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# CONVENTIONAL AND DECENTRALIZED WATER SUPPLY INFRASTRCUTURE: ENERGY CONSUMPTION AND CARBON FOOTPRINT

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ABSTRACT: Implementing a decentralized water supply system is a paradigm shift toward envisioning a pipe-less society where less energy will be consumed for water supply delivery. Objectives of this paper are: 1) estimate energy consumption for conventional water treatment and distribution systems; 2) estimate carbon footprint for a building from energy use (kWh/1,000 gallons) and in-building water use related to conventional water supplies; 3) estimate potable water savings due to installation of a decentralized rainwater harvesting system and the impact of potable water saving on energy consumption and carbon footprint. The study approach is applied to three buildings of different scales. Results show that for study buildings, the building carbon footprint can be reduced if rainwater harvesting/use is implemented. However, the possible impact of electricity that may be used to run a rainwater pump for in-building water distribution is not reflected in the study. The paper is concluded with a brief overview of potential for implementing integrated renewable energy and decentralized water management systems.
KEY TERMS: water supplies, rainwater harvesting, water conservation, energy conservation, carbon footprint

## INTRODUCTION

More than 60,000 water supply plants and 15,000 wastewater treatment plants operate in the United States. The demand for electricity at these facilities is 75 billion kWh per year and up to 80% of these electrical energy costs are attributed to pumping and distribution systems (Oliver and Putnam 1997). In the U.S., the energy use for water treatment and delivery is reported to be in the range of 0.25 – 3.5 kWh/1,000 gallons (AWWARF 2007). The U.S. Department of Energy estimated energy consumption for water treatment and distribution as 1.45 kWh/1,000 gallons (cited in Kloss 2008). Commercial buildings consume significant amounts of potable water supplied through public water systems. More than 65% of high quality potable water is consumed for non-potable uses such as flushing toilets and landscape irrigation. A decentralized water supply system is a paradigm shift toward envisioning a pipe-less society where less energy will be consumed for water delivery (Younos 2008). In this study, decentralized water systems refer to small-scale localized water supply systems that utilize rainwater harvesting systems. Rainwater harvesting is an important element of a sustainable building for water and energy conservation and is recognized in the Leadership in Energy and Environmental Design (LEED) rating system.

In general, rainwater harvesting refers to the storage and use of rainwater collected from various surfaces for various uses. In the developed and modern world, implementing rooftop rainwater harvesting for in-building non-potable water use such as flushing toilets or outdoor non-potable uses such as fountains, landscape irrigation, and groundwater recharge is an increasing trend. Table 1 shows two typical examples of existing rainwater harvesting/use systems in Virginia.

Table 1. Examples of Rooftop Rainwater Harvesting and Use in Virginia

| Building and Site Location | Harvested Rooftop Rainwater (gallons/year) | Water Use |
|---|---|---|
| Oscar Smith Middle School<br>Chesapeake City, VA | 3,730,000 | Landscaping,<br>Toilet Flushing |
| Western VA Regional Correction Facility<br>Roanoke County, VA | 4,600,000 | Laundry Facilities |

Source: Rainwater Management Solutions, Inc. http://www.rainwatermanagement.com/

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If a rainfall harvesting system is implemented, a significant potential for potable water savings and energy conservation exists. The objective of this paper is to estimate energy conservation due to potable water savings for rainwater harvesting systems and the impact of energy conservation on a carbon footprint.

## STUDY SITE AND APPROACH

### Conventional Water Supply System

The study site is the Town of Blacksburg and the main campus of Virginia Tech, a land grant research university, which is located within the Town of Blacksburg. Blacksburg is located in the mountainous areas of Southwest Virginia, about 2000 feet above sea level. The mountainous terrain is a notable factor in this study, as energy use for water distribution and pumping is highly dependent on the topography of the area. The 2000 Census recorded Blacksburg's population as 39,573, which did not include approximately 5,000 students who live on-campus. Virginia Tech daytime population, including students and employees, is about 40,000 people. With 170 residential/academic buildings, the Virginia Tech main campus resembles the microcosm of a high density urban area. Approximate water consumption in Blacksburg and Virginia Tech is 3.0 million gallons per day (MGD). The water treatment facility operated by the Water Authority is located about 7 miles from the Town of Blacksburg. The raw water is pumped up from the New River intake (350 ft lift) and transported to a conventional water treatment facility located about 2 miles from the river intake (http://www.h2o4u.org/). After treatment, the finished water is pumped to a high head storage tank (2.0 MG capacity) and then delivered to Blacksburg by using a booster pump station.

### Estimating Energy Use in Conventional Water Supply System

The amount of energy used to treat and distribute water depends on the quality of water to be treated, the distance for the water to be delivered and the topography of the area. In other words, energy consumption for water treatment and delivery is site specific for each utility and ultimate delivery point. For this study, three years of electricity data (2003 – 2006) for water treatment plant and pumping stations were obtained from the Water Authority to estimate total energy use for water treatment and delivery. Energy use (kWh per 1,000 gallons) was estimated from the total energy use and 3.0 MGD water delivered to Blacksburg area. Combined energy use for water treatment and delivery to the Blacksburg area was estimated to be 1.67 kWh/1,000 gallons. About two-thirds of energy use was attributable to pumping and delivery and the remaining one-third attributable to water treatment (Chen, Younos and Lohani 2007).

### Rainwater Harvesting Systems

A modern rainwater harvesting system consists of a rainwater capture surface (rooftop area), water conveyance components (gutters and downspouts), a water storage unit (tank or cistern), and a pump for indoor/outdoor water distribution (Figure 1). A vortex filter is usually used to remove particles from first flush rainwater before storage and use. Although not common, with appropriate treatment such as using a UV light unit for disinfection, captured rainwater can be used as potable water as well (Grady and Younos 2008).

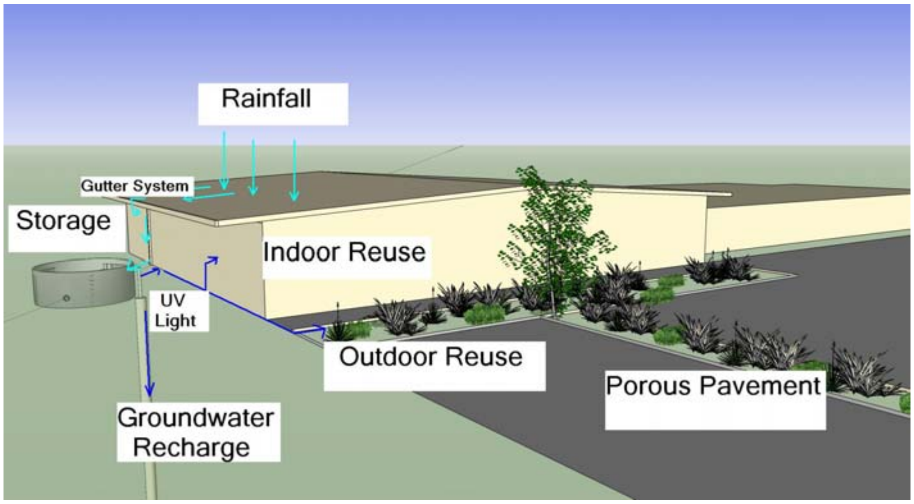

Figure 1. Components of a Rainwater Harvesting System

Basic required parameters to design a rainfall harvesting system are building rooftop area and monthly rainfall data using Equation 1 below:

$$\text{URV (gallons/month)} = \text{Roof-Area (sq-ft)} \times \text{Average Rainfall (inch/month)} \times C \times 0.6233 \qquad \text{(Eq. 1)}$$

where, URV is usable rainwater volume, C is collection efficiency (usually 0.8 which compensates for loss due to splash and evaporation) and 0.6233 is conversion factor to estimate water volume in gallons (LaBranche et al. 2007). Rooftop areas are estimated from building dimensions or aerial photos. Table 2 shows the average monthly rainfall amounts and total annual rainfall for Blacksburg, Virginia used in this study.

Table 2**.** Average Monthly Precipitation in Blacksburg, Virginia

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall (inches) | 3.37 | 3.02 | 3.83 | 3.83 | 4.39 | 3.93 | 4.17 | 3.68 | 3.39 | 3.19 | 2.96 | 2.87 |

Source: http://www.idcide.com/weather/va/blacksburg.htm Total Annual Rainfall: 42.63 inch

Rainwater harvesting scenarios for energy conservation and carbon footprint are evaluated for the following buildings: Blacksburg Motor Company Building; the YMCA Center in downtown Blacksburg; and an academic building on Virginia Tech campus. The Blacksburg Motor Company building (rooftop area 10,000 sq-feet) is a historic one-floor building that is being renovated to house the Town's planning and engineering departments. Blacksburg is using this opportunity to create a green building that will meet the goals of Sustainable Blacksburg and demonstrate green building techniques to the local engineering, development and building communities. It is assumed that on a daily basis 25 people will use the building. As a part of the overall renovation plan, the Town is planning to install rainwater harvesting BMP on this building for stormwater management and water conservation purposes (Gowland and Younos 2008). The YMCA building (rooftop area 14,606 sq-feet), was built about 56 years ago. This one-floor building is currently being renovated to become a green building and a community education center for green technologies and green infrastructure. Virginia Tech researchers are collaborating with the Y staff to design and implement the decentralized rainwater management system. The on-campus building selected for this study is Whittemore Hall, a 6-story building (rooftop area 23,480 sq-feet). The building houses academics and several research laboratories.

### Estimating Indoor/Outdoor Water Consumption

Indoor water usage in conjunction with rainwater harvesting for retrofit buildings can be obtained from water meter records and bills. For new buildings, water consumption can be estimated from anticipated population residing in the building, building functions and approximate daily water use per person. Outdoor water usage for landscape irrigation in the building vicinity can be estimated from expected irrigation application rate, irrigation frequency, and area of coverage.

### Estimating Potable Water Savings – Rainwater Harvesting

Theoretically, if a rainwater harvesting/use system is implemented, potable water savings will be equivalent to total amount of indoor and outdoor water use attributed to the harvested rainwater on a building. For example, if the total rainwater use is 100,000 gallons per year, and if at least that amount would have been used for non-potable uses (toilet flushing and outdoor watering), that amount will be equivalent to potable water saving.

### Estimating Energy Conservation – Rainwater Harvesting

Energy conservation, attributed to rainwater harvesting/use, can be estimated from potable water savings as less energy is used to treat and distribute an equivalent amount of water, and can be estimated from the following relationship:

$$\text{Energy Conservation (kWh/1,000 gal)} = (\text{Potable Water Saving (gal)} \times \text{Estimated Energy Use (kWh/1,000gal)}) - \text{Indoor/Outdoor Pump Energy Need (kWh)} \qquad \text{(Eq. 2)}$$

### Estimating Carbon Footprint

The carbon footprint for a water utility and a rainwater harvesting system can be estimated from carbon dioxide emissions from the fossil fuel source used for electricity generation. Table 3 shows the carbon dioxide emissions for three fuel types as estimated by the U.S. Department of Energy and cited in a recent USEPA report (Kloss 2008).

Table 3. Carbon Dioxide Emissions from Electric Power Generation (Kloss 2008)

| Fuel Type | Carbon Dioxide Output Rate Pounds $CO_2$/kWh | CO2 Output per MG Water Delivered (x 1.450 kWh) |
|---|---|---|
| Coal | 2.117 | 3,070 lbs |
| Petroleum | 1.915 | 2,775 lbs |
| Natural gas | 1.314 | 1,905 lbs |

The electric power generation in the Blacksburg area uses coal as the fuel source. Therefore, the estimation of a carbon footprint for case study sites described below is based on carbon dioxide output rate for coal (Table 3).

## RESULTS AND DISCUSSION

In this study, carbon dioxide output rate estimates are based on water consumption and pounds $CO_2$/kWh emissions due to water consumption. First, results are presented for the following scenarios: 1) carbon footprint for the conventional water supply system serving the Town of Blacksburg and Virginia Tech, and 2) carbon footprint for three individual buildings described above when totally using conventional water supplies. Then, the carbon footprint for the same three buildings is estimated using rainwater harvesting and potable water savings.

### Carbon Footprint for Conventional Water Supplies

Carbon dioxide emission for the water treatment and delivery in Blacksburg, VA, based on electricity used per 1,000 gallons of water delivered (1.67 kWh/1,000 gal), is estimated as follows:

3.0 MGD x 1.67 kWh/1,000 gal x 2.117 lb/kWh = 10606.17 lb $CO_2$/day (or 4,811 Kg/day)

The carbon dioxide emission value per MG water (1.45 kWh/1,000 gallon) in Table 3 will yield 4,177 Kg/day. As it was described earlier, this discrepancy is due to site specific conditions. The carbon dioxide emission attributed to water treatment and delivery in Blacksburg, Virginia (using 4,811 Kg/day) is 1,756 metric tons/year.

### Carbon Footprint for Buildings Using Conventional Water Supplies

Water consumption in each building is estimated from water meter readings. Annual electricity use is estimated from water consumption and kWh/1,000 gal water used. Each building's carbon dioxide emission is estimated using kWh used for coal generated electricity. Results are summarized in Table 4.

Table 4. Carbon Footprint due to Water Consumption for Buildings Using Conventional Water Supplies

| Building Name and Location | Annual water consumption - water delivered via conventional system - (Gallons/Year) | Estimated electricity use attributed to water use (kWh) (x 1.67 kWh/1,000 gallons) | Estimated $CO_2$ output lb/Year (kg/year) (x 2.117 $CO_2$/kWh) |
|---|---|---|---|
| Blacksburg Motor Company, Blacksburg | 51,000 | 85.17 | 180.30<br>(81.6) |
| The YMCA Center, Blacksburg | 121,500 | 202.9 | 429.5<br>(194.84) |
| Whittemore Hall, VT | 1,420,700 | 2372.6 | 5022.8<br>(2,278.0) |

From Table 4, it is obvious that increased water consumption results in increased carbon dioxide output to the environment. Water conservation measures such as rainwater harvesting systems are expected to conserve energy and decrease carbon output to the environment.

### Impact of Rainwater Harvesting and Use on Building Carbon Footprint

As discussed earlier, rainwater harvesting and use results in potable water saving and thus less energy is spent on water delivery from conventional water supplies. Table 5 shows summary results when rainwater harvesting is implemented.

Results in Table 5 indicate that for smaller buildings and low population, the total water demand can be met by the harvested rainwater, and remaining excess rainwater requires disposal. For the multistory and high water use building

(Whittemore Hall), the annual water consumption exceeds the available rainfall so the building still needs to be supplied water from the conventional system.

Table 5. The Impact of Rainwater Harvesting and Use on Building Carbon Footprint due to Water Consumption

| Building Name and Location | Rainwater harvesting/ use potential (Eq. 1) (gallons/year) | Difference between harvested rainwater and water consumption (gallons/year) | Estimated electricity use (kWh) for delivery (x 1.67 kWh/1,000 gallons) | Estimated $CO_2$ output lb/year (kg/year) (x 2.117 CO2/kWh) |
|---|---|---|---|---|
| Blacksburg Motor Company, Blacksburg | 209,943 | 51,000 < 209,943 (0) | 0 | 0 |
| The YMCA Center, Blacksburg | 708,373 | 121,500 <708,373 (0) | 0 | 0 |
| Whittemore Hall, VT | 500,000 | 920,700 | 1537.6 | 3255 (1476.5) |

Table 5 shows that for small buildings, if rainwater harvesting is implemented, the carbon footprint due to water consumption (does not include other in-building energy uses) can be reduced to zero, while for the multistory building the carbon footprint is reduced by 35%. The energy conservation and $CO_2$ output reduction for a single building is not significant but could have tremendous implications if rainwater harvesting is implemented on a large scale. Using rainwater for landscape irrigation of commercial and residential buildings can reduce potable water consumption 10-30% and consequently impact energy use and $CO_2$ output.

The impact of electricity that may be operated to run the pump for rainwater distribution inside and outside the buildings is not reflected in Table 5. If the storage tank is located on the top of a building and flow takes place through gravity then the energy requirements would be minimal. A pressure pump for water distribution will be needed if the rainwater storage tank is installed on the ground level or in the basement. In this case, energy consumption and carbon footprint for the building needs to be considered. For existing buildings, retrofitting building plumbing systems for indoor water use will be needed.

### A Peek into Future Technologies and Sustainable Water and Energy Infrastructure

The carbon footprint discussion in this article is focused on use of conventional electricity generation. In the future, development of integrated decentralized (green) energy and water systems is likely. For example, Figure 2 shows the conceptual vision of future generation of green buildings where renewable energy sources, namely solar and wind energy are used to meet in-building water and energy needs including water distribution. Also, in the future, green utilities will emerge where the power source for water treatment plants will be provided by a renewable energy source. Carbon footprint for these future facilities will be zero to minimum.

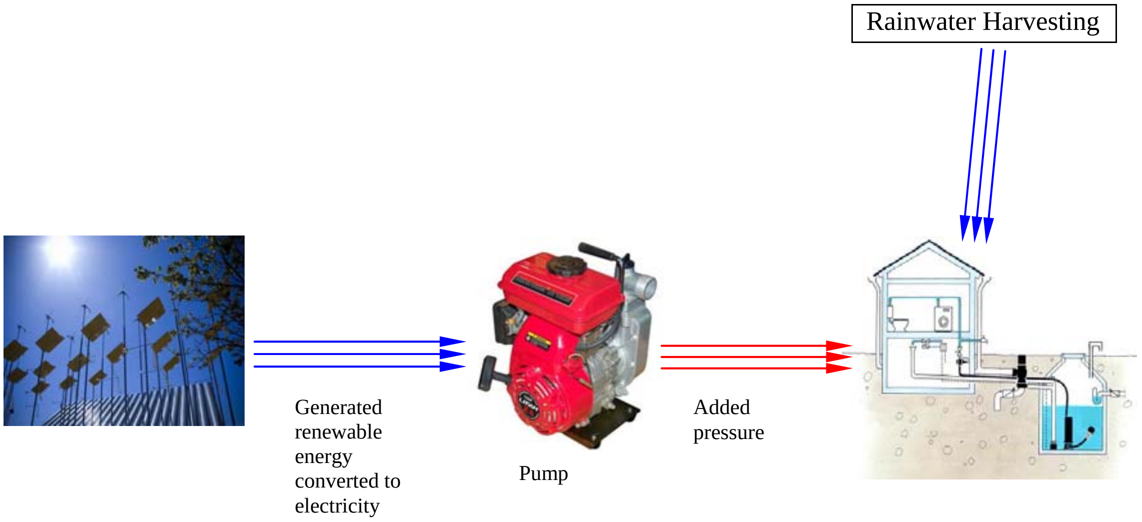

Figure 2. Renewable energy use and rainwater harvesting systems in a green building

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