the available storage as described in the above paragraph.

EXAMPLE #2:

A THOF will be built in Battle Ground, Washington. The owner has received multiple quotes from local well drilling companies and has determined it is prohibitively expensive to drill a well. They've asked their engineer to calculate the water storage tank size necessary for their rainwater harvesting system. The roof area of the THOF is 400 ft^2. Total water consumption is estimated at 32 gallons per day. The THOF is a seasonal home and will only be used from May to October. Assuming 90% collection efficiency, what size tank is recommended?

SOLUTION:

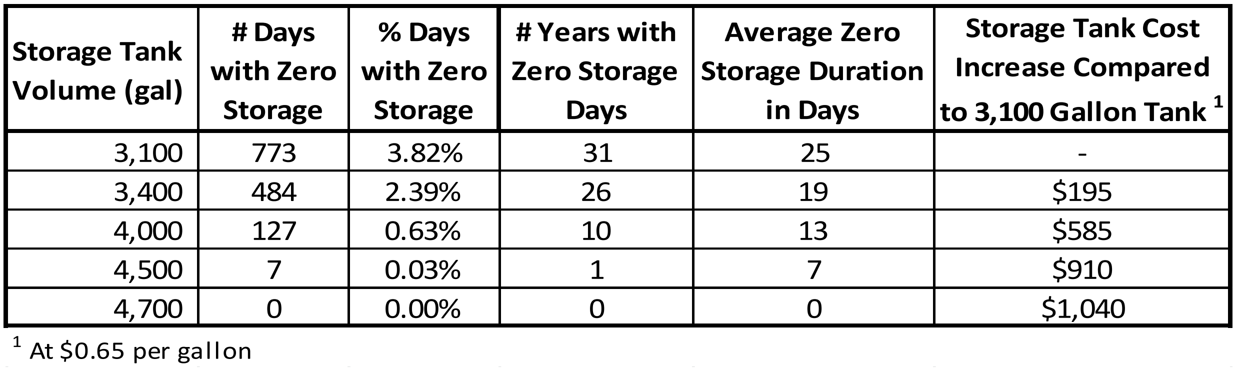
Using the provided software, start by sizing the storage tank using mean and median monthly precipitation data. Enter the provided values in the relevant input cells in the "Harvesting – Monthly" tab. The January end of month storage volume, when utilizing mean monthly data, calculated by the spreadsheet is 1,571 gallons when using our first tank size guess of 3,000 gallons. This volume was calculated by plugging the givens into Equation 2 for the first time step, as shown below:

$$\Delta V = \left[\left(7.48\frac{gal}{ft^3}\right)(400\ ft^2)\frac{7\ in}{\left(\frac{12\ in}{1\ ft}\right)}(0.90)\right] - \left[\left(32\ \frac{gal}{day}\right)(0\ days)\right]$$

$$\Delta V = 1{,}571\ gal - 0\ gal = 1{,}571\ gal$$

Looking at the end of month storage volumes, we see the mean monthly method shows all months have adequate water storage. However, September and October have no storage left by the end of the month when using median monthly precipitation data. This is because the historically extreme high and low months are included in the mean calculation, but essentially irrelevant when calculating the median. Increasing the tank size to 3,100 gallons (surprisingly a tank size that is sold), results in all months having enough end of month storage for both the mean and median monthly methods.

Click on the "Harvesting – Daily" tab to see the results using 56 years of historical daily precipitation data from the beginning of 1966 until the end of 2021. A 3,100 gallon tank would have had 773 days over this 56 year period without water in it, which is 3.82% of days. Moving to the "Graph" tab, you will see a visual overview of when this tank ran out of water. A quick count shows 31 separate years, which means there was a shortage of water more than every other year for an average duration of about 25 days, usually in the late August to early October timeframe. The most severe shortage looked to occur in 2018 when 52 days of no water storage was calculated. Since the material-only cost of storage tanks is $0.65 per gallon or higher, and it likely costs a minimum of $200 per bulk water delivery, it makes sense to increase the tank size by a minimum of 300 gallons ($200/$0.65=308). See Table 2 for a summary of tank sizes and various "zero storage" metrics.



Storage Tank Volume (gal)	# Days with Zero Storage	% Days with Zero Storage	# Years with Zero Storage Days	Average Zero Storage Duration in Days	Storage Tank Cost Increase Compared to 3,100 Gallon Tank [1]
3,100	773	3.82%	31	25	-
3,400	484	2.39%	26	19	$195
4,000	127	0.63%	10	13	$585
4,500	7	0.03%	1	7	$910
4,700	0	0.00%	0	0	$1,040

[1] At $0.65 per gallon

Table 2: Summary of Tank Sizes and "Zero Storage" Metrics for Battle Ground, Washington Example

Any tank size 4,000 gallons or greater would probably be acceptable and it might be appropriate at this time to present the results to the client to see if they are willing to reduce consumption when the tank storage level gets low or if they are open to using bulk water deliveries if they run out of water. From a financial standpoint, it probably makes sense to increase the tank size to at least 4,500 gallons since that $910 increased cost reduces the number of years with zero storage days from 31 to 1. Just three to four bulk water deliveries would likely cost more than the extra $910 capital cost. Alternatively, the design professional may decide they are only comfortable if they apply a safety factor on top of the 4,700 gallon size that shows no historical zero storage days.

Treating and Reusing Gray Water

Treating and reusing gray water is technically feasible. In fact, treating black water to drinking water standards has been occurring for years in several Texas municipalities. The method of treatment generally includes multiple filtration processes, reverse osmosis, and disinfection. Additionally, storage capacity is required since the waste is not generated at the same rate and time as consumption. On a small scale, treating and reusing gray water for off-grid non-drinking water purposes may be practical, but it's likely not for drinking water purposes. Not only is the upfront cost for treatment and storage likely high, but such off-grid systems wouldn't have the round-the-clock staff and constant water quality testing that occurs at treatment plants. Consequently, the most common off-grid gray water reuse is probably using the generated gray water for irrigation purposes to reduce or eliminate using potable water for irrigation.

Wastewater Treatment or Disposal

Tiny houses can have either combined or separate drain-waste-vent (DWV) systems. A DWV system is the piping and fittings located within a building which are responsible for removing black and gray water from fixtures. Combined plumbing systems have a single DWV system, while black water and gray water have different DWV systems in a separate system. 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.

A THOW with three separate discharge locations: a black water discharge for the flush toilet, a gray water discharge for the bathroom tub and sink, and a gray water discharge for the kitchen sink. This provides the opportunity to use the gray water effluent for reuse purposes and reduce the volume of black water treatment or disposal 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.

Potential wastewater treatment and disposal methods include centralized wastewater systems, septic systems, alternative technology/advanced treatment, gray water reuse systems, and tank storage with wastewater hauling. For the purpose of this course, all of these, other than centralized wastewater systems, would be considered off-grid options. The commonly used terms "on-site sewage treatment" or "decentralized wastewater treatment" are roughly synonymous with these off-grid options.

Figure 6 is a flowchart to help determine an appropriate toilet type, DWV system type, and wastewater treatment or disposal method for a THOW and its specific circumstances.

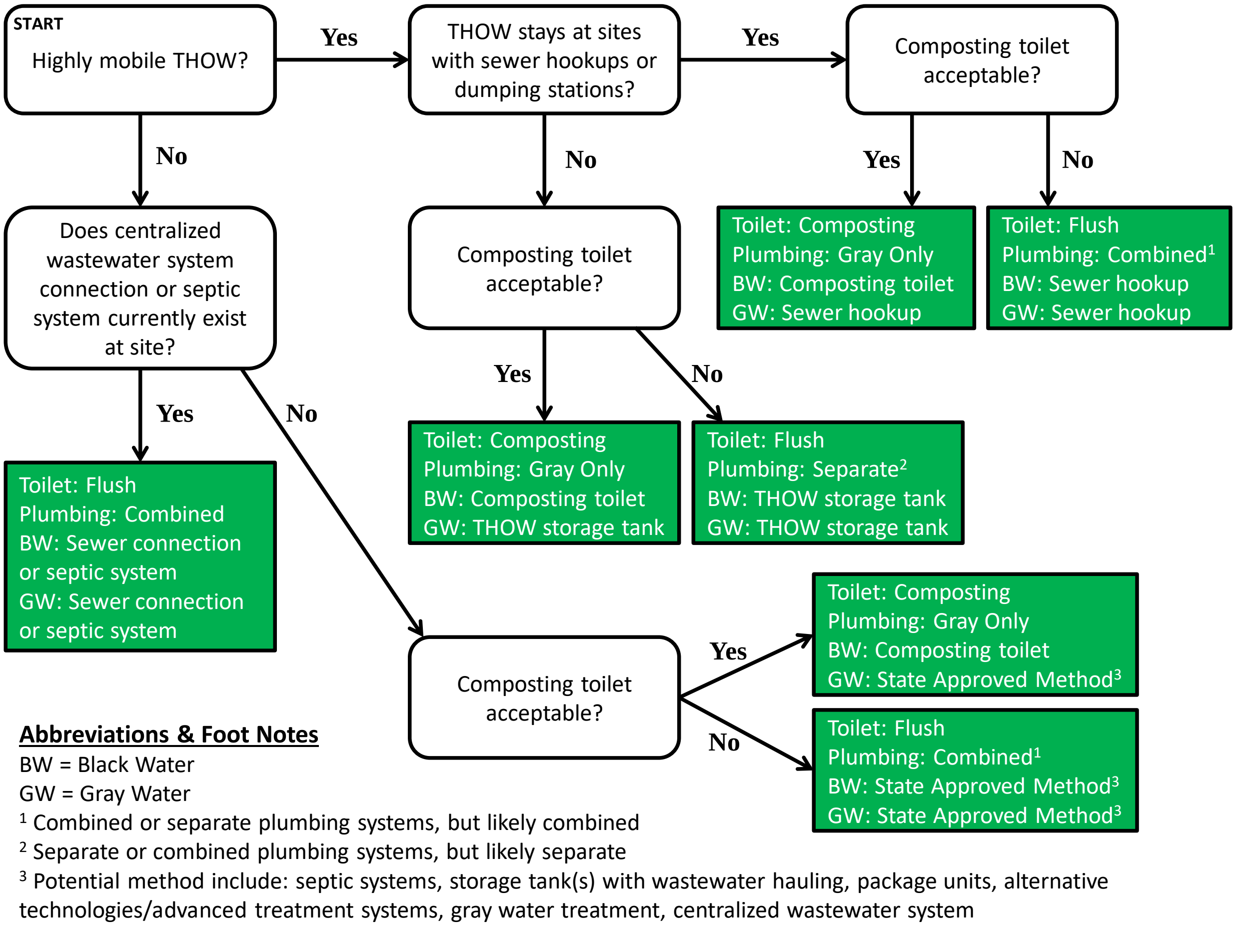


Figure 6: Wastewater Treatment or Disposal Selection Flowchart

Toilet Options

Both traditional flush toilets and composting toilets are common in tiny houses. Of course, flush toilets need a water supply and somewhere to discharge black water, such as a sewer connection to a centralized wastewater system or septic system. The most basic flush toilets cost 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. It does 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. Composting toilets cost anywhere from $900 to several thousand dollars.

Centralized Wastewater Systems

If available, disposing your wastewater to a centralized wastewater system (when Figure 6 states sewer connection or sewer hookup, this is what it's referring to) is likely your best route. If a THOW is located at a camp site or RV resort, likely the only items necessary to connect to the existing wastewater system are RV sewer hose(s) and an RV sewer adapter to fit inside the sewer hose connection point. For a THOW in a backyard, excavation and additional piping will likely be necessary to create a sewer hose connection point like at a camp site. If a sewer collection system exists in the street adjacent to the site, then a sewer lateral (pipe) and one or more cleanouts would ordinarily be needed. Most utility departments charge a connection fee or impact fee which is often a fixed fee per single-family residence or based on the associated water meter size. These fees often vary between $2,000 and $6,000 for a typical residence. If a sewer system is not already present in an adjacent street, the cost of extending the system is likely cost prohibitive for a single residence.

Septic Systems

According to the EPA website "nearly one in four households in the United States depends on an individual septic system or small community cluster system to treat its wastewater."

Usually a septic system is composed of two components: a septic tank and a drain field (sometimes alternatively called a leach field or soil absorption field). The septic tank isolates oils, grease, other floatables, and solids from the wastewater. Solids settle at the bottom of the tank and floatables rise to the top. The liquid portion of the wastewater, called the effluent, flows out of the septic tank by gravity, through a distribution box, and into a series of chambers or perforated pipes buried underground (the drain field) which disperse the effluent into the soil over time. Percolation through the soil removes many nutrients, bacteria, and viruses. This type of system is usually referred to as a conventional system. Perforated pipes are typically buried in a trench filled with stone or gravel, while chambers are usually backfilled with native soil. A conventional system's material and labor cost might range from $5,000 to $8,000.

Other types of septic systems include pressure distribution systems ($7,000 to $12,000 installed price), mound systems ($10,000 to $20,000 installed price), recirculating sand filter systems ($15,000 to $25,000 installed price), and constructed wetland systems. The EPA's website provides descriptions, summaries, and graphics of many of these systems (https://www.epa.gov/septic/types-septic-systems). These non-conventional systems provide solutions to sites with less than ideal soils, steep slopes, challenging topography that require pumps, high groundwater tables, shallow bedrock, etc. In addition to higher upfront costs, the ongoing maintenance costs (electricity, government mandated periodic inspections by licensed personnel, pump replacement, etc.) are higher than conventional systems. Conventional systems usually only need the septic tank pumped every three to five years to remove built-up solids.

Septic system regulations vary from state to state and often even from county to county in a given state. The local health department is almost always the permitting agency. However, if your exact building site is not known yet, a general overview of the likely requirements is available in the International Private Sewage Disposal Code (IPSDC). See the references section for a link to this model, primarily prescriptive code.

The major design inputs for one- and two-family dwellings are the number of bedrooms and the percolation rate for the soil in the drain field area. The required area of the drain field trenches is typically between 150 and 350 ft^2 per bedroom. The total required drain field area is larger than that because there are physical separation requirements between adjacent trenches, often six feet, and maximum individual trench lengths, typically 100 feet. Also, some jurisdictions require sizing based on a minimum of two bedrooms, even if a one-bedroom house is built. Septic tanks are typically between 750 and 1,500 gallons in volume, depending on the number of bedrooms.

You can frequently estimate the soil percolation rate, and the resulting drain field area needed, by reviewing permitting records of existing neighboring septic systems. The type of septic system will also be shown in these records, so this gives an indication if a conventional, or somewhat more advanced and expensive septic system, might be needed. Many counties make these permit records available in person or online.

For more detailed information on septic system design and soil permeability testing processes, see two SunCam courses in the references section of this course entitled *Septic System Design* and *Soil Permeability Testing*.

Alternative Technologies/Advanced Treatment

Occasionally, a property may have so many challenging conditions that a septic system by itself is not sufficient. In these instances, the use of on-site alternative technologies or advanced treatment may be appropriate. These systems treat wastewater to a higher standard than just a septic tank and drain field and are usually more expensive as well. The ability to use such systems is highly dependent on state or local laws and whether the specific system has regulatory approval in your state.

Package units, which are basically tiny wastewater treatment plants, are a ready-made solution. Also, there are numerous proprietary systems that add an additional treatment step between the septic tank and drain field. Some examples are BioMicrobics' suite of different Fixed Activated Sludge Treatment (FAST) systems, Enviro-Flo's BioRobix treatment system, Orenco's Advantex line of wastewater treatment systems, and the Whitewater Aerobic Wastewater Treatment system. The Glendon BioFilters system requires a septic tank, but no drain field in the typical sense.

Gray Water Reuse Systems

One common way to reduce the quantity of wastewater needing treatment or disposal is to reuse gray water for other purposes. By far, the most common reuse is for irrigation. Less frequently, toilets are flushed with the reused graywater. Regulation is highly variable from state to state. At one end of the spectrum, some states don't differentiate between black and gray water and require gray water to be treated the same as black water. At the other end of the spectrum, some states allow onsite reuse without a permit. Refer to the greywateraction.org link in the references section of this course for an attempt at summarizing gray water codes and policies in each state.

In some areas, no treatment whatsoever is required if the water is used for subsurface irritation. For those needing some basic level of treatment, there are commercially available systems that provide filters to remove lint, hair, etc. One such example is the Water Wise Aqua2use system which costs between $400 and $800, depending on the model. When greater treatment levels are required, chemical or biological treatment processes like the BioMicrobics BioBarrier Greywater-only Membrane BioReactor System (GWMBR) could be used. When chemical or biological treatment plus disinfection treatment is necessary, Orenco's Advantex greywater treatment system might fit the bill.

Diverting some or most gray water from a septic system or advanced treatment system should increase that system's longevity. It will likely not reduce the regulatory agency's sizing requirements of that system, but operation/maintenance costs should be lower. In my opinion, the greatest benefit of gray water reuse is the reduction in black water tank size if you haul your black water to a treatment facility or store it in a THOW with an integral black water tank.

Tank Storage with Wastewater Hauling

When the aforementioned treatment or disposal options are unavailable, impractical, or have prohibitively expensive upfront costs, storing and having your wastewater pumped and hauled away periodically may be an option. In many areas, portable toilet companies and septic tank pumping companies will bring their vacuum or pumper trucks to your site to empty your wastewater storage tank(s).

Cost for this service differs greatly depending on geographic region, and most importantly, how far the truck drives to get to your location and then to a treatment facility to unload. Expect to pay $0.25 to $0.40 per gallon for hauling and disposal, with a minimum per trip cost of $200 to $600. Compare this per gallon rate to less than $0.01 per gallon when connected to a centralized wastewater system or essentially nothing once connected to a conventional septic system.

Holding tanks and bladders for wastewater cost around the same per gallon as water storage tanks and bladders. The largest pumper truck you can hire probably has 5,000 gallons or less capacity, so economically there is little use in buying a storage tank larger than 5,000 gallons. While not a binding regulation in most jurisdictions, Section 805 of the 2018 IPSDC requires a minimum holding tank capacity of 2,000 gallon for one and two bedroom one- and two-family dwellings.

EXAMPLE #3:

Owners of a THOW have found the general area they would like to settle down in. While they look for their dream property, a local friend has offered to let them park their THOW in the back of a 1-acre lot. Water is available, but no wastewater treatment or disposal options are already present. Since the THOW owners only plan to stay for a year or less at their friend's property, they believe it makes little sense for them to install a septic system or other treatment method. Plus, it would take months to permit and build the system. They have no dishwasher or laundry facilities in their THOW so toilet, shower, and sink use are their only water consuming and waste producing fixtures. For the two owners combined, assume ten toilet flushes, 16 minutes of shower use, and12 minutes of kitchen/bathroom sink use per day. How many days can they go between pumper truck service calls if they have a 3,000 gallon sewage holding tank? If their THOW has separate plumbing systems for black and gray water, how many days can they go between pumper truck service calls? Assume they don't have a garbage disposal, so their kitchen sink wastewater is considered gray water. Also, assume they can dispose of the gray water using a simple underground irrigation system.

SOLUTION:

Combined Pluming System:

$$Daily\ Use = Toilet\ Use + Shower\ Use + Sink\ Use$$

$$Daily\ Use = (1.6\ gpf)(10\ flushes) + (2.5\ gpm)(16\ min) + (2.2\ gpm)(12\ min)$$

$$Daily\ Use = 82.4\ gallons$$

$$Days\ Between\ Service\ Calls\ = \frac{Holding\ Tank\ Volume}{Daily\ Use}$$

$$Days\ Between\ Service\ Calls\ = \frac{3{,}000\ gallons}{82.4\ gallons/day} = \ 36\ days$$

Separate Pluming Systems:

$$Daily\ Black\ Water\ Use = Toilet\ Use$$

$$Daily\ Black\ Water\ Use = (1.6\ gpf)(10\ flushes)$$

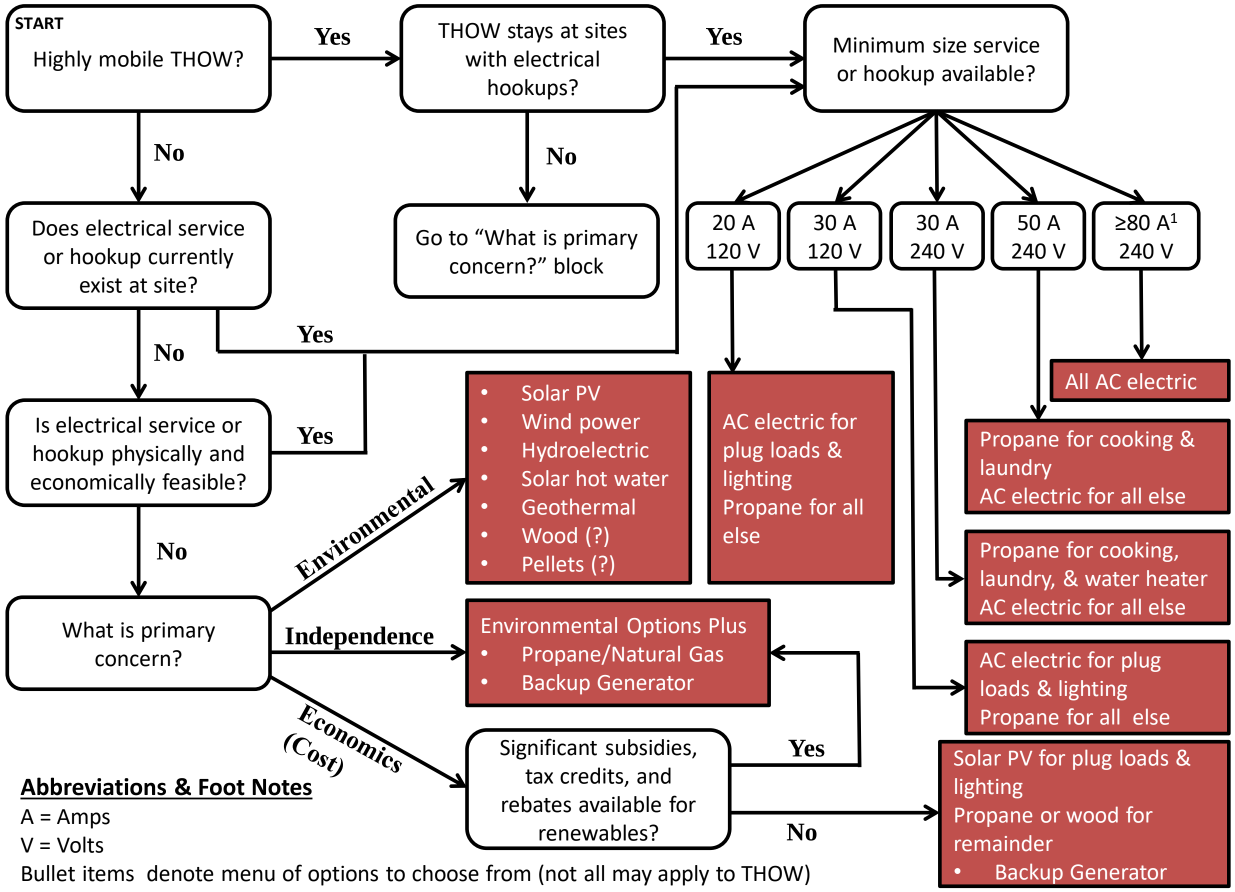
$$Daily\ Black\ Water\ Use = 16\ gallons$$

$$Days\ Between\ Service\ Calls\ = \frac{3{,}000\ gallons}{16\ gallons/day} = \ 187\ days$$

These calculations show the massive difference gray water reuse can result in. Even at a low price of $0.25 per gallon for hauling and disposal the difference in cost over one year is $6,059 ($7,519 for black and gray water and $1,460 for black water only).

Energy Sources

There are many potential energy sources conducive to THOF; however, the list for THOW is much more limited. THOW can utilize grid power, solar photovoltaic, wood, wood pellets, propane, and backup generators. THOF can add solar hot water, geothermal, natural gas, small-scale wind power, and small-scale hydroelectric to the previous list. 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 photovoltaics. No one energy source is ideal for all circumstances. This course will look at a few of the most commonly used energy sources. Figure 7 is a flowchart to help narrow the selection of plausible energy sources for a tiny house and its specific circumstances.



Abbreviations & Foot Notes

A = Amps
V = Volts
Bullet items denote menu of options to choose from (not all may apply to THOW)
¹ The IRC requires THOF to have ≥100 A services

Figure 7: Energy Source Selection Flowchart

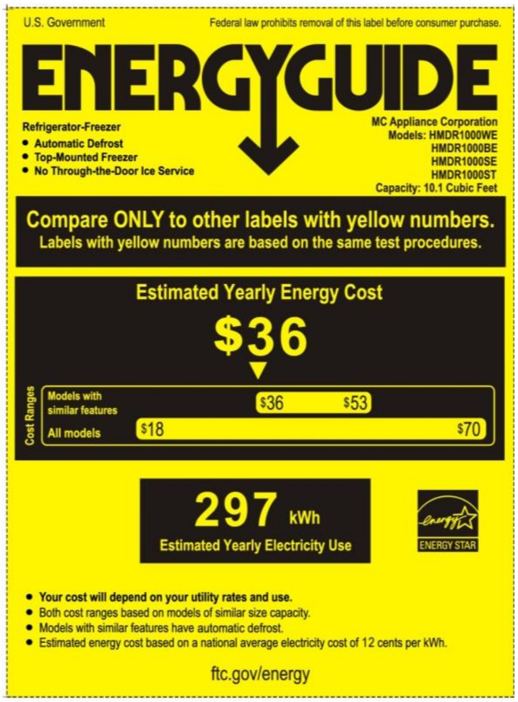
Within the flowchart, wood and pellets have a question mark after them because there is legitimate uncertainty whether their use is positive or negative for the environment. Also, use the following definitions/explanations when arriving at the "What is primary concern?" block of the flowchart:

- Economics – smaller monthly utility bills, as a hedge against increasing future electricity prices, government subsidies (tax credits, tax deductions, rebate, incentives), etc.
- Environmental – a desire to use renewable and/or "green" energy source(s)
- Independence – a desire to have power during outages, disconnect from the grid, etc.

For example calculations and explanation of how the recommended combinations of energy sources were arrived at for each grid power service or hookup size, refer to the *Tiny Houses Part 4* section on "Calculating Service Loads and Sizing Service Wires."

Peak Power and Daily Power Use

Before determining what energy source(s) you will use, it's imperative to understand the options available and how much energy various appliances and equipment might consume based on their use patterns. Peak power, or a fraction thereof, is used to size electrical services connected to grid power. Average daily power is used to size solar photovoltaic systems. Peak power can be obtained from product documentation or the physical nameplate on the appliance or equipment. The power listed on nameplates is output power, not input power. For very "efficient" appliances, they can be assumed identical for our purposes (for example a toaster oven). But for some appliances the difference is quite significant. For example, microwaves are only about 70% efficient in converting input power to output power, so a 900 watt output requires a 1,300 watt input. Average daily power use can be taken from the "Energy Guide" provided with some products. Most often it is reported in the form of estimated yearly electricity use, which is easily converted to daily use. Alternatively, if you already own the



U.S. Government
Federal law prohibits removal of this label before consumer purchase.

ENERGYGUIDE

Refrigerator-Freezer
- Automatic Defrost
- Top-Mounted Freezer
- No Through-the-Door Ice Service

MC Appliance Corporation
Models: HMDR1000WE
HMDR1000BE
HMDR1000SE
HMDR1000ST
Capacity: 10.1 Cubic Feet

Compare ONLY to other labels with yellow numbers.
Labels with yellow numbers are based on the same test procedures.

Estimated Yearly Energy Cost
$36

Cost Ranges
Models with similar features $36 $53
All models $18 $70

297 kWh
Estimated Yearly Electricity Use

- Your cost will depend on your utility rates and use.
- Both cost ranges based on models of similar size capacity.
- Models with similar features have automatic defrost.
- Estimated energy cost based on a national average electricity cost of 12 cents per kWh.

ftc.gov/energy

Figure 8: Example Appliance Energy Guide

product, energy usage can be directly measured using an electricity usage monitor like a Kill A Watt meter.

The photo to the right is from a gas range. It shows the maximum British Thermal Units (BTU) for each burner (RF = right front, LR = left rear, BAKE is for the oven). This model has separate baking and broiling compartments and physically uses the same 12,700 BTU element for both functions. An electric range nameplate will commonly show the stovetop burners and the oven compartment in maximum watts, whether that be the baking or broiling element. In both gas and electric ranges, this is the maximum output. Medium heat, simmering, baking at 350°F, etc. will use something less than the maximum output. To compare propane to electric appliances use the conversion ratio of 1,000 watts equals 3,412 BTU/hour. The provided software has a "Power Unit Converter" tab to assist with converting between various units of measure.

Amana®
Whirlpool U.S.A.
Benton Harbor, MI 49022
USA: 800.843.0304
120V 60Hz 10A 1 Phase

THIS UNIT IS FACTORY SET FOR USE WITH NATURAL GAS SEE THE INSTALLATION INSTRUCTIONS FOR CONVERSION TO L.P. GAS.

BTU RATINGS	RF	LF	RR	LR	BAKE	BROILER
4" WC NAT.	7000	9500	9500	7000	12700	---
10" WC LP	7000	8500	8500	7000	12700	---

SEE OTHER LABEL FOR FURTHER INFORMATION.
ALSO FOR INSTALLATION IN A MANUFACTURED (MOBILE) HOME
OR RECREATIONAL PARK TRAILER. MADE

Example Appliance Nameplate

See Table 3 for peak power and average daily energy used by common alternating current (AC) appliances and equipment. In the case of Table 3 for AC appliances and equipment, and Tables 4 and 5 for direct current (DC) and propane that follow, a representative manufacturer and model was selected and its information given. The tables are only rough guides and, of course, there is a wide range of energy usage and cost for each table line item. Certainly, appliances and equipment come in various sizes, power outputs, and efficiencies, but the duration of use can easily increase or reduce the average daily use by two or three times. Even a relatively non-interactive appliance like a refrigerator can consume half or twice as much energy per day as "normal" depending on the ambient air temperature and interior temperature(s) selected.

See *Tiny Houses Part 4* and this course's appendix for size ranges, approximate cost, and energy source availability information for AC, DC, and propane appliances and equipment.

Example Appliance or Equipment	**Peak Power (Watts)**	**Average Daily (kWh)**	**Cost**	**Comment**
Refrigerator with Freezer Magic Chef 10.1 ft^3 Top Freezer Refrigerator (Model #HMDR1000WE)	160	0.8	$400	
Range Frigidaire 24", 1.9 ft^3, 40A, Electric Range (Model #FFEH2422US)	9,450	1.9	$1,000	THOW often use ranges 20" to 24" wide. Peak power is 4 burners on high and broiler on simultaneously.
Cooktop Kenyon Mediterranean Series 12" Smooth Glass Electric Cooktop, 2 Elements (Model #B41596)	2,400	0.9	$325	May be built into a countertop or moveable, plug-in varieties. They usually consist of two to four burners.
Microwave (900W Output)	1,300	0.2	$129	Assumes 10 min/day at full power
Toaster Oven	1,300	0.4	$150	Assumes 20 min/day at full power
Toaster	750	0.05	$12	
Coffee Maker, 5 cup	600	0.15	$10	Assumes 15 min/day at full power
Dishwasher, 18"	1,400	0.7	$650	
Washing Machine, top load	600	0.6	$600	
Dryer	4,000	2.0	$500	120 and 240 volt dryers exist
Water Heater, 20 gallon	3,800	6.5	$400	
Ceiling Fan, 48"	65	0.1	$75	
Heater, In-Wall	3,000	6.0	$200	Assumes 2 hrs/day at full power
Heat Pump, 9,000 BTU, 20 SEER	960	1.9	$900	Assumes 2 hrs/day at full power

Table 3: Example Alternating Current (AC) Appliance and Equipment Information

Table 4 shows energy usage information for select DC appliances and equipment.

Example Appliance or Equipment	**Peak Power (Watts)**	**Average Daily (kWh)**	**Cost**	**Comments**
Refrigerator with Freezer SunDanzer, 15 ft^3 (Model #DCRF450)	70-110	0.89 at 90°F 0.55 at 70°F	$2,500	Volume is typically between 1 and 16 ft^3. 12, 24, and 48 volt models available.
Microwave	900	0.2	$800	24 volt
Washing Machine	60-400	0.2	$250	12/24 volt
Water Heater, 3 gallon	300	0.9	$700	12 volt
Water Heater Element	900	1.8	$30	For converting AC electric water heater to 24 volt DC electric
Heat Pump HotSpot Energy, 12,000 BTU (Model #ACDC12C)	<1,028	2.1	$1,800	3 to 6 solar PV panels required (870W minimum) Assumes 2 hrs/day at full power

Table 4: Example Direct Current (DC) Appliance and Equipment Information

Gas ranges usually can use either propane or natural gas. Often they come with the conversion parts included, but sometimes a conversion kit must be purchased separately. The conversion process is ordinarily quite simple and quick. The process involves removing the factory installed nozzle for each burner element and replacing it with a nozzle with a different orifice size. Propane orifices are smaller due to the higher pressures they operate under. Other appliances are sometimes convertible, but not always.

Refer to Table 5 for example propane appliance and equipment energy consumption information.

Example Appliance or Equipment	BTU Information	Cost	Comment
Refrigerator with Freezer EZ Freeze EZ-10W 10 ft^3 Propane Refrigerator	0.25 gal/day	$1,700	
Range Amana 20", 4 Burner, 2.6 ft^3 Gas Range (Model #AGG222VDW)	Two 7,000 BTU burners Two 8,500 BTU burners 12,700 BTU bake/broil oven element	$700	THOW often use ranges 20" to 24" wide. Igniter options include AC electric, batteries, and matches.
Cooktop, 2 burner	One 12,000 BTU burner One 4,000 BTU burner	$250	
Dryer	22,000 BTU/hr	$600	
Water Heater, 30 gallon	30,000 BTU/hr 0.40 gal/day	$900	0.40 gal/day calculated from Energy Guide (134 therms/yr estimated use)
Water Heater, tankless, 7.0 GPM	160,000 BTU 0.62 gal/day	$1,000	4.2 GPM at 65°F rise 0.62 gal/day calculated from Energy Guide
Furnace, RV, 12,000 BTU, 12V	0.26 gal/day	$850	Assumes 2 hrs/day at rated BTUs

Table 5: Example Propane Appliance and Equipment Information

Grid Power

A tiny house is on grid power whenever it connects to an existing electrical distribution system that receives power from centralized power production facilities. This could be in a campground, in the backyard of another house, or as the primary house on a residential service drop. If a THOW is parked at a camp site or RV resort, likely the only item necessary to connect to the existing power grid is the proper power cord. A THOW in a backyard will likely need a new circuit and proper receptacle added to the main house's electrical system since most houses only have 20 amp circuits and receptacles on their exteriors. A new residential service drop for a property is fairly inexpensive, and occasionally free or nearly free, if the utility already has power in the adjacent street and the residence is located close to the street. If the new service drop needs to extend many hundreds or thousands of feet, the cost may be prohibitively expensive for a tiny house. A $15 to $30 per foot installation cost would not be uncommon.

Tiny Houses Part 4 shows step-by-step how to calculate the service load for a tiny house. In this course we will only use the provided software to calculate the service load. The software is capable of using either of the two methods allowed by the NEC and IRC. The "Standard Method" can be used in a wide variety of applications while the "Optional Method" can be used in a narrower range of circumstances. The Optional Method only applies to dwelling units served by a single 3-wire service or feeder with an ampacity of 100 or greater. Many electricians use the Standard Method all the time to avoid using the Optional Method inappropriately.

EXAMPLE #4:

A THOF has 380 square feet of floor area (outside dimensions), 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 3/4 horsepower (hp)/115 volt garbage disposal, one 4,000 W clothes dryer, one 4,500 W water heater, one 32 amp/240 volt electric car charger, and three separately controlled fan-forced in-wall 1,500 W heaters units. What is the minimum total service load amperage using the Optional Method?

SOLUTION:

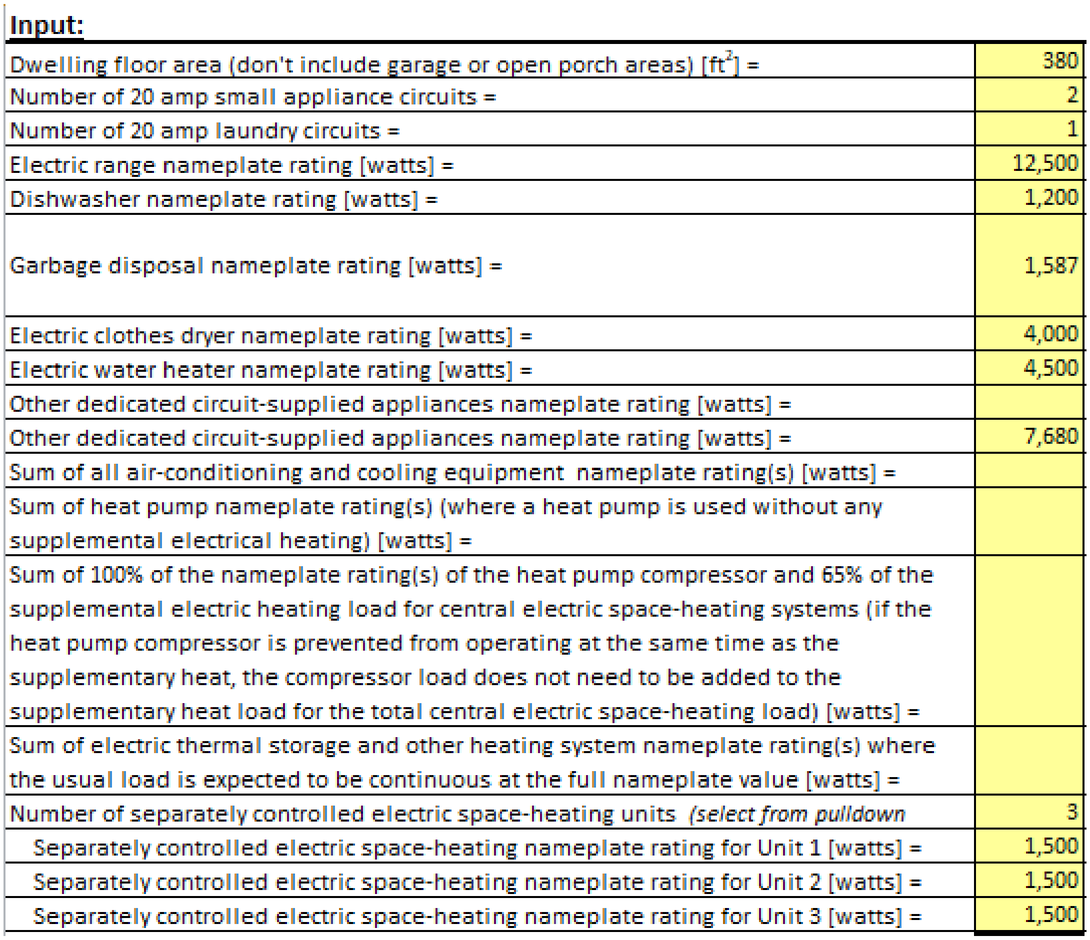
The garbage disposal amperage is found by using NEC Table 430.248 in the software's "Standard Method" tab. The amperage is then multiplied by the voltage (115 volts was given instead of 120 volts since that is the voltage used by the NEC table).

$$Garbage\ Disposal\ Wattage = (13.8\ amps)(115\ volts) = 1{,}587\ watts$$

The electric car charger wattage is calculated by multiplying the given amperage by voltage.

$$Electric\ Car\ Charger\ Wattage = (32\ amps)(240\ volts) = 7{,}680\ watts$$

Enter the appropriate numbers from the example scenario into the software's "Optional Method" tab input cells as shown below.



Input:

Dwelling floor area (don't include garage or open porch areas) [ft^2] =	380
Number of 20 amp small appliance circuits =	2
Number of 20 amp laundry circuits =	1
Electric range nameplate rating [watts] =	12,500
Dishwasher nameplate rating [watts] =	1,200
Garbage disposal nameplate rating [watts] =	1,587
Electric clothes dryer nameplate rating [watts] =	4,000
Electric water heater nameplate rating [watts] =	4,500
Other dedicated circuit-supplied appliances nameplate rating [watts] =	
Other dedicated circuit-supplied appliances nameplate rating [watts] =	7,680
Sum of all air-conditioning and cooling equipment nameplate rating(s) [watts] =	
Sum of heat pump nameplate rating(s) (where a heat pump is used without any supplemental electrical heating) [watts] =	
Sum of 100% of the nameplate rating(s) of the heat pump compressor and 65% of the supplemental electric heating load for central electric space-heating systems (if the heat pump compressor is prevented from operating at the same time as the supplementary heat, the compressor load does not need to be added to the supplementary heat load for the total central electric space-heating load) [watts] =	
Sum of electric thermal storage and other heating system nameplate rating(s) where the usual load is expected to be continuous at the full nameplate value [watts] =	
Number of separately controlled electric space-heating units *(select from pulldown*	3
Separately controlled electric space-heating nameplate rating for Unit 1 [watts] =	1,500
Separately controlled electric space-heating nameplate rating for Unit 2 [watts] =	1,500
Separately controlled electric space-heating nameplate rating for Unit 3 [watts] =	1,500

Figure 9: Screen Shot of Software Inputs for Example #4

Step 8 of the output section in the software calculates a minimum of 99 amperes is necessary. Select a 3-wire, 100 amp minimum service size and 100 amp minimum panelboard since those are 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)).

Solar Photovoltaics

The purpose of this course is not to show how to design an entire solar photovoltaic (PV) system. SunCam already has a five-part course on designing, installing, inspecting, and evaluating solar PV systems. Rather, this section will show you how to size the collection and energy storage components of an off-grid PV system. Mobility freedom in THOW is a major reason for using solar PV. People who regularly move their THOW and don't always stop where they can connect to the grid often use PV to produce enough power for plug loads, lighting loads, and select appliances and equipment.

First, a very brief overview of the major components of a solar PV system is necessary. The purpose of each major component is listed below:

- Solar PV Array – A solar collection system consisting of one or more connected PV modules (panels) that convert sunlight to DC electricity
- Racking – Structural system used to attach modules to the roof, ground, or other surface and hold the modules at the optimal or desired angle
- Combiner Box – A box where PV module wiring is connected together to produce the desired voltage output
- Battery Bank – The most commonly used residential energy storage method. Energy storage allows use of energy at a time other than when it is collected. Grid-tied (on-grid) systems may or may not have energy storage.
- Charge Controller – A control system that directs when electricity is used to charge batteries versus electricity release from batteries
- Inverter – Device(s) that convert DC electricity to AC electricity. Some PV systems use one large inverter while other systems use a microinverter at each PV module.
- Disconnect(s) – A DC disconnect allows isolation or shut-off of the DC side of a system for safety or service reasons. In a grid-tied system, an AC disconnect allows isolation or shut-off of the solar PV system from the power grid.
- Backup Power – Alternative power source when a PV system and battery bank (if present) cannot provide sufficient power for the electrical demand

Solar PV components are shown in Figure 10 and Figure 11. Figure 10 shows a grid-tied system which might be used for a highly mobile THOW moving between locations with and without electric grid access. AC only loads, instead of dual AC/DC systems are shown, but a dual electric system is certainly an option. If 2-way or 3-way appliances are desired, a dual electric system makes a lot of sense. The battery bank and charge controller are optional, but both are necessary to go off-grid.

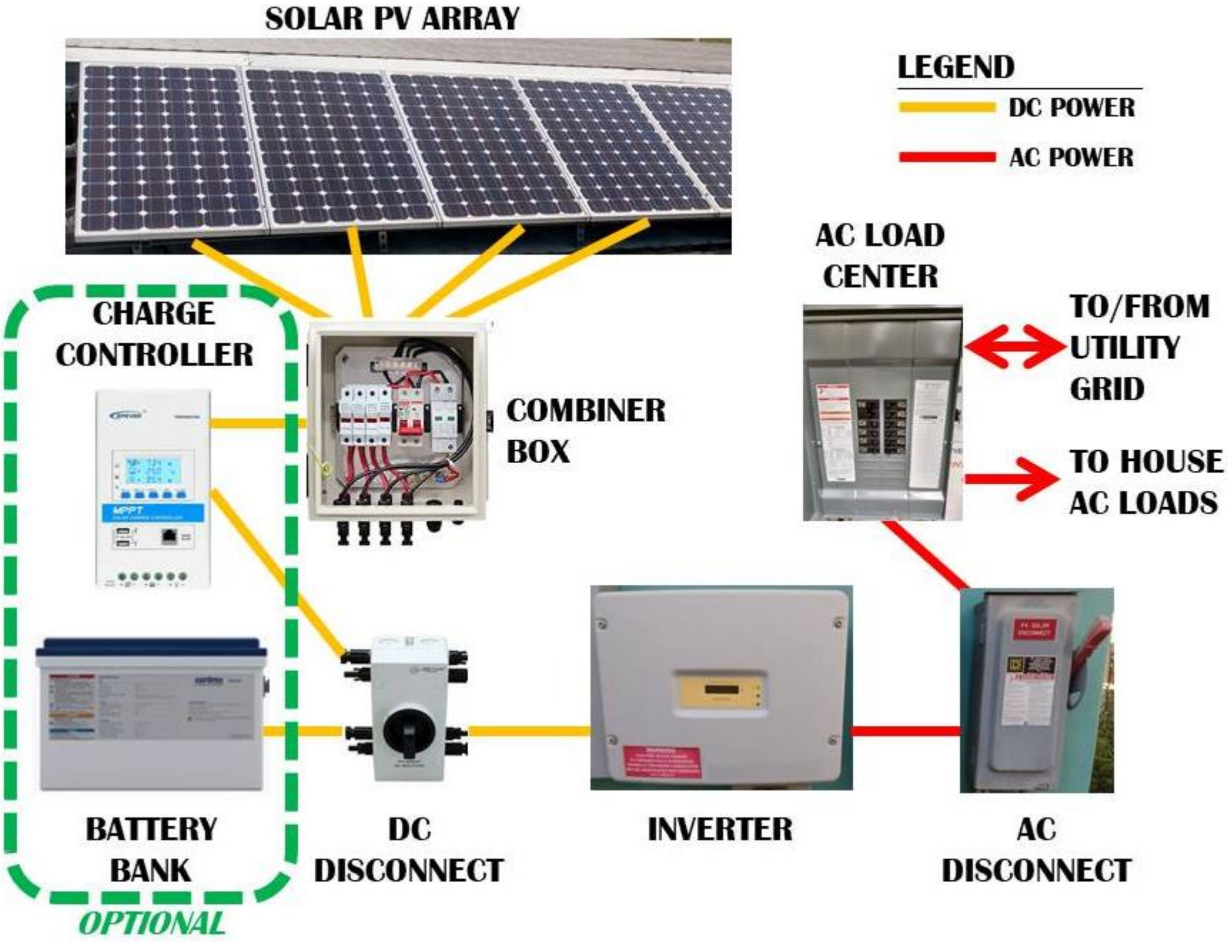


Figure 10: Major Components of a Grid-Tied Solar PV System

Figure 11 depicts a totally off-grid system with dual AC/ DC systems. The DC system is optional, but is often advantageous to avoid inverter losses of 10% to 20% when converting from DC to AC. The generator for backup power and battery charging is also optional. Backup power is useful, especially for an off-grid THOF.

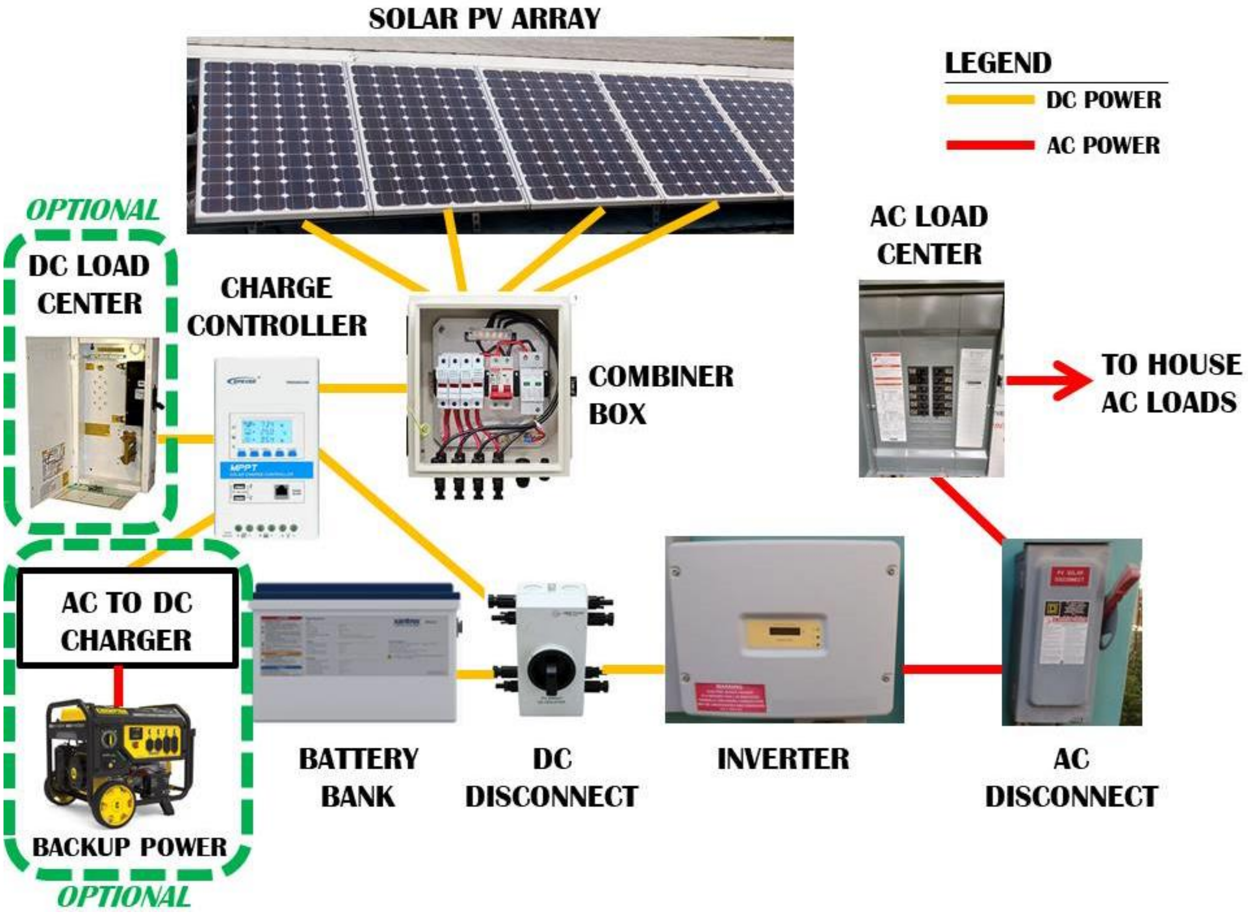


Figure 11: Major Components of an Off-Grid Solar PV System

Currently, most residential PV modules come in wattages ranging from 300 to 550 watts. The module wattage in a product description is the maximum rated power, which is the maximum the module can produce under Standard Test Conditions (STC). If there is a module voltage in a product description it is likely the nominal voltage. Modules commonly cost between $0.70 and $1.50 per watt. A 350 watt monocrystalline module is somewhere around 70" long by 40" wide and weighs approximately 45 pounds.

Modules spec sheets and nameplates sometimes list two or three different voltages. Open circuit voltage (*Voc*) is the voltage measured when no load is on the module. Voltage at maximum power (*Vpmax*) is the voltage when the module is producing the most power under STC. Module nominal voltage speaks to the voltage used for battery charging. Batteries are charged at a higher voltage than they discharge at. A 24 volt module (nominal) has a *Voc* around 44 volts and a *Vpmax* around 36 volts.

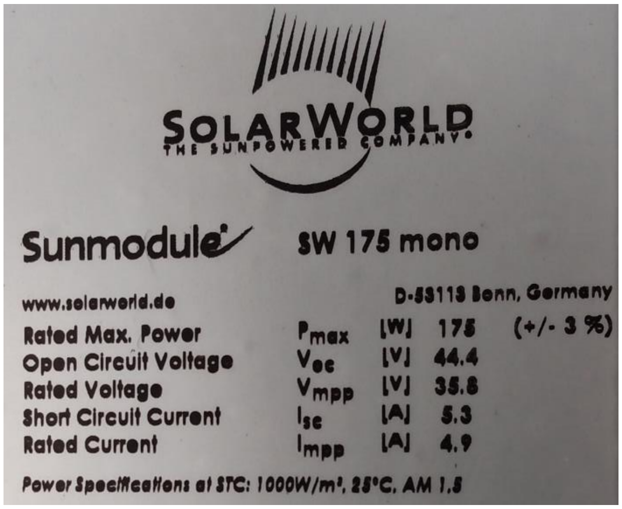
The relationship between power, voltage, and current is:

$$Ipmax = \frac{Pmax}{Vpmax} \quad (Equation\ 3)$$

Where: $Ipmax$ = Current at maximum power (sometimes called rated current)
$Pmax$ = Maximum power (sometimes called rated max power)
$Vpmax$ = Voltage at maximum power (sometimes called rated voltage)

In the photos of module nameplates below, you can use Equation 3 to calculate the $Ipmax$ and compare it to the nameplate values.

$$Ipmax = \frac{175\ watts}{35.8\ volts} = 4.9\ amps \text{ OR } Ipmax = \frac{40\ watts}{2.4\ volts} = 16.7\ amps$$



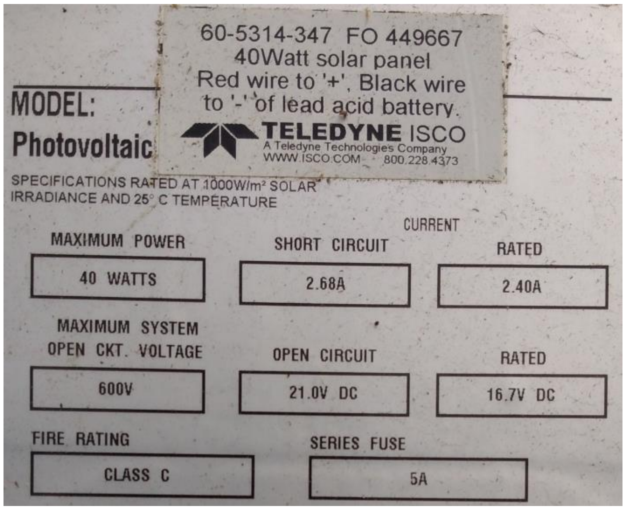
SOLARWORLD
THE SUNPOWERED COMPANY®

Sunmodule® SW 175 mono

www.solarworld.de D-53113 Bonn, Germany

Rated Max. Power	P_{max}	[W]	175	(+/- 3 %)
Open Circuit Voltage	V_{oc}	[V]	44.4	
Rated Voltage	V_{mpp}	[V]	35.8	
Short Circuit Current	I_{sc}	[A]	5.3	
Rated Current	I_{mpp}	[A]	4.9	

Power Specifications at STC: 1000W/m², 25°C, AM 1.5



60-5314-347 FO 449667
40Watt solar panel
Red wire to '+', Black wire to '-' of lead acid battery.
TELEDYNE ISCO
A Teledyne Technologies Company
WWW.ISCO.COM 800.228.4373

MODEL:
Photovoltaic

SPECIFICATIONS RATED AT 1000W/m² SOLAR IRRADIANCE AND 25° C TEMPERATURE

	CURRENT	
MAXIMUM POWER	SHORT CIRCUIT	RATED
40 WATTS	2.68A	2.40A
MAXIMUM SYSTEM OPEN CKT. VOLTAGE	OPEN CIRCUIT	RATED
600V	21.0V DC	16.7V DC
FIRE RATING	SERIES FUSE	
CLASS C	5A	

Left: Portion of nameplate from a Solar World SW175 module. It is a 175 watt, 24 volt (nominal) module.

Right: Portion of nameplate from a 40 watt, 12 volt (nominal) module.

Presently, batteries for solar applications come in sizes ranging from 30 amp-hours (Ah) to 400 Ah, with 100 Ah the most popular size. A 100 Ah, 12 volt, deep cycle, lithium-ion battery costs around $1,000, weights around 30 pounds, and has a physical volume of about 600 cubic inches. A 100 Ah, 12 volt, deep cycle, lead-acid battery costs around $250, weights around 60 pounds, and has a similar volume as the lithium-ion.

The average nationwide installed cost (material, labor, permitting, etc.) for a complete PV system without battery backup is around $2.94 per watt according to a 2021 study cited by *Marketwatch*.

Originally, PV systems were almost exclusively off-grid. It made sense to manufacture components at the same "standard" voltage so they could work together seamlessly. Or instead, double the previous "standard" voltage because you could wire components in series and double the voltage. Batteries were usually 6, 12, or 24 volts. DC appliances were almost all 12, 24, or 48 volts. PV modules were 12 or 24 volts (nominal). So you could use eight 6 volt batteries in series and four 12 volt modules in series to power a 48 volt appliance. Alternatively, you could use four 12 volt batteries in series and two 24 volt modules in series to power a 48 volt appliance. At this point in time, modules were often in the 40 to 200 watt range.

After grid-tied systems became more prevalent than off-grid systems, it became advantageous to create physically larger modules which produced higher wattage and voltages. This is because most grid-tied houses don't have DC appliances or battery banks and no system voltages need to be matched. Inverters convert the DC power to AC power which is used or sent back to the grid. Modules with nominal voltages of 20 volt, 27 volt, or higher now dominate the market. These newer voltages provide a challenge for PV systems with batteries, but the complications can be remedied using a maximum power point tracking (MPPT) charge controller that is able to lower the module output voltage to the necessary battery charging voltage.

The software provided with this course automates the PV array and battery sizing calculation steps. We'll use the software for case studies, but first let's go through the calculation step-by-step with an example scenario. To understand the impact of electricity hungry appliances on a PV system, the below example examines the size of PV system needed to power a heat pump.

EXAMPLE #5:

A highly mobile THOW moves around southern Arizona between off-grid and on-grid locations. The 120 volt AC heat pump draws 8 amps at maximum power. It runs the equivalent of 4 hours a day, seven days a week at maximum power. Assuming 90% inverter efficiency, a 24 volt DC system, 5 days of autonomy, and 85% battery discharge limit, how many 12 volt, 100 Ah lithium-ion batteries are needed for the heat pump? Assuming 80% battery efficiently, how many 200 watt, 24 volt (nominal) PV modules are needed for the heat pump?

SOLUTION:

Battery Sizing:

$$Power = (Voltage)(Amps)(Quantity) \quad (Equation\ 4)$$
$$Power = (120\ volts)(8\ amps)(1) = 960\ watts$$

$$Power\ per\ Day = \frac{(Power)(\frac{Hrs}{Day})(\frac{Days}{Week})}{7\ Days/Week} \quad (Equation\ 5)$$
$$Power\ per\ Day = \frac{(960\ watts)\left(4\ \frac{hrs}{day}\right)\left(7\ \frac{days}{week}\right)}{7\ \frac{days}{week}} = 3{,}840\ \frac{watt-hrs}{day}$$

$$\frac{Average\ Amp-Hours}{Day} = \frac{\left[\frac{AC\ Power\ per\ Day}{(Invertor\ Efficiency)} + DC\ Power\ per\ Day\right]}{DC\ System\ Voltage} \quad (Equation\ 6)$$
$$\frac{Average\ Amp-Hours}{Day} = \frac{\left(\frac{3{,}840}{0.90} + 0\right)}{24} = 177.8\ \frac{amp-hrs}{day}$$

$$Batteries\ in\ Parallel = \frac{(Average\ Amp-Hours\ Per\ Day)(Days\ of\ Autonomy)}{(Battery\ Discharge\ Limit)(Battery\ Amp-Hr\ Capaciy)} \quad (Equation\ 7)$$
$$Batteries\ in\ Parallel = \frac{(177.8)(5)}{(0.85)(100)} = 10.5\ \rightarrow\ round\ up\ to\ 11$$

$$Batteries\ in\ Series = \frac{DC\ System\ Voltage}{Battery\ Voltage} \quad (Equation\ 8)$$
$$Batteries\ in\ Series = \frac{24\ volts}{12\ volts} = 2$$

$$Total\ Batteries = (Batteries\ in\ Parallel)(Batteries\ in\ Series) \quad (Equation\ 9)$$
$$Total\ Batteries = (11)(2) = 22$$

Our calculations show twenty two 12 volt, 100 Ah lithium-ion batteries are necessary.

Array Sizing:

We first need to find out the peak sun hours per day for southern Arizona. Open the provided software, go to the "PV" tab, and scroll down to the Global Horizontal Solar Irradiance map from the National Renewable Energy Laboratory. Almost all of southern Arizona is the darkest red on the map. According to the map's legend this corresponds to greater than or equal to 5.75 kWh/m^2/day. One peak sun hour per day equals 1 kWh/m^2/day, so our peak sun hours per day are at least 5.75 hours. Please note this number does not take into account shading and obstructions from buildings, trees, etc. at a specific site. If a specific site it known, it is best to perform a solar site analysis using equipment made for that purpose. The map does take into account average cloud cover for areas, but doesn't take into account cloud cover specific to a site (e.g. next to a large body of water).

$$Array\ Peak\ Amps = \frac{Average\ Amp - Hours\ per\ Day}{(Battery\ Efficiency)(Peak\ Sun\ Hours\ per\ Day)} \quad (Equation\ 10)$$

$$Array\ Peak\ Amps = \frac{177.8\ \frac{amp - hrs}{day}}{(0.80)(5.75\ \frac{hrs}{day})} = 38.65\ amps$$

$$Peak\ Amps\ per\ Module = \frac{Module\ Wattage}{Module\ Rated\ Voltage} \quad (Equation\ 11)$$

Remember, 24 volt (nominal) modules have a rated voltage of 36 volts, so used 36 volts, not 24 volts

$$Peak\ Amps\ per\ Module = \frac{200\ watts}{36\ volts} = 5.56\ amps$$

$$Modules\ in\ Parallel = \frac{Array\ Peak\ Amps}{Peak\ Amps\ per\ Module} \quad (Equation\ 12)$$

$$Modules\ in\ Parallel = \frac{38.65\ amps}{5.56\ amps} = 6.95\ \rightarrow\ round\ up\ to\ 7$$

$$Modules\ in\ Series = \frac{DC\ System\ Voltage}{Nominal\ Module\ Voltage} \quad (Equation\ 13)$$

$$Modules\ in\ Series = \frac{24\ volts}{24\ volts} = 1$$

$$Total\ Modules = (Modules\ in\ Parallel)(Modules\ in\ Series) \quad (Equation\ 14)$$

$$Total\ Modules = (7)(1) = 7$$

Our calculations show seven 200 watt, 24 volt (nominal) PV modules are required. This would be considered a 1.4 kW system. The calculation methods presented placed batteries and modules in parallel and series to match voltages of the various components. A MPPT charge controller could negate the need for some parallel and series calculations, but the more traditional calculation procedures are presented here so a less sophisticated and less expensive charge controller could be sized and selected.

Wood and Wood Pellets

A cord is the common unit of measure for wood when used for burning purposes. A full cord, not to be confused with the much smaller face cord, is 128 ft^3 of stacked wood and is usually stacked in a 4' by 4' by 8' arrangement. Since split wood pieces don't stack perfectly against each other there are lots of air voids between pieces. This means there is not really 128 ft^3 of solid wood in a full cord. Between this variability in stacking, the wood moisture content, and the differences between wood species, the energy stored in a cord is not an exact science. Sources vary, but dried Douglas fir has around 21 million BTUs per full cord according to the United States Forest Service. A 50 year old, 24" diameter, 100' tall Doulgas fir tree has at least 2.5 full cords in it. Forest land in the Pacific Northwest likely has 150 such trees per acre. Both a THOW and a code-complaint 400 ft^2 THOF in the temperate Pacific Northwest likely would use less than one full cord per year, which is less than half of a 24" diameter tree. As mentioned previously, many rural properties have a lifetime or essentially indefinite supply of wood for onsite space heating use. My grandparents' lived for 40 years in the Northwest in a 1,800 ft^2 house heated by wood. They primarily lived on one of the two floors, so the whole house didn't need heating to the same degree (pun intended). They used maybe 2.5 full cords a year. They only occasionally felled a tree and mostly just cut up and split fallen trees. The two acres of Douglas fir forest on their land was much more mature and heavily forested at the end of the 40 years than at the beginning. Of course, not all of the energy stored in wood is converted to usable heat. Wood stove efficiency is often in the 60% to 80% range, but high efficiency stoves with catalytic combustors can each around 90% efficiency.

Woods pellets are made from compacted sawdust and other small waste byproducts from the manufacturing of wood products. Unlike wood, pellets are not easily harvested by the average homeowner.

Using wood or pellets for a highly mobile THOW during the heating months is difficult due to the extra storage space needed and the additional weight. It would only be practical if fuel could be collected or bought in small quantities at regular intervals.

Choosing wood or wood pellets as an energy source for a tiny house is an environmental concern for some people. Most people consider wood a renewable energy source since trees can be regrown. Certainly the time period between "harvest" on the same plot of land is greater than many other renewables, such as solar and hydropower. People are much more divided on whether wood combustion is "green" mostly because of differing definitions of what "green" means and the time scale it should be evaluated over. Wood combustion and incomplete combustion releases carbon monoxide, carbon dioxide, sulfur oxides, nitrogen oxides, and other particulates which are generally not desirable. I won't try to convince you one way or the other, but this topic is worth discussing with clients if environmental considerations are one of their top concerns.

Propane

The greatest upside to propane is it makes designing an off-grid and highly mobile THOW with all the standard appliances (washing machine, clothes dryer, full sized range, water heater, and heating/air conditioning) fairly easy, inexpensive, and low-tech compared to other energy sources.

On the negative side, all propane appliances and equipment require direct venting to the outside or indirect venting through a hood vent. This complicates installation compared to electric appliances and limits the location in a house the appliances can be easily placed (a propane appliance located against an exterior wall is the easiest to vent). Also, propane is not as environmentally friendly as some other energy options. Propane appliances and equipment are generally more expensive than comparable AC versions and less expensive than similar DC versions.

There are two very common questions about propane for tiny houses. How much propane will be used? What size tank is needed? To help answer these questions we need to know how much energy is available in a given volume or weight of propane. One gallon of propane contains approximately 91,500 BTUs of energy. At 77°F the density of propane is 4.11 pounds per gallon, so one pound of propane contains approximately 22,250 BTUs of energy. Standard propane tank sizes are 20, 40, and 100 pounds and hold roughly 4.5, 9, and 23 gallons, respectively.

EXAMPLE #6:

A tiny house will utilize a propane range and propane tankless water heater. Using the example BTU information for these two appliances in Table 5, calculate the average daily propane consumption. On average, the household uses a 7,000 BTU burner at max heat for 8 minutes per day, a 7,000 BTU burner at low heat for 20 minutes per day, an 8,500 BTU burner at max heat for 12 minutes per day, and bakes in the oven at max output for 10 minutes per day. Assume the low heat setting uses 25% of the burner maximum rating. Due to the number of people living in the tiny house and short duration showers, assume the tankless water heater usage is 25% of the table rate. Select the smallest standard propane tank size that will allow refilling no more than every 30 days.

SOLUTION:

Range:

$$Daily\ Consumption = \left(7{,}000\frac{BTU}{hr}\right)\left(\frac{8}{60}\ hr\right) + (0.25)\left(7{,}000\frac{BTU}{hr}\right)\left(\frac{20}{60}\ hr\right) + \left(8{,}500\frac{BTU}{hr}\right)\left(\frac{12}{60}\ hr\right) + \left(12{,}700\frac{BTU}{hr}\right)\left(\frac{10}{60}\ hr\right) = 5{,}333\ BTU$$

$$Daily\ Consumption\ = (5{,}333\ BTU)\left(\frac{1\ gal}{91{,}500\ BTU}\right) = 0.06\ \frac{gal}{day}$$

$$Days\ Between\ 20lb\ Tank\ Refill\ = \frac{4.5\ gallons}{0.06\ gallons/day} = 75\ days$$

$$Days\ Between\ 40lb\ Tank\ Refill\ = \frac{9\ gallons}{0.06\ gallons/day} = 150\ days$$

Tankless Water Heater:

$$Daily\ Consumption = (0.25)\left(0.62\ \frac{gal}{day}\right) = 0.16\ \frac{gal}{day}$$

Range and Tankless Water Heater:

$$Total\ Daily\ Consumption = 0.16\ \frac{gal}{day} + 0.06\ \frac{gal}{day} = 0.22\ \frac{gal}{day}$$

$$Days\ Between\ 20lb\ Tank\ Refill\ = \frac{4.5\ gallons}{0.22\ gallons/day} = 20\ days$$

$$Days\ Between\ 40lb\ Tank\ Refill\ = \frac{9\ gallons}{0.22\ gallons/day} = 41\ days$$

A 40 pound propane tank should be selected, based on the calculations, for the range and water heater combined.

Originally our personal THOW had both a tankless propane water heater and a propane range with four stovetop burners and an oven. We cooked one to two meals a day with the range and we refilled our 40 pound propane tank about every six weeks. We've since replaced the propane water heater with a tanked electric model, so the range is the only consumer of propane. We now refill our 40 pound tank every 120 to 180 days. Our experience seems to be in line with the above calculations. Between 2017 and 2022, the price of propane in our area has ranged from $2.00 to $3.75 per gallon, so it costs between $18 and $34 to fill our tank.

Backup Power

In grid-tied solar PV situations, the power grid could be considered the backup power. Usually, when talking about backup power, it's in reference to an off-grid system. Most commonly a gasoline or diesel powered AC generator with an AC to DC charger is selected, but other options include a DC generator or propane generator. A so called hybrid system has economic and reliability benefits, but its downside for highly mobile THOW is the logistical complication of fuel storage and refilling. Backup power is especially helpful during sustained cloudy periods or during high electricity use, like when trying to occasionally run a high load appliance like a clothes dryer. Backup power can also save massively on the upfront cost of battery banks. Reducing the "days of autonomy" in Equation 7 from five to two days can often reduce the cost of a battery bank by more than half.

Additional Highly Mobile THOW Considerations

Highly mobile THOW that will switch between on-grid and off-grid sites may find it useful to borrow features from RVs. That being said, there is much to learn, mimic, and tweak from RVs when designing this type of THOW. RV and boat parts and suppliers are a good starting place for finding items desirable for highly mobile THOW. Another potential source for inspiration is the "overlanding" community. Also called "overland camping", this group combines off-roading and camping with emphasis on self-sufficient, remote, long duration camping. There are many overlanding websites, blogs, video channels, etc. for finding and sharing information and ideas.

Resistance heating over long durations greatly increases a PV systems necessary size, and as a result, is usually avoided. Propane for water heating, space heating, and large cooking appliances is generally the chosen route. LED lighting (not incandescent or halogen) helps reduce PV system size for highly mobile THOW switching between on-grid and off-grid sites.

Figure 12 shows a typical RV plumbing system schematic.

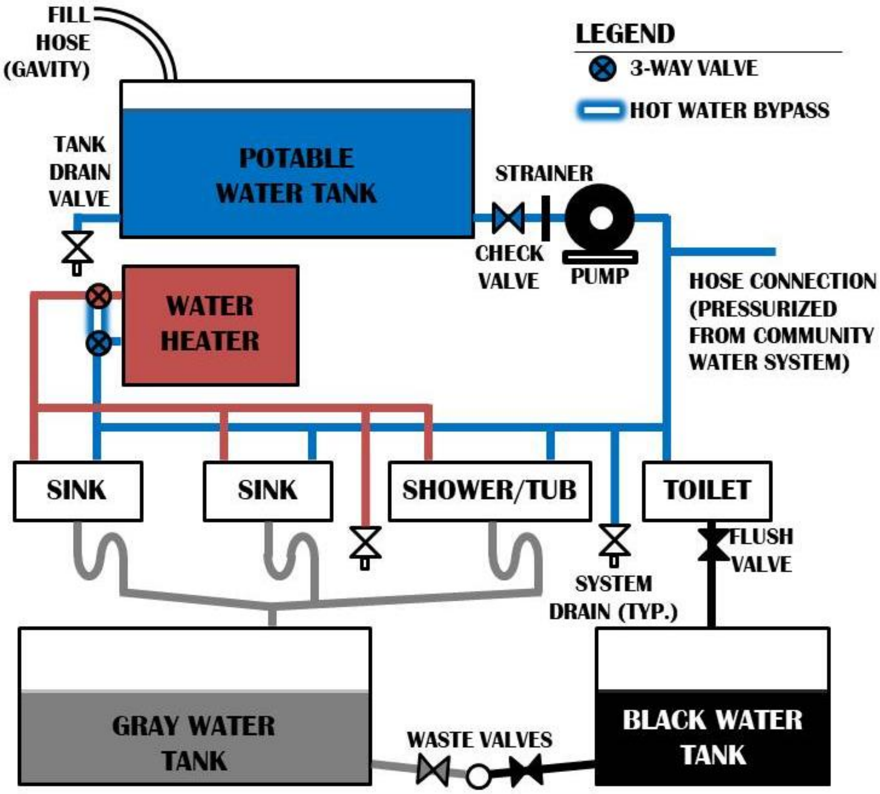


Figure 12: Typical RV Water System Schematic

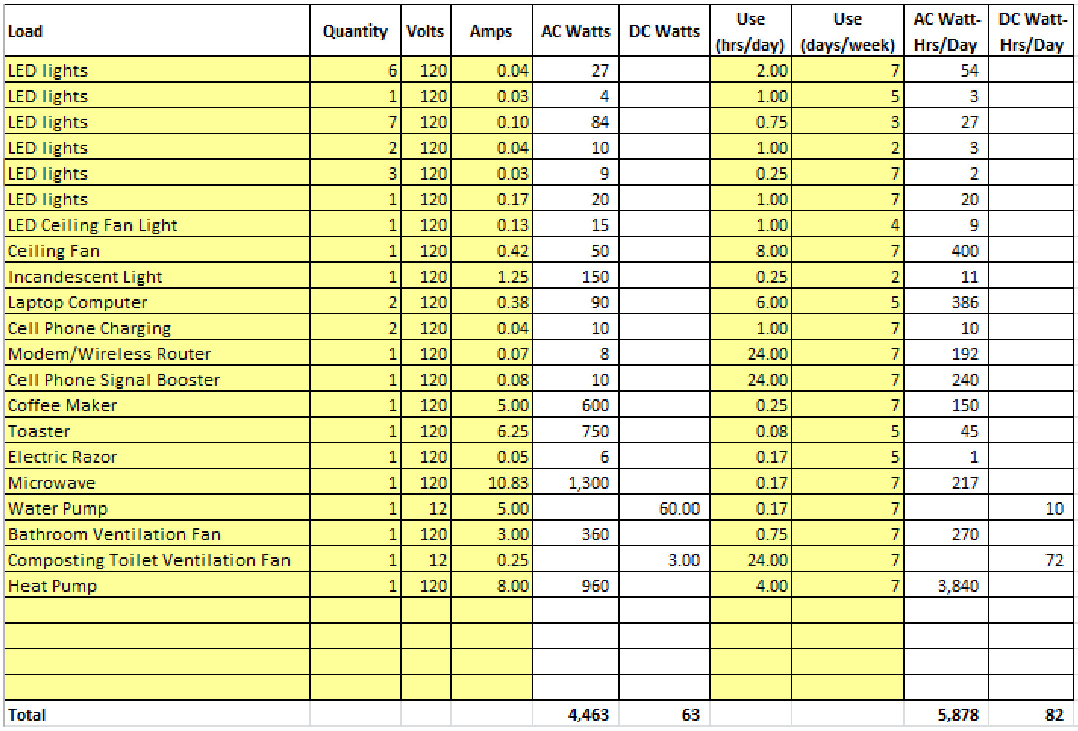
RV gray water and black water tanks generally range in size from 20 to 65 gallons and 15 to 50 gallons, respectively. RV potable water tanks are usually between 20 and 100 gallons. For all these types of tanks, the largest you can buy that are specifically for RVs is about 150 gallons. The gray and black water tanks fit between trailer framing members below the floor. The potable water tank is located above the floor elevation and often inside of built-in furniture. A 150 gallon tank full of water or wastewater adds approximately 1,250 pounds to the total RV/tiny house weight, so it is not trivial to use even larger tanks in a THOW.

Case Studies

Case Study #1

SITUATION:

A highly mobile THOW will be moved around southern Arizona between off-grid and on-grid locations. The water tank, wastewater tank(s), solar PV array/battery bank, and propane tank(s) may weigh no more than 2,500 pounds based on the total THOW weight that can be dedicated to those systems. The THOW roof area is 160 ft^2. Energy independence is their greatest concern. *Water:* The client's potable water use is 20 gallons/day. Five days of water autonomy is needed since not all sites will have a water source. What is the minimum tank volume? *Wastewater:* A composting toilet is acceptable to the client. Recommend a gray water tank size. *Energy:* Your client has provided estimated electrical loading (see below). The THOW will have a propane range, water heater, and refrigerator. Assuming 90% inverter efficiency, a 24 volt DC system, 5 days of autonomy, and an 85% lithium-ion battery discharge limit, how many 12 volt, 100 Ah lithium-ion batteries are needed? Assuming 80% battery efficiently, how many 200 watt, 24 volt (nominal) PV modules are required? Assume the propane usage for the range, water heater, and refrigerator are 0.06 gal/day, 0.35 gal/day, and 0.25 gal/day, respectively.



Load	Quantity	Volts	Amps	AC Watts	DC Watts	Use (hrs/day)	Use (days/week)	AC Watt-Hrs/Day	DC Watt-Hrs/Day
LED lights	6	120	0.04	27		2.00	7	54	
LED lights	1	120	0.03	4		1.00	5	3	
LED lights	7	120	0.10	84		0.75	3	27	
LED lights	2	120	0.04	10		1.00	2	3	
LED lights	3	120	0.03	9		0.25	7	2	
LED lights	1	120	0.17	20		1.00	7	20	
LED Ceiling Fan Light	1	120	0.13	15		1.00	4	9	
Ceiling Fan	1	120	0.42	50		8.00	7	400	
Incandescent Light	1	120	1.25	150		0.25	2	11	
Laptop Computer	2	120	0.38	90		6.00	5	386	
Cell Phone Charging	2	120	0.04	10		1.00	7	10	
Modem/Wireless Router	1	120	0.07	8		24.00	7	192	
Cell Phone Signal Booster	1	120	0.08	10		24.00	7	240	
Coffee Maker	1	120	5.00	600		0.25	7	150	
Toaster	1	120	6.25	750		0.08	5	45	
Electric Razor	1	120	0.05	6		0.17	5	1	
Microwave	1	120	10.83	1,300		0.17	7	217	
Water Pump	1	12	5.00		60.00	0.17	7		10
Bathroom Ventilation Fan	1	120	3.00	360		0.75	7	270	
Composting Toilet Ventilation Fan	1	12	0.25		3.00	24.00	7		72
Heat Pump	1	120	8.00	960		4.00	7	3,840	
Total				**4,463**	**63**			**5,878**	**82**

ONE POSSIBLE SOLUTION:

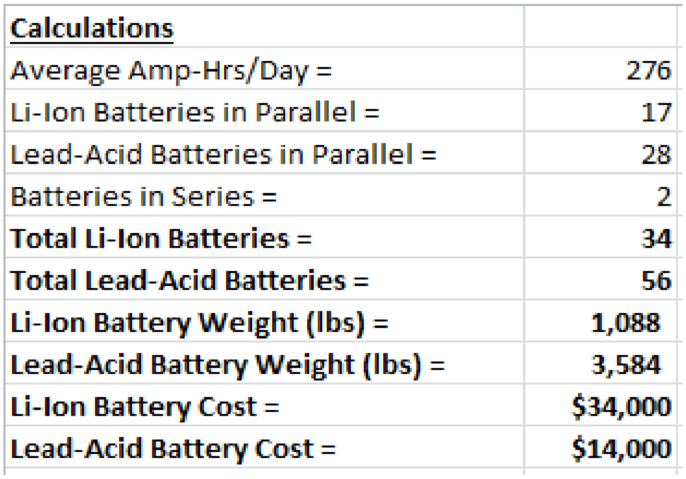
Water: Using the Water Source Selection Flowchart (Figure 1), it is apparent an integral water storage tank is needed. The minimum water tank size based on the client's consumption is:

$$Potable\ Water\ Tank\ Volume\ = \left(20\ \frac{gal}{day}\right)(5\ days) = 100\ gal$$

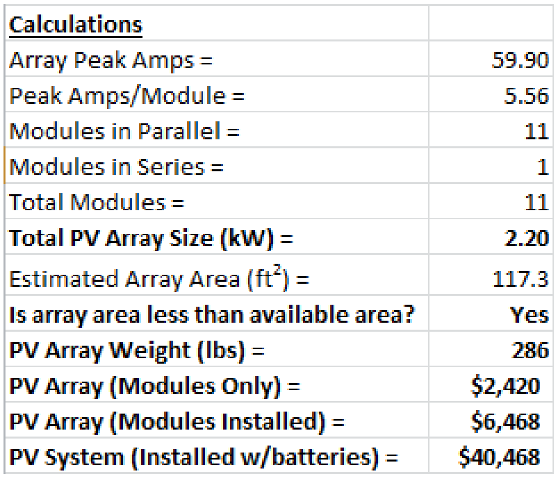
$$Potable\ Water\ Weight\ = (100\ gal)\left(8.3\ \frac{lbs}{gal}\right) = 830\ lbs$$

Wastewater: Based on the Wastewater Treatment or Disposal Selection Flowchart (Figure 6) and the client's willingness to use a composting toilet, the first option is to handle black water with a composting toilet and gray water with an integral storage tank. The minimum gray water tank size is the same as previously calculated for potable water (100 gallons).

Energy: For this case study, the Energy Source Selection Flowchart (Figure 7) suggests any energy sources compatible with a highly mobile THOW are options. Most often, solar PV for plug loads and lighting and propane for everything else would be chosen. Since we're dealing with a hot climate, and propane air conditioners and heat pumps are not readily available, an electric heat pump will also be powered by solar PV. Utilizing the provided software, enter the given electrical loads, battery, and array information in the "PV" tab. The battery sizing and array sizing outputs from the software are:



Calculations	
Average Amp-Hrs/Day =	276
Li-Ion Batteries in Parallel =	17
Lead-Acid Batteries in Parallel =	28
Batteries in Series =	2
Total Li-Ion Batteries =	**34**
Total Lead-Acid Batteries =	**56**
Li-Ion Battery Weight (lbs) =	**1,088**
Lead-Acid Battery Weight (lbs) =	**3,584**
Li-Ion Battery Cost =	**$34,000**
Lead-Acid Battery Cost =	**$14,000**



Calculations	
Array Peak Amps =	59.90
Peak Amps/Module =	5.56
Modules in Parallel =	11
Modules in Series =	1
Total Modules =	11
Total PV Array Size (kW) =	**2.20**
Estimated Array Area (ft^2) =	117.3
Is array area less than available area?	**Yes**
PV Array Weight (lbs) =	**286**
PV Array (Modules Only) =	**$2,420**
PV Array (Modules Installed) =	**$6,468**
PV System (Installed w/batteries) =	**$40,468**

So, thirty four 12 volt, 100 Ah lithium-ion batteries and eleven 200 watt, 24 volt PV modules are needed (a 2.2 kW system). You can see from the output results, the weight and cost of the battery bank dwarfs that of the PV array. Please note, the software calculates the size of array, but doesn't take into account roof dimensions or module dimensions, other than telling you if the total area of the array is larger or smaller than the total roof area.

__Weight:__ Calculate the propane weight:

$$Total\ Daily\ Consumption = 0.06\ \frac{gal}{day} + \ 0.35\ \frac{gal}{day} + \ 0.25\ \frac{gal}{day} = 0.66\ \frac{gal}{day}$$

$$Days\ Between\ 20lb\ Tank\ Refill\ = \frac{4.5\ gallons}{0.66\ gallons/day} = \ 7\ days$$

$$Days\ Between\ 40lb\ Tank\ Refill\ = \frac{9\ gallons}{0.66\ gallons/day} = \ 14\ days$$

Our calculations show a 20 pound tank would be sufficient for greater than the five days of autonomy the client is requesting. Due to the small increase in weight, it seems prudent to specify at least one 40 pound tank and possible two 40 pound tanks to extend the time between refills to 14 or 28 days.

The total weight of the water/gray water, solar PV array, battery bank, and propane tanks is 2,284 pounds (830 + 286 + 1,088 + 40 + 40), which is less than the previously stated 2,500 pound maximum. The total weight of water and gray water is the same as the original potable water weight because water leaving the potable water tank ends up in the gray water tank. Now let's check if using a flush toilet instead of a composting toilet is feasible. Using a low flow toilet and the average number of daily flushes per person in the United States, we calculate the additional weight as:

$$Black\ Water\ Weight = \left(1.6\ \frac{gal}{flush}\right)\left(5\ \frac{flushes}{day}\right)(5\ days)\left(8.3\ \frac{lbs}{gal}\right) = 332\ lbs$$

This additional weight would push us over the limit given so a flush toilet is not selected.

Case Study #2

SITUATION:
The same as Case Study #1, except:

- Change the propane refrigerator to a 12 volt DC model using the equivalent of 2.50 amps constantly (24 hours/day, 7 days/week).
- Change the propane range to a 240 volt AC model using the equivalent of 17 amps for 50 minutes/day, 7 days/week.
- Change the propane water heater to a 240 volt AC model using the equivalent of 15.83 amps for 90 minutes/day, 7 days/week.

Making the above changes in order, one at a time, how many 12 volt, 100 Ah lithium-ion batteries are needed for each scenario? What is the total PV array size for each scenario? Next, answer the same two questions with simultaneous electric refrigerator, range, and water heater. Finally, answer the same two questions without an electric refrigerator, range, water heater, and heat pump.

SOLUTION:
The answers for the above questions are:

- For the refrigerator change only, the software calculates 36 batteries and a 2.4 kW PV array. The estimated PV system cost is $43,000.
- For the range change only, the software calculates 52 batteries and a 3.4 kW PV array. The array is larger than the roof area, which is problematic unless an expandable racking system is used. The estimated PV system cost is $62,000.
- For the water heater change only, the software calculates 64 batteries and a 4.4 kW PV array. Again, the array is larger than the roof area. The estimated PV system cost is $77,000.
- For the simultaneous electric refrigerator, range, and water heater, the software calculates 86 batteries and a 5.8 kW PV array. Of course, the array is larger than the roof area. The estimated PV system cost is $103,000.
- For the last scenario of only lighting and plug loads (no heat pump), the software calculates 12 batteries and a 0.8 kW PV array. The estimated PV system cost is $14,000.

From the above analysis, we can surmise the practicality of using a high efficiency DC refrigerator with a mobile PV system and the relative impracticality of using the other appliances and equipment. Note even the large difference between Case Study #1 results with a heat pump and the final result shown for only lighting and plug loads. The system size is less than half as small and the cost is about $26,000 less, even for equipment which is very efficient compared to most conventional electric space heating and cooling options.

Case Study #3

SITUATION:

A THOW is in a suburban residential backyard, but the THOW owners can't move in until their utility situation is worked out. They've come to you for engineering assistance with the utilities.
Water: An existing hose bibb is in the back yard and is available for use. The water comes from the local community water system so there are no water use limits. The owners have already connected a drinking water hose from the hose bibb to the THOW.
Wastewater: The main house on the property is connected to a centralized wastewater system, but there is no existing sewer hookup in the backyard. A composting toilet is acceptable to your clients, but they are unsure if the initial cost of the composting toilet is more or less than the cost of installing a sewer hookup and using a flush toilet. They have requested your assistance in evaluating the cost difference. The composting toilet they are considering is $1,500. They have excavated a hole to expose the main house's existing sewer lateral. The distance of the sewer extension would be 70 feet. You have confirmed the elevation drop between the THOW and tie-in location is sufficient. The clients are willing to install the extension themselves, but are unsure of the materials needed, material costs, and equipment rental costs.
Energy: You inspect the THOW and its electric load center/panelboard. Your visit reveals:

- The THOW main floor area is 187 ft^2 and the total loft area is 102 ft^2
- There are two 20 amp small appliance circuits
- The dishwasher nameplate shows a 900 watt rating
- The 240 volt electric water heater has a 3,800 watt element
- There is one 2,000 watt, 240 volt electric space heater
- There is a 4-burner propane range with oven and broiler and a 40 pound propane tank
- The distance from the main house panelboard to the THOW panelboard is 60 feet

Determine the minimum 240 volt electric service amperage using both the standard and optional methods. Specify the service wire sizes and receptacle type needed for the new feeder from the main house's panelboard. Assume the main house's electric service and panelboard have capacity for this new THOW circuit. Either the standard or optional method could be applied to the entire house to verify this assumption in a real life situation.

SOLUTION:

Wastewater: You know from IRC Table P3005.4.2 the sewer pipe must be 3" diameter or larger if a flush toilet is connected to it. After researching local prices you are able to calculate the cost for the flush toilet and sewer extension.

$$\begin{aligned} Cost &= Equipment\ Rental\ Cost + (Pipe\ Cost\ Per\ Foot)(Pipe\ Length) \\ &\quad + Pipe\ Fittings\ Cost + Flush\ Toilet\ Cost \\ Cost &= \$600 + (\$4/ft)(70\ ft) + \$80 + \$140 = \$1{,}100 \end{aligned}$$

As a result, you recommend they rent a mini excavator for two days, install a 3" PVC sewer extension with cleanout, and install a flush toilet in the THOW.

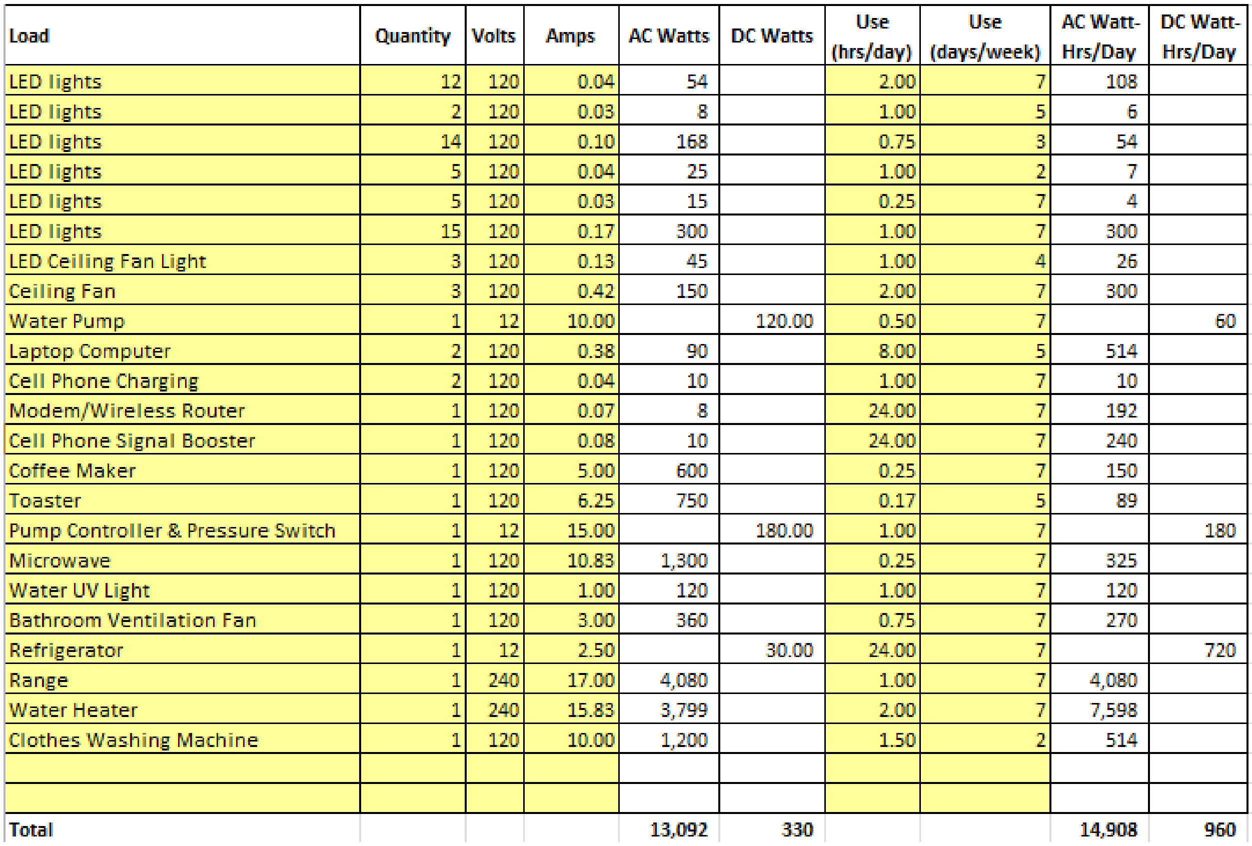
Energy: Add the main floor and loft areas together when calculating the electric service size. Employing the provided software, enter the given information in the "Standard Method" tab. Step 12 of the output section calculates a 41.7 amp service using this method. Next, using the provided software, enter the given information in the "Optional Method" tab. Step 8 of the output section gives a 41.1 amp service using this method. The two methods are in close agreement. From a strictly code perspective, the Standard Method is the correct method to use in this case. Since the next standard breaker size is 50 amps, specify a 2-pole, 50 amp breaker for the tiny house.

Use IRC table E3705.1 (https://codes.iccsafe.org/content/IRC2018/chapter-37-branch-circuit-and-feeder-requirements) to size the conductors. Assuming copper wires and a conductor temperature rating of 60°C, 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'll 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 a neutral, but that is beyond the scope of this course. Finally, use IRC Table E3908.12 (https://codes.iccsafe.org/content/IRC2018/chapter-39-power-and-lighting-distribution) to size the ground wire. Select a 10 AWG copper wire from the table's 60 amp breaker row because there is no 50 amp breaker in the table. The new circuit could be either direct wired to the THOW or terminated to a NEMA 14-50R receptacle. This is the standard 50 amp RV receptacle that would accept a 50 amp RV power cord.

It's recommended to perform a voltage drop calculation for 30 amp, 120 volt cords/services over 50 feet in length and 50 amp, 240 volt cords/services over 150 feet in length. The distance in this case study is 60 feet, so no voltage drop calculation will be performed.

Case Study #4

SITUATION:
A 400 ft^2 THOF and barn are slated for construction in the general vicinity of Battle Ground, Washington. The THOF will be built on a rural, heavily forested, 20-acre parcel miles away from any community water system, centralized wastewater system, or grid power. You're on retainer to provide engineering consulting services.
Water: The property owner obtained three separate quotes from local well drilling companies and has determined it is prohibitively expensive to drill a well. There are no springs or surface water present on the property. From Figure 1, it seems rainwater harvesting or bulk water deliveries are the two options for drinking water. Total water consumption is estimated at 100 gallons/day and the THOF is occupied year-round. Based on this daily water usage, the property owner has determined bulk water delivery is too costly. The roof area of the THOF is 484 ft^2 and the roof area of the barn is 1,500 ft^2. A beginning storage volume of 1,000 gallons is expected since the harvesting system will be completed prior to the THOF certificate of occupancy (C.O.) issuance. Assuming 95% collection efficiency, what size water storage tank is recommended for rainwater harvesting? (Use daily precipitation data and design for 0.15% or less days with zero storage).
Wastewater: There is no septic system currently on the property. A composting toilet is not acceptable to the client. Recommend a method for wastewater treatment or disposal.
Energy: You've already sat down with your client to discuss energy source options. Their primary concern is energy independence, so pretty much all options except connecting to the grid and hydroelectric power (no onsite surface water) are potential options. Due to the proliferation of wood on the property, they decide to use wood for space heating. Clothes will be line dried. Everything else will use solar PV. Working together, the following electrical loads were developed (see below). Assuming 90% inverter efficiency, a 24 volt DC system, 5 days of autonomy, and 50% lead-acid battery discharge limit, how many 12 volt, 400 Ah lead-acid batteries are necessary? Assuming 80% battery efficiently, how many 200 watt, 24 volt (nominal) PV modules are needed?



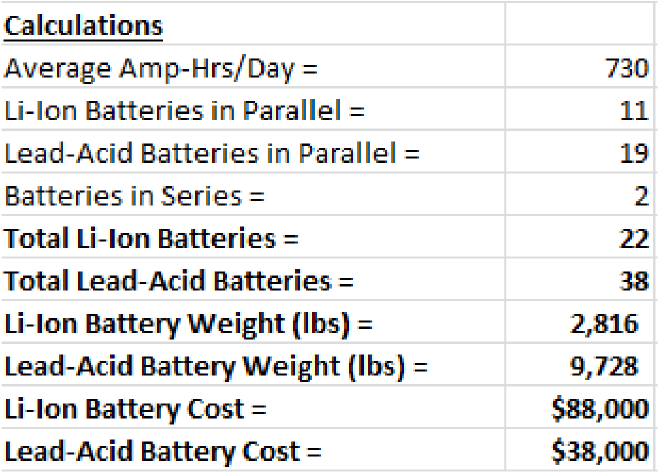
Load	Quantity	Volts	Amps	AC Watts	DC Watts	Use (hrs/day)	Use (days/week)	AC Watt-Hrs/Day	DC Watt-Hrs/Day
LED lights	12	120	0.04	54		2.00	7	108	
LED lights	2	120	0.03	8		1.00	5	6	
LED lights	14	120	0.10	168		0.75	3	54	
LED lights	5	120	0.04	25		1.00	2	7	
LED lights	5	120	0.03	15		0.25	7	4	
LED lights	15	120	0.17	300		1.00	7	300	
LED Ceiling Fan Light	3	120	0.13	45		1.00	4	26	
Ceiling Fan	3	120	0.42	150		2.00	7	300	
Water Pump	1	12	10.00		120.00	0.50	7		60
Laptop Computer	2	120	0.38	90		8.00	5	514	
Cell Phone Charging	2	120	0.04	10		1.00	7	10	
Modem/Wireless Router	1	120	0.07	8		24.00	7	192	
Cell Phone Signal Booster	1	120	0.08	10		24.00	7	240	
Coffee Maker	1	120	5.00	600		0.25	7	150	
Toaster	1	120	6.25	750		0.17	5	89	
Pump Controller & Pressure Switch	1	12	15.00		180.00	1.00	7		180
Microwave	1	120	10.83	1,300		0.25	7	325	
Water UV Light	1	120	1.00	120		1.00	7	120	
Bathroom Ventilation Fan	1	120	3.00	360		0.75	7	270	
Refrigerator	1	12	2.50		30.00	24.00	7		720
Range	1	240	17.00	4,080		1.00	7	4,080	
Water Heater	1	240	15.83	3,799		2.00	7	7,598	
Clothes Washing Machine	1	120	10.00	1,200		1.50	2	514	
Total				13,092	330			14,908	960

ONE POSSIBLE SOLUTION:

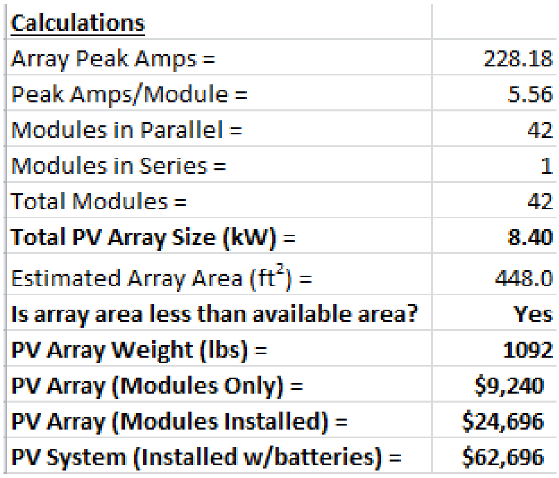
Water: The location and precipitation data is the same as in Example #2, so we're ready to begin entering the other given project information into the software. First, click on the "Harvesting – Monthly" tab and enter all relevant input values. The total roof area is 1,984 ft^2 (THOF plus barn roof area). Slowly increasing the storage volume, we see the end of month storage is greater than zero for all months at around 6,200 gallons of storage. Next, click on the "Harvesting – Daily" tab to see the results when using historical daily precipitation. We see with a 6,200 gallon tank, there would be 1,410 days of zero storage (6.97%). So we again start increasing the size of the tank until that number goes below 0.15%, which occurs at around 12,000 gallons. You select two 6,000 gallon tanks for rainwater harvesting storage.

Wastewater: For this situation, Figure 6 suggests a flush toilet, a combined black and gray water plumbing system, and a state approved method (some type of septic system or wastewater hauling). Based on the owner's previous research on bulk water delivery, we know the remote nature of the property makes wastewater hauling impractical. Looking at the site topography and your familiarity with the prevalent soils in this county, you know septic systems are relatively easy to permit, design, and construct. Consequently, you recommend a septic system to the client with a suggested budget of $5,000 to $12,000 for permitting and construction.

Energy: Using the provided software, enter the given electrical load, battery information, and array information in the “PV” tab. The Global Horizontal Solar Irradiance map shows Battle Ground, Washington (located about 25 miles northeast of Portland, Oregon) receives less than 4.00 kWh/m^2/day. Battle Ground is near the boundary of the 4.00 to 4.25 kWh/m^2/day zone, so assume 4.00 kWh/m^2/day. One peak sun hour per day equals 1 kWh/m^2/day, so the peak sun hours per day are 4.00 hours. The battery sizing and array sizing outputs from the software are:



Calculations	
Average Amp-Hrs/Day =	730
Li-Ion Batteries in Parallel =	11
Lead-Acid Batteries in Parallel =	19
Batteries in Series =	2
Total Li-Ion Batteries =	**22**
Total Lead-Acid Batteries =	**38**
Li-Ion Battery Weight (lbs) =	**2,816**
Lead-Acid Battery Weight (lbs) =	**9,728**
Li-Ion Battery Cost =	**$88,000**
Lead-Acid Battery Cost =	**$38,000**



Calculations	
Array Peak Amps =	228.18
Peak Amps/Module =	5.56
Modules in Parallel =	42
Modules in Series =	1
Total Modules =	42
Total PV Array Size (kW) =	**8.40**
Estimated Array Area (ft^2) =	448.0
Is array area less than available area?	**Yes**
PV Array Weight (lbs) =	**1092**
PV Array (Modules Only) =	**$9,240**
PV Array (Modules Installed) =	**$24,696**
PV System (Installed w/batteries) =	**$62,696**

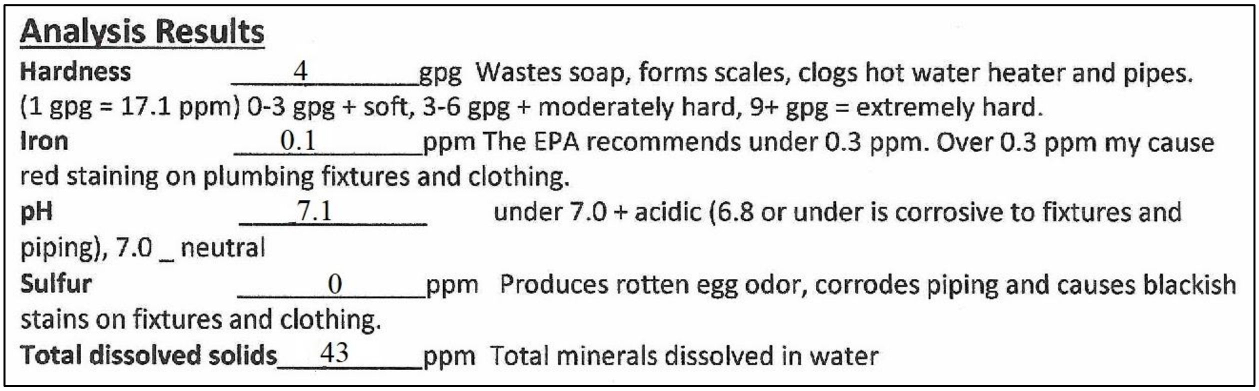
So thirty eight 12 volt, 400 Ah lead-acid batteries and forty two 200 watt, 24 volt PV modules are needed (a 8.40 kW system). Tax credits and/or rebates are likely available to reduce the cost of the PV system since this is a house on a foundation.

Case Study #5

SITUATION:

A 400 ft^2 THOF is scheduled for construction on the outskirts of Terre Haute, Indiana. The property is flat and lightly forested around a portion of the perimeter. No community water system or centralized wastewater system is nearby; however, grid power runs along the adjacent road and the connection fee is reasonable. You’re under contract to provide engineering consulting services for the project.

Water: There are no springs or surface water present on the property, but the property has an existing low production well. A well flow test was performed and the well can reliably produce 365 gallons/day. The owner is a hobby farmer and needs 300 gallons/day for irrigation purposes. The farmer wants to know if the well is sufficient for both irrigation and domestic uses. If not, rainwater harvesting or bulk water deliveries are the two options for supplementing the well. You develop the following estimates of daily domestic water use with the farmer: 10 toilet flushes (1.6 gpf), 14 minutes of showering (2.5 gpm), 10 minutes of sink use (2.2 gpm), 10 gallons for clothes washing, and 7 gallons for machine dish washing. The THOF is occupied year-round. The roof area of the THOF is 462 ft^2. A beginning storage volume of 500 gallons is expected since the harvesting system will be completed before the C.O. is issued. Assuming 90% collection efficiency, what size water storage tank is recommended for rainwater harvesting? (Use daily precipitation data and design for 0.30% or less days with zero storage). Compare this to the cost of bulk water delivery over a period of 20 years. The current local cost is $300 for a 3,000 gallon truckload of potable water. The company that performed the well flow test also performed a basic water quality analysis. The results are shown below. What, if any, water quality treatment measures do you recommend?



Analysis Results

Hardness ____4____gpg Wastes soap, forms scales, clogs hot water heater and pipes. (1 gpg = 17.1 ppm) 0-3 gpg + soft, 3-6 gpg + moderately hard, 9+ gpg = extremely hard.

Iron ____0.1____ppm The EPA recommends under 0.3 ppm. Over 0.3 ppm my cause red staining on plumbing fixtures and clothing.

pH ____7.1____ under 7.0 + acidic (6.8 or under is corrosive to fixtures and piping), 7.0 _ neutral

Sulfur ____0____ppm Produces rotten egg odor, corrodes piping and causes blackish stains on fixtures and clothing.

Total dissolved solids____43____ppm Total minerals dissolved in water

Wastewater: There is no septic system currently on the property. The property is located near a floodplain, so the local health department would mandate a mound septic system with construction elevations based on specific flood elevations. The estimated cost of such a system, including trucking the fill in, is $21,000. A composting toilet is not acceptable to the client. Compare the septic system cost to the local $0.30 per gallon cost for hauling and disposal of wastewater over a period of 20 years and recommend a method for wastewater treatment or disposal. Initially assume gray water could be reused for irrigating certain plants when comparing costs.

Energy: The house is 100% powered by electricity. The local utility sizes the electric service as part of their connection fee, so you don't need to perform any work related to energy sources.

ONE POSSIBLE SOLUTION:

Wastewater: Evaluate the wastewater situation first for this case study because the decision to reuse gray water could impact the water source analysis. Hauling black water away would cost:

$$Black\ Water\ Hauling\ Cost = (1.6\ gpf)\left(10\ \frac{flushes}{day}\right)\left(\frac{365\ days}{year}\right)(20\ years)\left(\frac{\$0.30}{gal}\right)$$
$$Black\ Water\ Hauling\ Cost = \$35{,}040$$

Evaluating wastewater options only (not in combination with the impact on water source selection), you recommend the mound septic system. There is no need to determine the cost of a gray water treatment system, black water tank, or gray water tank because the cost of hauling is already significantly above the septic system cost.

Water: The estimated daily domestic water is calculated as:

$$\begin{aligned}Daily\ Use &= Toilet\ Use + Shower\ Use + Sink\ Use + Clothes\ Washer\ Use\\ &\quad + Dishwasher\ Use\\ Daily\ Use &= (1.6\ gpf)(10\ flushes) + (2.5\ gpm)(14\ minutes)\\ &\quad + (2.2\ gpm)(10\ minutes) + 10\ gal + 7\ gal\\ Daily\ Use &= 16 + 35 + 22 + 10 + 7 = \ 90\ gal\end{aligned}$$

Based on the farmer's input, you estimate total domestic water consumption is 90 gallons/day. You inform the farmer a supplemental water source is necessary. The amount of supplemental water needed each day is:

$$Daily\ Supplemental\ Water = Irrigation + Domestic - Well\ Production$$
$$Daily\ Supplemental\ Water = 300\ gal + 90\ gal - 365\ gal = 25\ gal$$

You investigate gray water reuse further and discover the State of Indiana's lack of guidance on the subject is an issue with your professional liability insurance provider. As a result, you eliminate gray water reuse as an option.

Next, go to the "Harvesting – CS#5" tab and enter all relevant input values including the above calculated 25 gallons/day of "consumption." Precipitation data for the project location is already preloaded in this tab. Starting with a 3,000 gallon tank, there would be 251 days of zero storage

(1.18%). Increase the size of the storage tank until the percent days with zero storage is less than the requested 0.30%. This occurs at around 5,000 gallons.

The cost of trucking potable water for 20 years is:

$$20\ Year\ Bulk\ Water\ Cost = \left(25\frac{gal}{day}\right)\left(365\ \frac{days}{year}\right)(20\ years)\left(\frac{\$300}{3{,}000\ gal}\right) = \$18{,}250$$

Both rainwater harvesting and bulk delivery require storage tanks. So the cost comparison between the two methods is mostly the cost of the supplemental equipment for rainwater harvesting ($4,000 to $6,000 for a pump, pressure tank, disinfection equipment, etc.) versus the bulk water delivery cost. In this case, the rainwater harvesting costs are much lower. As a result, you select one 5,000 gallon tank for rainwater harvesting storage.

Finally, based on the hardness of 4 gpg reported in the water quality analysis results, you recommend a water softener for the domestic water use. All other reported water quality results are within generally accepted ranges.

Conclusion

This course first focused on developing a toolbox for off-grid tiny houses and highly mobile, off-grid THOW. The toolbox flowcharts, methods, and products helped show possible solutions for tiny house water, wastewater, and energy needs. Five different case studies were presented and potential solutions were developed for each case study.

Appendix – Appliances

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. Table A-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 A-1: Common Appliance Energy/Fuel Source Options

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