QUEEN'S SOLAR DESIGN TEAM

ENVIRONMENTALLY CONSCIOUS HOME DESIGN

Info Package and Design Exploration

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Preface

The Queen's Solar Design Team is pleased to present this informative report discussing the conceptual design of sustainable housing projects. Following the goals and constraints outlined by standards like LEED® and Passive House, the team has prepared this short report to discuss notable completed projects built by others, considerations for water, electricity, heating, and construction, as well as design goals and requirements.

This report covers the following areas:

- Off-grid home design inspiration from existing projects.
- Utility requirements and options.
- Construction/Design considerations.
- Next steps.

We hope this document will help you to gain inspiration to set forth and build the green home of your dreams!

The Queen's Solar Design Team

1. Off-Grid Homes

EARTHSHIPS

Earthships are a type of passive solar home which focus promote the use of recycled materials, green construction practices and use of sustainable resources to create off-grid housing. Earthships come in many shapes and sizes and see DIY home projects integrated with professional design and construction making each home unique. A large community exists for making homes such as this possible through design plans, volunteer construction and support resources. Below, some examples of earth ships in Ontario are shown to outline the diversity of these homes and serve as a base for your own exploration into their potential.

Wind Chasers Earthship – Clear water Ontario

Figure 1: The Wind Chasers Earthship

Most earthships constitute a simple or rustic design with smart engineering and construction as can be seen above with this home in clear water. Connie and Craig built this 2,900-square foot home for $55k. Using solar power and rainwater collection the couple lives entirely off the grid with enough power for a washing machine and small appliances. This type of home especially illustrates the self-sustaining principles of these buildings with an in-home greenhouse which takes advantage of the 840-square feet of window that allows for solar energy to power most of their heating. [3]

More about this home can be seen in an interview tour of the house. Connie and Craig's website is another helpful location for related resources concerning earthship planning. [4]

Figure 2: Greenhouse View

Collingwood Earthship – Collingwood Ontario

Figure 3: Matt's Earthship in Collingwood, ON

A great example of the higher end possibilities of earthships can be seen in Matt's 3-bedroom Collingwood home above. Built from recycled materials including locally sourced tires Matt built his own home after studying with the creator of earthships, Mike Reynolds. The house features a combination of passive systems such as solar driven air flow, supported by a high-tech PV array and heating system that is best described in a video tour of Matt's house. [1]

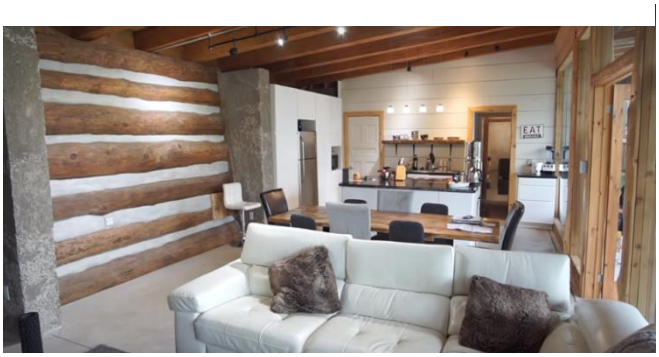


Figure 4: Indoor View showing luxurious living conditions

Matt also has a website detailing some of the process involved in building his home including site planning, construction and the different types of earthships that are suitable for a north American climate and a volunteer page. See a tour of Matt's home and Matt's website linked below to explore more resources regarding his home and building process. [2]

OWNING AN EARTHSHIP

Lifestyle

Choosing to live in an earthship can be a wonderful decision and come with several benefits. Both the negative and positive aspects of owning and living in an earthship should be weighed before a decision is made.

The foremost difference in lifestyle is the more conscious approach to energy use that one must adapt to. With variable energy supply, one must grow accustomed to the amount of energy they consume along with when they consume it. This could mean needing to perform high energy demand activities such as washing and drying in the day and a general decrease in the use of high energy appliances. In the winter when solar power is weak and demand is high, this could mean little to no excess power if the system is not large enough or supply has been particularly weak. These power sacrifices can be mitigated but this comes both with monetary cost and loss of the earthship principles.

Design

What most earthship owners are most proud of is the design of their home. Designing a home to your specifications and seeing it work as intended is a special experience and all earthships are unique to those who made them. In this process you are the master of the outcome of your home and it becomes what you make of it.

The double-edged sword of earthship design is the need for certain design elements. Certain aspects of earthships are must haves. For instance, large windows, thick walls and long south facing exposures are typical. In addition to this, a knowledge of the design is needed for proper use and maintenance of passive and active systems.

Function

The outstanding benefit of an earthship is its ability to utilize natural resources. Properly designed, most of an earthship's heating and cooling will be passively maintained; there will be a constant supply of water, electricity will be generated on site, and utility bills will be non-existent.

While independence of the grid can be a good thing, it means that you must be able to be self-dependant. Systems in the home must be properly maintained and failure of one of the systems without a backup would mean no access to that utility. Additionally, while in the long run you will save money on utility, the initial investment will be higher and maintenance costs will increase.

Other useful links

Earthship locator and plan resource: [5]

Extensive resource on systems, planning and building: [6].

Alberta Earthship: [15]

Great resource for solar and hydronic heat systems. Volume 3,6 are especially relevant covering solar collector systems and hydronic floor systems [25]

TRADITIONAL HOUSING

Many off-grid houses have been built in central Ontario, particularly as second homes or vacation properties. These houses can be built with any degree of environmental consciousness desired. Some aim for set standards when building their houses, such as the PassivHaus standard, although just achieving an improved footprint through the implementation of green technologies is admirable. Below, consider several examples of green homes that use "traditional" construction techniques but implement notable green technologies.

Abercorn, QC - Passive House

Figure 5: Abercorn Passive House

This house, built by Sarah Cobb and William Murray, makes use of some simple but effective means to drastically lower their energy bill and grid dependence, despite living in a cold climate. They built their 2000 sq. ft house with double framed stud walls, accommodating a staggering 17" of dense packed cellulose [13]. Hence, they were able to achieve R-60 walls and an R-100 roof, lowering the total heating cost of the building to just $200 per year [13]. Heat pumps and a high-end air exchanger ensure that the heated air circulating the house is fresh and breathable. Without necessarily achieving any set standard of LEED or Passive House, this house shows that simply adopting those systems' goals can very easily make your house drastically more efficient.

Figure 6: Double Studs, Photo Credit: Rocket Construction Inc. [13]

Ottawa, ON – Casey and Natasha's Passive House

Figure 7: Casey and Natasha's Passive House [20]

Casey and Natasha, popular online bloggers who discuss eco-conscious living, practice what they preach, living in a passive house that they built with their company, The Conscious Builder, Inc. [20]. Their passive house in Ottawa uses a 10 kW solar array to supply all their power and heating needs, which are very low thanks to the high insulation factors of the walls and the south facing windows positioned for maximum solar gain. Large roof overhangs, air-source heat pumps and heat recovery units, and prioritizing the use of locally sourced building materials make the footprint of this beautiful home very modest. Read more about the house by following the link [20][24].

More on Passive Houses

Passive houses trade off increased initial expense for a much lower annualized cost of ownership of a home. Many past passive house builders have advertised that their homes cost 10-20% more than a typical house construction, but cost 80-90% less to heat and power. Hence, it is an economical option for a house that will be owned and occupied for a long period of time.

The PassiveHaus construction standard is a formal set of guidelines that dictates the minimum criteria for a house to technically be "passive". This includes parameters like minimum airtightness (0.6 air exchanges per hour), maximum heat consumption, maximum water/electricity use per person, and more [21]. The full guidelines can be found here.

Demands of a Home

WATER

Off-grid buildings get their water either from rainwater collection or from a well. Both are viable options for the project being proposed; however, each has clear advantages and disadvantages.

A rainwater collection system collects rainwater from roof surfaces into large cisterns for on-demand use. From this stage water must be pumped through a filtration system to make it suitable for drinking and pressurized for distribution. This system is fairly autonomous and generally low maintenance. The largest concern for rainwater is supply. Collection to supply a sustainable amount of rainwater will depend on collection area, weather data and load.

Figure 8: A Rainwater Cistern

Wells are tried-and-true technology for water supply in rural environments. Fairly simple to install and maintain, a well is a natural option for water supply in this house. However, the source water must still be treated before consumption and pressurized. Up-front costs of installing a well can be higher if there is a deep water table on the property. An analysis of your property will need to be done before a well is deemed appropriate.

Further investigation of rainwater supply, geography, house design and water needs will be required to determine the appropriate system for your home. However, a rainwater cistern will likely be suitable for the barn. The collected rainwater can be used to feed animals or water which are subject to a lower water quality standard.

POWER

System Overview

While many different types of solar panels exist the basic layout for an off-grid power system will follow the same fundamental design. In the figure below we can see the basic layout of an off-grid solar power system. Batteries are used to store the power. The charge adjusts the voltage from the panels to make sure the batteries are charged as efficiently as possible. An inverter will convert DC electricity outputted by the batteries to AC power which is used by most appliances. Most inverters also have an AC charging terminal where a generator can be plugged in and used to charge batteries. This can be useful in the winter or any time when there is a not a lot of sunlight for multiple days. Another use is for high powered devices which may not ordinarily be used such as tools.

All off-grid systems will use these 5-6 components to handle power generation. Some unique components exist such as PVT panels which are designed to generate electricity while using excess heat to supply hot water to the house and DC appliances which take load off of the inverter. However, a more in depth economic and feasibility analysis will need to be done to determine which of these are best suited for your home.

Alt-E has a good series of videos which can be found in this playlist which go into much more detail of all of the steps of designing an off-grid solar system. These videos are a great starting point and can be found in the links at the end of this section.

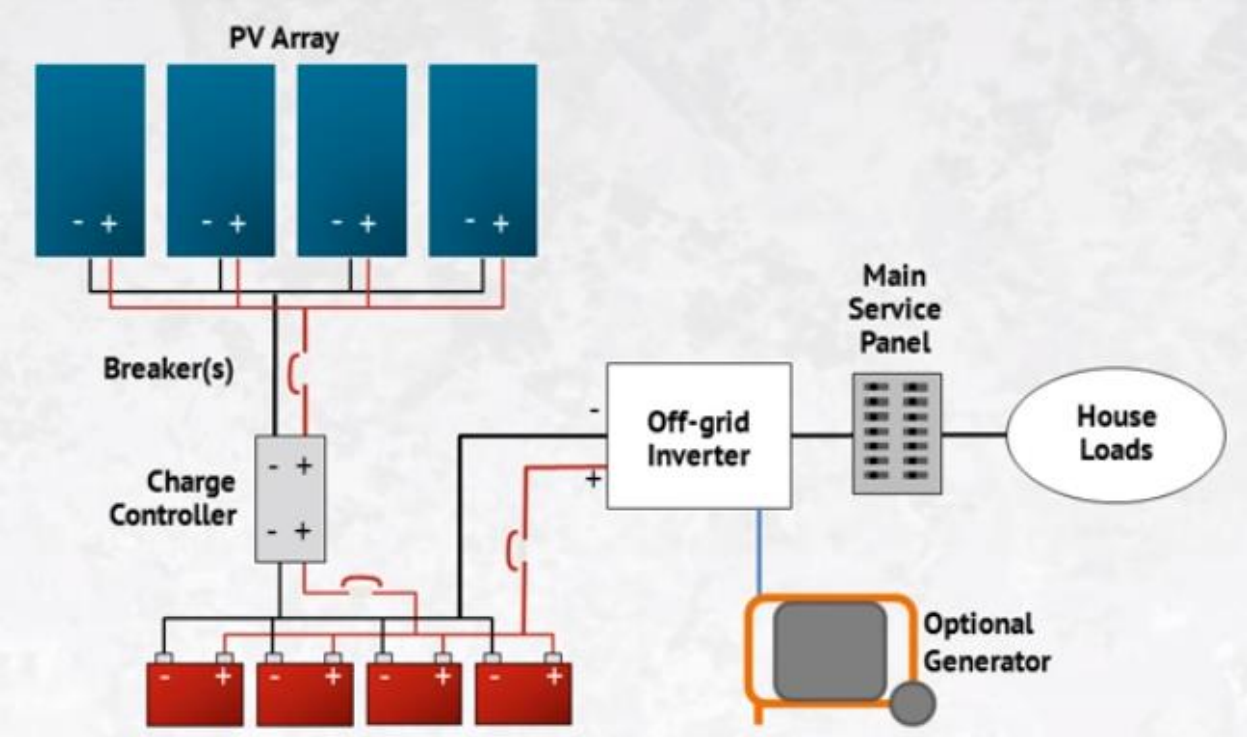


Figure 9: A general off-grid solar power layout. Photo credit: alt-E [16].

Sizing Your System

System sizing is a critical step in the design of your home. This step will need to consider both load and supply on a daily and seasonal basis to meet your power demands at all times of the year. An important step in this process is deciding if the use of a generator is required. This decision will be heavily influenced by the efficiency of your passive systems and the comfort/insurance level that you desire.

In sizing your system you must first determine what you will be powering and for how long. This will give an approximation of the energy you will use in a day. *Alt-E* has a useful load calculator spreadsheet on their website. This spreadsheet is used to determine the power that you will need as well as energy used each day.

Power, measured in watts, differs from energy in that it is the rate of energy use. Think of it as the relation between speed and distance, where speed is power and distance is energy. Energy is usually measured in watt-hours (Wh) or kilowatt-hours (kWh), and is simply the power in watts drawn by a device times the number of hours it is on. If a kettle which draws 1500 W is on for 5 minutes a day, then the energy used in that time would be:

$$1500\ W \times \frac{5}{60} h = 125\ Wh$$

Many devices may not have the wattage listed on them but will have voltage and current. This information is usually on or near the power cable. Power in watts is calculated by multiplying the voltage in volts and the current in amps. In the case of the device shown below, use the input values as this is what the device is drawing from the wall (you will notice the output power is lower because

transformers are not 100% efficient). If the input voltage shows a range as it does in the picture below, use 120V in the calculation unless it is for a 240V device such a stove or a washing machine.

Figure 10: Power information on a household device.

Sometimes energy use is more difficult to determine for devices such as a fridge or HVAC systems which turn on periodically. The manufacture may give annual energy use on a fridge which you can use to approximate your daily energy.

Use of DC appliances is another consideration in system sizing. QSEC uses some DC appliances (such as our DC fridge) which allow for a smaller, less expensive inverter to be used. However, DC appliances are fairly uncommon and difficult to implement due to the large wire losses associated with DC power. The most practical use of this would likely be to power DC lights in your home.

Choosing Batteries

A battery bank is essential if you plan on using power when there isn't sunlight. Once you have figured out your loads, you can start thinking of a battery bank. *alt-E* also has a great video laying out the details of sizing your battery bank based on your load calculations in their playlist.

Something that is not touched on in the alt-E videos is the different composition of batteries. The three main types used in solar power systems are lead-acid, sealed AGM, and lithium batteries. Though more expensive than lead-acid, sealed AGM are a good idea if the house is going to be frequently left alone as they require no maintenance. On top of maintenance, lead-acid batteries also need to be in a vented enclosure to evacuate hydrogen gas. Lithium batteries are a newer technology which are more expensive but are very resilient and user friendly, allowing to be discharged to greater depths without hurting the longevity of the battery.

Solar Panels

The first thing to consider when selecting solar panels are whether they will be roof mounted or ground mounted. Solar panels operate most efficiently facing South inclined towards the sun. Many ground mount modules also have adjustable poles to tilt the panels and better shed snow. If the roof or space where you are placing your panels is limited in area, you may have to find more efficient panels to give you the power you need in the allowed space. For roof mounting you will also have to match the panel mounting method to your roof type.

As previously mentioned, another technology is PVT panels which combine solar collectors and solar panels into one body. This both saves space and works to the benefit of both technologies.

Useful Power Links

Alt-E solar power system design playlist [16]

Batterystuff.com: wiring batteries in series or parallel [17]

Solar insolation in Canadian cities [18]

Wholesalesolar.com: lots of info on parts of a solar power system [19]

HVAC

HVAC (Heating, Ventilation, Air-Condition) constitutes all the air and heat systems in your home. This is the largest energy demand in traditional homes at around 80% of annual energy use in Ontario. While passive systems play a large role in carrying the load of this energy demand, Auxiliary or back-up systems are recommended to provide essential utilities where passive can not.

The technology you chose for your home will depend on several factors including the expected use and other systems that work alongside it.

Passive Systems

Solar Gain

Although most people think of windows as potential for heat loss, south facing windows will have day long exposure to the sun allowing for large amounts of heat to pass into the house. An important part to taking advantage of this effect is to use a thermal mass to capture this heat energy. Materials such as concrete can store heat energy similar to a battery and maintain temperature passively through the night. Furthermore, because of the seasonal trajectory of the sun, this system can reduce this effect in the summer acting as a completely passive system. Use of passive house technology can allow for heat savings up to 90% compared to typical structures.

Natural ventilation

Using the principles of natural convection, it is possible to provide conditioned air to a home featuring the use of cooling tubes. Hot air leaving the top of the house pulls air through long sloped

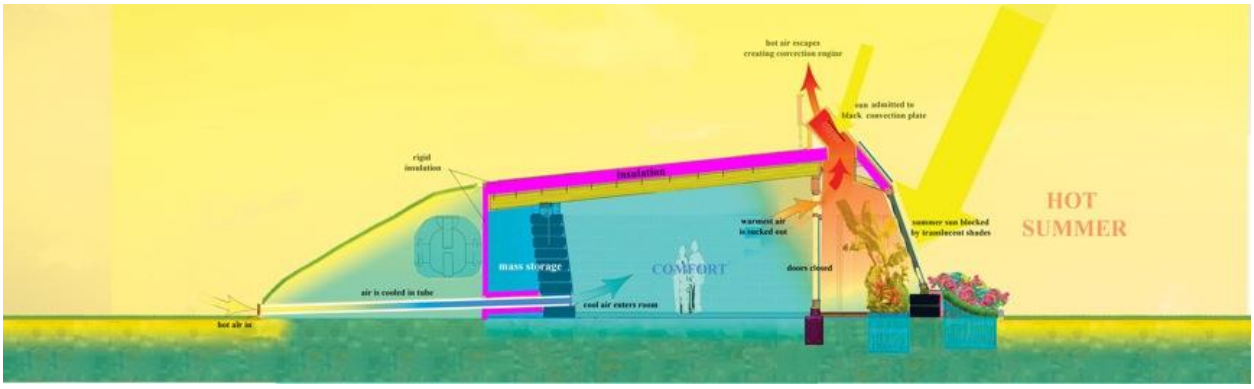


Figure 11: Depiction of Solar Gain in an Earthship

cooling tubes surrounded by a cold thermal mass. As hot air enters the tube the surrounding mass cools the air, precipitating moisture and providing a flow of cool fresh air. This technology has been effectively implemented in several Canadian earthships. These systems operate using no power at the sacrifice of no external control [7].

Solar Collectors

Converting solar energy into hot water can also be done most efficiently with solar collectors. Solar collectors are more efficient at capturing energy than PV panels and can provide preliminary heating to hot water systems. A variety of types of solar collectors exist with some using powerful vacuums to minimize heat loss creating a tube that generates hot water in the wintertime. Solar collectors are not ideal for the Canadian climate; however, many instances of solar collectors being successfully implemented in Canadian homes exist. As a preheating system for an off-grid home, solar collectors can offset the cost of propane and may be a cost effective part of a hot water plan.

Figure 12: Typical Vac Tube Solar Collectors

Powered Systems

Boiler

The most reliable source of heat one could ask for is a boiler. Powered by wood, coal or gas a properly sized boiler can supply the entire heating load of a house given you can supply the fuel. Boilers will supply water at a higher temperature than other systems but run a utility bill to operate.

From a sustainable standpoint wood is the best fuel to use being carbon neutral. However, even in the Collingwood earthship shown above, a propane boiler is used as a back-up. Propane is a relatively clean burning gas producing more heat than natural gas with a lower carbon content and

GHG emission rate that gasoline. Some homes are run entirely off propane and QSDT plans to use a propane tank as auxiliary heating in our project house QSEC.

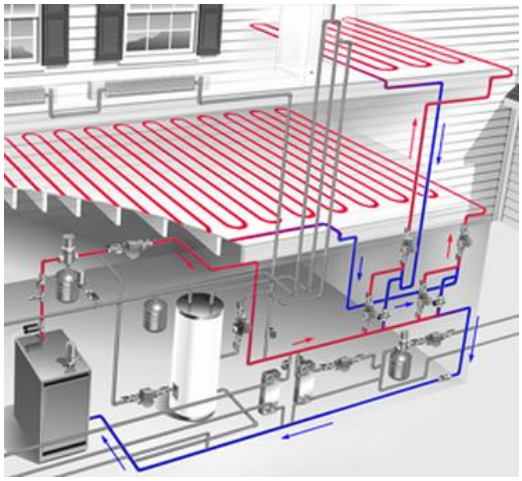
Heat Pump

A heat pump uses electricity to move heat between mediums. Using principles of thermodynamics, a heat pump can move 3-4 times as much heat as energy is put into it. Another feature of heat pumps is their ability to reverse the direction of operation and pump heat out or in. Because of their efficiency and ability heat pumps offer a great potential in off-grid housing.

One application of a heat pump is to supply heat to a hot water tank. In doing so a heat pump will draw heat from the home, actively cooling the environment while supplying heat to the water tank. However, electrical demand for a heat pump is high, and when supply is an issue, a heat pump may not be the solution.

Hydronic Heating

For a controllable heating system, hydronic heating is very suitable. Using pumped hot water, heat is transmitted through tubes into a thermal mass generally in the floor. Hydronic heating uses less power than traditional heating, creates a more favorable "bottom-up" heat distribution and can be controlled, unlike passive systems. Many off-grid homes and earthships take advantage of the benefits of hydronic heating as a means of distributing heat.



Hydronic heating generally compliments the other systems mentioned in this section. This system uses lower temperature hot-water and can use the same thermal mass used in the solar gain system. Additionally, with hydronic heating both air and water heating can be powered by one auxiliary boiler.

Useful Links on Heating Systems

Blog post about heat system experience living off grid in Canada [8]

Article on heating off-grid homes [9]

Extensive blog post about solar heating/ community resource for eco home design [10]

WASTE

Human waste and garbage disposal have an impact on a home's environmental footprint. For an off-grid home, it is important to consider the means of disposal. With no sewer line, human waste must be diverted to a septic system, where it can be emptied and cleaned at intervals. Moreover, wastewater must also be diverted. Yet, wastewater can prove valuable in systems that recycle it through the home. For example, a simple diversion pipe and small holding tank (depicted to the right) can divert water from bath and sink drains to use in toilet flushing and exterior irrigation; because pathogenic contamination from E. Coli, Giardia, Cryptosporidium, and other viruses and bacteria exist only in trace amounts in greywater samples, it is appropriate for use in toilet flushing, where this water isn't being ingested.

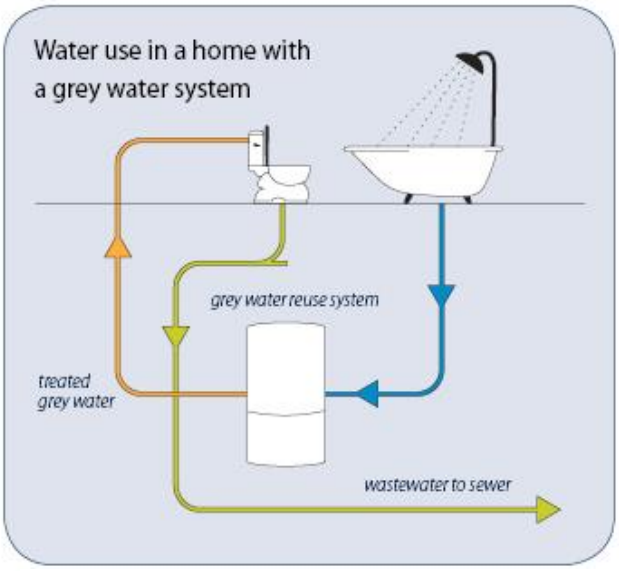


Figure 13: Greywater flushing [22]

Garbage and recycling systems in a typical home are already well configured to prevent additional waste and carbon footprint. Nonetheless, at home composting of all food waste with a simple aerobic composting unit can be a resourceful means to produce soil for gardening use, lowering the use of environmentally damaging synthetic fertilizers. For example, the GESTION USD® composter from Rona, which costs only $75, can accommodate 300L of waste, and is manufactured from recycled plastic to lower its footprint [23].

CONSTRUCTION

Construction of an off-grid home will require careful planning, as contractors will need access to some utilities during the construction process. Moreover, some systems installed in sustainable homes require specialized labour to install. However, for the purpose of this initial report, it is assumed that all skilled labour requirements are being met by the client's family. Consider some notable construction materials that could contribute to the performance of this house below.

Metal roofing

Metal roofs are an ideal choice for buildings in rural areas or for off-grid home applications. Although they are slightly more expensive than a typical asphalt shingle roof, improved longevity and a more durable surface are draws for implementing metal. Instead of 20 years for an asphalt roof, metal roofs can last 50 years or more [11]. Furthermore, for rainwater collection, metal is optimal, since its smooth surface with low porosity will provide cleaner and more abundant rainwater to the collection tanks.

High-Performance Framing

An integral part of minimizing a house's energy requirements is having a well sealed and insulated building envelope. This involves using advanced framing techniques to maximize the insulated area of a wall.

Typical exterior wall assemblies can be 25% wood, or more. Wood is a poor insulator, and wall studs provide thermal bridges, allowing heat to travel into or out of the home more easily. Multiple methods exist to combat this issue and improve walls' performance.

1. T-stud
   The "T stud" is a new framing product that replaces 2x6 wall studs with an engineered truss made of two 2x3 boards connected with dowels [12]. The space between the boards is then filled with sprayed in foam, offering a finishes assembly that is both three times stronger and three times better of an insulator than typical 2x6 studs [12]. Although it is an added expense, this product can drastically improve the pace of construction and the efficiency of the finished building.

2. Double Wall Framing
   Another framing strategy to augment the air tightness and heat retention of a house is double wall construction. Here, a second framed and insulated wall is built inside of the exterior wall, with the studs offset. This drastically increases the house's insulation, while also allowing for easier installation of plumbing and electrical fixtures if a small cavity is left between the walls for utilities. However, material and labour costs will be much higher to build double walls.

3. Exterior "Jacket Insulation"
   As already mentioned, thermal bridging caused by the wall studs continuing through the exterior wall can reduce a house's heating efficiency. To combat this, a clever option, discussed by popular builder Matt Risinger, is to wrap the entire finished wall assembly with an exterior layer of rigid foam board insulation, which acts as a "jacket" to insulate the house [14]. Over this, the finish material (roof or siding) is placed. Preventing thermal bridges and adding an extra layer of insulation over the entire building envelope can also lower air leakage and greatly reduce overall heat use.

Partially buried structure with insulated topsoil/thermal mass

Adopting a concept used by Earthship construction methods, by building a property on an inclined lot, and partially burying the lower floor of the structure (with a walk-out basement or otherwise), Heating costs can be reduced. Insulating the ground for several feet out from the foundation just under the surface can trap heat in the ground, helping the ground surrounding the foundation to perform as thermal mass, reducing heating loads. This is a low-cost upgrade, requiring only a small amount of digging and XPS insulation panels, but is only applicable for a full basement building.

Resources

Many useful resources exist online for those interested in sustainable housing design and construction. We have compiled some of the most information rich websites and summarized them below.

- **Canada Green Building Council** (https://www.cagbc.org/)
  The definitive resource on sustainable construction in Canada, the CaGBC website provides many useful resources, including LEED certification procedures and information, academic studies, articles and news on building science and notable projects in Canada.

- **EcoHOME** (https://www.ecohome.net/)
  EcoHOME is a site that has a wealth of information on eco-friendly home design, notably including build logs / features from people and their projects, and general information on the process. From an information gathering / interest stage, this is a great website to peruse.

- **SunPlans** (https://www.sunplans.com/house-plans/list)
  Run by Debra Rucker Coleman, an independent architect, this website offers pre-made house plans for Solar-Centric or environmentally conscious house designs. This would be a good starting point for some design ideas; moreover, this architect could be a good consultant for your project.

(disclaimer: we have no sponsorship or other agreement with any of these businesses; this is purely informational)

Next steps

Hopefully upon reading this document you will have a better grasp on the technologies and considerations that you will encounter when designing your home. The next step you should take would be to explore some of the many links and resources provided in this document. These sites contain helpful information from individuals who have been in your shoes. In these links you will find discussion boards, designs, links to further resources and more comprehensive descriptions and explanations. Having a good understanding of the technology available to you will help you determine the design and systems that best align with your needs and vision.

While the design and technical aspects of these technologies are important, your research at this stage should focus on answering larger questions like:

- What type of house do I want? What do I want it to be?
- What utility demand will the residents of my house need?
- Which technologies stand out to me and why?
- What is my budget and what can I include accounting for a payback period?

Once you have answered the larger questions regarding direction, vision and needs you will move on to the second stage of planning. In this stage you will narrow down general but more specific details of your home such as:

- The location of the home on your property
- The size of your home
- An overview of the technologies and construction methods you will include in the design

QSDT welcomes you to reach out for advice or consultation on the construction or integration of sustainable energy technologies into your home.

Links

[1] https://www.youtube.com/watch?v=j7SUjcwXY8w

[2] https://collingwoodearthship.wordpress.com/

[3] https://www.youtube.com/watch?v=oTU2KlwOnQw

[4] http://windchasers.ca/resources/links/

[5] http://www.darfieldearthship.com/map/

[6] https://pangeabuilders.com/earthships/

[7] https://pangeabuilders.com/cooling-tubes/

[8] https://www.greenbuildingadvisor.com/article/off-grid-in-canada-what-we-did-for-heat

[9] https://www.haliburtonsolarandwind.com/2018/12/14/heating-your-off-grid-home/

[10] https://www.ecohome.net/guides/2366/solar-heating-and-energy-generation/

[11] https://www.statefarm.com/simple-insights/smart-ideas/wondering-about-metal-roofs-here-are-the-pros-and-cons

[12] https://www.tstud.com/

[13] https://www.ecohome.net/guides/1047/an-ownerbuilders-account-of-building-a-passive-house/

[14] http://mattrisinger.com/exterior-rigid-foam-w-modern-hardie-plank-siding-details/

[15] https://thetyee.ca/Culture/2015/01/30/Build-an-Earthship/

[16] https://www.youtube.com/playlist?list=PLoHd6hGDqS07bbZkyi_4ntfiySUKjPsUL

[17] https://www.batterystuff.com/kb/articles/battery-articles/battery-bank-tutorial.html

[18] https://www.solar-store.com/Insolation%20Chart.pdf

[19] www.wholesalesolar.com

[20] https://www.harrowsmithmag.com/289/casey-grey-passive-house-eco-home

[21] https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm

[22] https://guelph.ca/living/environment/water/water-conservation/greywater-reuse-system/

[23] https://www.rona.ca/en/composter?viewStore=55070&cm_mmc=shopping_google-_-g_127_87-_-1701008834-_-ON-44115008&gclid=Cj0KCQjws7TqBRDgARIsAAHLHP4pbApPhEyi257wWnqCx-9U65RFxrLuBc0pJMpP1eFKaAWKTinx1fcaAjF_EALw_wcB

[24] https://www.youtube.com/watch?v=Bx0aDeru_Xw

[25] https://www.caleffi.com/usa/en-us/technical-magazine