Off Grid: Meaning, Technologies, and Applications

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Abstract

"Off grid" or "off the grid" refers to a building or buildings that are not connected to any public utility systems. Energy, water, and waste disposal are dealt with on site without any ties to a municipal system. This overview and analysis addresses the apparent lack of knowledge and expertise in this area not only at the most basic levels but also the void that exists within the intelligentsia as to what it takes to go off grid and what that means. Off grid is its own entity and not just part of sustainability, conversely, off grid most often does incorporate sustainability. Many resources exist on the individual components of an off grid system but there is little information available that addresses how to combine these components into a building for it to become off grid and thus the prevalent ignorance among laypersons and scholars alike. This paper houses them together and shows how they relate to the overall built environment.

Keywords

Off Grid
Renewable Energy
Sustainable Architecture/Design
Alternative Energy
Water Conservation

1. Introduction

No one knows precisely how many people across the country are living completely off the grid. “They’re very hard to find,” said Richard Perez. “They don’t pay electric bills [1].”

This paper familiarizes, explains, and demonstrates what an off grid building is by defining the term off grid and by examining the various components involved and their applications. It introduces the overall systems of an off grid built environment and purposes them as an alternative to fossil fuels.

The following research is not intended to be a list of every possible off grid scenario. It provides an introduction to the different features in order to gather in one place an overview of what is involved to enable the reader to then have a basic vocabulary and understanding of an off grid building.

“Off grid” or “off the grid” refers to a building or buildings that are not connected to any public utility systems. Thus, municipally supplied energy, water, and waste disposal are foregone and instead are dealt with on site with renewable energy sources (RES). Considered natural and sustainable, these renewable energy sources are for the most part provided by the sun i.e. solar energy.

Part of the confusion with what exactly an off grid system is arises from the scope of what has to be addressed at the macro and micro levels. At the macro scale it simply involves energy, water, and waste disposal, but within each of these are subsections and a wide variety of technologies at the micro level (Figure 1).

In order to examine the above, this paper is organized into overarching sections and then further divided into subsections that explain what is available within the overall sphere and how to apply that technology or system. First, the energy section contains information on how to minimize energy demands and subsections on renewable energy systems such as photovoltaics, fuel cells, small-scale hydropower, wind, and biomass. Second, the water section addresses minimizing water demands, how to provide potable and non-potable water, and how to utilize greywater. Third, waste disposal deals with blackwater.

1.1 Off Grid Defined

Off Grid is defined as a building that is not connected to a grid system of any kind such as energy, water, or plumbing.

1.2 Background on Renewable Sources of Energy

Renewable sources of energy have been employed since humankind began sheltering itself. Using the sun to heat buildings, taking advantage of available water, trees, and wind for cooling and using water, wood, and wind for energy as well, the first humans lived off grid remaining that way for most of human history. It is in relatively recent history, at the advent of the Industrial Revolution, that we see society creating a grid to tie into to provide the lifeblood for their buildings.

However, this heavy reliance on a grid system eventually led to the present depletion of resources that supply the grid i.e. fossil fuels, water, land, etc. Other byproducts of our dependence

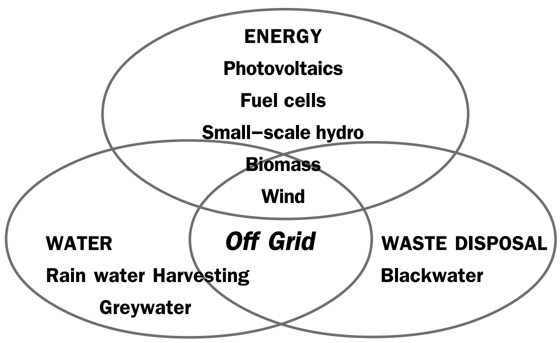

Figure 1. Overlapping technologies and components of an off grid building.

include: unprecedented pollution and unforeseen political, cultural, and societal upheaval examples include: Chernobyl, the Gulf Wars, 9/11, military coups, World Trade Organization Protests, and the increasing concentration of wealth into the hands of a few. The interest in renewables in modern history stems from the oil crises of 1973, 1979-1980, and the current oil crises. These in turn caused the money invested in these systems to increase significantly. Renewable energy also owes a lot of its development to the space and military industrial complex. Because of this we are now experiencing a worldwide movement rapidly gathering momentum of building off grid, and an explosion in the green building market [2-4].

"Building green is becoming less of a high-end option and more of a necessity in sync with the threats of accelerating energy costs, global pollution concerns, the need for businesses to attract and retain the best employees, and a long list of health concerns [5]."

2. Energy

Economic, political, and social pressures are all contributing to a rise in awareness of the need for alternatives to our dwindling resources. One of the most seriously threatened resources is the supply of energy, a lot of which is wasted unnecessarily and easily conserved.

Engaging in the conservation of energy in a building from the beginning of a project is paramount. Orienting the building properly on the site, acknowledging the seasons, noting which direction the sun and wind travel and observing the flora and fauna, can all contribute to greatly reducing energy demands from the start. Energy demand can also be minimized through measures as simple as turning off lights, taking short cold showers, minimizing air conditioning and heating or doing without it altogether, not letting the water run while brushing teeth or shaving, etc. Also, insulating the building properly provides a constant temperature that does not require artificial means of heating and cooling.

Subsequent to minimizing the energy demands and calculating the remaining energy requirement, exploring different ways of providing that energy follows. Current technologies, whether used alone or in conjunction with each other to form hybrid systems include: photovoltaics (PV's), fuel cells, micro-hydropower, wind energy, and biomass. These renewable energy systems can power a building or group of buildings.

2.1 Photovoltaics

The photovoltaic cell (PV), which is made of semi-conducting materials absorbs light and converts it into electricity. Individual PV cells connect together in modules to form an array (Figure 2). The size of individual cells and the size of the array depend on the energy demand. PV's take many shapes ranging from thin films and multi-junction devices (stacked solar cells) to building integrated photovoltaics (BIPV). BIPV's produce electricity while also acting as a building component like a curtain wall, skylight, window, roof, etc. (Figure 3).

A PV cell or solar cell is comprised of a small crystal wafer that has a permanent electric field. An electric current is generated when sunlight hits the cell and electrons are released. A solar panel or module is a grouping of PV cells. A solar array is formed from multiple solar modules. This solar array is where the electricity is generated.

Once the electricity is created it usually flows through an inverter in order to change its DC (direct current) into AC (alternating current), which is the standard in most buildings. Excess energy is stored in batteries (note: if the system

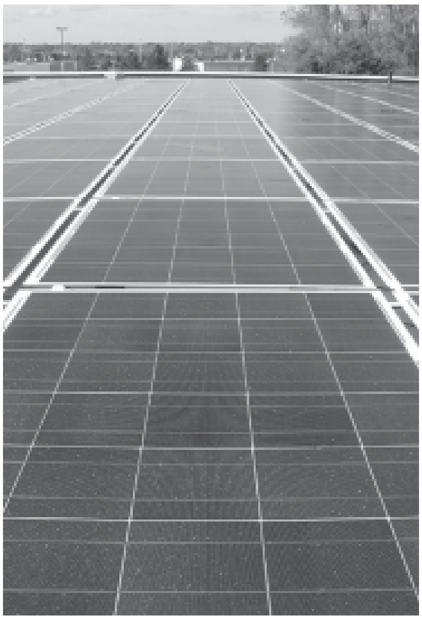

Figure 2. Photovoltaic array [6].

Figure 3. Building integrated photovoltaics (background: tall building windows) [7].

is tied to a grid, the excess energy is fed back into the grid for credit with the utility, if the utility company provides net metering.)

Photovoltaics can be used almost anywhere there is adequate light including urban areas. According to A. Zahedi "they are often the most appropriate technology to meet energy demands of off grid communities [8]." Currently they are mostly used in building applications where the grid does not reach. This is for psychological, environmental, and monetary reasons. PV's can be used at remote sites for electricity, telecommunications, navigational aids, water pumps, and refrigeration.

2.2 Fuel Cells

Unlike PV's that generate electricity when sunlight hits the cell, fuel cells generate electricity by a chemical reaction. Most fuel cells work by converting hydrogen and oxygen into water, which then produces electricity. They also have to be converted by way of an inverter from DC to AC. Two electrodes: the cathode (positive) and anode (negative) make up the fuel cell. The activity at the electrodes produces the electricity. Every fuel cell needs a catalyst and an electrolyte. The catalyst speeds reactions at the electrodes while the electrolyte carries electrically charged particles from one electrode to the other. Since chemicals constantly flow into a fuel cell it never goes "dead."

Different types of fuel cells are classified by the kind of electrolyte they use. Some fuel cells are suited for powering cars and small portable applications while others work well in stationary power generation plants. Different types of fuel cells include: alkaline, direct methanol, phosphoric acid, molten carbonate, solid oxide, and most promising: the proton exchange membrane or PEM (Figure 4).

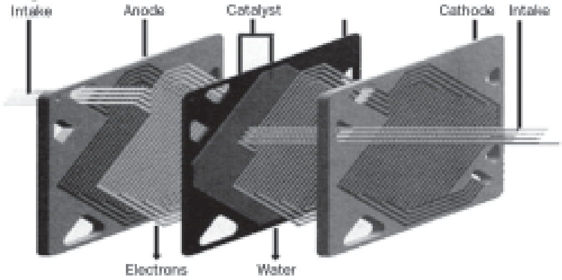

Figure 4. Proton exchange membrane [9].

PEM's have more varied applications, are more responsive to varying loads, and its costs are decreasing. Fuel cells, like PV's are usually grouped since one cell alone generates little electricity. Groups of fuel cells are called fuel cell stacks. See Table 1 for a chart of fuel cell types and applications.

An urban application of fuel cells, as well as photovoltaics, features in the Conde Nast building at Four Times Square (Figure 3). While not permanently off grid the system is designed so that it can go off grid during a blackout. The fuel cells are powered by natural gas and generate 400 kw of electricity while simultaneously generating *thermal energy that provides the building's perimeter heating. According to the Durst Corporation, who commissioned the building, the fuel cells were chosen for a variety of reasons including reliable power, low noise, low emissions, and for being environmentally friendly. An article by the Rocky Mountain Institute (RMI) based in Aspen Colorado asserts, "the two main applications of fuel cells are electricity generation and powering motor vehicles. Power applications could involve central generation by utilities, industrial co-generation (of heat and electricity), or distributed generation (DG) on or near the premises of commercial or residential customers [10]."

2.3 Micro-hydropower

Hydropower is another source of renewable energy that doesn't burn fossil fuels or use nuclear energy. Hydropower, whether large or small, uses the flow of water to create electricity. However, large hydro isn't considered "green" or sustainable because of its disruption to ecological habitats. A micro-hydropower system on the other hand, defined as generating less than 10 kw's of electricity, is considered sustainable and is also a continuous renewable resource that is non-

Table 1. Comparison of Fuel Cell Technologies [11].

Fuel Cell Type	Common Electrolyte	Operating Temperature	System Output	Efficiency	Applications	Advantages	Disadvantages
Polymer Electrolyte Membrane (PEM)	Solid organic polymer poly-perfluorosulfonic acid	50-100°C 122-212°F	<1kW-250kW	50-60% electric	• Back-up power • Portable power • Small distributed generation • Transportation	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Requires expensive catalysts • High sensitivity to fuel impurities • Low temperature waste heat
Alkaline (AFC)	Aqueous solution of potassium hydroxide soaked in a matrix	90-100°C 194-212°F	10kW-100kW	60-70% electric	• Military • Space	• Cathode reaction faster in alkaline electrolyte so high performance	• Expensive removal of CO_2 from fuel and air streams required
Phosphoric Acid (PAFC)	Liquid phosphoric acid soaked in a matrix	150-200°C 302-392°F	50kW-1MW (250kW module typical)	80 to 850% overall with combined heat and power (CHP (36-42% electric)	• Distributed generation	• High efficiency • Increased tolerance to impurities in hydrogen • Suitable for CHP	• Requires platinum catalysts • Low current and power • Large size/weight
Molten Carbonate (MCFC)	Liquid solution of lithium, sodium, and/or potassium carbonates, soaked in a matrix	600-700°C 1112-1292°F	<1kW-1MW (250kW module typical)	85% overall with CHP (60% electric)	• Electric utility • Large distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High temperature speeds corrosion and breakdown of cell components • Complex electrolyte management • Slow start-up
Solid Oxide (SOFC)	Solid zirconium oxide to which a small amount of ytira is added	650-1000°C 1202-1832°F	5kW-3MW	85% overall with CHP (60% electric)	• Auxiliary power •Electric utility • Large distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte reduces electrolyte management problems • Suitable for CHP	• High temperature enhances corrosion and breakdown of cell components • Slow start-up

* Direct Methanol Fuel Cells (DMFC) are a subset of PEM typically used for small portable power applications with a size range of about a subwatt to 100W and operation at 60-90°C.

polluting with low operational and maintenance costs [12]. In order to generate electricity; water as it flows downstream is captured going from a higher elevation to a lower one, and then it is run through a turbine and generator. Predictably, the higher and faster the water is, the more electricity is created (Figure 5).

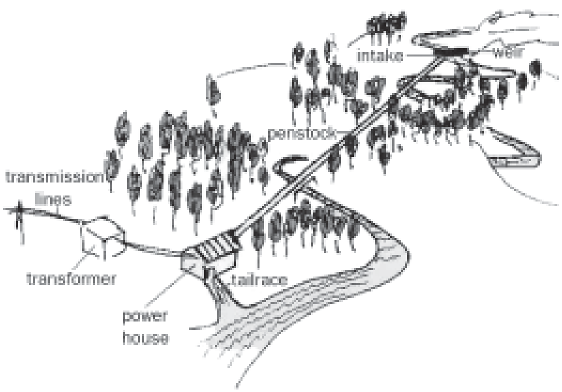

Figure 5. Small-scale hydropower [13].

Head and flow determine whether or not the site is a feasible location for micro-hydropower. Head is the vertical height distance the water falls and flow is how much water is falling. To calculate the amount of watts generated: net head [9 feet x flow (US gpm)]/10 = W. Micro-hydropower is suitable for homes, small farms, small resorts, and developing countries without a grid in place and especially for rural communities.

2.4 Biomass

The U.S. Department of Energy states that biomass is "The largest U.S. renewable energy since 2000…" and that "Biomass use strengthens rural economies, decreases America's dependence on imported oil, avoids use of MTBE or other highly toxic fuel additives, reduces air and water pollution, and reduces greenhouse gas emissions [14]."

Biomass like wind and micro-hydro, also creates electricity via a generation turbine, which can use landfill gas, human, animal and/or agricultural waste and transform it into energy. While there are different types of biomass power systems, for example: direct-fired, anaerobic digestion, landfill gas, co-fired, and modular, the most common is direct-fired.

In a direct-fired system energy is derived from agricultural waste by burning the waste and using the heat to boil water, which creates steam that turns the generation turbines. Anaerobic digestion and landfill gas captures the gas emitted as human, animal, and/or landfill waste breaks down and converts it into electricity. Co-firing, which substitutes a portion of biomass for coal, has the added bonus of being able to use existing power plant facilities. Modular systems rely on the same technologies previously mentioned and are being considered for developing countries.

With all of these processes it is important to avoid using non-sustainable sources or sources that promote pollution and/or environmental degradation. For instance, cutting down old growth forests or burning trash is not the intention of using biomass as a renewable off grid energy source.

Using biomass as a source of energy can be applied to a small or large scale, providing electricity for the whole village or for an individual building. For individuals or groups of individuals a small-scale biogas plant or small-scale biogas generator is most applicable. Non-toxic waste products of these communities can provide energy to their buildings and divert waste from the landfill. Figure 6 shows the Biomax 15\35 a prototype downdraft small-scale gasifier suitable for small businesses, rural homes, and schools developed by the Community Power Corporation, located in Denver Colorado. It converts agricultural and forest waste into 15 kw of electricity.

Figure 6. Biomass for small-scale heat and power [15].

2.5 Wind

By utilizing strong steady winds, wind turbines allow a building(s) to go off grid with the added benefits of being pollution free and taking up very little space. Wind turbines incorporate two or three blades mounted on top of a 30m high tower. When wind at this height, which is faster and less turbulent, spins the blades the blades connected to a rotor turns the main shaft, which spins a generator that produces electricity (Figure 7). The windier it is, the more electricity is produced and at a cheaper cost. Conversely wind can be intermittent, cannot be stored without the aid of batteries, and most of the good winds are located in remote areas away from cities.

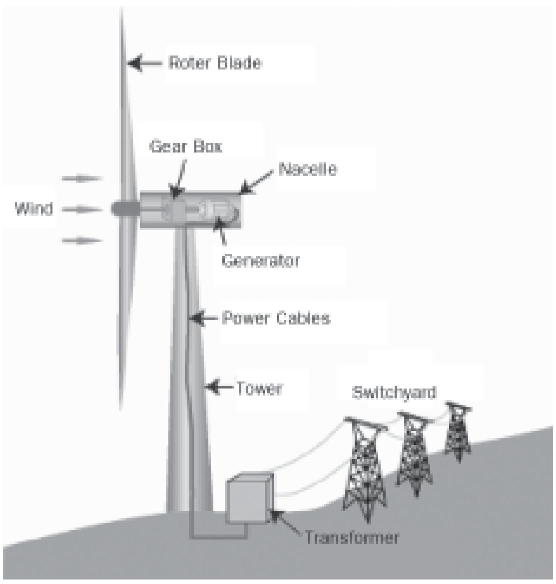

Figure 7. Wind turbine [16].

Charles J. Kibert in his book *Sustainable Construction* claims "Wind Energy is the fastest-growing form of energy production, with an estimated year-on-year growth of 25 percent [17]." The American Wind Energy Association (AWEA) recommends wind turbines for residential applications on at least one acre of land unless using a very small wind turbine. Wind turbines are used on farms, for home systems, for remote villages, water pumps, and in hybrid systems.

3. Water

3.1 Potable and Non-potable

As mentioned at the beginning of this paper, conservation of resources should be the first consideration in construction or renovation. This idea of conservation applies to water as well. For instance, the *Sustainable Building Sourcebook* cites the following percentages for typical household water usage: 20% shower and baths, 9% potable uses, 16% clothes and dishwashing, 19% toilets, and 36% for lawns and gardens [18]. By choosing the proper fixtures and by limiting the amount of water used (i.e. short showers, not letting the water run while using the sink, using an efficient dishwasher, Xeriscaping, waterless urinals, etc…) upfront water usage decreases. It is important to estimate how much water the building or buildings will need and then explore how to meet these needs through the available resources on site. Alternatives include using rainwater catchment systems, a greywater system, and a blackwater system (see the section on waste disposal below.)

Rainwater catchment systems range from the basic to the high tech and usually consist of cisterns or some other device to store the water, pipes that collect the water and transport it to the tanks, and a filter to clean the water

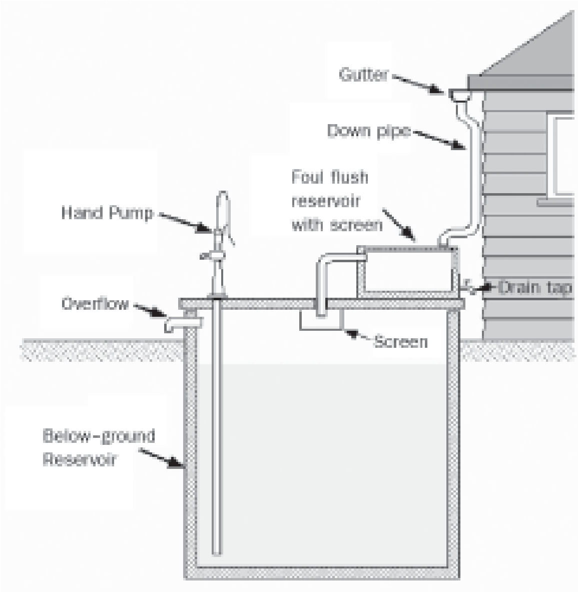

Figure 8. Rainwater catchment system and below ground storage [19].

(Figure 8). The water is collected from the roof or other areas before it reaches the ground. Some systems have a diversion system in place if the rain is collected off of a roof prior to use. This diversion system automatically diverts the amount of water it takes to wash the roof of dirt and debris before sending the "clean" water to the filter and storage tank. The filters differ as well. Basic filters such as sand filters prepare the water for indoor non-potable uses such as flushing toilets, showers, laundry, and irrigation. UV, ozone, or distillation processes can prepare the water for drinking and other uses that require contact with human or animal bodies.

Some issues to consider with rain water collection is whether or not the tank needs to be buried (to keep the water from freezing in certain climates or to keep it cool in warmer climates) and whether it is legal to collect the rain water (for example in some areas in the Western United States where water rights are an issue it cannot be diverted without seeking permission from the government first). Also consideration needs to be given to how to get the water to where it is wanted. This can be accomplished by using gravity or pumps. The pumps can be powered by solar or fuel cells. If gravity is used, the water needs to be high enough to create the amount of pressure to distribute it throughout the building. Raising your catchment device or locating it on the roof can accomplish this. Another alternative is to use a closed loop water collection system.

Besides a rainwater catchment system to provide water, a solar distillation unit is now available. Its intended use is to provide high quality drinking water from ocean water, contaminated ground water, degraded wells, and streams with mineral contaminations and can be powered by photovoltaics.

Lastly water can be harvested from a source of fresh water on the site such as a stream or pond and utilized as long as it is treated before consumption.

3.2 Wastewater

Greywater is wash water that doesn't contain any food or toilet waste. It can be collected, treated, and reused for irrigation. (See section on Waste Disposal below for blackwater). Greywater is separated out from other water through the use of a dual waste pipe system that runs to a centralized location. The piping should be equipped with a control valve and overflow system that will allow the greywater to go to an overflow site or tank. Greywater can be treated through the use of natural filters such as plant beds or through distillation. However, the filters need to be easily accessible or self-cleaning to avoid any filter maintenance problems. Because of the risk of pathogens, greywater should be treated first and not stored for lengthy periods of time (not more than 24 hours).

The *Sustainable Building Sourcebook* lists four different subsurface distribution types of greywater systems: evapotranspiration (ET) systems, shallow trench, shallow mound, and pressure effluent dosing and drip irrigation. Ideally all should be used with Xeriscaping to conserve water. Also, all assume employing a vegetative cover over the drainfield to reduce soil erosion [18].

In an ET system, greywater flows from the house to a septic tank and then through perforated pipes to a shallow sand bed with vegetation. Here it is converted by the roots of the plants into vapor which is then released through the leaves. An organic or inorganic impermeable liner below the plants absorbs the water and prevents the greywater from soaking into the ground. An alternative way to use an ET system is to create a constructed wetland. Using crushed gravel as a pre-filtering device coupled with living beds of marsh plants creates the wetland. This alternative is recommended for sites that need to have strong control over where the greywater flows.

Both shallow trench and shallow mound place the pipes close to the soil surface and thus the plant roots. In a shallow trench system grey-water is treated and then fed through closely spaced pipes. A shallow mound system pumps the grey water to an absorption area, i.e. a mound of dirt over existing soil after pretreatment (Figure 9).

Similar to shallow mound, shallow trench and ET systems, pressure effluent dosing and drip irrigation flows from the house to a septic tank or other pretreatment and after leaving pretreatment it is pumped through perforated pipes to an absorption bed. This system is employed the most and requires more upkeep, but can be used on many different types of sites.

With all of the above systems, calculations must first be performed on how much water the building uses and needs and how much irrigated water is needed. Unsurprisingly, the installation of low to no flow fixtures is highly recommended. Low to no flow fixtures include: faucets, composting toilets, waterless urinals, the use of sensors so water doesn't continually run, showers, drinking fountains and any other fixture used in conjunction with water.

The weakness of these systems is maintenance. The pipes tend to get clogged and the filters must be vigilantly cared for. The other concern, as mentioned previously, is not to let the greywater stand for too long or it begins to smell. However, these issues if addressed properly render greywater an effective way to reduce the off grid buildings overall water demand.

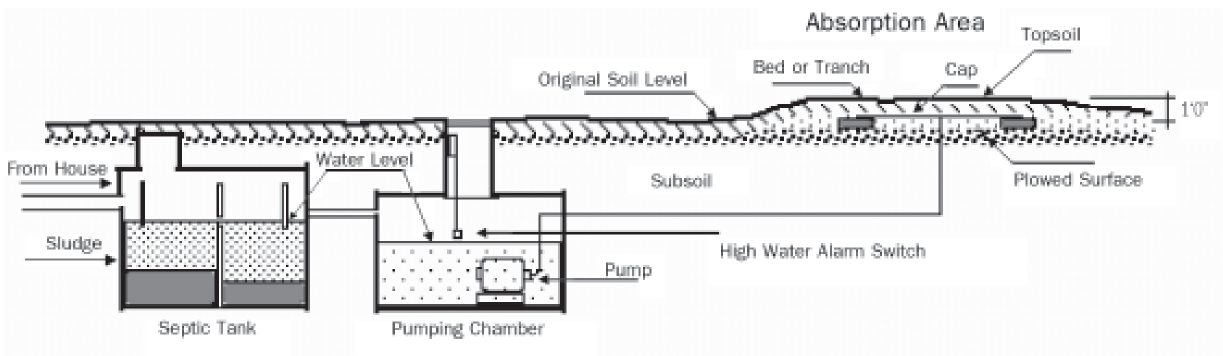

Figure 9. Shallow mound section view [20].

4. Waste Disposal

Waste disposal addresses blackwater. The waste created by a building that this paper is concerned with is generated by sewage.

4.1 Blackwater

Treatment of blackwater on site allows the building, along with a grey water system and the previously discussed water sources, to disconnect from the plumbing grid. Blackwater is defined here as water that contains feces and urine. This can be handled on site by providing a composting toilet, incinerating toilet or a septic tank.

4.2 Composting Toilets

All composting toilets work towards the same goal of breaking down waste materials into compost. This outcome is achieved through aerobic decomposition. In order to work, the compost needs to be the correct temperature (70 degrees Fahrenheit or higher), the right amount of dampness, and the proper ratio of oxygen to nitrogen. If the material freezes it will resume composting once it warms up again. To achieve the proper dampness, water needs to be added or evaporated off. If evaporation doesn't happen quickly enough then an overflow system should be provided. A vent pipe can also be used to transport moisture away. By adding sawdust, hay, weeds, and the like in the proper amounts (which vary) to the compost, the correct oxygen and nitrogen ratio can be achieved.

There is a wide variety of composting toilets. Some require turning of the compost, while others work by layering organic materials, some need vent pipes and fans, and some turn automatically, others are stand alone systems, and others are made for low or high volume usage.

For instance, the bio-toilet is used throughout Japan and is designed for high usage in parks, tourist areas, and for personal residences (Figure 10). "Bio-toilet is the name of a dry toilet or composting toilet that uses sawdust as a bulky matrix for bioconversion of human excreta into compost which can be used either as organic fertilizer rich in N, P, and K, or as a soil conditioner [21-22]." It is operated electrically but can be manually operated as well. Human excreta is treated through a "heating and mixing system that ensures a continuous thermophilic-aerobic biodegradation process…the moisture content in the composting reactor is kept in the range 50-60% by heating, mixing, and ventilation [23]." How often the waste is removed depends on the volume of usage.

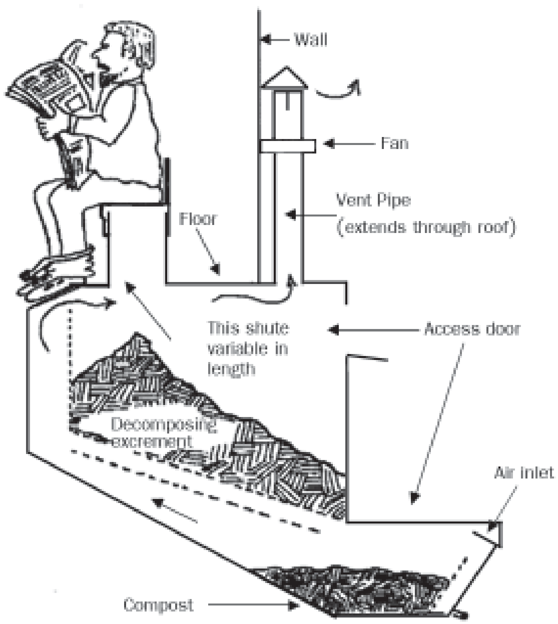

Figure 10. Composting Toilet. Bio-toilet used throughout Japan [24].

4.3 Incinerating Toilets

Like composting toilets, incinerating toilets do not need to be attached to waterlines. However, they do require electricity or a source of natural or propane gas.

An electric incinerating toilet looks like a western style toilet on the outside. The difference on the inside is that a liner is placed into the bowel before using it to keep it clean and non-smelly. Waste is collected in a holding area below the user out of sight where after a recommended number of deposits (usually 2-4) the user "flushes." "Flushing" involves pushing a button, which heats the waste to such a high temperature (1400 degrees Fahrenheit in some models) that it turns the waste into about a tablespoon of ash after approximately an hour. Exhaust blowers and fans cool the unit back down. It is important to vent above the roofline to prevent odors.

Natural and propane gas incinerator toilets also burn off the waste, but only after anti-foam chemicals have been applied to the liquid portion of it and a cover plug put over the toilet bowl to act as a firewall. These gas incinerator toilets can be attached to a constant source of gas or temporarily to propane gas cylinders. Unlike the previous toilets whose appearance resembles a western style toilet, these gas toilets look like outhouses and the waste drops directly into the holding chamber below the user, i.e. there is no toilet bowl. Venting is very important with gas incinerator toilets and intake air may be appropriate for an enclosed room and they may not be installed, for obvious reasons, in an airtight room. Accordingly, in order to have the proper airflow/draft during incineration an air space must be maintained underneath it as well without any hazardous materials such as carpets or rugs. Lastly, these toilets do not require water, plumbing, or electricity.

4.4 Septic Tanks

A septic tank on the other hand does require water and a place for the treated wastewater to flow into. A septic tank receives waste from a pipe connected to the building. Once inside the tank the waste heavier than water sinks to the bottom and becomes sludge while the lighter waste floats on top and is referred to as scum. In between this is water filled with chemicals that act as fertilizer. As new water comes into the tank it displaces the water already there. The displaced water leaves the tank and is transported to a drain field consisting of perforated pipes buried in gravel. This system works by the force of gravity with each successive step lower than the previous.

5. Conclusion

Off-grid buildings are buildings free from the public utility systems and require three major components: energy, water, and wastewater disposal. Within each of these three major components are sub-components and systems to achieve that goal. The first step in going off-grid is conservation and then calculation to understand what the building requirements are in each area. Next is to identify which components work best for the building(s) being considered and this paper's goal was to help in that endeavor.

Presently large market growth is happening in all of the areas: energy, water, and wastewater disposal while simultaneously the prices of the systems keep falling and quality keeps improving. What started as a fringe movement for mostly remote residents is spreading in all parts of the world and especially in developing countries where large populations have no access to a grid or funds to pay for the ever-rising cost of energy, water, and waste disposal.

Also, while outside the scope of this paper, further research should include a cost analysis of the various components, more in depth analysis of their limitations, and the effect these systems have on the architectural design process.

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