Journal of Sustainability Education
Vol. 22, March 2020 Water and Climate
ISSN: 2151-7452

Dissecting the Average Shower and Its Impact on the Planet: An Invitation to Collaborate
Part Two: The Recirculating-Shower Design Elements

Linda C. Pope
Prescott College
linda.pope@student.prescott.edu

Abstract: Part Two of a two-article series describes water conservation through graywater use and rainwater harvesting. Sustainable methods of heating water for a recirculating shower, and potential methods for water filtration and purification are presented. Also addressed is the feasibility of sustainable showering alternatives. An opportunity for educators and students to collaborate in the development of an off-grid recirculating shower is provided as well.

Keywords: recirculating shower, water literacy, bathing, shower water use, water conservation

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Author Bio: *Linda Pope taught sustainability, environmental science, and other life sciences for 20 years. She also taught special programs in science to Pre-K through 5th grade for 10 years. She completed her undergraduate education at Goddard College in Vermont where she learned creative approaches to learning and life. She has a Master's degree in landscape architecture from Harvard University, a second Master's in plant physiological ecology from the University of Maryland-College Park. She developed individual sustainability courses for Portland Community College, Portland Oregon. She is currently working on her doctorate in sustainability education at Prescott College with interests in experiential education, including project-based/ community-based learning and the use of board games in education.*

Introduction

It is well established that future water resource use and reuse must be adjusted if we are to meet the water requirements of all species. Concern over global water resources, their quantity and quality, as well as the need to reestablish a healthy baseline of use, has been expressed for decades (for example, see N.W. Arnell, 1999; P.E. Waggoner, 1990). In much of the world, showering is an activity that uses a significant amount of freshwater resources (Figure 1) and offers an excellent focal point from which to address better ways to reuse water. Toilets also use a significant amount of water (Figure 1), however this can be easily addressed by reviewing the work of Jenkins (2005). If we find and repair leaks immediately, address how we use water in toilets and showering, we will have reduced our residential water consumption by half.

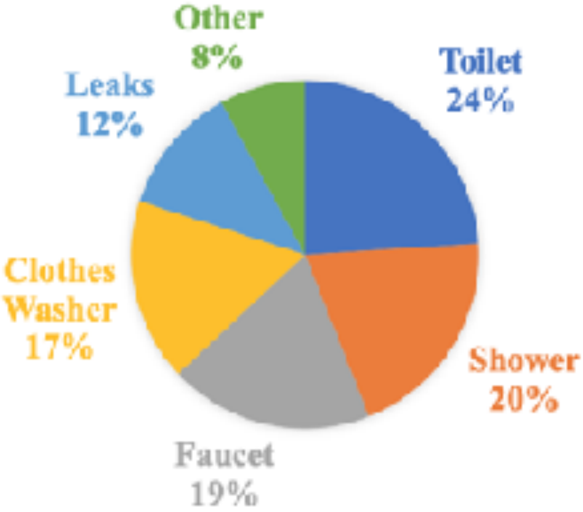

Figure 1. Residential Water Use.
(Adapted from https://www.epa.gove/watersense/how-we-use-water)

The purpose of this article is to investigate design options for construction of a passively heated, solar-powered recirculating shower that is economical both in resource use and financial cost. As the effects of climate change confront us with ever-growing new concerns, developing methods that address water issues locally and globally will grow in importance. These methods should include ways to reduce impacts even in areas with adequate water resources, as well as provide solutions in areas with limited resources. Can design options be explored by schools, colleges, and universities as a collaborative endeavor, and, through this challenge, simultaneously illuminate the essential need for greater water literacy? Addressing this issue at any scale will contribute to future climate resilience.

By involving multiple educational facilities, students can learn the value of collaboration, and develop skills needed to address sustainability concerns as a team. Experiential learning is critical to our future and adds a level of learning that is not available through lectures and PowerPoint presentations. Crookall and Thorngate (2009) describe the current educational disconnect between learning and action. There are many ways to address this disconnect including community-based learning or project-based learning. Project-based learning is:

> …a teaching method in which students gain knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging, and complex question, problem, or challenge" (What is PBL?, n.d.).

Community-based learning is defined by the University of Colorado as:

> …an intentional pedagogical strategy to integrate student learning in academic courses with community engagement. This work is based on reciprocal and mutually beneficial partnerships between instructors, students, and community groups. The goal is to address community-identified needs and ultimately create positive social change. Critical reflection is an essential component of community-based learning; it serves to enhance students' learning of course content, understanding of the community, and sense of civic agency (What is Community-Based Learning?, n.d.).

Experiential learning is learning that lasts (Zlotkowski and Duffy, 2010). Perhaps we are ready to recognize that an experiential, community-based, project-based form of education is critical to our future. The collaborative aspect of this recirculating shower design effort intends to create a project where all of these experiences can be incorporated into a single educational environment.

The eventual goal for this article is to provide, through collaboration, one or more self-contained shower designs that extract as little water as possible, use off-grid energy sources, and simultaneously provide a level of comfort not otherwise available using conservation methods alone.

This article (Part Two) is divided into the following sections:

1. Rainwater Harvesting
2. Solar Water Heating
3. Passive Solar Heating of Water
4. Compost Heat Recovery Systems
5. Filtration Systems
6. Existing Recirculating Shower Systems

1. Rainwater Harvesting

Most Americans do not think about where their water comes from. Public water utility companies currently supply 86% of the American population with its water (Payne, 2017). However, dependence upon municipal water delivery is becoming a luxury. Droughts worldwide are changing the politics, price, and availability of municipal water delivery. Even in cities known for plentiful rain, such as Portland, Oregon, restrictions are being placed on water use due to droughts (Oregon Water, 2015). Throughout the world, people are beginning to recognize the benefits of rainwater use and rainwater harvesting (RWH) (Cain, 2014; Zavala, et al., 2016). While not a new idea – it's been done for thousands of years (Boers and Ben-Asher, 1982) – the growing demands put on our natural water resources, exacerbated by climate change, make it more apparent that our future needs will necessitate rainwater harvesting and graywater reuse.

Zavala et al. (2016) describe this inevitability and the essential incorporation of both methods into mainstream populations. Some communities, especially drought-prone areas such as the southwestern United States, are already encountering seasons with severe shortfalls in water supplies (Payne, 2017). A running list exists in California for municipalities that are likely to run out of water within 60 to 120 days (Payne, 2017). In 2014, Rogers (2014) reported that 17 communities were on the list. In 2019, California is no longer experiencing drought conditions, however, conservation measures are still critical for the future (Lohan, 2019). In 2020 California, Arizona, and Nevada, as well as Wyoming, Colorado, Utah, New Mexico up-steam, and Mexico downstream begin to negotiate for the water in the Colorado River. There is not enough to go around.

Interestingly, on the other side of the world, the City of New Delhi and the state of Kerala in India have mandated rainwater harvesting for all new buildings with a roof size of 100m^2 (1,076 ft^2) or a plat size of over 1000m^2(0.25 acre). Everyone benefits from storing rainwater. For rural farmers, "Every liter of water that does not have to be hauled from a communal water source or purchased from a vendor allows poor households to free up time and money for more productive purposes, resulting in an economic boost" (Cain, 2014).

Rainwater harvesting only works when there is enough rainwater to capture. Wichita Falls, Texas, lost 70% of its water supply after two years with no rain and many 100-degree days. As a consequence, conservation was not going to be enough (Payne, 2017). It became the first U.S. city to gain approval to reuse water being discharged into the ocean and recycle it back into drinking water (Payne, 2017).

Australia has one of the highest levels of potable water consumption in the world. However, this is offset by the fact that rainwater harvesting (RWH), has been adopted by 34% of the households, the highest adoption rate in the world (Amos et al., 2016). Water savings are the primary benefit of RWH systems. The cost of water is increasing faster than incomes. For example, the average GDP real growth rate in Australia was only 3% over 10 years, but the city of Melbourne expects a potable water price increase of 100% in the next 5 years (Amos et al., 2016). Another benefit to using rainwater is that less energy is required to heat soft rainwater (Amos et al., 2016).

According to Amos et al. (2016), if the water (rainwater or graywater) is heated to 60°C (140°F), harmful bacteria are destroyed, and other filtration or water treatment is not unnecessary (Amos et al., 2016; Australia Standards, 2009). This is very important to the development of graywater recirculating systems and to rainwater harvesting. The idea is to have a system that functions properly and is affordable but not overbuilt, as that adds to the cost of the shower with no additional benefit. In the United States, the water standards are established by the Environmental Protection Agency, who make sure that state or local agencies implement those standards (CDC, n.d.).

Governments could take advantage of the increased implementation of RWH systems as the increase in their use can defer the costs of additional infrastructure updates. For example, in Australia, a $100 million-dollar dam could be deferred if water-use efficiency were improved by a 3% reduction by the population (Amos et al., 2016). Residences benefit, as the addition of RWH systems increases the value of the home as an "eco-friendly" feature (Amos et al., 2016).

RWH system design is critical when considering financial (time required to recover the added cost of implementing a RWH system) or reliability claims. The tank size is often based on the home location, rainfall, and roof area capturing the water. It has been found that a daily or even hourly rainfall data is preferred to produce a more accurate estimation, however, the daily version overestimates the yield by 2% over the hourly data collection, whereas the monthly data (often more readily available) overestimates the size of the tank needed (Amos et al., 2016). The importance of better methods of calculation are being recognized and developed so that RWH systems are optimized. For example, Jones and Hunt (2010) note that a poor estimation in future usage contributed to irregularities, due in part to the perceptions held by the public regarding harvested rainwater. Their simulations showed that barrel-size selection was inappropriate: water was depleted when used for family irrigation and overflowed during high rainfall events (Jones & Hunt, 2010). Jones and Hunt noted that rainwater harvesting systems were often underutilized due to poor estimation of the forecasted water usage and determined that a small cistern that became frequently depleted and subsequently refilled is the most economical choice. Optimization of these calculations will be necessary if the general population is to accept this updated method. However, Jones and Hunt conclude by reminding us that using any rainwater harvesting system still reduces the demand on the municipal water systems and prevents the negative impacts of urban runoff during heavy rainfall events.

Once the water is collected, the importance of proper filtration is essential. Many potential pathogens have been found in collected rainwater (Hamilton et al., 2016) and graywater (Leong et al., 2018). Wildlife that lands on or walks on the collection surface can carry potential pathogens that could then be introduced into the storage tanks; this includes fecal matter from birds, insects, bats, possums, and reptiles (Hamilton et al., 2016). Many researchers, including Leong et al. (2018) conclude that graywater must be treated prior to reuse. Brown et al. (2005) describe the methods to treat rainwater (Table 1); this aligns exactly with the same treatments for recommended for graywater. Cain (2014) reiterates that “chlorine, biosands, ceramic vessels, solar-powered UV-disinfection, flocculation, filtration-or, ideally, some combination of these approaches-provide a greater margin of safety and have proven effective in the developing world” (p.154).

There is much information available regarding the various components of a rainwater harvesting system. But all the most important features are difficult to find in a single source: the roofing material, the gutter guards, and a first-flush system. Rainwater harvesting must take place over a metal or tile roof surface (no asphalt shingles) to prevent added toxins from entering the water. Some form of gutter guard is essential to prevent large debris from collecting in the

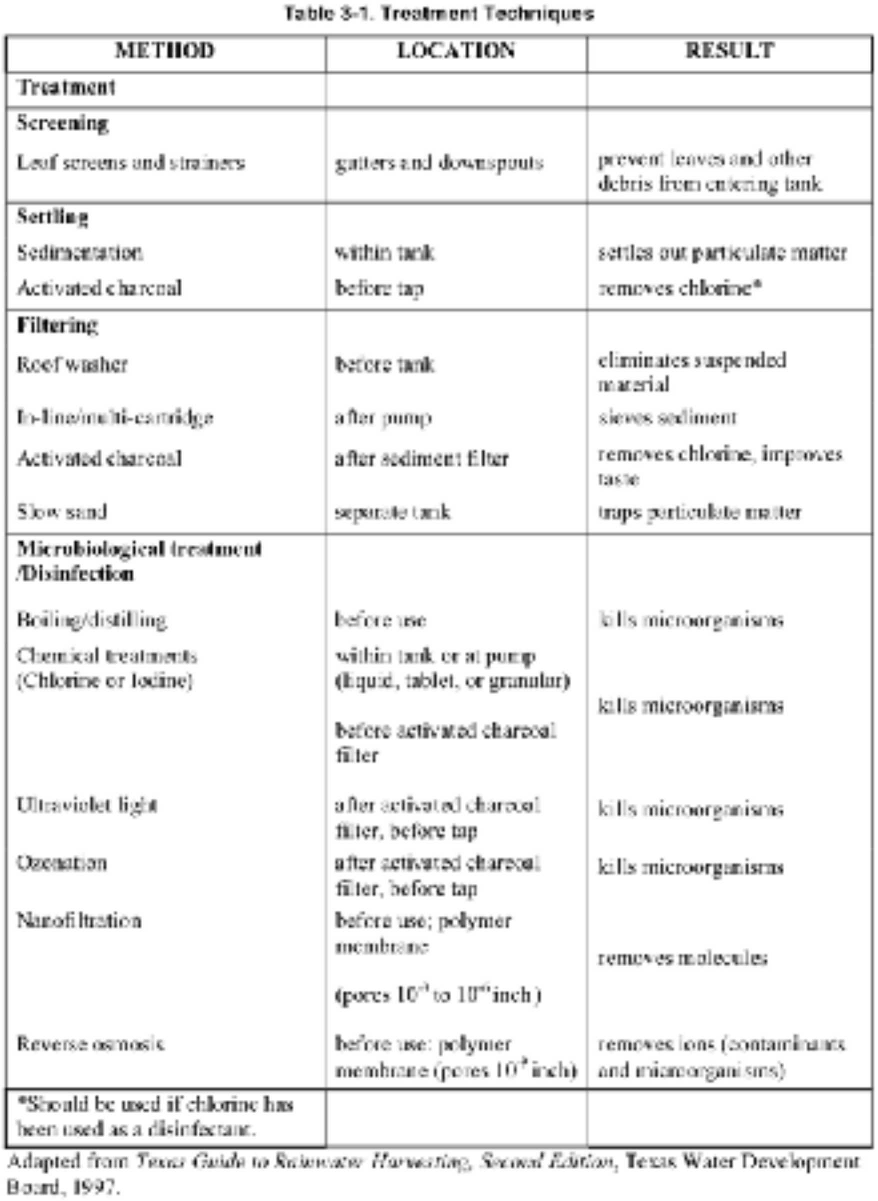

Table 3-1. Treatment Techniques

METHOD	LOCATION	RESULT
Treatment		
Screening		
Leaf screens and strainers	gutters and downspouts	prevent leaves and other debris from entering tank
Settling		
Sedimentation	within tank	settles out particulate matter
Activated charcoal	before tap	removes chlorine*
Filtering		
Roof washer	before tank	eliminates suspended material
In-line/multi-cartridge	after pump	sieves sediment
Activated charcoal	after sediment filter	removes chlorine, improves taste
Slow sand	separate tank	traps particulate matter
Microbiological treatment /Disinfection		
Boiling/distilling	before use	kills microorganisms
Chemical treatments (Chlorine or Iodine)	within tank or at pump (liquid, tablet, or granular) before activated charcoal filter	kills microorganisms
Ultraviolet light	after activated charcoal filter, before tap	kills microorganisms
Ozonation	after activated charcoal filter, before tap	kills microorganisms
Nanofiltration	before use; polymer membrane (pores 10^{-3} to 10^{-6} inch)	removes molecules
Reverse osmosis	before use: polymer membrane (pores 10^{-9} inch)	removes ions (contaminants and microorganisms)
*Should be used if chlorine has been used as a disinfectant.		

Adapted from *Texas Guide to Rainwater Harvesting, Second Edition*, Texas Water Development Board, 1997.

Table 1. Treatments recommended for rainwater harvesting are similar to graywater treatments.

system. A first-flush system is necessary to filter out small debris, dirt and silt (this initial downspout diverts the first rainwater that washes debris off the roof). The first tank should store water briefly. The captured water is filtered as soon as possible to prevent the growth of pathogens. In some cases, the water is subsequently exposed to UV radiation to eliminate all bacteria and viruses. The water can then be stored in a container with restricted light (to prevent algal growth). The filtration and UV-radiation requirements are true for both rainwater and graywater.

If we are to build a sustainable future, one that leaves room for other species to co-exist with us, conserving our water supply use through conservation methods, recycling our water as many times as possible before appropriately discarding and harvesting rainwater will all become commonplace in our homes and neighborhoods (Zavala et al., 2016). For rainwater harvesting, as well as graywater reuse filtration, the scale at which it occurs may be important. Cain (2014) describes a "soft path" for water capture, meaning a smaller scale than currently implemented, and emphasizes the importance of using the community scale. Just as with community solar power use, if your roof is not facing in the right direction to make solar panels practical, but a neighbor's house has the correct direction and inclination, sharing becomes an option. With water harvesting, if your location necessitates the storage of significant amounts of water in order to make it through dry seasons, working with neighbors or the community may provide partners that will make storage more economically possible.

How much water can you collect from a roof? An easy relationship to remember is 1 inch of rain on 1,000 ft2 = 623 gallons of water. Innovative Water Solutions gives methods for English as well as metric users (https://www.watercache.com/resources/rainwater-collection-calculator):

1) Roof Area (ft^2) X Precipitation Amount (in) X 0.623 = Amount Collected (gallons)
or in the metric system,

2) Roof Area (m^2) X Precipitation Amount (mm) = Amount Collected (liters).

How much water do you need to collect? That depends upon usage. For most people and most situations, the World Health Organization says 7.5 liters (~2 gallons) per person per day. In emergencies they actually recommend double this (15-20 liter or 4 gals per person per day) (WHO, 2018). However, the average consumption for a U.S. resident is 80-100 gal per day (USGS, 2016), showing that what we need and what we use are significantly different.

2. Solar Water Heating

Showers use the most *energy* of any other residential activity: 17% of our total home energy requirement (#AskEnergySaver, 2014). Traditional methods of heating water include natural gas and electricity. Since both of these methods generate considerable global warming potential, investigating other methods is recommended. The use of solar energy in both passive and active systems is gaining attention. From the information provided by the resources in this article, it is clearly possible to produce enough heat for a recirculating shower system using active and passive systems. Each system just needs to be refined.

There is a massive amount of information available regarding solar heating and cooling. Ge et al. (2017) summarizes the present and future development of both solar heating (including hot water heating) and cooling in passive and active systems. They state that "solar water heating is one of the most widely used water heating systems worldwide," with the majority of that capacity installed in China. China is by far the leader in solar hot water generation with 70% of the global capacity (Pariona, 2017). The United States, having hardly left the starting line, is a distant second with only 4.5% of the capacity (Pariona, 2017).

There are four parts to a solar water heating system: the solar collector, a storage tank, a fluid for heat transfer, and the circulation pipelines (Ge et al., 2017). In passive systems, it is just the density differences between the cold water and the warmed water that cause the circulation

(Ge et al., 2017). There are many types of systems in development to trap heat losses from the back of the solar collector, and to integrate the collector and the storage tank to generate compact, affordable and attractive units (Ge et al., 2017). In an active solar hot water system, a pump moves the fluid being heated from the solar collector to the storage tank. It may use two loops: one a collector loop and the other a water tank loop making its function possible even when the ambient air temperature is below freezing (Ge et al., 2017). The EPA (2016) offers a simplified description of the various solar heating collectors and how they function.

There are sections of the country where solar energy capture is highly useful, but it may not be ideal for the whole country, including much of the Northeast, Midwest and coastal regions of the Pacific Northwest (Figure 2). But the Southwest has more than enough solar energy. Wasserman (2013) writes that covering Arizona and New Mexico with solar panels would provide more than enough energy for the whole country. But availability of the energy is only one aspect of the issue. Storage and transport to where the energy is needed are other challenges (Wasserman, 2013). Interestingly, areas with low solar resources available sometimes have higher rainfall that keeps the solar panels cleaner, which makes them more efficient than in areas with higher solar resources (Mejia et al., 2014).

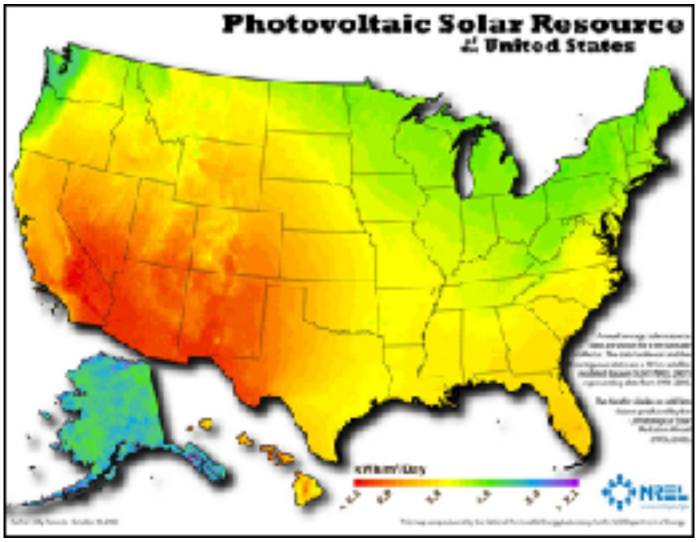

Figure 2. Average solar resources available. Retrieved from https://www.bls.gov/green/solar_power/

3. Passive Solar Heating of Water

Solar certainly will be a large component of our renewable energy combination in the future. Narrowing the search to those systems available for do-it-yourself parameters still yielded more information than could be addressed in this paper. It is important, however, to locate reliable local sources of energy that are not weather dependent and that can also become an additional important part of our future energy mix. One such option may be the multiple facets of compost heat recovery systems, as described next.

When we think about passive sources of energy for water heating or even space heating, solar is our first thought. However, solar energy has limitations related to the time of day, seasons, and weather conditions. Therefore, other options should be explored. Compost heat-recovery systems not previously under our consideration are beginning to attract attention. Using compost as a source of heat is not a new idea, and in fact has been used for over 2,000 years (Brown, 2014; Smith et al., 2017). It is only in the last 40 to 50 years that individuals and businesses have begun to research in depth how to access this free energy source (Anderson, 2018). The system that Jean Pain developed in the 1970s and 1980s is an inexpensive system that extracts energy and fertilizer from waste plant material, and he has attracted the research interests of energy experts from around the world (Anderson, 2018). There are limited peer-reviewed articles about this topic in general as most advances occur at an applied level (Smith et al., 2017). Smith and his colleagues are encouraged and feel compost heat recovery is becoming 1) a viable alternative energy source and 2) is much closer to becoming a mainstream process.

4. Compost Heat Recovery Systems

The process of using the decomposition of plant material to heat water is called a compost heat recovery system. It is a natural process that uses the heat that is generated as plant material decomposes. There are three stages to recovering the heat from compost processes: heat production, heat capture, and heat utilization. There are many factors that determine the amount of heat that can be produced: "feedstock energy content, feedstock degradability, duration of composting, and the conditions prevailing during composting (e.g., moisture, temperature, substrate consistency, and particle size)" (Smith et al., 2017). Some form of tubing, usually copper or cross-linked polyethylene (commonly called PEX tubing) transports water through the compost pile, and heat is transferred from the composting processes to the water circulating through the tubing. Each tubing option has its advantages and disadvantages. PEX is cheaper but cannot be exposed to sunlight. Copper is expensive and more difficult to work with.

In a recirculating system, the speed at which water returns to the compost system impacts the performance and efficiency of maintaining the compost pile temperature. If the hot water is removed through the compost heating system and replaced with cold water too quickly, it is possible to remove too much heat from the system, reducing the effectiveness of the compost (Smith et al., 2017). The size of the compost mound is a component too. Pain and Pain (1972) reported building a 50 Mg (~55 ton) brushwood compost pile and was able to increase water temperatures 50 °C at a rate of 4 liters (~1 gallon) per minute for 6 months without any detrimental effect to the compost pile. In a much smaller system, Vemmelund and Berthelsen (1979) suggested a 4-bin system (each one a meter cubed) that might be capable of producing 50 °C water (122 F).

It is important to maintain a proper brown (carbon) to green (nitrogen) ratio of material in the compost pile (Rhoades, 2018). Leaves and shredded paper are considered brown material and should represent 80% of the material in the compost pile. Green materials are grass clippings and vegetable scraps representing the remaining 20%. If the compost pile is not heating up adequately, it is probably lacking adequate green material (nitrogen) (How much can a compost pile heat, n.d.; Rhoades, 2018). The heat produced in the compost pile can be monitored using a compost thermometer. The pile should remain between 90 °F and 140 °F (32 to 60 °C) for the microorganisms to perform their decomposition function properly. If not held within this temperature range, odors may occur, or it may take too long for the plant material to biodegrade (Rhoades, 2018). A specific moisture level is also required for microbial activity. If there is no activity, the appropriate bacteria may be missing. Average soil contains the necessary bacteria, so a shovelful may be all that is needed to activate the compost process (Rhoades, 2018).

In order to reach the desired temperature range (90 °F to 140 °F), the compost pile must be at least 3 feet by 3 feet by 3 feet (1 meter cubed) (How much can a compost pile heat, n.d.). The compost pile should not be allowed to be taller than 10 feet. At 13 feet it may contain enough heat to spontaneously combust (catch on fire!) (How much can a compost pile heat, n.d.).

It is important to delay heat extraction from the compost pile for 4 to 5 days until the process reaches 60 °C (140 °F). This protects the microbial activity within the pile. The work of many researchers state that removing heat from the pile too soon could inhibit the microbes and reduce the compost temperature (as described in Smith et al., 2017).

If a compost pile has the consistency of a wet sponge, this indicates that the pile has adequate moisture (Rhoades, 2018). Grant (2018) states that if the compost pile is too wet it may become moldy, but it should not be allowed to dry out either. If the compost pile is in contact with the ground and covered with a tarp, adequate moisture is retained, and worms can access the pile contributing their rich castings to the end product (Grant, 2018).

By pre-heating water (potentially through a passive solar system), hot water temperatures can be maintained even when air temperatures are well below freezing. It helps if the compost system is well insulated (Smith et al., 2017). Alwell (2014) recommended foam board insulation, although in some cases the compost may reach extreme temperatures which can lead to other concerns, such as chemical leaching (McSweeney, 2019). To heat the shower and dressing room space, Adams (2005) recommends the cast iron radiators that are found at recycling centers. The coiled pipe within the compost pile would connect to the radiator within the adjacent shower dressing area.

When building the compost heat exchanger, copper pipe coiled within the pile will heat up faster and hold the heat longer (Roberts, 2017). The longer it is in the compost pile, the hotter the water will become (Roberts, 2017). Some data suggests that turning the compost will increase the rate of decomposition. But if you are using the compost pile for hot water heating, a slow decomposition rate is desired (Roberts, 2017). Wood chips, a good source of carbon for water heating, can take 1 to 2 years to break down (Roberts, 2017).

For large industrial scale systems, 30,000 and 40,000 BTUs of energy per hour are captured from a series of 40-ton compost piles, or up to a million BTUs of energy per ton of material composted (Brown, 2015). One cubic meter of compost material weighs approximately 1 ton. The capture rate of 1,000 BTUs per hour per ton of active compost represents the maximum heat capture from compost (Groton, 2012). This rate may last for 18 months, but more realistically for 6 months (Groton, 2018). Depending upon where you live and using this range estimate, it might be best to start a compost heat recovery system in the fall. This would allow the composting process to provide the maximum heat through the winter months when the option of solar passive heating might be minimal.

For a smaller industrial-scale system (200-cubic-meters) built from tree debris, 23,400 kilocalories per hour can heat a 200 square-meter greenhouse and provide 80 cubic-meters of humus every two years (Anderson, 2018).

If well water passes through 200 meters of tubing, it emerges at 60 °C (140 °F). If the compost pile ferments for 18 more months, the pile can provide a source of hot water at the rate of 4 liters (1 gallon) per minute. This is enough for normal household hot water usage (Anderson, 2018). The fermentation, according to Pain, is much more efficient if the tree boughs are finely chopped (Anderson, 2018). When the heat is diminished, the resulting compost is ready to be applied to a garden as fertilizer (Engels, 2017).

Composting is much more efficient if the moisture content of the material is about 50% and the size of the particles between 1/2 inch and 2 inches (Coker, 2014). Pain recommended that the underbrush or wood chips be reduced to 1/16-inch slivers for the best results (Mother Earth News, 1980-2018). All composting is limited by the amount of carbon that is available (Groton, 2012). Many researchers recommend contracting with local tree cutting services to have a constant supply of carbon (Anderson, 2018; Roberts, 2017).

From the information provided by the resources described in this paper, the ability to produce enough heat for a recirculating shower system using compost heat recovery seems entirely possible. Balancing the compost carbon to nitrogen mixture, maintaining the proper moisture levels, developing the appropriate heat exchangers, pumping mechanisms, and water storage systems will be essential to its success. Using compost as a heat source has the potential to be an alternative energy source in balance with the planet.

This review of the composting process does not cover the additional benefits potentially provided by this system. When the heating process ends, and the resulting compost is in cooling mode, it has matured and is ready to be returned to the earth as humus, a natural source of fertilizer (Anderson, 2018). The humus is removed from the compost bins, used to enhance the health of the soil, and the empty bins are refilled to repeat the process. If additional energy is needed, the methane that is released during the process of decomposition can also be trapped and used (Anderson, 2018). As the plant material decomposes both heat and methane are biproducts as part of a natural process. For examples, Anderson (2018) describes the work of Jean Pain who perfected many of the techniques used in current composting as well as methane collection in the early 1970’s.

5. Filtration Systems

Having a clean water supply is a concern for every population on the planet (Stellar, 2010). Many developing countries do not have access to clean water and this situation is becoming a growing concern in the United States as well (Zimmerman et al., 2008). Due to increasing usage by agriculture and industry, expanding human populations, and continued changes in our global climate, water quality and quantity are global issues (Water Quality, 2014).

A Kashmiri proverb says, “It is easy to throw anything into the river, but difficult to take it out again.” Two million tons of sewage and other pollutants are dumped into the waters of the world every day and more people die from exposure to unsafe drinking water than all forms of violence including wars (Water Quality, 2014). It is time we considered being responsible for our own personal water supply.

The issues related to water quality and quantity can be addressed at many levels, from the international scale, national, watershed, and community to the individual household level (Water Quality, 2011 pp 11-12). Showering and bathing require more water than any other water use. If all showers could be designed to recirculate water, the potential to dramatically change our individual water usage becomes possible. Water cleaning (filtration) and the quality of the water would be dependent upon the individual, not the city or municipal water company.

Recirculation of water starts with filtration or cleaning the water. James (1997-2018) provides an overall description of organisms that we wish to eliminate from our water supply. Physical filters range from 0.002 microns (μ) to 0.3 μ. Water purifiers frequently are able to remove at least 99.9% of bacteria, protozoa, cysts and chemicals, but not viruses. If a filter were the means to remove viruses, a very expensive 0.002 μ filter would be required. UV light can destroy about 99.9% of bacteria, protozoa, molds, algae, viruses and other microbes, including several of the waterborne diseases of concern: E. coli, hepatitis, cholera, dysentery, and typhoid fever, and viruses (Blum, 1959; James, 1997-2018; Water Treatment, 2018).

Simple designs for water filtration are readily available. The Environmental Protection Agency even provides a description and illustration for children to learn about filtration (Figure 3). For graywater filtration, Ghtair (2011) recommends that graywater first pass through a coarse mesh filter bag to collect hair or lint found in the water.

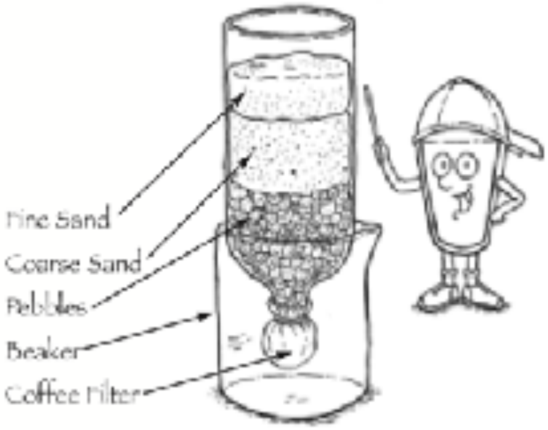

Figure 3. EPA water filtration diagram for children. Retrieved from https://www3.epa.gov/safewater/kids/pdfs/activity_grades_4-8_waterfiltration.pdf

In addition to filtration, recycled water must be disinfected (Rakovitsky et al., 2016). Rakovitsky describes many ways that this can be accomplished; methods that were the most relevant include the use of pine bark and activated charcoal. These were very effective agents for detergent and bacterial removal from graywater (Dalahmeh et al., 2012). Santos et al. (2012) used a self-cleaning filter and UV disinfection. A mixture of micelle-clay and sand were tried by Shtarker-Sais et al. (2013), and Brook et al. (2015) added an organic material to this filtration system with graywater from sinks and showers and found it was effective at removing bacteria. Rakovitsky et al. (2016) used "a granulated complex of micelles of the organic cation ODTMA (octadecyltrimethylammonium) with montmorillonite" in their filtration method and found it to be efficient in filtering graywater (p.267). Amos et al. (2016) stated that if rainwater is heated to 60°C (140°F), harmful bacteria are killed, and this avoids the need for other costly treatments.

Hagan et al. (2009) describe a ceramic filter that eliminates 95.1% average (up to 99.99%) of *E. coli* in the filtered water, and 90-99% reduction in viruses. The pore-size of the ceramic material (0.6 to 3.0 µm) filters out sedimentation particles as well as bacteria. A silver coating on the ceramic acts as a biocide that inactivates bacteria and viruses. The Laterite clay mixture which can be used is high in iron oxides and removes viruses from water. Hagan's downloadable Ceramic Water Filter Handbook includes directions to build your own local factory for the ceramic filters.

After physical and biological filters have been utilized, ozonation (a very expensive technique using ozone gas) or UV radiation (light) are often used. UV systems can also be expensive; however, there are some small systems available online for $121 for a 12-gallon-per-minute capacity which would be more than enough flow for a shower system (UV Filter, 2018). In designing an off-grid system, this could be powered through solar panels or wind turbine energy stored in batteries.

Guidelines for drinking water have been established for all contaminates by the World Health Organization in a 564-page report (2008). Overall, options for filtration include the systems that are being built around the world that may or may not meet the highest of standards, to the purchasing of existing systems, which can be expensive. Determining an appropriate water reuse filtration system is a research project unto itself. Individuals, non-profits, and corporations around the world are attempting to develop economical, efficient filtration systems.

6. Existing Recirculating Shower Systems

The only true recirculating shower found in my research was the Orbital System from Sweden. Their design recirculates water with no flushing at the end of the shower (Orbital Systems, 2018). Several years ago, the system was being marketed for ~$4,100 for the household version. The company is currently working with recreational vehicle manufacturers. "Take three days of water and turn it into 30 days!" (OAS Mobile, 2018). This version is expected to cost in the neighborhood of $5,000.

A true recycling shower, such as the Orbital System, and without the expensive price tag, would be an ecologically desirable goal for future designers. The company Showerloop is close to this ideal with their self-assembly kit available for ($655 US), which includes all components (some laser-printed) and detailed instructions (Showerloop, n.d.). Their design reduces water usage by 90% and saves 70%-90% of the energy required for a 10-minute shower that has a flow rate of 10 liters/min. The Showerloop product is "open source - open hardware - ecological – economical" and is available from Finland.

A number of retailers, mostly European or Australian, are designing and marketing varying types of other recirculating showers. One Australian design won awards between 2011 and 2013 for a shower system that filters and heat-pasteurizes water for reuse (Cintep, n.d.). In this version, the shower uses 2.7 liters per minute but, through recycling, delivers 9 liters per minute. This is a 70% savings in water and energy (to heat the water). However, no water is stored in the system or ever shared with another user. The water is flushed between users. Some locations and some situations may need more than this flushing-between-users version. The system was expected to be released in 2015, but no product appears available in recent online searches.

Quench Showers (n.d.), also from Australia, is a variation on the Cintep system. They suggest (and assume!) that you soap up, shampoo, and rinse in 2 minutes using approximately 20 liters (5 gallons) of water as the first step. A separate 1-gallon reservoir is filled and used for the "therapeutic aspect" of the showering experience. This water is reheated and recirculated repeatedly as long as you wish to remain in the shower. All water is flushed at the end of the shower. It is good that they consider this therapeutic aspect of showering, but they are optimistic in their expectations of a 2-minute pre-shower. The initial cost was $2,365 per shower. The average household should save enough water and energy within the first 3 years to recover the initial investment (Quench, n.d.).

Similar to the Quench system is the Hamwells e-Shower from The Netherlands. The "Classic Shower" setting delivers 1.5 gallons per minute. When the "Refresh Cycle" is selected, water is drawn from a reservoir that delivers 15 liters (3.3 gallons per minute), although it uses only 1.5 liters (0.3 gallons) (Robarts, 2015). Worldwide distribution was expected in 2016 with a cost of $3,200.

Although attempts are being made to construct recirculating showers, acceptability may come into question. For example, comments in blogs are fairly negative. Users with yachts insist on having a sufficient supply of fresh water onboard for daily use (Yacht Forums, 2013-2014), stating that "recycled water is used for watering the garden or the golf course, not having the guests taking a shower with it." On a remodel do-it-yourself blog, Furd, an engineer stated, "… my sewer fee is a fixed amount … so there is no incentive to lessening the amount of water I use while in the shower" (Love, 2010-2012). Obviously, the problem of acceptance may be related to education, billing method, and the fact that we currently live in a country with adequate water supplies. BarryM (Love, 2010-2012) in the same blog is more optimistic, "there could be a tank in the bottom, with a filtration system, heater and pump that recirculates the water that runs into it. Water can be filtered to be as clean as you want it, even purer than what comes out of the faucet." Since water quality is in decline in our country (Gusovsky, 2016), being able to have water purer than that which comes out of the faucet might be an advantage, even to the rich that can afford any amount of water.

The preliminary research expressed in this article shows that it is entirely possible to build this recirculating shower, and that there are many options available for each of the necessary components. Additional research may provide even more options. Water for the shower can be captured through rainwater, and used shower water can be cleaned, filtered, sterilized, stored, reheated and reused. The shower should also be economical to purchase or to build so that everyone will have access to it. Taking long, therapeutic showers need not elicit feelings of guilt if we are changing our habits and restoring our balance with the environment.

There are many additional benefits to a collaboration of educators and students of all ages working together to develop this recirculating shower. The first is, of course, the benefit of investigating the various design options. The secondary aim is to spur a widespread interest in and effort towards design and testing of this type of shower. The eventual goal is to provide one or more designs that use as little water as possible, while providing a level of comfort not otherwise available using conservation methods alone. The development of creative skills, working as a team, solving technical and financial aspects, using a community-based learning environment (both within each class/course/school and between the same), add up to benefits beyond the shower itself.

Some of the questions that remain to be answered include:

1. How much filtration is required to meet showering standards? How can water be easily tested to verify purity of cleaned shower water?
2. How can the filtration system be provided within a minimal height requirement?
3. What is the best way to pump the water to provide a satisfying shower-water pressure? Can the design be developed to use only one pump or are two needed (one for hot water and one for cold)?
4. In order to reduce costs, what sources of water tanks are available, especially within restricted height designs, other than those used for recreational vehicles?
5. How should a compost heat recovery system be designed? Can it provide adequate hot water year-round? How much compost is needed to provide this hot water?
6. What is the best orientation for tubing through the compost pile? Is turning the pile beneficial to maintain a consistent water heat source or does it just cause the compost to decompose faster?
7. Once developed, how can all the components function together?

I invite you to participate in this design-build challenge. Additional specific information regarding current design status of each aspect of the shower will be made available to participating collaborators as a potential starting point.

Conclusion

The research gathered for this paper shows that the information needed to build each component of a recirculating shower is readily available and all we need to do is continue to work on better and new designs that move the idea forward. It is necessary to find passive ways to heat water, and to find the best, most effective ways to filter the water at the lowest possible cost. As water quality and quantity decline globally, products such as a shower design that continually reuses the same water will become critically important. A forward-looking plan would be one that incorporates conservation, efficient resource use, and financial economy now.

Education about water and these new efficiency systems will be important. Changing our perceptions related to water reuse is integral to the change process. This is particularly paramount in countries such as the United States, where most of the country is under the impression that we have plenty of water and that its quality can be maintained forever.

It is not possible to think about a sustainable world without addressing our relationship to water. Water is included, in one form or another, in most lists of the most serious environmental issues facing the world (Wright & Henson, 2018). At this point in time it is critical to make the necessary changes to our lifestyle in order to protect and restore all earth systems. Even if we don’t fully understand the processes or the consequences, if we consider changing our lifestyle, many of these issues can be addressed without a great deal of sacrifice, and the water literacy benefits are huge. In fact, these everyday changes could create a world we have all been waiting for.

In summary, this article represents the current literature regarding the many aspects that must be considered when designing a recirculating shower. The systems include:

- Water collection, pumping and circulation
- Compost heat recovery
- Water filtration
- Solar power for water pumping and shower lighting

Each system needs to be designed, tested, refined, and optimized. I would like to invite teachers, instructors, and professors to participate in a collaboration to build the first recirculating shower. This literature review does not include work that has already been started in an attempt to build the first prototype. After each system is optimized, successfully integrating all systems into a single shower will be the final step. Contact the author if you would like your students to be involved in the development of part of the project. I'm looking forward to a collaboration beneficial to us all!

References Cited

Adams, Z. (2005). Understanding biothermal energy. Master's Thesis. University of Vermont, Burlington.

Alwell, A. 2014. Innovative system uses composting process to heat high tunnel. Organic Broadcaster 22:5.

Amos, Caleb Christian, Ataur Rahman and John Mwangi Gathenya. (2016). Economic Analysis and Feasibility of Rainwater Harvesting Systems in Urban and Peri-Urban Environments: A Review of the Global Situation with a Special Focus on Australia and Kenya. *Water.* 8, 146; doi:10.3390/w8040149

Anderson, Bill (2018). Compost for heat and methane power. Electricity - Make It, Don't Buy it. Retrieved from https://electricitybook.com/composting-for-heat/

Arnell, N.W. (1999). Climate change and global water resources. *Global Environmental Change* 9: PP. S31-S49.

AskEnergySaver: Home Water Heating. (2014). Energy.gov. Retrieved from https://www.energy.gov/articles/askenergysaver-home-water-heating

Australia Standards. (2009). As 3498-2009 Authorization Requirements for Plumbing Productsewater Heaters and Hot Water Storage Tanks. Committee EL-020, Electric Water-heating Appliances: Sydney, Australia.

Blum, Harold Francis. (1959). *Carcinogenesis by Ultraviolet Light.* Princeton University Press.

Boers, Th.M. and J. Ben-Asher. (1982). A Review of Rainwater Harvesting. *Agricultural Water Management.* Vol. 5. PP. 145-158.

Brook, I., Malchi, T., Nir, S., 2015. Removal of anionic detergents from water and treatment of greywater by micelle-clay composites. *Desalinization. Water Treatment*. 53, 2184–2192. http://dx.doi.org/10.1080/19443994.2013.860405.

Brown, Chris, Jan Gerston, Stephen Colley, and Hari J. Krishna. (2005). The Texas Manual on Rainwater Harvesting. Third Edition. Texas Water Development Board. Retrieved from http://www.rwh.in/RainwaterHarvestingManual_3rdedition.pdf

Brown, Gaelan. (2014). *The compost-powered water heater*. Woodstock: The Countryman Press.

Brown, Gaelan. (2015). Advances in Compost Heat Recovery. *BioCycle*. March-April. Vol. 56 Issue 3, p34, 3 p.; JG Press, Inc.

Cain, Nicholas L. (2014). A Different Path: The Global Water Crisis and Rainwater Harvesting. *Consilience: The Journal of Sustainable Development.* Vol. 12, Issue 1, Pp. 147–157

CDC. (n.d.). Center for Disease Control and Prevention. Regulations: The Safe Drinking Water Act. Retrieved from https://www.cdc.gov/healthywater/drinking/public/regulations.htm

Cintep. (n.d.). Water Recycling Shower | Every litre in gives 3.3 litres at the showerhead. Retrieved from http://www.recyclingshower.com.au

Coker, Craig. (2014). Aerobic Composting and Anaerobic Digestion. *Biocycle.* March/April.

Crookall, D. and W. Thorngate, Editors. (2009). Acting, Knowing, Learning, Simulating, Gaming. *Simulation and Gaming.* Vol. 40 Number 1. Sage Publication. PP.8-26. Retrieved from https://journals.sagepub.com/doi/pdf/10.1177/1046878108330364

Gorton, Sam. (2018). Compost Power! Is it really possible to extract heat from compost to warm your barn, greenhouse or home? A grassroots research network is finding out. Cornell Small Farms Program. Cornell University. Retrieved from http://smallfarms.cornell.edu/2012/10/01/compost-power/

Dalahmeh, S., Pell, M., Vinnerås, B., Hylander, L., Öborn, I., Jönsson, H., 2012. Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater. *Water Air Soil Pollution*. 223, 3657–3671.

Engels, Jonathon. (2017). How to Make a Hot Water Heater with Compost. *One Green Planet*. Retrieved from http://www.onegreenplanet.org/lifestyle/hot-water-heater-with-compost/

EPA. (2016) Solar Heating and Cooling Technologies. Renewable Heating and Cooling. Retrieved from https://www.epa.gov/rhc/solar-heating-and-cooling-technologies

EPA - Water Filtration. (2004). Retrieved from https://www3.epa.gov/safewater/kids/pdfs/activity_grades_4-8_waterfiltration.pdf

Ge, T.S., R.Z. Wang, Z.Y. Xu, Q.W. Pan, S. Du, X.M. Chen, T. Ma, X.N. Wu, X.L. Sun, and J.F. Chen. (2017). Solar Heating and Cooling: Present and Future Development. *Renewable Energy*. 126:1126-1140. Retrieved from https://www.sciencedirect.com/science/article/pii/S0960148117305852

Ghtair, Ayoup M. (2011). Greywater Filtration Systems for a Sustainable Water Culture. *Royal Scientific Society.* Clean Technology Applications in Energy, Water, and Environment Workshop. Retrieved from https://wrrc.arizona.edu/sites/wrrc.arizona.edu/files/pdfs/Greywater_Filtration_sustainable_water_11_2011.pdf

Grant, Bonnie L. (2018). Storing Compost – Tips On the Storing of Garden Compost. Retrieved from https://www.gardeningknowhow.com/composting/basics/storing-compost.htm

Groton, S. (2012). Compost Power! Cornell Small Farms Program. Retrieved from https://smallfarms.cornell.edu/2012/10/compost-power/

Gusovsky, Dina. (2016). America's Water Crisis Goes Beyond Flint, Michigan. The World's Biggest Risks. CNBC. Retrieved from https://www.cnbc.com/2016/03/24/americas-water-crisis-goes-beyond-flint-michigan.html

Hagan, J.M., Harley, N., Hughes, R., Chouhan, A., Pointing, D., Sampson, M., Smith, K., and Soam, V. 2009, *Resource Development International - Cambodia Ceramic Water Filter Handbook -, Version 1.3,* Phnom Penh, Cambodia.

Hamilton, K.A., W. Ahmed, A. Palmer, J.P.S Sidhu, L. Hodgers, S. Toze, and C.N. Haas. (2016). Public health implications of Acanthamoeba and multiple potential opportunistic pathogens in roof-harvested rainwater tanks. *Environmental Research.* 150. Pp. 320-327.

How Much Can A Compost Pile Heat? (n.d.). Retrieved from https://homeguides.sfgate.com/much-can-compost-pile-heat-78477.html

James, Carol A. (1997-2018). Biological Water Purification Methods. *InspiredLiving.com*. Retrieved from http://www.inspiredliving.com/water-filters/methods.htm

Jenkins, J. (2005). *The Humanure Handbook*. Third Edition. Grove City, PA, USA.

Jones, Matthew P. and William F. Hunt. (2010). Performance of rainwater harvesting systems in southeastern United States. *Recycling.* Vol. 54 Issue 10, August. PP 623-629.

Kanter, Rosabeth Moss. (2012). Ten Reasons People Resist Change. Change Management: Harvard Business Review. Retrieved from https://hbr.org/2012/09/ten-reasons-people-resist-chang.html

Leong, Janet Yip Cheng, Meng Nan Chong, and Phaik Eong Poh. (2018). Assessment of greywater quality and performance of a pilot-scale decentralised hybrid rainwater-greywater system. *Journal of Cleaner Production*. 172. Pp. 81-91.

Lohan, Tara. (2019). 2019 Will Be a Big Year for Water. *EcoWatch.* Retrieved from https://www.ecowatch.com/ozone-depletion-arctic-warming-2644883057.html

Love, Terry. (2010-2012). Recirculating Shower | Terry Love Plumbing & Remodel DIY and Professional Forum. Retrieved from https://terrylove.com/forums/index.php?threads/recirculating-shower.37303/ .

Martin, Jean-Louis, Virginie Maris, and Daniel S. Simberloff. (2016). The need to respect nature and its limits challenges society and conservation science. *PNAS.* Volume 113, No. 22. Pp 6105-6112. Retrieved from https://www.rivernetwork.org/wp-content/uploads/2015/10/The-Carbon-Footprint-of-Water-River-Network-2009.pdf

McSweeney, J. (2019). Community-Scale Composting Systems: A Comprehensive Practical Guide for Closing the Food System Loop and Solving our Waste Crisis. Chelsea Green Publishing. White River Junction, Vermont. Pp. 167-168

Mejia, F., J. Kleissl and J. L. Bosch. (2014). The effect of dust on solar photovoltaic systems. SolarPACES 2013. Energy Procedia. Vol. 49. 2370-2376.

Mother Earth News Editors. (1980-2018). Second Generation Compost Heater. *Mother Earth News.* Ogden Publications, Inc. Topeka, Kansas. Retrieved from https://www.motherearthnews.com/diy/compost-heater-zmaz80sozraw

OAS Mobile. (2018). New Partnership Makes The OAS Mobile. Retrieved from https://orbital-systems.com/press/new-partnership-makes-the-oas-mobile/

Orbital Systems. (2018). Retrieved from https://orbital-systems.com/savings/

Oregon Water Technology Staff. (2015). Oregon begins water restrictions as drought worsens. *Water Technology.* August 4. Retrieved from https://www.watertechonline.com/oregon-begins-water-restrictions-as-drought-worsens/

Pain, I., and J. Pain. 1972. The methods of jean pain: Another kind of garden. Draguignan: Ancienne Imprimerie NÉGRO.

Pariona, Amber. (2017). Countries with the Highest Solar Water Heating Capacity. World Atlas – Environment. Retrieved from https://www.worldatlas.com/articles/countries-with-the-highest-share-of-solar-water-heating-collectors-global-capacity.html

Payne, Heather. (2017). A fix for a thirsty world--making direct and indirect reuse legally possible. *William & Mary Environmental Law & Policy Review*. Fall2017, vol. 42 issue 1, p201-283.

Quench Showers. (n.d.). Retrieved from http://quenchshowers.com/static/uploads/quench-recirculate-showers.pdf

Rakovitsky, Nadya, Ilya Brook, Jaap Van Rijn, Mark Ryskin, Zanele Mkhweli, Hanoch Etkin, and Shlomo Nir. (2016). Purification of greywater by a moving bed reactor followed by a filter including a granulated micelle-clay composite. *Applied Clay Science* 132–133 pp. 267–272.

Rhoades, Jackie. (2018). Heat and Compost – Heating Up Compost Piles. Retrieved from https://www.gardeningknowhow.com/composting/basics/heating-up-compost-pile.htm

Robarts, Stu. (2015). Hamwells e-Shower rains down water and energy savings. Retrieved from https://newatlas.com/hamwells-e-shower/40976/

Roberts, Tobias. (2017). How to Make a Compost Water Heater. *Permaculture Research Institute.* Retreived from https://permaculturenews.org/2017/07/19/make-compost-water-heater/

Rogers, Paul. (2014). California drought: 17 communities could run out of water within 60 to 120 days, state says, *MERCURY NEWS* (Jan. 28, 2014). Retrieved from http://www.mercurynews.com/sci ence/ci_25013388/california-drought-17-communities-could-run-out-water [https://perma .cc/AE46-FGHG].

Santos, C., Teveira-Pinto, F., Cheng, C.Y., and Leite, D., 2012. Development of an experimental system for greywater reuse. *Desalination* 285, 301–305.

Showerloop. (n.d.). Retrieved from https://showerloop.org

Shtarker-Sasi,, A., Castro Sowinski, A., Matan, O., Kagan, T., Nir, S., Okon, Y., Nasser, M.N., 2013. Removal of bacteria and Cryptosporidium from water by micelle–montmorillonite complexes. *Desalinization. Water Treatment*. 51, 7672–7680.

Smith, Matthew M., John D. Aber & Robert Rynk (2017) Heat Recovery from Composting: A Comprehensive Review of System Design, Recovery Rate, and Utilization, Compost Science & Utilization, 25:sup1, S11-S22, DOI: 10.1080/1065657X.2016.1233082

Stellar, Daniel. (2010). Can We Have Our Water and Drink It, Too? Exploring the Water Quality-Quantity Nexus. *State of the Planet.* Retrieved from https://blogs.ei.columbia.edu/2010/10/28/can-we-have-our-water-and-drink-it-too-exploring-the-water-quality-quantity-nexus/ .

USGS. (2016). How much water does the average person use at home per day? Retrieved from https://water.usgs.gov/edu/qa-home-percapita.html

UV Water Purifier Filter. (2018). *Amazon.com*. Retrieved from https://www.amazon.com/Ultraviolet-Light-Water-Purifier-Filter/dp/B07B66WC54/ref=asc_df_B07B66WC54/?tag=hyprod-20&linkCode=df0&hvadid=242024228564&hvpos=1o2&hvnetw=g&hvrand=10140874508526098979&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061081&hvtargid=pla-456506205778&psc=1

Vemmelund, N., and L. Berthelsen. 1979. A note on heat recovery from mechanically aerated farm-yard manure. Agric. Waste 1:157–60.

Waggoner, P.E. (1990). *Climate change and US water resources*. United States: N. p., 1990. Retrieved from https://www.osti.gov/biblio/5765798

Wasserman, Matt. (2013). How much land would be needed to fulfill current US electricity needs using solar energy? *Quora.* Retrieved from https://www.quora.com/How-much-land-would-be-needed-to-fulfill-current-US-electricity-needs-using-solar-energy

Water Treatment. (2018). The Pros and Cons of Using Ultraviolet Rays For Water Treatment. Skillings & Sons, Inc. Retrieved from https://www.skillingsandsons.com/blog/the-pros-and-cons-of-using-ultraviolet-rays-for-water-treatment

Water Quality. (2014). *International Decade for Action 'Water for Life' 2005-2015.* United Nations Department of Economic and Social Affairs (UNDESA). Retrieved from http://www.un.org/waterforlifedecade/quality.shtml

Water Quality – UN Water. (2011). *Policy Brief.* Retrieved from www.unwater.org/app/uploads/2017/05/waterquality_policybrief.pdf

What is Community-Based Learning? (n.d.). CU Engage. University of Colorado, Boulder. Retrieved from https://www.colorado.edu/cuengage/about-us/what-community-based-learning

What is PBL? (n.d.). PBLWorks. Buck Institute for Education. Retrieved from https://www.pblworks.org/what-is-pbl

WHO. (2018). Water Sanitation Hygiene. World Health Organization. Retrieved from http://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/

World Health Organization (WHO). (2008). Guidelines For Drinking-Water Quality. Third Edition Incorporating the First and Second Addenda. Volume 1 Recommendations. Retrieved from http://www.who.int/water_sanitation_health/dwq/fulltext.pdf

Wright, Pam and Bob Henson. (2018). Earth Day 2018: The 10 Most Pressing environmental Concerns Facing Our Planet – And Rays of Hope for Each. The Weather Channel. Retrieved from https://weather.com/science/environment/news/2018-04-18-earth-day-2018-10-concerning-things-future-of-planet

Yacht Forums. (2013-2014). Recirculating Shower Systems. Retrieved from https://www.yachtforums.com/threads/recirculating-shower-systems.21268/#post-178232

Zavala, Miguel Ángel López, Ricardo Castillo Vega, and Rebeca Andrea López Miranda. (2016). Potential of Rainwater Harvesting and Greywater Reuse for Water Consumption Reduction and Wastewater Minimization. *Water* 2016, *8*(6), 264; doi:10.3390/w8060264

Zimmerman, Julie B., James R. Mihelcic and James Smith. (2008). Global Stressors on Water Quality and Quantity. *Environmental Science and Technology.* The American Chemical Society. Retrieved from https://pubs.acs.org/doi/pdf/10.1021/es0871457

Zlotkowski, Edward & Donna Duffy. (2010). Two Decades of Community-Based Learning. *New Directions for Teaching and Learning*. No. 123, 33-43.

Linda C. Pope

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