Water Saving Devices Save More Energy Than You Think

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ABSTRACT

Most energy utilities don't claim the energy savings that water and wastewater (W&WW) utilities realize when customers install water saving measures through energy efficiency programs. However, each gallon of water saved reduces the W&WW utilities' energy requirements for collecting, treating, storing, and transporting water and wastewater. The level of energy savings depends on the energy intensity of the W&WW system serving the customer, which in turn depends on the source of water, the characteristics of the treatment plants, and the topography of the area. Typical energy intensity values range from 1,500 to 2,500 kWh per million gallons (kWh/MG) for public water supply and from less than 1,000 to 3,000 kWh/MG or higher for wastewater treatment. Therefore, roughly 2,500 to 5,500 kWh of energy is *embedded* in every million gallons.

Oklahoma Gas & Electric (OG&E) contracted with Applied Energy Group to estimate the embedded energy savings for water saving devices installed through OG&E's DSM programs (Ehrhard et al. 2014). The study quantified savings due to both avoided water supply and avoided wastewater treatment. It involved interviewing W&WW utilities and collecting data to determine typical energy intensity values for representative cities in OG&E's service territory. It also included a literature review of energy intensity values to validate findings from the interviews. The team used the research results to develop kW and kWh savings values per gallon of avoided water as a function of location, and has since applied the savings to OG&E's program year 2013 and 2014 evaluation results. This same approach can be readily extended to other utility programs.

Introduction

The purpose of this study was to determine kW and kWh savings associated with water saving measures installed through OG&E's Commercial and Industrial Direct Install program, Student Energy Education LivingWise® program, and Multi-Family Direct Install program. These programs provide participants with water saving devices (pre-rinse spray valves, faucet aerators, and low-flow showerheads) that also save energy by reducing hot water usage. Specifically, the study focused on quantifying embedded energy savings due to avoided water supply and wastewater treatment. These embedded W&WW energy savings are in addition to *direct* energy savings achieved from avoided hot water heating.

The study had five main tasks:

- **Literature Review:** The team conducted a literature review to investigate current or recent water-energy programs and water-energy studies that have focused on quantifying embedded energy savings from water saving measures. The main purpose of the literature review was to determine energy intensity values (kWh/MG) for W&WW systems as a function of system characteristics.
- **Primary Data Collection:** The team conducted interviews with W&WW agencies serving customers in OG&E's Oklahoma (OK) and Arkansas (AR) service territories to gather the data necessary for determining energy intensity values for representative cities and locales. During the

interviews the team discussed factors affecting energy demand both from the water delivery side and the wastewater management side.

- **Prototype Development:** During a recent project for the Electric Power Research Institute (EPRI) and the Water Research Foundation (WaterRF), members of the team (R. Ehrhard and K. Parmenter), along with several other W&WW industry experts developed a tool to estimate composite energy intensity values for prototypical W&WW systems based on system characteristics (EPRI & WaterRF 2013). The team used the tool to develop prototypes for the OK and AR W&WW systems to validate energy data collected during the agency interviews.
- **Analysis:** Based on findings during primary data collection and prototype development, the team determined energy intensity values for water supply and wastewater treatment in key cities and for the region as a whole.
- **Recommendations:** The team recommended per-gallon embedded energy and demand savings values to apply to water savings measures offered through OG&E's programs.

Literature Review

The literature review covered three topics: 1) water-energy programs that are currently active or were recently in operation; 2) water-energy studies that have focused on quantifying embedded energy savings from water saving measures; and 3) industry-wide energy intensity estimates from various sources. It built upon the recent work conducted for EPRI and WaterRF. The findings from the literature review showed that typical energy intensity values for public water supply range from 1,500 to 2,500 kWh/MG, and typical energy intensity values for wastewater treatment range from less than 1,000 kWh/MG to upwards of 3,000 kWh/MG, depending on size and type of treatment and other factors. By adding the lower and higher bounds of these values, it is reasonable to expect the combined embedded energy impacts for typical W&WW systems serving customers to be in the range of 2.5 to 5.5 Watt-hour/gal (or, 2.5 to 5.5 kWh/1000 gal). Of course, the energy intensities for some W&WW systems will be out of these ranges.

Data Collection

Embedded energy for W&WW treatment varies with size and type of treatment plant and other conditions unique to certain geographical areas such as inter-basin pumping and system pumping. To represent the embedded energy for W&WW use in OG&E's service area, the team discussed OG&E's customer base and selected several cities of varying size and in different geographical locations for data collection and analysis:

- Oklahoma City, OK
- Ardmore, OK
- Muskogee, OK
- Fort Smith, AR

The majority of OG&E's OK customers (two-thirds of 2014 program participants) live in the greater Oklahoma City area. Ardmore and Muskogee represent other key OK cities served by OG&E. Nearly all of OG&E's AR customers live in the greater Fort Smith area. The process for collecting site information included a combination of site interviews, internet searches, and electric metering data provided by OG&E. The team contacted representatives for each of the W&WW agencies in the four key cities by email and/or phone calls and provided them with a data collection guide. The guide assisted the local officials in obtaining and providing the requested site information. Key information requested included the following:

- Operator contacts for the W&WW plants serving the cities

- Plant names and addresses
- Population served
- Plant types, design capacity, and actual treated monthly flows for past 12-24 months
- Additional pump station sizes and use
- Monthly energy use data per location for past 12-24 months
- Other factors that could impact energy use

The agencies and plants provided average daily flow data based on the plant's internal records. The team multiplied the flow numbers over the course of each month to determine monthly and consequently total annual flow. The team then divided total annual energy use at each plant by the total annual treated flow to determine the energy intensity of each operation in kWh/MG. The combined energy intensity for both the drinking water and wastewater systems make up the total energy intensity for overall water use.

Developing Plant Prototypes

To estimate plant-level energy intensity values for the specific types and sizes of W&WW systems found in the four OK and AR cities, the team used tables of energy values for different system components (referred to as *unit processes*) commonly encountered in W&WW systems. The tables were compiled during the 2013 EPRI and WaterRF study and are contained in an Excel-based calculation tool that is used to develop energy estimates for prototypical systems. The energy values for the unit processes are expressed in units of kWh/day and are tabulated for plant average flowrates ranging from 1 to 250 million gallons per day (MGD). The unit processes are categorized into six groups of technologies for drinking water systems and eight groups of technologies for wastewater systems (see Table 1).

Table 1. Categories of Unit Processes in the W&WW Energy Intensity Calculation Tool

Drinking Water System	Wastewater Systems
• Source water pumping • Clarification • Filtration and solids handling • Disinfection • Finish water pumping • Non-process loads	• Wastewater pumping • Primary treatment • Secondary treatment • Solids handling, treatment, and disposal • Filtration and disinfection • Plant utility water • Non-process loads • Energy recovery (negative energy intensity values)

The tables of unit processes can be used to estimate composite energy use for prototypical plants made up of different combinations of unit processes. The composite energy use can be expressed in units of kWh/day for a given flowrate or as an energy intensity value in units of kWh/MG. Figure 1 is a simplified illustration of the process for developing a prototype for a water treatment system. It begins with selection of the plant's average flowrate (MGD) and the water source (usually ground water or surface water) and ends with aggregation of the corresponding energy use values for each unit process in the system. To get energy intensity, divide daily energy use (kWh/day) by plant flowrate (MGD).

Similarly, Figure 2 is a simplified illustration of the prototype development process for a wastewater treatment plant. It starts with selection of the average flowrate, continues through the stages of treatment, and then includes biosolids processing, disinfection, and filtration as applicable. The process also incorporates adjustments for odor control, channel aeration, and energy recovery from conversion of biogas to electricity.

Figure 1. Process for Estimating Electricity Use for Prototypical Water Treatment System (EPRI & WaterRF 2013)

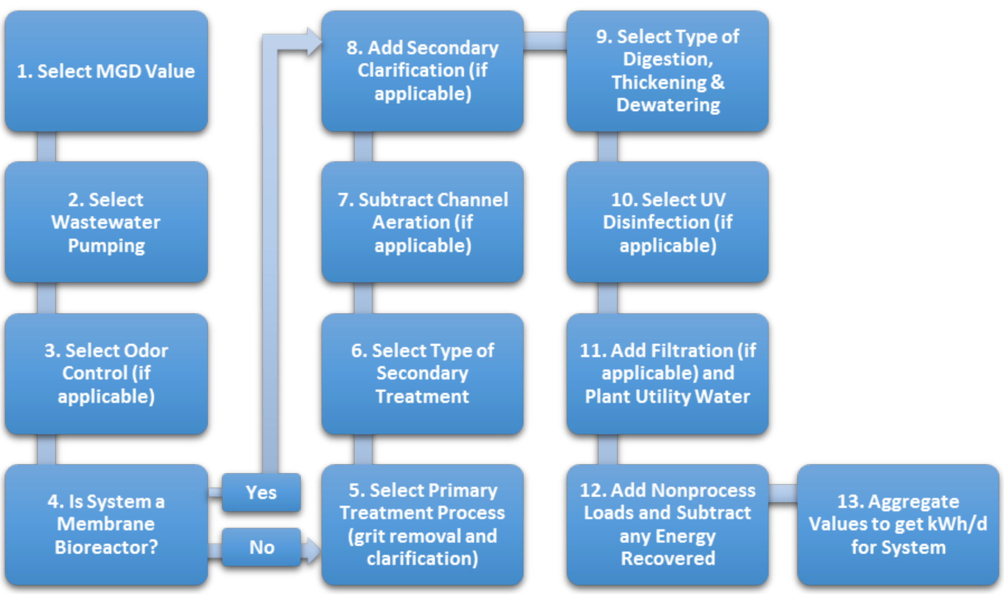

Figure 2. Process for Estimating Electricity Use for Prototypical Wastewater Treatment System (EPRI & WaterRF 2013)

The team used the tables of unit processes and the Excel-based tool to develop composite energy intensity values for prototypes that matched characteristics of the W&WW plants in the four OK and AR cities investigated. The team then used the prototype results to compare with the energy data obtained from interviews with the agencies. Essentially the prototype results served as a reality check to make sure the energy data collected and subsequently used to calculate the regional energy intensities for the OK and AR W&WW systems were complete and within expected ranges.

Energy Intensity Analysis

The following subsections present the detailed findings from the interviews and analysis for the various locations investigated.

Oklahoma City, OK

Oklahoma City has the largest and most involved W&WW systems of the four cities analyzed for the study. The systems involve multiple plants of varying size as well as a significant number of pump stations and ancillary facilities. The data for Oklahoma City was very complete and the team was able to verify energy use numbers provided by the city with billing data provided by OG&E for the numerous meters associated with the city's systems.

Drinking Water. The city delivers tap water to more than 580,000 citizens. Average daily water use is 110 million gallons. Other communities rely on Oklahoma City water as a primary source of tap water or to supplement their own water supplies. These wholesale customers include 20 communities and water districts and 6 businesses that buy water for power generation, operations or irrigation. A sophisticated water infrastructure—about 3,200 miles of pipeline—lies beneath Oklahoma City and takes the water straight to more than 200,000 homes and businesses. Oklahoma City operates three drinking water plants:

- Draper Plant – 150 MGD
- Hefner Plant – 75 MGD
- Overholser Plant – 28 MGD

The Draper and Overholser plants are conventional treatment plants, while the Hefner plant uses ozone to provide enhanced water treatment. The energy mix also includes an inter-basin transfer system consisting of pumping and delivering water from Lake Atoka though 100 miles of 60 inch piping, over 11 large booster pumping stations, and ancillary facilities.

Table 2 shows the energy intensity findings for the Oklahoma City Drinking Water system. The addition of the inter-basin pumping facilities to transfer water to the area accounts for a sizable share of the embedded energy of the drinking water system. Compared to typical water system energy intensities of 1,500 to 2,500 kWh/MG, Oklahoma City's system is quite high at nearly 3,000 kWh/MG.

Table 2. Oklahoma City Drinking Water System

Plant or Pump Station	2012 Electric Usage (kWh/yr)	Treated Water (MG/yr)	Energy Intensity (kWh/MG)
Draper	35,574,720	22,617	1,573
Hefner	22,421,600	12,747	1,759
Overholser	2,217,600	1,383	1,603
Atoka Transfer Pump Station	38,179,200	22,617*	1,688
Additional Pump Stations	11,710,587	NA	NA
Total	**110,103,707**	**36,747**	**2,996**

*Not included in the total since it would be double-counting

Wastewater. Veolia Water provides operations, maintenance, and management services to Oklahoma City to operate four wastewater plants in the region:

- North Canadian Plant - 80 MGD
- South Canadian Plant - 6 MGD

- Chisholm Creek Plant - 5 MGD
- Deer Creek - 15 MGD

All of the plants use conventional activated sludge technology with the exception of the South Canadian Plant, which runs a Sequencing Batch Reactor (SBR) activated sludge system. SBR technology uses more energy, which explains the South Canadian Plant's higher energy intensity value relative to the other plants. Information on the system pumping for the sewer system was not provided and assumed negligible since it is primarily served by gravity sewers. Table 3 shows the findings for the Oklahoma City wastewater facilities.

Table 3. Oklahoma City Wastewater System

Plant or Pump Station	2012 Electric Usage (kWh/yr)	Treated Water (MG/yr)	Energy Intensity (kWh/MG)
North Canadian Plant	23,118,978	14,564	1,587
South Canadian Plant	5,301,600	1,795	2,953
Deer Creek Plant	7,289,100	3,792	1,922
Chisholm Creek	4,193,680	1,949	2,152
Total	**39,903,358**	**22,100**	**1,806**

Energy intensity values vary significantly with treatment plant size, treatment technology, water flowrate, and water distribution pumping requirements. As an example of this, Figure 3 shows energy intensity as a function of average daily flow for the four wastewater treatment plants in Oklahoma City. For a given treatment technology, smaller plants and smaller flows (e.g., Chisholm Creek) have higher energy intensity values; energy intensity starts to level off for the largest plant at higher flows (North Canadian). The energy intensity for the South Canadian SBR plant is especially sensitive to water flow rates.

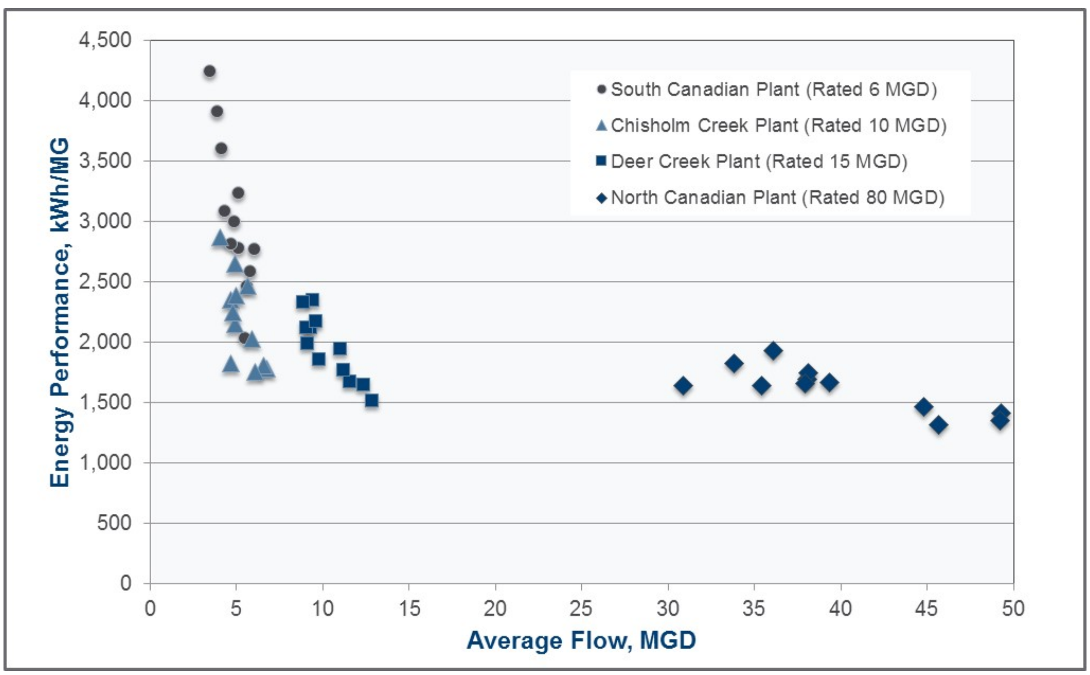

Figure 3. Energy Intensity vs. Average Daily Flow, Oklahoma City's Wastewater Treatment Plants

Figure 4 shows monthly fluctuations in energy intensity for Oklahoma City's wastewater treatment plants. The energy intensities are lowest in spring when flow is greatest. In addition, the energy intensities are most stable for the largest plant and tend to fluctuate more for the smaller plants.

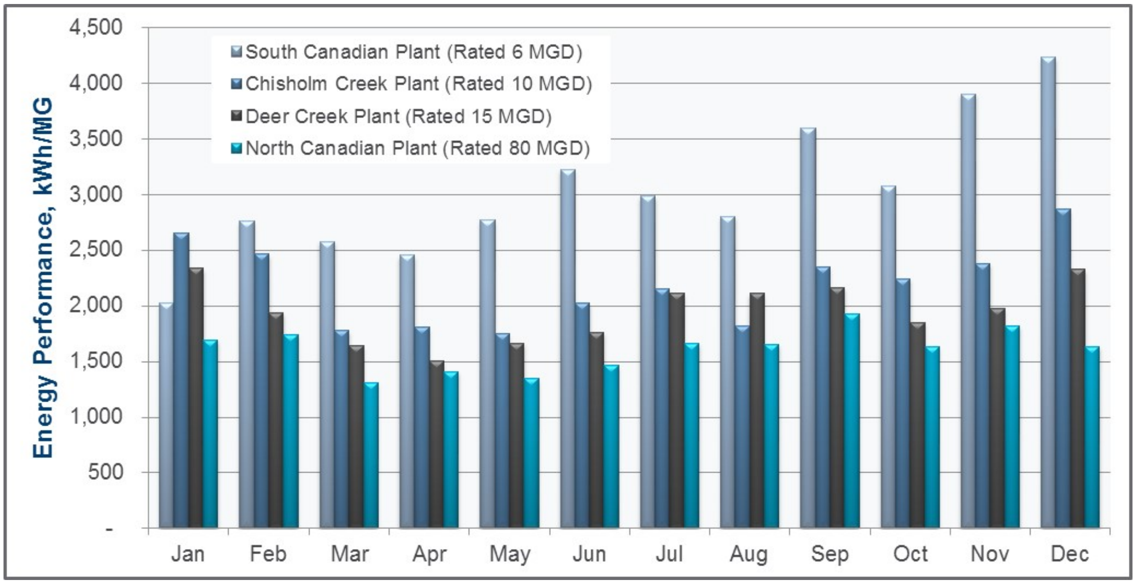

Figure 4. Monthly Fluctuations in Energy Intensity, Oklahoma City's Wastewater Treatment Plants

Ardmore, OK

Ardmore is located 90 miles south of Oklahoma City with a city population of around 25,000. The city operates one drinking water plant and one wastewater plant. The sewer system also has lift stations throughout the city.

Drinking Water. The Ardmore drinking water plant is a 13 MGD conventional treatment plant located on Ardmore Lake Road.

Wastewater. The Ardmore wastewater plant is an SBR activated sludge plant with a design capacity of 6 MGD. The city's normal average flow is 3.5 MGD. There are 13 lift stations which pump about 2 MGD of wastewater to the plant.

Table 4 provides the findings for the Ardmore drinking water and wastewater systems. OG&E provided monthly electric use data for the plants and the city provided actual monthly treated flows. The team added a nominal energy intensity estimate of 100 kWh/MG for the sewer lift stations based on engineering estimates.

Table 4. Ardmore Drinking Water and Wastewater Systems

System Component	2012 Electric Usage (kWh/yr)	Treated Water (MG/yr)	Energy Intensity (kWh/MG)
Drinking Water Plant	4,249,200	2,890	1,470
		Drinking Water Total	**1,470**
Wastewater Plant	4,071,600	1,278	3,187
Lift Stations	-	-	100
		Wastewater Total	**3,287**

Muskogee, OK

Muskogee is located between Tulsa, OK and Fort Smith, AR. The city population is around 38,000. The city operates one drinking water treatment plant and one wastewater treatment plant, with a variety of lift stations.

Drinking Water. The drinking water plant uses conventional water filtration for treatment and has a design capacity of 13 MGD. The plant also provides drinking water to six rural water districts and four towns. In addition, the city operates two lift stations with pumps ranging from 7.5 horsepower to 40 horsepower. Calculations using the pump station horsepower and estimating a duty cycle of 30% resulted in an additional energy intensity 53 kWh/MG. The team added this value to the treatment plant energy intensity value for the final system energy intensity results.

Wastewater. The wastewater plant is a trickling filter treatment plant with a design capacity of 14 MGD. Approximately 15 pump stations are used to lift sewage from the sewers to the treatment plant. These pumps range in size from 5 HP to 100 HP. Calculations using the pump station horsepower and estimating a duty cycle of 20% resulted in an additional energy intensity 855 kWh/MG. This lift station value is high relative to systems in some of the other cities because of the large number of lift stations and the small amount of flow in Muskogee. The team added this value to the treatment plant energy intensity value for the final system energy intensity results.

Table 5 provides the findings for the Muskogee drinking water and wastewater systems.

Table 5. Muskogee Drinking Water and Wastewater Systems

System Component	2012 Electric Usage (kWh/yr)	Treated Water (MG/yr)	Energy Intensity (kWh/MG)
Drinking Water Plant	6,964,800	5,213	1,336
Lift Stations	-	-	53
		Drinking Water Total	**1,389**
Wastewater Plant	2,496,300	1,759	1,419
Lift Stations	-	-	855
		Wastewater Total	**2,274**

Fort Smith, AR

Fort Smith lies on the AR-OK state border, situated at the junction of the Arkansas and Poteau Rivers, also known as Belle Point. The city population is around 87,000 with a regional population just under 300,000. The city operates two drinking water plants and two wastewater plants.

Drinking Water. The drinking water plants use conventional treatment equipment. One of the drinking water plants is served by Arkansas Valley Electric Cooperative and was not included in this study. Data was collected from the Lake Fort Smith treatment plant.

The Lake Fort Smith plant is uniquely situated at an elevation that requires no raw water pumping and little service water pumping (Figure 5). The gravity service is available for water demands up to approximately 18 MGD; lower demands occur primarily during the winter season. When water demands approach or exceed that range, the plant uses the finished water pump station to meet the water demands between 18 and 40 MGD. As the system grows, the water demands will continue to exceed the plant's ability to take advantage of gravity service and the plant will need to pump more on a regular basis. For this study, the team used the data for flow and energy collected during 2012. This calculations result in very low energy intensity values due to minimal finished water pumping requirements. These values are expected to rise each year as more water service is needed.

Figure 5. Lake Ft. Smith Drinking Water Plant Located Below Dam

Wastewater. The city's P Street Plant is a conventional activated sludge plant with a daily average treated flow of 8.2 MGD. The Massard Wastewater Plant is a conventional activated sludge plant with a daily average treated flow of 7.1 MGD. Approximately 24 lift stations are used to transfer wastewater in the sewer system to the treatment plants. The team was unable to obtain detailed energy information for the lift stations; therefore, the team added an engineering estimate of 300 kWh/MG to the treatment plant energy intensity calculation to represent the lift station use. This estimate accounts for the fact that the Fort Smith topography is relatively hilly and, therefore, should require more pumping energy for the lift stations relative to an area with flatter topography.

Table 6 summarizes the results for the Fort Smith drinking water and wastewater systems.

Table 6. Fort Smith Drinking Water and Wastewater Systems

System Component	2012 Electric Usage (kWh/yr)	Treated Water (MG/yr)	Energy Intensity (kWh/MG)
Lake Fort Smith Plant	3,466,080	7,227	480
		Drinking Water Total	**480**
P Street Plant	4,492,000	2,993	1,501
Massard Plant	4,538,183	2,592	1,751
Wastewater Subtotal	***9,030,183***	***5,585***	***1,617***
Lift Stations	-	-	300
		Wastewater Total	**1,917**

Comparison of Results

Table 7 summarizes the energy intensity results for each city. The table also includes values of demand intensity in units of kW per million gallons. The team estimated demand impacts by dividing the energy impacts by 8760 hours per year. Thus, the demand intensity values are conservative, but are appropriate considering the intermittent use of water throughout the day. This approach is consistent with the way OG&E estimates demand savings due to the direct energy impacts from the water saving measures. Peak demand values are not considered in this analysis. The table also includes the weighted averages across all plants based on annual treated water flows. Since the treated water flows for Oklahoma City are much larger than for the other cities, the weighted averages are relatively close to the Oklahoma City values.

Table 7. Summary of Energy Intensity and Demand Intensity Estimates for Drinking W&WW Agencies Serving OG&E's Customers

Location	Energy Intensity (kWh/MG)			Demand Intensity (kW/MG)		
	Drinking Water	Wastewater	Total	Drinking Water	Wastewater	Total
Oklahoma City, OK	2,996	1,806	4,802	0.34	0.21	**0.55**
Ardmore, OK	1,470	3,287	4,757	0.17	0.38	**0.54**
Muskogee, OK	1,389	2,274	3,663	0.16	0.26	**0.42**
Fort Smith, AR	480	1,917	2,397	0.05	0.22	**0.27**
Weighted Average	**2,401**	**1,914**	**4,316**	**0.27**	**0.22**	**0.49**

The team compared these energy intensity numbers with those estimated using the prototype tool. The values correlated well, with one exception. The energy intensity for the Fort Smith drinking water plant seemed too low at first, as if energy data were missing for raw or finished water pumping. However, once the team discovered the Fort Smith plant is situated below a reservoir and at an elevation that allows for gravity service to meet much of its water demand (as shown in Figure 5), it made perfect sense for the pumping energy requirements to be less than for typical plants of the same type and size.

Another value that stands out in Table 7 is the wastewater energy intensity for Ardmore, which is considerably higher than for the other cities. Ardmore's high values is due to the type of treatment technology used at the wastewater plant; it is an SBR activated sludge plant. As explained previously, SBR technology is much more energy intensive than conventional activated sludge technology.

Impact on Energy Savings

For simplicity, the team recommended that OG&E use the weighted averages in Table 7 and apply the same embedded energy and demand intensity values for all customers who install water saving measures through OG&E's DSM programs:

- Energy savings = 4.3 Watt-hr per gal avoided
- Demand savings = 0.0005 W per gal avoided

For greater accuracy, OG&E could instead apply the regional values, or use a weighted average of the OK values for OK customers and the Fort Smith values for AR customers. The approach to determine annual embedded energy and demand savings for a given measure is to multiply the estimated gallons saved per year for the measure by the respective intensity value.

The following is an example of how embedded energy savings combine with direct energy savings to increase the overall energy impacts for water saving measures (Table 8). It is for a residential faucet aerator that decreases water flow from 2.2 gpm to 1.5 gpm, saving 381 gallons per year. The direct energy savings values are due to reduced hot water heating requirements and they vary depending on the type of water heater in the home. The example shows that including embedded energy in the calculation increases overall energy impacts by 5-9% depending on the type of water heating technology. The additional embedded impacts for a single faucet aerator are small, but they are significant if widely applied across customers in the service territory.

Table 8. Example of Applying Embedded Energy Savings to a Residential Faucet Aerator Measure

Metric	Electric Water Heater	Heat Pump Water Heater
Annual water savings	381 gal/yr	
Embedded energy savings	4.3 Watt-hr/gal x 381 gal/yr = 1.6 kWh/yr	
Embedded demand savings	0.0005 W/gal x 381 gal/yr = 0.2 W	
Direct energy savings	35 kWh/yr	16 kWh/yr
Direct demand savings	4 W	2 W
Overall energy savings	36.6 kWh/yr	17.6 kWh/yr
Overall demand savings	4.2 W	2.2 W
Increase in impact over direct savings alone	5%	9%

These embedded savings have since been applied to OG&E's program year 2013 and 2014 evaluation results for faucet aerators and low-flow showerheads in single family and multi-family homes and for aerators, showerheads, and pre-rinse spray valves in commercial and industrial facilities. In AR alone, including embedded savings in the evaluated results for the 2014 program year added savings of over 58,000 kWh and 6.7 kW across the three programs with water saving measures: Commercial and Industrial Direct Install, Student Energy Education LivingWise®, and Multi-Family Direct Install.

Concluding Remarks

The embedded energy associated with the drinking water supply and wastewater treatment cycle has been understood for some time, but is rarely considered in water-energy programs. The vast majority of programs offered by energy utilities focus solely on direct water savings and direct energy impacts resulting from reduced hot water use, so most utilities only claim the direct water and direct energy savings achieved through the programs. Exclusion of the embedded energy impacts is partly due to the fact that the energy intensities of water supply and wastewater treatment vary widely from system to system and these intensity values are not well known by energy practitioners, or even by the W&WW agencies themselves.

This study illustrates the importance of incorporating embedded energy along with direct energy into the energy savings equation when promoting water saving programs. It brought together energy and W&WW industry experts to develop a straightforward and reliable method for determining embedded energy savings using primary and secondary research. The approach is directly applicable to other jurisdictions and any programs focused on saving water.

The authors recommend that utilities interested in including embedded savings for any water saving measures they offer through their programs start by following the approach presented in this paper, which is summarized below:

- Identify W&WW agencies serving customers in your service territory.
- Select a short-list of agencies who represent plants in key locales and provide water to a large share of your customer base.
- Use utility records to compile 12-24 months of energy data for the W&WW treatment plants and other system components (e.g., pump stations).
- Interview agencies and plant representatives to determine the types and sizes of the treatment plants associated with the selected W&WW systems and to obtain details on specific unit processes and other factors affecting energy use. For each system, request 12-24 months of average flow data and any additional component-level energy data available.
- Download the EPRI & WaterRF report and use the tables of unit processes to estimate energy use and intensity for prototypes that approximate each type of W&WW system selected.
- Calculate energy intensities using actual energy and flow data for each selected system and compare with prototype estimates to ensure the energy data obtained is complete.
- Develop weighted energy intensities for the service territory or use regional values.
- Multiply the energy intensities by gallons of water saved for each participant to calculate the embedded energy savings for the water saving measures.
- Combine the embedded energy savings with direct water heating energy savings to determine the overall energy savings for the measures.

The embedded energy savings at water supply and wastewater facilities resulting from utility programs are real and quantifiable. Including embedded energy savings in claimed savings is an innovative concept that is justifiable and deserves a place in policy discussions focused on energy and non-energy impacts beyond the customer meter.

References

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